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Reji Kumar Pillai
Girish Ghatikar
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Contents

Cyber Risk Analysis of Critical Information Infrastructure

(A Quantitative Approach)

Dharmendra Kumar, Darshana Pandey, Aamir Hussain Khan, and Himanshu Nayyar

Abstract Cyber-Physical Security (CPS) of critical infrastructure comprises of securing interacting digital, analog, physical, and human components engineering for functioning in an integrated manner (E.g. ADMS/ SCADA, Smart Meters, Field Force Automation devices, etc.). These solutions are required to be exposed to networks or environments which have normally functioned in an isolated environment with minimal cybersecurity controls in place. This new security challenge demands for an appropriate risk assessment of Cyber-Physical Systems and development of a unified framework addressing taxonomy of threats, vulnerabilities, attacks and controls on device controllers (RTU's, FRTU's, PLC's), plant-level distributed control, and system-wide SCADA components spanning wide geographic areas. Cyber-Physical Systems must often meet strict timing requirements during normal operation as well as during recovery. Cyber-Physical security is crucial to maintain stable and reliable operation during the contingency situation in-case of failure of any critical system component. Due to the cyber-attacks, Critical Information Infrastructure (CII) may face operational failures and loss of synchronization, damaging critical physical system components that may interrupt the services and make the system unstable resulting in a debilitating impact on the national economy, public health, and safety. To ensure CII operates in a safe, secure and reliable manner, cybersecurity is required to be implemented at each layer of cyber-physical systems and hence it demands in-depth analysis of data transmission and storage procedures.

Keywords CII · SCADA · OT · IT · Physical security

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Abbreviations

ADMS: Advance Distribution Management system
CII: Critical Information Infrastructure
CPS: Cyber Physical System
CERT-In: Indian Computer Emergency Response Team
ICS: Industrial Control Systems
IT: Information Technology
NCIIPC: National Critical Information Infrastructure Protection Centre
O.E.M: Original Equipment Manufacturer
OT: Operation Technology
OS: Operating System
PLC: Programmable Logic Controller
RTU: Remote Terminal Unit
SCADA: Supervisory Control and Data Acquisition

1 Introduction

In the age of digitalization, each utility has developed its own technology roadmap for installing Information and Operational Technologies catering to the needs of the customer, thereafter enhancing customer satisfaction along with building a brand. The deployment architecture at utilities is built around various external O.E.M products, therefore creating a multi-vendor technology environment.

Threat vector in such an environment enforces the organization to adopt a proactive approach to develop cybersecurity practices within the organization.

Tata Power-DDL is supplying electricity to the various critical infrastructure of the national capital and hence unavailability of its key systems may have a debilitating impact on the national economy, public health. Security and safety of citizens. As seen in the past, hackers for their notorious aim have targeted the country's critical information infrastructure leading to a devastating impact on the economy. Cyber-physical components of IT & OT networks are now being exposed to the public network that poses a major risk to CII. Cyber-attacks include denial of service, phishing, theft or manipulation of data that are common in today's scenario. Any failure to address the cyber vulnerability in any of the components of critical infrastructure may create havoc in the entire network resulting in the unavailability of system and services.

Consequences of Breach of Incidents:

- Damage to company brand or reputation
- Loss of customer confidence
- Damage to the products and services quality
- Loss of contracts or business opportunities
- Violation of regulatory requirements

2 Challenges

Cybersecurity solutions for physical systems have not seen the same pace and development. Therefore the network is more prone to advance forms of cyber-attacks. In addition to this following are some of the major challenges that a utility is facing today while planning to protect its Critical Infrastructure:

- State-Sponsored Attacks
- Hacktivism
- Insider Threats
- Lack of formal agreement or arrangement with appropriate agencies
- Geo-Political Challenges (Table 1)

Hence in order to cater to the above techniques, a holistic solution to following gaps based on technical, governance and user level should be addressed:

A. Technical

  - Outdated and vulnerable software
  - Inadequate network segregation
  - Lack of system hardening
  - Weak access control
  - Insufficient logging and monitoring
  - Cyber Security not considered during the fundamental design phase
  - Vendors prefer to fix vulnerabilities in the next release of their product

B. Governance

  - Overall governance of cybersecurity in Operation Technology is low
  - Staff training and security awareness
  - Business continuity plan
  - Incident response planning

Table 1 Recent attacks on CII systems

Recent attacks	Various attack vector	
Target	Technique	Year
New York City Dam	Google dorking technique	2013
European ICS manufacturers	HAVEX Malware	2014
Ukraine power grid	Black energy, industroyer and notPetya malware	2015/2016/2017
Saudi petrochemical company	Triton malware	2018
US power grid	Grizzly steppe	2018
Norsk hydro	LockerGoga ransomware	2019

C. User

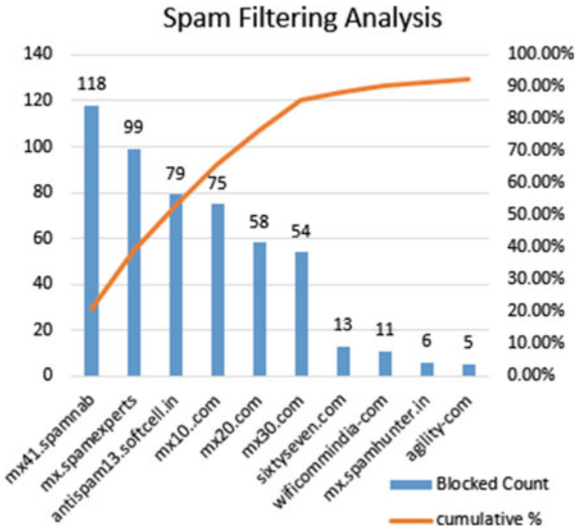
- Access to SCADA Network-Troubleshooting/installation
- Clicks on a Specially crafted Phishing email
- Exposing network for Business Reasons
- Connects virus infected Pen drive

3 Methodology to Address Challenges

In view of the list of challenges faced by utilities, the best approach to defend critical infrastructure would be to carry out an analysis of behavior patterns for cyber vulnerability databases, security advisories, known exploits, etc. based on factors like port numbers, domain, vulnerability type, types of possible attack, etc. to develop a robust strategy for addressing this very unique challenge. Establishing an association with NCIIPC for identification of Critical Information Infrastructure. Advocacy at various forums like CEA, MoP, ISGF, etc. Data Analysis based on the following attack vectors:

- Cyber Security Advisories
- External traffic on gateway
- Suspicious IP's and Ports
- User Behaviour Analysis
- Malware Analysis
- Network Traffic Analysis (Figs. 1, 2, 3, 4, 5 and 6, Table 2)

Fig. 1 Suspicious spam/phishing mails



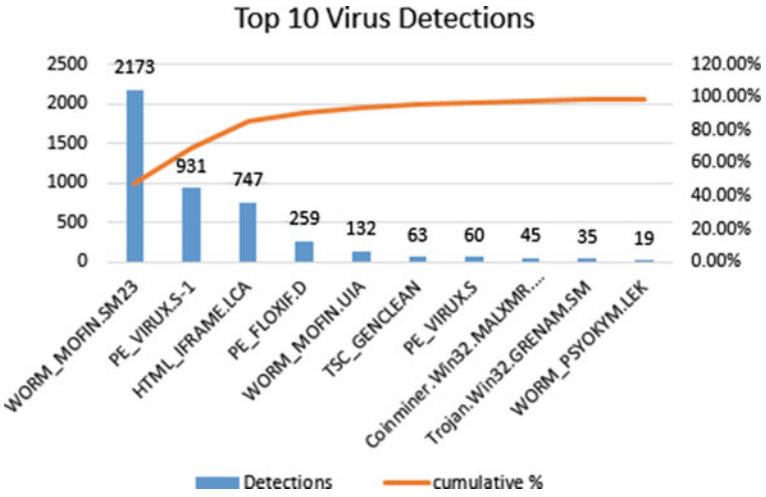


Fig. 2 Virus detected in CII systems

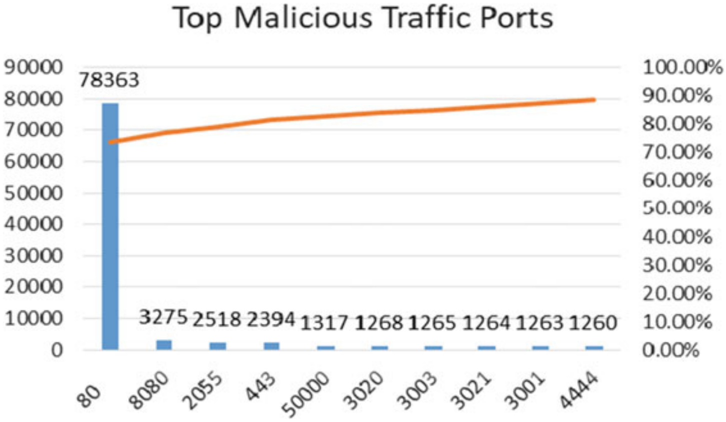


Fig. 3 Top ports receiving malicious traffic

4 Conclusion

To achieve organizational efficiency, you need to balance the three methodologies and maintain good relationships among them:

People: Align business concerns with the current threat environment to ensure that awareness and education of your hybrid workforce are actually achieved.

Process: Invest in a formal assessment of your "as is" processes and identify the weak links before creating a "to be" environment, including procuring technology.

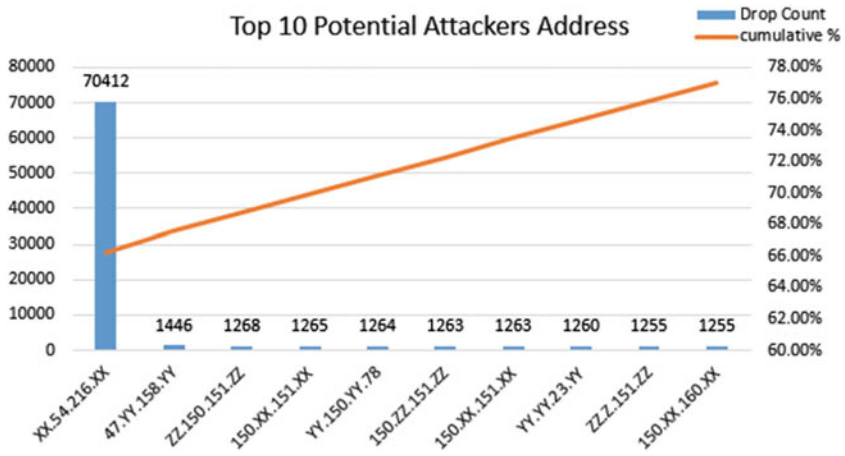


Fig. 4 Attackers address identified & blocked

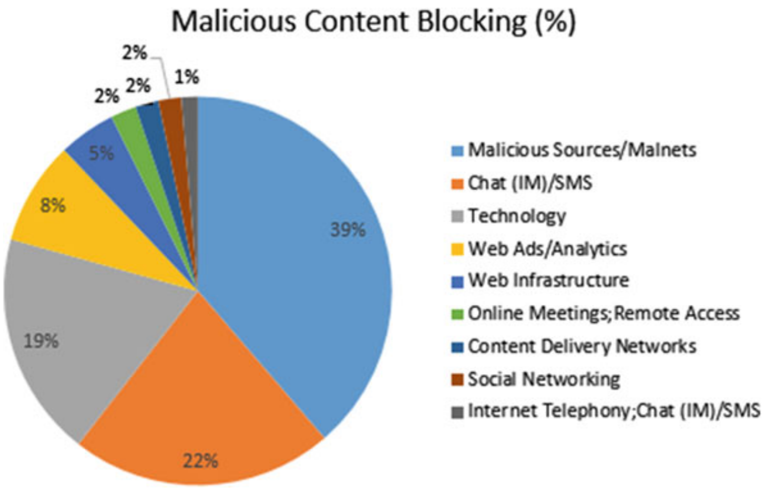


Fig. 5 Malicious content blocked

Technology: Improve visibility into assets and infrastructure. Establish an inventory of assets.

Establish the process of maintaining an OT/IT asset inventory over time.

It has been observed that there are various factors that an organization has to keep track of to ensure a cyber-resilient environment and there is no one-stop solution to address the varying nature of vulnerabilities. The following approach may be adopted by an organization to develop a safe and secure network for cyber physical systems of critical infrastructure.

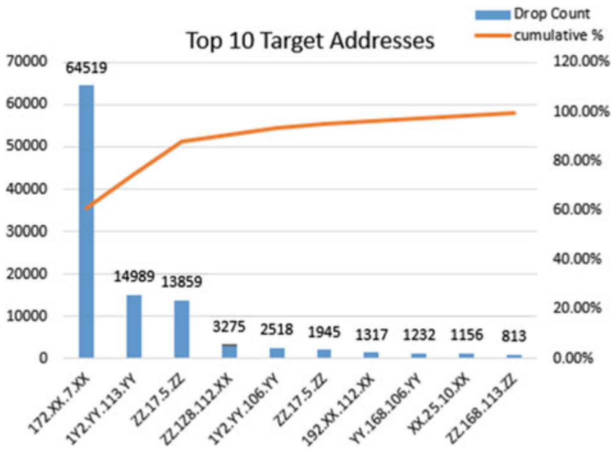


Fig. 6 Recent attacks on CII systems

Table 2 Categorisation of cyber security advisories

Apr'2018 to Jun'2019			
Month	Malicious source	Suspicious	Phishing
Apr	132	43	13
May	658	126	20
June	904	247	15
Jul	1199	341	34
Aug	538	111	11
Sep	431	121	15
Oct	331	200	7
Nov	12	16	0
Dec	631	175	45
Jan	320	50	5
Feb	434	126	19
Mar	659	87	6
Apr	26	10	2
May	25	124	13
Jun	54	6	0

- Implementation of Information Security Management System framework for both IT& OT systems.
- Implementation of Firewall between IT & OT networks to restrict any unauthorized traffic
- Disabling of "administrator" level access of local user machines to deter users from installing any unauthorized or potentially harmful programs.

- Commissioning of DMZ (Demilitarized Zone) to host and segregate applications meant for accessing the public network.
- Vulnerability Assessment and Penetration testing analysis for network and key applications
- Availability and regular drills for Business Continuity /Disaster Recovery Plan.
- Insurance of IT Assets against cyber liability
- Implementation of 24 X 7 Security Operation Centre for monitoring of security Incidents.
- Backup of Critical Data at a pre-defined interval
- SCADA Network designed on a different subnet as compared to enterprise Network
- Blocking of USB ports of HMI systems
- The technical specification should include a dedicated cybersecurity section
- OEM product should contain IT security compliance certification
- OEM should be held equally responsible for any breach in utility.

5 Way Forward

The future work shall involve carrying out a demonstration of most common attack types on Critical Infrastructure systems and studying the various real-world cyber-attacks carried out on critical infrastructures organizations till now. In addition to studying the various attack techniques shall provide, critical infrastructure organizations will work closely with various solution providers in a collaborative manner so that they can align their cybersecurity strategy in accordance with the vulnerable areas and make more informed decisions using capability maturity model integration for calculating individual risk score associated with CII assets. Therefore, it is used to describe the variations in Y from the given changes in the value of X. It can be expressed using the below equation:

$$\mathbf{Y} = \mathbf{C} - \mathbf{C1}\,(\Sigma\mathbf{X1}) + \mathbf{C2}\,(\Sigma\mathbf{X2})$$

where X1 is the dependent variable and X2 is the independent variable. The parameters ‘C’ are unknown constants.

Y = Cyber Risk Score of CII.

X1 = Active Threat Vectors (Monthly).

X2 = Security Measures Deployed (Monthly).

C, C1, C2 = Constant Values.

ΣX1 = Virus Detected, Unauthorised Access, Target Address Hits.

ΣX2 = Anti-Virus, Packets Dropped, VA&PT Conducted, Successful Backup, Security Patches Updated.

In order to conclude the analysis based risk score, boxplot analysis should conducted by the utilities based on which UCL- Upper control limit & LCL- Lower control limit of the risk associated with the CII system will be determined, if any value at any particular instance is outside this control limit we can trigger the Causal Resolution Analysis (CAR) along with Correction and Corrective action.

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Smart Green Transport Grid

Abhijit Malankar

Abstract As India plans to have 100% electric mobility by 2030, the grim reality today by early 2020 is that we have just around 100,000 shared and private EVs running on Indian Roads crippled with almost complete absence of public EV charging infra & very high cost of Electric Cars which is around 10 Lakh + INR well beyond middle class price ceiling range of 4–5 Lakh INR which will push Indians to buy another 50–100 million new fossil fuel vehicles in the next 10 years and cause irreversible damage to Indias Electric Mobility and clean energy dreams. If India ends up adding 50–100 million new fossil fuel vehicles in the next 10 years on its roads it will at the same time put at high risk the worldwide climate change mitigation efforts too & we will be staring at a devastating beyond 2 + degrees rise on global climate scale. This paper attempts to put together a sustainable, cost effective & fast deployment solution in the form of creating a new "Dedicated Smart Green Transport Grid open platform for E-Mobility" combining together the strength of distributed private renewable energy generation which will combine to enable faster transition of India to the Electric Mobility Era. The paper puts forth a very detailed plan of implementation of such a solution providing new age alternatives like shared public private ownership of the Smart Green Transport Grid, enabling both battery less & battery based shared & private electric mobility for both people and freight and also discusses ways to extend this Smart Green Transport Grid from land over to water (for E-Ships), over Air (for E-drones/Air Taxis) and over Farms (for Irrigation applications like E-Tractors, E-Pumps).

Keywords Electric mobility · Electric mobility as a service (EMaaS) · Battery energy storage systems · Multi modal electric mobility · Climate change mitigation · Smart green transport grid · Electric drones · Air taxi · Electric ships · electric tractors · Distributed roof top renewable energy · Renewable energy PPAs

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1 Introduction

India has set itself an ambitious e-mobility deployment target of 100% by 2030. As we set our foot in the new decade of 2020, we are faced with numerous hurdles in realizing this target. These hurdles can be summarized as below—

- Capital cost of Electric vehicles in India is a big hurdle for private buyers to switch over from ICE vehicles. These at the moment range from upwards of 10 Lakh + INR, which is well beyond middle class price ceiling range of 4–5 Lakh INR to buy a new small car. Another important point to note here is most Indians end up using there new cars well beyond 5 years or atleast want to have a good resale value for a new car if they resale the car around the age of 5 years. The prevalent battery of Li-ion has a life of around 3 yrs to 5 yrs and the cost to replace is almost 50% of the EV cost which will be around 5 lakhs more. Hence to buy a new electric car which the Indian buyer wants to use beyond 5 years, the cumulative capital cost will come upwards of 15 Lakh INR, which very few new car buyers will opt for.
- Almost complete absence of public charging Infrastructure for Electric vehicles.
- Very few incentives and subsidies offered by the government to the new electric car buyers.
- Range issue with electric cars. A 200 km range is good for inter city travel, but then you still need an ICE car for Intracity travel. Indian small families which are the biggest consumers of the largest selling small cars segment are not known to buy 2 cars at a time since they cannot afford it. The moment you think of cars beyond the range of 200–500 km, the cost increases between 20 Lakh INR to 25 Lakh INR, this again is far away from the comfort price segment of 4–5 Lakh INR for Indian consumer.
- It is equally important to note that increasing the private ownership of electric cars will also increase the congestion on Indian city roads, since the space required by an electric car on road is sadly same as that of ICE car. Hence as a first step, going for shared electric public & freight transport in the Indian context is a must as also rightly pointed out by Mr. Chetan Maini (*Founder of Reva India and co-founder of* SUN Mobility India) which I quote here [1] "*In India only 22 people per 1,000 own cars, while in the U.S., it is 980 per 1,000 individuals. So, it makes sense for India to first pursue the path of electrifying public and shared transport*."
- Another important factor to get maximum benefits from electric mobility transition is to go for renewable energy to exclusively charge the electric vehicles. Sadly the roof top renewable energy sector in India is not as dynamic or mature as in Germany which has had the well thought of "*Energiewende*" process [2] in Germany to help lead this massive social deployment of roof top renewable energy. This green energy factor is also rightly pointed out by Mr. Chetan Maini [1], which i quote "*EVs offer all of these benefits, but it is important to link EVs to renewable energy to truly make the mobility ecosystem sustainable. In this aspect, the government is targeting to install 175 GW of renewable energy by 2022*"

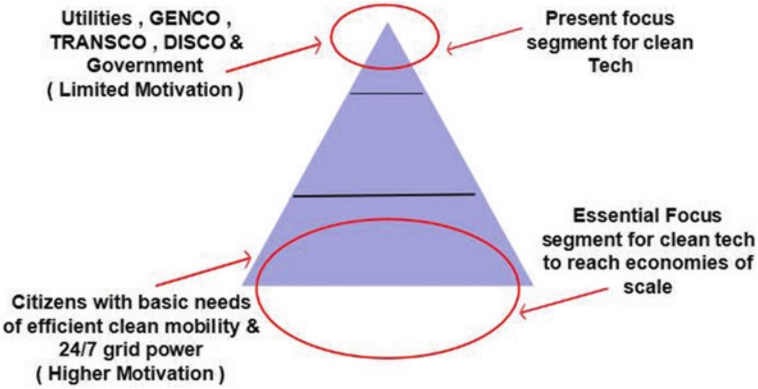

Fig. 1 Essential focus segment for deployment of Clean Tech

Summarizing these hurdles it can be noted that the clean energy roof top deployment and electric vehicles adoption lead, needs to be taken up by the common citizens which stand to gain the maximum benefits and hence will have higher motivations for this transition to happen, rather than just the government or energy utilities which will always have limited policy & budget restricted motivations as captured in this “Fig. 1”.

This paper in the following strategies explains exactly how to shift to this essential focus segment where common citizens with higher motivations can help deploy clean tech at scale for faster transition to electric mobility era for India.

2 About the Smart Green Transport Grid

The Smart Green Transport Grid “Fig. 2” can be seen as a long term & scalable solution to the above hurdles for deployment of electric vehicles at scale in India.

The salient points of Smart Green Transport Grid (SGTG) are as follows—

- The SGTG will be the latest in Smart Grid Technologies and will be backed up by the Central Grid for load balancing purpose.
- The SGTG can be set up in a Public + Private partnership mode or in 100% Private mode for faster implementation, integration and scale up.
- The SGTG can be charged using the renewable energy, generated through the roof top solar and wind energy, that can be purchased through PPAs, thus giving impetus to the Renewable Energy sectors in India.
- Energy storage segment can also be very helpful in providing the necessary back up to the SGTG at peak dispatch times
- SGTG & Central Power Grid as in “Fig. 2”, can act as mutual back up for each other &help stabilize each other during peak dispatch times

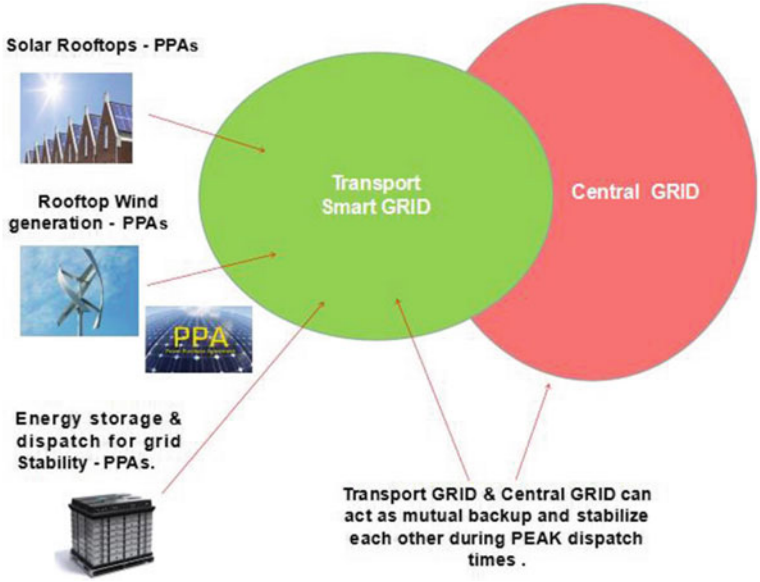

Fig. 2 Smart green transport grid & its Green components

- The SGTG can be scaled up from land over to water (for deploying E-Ships), over Air (for deploying E-drones/Air Taxis) and over Farms (for deploying Irrigation applications like E-Tractors, E-Trucks & E-Pumps).
- The SGTG will be truly smart and ready for future requirements like those of Renewable Energy to Grid Integration, Vehicle to Grid (V2G), Battery to Grid (B2G), Charging in Multi-Unit Dwellings (MUDs), Workplace Charging (WPC) etc.
- Almost 100% of the SGTG can be manufactured in India generating much needed local employment.

3 Why Battery Less Trolley Buses Are Crucial for Shared Public & Freight Mobility in India

As we have seen in the Introduction section earlier that shared electric multi-modal mobility is very important for faster transition to electric mobility for India, given the exorbitant costs of owning an Electric Vehicle, the proven battery less & trackless Electric Trolley Bus Technology "Fig. 3" can be a big boon for a faster transition to electric mobility for India.

Electric Trolley buses [3] have the following advantages—

- Electric Trolley buses are 100% battery less in operation.
- They do not have recurring battery change expenses.

Fig. 3 Battery less & trackless electric trolley buses

- They are trackless and run on tyres like normal buses, hence no digging of roads or traffic diversions are necessary for their deployment
- Electric Trolley Bus network over 100 s of kms can be made operational in just couple of months.
- They do not need charging station network for operation & hence have no range limitations as such.
- Since they are free of batteries, overloading does not effect their performance or range.
- The same trolley bus network can be used for freight transport to improve network utilization and faster ROI.
- One faulty route (track) does not halt line operations
- Existing infra of BRT, old buses can be efficiently re-purposed & reused
- Following advantages compared to Metro Rail—63% Less Total capital cost/km, 61% Less Operational cost/km, 41% Less Expensive per operating hour
- Highly scalable, 130 years old proven system, operational in 43 countries, on 300 locations at the moment.
- Can be 100% manufactured in India, boosting the Make in India goal and improving economies of scale for Electric Vehicle ancillary & component manufacturers which cross subsidize to indirectly help reduce cost of mainstream battery based electric cars
- Is available in multiple Hybrid propulsion platform models for further customized implementations on case to case basis, as in “Fig. 4”

4 Enabling the Roof Top Renewable Energy Sector Using the Smart Green Transport Grid

The Smart Green Transport Grid can be made to run on 100% renewable energy “Fig. 2” in a step wise fashion either through deploying captive renewable energy generation plants & additionally with a mix of buying renewable energy through PPAs from roof top solar & small wind farms. This will act as a big boost to the Solar Energy and small wind manufacturing sectors in India since as yet the Solar

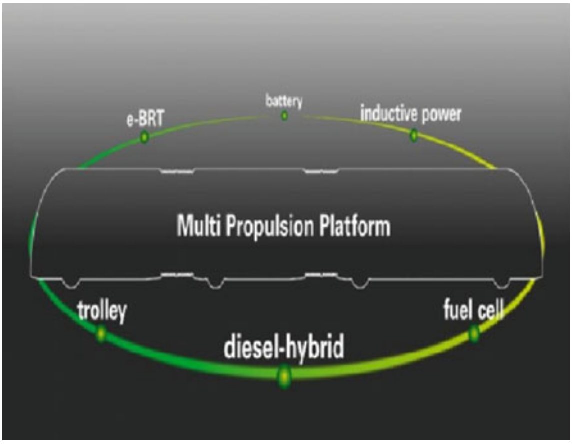

Fig. 4 Multi propulsion platforms for Electric Trolley Buses

Rooftop sector in India has not matured enough since it had only the net metering policy to support it till now.

But the presence of Smart Green Transport Grid can help to create a robust PPA market, something on the lines of the German "*Energiewende*" [2], which can help act as a catalyst to boost the deployment of Solar & Small wind Roof tops in India.

5 Extension of Smart Green Transport Grid Over Water, Air and Irrigation Sectors

The biggest asset of the Smart Green Transport Grid is its scalability to deploy multi-modal electric mobility not just over different terrains on land but also on water, air and farmlands.

A. *Extending the Smart Green Transport Grid over Water*

The Smart Green Transport Grid can be seamlessly extended over waterways on rivers, lakes & canals to improve mobility of people and freight through E-boats and E-ships "Fig. 5". This will also help reduce congestion on roads and help reduce carbon emissions through mobility on both land and in water.

As a side effect this will also help in building new waterways and canals thus improving farmland connectivity and irrigation as well. Over water the Smart Green Transport Grid can be charged additionally through floating solar panels, which can also help reduce water evaporation in lakes and canals.

B. *Extending the Smart Green Transport Grid over Air*

The Smart Green Transport Grid can be scaled up to support Electric Air Transport "Fig. 6" through use of Autonomous Air Taxis. This can be a big boost to reduce

Fig. 5 The 25-ton ship, named BB Green, a first all-electric Air Supported Vessel (ASV) in Riga, Latvia using Leclanché Battery Technology [4]

Fig. 6 E-Hang Autonomous Air Taxi [5]

rush hour congestion in cities and can further help to reduce congestion on roads and help reduce carbon emissions through mobility on both land and in the air.

This can also be looked upon as the preferred mode of transport of VIPs in the city which will help avoid unplanned traffic stops & improve land based traffic flow in the cities. Medical Emergencies sector can also benefit from this mode of Air based E-Mobility.

C. *Extending the Smart Green Transport Grid over Farmlands for Irrigation Sector*

The Smart Green Transport Grid can be scaled up over farmlands to support Irrigation equipment's like Electric Tractors "Fig. 7", Electric Trucks as well as Electric Water Pumps.

Considering 80% of India's economy to be Agriculture base, this electrification of Agriculture economy will help reduce substantial carbon emissions. Additionally

Fig. 7 The Fendt e100 Vario: The battery-powered compact tractor [6]

the Bio-Gas sector can get the much needed impetus since in farmlands Bio-Gas is available in plenty which can be used to charge the Smart Green Transport Grid as well. The Electric Trolley Buses can also form part of this picture in Agriculture economy to help lay the right foundation of shared electric mobility in the Rural sectors.

6 How the Smart Green Transport Grid Aligns Perfectly Well with the Government of Indias Goals and Vision

All of the domains of implementations that we have seen for the Smart Green Transport Grid align very closely to the defined goals of various sectors by the Government of India, which is very essential for the success of any new E-mobility deployment model being worked upon, these goals namely are—

D. *FAME India—for Faster adoption and Manufacturing of Electric Vehicles* (Fig. 8).

E. *Make In India*—(Fig. 9)

F. *Renewable Energy Targets of 175 GW by 2022* (Fig. 10)

Fig. 8 FAME India policy for E-Mobility Logo

Fig. 9 Make in India Logo

Fig. 10 The Renewable Energy Deployment Goals for India

7 Conclusion

From the points elaborated in this paper it can be concluded that the Smart Green Transport Grid lays down a very step by step approach to tackle all the hurdles currently faced during deployment of the E-Mobility in India.

The goals of Smart Green Transport Grid are very closely aligned with the Clean Tech policies of Government of India, and once implemented in the phase wise manner over the next 5 years it can certainly help realize following to begin with—

- Can help Deploy close to 10 million EVs on land, Air, Water and Farming sectors.
- Can be 100% locally manufactured, will hence help improve local sustainable employment opportunities
- Can help reduce 100 MMT carbon emissions/year
- Will help deploy close to 100 Giga Watts of distributed Renewable Energy Capacity

- Will help create the much needed economies of scale for both Electric mobility as well as Renewable Energy Manufacturing sectors in India, which will help bring down the costs of finished goods in these sectors
- Private ownership of the Smart Green Transport Grid will help it become more Agile in deployment and faster in many ways to make any necessary transitions and developments in its technical structure driven by the market requirements
- Will help save considerable foreign exchange $ for India in Crude oil imports, which will be instead supported by the sustainable renewable energy capacity deployed to support the transition to Electric Transportation over land, water and Air through the Smart Green Transport Grid.

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Standards and Interoperability of Equipment and Systems for Smart Grid in India

Amit Jindal, Manoj Bansal, and Amit Kumar

Abstract The smart grid is the complex system which leverages the convergence of communication, various hardware and software technologies adding intelligence to the electric power industry. To achieve this objective, standards and interoperability of the various system is a pre-requisite. Standardization of the product/services would be required for scaling up of the prototype. A standard is an established norm for accomplishing defined task. Standardization is a formal document to establish engineering design, technical parameters, guidelines, processes, and practices. These standards are formulated to bring together all stakeholders towards achieving common objective. Interoperability is the capability of two or more devices, systems, appliances, networks, applications, or components to share and readily use information securely and effectively without any inconvenience to the stakeholders. It promotes open architecture of technologies considering both physical and logical interaction with other systems. An interoperable SG fosters competition among suppliers, innovation, choice, reduced costs and reduced capital risk caused by technology or vendor obsolescence, and enables automation to improve system value and reliability. Unfortunately, interoperability cannot realistically be achieved by a single entity and requires collaboration from numerous organizations including utilities, regulatory bodies, standards bodies, market players, stakeholders and more. Due to the system complexity, scalability and devices involved in creating an effective SG solution, interoperability between the various systems is the key to success. Utilizing a standardized approach methodology to develop use cases and functional requirements to support integration of emerging technologies as well as identify gaps in existing standards providing focus for research and development.

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1 Introduction

Smart grid is a complex IT-based solutions which includes a variety of operation and energy measures including hardware, software, analytics, energy sources and energy efficient resources. Electronic power conditioning, self-healing and control of the generation, transmission and distribution of electricity are important aspects of the smart grid. It endures complex distribution systems to meet the more decentralized power generation due to microgrids. The technology in microgrids ensure availability of power at cheaper cost cheaper for households than buying from utilities. Additionally, residents can manage their energy consumption easier and more effectively with the connection to smart meters. However, microgrid performances, accessibility and reliability strongly depend on the continuous interaction between power generation, storage and consumption/requirements.

Smart Grid system should have real-time communication, inter-operable, secure, reliable, scalable, manageable, and extensible without human intervention. To meet such objective, Smart Grid should integrate with advanced sensing technologies, control methods and integrated communications into current electricity grid into Generation, transmission and distribution levels.

A transformative aspect for interoperability in the future electric system is synchronized operation of various devices, apparatus and systems at the edges of the grid infrastructure. Interoperability is a key obligation for successful implementation of smart grid system. Interoperability denotes to the ability of two or more networks, devices, systems, applications, or components supplied from the same vendor, or different vendors, to exchange information for work together without substantial user intervention and use that information in order to perform required functions." In addition, "Interoperability between various systems in a smart grid solution must be specified in design documents with consideration of functional/non-functional requirements, Use & Test Cases (TC)" (Fig. 1).

An interoperability is a foundational requirement of the modernized or "smart grid," which is a large, diversify, complex "system of systems" with many stakeholders who each have diverse needs that must be met. To realize the benefits of the modernized grid, a multitude of independently devices developed/invented by a range of different manufactures or suppliers, managed by various utilities with diverse business, and utilized by a countless number of customers—must effectively communicate and work together. Additionally, these devices and systems deployed with utilities must be compatible for data exchange and connectivity with consideration of business and regulatory perspective. Smart Grid architecture framework provides high-level context with many complex interactions for interoperability of these devices on the modernized grid.

The interoperability can be achieved with though the use of standards, detailed system specifications and rigorous system testing. To achieve an interoperability

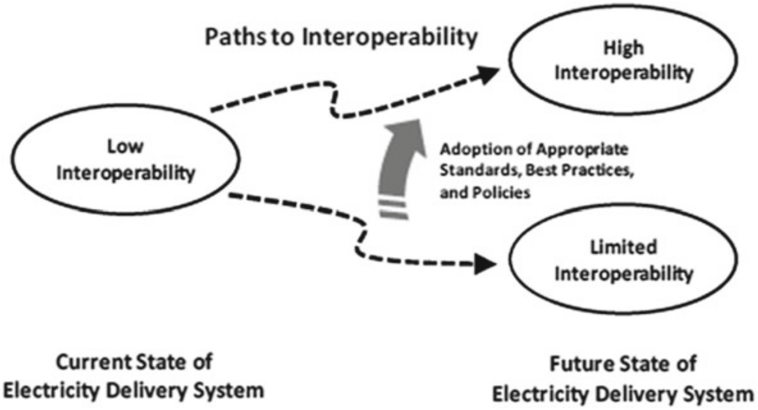


Fig. 1 Paths to Interoperability. *Source* Grid-Wise, Interoperability path paper

of various systems, several steps should be taken such as: the definition of functionalities, respective standards, and creation of profiles and detailed testing of device/system which includes both the conformance and the interoperability testing. Therefore, a systematic methodology should be adopted to verify the ability of a given equipment under test to communicate effectively with other components. The "systematic" methodology means to analyses any interoperation flaw against business and user requirements. Further analysis could be applied to assess the impact of any inconsistency and propose potential solutions. so that interoperability of different subsystems or electric grid components with consideration of business requirements can be achieved.

2 Background

In August 2013, the Ministry of Power, Govt. of India, released a vision document namely "***Smart Grid Vision and Roadmap for India***" to provide a roadmap for setting up smart grids in India by the year 2027. The smart grid road map spreads over 12th, 13th and 14th five-year plan periods from 2012 to 2027. The vision behind the road map is to transform the Indian power system into a secure, adaptive, accessible, sustainable and digitally enabled eco-system to provide reliable and quality energy for all with active participation of all stakeholders.

Ministry of Power (MoP) has taken several initiatives such as setting up the India Smart Grid Task Force (2010) and the India Smart Grid Forum (2011) for providing policy direction to smart grid initiatives and accelerating the development of smart grid technologies. In 2015, MoP has launched National Smart Grid Mission (NSGM) to plan and monitor the implementation of smart grid policies and programs and undertaking smart grid pilot projects (2012) to test and show case various smart grid functionalities. Though housed under the Ministry of Power, it also liaises with Ministries of New and Renewable Energy (MNRE), Urban Development (MOUD), Heavy Industry (MOHI), Communications and with State Governments and Utilities to fulfill its goals.

Another important development towards smart grid is net metering policies for renewable energy. As on January 2016, 25 state electricity regulatory commissions (out of 29 in the country) have issued net metering policies that would empower customers to become "prosumers" as envisioned in the smart grid roadmap. Government of India is aggressively promoting roof top PV program with a target of 40 GW from 20 million roofs by 2022 and the net metering policies in almost all big states will facilitate faster rollout of this rooftop PV program.

MoP with inputs from USAID and other stakeholders prepared a Model Smart Grid Regulation and got it approved by the statutory body, Forum of Regulators (FOR) issued the Smart Grid Regulations in September 2016 and Draft Smart Grid Regulations have already been issued by various SERCs. In line with India's vision, Bureau of Indian Standards (BIS) finalized the national standard for smart meters in October 2015, IS-16444, to standardize anti-tamper measures and enable modular plug-and play communication. BIS issued IS 15959 (Part 2) and IS 15959 (Part 3), the standards for data exchange protocols for smart meters, in March 2016 and April 2017 respectively.

Ministry of Power, launched ***Ujwal DISCOM Assurance Yojana (UDAY)*** which is financial turnaround and revival package for DISCOMs initiated by the Government of India with the intent to find a solution to the financial mess that the power distribution is in. The scheme envisages financial turnaround, Reduction of cost of generation of power, improvement in operational efficiency, Development of Renewable Energy and Energy efficiency & conservation. The UDAY scheme has targeted activities like Compulsory feeder & DT metering, Smart metering of all consumers consuming more than 200 units/month and Demand Side Management like LED lighting, energy efficient appliances. "**UDAY 2.0 to focus on checking power theft, promoting smart meters**".

Smart Grid Knowledge Center (SGKC) is being developed by POWERGRID with funding from Ministry of Power. This will act as a knowledge hub for providing technical support to the mission in all technical matters, including sharing of learning achieved from various projects, best practices, capacity building, outreach and suggesting curriculum changes in technical education etc.

3 The Need for Interoperability

It is important that diverse devices and systems are available within the utility, which play crucial role to achieve an ability to inter-operate in smart grid. The moment we change/install or upgrade the any hardware like meters, distribution equipment, substation equipment and software like back office applications, SCADA systems etc. then deployed smart grid solution should automatic identified new device and configure the same without human intervention.

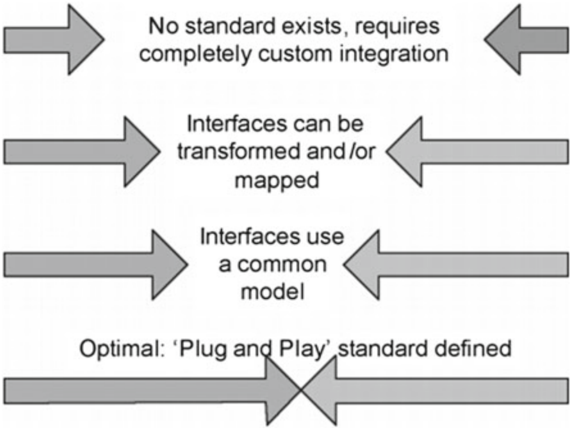
"Interoperability among devices, appliance, systems and applications is important for several reasons. First, innovation of new technologies, which have created new industry-changing activities such as distributed energy resources (DER), microgrids and advanced demand response field devices, which are technical/physical disparate, require to work together remotely near real time. Secondly, it is key requirement for successful implementation and operation of an efficient, cost-effective and secure grid. Interoperability allows the utilities to leverage existing grid network infrastructure and underutilized assets. Furthermore, it reduces the effort in device configuration, management and commissioning. Finally, the expected and growing implementation of DER and microgrids will require distributed analytics and operations."

Attaining "**plug-and-play**" capability is a well-known example of interoperability where standard hardware devices/components can be discovered in a system and configure remotely without human intervention. In such a scenario, a user can integrate a device simply by plugging it in without any support. system background processes assess the new device, collect technical parameters and configure it so it can function properly within utility system. The most common example of physical interoperability is standard electrical outlets. Having a standard outlet within the India allows for the interoperable use of appliances and electronics throughout the country. Another excellent example of the benefits of interoperability is the circuit breaker, where the one manufacturer of circuit breaker can be replaced with different manufacturer of circuit breaker and it handles the entire integration process without human intervention.

Smart Grid architecture model contains various layers like Business layer, Functional layer, Information layer, Communication layer and Physical/Component layer for interoperability purpose. These layers have to interactions (i.e. based on physical, information and process) includes the field level (e.g., substation automation, distribution automation, distributed energy resources), to remote operations (e.g., remote grids management), market management, service management, customer management, etc. should assure the interoperability principle.

In addition to *physical interoperability*, other layers of interoperability are important, many of which build upon the basic physical layer. As an example, smart meter may exhibit physical interoperability via their plug-and-play capabilities, but for read the information contained within the smart meter, there must be *syntactic interoperability* that enables shared understanding of the data structure in the messages exchanged. Further, for an application to utilize and integrate the data into an existing analysis there must be similarly defined variables and *semantic interoperability* that enables shared understanding of the concepts contained within the message data structure. *Business and regulatory interoperability* layers are additional levels that must be considered. Ultimately, different interoperability standards may be needed to address each of these layers.

Exhibit 1 Distance to Integrate. *Source* Scott Neumann, UISol position paper



Interoperability can be facilitated by the development of open standards,[1] an adherence of standards by stakeholders, and compliance verification through independent testing and certification. Interoperability standards that are open and consensus-based increases consumer choice. This may become even more important as smart appliances, smart thermostats, and smart building management system become more widespread.

Value of Interoperability

- Reduces the cost and effort for system integration
- Extension of asset/infrastructure life
- Improves grid performance and efficiency
- Facilitates more comprehensive grid security and cybersecurity practices
- Increases customer choice and participation
- Establishes industry-wide best practices
- Generation of economic benefits

Additionally, encouraging system interoperability through the development and implementation of interoperability standards can generate important benefits. For example, standards can **enable future compatibility** by providing a structured interface for future developments and help ensure that technologies deployed today (such as AMI), are interoperable with more advanced technologies or future AMI deployments. Standards that advance interoperability can also **decrease system integration costs** by enabling the use of common, specified interfaces (as opposed to necessitating customized interfaces for each new system or component that is added), thereby reducing the cost of introducing new technologies and applications onto the system.

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[1] An "open standards" is a standard that is publicly accessible and use without constraints in a manner equally available to all parties without dependent on formats or protocols. These standards should be free from legal or technical clauses that limit its utilization by any party or in any business model. Any party can manage, customize and further develop as per their business requirements.

Similarly, it can extend the useful life of legacy infrastructure. Additionally, interoperability and associated standards can help **encourage innovation** by increasing the likelihood that new technologies can be deployed across the grid, thereby providing a reliable market for end products. It can further reduce costs and can reduce investment uncertainty by reducing market fragmentation, decreasing transaction costs, promoting competition among vendors, helping avoid "vendor-lock," and enabling economies of scale.

The interoperability standards will allow utilities to procure device or pieces of equipment from any supplier considering that new device /equipment/component will work seamlessly with each other and with existing equipment at every level. These standards will allow physical interfaces—one plug fitting with another, syntactic interfaces to understand data structure of shared information and semantic interfaces for enables shared understanding of the concept at all levels in a given system. The entire system not only need to speak the same language but also have to understand each other's "thought" processes.

While standards do promote interoperability, they do not guarantee interoperability. Testing of device/product is desired for quality assurance, standard compliance and interoperability. Standards states technical specifications, functional requirements, device performance and testing programs provide the compliance verification that the standards have been implemented appropriately to provide interoperability. Testing and certification is taking on increased urgency driven by the fact that while there are many smart grid standards, there remains a large gap in the availability of test programs corresponding to these standards.

4 Interoperability of Smart Grid Components

The electric system, which is large and multifaceted, is in transition toward a future/modern grid. With the introduction of digital technologies like smart hardware, software, analytics, blockchain, Internet over Things (IoT) etc., it's becoming more complex and necessitating greater integration and interoperability. These types of large, integrated, and multidimensional systems require various layers of interoperability within system architecture framework.

The interoperability will enable the accessibility of integrated solution with their functionality and commensurate benefits delivered by the future/smart grid. Architecture framework with the appropriate approaches to establishing standards play vital role to achieving high interoperability. *Successful outcomes from standards development and standards selection can accelerate technology adoption by decreasing costs, reducing investment risk, and encouraging innovation. Unsuccessful outcomes will dampen investment, restrict synergies, limit the eventual benefits of the smart grid, and cause expensive redesign and reconstruction.*

The Smart Grid Architecture Model (SGAM) is an evolving framework that can be used to guide the development of the smart grid. The SGAM includes architectural goal, concepts, methodology, legacy system fitment, information network and conceptual business services. Several different grid architecture frameworks are promoted worldwide, which must support:-

- Devices and systems developed independently by many different solution providers
- Covering wide spectrum of utilities like Electricity, Water, Gas etc.
- Millions of industrial, business, and residential customers
- Different regulatory environments

The SGAM deliberates the interoperability component of the smart grid in layers, which was originally defined by GWAC and is referred to as the Grid-Wise Architecture Council (GWAC) Stack. The original GWAC Stack provides the most useful basis for understanding the types of interoperable functionality needed by components of the distribution system. GWAC framework spans the entire electricity supply chain and provides a logical organization of the standards desired for interoperability among various devices/components in the Smart Grid. The framework also provides a structure to identify areas of concern and their interdependencies that would need to be addressed. The GWAC Stack layers represent a "vertical cross-section of the degrees of interoperation necessary to enable various interactions and transactions on the Smart Grid."

The GWAC Stack includes eight layers of interoperability (see Exhibit 2) that represent the different types of interoperation that are needed in order to allow devices and systems on the smart grid to communicate, interact, and conduct transactions effectively. In the utilities, the key technologies and components that most necessitate interoperable functionality include, but are not limited to AMI, integration of distributed renewable energy generation and storage, distribution grid management, DR, consumer energy efficiency, and network communications.

The lowest layers of interoperability, such as basic connectivity and network & syntactic interoperability, include simple functionality (e.g., interoperability of physical device, data communication and software for information exchange). The middle layers, such as semantic understanding and business context, include communications practices and functionality (e.g., the content, meaning, and format for informational flows). The highest layers, such as business procedures and objectives, as well as economic/regulatory policy, address relationships between individuals and/or organizations at various parts of the system, such as business (e.g., contracts), legal (e.g., intellectual property rights), and policy (e.g., regulations).

The eight GWAC layers can be grouped into three categories of interoperability: technical, informational, organizational. To achieve full, effective interoperability all category must be addressed. These layers are required to interoperate to attain the desired outcome as devices/systems become more complex in nature. Each layer builds upon and is coupled by the lower layers. According to the National Institute of Standards and Technology (NIST), "the most important feature of the GWAC Stack is that the layers define well-known interfaces which are loosely-coupled: establishing interoperability at one layer enables flexibility at other layers."

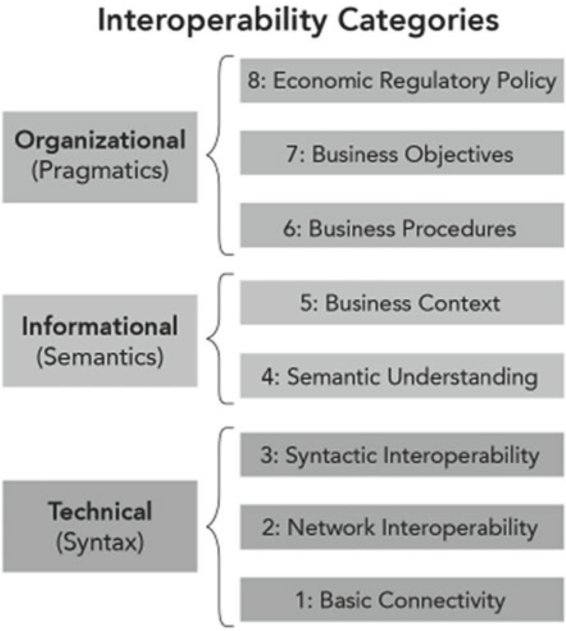

Exhibit 2 GWAC stack. *Source* Grid-Wise® Interoperability Context-Setting Framework is a work of the Grid-Wise Architecture Council

5 Interoperability Challenges: Technical, Security, and Financial

The utilities in India are making significant investments for digitalization and deployment of new technologies like Smart Grid in order to improve their systems and capture the claimed benefits. However, in the open and interconnected environment, where Smart Grid technologies are deployed, there is a risk that system components do not properly operate in an integrated system, resulting in interoperability issues, even though these devices normally undergo individual quality control and operability tests.

The major challenge is an implementation of common standards and integrate of interchangeable parts from a variety of different providers worldwide. Creation of standards and acceptance from the manufacturers will unleash the open market, which comes with innovation & services, that enable interoperability & integrate at all levels of power systems. In addition, to be truly effective, the grid must also be prepared to interact with standards from various industries, such as industrial equipment, distributed energy resources (DERs), battery storage, building and process control systems, home automation, appliances, and plug-in hybrid vehicles (PHEV). ***A major challenge for interoperability is the integration across domains. Interoperability is an intangible quantity, so its measurement poses a major challenge***.

Achieving all the benefits of a smart grid will not be easy. The task is very complex and furthering standards alone will not get the job done. The scope is global and thousands of companies and organizations working together are necessary to achieve a smart grid. By collaborating to further standards as well as identify critical gaps in standards and technologies, the collaborative becomes a powerful force that will result in a market that fosters a capitalistic environment with a long-term goal of system wide interoperability.

Physical, network and Data exchange are basic requirement for technical interoperability from various devices/component of smart grid. Until there is transparent communication interoperability from various devices, there would be significant risk to invest in non-standardized systems. The lack of technical interface and interoperability is one of the primary factors to utilities from deploying smart grid systems and further development of controllable system interfaces and devices. Although the Internet has provided many of the transport level standards (e.g. Ethernet, IP addresses), while power industries often use proprietary protocols. Very few systems have implemented the application level communication standards, and therefore need human intervention for data exchange and information extraction.

Furthermore, only few needed standards have been developed yet and much less implemented by stakeholders. Particularly in the novel realm of AMI, utilities are bound to deploy proprietary systems due to absent of desired standards and lack of innovation/development by vendors. Long time is needed for development of new standards. Even if a new standard is developed and touted as the perfect answer, “paper” standards always need to go through extensive assessment and testing on “real” systems before they are ready for general deployment.

Security has also made interoperability more of a challenge. No longer someone just plug in a new device, but it must be authenticated. For instance, if a disgruntled user plugged in a device that smart grid system thought was a smart meter, but really was a “Man in the Middle” hacker’s device, he could enter in the utility system to snoop on all information. So new measures to ensure the real identity of devices must also be developed and installed.

Financial considerations are also important in moving toward interoperability. Even if all the new technology, standards, and security were available, no utility could afford to throw out older, non-compliant systems. Therefore migration paths toward interoperability have to be planned, with systems, applications, and devices gradually replaced. stakeholders also cannot afford to upgrade their systems the moment a new standard is approved. This is in part just the time and effort to implement the new standard, but a larger financial burden is in the extensive testing of the upgraded systems particularly for revenue sensitive equipment such as meters.

And, as wryly stated by some standards experts, “***The best thing about standards is that there are so many to choose from***,” leaving many vendors and utilities perplexed about which standards will have the staying power and flexibility required to remain relevant for a reasonable number of years.

6 Ongoing Interoperability Efforts and Standards Development

Efforts for development of standards and Interoperability of Equipment and Systems for Smart Grid are underway at the international and national level among industries, utilities, stakeholders and relevant authorities. Government designated entities like BIS, CBIP, CPRI etc. plays vital role in addressing the opportunity of interoperability, including:

- Promoting “open standards for devices/components to integrate and interoperable”
- Convening and building consensus with industry and market players to develop an interoperability vision
- Foundational support needed for new approaches, technologies, and the requisite skilled work force to support the realization of the latent value that resides in buildings
- Recognizing explicitly the value connected smart equipment can play in helping to realize the goals of renewable portfolio standards

At international level, Industry organizations such as the Institute of Electrical and Electronics Engineers (IEEE), the International Electrotechnical Commission (IEC), the American National Standards Institute (ANSI), the International Organization for Standards (ISO) and the Internet Engineering Task Force (IETF) and North American Energy Standards Board (NAESB) among others, lead interoperable standards development efforts. Government entities such as the Smart Grid Interoperability Panel (SGIP) and the National Institute of Standards and Technology (NIST) have all supported the formulation of the smart grid framework for interoperability in various ways.

In India, At national level, Industry organizations such as Indian Electrical and Electronics Manufacturers Association (IEEMA), The National Association of Software and Services Companies (NASSCOM), Telecom service providers (TSP), Federation of Indian Chambers of Commerce & Industry (FICCI), among others, along with State utilities, National Smart Grid Mission (NSGM), Bureau of Indian Standards (BIS) and Central Board of Irrigation & Power (CBIP) are developing interoperable standards with all desired support.

At the National level, Bureau of Indian Standards (BIS) has formed a committee namely LITD 28 for Standardization in Electro-technical & ICT aspects and development for **Unified & Secure ICT** Architecture for Smart Cities/Grid Infrastructure. Under LITD 28, following areas identified for standardization.

- Unified & secure Last Mile Communication Protocols for Smart Infrastructure
- Common Service Layer for Smart Infrastructure
- ICT Reference Architecture for Unified & Secure Smart Infrastructure
- Data Semantics Framework for Smart Infrastructure
- Common Gateways for Smart Infrastructure
- Use Cases for ICT & Electrotechnology in Smart Cities

- Implementation Challenges in ICT & Electro-technology related deployments in Smart Cities
- Standards Inventory and Mapping
- RF Spectrum allocation & de-licensing implications
- 5G imperatives for Smart Infrastructure
- Unified & Secure Common Citizens' Payment Systems Framework"

Draft standards are part of the series of standards for unified ICT Reference Architecture and BIS has blocked IS numbers IS 18000 to IS 18050 to the entire series. It is appropriate to do the wide circulation after allotting the IS numbers to all the standards in the series which are mentioned/referred to in these documents.

Apart of LITD 28, Bureau of Indian Standards (BIS) also has formed a committee namely ETD 13 for Standardization in Electro-mechanical development of smart grid devices like meter, communication module & power supply for Smart Grid Infrastructure. Under ETD 13, following areas identified for standardization.

- Specify meter electrical & mechanical layer size
- Introduction of a test method for IPv6
- Inclusion of Smart meters testing in IS 15707
- Changes in sampling and testing requirements
- Development of Indian standards on dc energy meter
- Revision/amendment of IS13779, IS14697, IS16444 & IS15959 standards
- Redefine communication protocol & Load Switch under IS16444

ETD 13 committee has proposed to change in technical parameters of IS13779 & IS14697 for impulse voltage test in line with IEC to increase the impulse application from 5 to 6 kV. Secondly, Surge Immunity test with test voltage changed to 4 kV in place of 6 kV.

The Central Power Research Institute (CPRI) of India is establishing a Smart Grid testing facilities for test Smart Grid technologies and systems as well as establishing quality and performance standards for such equipment and systems. CPRI already has test facilities for some of the building blocks of Smart Grid, including protocol laboratories for SCADA, Meters and IEDs and is uniquely positioned to cater to utilities' and manufacturers' Smart Grid requirements in the area of third party, testing, validation, training, consulting and research and development. Such facilities will allow for the research of technologies and systems for a wide range of Smart Grid applications to perform specialized, controlled laboratory evaluations of integrated Smart Grid technologies including substation automation, load management, smart meters, cyber security, network sensing, energy management, renewables integration, and plug in hybrid electric vehicles (PHEV). The testing facilities would be used by manufacturers, utilities, integrators, consulting firms and academics for various activities including testing, certification and training.

Often de facto standards are being developed either by a leading organizations (e.g. IBM's ASCII and Microsoft's OLE) or by a consortium of vendors (e.g. Zigbee Alliance) in place of an authorized organization, Nevertheless can be widely used.

In many cases, successful de facto standards eventually become formalized into real standards. In other cases, recommended practices can help narrow the choices.

Most standards are developed by vendors and consultants, with limited involvement of utilities.

7 Conclusion

Interoperability is a critical enabler for successful implementation of smart grid. It allows new emerging technologies to scale up and accommodate without dependency on manufacturers/suppliers. A successful development and deployment of the smart grid requires a better understanding of components/system interoperability. Standards ensure that new devices should capable to interoperate in a secure environment for advancing the economic and energy security of the country. Standards should be flexible enough to add new functionality or select certain options. Standards are considered as minimum bare requirements to address for interoperability needs and flexibility enough to meet specific requirements and unforeseen requirements in the future. The on-going smart grid interoperability process promises to lead to flexible, uniform, and technology-neutral standards for future grid that enable innovation, consumer choice and economies of scale. Standards are considered not only product/device technical information but also in conjunction with business processes, markets and the regulatory environment.

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Integrated Network Management System Paper

Anil Kumar Ojha and Abhinav Mogha

Abstract Utilities are trying to minimize AT&C losses with improved reliability indices. A Smart grid roadmap was adopted by TPDDL and technologies were implemented like Grid Substation & Distribution Automation, SCADA/ ADMS, GIS, AMI, DSM, Smart Meters, Communication Infrastructure and RF Canopy. Moving ahead, there is an increasing interests of Utilities on IT-OT convergence and adoption of IIOT based solutions to fulfill interfacing of different digital platforms like.

- Advanced Mobility Solutions, FFA.
- Distributed Energy Resources integration (Solar, Wind and Captive plants)

Focus is now being shifted from "**Energy Value**" to "**Information Value**". Large numbers of IEDs are getting integrated, making the Distribution Grid a complex ecosystem having two way flow of Electricity & Information with multi-dimensional deployment of "Intelligent Electronic Devices". These IEDs are the building blocks of digital revolution in Utility. While, IEDs have certainly improved the performance of the Distribution Electrical system but very less focus was given to the health & performance monitoring of these IEDs. IEDs are being passively managed in Silos in different verticals of Utility operations. Teams act on "Post fault scenario" and sometimes resulting in cascaded IEDs failures. Effective m**aintenance and management** of whole IED's network is a challenge due to absence of a "Centralized IEDs health and performance" monitoring system. A centralized INMS system has been developed for "Health & Performance" monitoring of Grid IEDs. All Grid equipment's/IEDs which uses TCP/IP frames communicate with a central computer/server based system. Each IED's system diagnostic data is monitored and analyzed on real time basis. IEDs network topologies layouts were formalized with alarms & alerts generation and auto tickets assignment which trigger "condition based or predictive maintenance" over conventional maintenance approaches. IED failure analysis

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is done & it also provide inputs for inventory management. Efficient IEDs "Health and Performance" monitoring facilitates optimum utilization of these large number of IED's network which has improved the Operational Efficiencies in Distribution Grid with better SAIDI and SAIFI reliability indices and reduction in AT&C losses. This paper explicitly describe about the needs/ purposes, methodologies adopted and hindrances faced in the implementation of INMS.

Keywords Advanced distribution management system · Integrated network management system · Simple network management system · Operations technology · Grid Substation automation system · System average interruption duration index · Mean time to restore · Internet message control protocol · Remote terminal unit · Intelligent device

Abbreviations

TPDDL:	TATA Power Delhi Distribution Limited
SCADA:	Supervisory Control and DATA Acquisition System
ADMS:	Advanced Distribution Management System
RTU:	Remote Terminal Unit
INMS:	Integrated Network Management System
OT:	Operations Technology
IT:	Information Technology
SNMP:	Simple Network Management Protocol
SSL:	Secure Socket Layer
MU:	Millions Unit
CAPEX:	Capital Expenditure
OPEX:	Operational Expenditure
LAN-	Local area Network
WAN-	Wide area Network
IP-	Internet Protocol
SL –	Service Level
OEM:	Original Equipment Manufacturer
AT&C:	Aggregate Technical and Commercial
AMI:	Automated Metering Infrastructure
GIS:	Geographical Information System
DSM:	Demand Side Management
RF:	Radio Frequency
FFA:	Field Force Automation
IED:	Intelligent Electronic Device
DER:	Distributed Energy Resource
TCP/IP:	Transmission Control Protocol/ Internet Protocol
SAIDI:	System Average Interruption Duration Index
SAIFI:	System Average Interruption Frequency Index

TMU:	Transformer Monitoring Unit
IIOT:	Industrial Internet of Things
HES:	High End System
MDM:	Meter Data Management
IP/MPLS:	Intelli Protection/ Multi Packet Label Switching
ICMP:	Internet Message Control Protocol
Syslog:	System Logs
DTL:	Delhi Transco Limited
CPU:	Central Processing Unit
GSAS:	Grid Substation Automation System
MTTR:	Mean Time To Restore

1 Introduction

Tata Power Delhi Distribution Limited (TPDDL) is a Power Distribution Utility, distributes electricity in North and North- West part of Delhi, serving about 1.7 million consumers. TATA Power-DDL has always been an early implementer of latest technologies & procedures in India and has perhaps most number of standalone and integrated platforms in use. These procedures have also been instrumental in improving the overall performance of the company and also been able to deliver business benefits in terms of return on capitalization of assets and improving reliability. TPDDL's competence in adaptation of latest technologies makes it very appropriate to achieve high standards in optimization of resources in maintenance and management of Grid networks.

Grid Substation Automation at TPDDL was started in 2006. Major technology up gradation carried out where in:-

- Old Electromechanical relays were replaced by Digital Communicable relays
- Bay Control Units were introduced
- Gas Insulated Switchgears compact Substations were installed.
- Old transformer RTCC panels were replaced by compact TMUs (Transformer Monitoring Units)
- Digital Substation process bus integration

All this technological shift took place with the introduction of "Intelligent Electronic Devices". IEDs revolutionizes the conventional Grid substations monitoring and control. Large numbers of IEDs were added in the system to enhance the system performance. These IEDs performs various complex functions like:-

- Advanced numerical, differential, distance Protection of Grid Electrical equipment's and reporting of the same to master SCADA.
- Digitization of Electrical Processes.
- Centralized remote Monitoring & Controlling of Grid equipment's & networks.

- Enhanced Transformers Monitoring and remote OLTC operations for voltage optimization.
- Energy metering and audit purposes.

Currently, we are having more than 3000 OT devices (IEDs) installed in our Grids which are communicating on TCP/IP frames. These IEDs are from different OEMs like ABB, GE, SIEMENS, ALSTOM, Aeberley & SYNERGY which supports different protocols like IEC 61,850 or IEC-104 resulting into a complex ecosystem of OT devices.

2 Approach to Way Forward

2.1 Problem Statement/ Understanding the Need/purpose and Objective

With Increasing focus of Utilities on Automation and adoption of IIOT based solutions to fulfill their IT-OT business objectives of achieving and complying all Service Levels of Automation which include:-

1. SL1:- Grid Substations OT devices.
2. SL2:- Zonal Switching Stations Distribution Automation Devices.
3. SL3:- LV Automation (Feeder pillar automation or ACB automation).
4. DER:- Distributed Energy Resources integration with existing Grids for e.g. Solar roof tops, Wind, Captive plants etc.
5. AMI:- Advanced metering infrastructure. Smart Meters deployment and integration with HES / MDM and SCADA / ADMS.
6. Communication Infrastructures like RF Canopy, Cellular Modems and IP/MPLS panels.

In addition, there is also a huge pressure on Indian Utilities for Smart Grid compliance. In simplest definition, there are projections that many more numbers of OT devices will be deployed in all verticals of Power Grid Networks for real time information exchange and advanced big data analysis.

A future Power Grid will be a complex system with two way flow of Electricity & information with multi-dimensional deployment of OT IEDs for e.g.

- Multi layers sensors, Analog to Digital converters, High end transducers
- Advanced Telemetry and Communication solutions like Optical, RF, Cellular, IIOT based
- High end computing processors, algorithms, servers

It is clearly indicative that, performance of Power Grid Networks is or will be directly linked to the performance of these OT IEDs network. Maintenance and Management of these IED’s has been a challenge for any Utility due to absence of

"Centralized Asset Health and Performance Monitoring System" which functions on real time basis. Conventionally, maintenance teams act on "Post Fault" scenario of IEDs failures which results in MU losses and compromised reliability indices (SAIDI & SAIFI).Thus a well-placed Integrated Network Management is very much required which would ensure the performance, availability and reliability of these IEDs. Efficient real time monitoring of Grid networks will increase the efficiency and productivity of Power grids which will subsequently results in reduction of AT&C losses.

3 TATA Power DDL Steps Towards Implementation of INMS

A centralized solution "NNMi" for OT devices has been developed which uses integrated Network Management System of IT for "Health & Performance monitoring of RTUs/IEDs which are installed in our Grid Substation Automation system. IT also can be used as a diagnostic tool. In this, all equipment/IEDs which uses TCP/IP frames communicates with your central computer/server based system. It dramatically improves performance, compliance, efficiency, productivity, automate analysis & can also provide inputs for inventory management (Fig. 1).

Integration philosophies adopted during the mapping of OT (RTUs/IEDs) devices:-

- Integration over ***ICMP*** protocol—All the Devices which uses TCP/IP frames support this protocol and Node Up & Node Down alarming is configured in this.

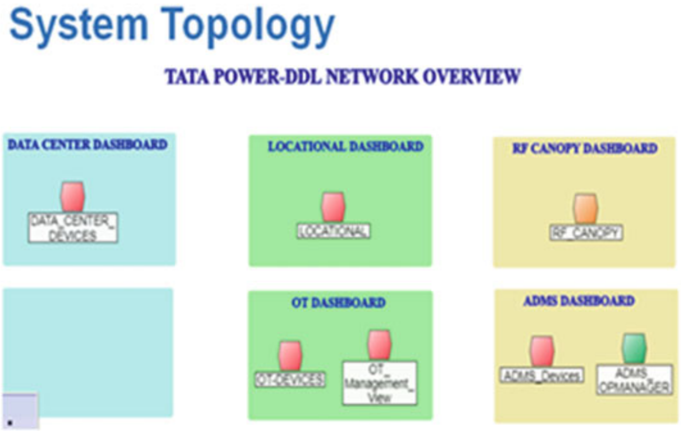


Fig. 1 System topology of TPDDL IT OT network

- Integration over ***SNMP*** protocol—SNMP protocol stands for Simple Network Management Protocol and more diagnostics health and performance parameters are mapped through this for e.g. CPU Memory, CPU Usage, SysUp Time etc.
- Integration over ***Syslog*** protocol—Few more special diagnostic parameters and logs are being fetched through Syslog servers from OT devices in this for e.g. Security Logs, Access Logs, and System diagnostic logs.
- Integration of Serial RS-485 devices through SNMP compatible RTUs:—This is another level of integration of legacy Serial RS-485 devices through SNMP compatible RTUs.

4 Scale/Size of Project

Key features implemented during the Project (Fig. 2):-

- **Alarms and alerts generations**—To get real time alerts of devices when they get offline
- **Report generation**—Auto report are being generated for e.g. RTU failure, Bay Offline, Ethernet Switches failure, CPU load and CPU memory.
- **Tickets assignment**—Auto tickets assignment as per the Responsibility and Escalation matrix platform has been devised.
- **Centralized/ Noc room** has been developed where all the daily routine maintenance work orders and caution orders being issued and work culture is maintained for optimized performance of RTUs/ IEDs.
- **Fault Management**—Detect, isolate, notify, and correct faults encountered in the device/network.

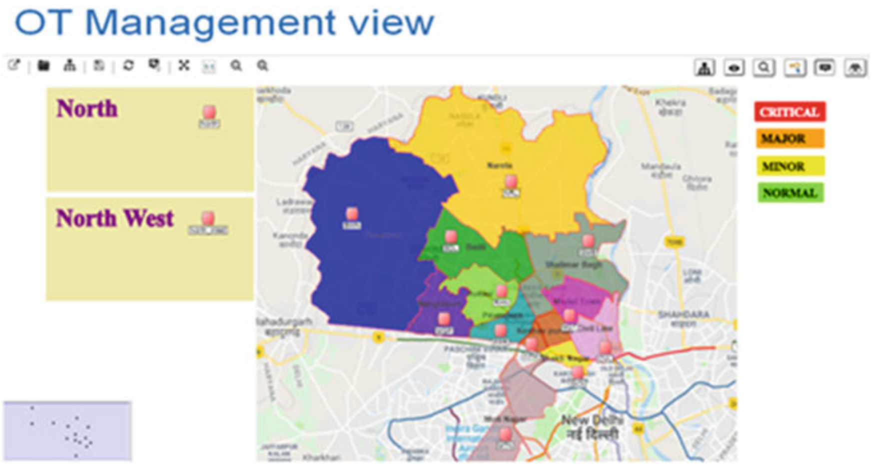


Fig. 2 OT management view

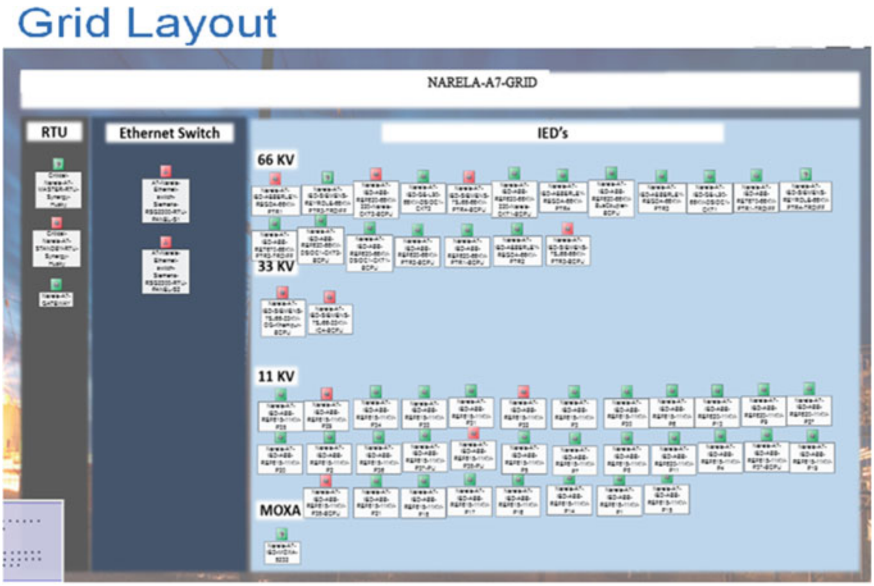


Fig. 3 Grids layout

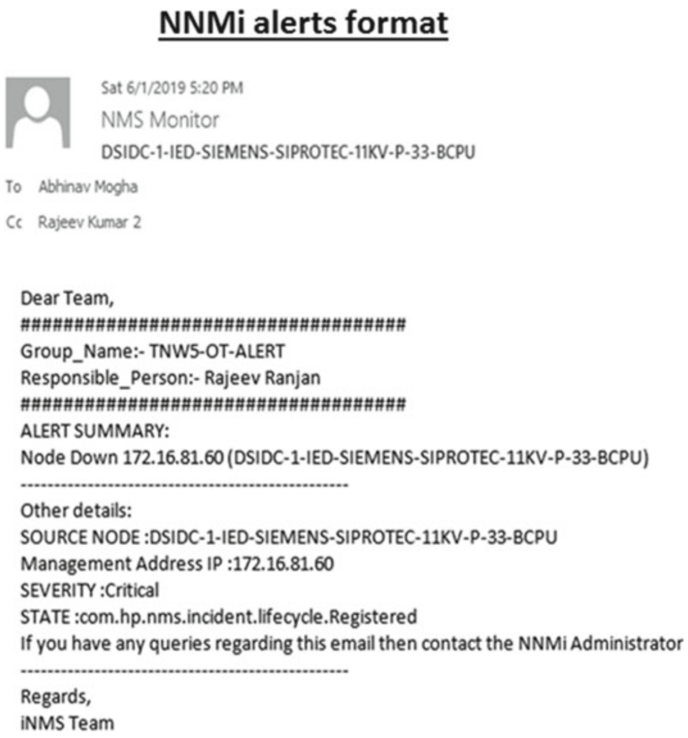
- **Configuration Management**—Configuration aspects of OT network devices such as configuration file management, Equipment's getting faulty analysis for inventory management, and software management.
- **Performance Management**—Monitor and measure various aspects of performance so that overall performance can be maintained within the acceptable levels.
- **Security Management**—Provide access to network devices and corporate resources to authorized individuals. Role based access control (Fig. 3).

All this is done to enhance the availability and reliability of RTUs/ IEDs and consequently will increase reliability of Power Supply which will improve internal and external consumer satisfaction index (Figs. 4, 5 and 6).

5 Analysis & Impact

1. Significant increase in numbers of Successful breaker operations due to increased availability of GSAS OT devices (Fig. 7).

2. Predictive Maintenance approaches have been adopted like Real time CPU load of RTUs/IEDs is monitored through I-NMS which is very helpful in predictive maintenance of OT devices (Fig. 8).



NNMi alerts format

Sat 6/1/2019 5:20 PM

NMS Monitor

DSIDC-1-IED-SIEMENS-SIPROTEC-11KV-P-33-BCPU

To Abhinav Mogha

Cc Rajeev Kumar 2

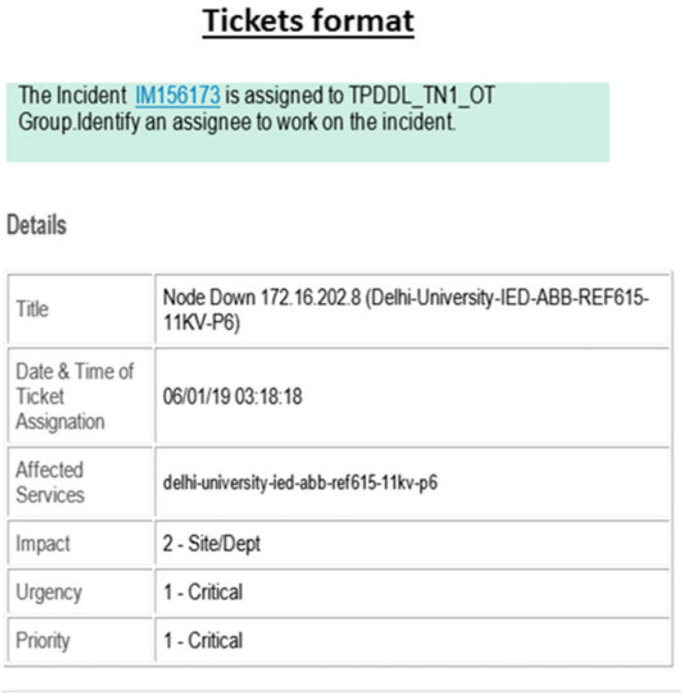
```
Dear Team,
######################################
Group_Name:- TNW5-OT-ALERT
Responsible_Person:- Rajeev Ranjan
######################################
ALERT SUMMARY:
Node Down 172.16.81.60 (DSIDC-1-IED-SIEMENS-SIPROTEC-11KV-P-33-BCPU)
--------------------------------------------------
Other details:
SOURCE NODE :DSIDC-1-IED-SIEMENS-SIPROTEC-11KV-P-33-BCPU
Management Address IP :172.16.81.60
SEVERITY :Critical
STATE :com.hp.nms.incident.lifecycle.Registered
If you have any queries regarding this email then contact the NNMi Administrator
--------------------------------------------------
Regards,
iNMS Team
```

Fig. 4 NNMI alerts format

Threshold values have been configured for CPU load/memory consumption of all OT devices which supports SNMP (Fig. 9 and 10).

6 Return on Investment

- Reliability parameters like SAIDI, SAIFI etc.is main criteria to measure performance of any utility. I-NMS play a vital role in real time monitoring & predictive maintenance of Bay Control & Protection Units which ensures high availability of system and successful breaker operations while supply restoration during faults thus reducing SAIDI to an extent.
- Real time identification and timely restoration of automation system significantly increases system availability and reliability, mean time to restore (MTTR) the supply during breakdown also improved which helped to improved consumer satisfaction and reduction in MU losses.



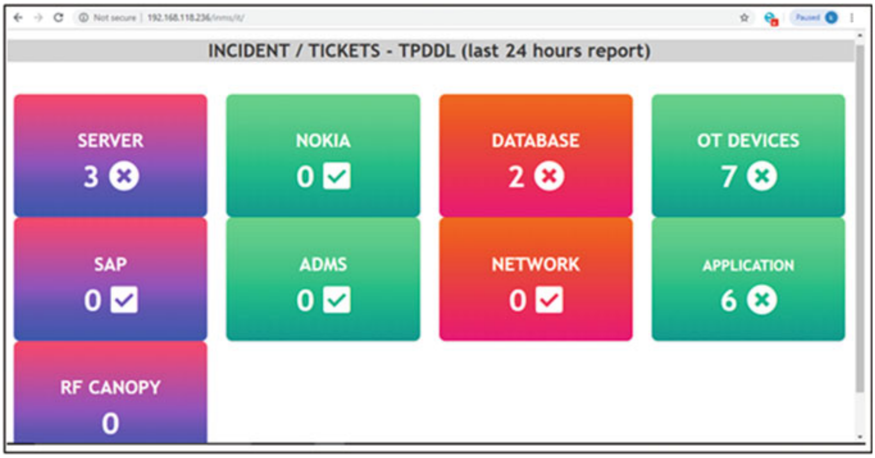
Tickets format

The Incident IM156173 is assigned to TPDDL_TN1_OT Group.Identify an assignee to work on the incident.

Details

Title	Node Down 172.16.202.8 (Delhi-University-IED-ABB-REF615-11KV-P6)
Date & Time of Ticket Assignation	06/01/19 03:18:18
Affected Services	delhi-university-ied-abb-ref615-11kv-p6
Impact	2 - Site/Dept
Urgency	1 - Critical
Priority	1 - Critical

Fig. 5 Ticket generation



INCIDENT / TICKETS - TPDDL (last 24 hours report)

SERVER 3 ☒	NOKIA 0 ☑	DATABASE 2 ☒	OT DEVICES 7 ☒
SAP 0 ☑	ADMS 0 ☑	NETWORK 0 ☑	APPLICATION 6 ☒
RF CANOPY 0			

Fig. 6 Tickets dashboard

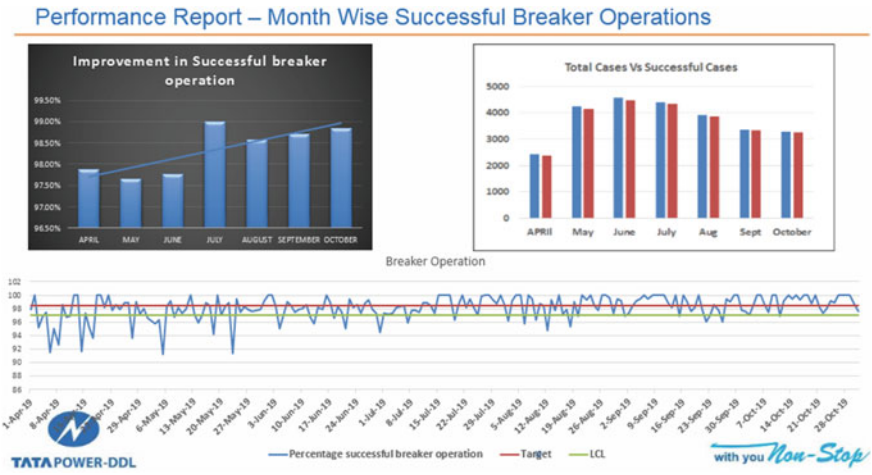


Fig. 7 Month wise successful operations

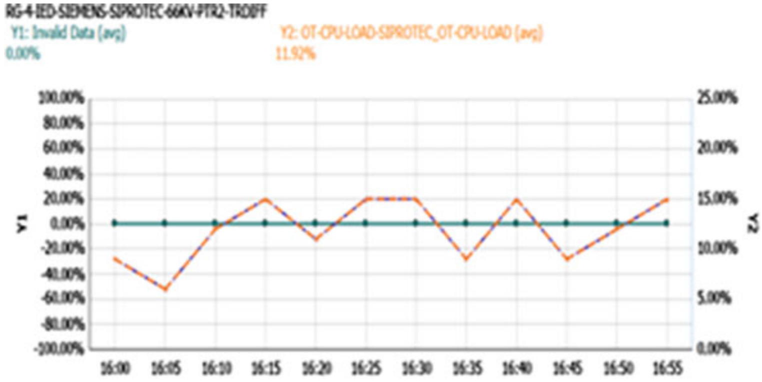


Fig. 8 RTU/IED CPU load graph

- OT devices monitoring through single platform will also decrease carbon footprints on account of team mobilization for manual monitoring and will further increase manpower utilization.

7 Uniqueness of Project

No Power utility in the world has adopted this technique of integrating the RTUs/IEDs with the integrated Network Management System where complete IT & OT environment is being monitored through one centralized location. This implementation

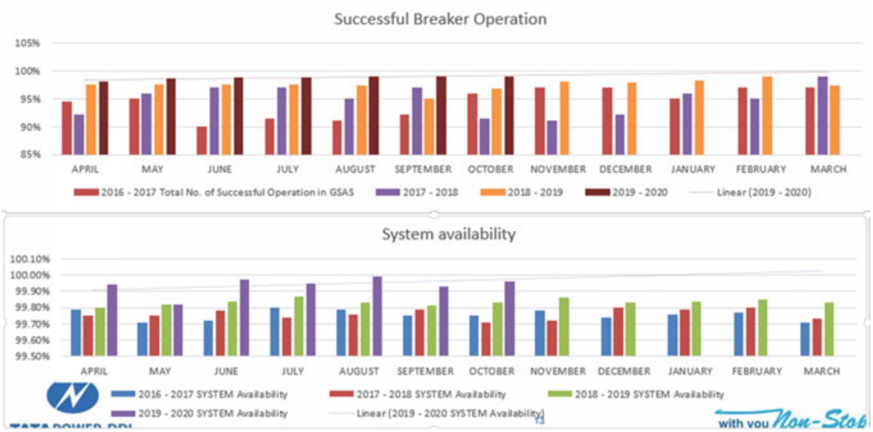
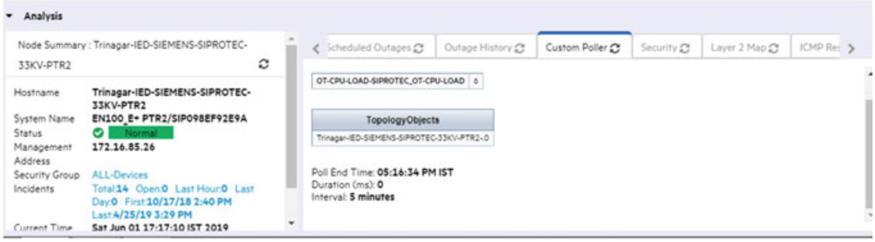


Fig. 9 Successful operations and system availability



Node Summary : Trinagar-IED-SIEMENS-SIPROTEC-33KV-PTR2

Hostname Trinagar-IED-SIEMENS-SIPROTEC-33KV-PTR2
System Name EN100_E+ PTR2/SIP098EF92E9A
Status Normal
Management Address 172.16.85.26
Security Group ALL-Devices
Incidents Total:14 Open:0 Last Hour:0 Last Day:0 First:10/17/18 2:40 PM Last:4/25/19 3:29 PM
Current Time Sat Jun 01 17:17:10 IST 2019

OT-CPU-LOAD-SIPROTEC_OT-CPU-LOAD 6

TopologyObjects
Trinagar-IED-SIEMENS-SIPROTEC-33KV-PTR2-0

Poll End Time: 05:16:34 PM IST
Duration (ms): 0
Interval: 5 minutes

Fig. 10 IEDs System diagnostic information

would surely open the pathways for next level of health & performance monitoring of OT devices as generally so many make & model devices are present in OT environment.

Up till now, it was a general consensus of integrating only IT and networking devices with Network Management Systems but this was a typical project in which even OT devices like RTUs & IEDs were successfully mapped under the same NMS umbrella with IT devices. These many OT devices monitoring through single platform will also decrease carbon footprints on account of team mobilization for manual monitoring and will further increase manpower utilization.

8 Challenges Faced During INMS Implementation

Basically, RTUs/IEDs installed in Grid substations are Operational Technologies devices and their primary & major function is to digitized and transmit Electrical Process data from local substations to centralized SCADA systems for monitoring and controlling. And integration of these devices with iNMS was a big challenge as most of the devices were not compatible with the ready protocols being used in iNMS systems like SNMP, SysLog, SSL etc. So many make & model devices are installed in our Power system like ABB, Siemens, GE, Areva, Schneider, Synergy and to coordinate with this number of OEMs was a big challenge. So many developments related to configuration changes, firmware's up gradation & subsequent integration testing's were carried out with the coordination of different OEMs. Still so many OEMs are still being pursued to develop compatible protocols for iNMS integration. Proof of concepts were carried out with different OEMs. Services of OEMs were taken during the projects execution.

Few More Challenges Faced:-

- OT & IT layouts synchronization.
- Reports generation as per conventional philosophies.
- Auto tickets assignment mechanism.

Key risks likely to face moving forward:-

- OT environment is getting exposed to outer levels:—We are already in process of implementing Cyber Security in our all grid substations.
- New Devices like RTUs/IEDs are getting added in OT environment on continual basis, thus integration activities will be never ending process. We have already taken the enough licenses and services too.

OT devices compatibility to iNMS ready protocols:—We have revised our specifications for RTUs and IEDs for protocol compatibility.

9 Conclusion

TPDDL works under regulatory business where CAPITALIZATION & OPERATIONAL expenses are closely monitored by DERC. Our company always strive to control our overall CAPEX/OPEX expenses, these initiatives will definitely improve the performance of RTUs/ IEDs as measures will be taken before actual fault scenario. Power system reliability will get improved and MUs loss will reduce. Also, these many OT devices monitoring through single platform will also decrease carbon footprints on account of team mobilization for manual monitoring and will further increase manpower utilization.

This solution facilitate us to act on pre-fault scenario like if any of the RTU or IED is reporting high CPU load parameter then it will be attended and rectified before actual fault thus saving us heavy in terms of MU loss. Also this will improve manpower utilization and reduced carbon footprints on account of site movements as all the RTUs/IEDs will be monitored automatically from one location.

Reference

1. I-NMS paper has been selected for ISUW2020

Rise of Algorithmic Trading in Today's Changing Electricity Market

Anindya Pradhan, Easwar Subramanian, Sanjay Bhat, Praveen Paruchuri, and Sujit Gujar

Abstract Electricity markets are getting more dynamic and complex today. On the one hand, there are outside-in factors like new entrants and increasing competition, regulatory mandates, and volatility of the electricity prices. In contrast, on the other hand, there are inside-out factors like the adoption of renewable energies, storages, and EV, emphasis on the generation and retail portfolio optimization together with creating affinity services around the empowered consumers. The paper will start with the introduction of this dynamic environment across the globe with a specific focus on Australia, the UK, and US electricity markets. Introduction of 5 min settlement in Australian Electricity Market, the rise of ancillary service products in the UK, or new roles like Community Choice Aggregators (CCA) in the US are some of the examples of these. The paper will then individually focus on wholesale, retail, and balancing electricity markets and illustrate the role of algorithmic trading in each of them. The paper will then discuss the design, implementation and performance of an electricity broker agent which uses algorithmic approach to perform various activities in a competitive smart-grid-based electricity market.

Index Terms Energy bidding · Algorithmic trading · Reinforcement learning · Markov decision process

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1 Introduction

Electricity market is becoming a technology driven business today. Energy technologies like distributed generation, energy storage, electric vehicles, demand-side management etc. along with exponential technologies like smart sensors/Internet of Things (IoT), big data and artificial intelligence (AI), augmented reality (AR)/virtual reality (VR) and blockchain are creating significant opportunity for a technology play in the entire electricity value chain. In addition, the advent of smart grids has not only resulted in proliferation of insightful information, both in terms of velocity and volume, but has also heightened the need for collection, profiling, aggregation and settlement using complex calculations and business logic.

In the wholesale market, predicting the demand (both for the overall market as well as for one's own retail portfolio) as well as market clearing price considering the weather and prosumer's supply/demand is becoming very important, whereas in the retail market, offering the right kind of tariff (like flat, tiered, time of use) considering the customers' past consumption and inertia, and positioning it to the right consumer segment is becoming very important. Similarly predicting the direction of the market imbalance in the balancing market and how to leverage the imbalance on one's own portfolio to mitigate market imbalance is yet another important decision facing a market participant.

There is thus a need for an intelligent trading agent which can define an integrated strategy for portfolio profit maximization considering the three dimensions of market, customer and strategy. The main objective of this paper is to describe the working of VidyutVanika (VV), an autonomous learning electricity broker agent which bids intelligently in the wholesale market to decrease procurement costs, reacts to competing tariffs and offers attractive retail tariffs to increase its share of the retail market, and uses demand response to mitigate transmission capacity costs.

The outline of this exposition as follows. In Sects. 2 and 3 we review the changing nature of electricity markets and the challenges posed by these changes to various market participants. In particular, we argue that these challenges create a strong need for a data-driven, algorithmic approach to decision making in energy markets. A particular instance of such an approach is a software broker agent which can autonomously make buy-sell decisions in an electricity markets and also possess the ability to attract retail customers with suitable tariffs in the presence of competitors. In Sect. 4, we provide an overview of one such autonomous broker agent, namely, VidyutVanika (VV). Specifically, we describe the architecture and the main modules of VV and comment on how these modules address the challenges mentioned above. In Sect. 5, we present the results of simulations performed on the Power Trading Agent Competition (PowerTAC) platform to demonstrate the performance of VV. Finally, in Sect. 6 we present our conclusions.

2 Electricity Market: A Transforming Industry

Various outside-in and inside-out factors have contributed to making the electricity markets more dynamic. Examples of outside-in factors include empowered consumers, new regulations such as Reforming Energy Vision in the US, Power Responsive in the UK and Power of Choice in Australia, convergence of industry boundaries (consider, for example, the entry of banks into connected homes) and volatile commodity and fuel prices. Inside-out factors include consumerization of energy technologies represented by electric vehicles (EV), energy efficient appliances, demand side management, renewables, storage, an increasing focus on portfolio optimization and managing risk against extreme events like the polar vortex, grid flexibility in the form of value-based transactive signals and market transparency (exemplified, for instance, by the transition from the 30 min settlement regime to the 5 min settlement regime in Australia). Along with the advent of new enablers, the interaction among the new enablers such as EV, photovoltaic (PV) and storage, and user behavior in the form of charging patterns are making the grid much more complex and demanding in terms of low latency. Electricity markets are thus moving from the low-complexity-high-latency quadrant to the high-complexity-low-latency quadrant as depicted in Fig. 1.

Below we provide three examples to illustrate the necessity for power markets to move towards the low-latency-high-complexity quadrant of Fig. 1.

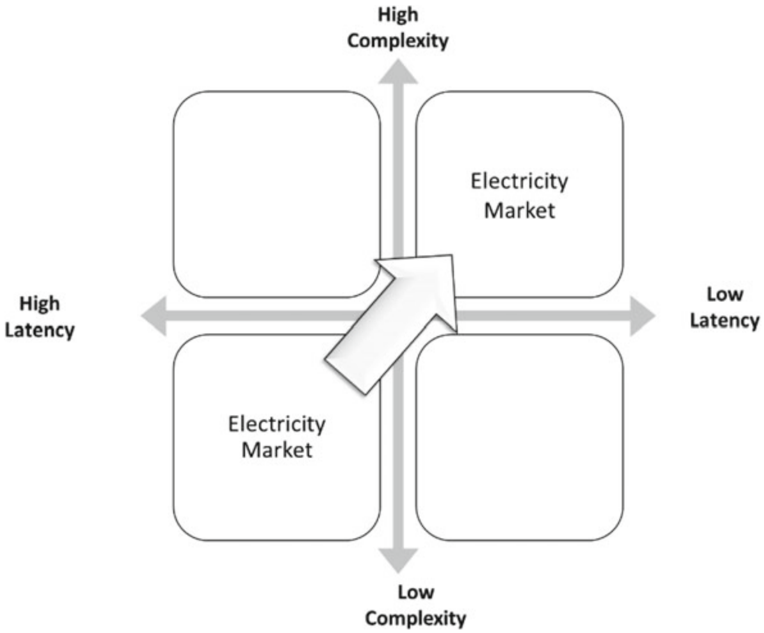

Fig. 1 Evolution of Electricity Markets—Journey towards low latency and high complexity

(1) *Australia Market—Settlement Regime:* In Australia, the energy regulator Australian Energy Market Operator (AEMO) is making a transition from a 30 min settlement regime to a 5 min settlement regime to achieve efficient demand side participation, efficient signals for investment in capacity, and improved incentives [1]. In the current regime, which involves a 5 min dispatch window and a thirty-minute settlement window, a generator makes offers/bids to supply electricity to the National Electricity Market (NEM) every 30 min. An offer or bid consists of price and quantity for the six 5 min dispatch intervals in the 30 min settlement window. However, the price the generator receives in the 30 min settlement window is calculated by averaging the dispatch prices of the six dispatch intervals in that settlement window. The current regime provides little encouragement for flexible generators, and can lead to distorted bidding behaviors like early price spike, late price spike, and piling in of generators. In the new 5 min settlement regime, a generator makes offers/bids to supply electricity to the NEM at every 5 min, and the price the generator receives will be the 5 min trading interval price. Thus, in the new regime, a generator can make offers for 288 trading intervals in a day rather than 48.

(2) *UK Market—Ancillary Products:* In the UK, the electricity system operator is encouraging the increased participation of different forms of flexible technologies such as demand side response (DSR) and storages for balancing of the grid [2]. We also see the advent of Non-Balancing Mechanism Units (Non-BMU) to support the ancillary service markets with reserve products like Short Time Operating Reserve (STOR) and frequency products like Frequency Control by Demand Management (FCDM). The characteristics of a typical non-BMU product are shown in the diagram in Fig. 2.

(3) *US Market—Community Choice Aggregators:* In the US market, we see the increasing dominance of the Community Choice Aggregator (CCA). CCA are

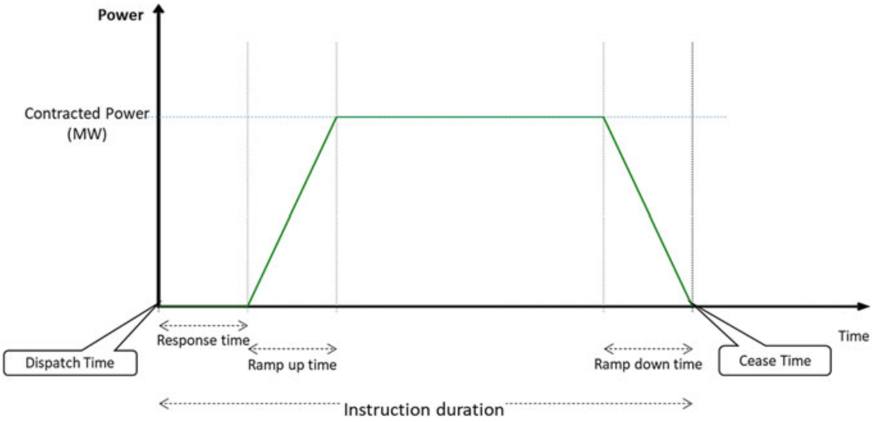

Fig. 2 Characteristics of a typical non-BMU seen in UK energy markets

local government entities that purchase electricity on behalf of the retail electricity customers. CCA have the advantage of a large customer base resulting in higher negotiating power in the wholesale market. If required, CCA can choose more renewable energy than the incumbent utility.

3 Challenges in Decision Making for Market Participants

Participants in electricity market operate in wholesale, retail and balancing markets. The wholesale market is where the electricity is bought in bulk from power generators. The retail market consist of various of prosumers who buy or sell power in low volume. The aim of a participant in the balancing market is reduce supply demand mismatch. An electricity broker agent is needed to make the following key decisions in these three markets.

(1) **Wholesale Market**: The price and quantity for a bid, the frequency at which bids should be placed, type of order (market order or limit order) to be placed, type of information to be used for making the decision.
(2) **Retail market**: Type of customer to target, type of tariff to offer from among fixed, time-of-the-day, variable etc., and the tariff amount.
(3) **Balancing market**: Kind of participation in the balancing market (specifically, whether to create an imbalance that reduces the overall imbalance in the market, or to offer incentives to customers to keep their load flexible).

To make decisions related to the wholesale market, a market participant may have to rely on weather data, and consumption and production profiles of enrolled customers. Likewise, retail market decisions may have to be based on weather data, previous consumption history, and other consumer data. Since commitments for buying or selling power have to be typically made in advance, an additional input to decision making could come from predictive models yielding estimates of future demand and clearing price. Predictive analytic models and advanced data-driven decision-making algorithms can enable a broker agent to convert different scenarios into revenue-making opportunities. To illustrate this, consider the following scenarios and their associated opportunities.

- **Scenario 1**: The demand in the balancing market is high for a certain future time slot
    - *Opportunity 1*: If the broker can predict the scenario, then the participant can buy a larger quantity in the wholesale market and sell the excess power to the balancing market at the future time slot.
    - *Opportunity 2*: The broker can give out an attractive tariff for prosumers to increase its prosumer base, so that the participant can purchase power from this prosumer base and sell it in the balancing market at the future time slot.

  - *Opportunity 3*: The broker can increase its share of consumers with storage devices like battery and EV, and sell the stored energy in the balancing market at the future time slot.

- **Scenario 2**: The supply in the balancing market is is high for a certain future time slot.
  - *Opportunity 1*: The broker can give out an attractive tariff for consumers to increase its consumer base, so that the additional load that can absorb the extra future supply in the balancing market.
  - *Opportunity 2*: If the predicted future balancing market price is less than the current wholesale market price, then the broker can bid for lower quantity in the the wholesale market and purchase the remaining power at the future time slot from the balancing market.
  - *Opportunity 3*: The broker can tap into the storage capacity of its customers to store the predicted extra supply and sell it at a later time.

4 Overview of AI-Based Broker Agent VidyutVanika

In Sects. 2, 3, and 4, we have outlined challenges posed by the move towards low-latency-high-complexity regimes as well as possible opportunities for market participants to prevail over these challenges by leveraging predictive analytics and decision algorithms. We argue that these challenges highlight the need for market participants to increasingly use algorithmic trading as an element of their decision making. In this section, we look at one particular way of implementing algorithmic trading, namely, in the form of a software broker agent. More specifically, we describe VidyutVanika (VV) [3–5], a software broker agent that can operate autonomously in a smart-grid-based electricity market. In particular, we explain different modules and submodules of VV, which are built to address the challenges discussed in Sect. 3.

The broker agent VV consists of two main modules, namely, *Wholesale Module* (WM) and *Tariff Module* (TM). WM generates bids/asks to purchase/sell energy contracts in the whole-sale market. TM is responsible for publishing and revoking tariffs in the tariff (or retail) market. The bidding problem in the wholesale market is modeled as a Markov Decision Problem (MDP) [6], a framework for dynamic optimization in uncertain environments. The MDP is solved online using dynamic programming [7]. Tariff design is accomplished by formulating a separate MDP, which is solved approximately using Q-learning [8]. In addition to these two modules, VV incorporates a Customer Usage Predictor (CUP) sub-module built using neural networks (NN) to predict the usage of all subscribed customers in a future time slot, by using weather forecasts and past usage pattern of each customer. VV aggregates the predicted usage across all its subscribed customers to estimate the amount of energy to be procured in the wholesale market. Doing so helps VV reduce the imbalance on its portfolio. Figure 3 depicts the architecture of VV in terms of its various modules and sub-modules.

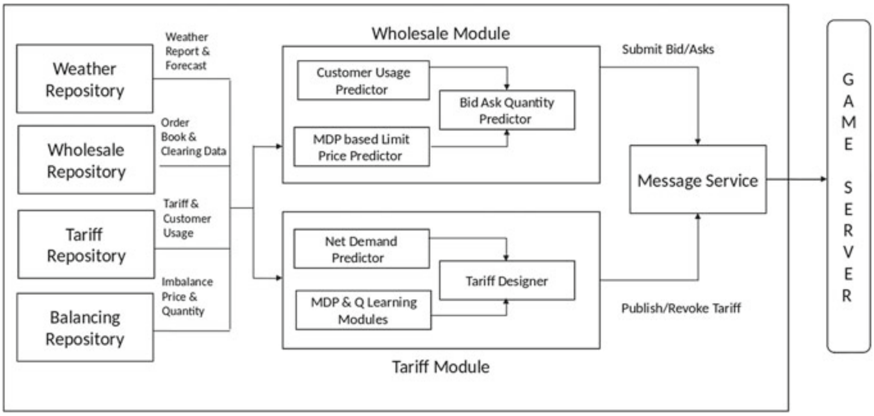

Fig. 3 Broker agent architecture

Next, we describe TM and WM along with their sub-modules in detail.

A. *Wholesale Module (WM)*

In order to balance the net usage in its tariff portfolio at a future consumption time t, VV participates in all preceding wholesale market auctions for the time t by placing bids/asks of the form (*energy amount, limit-price*). The limit price is determined by a Limit Price Predictor (LPP), which uses dynamic programming to solve a MDP to find the limit price. The energy amount to be purchased is determined by aggregating the usage predicted by the CUP.

The customer usage prediction module (CUP) is responsible for predicting the net usage of the broker's tariff portfolio for a future target time-slot t, by summing over the predicted usage of each customer subscribed to the broker for that target time-slot t. For each customer, the CUP uses a small feed forward neural net to predict the actual usage of the customer from the actual weather data, time of the day, and day of week. During prediction, the weather forecast is used in place of the actual weather data. The model is improved as more data points become available with time.

VV's Limit Price Predictor is primarily motivated by the work of [9] on MDP-based wholesale bidding strategy, which in turn is based on [10]. Although VV uses a similar MDP structure, the novelty lies in the reward, solution and application to place bids. First, VV does not bid for the entire predicted energy requirement in a single auction as proposed by [9]. Instead, VV participates in all possible auctions to procure the required amount of energy for a future time slot so that larger amounts of power can be purchased in those auctions in which the clearing price is expected to be less. Second, VV uses the limit-prices obtained by solving the MDP to place several small bids to purchase small quantities of energy. These small bids help in calculating better estimates for the probability of a bid getting cleared for a given limit price.

VV maintains two instances of the MDP at all times; one for bids, and the other for asks. The state of the wholesale MDP is the number of bidding opportunities left to buy energy for a future time slot. The action is a limit price that would be used in the bidding process. The reward is the amount of cost incurred in obtaining the total amount of energy required for a future time-slot. The detailed description of the MDP can be found in [3]. The solution to the MDP is a sequential bidding strategy that minimizes the cost per unit energy procured.

B. *Tariff Module (TM)*

TM, the tariff module of VV, maintains two active time-of-use (TOU) tariffs, namely, (i) MDPTOU and (ii) WeeklyTOU. MDPTOU is the result of solving an MDP problem for retail market using reinforcement learning, and is revised every twenty-four hours. WeeklyTOU is an empirically determined, fixed weekly TOU tariff, which remains active throughout.

MDPTOU is generated through a two-step process. First, a fixed price tariff (FPT) is generated by using reinforcement learning. Next, the FPT is converted to a TOU tariff for consumption customers by predicting the overall demand profile for the tariff market over a future time horizon.

The tariff MDP formulation is primarily motivated from the work of [11]. The state of the MDP at any decision instant is a set of market features that captures rationality of the tariff market, the agent's predicted energy surplus calculated as the difference between the power already purchased and the estimated demand for the future consumption slot, and rank-based comparison of VV's current tariff with tariffs offered by competitors. At each decision time, VV observes the state and selects one of eight actions, each of which lets *VV* modify its previous production and consumption tariff in a specific fashion. A detailed description of the state and action space of the MDP can be found in [11].

TM is trained to provide near-optimal tariffs by using the reinforcement learning algorithm called *Q*-learning over repeated simulations. In each simulation, the module is provided "rewards" such that the total reward in a simulation captures the net profit made by VV ignoring balancing charges. Specifically, the reward at each time is the net revenue earned by selling or buying power from consuming and producing customers, respectively, at current tariffs, less the amount spent in the wholesale market to procure the power required to cover unfulfilled demand. Over several simulations, the *Q*-learning algorithm learns the value of the maximum possible total reward that can be achieved by taking a given action in a given state. This information is then used to identify the best possible action in the current state. The chosen action is then converted to a tariff.

For production customers, the tariff suggested by the MDP agent is published without any change. For consumption customers, the FPT tariff is converted to a TOU tariff before being published. For this, VV first predicts the net demand in the market for the next twenty-four hours of the simulation. Thereafter, at each of the next twenty-four time slots, the FPT is modified by an amount that is proportional to the excess estimated net demand at that time slot over the mean estimated demand for the twenty-four hour period. For details, the reader is referred to [3]. The TOU tariffs published in this manner helps in offsetting some of the transmission capacity charges triggered by high peak demand.

5 Validation of the Algorithimic Trading in Powertac Tournament

The performance of VV was tested using the Power TAC simulation platform [12]. Power TAC is an open source smart grid simulation environment, featuring a wholesale market with bulk power generators, a retail market with a diverse population of customers, a balancing market, and a distribution utility, all operating at a real geographical location with its own weather dynamics. The retail market comprises individual customers, residential communities, as well as businesses, and includes customers with production and storage capability. The platform contains evaluation and preference models that customers deploy to decide between tariffs, as well as consumption models that determine their consumption and demand response patterns. The balancing market operates through balancing orders placed by broker agents having customers with flexible loads. In addition to providing the transmission infrastructure, and acting as the broker of last resort, the distribution utility also charges transmission capacity fees for contributing to peak consumption. The platform can accommodate multiple independent broker agents, who have to compete to operate profitably in the Power TAC environment.

The Power TAC platform is used every year to run a competition, also abbreviated as Power TAC, among broker agents submitted by different teams. To benchmark the capabilities and performance of VV, VV was entered in the Power TAC 2017 and 2018 finals. The Power TAC 2018 finals had 7 brokers from research groups across the world. The tournament had a total of 324 games, with all possible combinations of 7-broker games (100 games), 4-broker games (140 games; 80 games for each broker), and 2-broker games (84 games; 24 games for each broker). Table 1 shows the net profit of all brokers across different game configurations, percentage of profit in comparison to the winning agent, AgentUDE, and the corresponding normalized scores. Despite winning more games than AgentUDE, VV was placed next to AgentUDE in overall ranking of Power TAC 2018. This is because, the determination of the winner is made based on normalized cumulative profits in each configuration across all games in the tournament. Specifically, AgentUDE netted high profits against competing agents (excluding VV) in 2-player games that helped in cementing its place as the winner of the tournament.

VV won the most number of games in the tournament with 112 wins out of the 204 it participated in, with AgentUDE coming second with 92 wins out of 204. VV had the most wins in 7-broker and 4-broker games, and had the second highest number of wins, behind AgentUDE, in 2-broker games. It is important to note that, overall, VV finished in the top two, 72% of the time whenever it played in a game with more than 2 brokers. In comparison, AgentUDE stood at 65%. On a head-to-head comparison with AgentUDE, out of 100 7-broker games, AgentUDE and VV both shared 39 wins each. However in 4-Broker games in which both VV and AgentUDE participated, VV won 31 times out 40, with AgentUDE winning the remaining 9. In the four 2-broker games involving both brokers, AgentUDE ended up winning three games. VV led in all these three lost games almost till the end, only to fall behind

Table 1 POWER TAC 2018—Net profits and normalized scores (denoted by (N)) of each broker

Broker	7-broker	4-broker	2-broker	Total	7-broker (N)	4-broker (N)	2-broker (N)	Total (N)
AgentUDE	49964603 (100)	62138484 (100)	134908672 (100)	247011760 (100)	1.091	0.634	1.565	3.291
VidyutVanika	48197051 (96)	101942819 (164)	47541635 (35)	197681504 (80)	1.056	1.061	0.336	2.453
CrocodileAgent	27659543 (55)	45441732 (73)	62881837 (47)	135983111 (55)	0.648	0.455	0.552	1.655
SPOT	−6979768 (−14)	32981756 (53)	49183707 (36)	75185695 (30)	−0.041	0.322	0.359	0.64
COLDPower18	2063729 (4)	10289982 (17)	521330 (0.3)	12875040 (5)	0.139	0.078	−0.326	−0.109
Bunnie	−67983216 (−136)	−25049555 (−40)	−19596577 (−15)	−112629348 (−46)	−1.254	−0.3	−0.609	−2.163
EWIIS3	−87271195 (−175)	−206960249 (−333)	−109800161 (−81)	−404031605 (−164)	−1.638	−2.25	−1.878	−5.766

finally due to transmission capacity fees. We also looked at the number of games in which each broker ended up with a negative profit. CrocodileAgent had the fewest games with negative profits, with VV coming second in this category with four times the average market share. Thus, VV managed to make up for its losses on a consistent basis, and rarely ended up being non-profitable.

TM played a crucial role in VV's success, offering tariffs which were attractive to majority of the customers and contributing the most in revenue. VV had the highest market share on average in 2-broker games, 7-broker games and overall, and the second highest in 4-broker games. In contrast, AgentUDE had only a quarter of the overall average market share of VV. While one may expect a greater market share to lead to more profits, it usually leads to higher transmission capacity fees and distribution costs, which can cause higher losses unless managed properly. As a result, agents with lower market share often tend to make less losses, and end up winning. VV also had one of the best tariff market income-to-cost ratio (1.14), with only AgentUDE (1.43) and CrocodileAgent (1.32) having better ratios. However, both AgentUDE and CrocodileAgent had very low average market share compared to VV. Thus, VV is very efficient at making profits despite having a higher market share. Finally, although there was no explicit strategy for balancing market, VV had less imbalance costs even with high market share which exhibits the effectiveness of net usage prediction strategy using neural networks.

6 Conclusion

We foresee a strong need of algorithmic trading in days to come. There can be convergence of wholesale and retail market in future. Connected homes may directly participate in the wholesale market and buy or sell power on their own. Similarly, in peer-to-peer trading, consumers will trade electricity among themselves rather than going to the market, and market will only act as a last balancing resource. Algorithmic trading, possibly implemented in the form of autonomous software broker agents, can play a very important role in decision making in all these futuristic scenarios. In this paper, we have described the architecture and design of one such software broker agent.

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Electric Vehicle and Charging Stations in Distribution System: Practical Experience

Ashutosh V. Pailwan, Indranil Chatterjee, and Bhushan Choudhari

Abstract Electric cars are predicted to be the next disruptive market force for transportation and technology. One of the primary reasons for the introduction of electric cars into the market is the concern over greenhouse gas emissions and their contribution to global warming. The greatest impact of reduced carbon emissions is in densely populated urban areas like Mumbai. The Indian government has set ambitious targets to accelerate the adoption of EVs. By 2023, it wants all three-wheelers to run on batteries. By 2025, the rule will be applicable to most two-wheelers. Incentives are being offered to make OEMs develop new EV models and manufacturing components such as lithium-ion batteries and electric motors. Moreover, it has been looked upon as a prospective option for Demand Side Management. AEML, as a responsible Corporate, has proactively taken steps by procuring Electric Vehicles, viz. 4-wheelers and 2-wheelers, necessitating in-house movement for their O&M activities spanning 400 km^2 catering to the electricity needs of almost 3 million customers today. Moreover, it has installed Charging Stations at strategic locations spread out in their divisional offices across their licenced area. Fuel saving resulting from these EV's is estimated to be around a couple of lakhs per month, leaving alone the significant carbon foot-prints reduction. This paper explains facts and experiences of electric vehicles and charging stations in Adani Mumbai Distribution Business. Challenges, however, remain.

Keywords Electric · DC charging · Integration · Power quality · Protection · Network planning

1 Introduction

Presently, to provide reliable power supply and minimise commercial losses, there is requirement for efficient and cost-effective movement of manpower in any utility. AEML has in-house efficient transportation system operating on conventional fuel

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viz. petrol & diesel. However, to have minimum impact on environment due to vehicular pollution and to have cost effective transportation, AEML has purchased electric vehicles for its day to day operation. Moreover, AEML had installed charging stations at strategic locations. The vehicle and charging station are in operation for last two years, leading to understand its practical aspects. The report will detail methodology adopted for selecting electric vehicle and its specification. Moreover, details about AEML experience and observation is explained in the report.

The motivation to adopt new technology is explained in Sect. 2. However, specification and experience of electric vehicles procured by AEML is explained in Sect. 3. While, charging station both private and public, specification and experience is explained in Sect. 4. The actual site measurement of Charging station is indicated in Sect. 5. Moreover, utility way ahead and conclusion is elaborated in Sects. 6 and 7.

2 Motivation for Electric Vehicle

The electric vehicle selected by AEML had power consumption of Rs 1.15/km (electricity rate considered is Rs 7/KWH). However, existing diesel/patrol operating vehicles had power consumption with unit rate Rs 13/km. This has envisaged to save fuel worth Rs 10,000 per month. Moreover, maintenance cost is bare minimal. Over and above, the indirect benefit due to inception of electric vehicles was reduction in carbon footprint in urban area.

3 Electric Vehicle Specification and Experience

As on pilot basis, Adani has procured 6 numbers of electric vehicles. In them 1 Nos sedan car (Fig. 2), and other five were passenger vehicle van (8-seater Fig. 1). The passenger vehicle was deployed to assist day to day operational activities, while, sedan was specifically procured for executives' movement.

The estimated daily travel distance for passenger vehicle is near about 100 km. Moreover, the movement of vehicle was in traffic prone areas. Furthermore, availability of charging station are at strategic locations. The charging stations are located at AEML divisional office only. The vehicles are used for almost 14 h with available maximum charging time for 8 h. Since, vehicles are few in numbers, AC slow 3 kW charging station were considered for pilot. Based on above requirement following are specification of the passenger vehicle considered (Table 1).

Moreover, to ensure fast movement of technician to troubleshoot issue during small area blackout, twelve number of e-scooter (Fig. 3) were procured. The scooter can cover 60 km for fully charged battery with top speed of 25 kmph. The battery was of 28 A hour capacity. The vehicles require five hours to charge the battery completely.

Fig. 1 e-Supro (passenger vehicle 8-seater)

Fig. 2 E-Verito (D6 variant with fast charging)

Table 1 Technical Specification of E-Supro

Sr. no	Description	Units
1	Motor	Three phase induction motors
2	Maximum power	25 kW @3000 rpm
3	Maximum torque	90 Nm @ 3000 rpm
4	Seating capacity	8 Personnel
5	Top speed	60 kmph
6	Charging time	8 h
7	Range	100–120 km
8	Battery pack rating	200 Ah with 3 years/40,000 km warranty
9	Vehicle dimension	3.8 m × 1.5 m × 1.9 m
10	Brakes	Front hydraulic disc Rear hydraulic drum
11	Revive	7 km of extra charge available

Fig. 3 Hero dash electric scooter

Experience

1. Presently, after two years of electric vehicle usage experience, maintenance cost of electric vehicle is very low or say negligible compared to traditional vehicles.
2. In Mumbai, due to heavy rains during monsoon period, water logging is observed in low lying areas. Thus, we have observed that Electric vehicles become non-functional when water reaches up to vehicle floor.
3. The special towing vehicle is required to tow the vehicle to nearest repair shop.
4. Only one authorized repair shop is available in Mumbai area for vehicles procured by AEML.
5. Initially, as specified, vehicle used to travel distance up to 100 km with full charge. However, later-on (after one year), performance degraded up to 60 km only.
6. Due to dense population of Vehicles in Mumbai, there is huge traffic congestion during most of the day. Thus, with full charge, the travel distance used to reduce further to 40–50 km only.
7. Due to limited charging stations, the freedom of travel at any length and breadth of Mumbai AEML boundaries is restricted.
8. In AEML, vehicle is used for 8 h shift and for remaining period it is kept for charging at nearby divisional offices.
9. The E-scooter cannot climb the slopes. Moreover, it cannot carry more than one person. Thus, they are not possible to be deployed for our technicians with tools and tackles.

Fig. 4 AC charging (15 Amp) at Devidas lane Borivali West Mumbai

4 Charging Station Specification and Its Experience

The charging station opted by Adani were Type 2 category AC001 with Bharat Protocol. The capacity was 3 kW and 7 KW. These are basically slow charging station located at AEML Divisional office. The charging stations are for self-procured electric vehicles. However, AEML has went ahead for public charging station also with outsourcing the logistics, located at two strategic location Kalanagar Bandra and Andheri near Seepz gate No. 3. These charging stations are 10kW DC 001 Type 2 with Bharat protocol. They are fast charging stations. However, still it consumes at least 2 hr to charge a sedan vehicle. The experience is that, only one charging station is been utilized with monthly consumption of 1000 KWH per unit, located in Bandra. However, other is still not utilized to its capacity. For public charging station, parking of vehicles is very difficult in available space near Adani substations. Thus, Adani has observed that, public charging stations can be placed in private or public parking lot only. The photograph (Figs. 4 and 5) of fleet vehicle charged at public charging station located near Adani 33/11kV substation Kalanagar.

5 Performance Measurement of Charging Stations

(A) DC Fast charging station of 10 KW.

The power quality of input energy to charging station was measured with the help of HIOKI class A power quality instrument. The total harmonic current distortion was observed to 7% only. However, there is unbalance in phase current i.e. R-phase 20 Amp and other two phase carry 10 Amp. These unbalance current may overload the utility neutral. However, input displacement power factor was 0.99. The total

Fig. 5 Fleet vehicle is being charged at 10 kW DC charging station in KalaNagar BKC

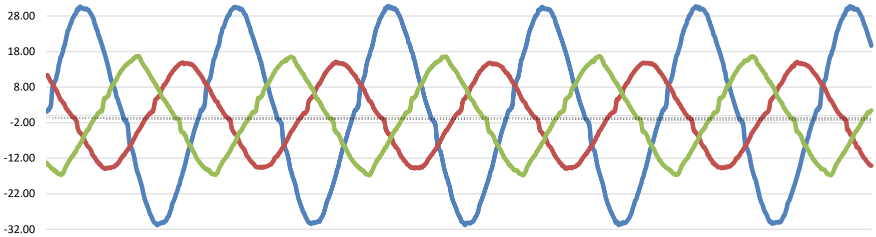

Fig. 6 10 KW DC charging station input AC current

reactive power requirement is 2 KVAR. The efficiency of charger was observed to be 95%. The waveform captured is indicated in Fig. 6 Moreover, constant current was delivered to the charging station i.e. there were no sudden spike in current.

(B) Single Phase AC charging station for inhouse vehicles.

The inhouse passenger vehicle (E-Supro) and electric scooter is charged from single phase 15 A socket. They have extra charging accessories to charge its batteries. The harmonic content observed was very high (165%) for both the vehicles. The captured AC input waveform to electric vehicle charger is indicated in Fig. 7.

6 Way Ahead

Based on AEML experience of last two years for electric vehicle, following are few takeaways to increase its proliferation in Indian market.

Fig. 7 15 Amp AC charging station input current

1. The number of public charging station should be increased and placed in public or private parking lot only, for densely populated city like Mumbai.
2. The public charging station should be Fast Charging only.
3. The location of charging stations should be at all meeting hubs viz. railway stations, shopping mall, office complex, Bus Depots, parking lots etc.
4. Moreover, slow charging stations should be in every housing complex and in every parking space.
5. The network of public charging station should be privately owned and controlled. However, they should have energy purchase agreement with Utility.
6. Existing utility substations located in public stations can be rented out for installing public charging stations.
7. There should be speedy repair mechanism establishments.
8. The multiple option should be available for repairing or non-functional vehicles.
9. The towing options should be flexible.
10. Issues of non-functionality during water logging should be addressed.
11. Battery usage during Traffic congestion should be made optimal.
12. The Charging station must import balanced power from utility to avoid neutral over loading. Moreover, current drawn should have minimal harmonic.

7 Conclusion

Considering environmental impact due to pollution from vehicles operated by conventional source of energy, electric vehicle is inevitable. In view of it, public fast charging stations should be deployed on top priority by private players with mutual agreement between utility and private players. The public spaces like government offices, parking lots, shopping malls, housing societies should be explored for deploying charging stations. The charging stations near roadside is highly impossible, due to traffic issues. Moreover, electric vehicle repair shops should be located at strategic locations considering electric vehicle traffic and movement. The battery sizing should be considered in due consideration of it getting trapped in traffic snarls. Thus, once basic infrastructure is erected, consumers will be inclined/comfortable to buy vehicles and increase its usage.

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Design and Operational Strategies of Urban Micro-grid that Benefits Utilities, Consumers as Well as the Environment

Ashwini G. Mudgal, Kapil Muddineni, and Shirish Garud

Abstract Renewable energy provides clean power and is gaining more and more share in the India's electricity. With rising electricity demand, grid tariff and declining costs of renewables, micro-grids based on renewable sources and connected to the utility grid are becoming relevant particularly in the urban landscape. However, currently the functionality of these micro-grids is limited to providing power to the connected captive loads and pumping excess power into the grid. A true ecosystem will be created only when the utility grid is able to interact with the distributed micro-grids. Such micro-grids can support the utility grid during periods of peak demand and conversely absorb power if there is a drop in energy demand, provide reliable power to consumers, and reduce emissions that result from consumption of fossil fuel based power. Thus such micro-grids can benefit the utilities, the consumers as well as the environment. This paper discusses design and operational strategies to be considered to create an ecosystem where the micro-grids and the utility grid co-exist and serve a larger purpose of enabling the smart grid environment through interaction between the micro-grids and the utility grid.

Keywords Advanced microgrids · Interactive microgrids · Interoperability · Energy management systems · Demand response

1 Introduction

Utility grid is transforming from a traditional grid to a modern 'smart grid'. The traditional grid is primarily powered by coal-based plants and it transmits electricity over long distances to sub-stations and finally through a distribution network to

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consumers. Traditionally grid did not have any control on the demand side. This scenario will change with the advent of the smart grid. The smart-grid, already a reality in many parts of the world is characterised by distributed generation from diverse power sources, sensing capabilities and two-way communication throughout the network. With these transformations, the grid is evolving to have both centralised and decentralised power generation. Thus, ability of distributed generation systems to interact with the grid is a necessity for the future grid network.

Electricity is the lifeline of modern world and this demand has been compounded by addition of loads such as electric vehicles, electric cooking etc. This rising demand has additional challenge of being non-uniform interspersed with high ‘peak’ hours of demand which makes forecasting of demand and supply of electricity challenging.

Microgrids play a crucial role amidst these uncertainties of power demand. Due to their ability to generate power and control the connected loads, they augment the overall grid capacity while simultaneously reducing the demand on the grid network. ‘Demand Response’ programs run by utilities also offer flexibility to manage the grid and alleviate the necessity to increase infrastructure capacity.

Thus creating grid interactive microgrids enhances the capabilities of the microgrid by adding the feature of demand response thus giving them the ability to respond the utility signals and participate in grid management. This also essentially improves grid flexibility which benefits utilities, consumers as well as the environment. The paper discusses some of the commonly used energy management strategies and case studies that have benefited from such energy management programs.

2 Grid-Connected Microgrids and Their Functions

As per US department of Energy Microgrid Exchange group definition: “A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected and island mode” [1]. Microgrids can be dc microgrids, ac microgrids or hybrid ac-dc microgrid. It could be standalone or connected to the grid. In the scope of this paper we consider grid-connected ac microgrids.

The microgrid operates in two modes (1) grid-connected mode and (2) islanded mode. The microgrid connects with the main grid totally or partially and imports or exports power from or to the main grid. The microgrid may island intentionally or intentionally [2].

The basic functions of a microgrid are.

(a) Control of power flow from various generation sources.
(b) Load management
(c) Management of the connected energy storage devices
(d) Islanding detection

Additional functions performed by a grid-interactive advanced microgrid are.

(e) Performing active and reactive power control to maintain stable voltage and frequency.
(f) Load shifting or load shedding strategies using demand side management with energy storage support
(g) Communication with the main grid and ability to respond by islanding, load shedding, exporting power etc.

Grid-connected microgrids have the ability to import and export power to the grid, transforming the grid from a passive network to an active network creating an opportunity for control of bi-directional power. Energy management of a microgrid when employed with demand side management techniques has the promise of overall reduction in power consumption while simultaneously assisting in grid management. This benefits the consumer, the utility and the environment. The consumer receives reliable and continuous power, utility can benefit from enhanced power quality and environment benefits as excess power generation is avoided.

Management of energy within a microgrid has benefits such as generation dispatch, customer participation, and frequency regulation creating an economical, sustainable and reliable grid. The EMS optimizes the microgrid operation through decision making strategies to achieve goals of reliability, energy efficiency and reduced cost of operation.

3 Demand Response Programs

Demand response is a demand side management (DSM) technique to alter power demand to better match it with supply.

Demand response programs offers flexibilities to system operators to manage the grid through demand response programs at low costs by involving customers to curtail or shift demand. Demand response is primarily focused on moving the time of energy consumption. For consumers, this may mean changing their consumption patterns, for example, charging electric vehicles or pumping water to overhead tanks during non-peak periods. By voluntarily adjusting their regular electricity use because of pricing signals or requests, consumers can provide flexibility to utilities.

Types of Demand Response

Demand response programs are primarily of two types viz; Price based demand response and Incentive based demand response [3].

A. Price based demand response

Price based demand response can be incorporated in one of the following ways.

- Time-of-Use (TOU) is a rate plan in which the rates vary for time of the day, season and day type (weekday or weekend/holiday). Higher rates are charged during the peak demand hours and lower rates during off-peak (low) demand hours. Rate may be higher in summer when demand is higher as compared to winters. The

consumers are expected to shift their energy usage from peak hours to off-peak hours.
- Real Time Pricing is a rate in which the price of electricity typically fluctuates hourly reflecting changes in the wholesale price of electricity. Customers are notified of RTP prices on a day-ahead or hour-ahead basis.

B. Incentive based demand response

Incentive based demand response can be incorporated in the following ways.

- Direct load control is a program in which the utility remotely shuts down or cycles a customer's electrical equipment (e.g. air conditioner, water heater) on short notice to address peak demand issues. Customer approval is desirable for such programs with customers having the option to opt out of the program. Direct load control programs are primarily offered to residential and small commercial customers.
- Interruptible/curtailable (I/C) service is a program in which customers are given a rated discount each time they reduce load when intimated by the distribution company. Another form of the program may levy penalties on customers who fail to participate in the program. Interruptible programs have traditionally been offered only to the largest industrial (or commercial) customers.
- Emergency Demand Response Programs are programs that provide incentive payments to customers for measured load reductions during reliability-triggered events; emergency demand response programs may or may not levy penalties when enrolled customers do not respond.

Energy management systems within microgrids can manage the captive loads as well as provide a facility to participate in demand response programs in response to utility signals.

4 Energy Management System

Energy management is carried out within a microgrid with multiple objectives; some of them could be to,

- Maximise power availability for consumer
- Minimise operation cost of the microgrid
- Minimise environmental impact i.e. minimise emissions
- Minimise power purchased from the utility grid etc.

These objectives may be achieved through various techniques like linear programming, predictive control multi-agent system etc. Here we discuss in detail three kinds of such management methods:

(a) *Rule based load management*

A rule-based load management scheme is discussed in [4] for a residence. The rule-based scheme is based on load prioritising and shifting subject to certain rules. Load management was employed to satisfy loads so as to maximise available solar PV energy as well as maintain battery charging levels within desirable limits. In this approach the loads are classified into critical loads (CLs) and un-critical loads (ULs) such as.

- Critical loads (CL): lighting, freezer, blender, TV
- Un-critical loads (UL): water pump, washing machine and water heater.

The un-critical loads are controllable, and their operation can be shifted to a less energy-intensive time.

Four approaches were tested.

i Base case wherein load management was not done.
ii During daytime both CL and ULs are supplied through PV as battery and during night-time also both CLs and ULs were powered by battery.
iii During daytime only CLs are powered through both PV and battery, only PV is used to power the ULs, during night, only CLs are powered through batteries while ULs are left unused.
iv During daytime both the CLs and ULs are powered by PV, at night, batteries power only the CLs while the ULs are left without supply.

(b) Multi-agent system.

Agents are algorithms designed to perform dedicated and pre-defined tasks. A multi agent system has more than one of such agents. In MAS, agents perform individual tasks, communicate with other agents and resolve conflicts to arrive at a common goal [5].

In the microgrid context, there may be agents responsible for performing particular tasks related to generation, demand and other auxillary task; these are defined as producer agents, consumer agents and observer agents.

The producer agents perform tasks such as,

- Monitor active and reactive power from each source
- Determine per unit cost of power from each source
- Give commands regarding start-up, shutdown and quantity of real and reactive components to produce
- Communicate with other agents

The consumer agents perform tasks such as.

- Monitor the various loads connected in the microgrid including batteries
- Give commands to controllable loads to start or shut down

The observer agents perform tasks such as.

- Monitor the state of health of all components
- Monitor of battery temperature and other critical parameters
- These agents collectively derive a solution for cost and performance optimisation problem of the microgrid.

(c) Fuzzy logic

Fuzzy logic is a system in which input values are categorised into sets and the output level is determined by estimating the state of the input and the rate of change of the state.

One example of how fuzzy logic is implemented for energy management of a microgrid is given by [6].

Here the objective is to modify the load profile by shifting the controllable based on the input parameters such as electricity price, time of day, load values and input PV power values.

Here the parameters of Excess Demand, Electricity Price is categorised into sets such as.

Electricity Price: Low (L), Medium (M), High (H).

Excess demand: Negative Large (NL), Negative Small (NS), Zero (Z), Positive Small (PS), Positive.

Large (PL) and the corresponding expected output is mapped as follows.

A couple of cases are given below with input conditions and corresponding output.

Case 1:

This condition occurs during daytime while the demand for power is very low and electricity price is also low, power may be purchased from the grid and shedding of loads is not necessary. On the contrary if the condition is such that electricity price is high then shedding of loads is preferred to purchase of power from grid.

Case 2:

If power produced is greater than load demand and electricity price is high then the excess power produced may be sold to the grid.

In this way fuzzy logic maps the desired output of power purchase and load shedding depending on the state of the input parameters.

http://www.uoguelph.ca/~syang/complexsys/Vol%203/1/07.pdf

5 Case Studies

The following case studies illustrate the successful implementation of demand side management [7]

Inland Empire Utilities Agency (IEUA)

The IEUA, a water utility in San Bernardino County, California had distributed resources like 3.5 MW solar plant, 1 MW wind turbine, 2.8 MW fuel cell, 3.65 MW Li-ion batteries and 2.5 MW diesel generators. These resources were being operated independently. Then IEUA decided to create an interconnected system, with the ability to island during outages, control resources and costs, and supply energy and services to the regional grid.

The IEUA has been able to provide grid services to Southern California Edison (SCE) such as load reduction for demand response programs, congestion management, and voltage support without disrupting grid operations.

2500 R Midtown Development

Another example is the demand response application implemented by 2500 R Midtown microgrid situated in Sacramento, California. The microgrid consists of 2.25 kW solar PV and 11.6 kWh Li-ion batteries installed for each residence in a 34-family community. In this housing community, excess energy is exported to the grid during peak demand periods. During grid outage events, the microgrid islands itself and dispatches the stored energy to satisfy the critical load demand.

2500 R Midtown has demonstrated integration of solar PV and storage with utility grid benefitting both the utility and the consumers.

L&T campus in Chennai, India

Microgrid implemented in the L&T campus in Chennai, India, consists of 130 kW of solar PV, 7.2 kW, micro wind power, 2 800 kVA diesel generators and 32kWh Li-ion battery energy storage systems. The energy within the microgrid is managed by load management techniques like load shedding shifting etc. thereby reducing the power drawn from the grid.

Eagle-Picher

EaglePicher installed a microgrid in Joplin, Missouri that consists of 20 kW solar PV, 10 kW wind power along with 2 MWh lead acid batteries. The microgrid manages onsite, solar, wind power, grid power and loads to optimize TOU rates. The batteries in the microgrid are charged during low-cost energy times and discharged during peak periods. The microgrid can also operate in islanded mode during grid outages. This microgrid can shave ~ 200 kWh of its total daily demand of 500 kWh.

All the above cases demonstrate advanced microgrid features that benefit both the utility and the consumers by providing reliability, resiliency, reduction of carbon footprint, provision of ancillary services, energy revenue transactions etc.

Table 1 Scenarios for power supply to loads

Without energy management deployment (Base Case)			
	Operating Period	Load Category	
		CL	UL
Case1	Day time	PV, Battery	PV, Battery
	Nigh-time	Battery	Battery
With energy management deployment			
	Operating Period	Load Category	
		CL	UL
Case 2	Day time	PV, Battery	PV, Battery
	Night-time	Battery	Battery
Case 3	Day time	PV, Battery	PV
	Night-time	Battery	-
Case 4	Day time	PV	PV
	Night-time	Battery	-

6 Conclusion

Microgrid is a group of generation sources, energy storage and loads operated to for the benefit of the consumer. The microgrid controllers help in maintaining energy balance and power quality in the system by controlling the loads and power sources. A significant feature of the microgrid is its presentation to the grid as a single unit of electronic loads with local generation. This paper discussed various methods of employing demand response and load management within a microgrid and a few case studies that demonstrate implementation of these. This interaction between microgrids and main grids will be a necessary feature as the grid gains more intelligence. Features like reliability, resilience, electricity grid support, load management capabilities will remain important metrics of a microgrids performance.

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Minimized Operational Cost and Enhanced Battery Life in Solar, Battery and Building Integrated EV Charging Station

Bharat Gupta, Uday Mumbaikar, and Rashi Gupta

Abstract A reduction in operating cost of electric vehicle (EV) charging station will accelerate the development of EV charging infrastructure. In this paper, an intelligent optimal energy management algorithm is developed to minimize the operating cost of EV charging station. An EV charging station integrated with solar generation, battery energy storage system (BESS) and a building is considered. A diesel generator (DG) is used during unavailability of renewable generation and grid supply. The DG is operated at maximum efficiency by controlling the operating point with help of BESS. For implementing the energy management strategy, the state of charge (SoC) of battery needs to be known accurately. The life of battery depends on variation of its SoC. Battery management system (BMS) must accurately estimate battery SoC to get maximum battery life. As the capacity of battery degrades over time, the updated battery state of health (SoH) is essential for accurate SoC estimation. Simultaneous and real time estimation of battery SoC and SoH algorithm is also developed for the battery management system used in BESS. This algorithm can also be easily used in EVs for improving their battery life. The BMS with accurate SoC estimation is implemented in a building integrated with solar, BESS and DG in India. The results of the implementation are discussed and used for validating the performance of the optimal energy management strategy developed. Further simulation studies are performed with EV charging station integrated in the building and effectiveness of the algorithm is discussed.

Keywords Energy management system · EV charging station · Deep reinforced learning · State of Charge (SoC) · State of Health (SoH)

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1 Introduction

The use of EVs is rising all over the world. With rise in EV there will be equivalent need of electricity. For faster rise in use of EV there should be increase in availability of EV charging points and cost of electricity should also be minimum. For EV to truly reduce emission they should be charged with renewable generation. Buildings are a major consumer of energy globally and integrating renewable generation with them can significantly reduce their emission. Also the use of renewable generation is increasing worldwide. However, it is intermittent in nature and depends on availability of renewable energy like sun and wind in case of solar and wind generation. Energy storage is being used for reducing intermittency of renewable generation and improving quality and stability of supply. Developing countries like India suffer from weaker grid due to which diesel generators (DG) are often used during grid outage. With rising cost of diesel many buildings are adding renewable generation and BESS to get a reliable supply at reduced cost.

The building energy consumption is rising with time which is increasing the peak demand on the power system. Dynamic pricing is often implemented for encouraging demand side response. The operating cost of buildings can be reduced with intelligent energy management. Reduction in operating costs will encourage adoption of EV and integration of EV charging station in buildings. Since demand on EV charging station will be highly variable in initial phase of EV adoption. Integrating with building will ensure better management of renewable generation and reduce wastage of solar generation.

An intelligent energy management strategy is implemented in this paper for minimising the operating cost of a solar battery and building integrated charging station. Various methods have been used to solve energy management problem like heuristic methods, linear and dynamic programming, fuzzy methods etc. [1]. These methods compute either all the possible solutions or certain portion of solutions each time computation needs to be done. This frequently leads to an increase in computation time. Machine learning is perceived as a better alternative for solving such problems since it can automatically decipher energy flow pattern and find the optimal path. The machine learning model are not dependent upon information about load and renewable generation uncertainty and real time variation in electricity price [2]. Reinforced learning (RL) is often used for cost minimisation problems due to their ability to find optimal set of actions. Q learning method based on RL has been applied for energy management of solar microgrid [3]. However, as the dimensionality of problem increases, Q learning does not remain feasible solution. The problem of higher dimension are solved with a combination of deep learning with RL (Fig. 1).

In this work a building integrated with solar BESS and DG is considered in India for implementing energy management strategy. Due to unreliable supply the building has a diesel generator. Although currently charging station is not integrated in the system, energy management strategy will remain same with charging station integrated which will only contribute to increase in load.

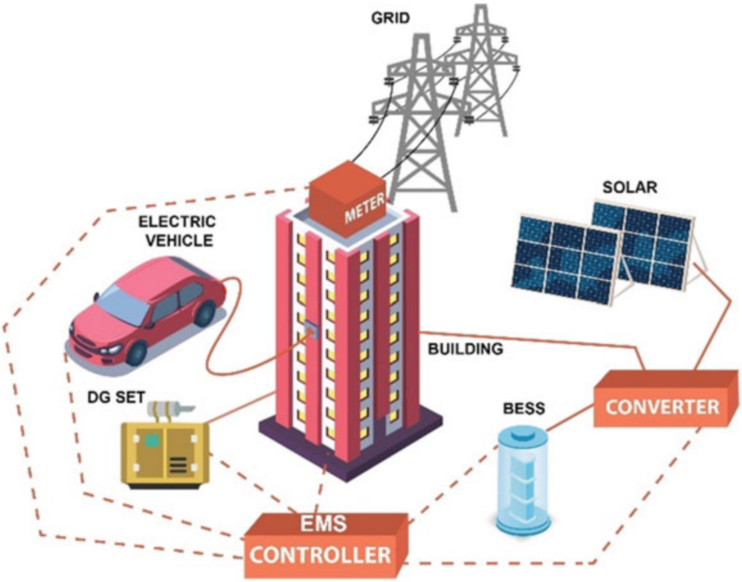


Fig. 1 Schematics of building integrated EV charging station

The building has 10kWp of solar generation installation. A BESS of 11.2 kWh is also used for obtaining uninterrupted power supply to the building. A plot of buildings consumption of solar generation and building load are shown in Figs. 2 and 3.

The existing energy management algorithm does not considers dynamic pricing of supply. Also due to absence of load solar generation is wasted. During grid outage the load is supplied initially by battery and then by diesel generator, when battery is discharged. The operating point of diesel generator depends on load which reduces

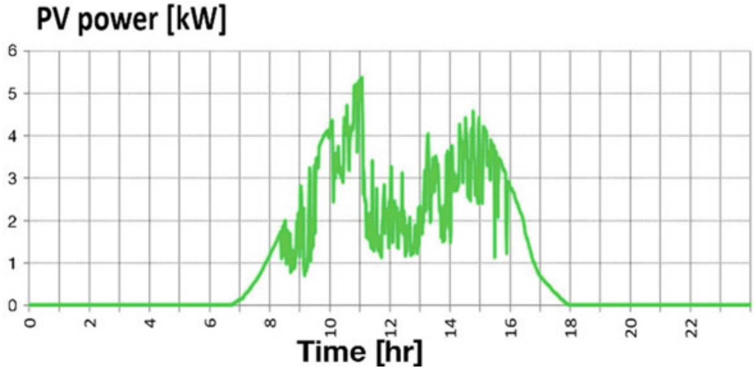


Fig. 2 PV power consumed by load

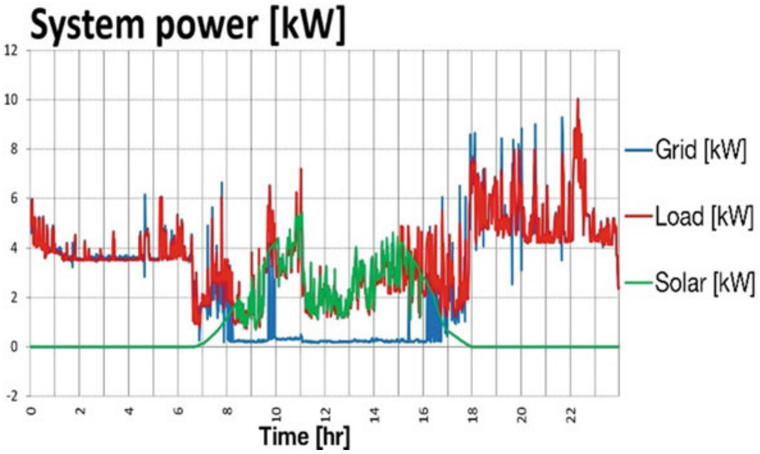


Fig. 3 System power

efficiency of generator. The energy management algorithm developed uses BESS to maintain the operation of DG at maximum efficiency. The charging power limit of battery is continuously updated such that DG is operated at 80% loading.

The energy management strategy implemented in this paper is based on deep RL method. Finite Markov decision process (MDP) formulation [1] is used for solving the problem. The goal of the energy management strategy is to find optimal path of actions such that operating cost of building integrated charging station is minimum. The strategy is implemented using two networks namely an actor and a critic network. The action to be implemented is obtained from the actor network using which the electricity to be purchased from grid can be calculated. The effect of this action or reward associated with it is calculated by the critic network. Gated recurrent unit (GRU) is used in the two networks to determine action and reward with the input data.

The MDP is defined with five tuples $(S, A, T(.,.), R(.,.), \gamma)$, where S represents the states of the system. A consists of feasible set of actions, $T(.,.)$ is the system state transition probability, $R(.,.)$ denotes the reward function and γ stands for discounted factor.

(a) s_t a state of the system at time t comprises of battery SoC, hourly price of electricity for past 24 h $(P_{\mathrm{t}-23}, \ldots, \mathrm{P}_t)$, hourly average load for past 24 h $(L_{t-23}, \ldots, L_t)$ and hourly average solar generation for past 24 h $(S_{t-23}, \ldots, S_t)$.

(b) Action a_t indicates the quantity of electricity to be purchased from utility over the next hour.

(c) Probability of state transition from state s_t to s_{t+1} is obtained from $s_{t+1} = f(s_t, a_t, \omega_t)$ wherein ω_t being the randomness. The SoC of battery in the next state is obtained by $SoC_{t+1} = (SoC_t \times C_0 + a_t - L_t)/C_0$ where C_0 is the capacity of battery. Randomness is associated with the load L_t due to uncertain nature of load. Electricity prices are assumed to be known since day ahead pricing schedule is normally provided by the utility operator. However, real time pricing can also be incorporated in this process with ω_t compensating for uncertainty in pricing.

(d) The value of reward is determined using

$$r_t = -P_t \times a_t - \lambda(SoC_{\min} - SoC_t) \tag{1}$$

where $SoC_{\min}$ is the minimum SoC, battery should maintain while participating in energy management strategy. In the system considered in this paper, BESS is allowed to discharge upto 60% of its capacity. 40% of battery capacity is reserved for backup during grid outage.

2 Q Learning

The performance of action a when system is in state ‘s’ is evaluated with function $Q_\pi(s, a)$. $Q_\pi(s, a)$ represents the expected total reward while performing action a starting from state ‘s’ and following π policy thereafter

$$Q_\pi(s, a) = E_\pi\left[\sum_{k=0}^{K} \lambda^k r_{t+k} | s_t = s, a_t = a\right] \tag{2}$$

where the actions to be performed in each state is given by policy π. The number of future steps is represented by K. Here discount factor $\gamma = 1$ implies all rewards have same value. Optimal action sequence is obtained when total expected reward is maximum.

$$Q^*(s, a) = \max Q_\pi(s, a) \tag{3}$$

$Q^*(s, a)$ gives the optimal sequence of actions for maximum rewards and minimum operating costs.

$$Q^*(s, a) = \max \sum_{k=0}^{23} r_{k+1} = \min \sum_{k=0}^{23} P_{k+1} * a_{k+1} \tag{4}$$

Determining the optimal policy π analytically is highly complicated in the considered energy management problem since load and solar generation is not known. Q values can be updated iteratively as

$$Q(s, a) = Q(s, a) + \alpha(r + \gamma \max Q_\pi(s, a) - Q(s, a)) \tag{5}$$

3 Deep Reinforced Learning

Calculating value $Q(s, a)$ for each state is computationally challenging since number of sates is very high. Instead the value of $Q(s, a)$ for each state is computed using a model. The deep RL based model makes use of an actor and a critic network to find the approximate value of $Q(s, a)$ [1]. It takes the battery SoC, hourly price of electricity for past 24 h, hourly average load for past 24 h and hourly average solar generation for past 24 h as input. Using which instantaneous action a_t is derived which further gives the reward r_t.

A. Network Architecture

Network architecture in the deep RL based model is shown in Fig. 4 wherein action a_t which specifies the required electricity purchase is generated by actor network. And critic network is responsible for producing $Q(s, a)$ using action a_t and reward r_t. Recurrent Neural networks are found to be suitable for time series data processing. In this deep learning model GRU is used to process the time series data.

(1) Actor Network: It is made up of three GRU networks each of 23 cells each. The 23 cells in each GRU network take gradient of $(P_{t-23}, \ldots, P_t)$, $(L_{t-23}, \ldots, L_t)$ and $(S_{t-23}, \ldots, S_t)$ as input. $d_t = P_t - P_{t-1} \ldots d_{t-21} = P_{t-21} - P_{t-22}$ and $d_{t-22} = P_{t-22} - P_{t-23}$ are gradients for electricity prices Similarly $f_t = L_t - L_{t-1}, \ldots, f_{t-22} = L_{t-22} - L_{t-23}$ and $h_t = S_t - S_{t-1}, \ldots h_{t-22} = S_{t-22} - S_{t-23}$ are gradients for load and solar generation. Figure 5 shows the architecture of each cell. The significance of past information is decided by reset gate g_t.

$$g_t = \sigma\big(W_g * d_t + U_g * y_{t-1} + b_g\big) \tag{6}$$

W_g, U_g and b_g are weights and bias terms and σ represents sigmoid function (Fig. 6).

$$c_t = \tan h(W * d_t + U * (g_t \odot y_{t-1})) \tag{7}$$

$$Z_t = \sigma(W_Z * d_t + U_z * y_{t-1} + b_z) \tag{8}$$

y_{t-1} is the obtained from previous cell, if cell exists, else its taken as zero. $tanh$ and $\odot$ represents the hyperbolic tangent function and element wise multiplication. W, W_Z, U, U_Z, b and b_Z being the weights and bias terms.

$$y_t = Z_t \odot c_t + (1 - Z_t) \odot y_{t-1} \tag{9}$$

y_t^p is output of one GRU network, output of other two GRU networks and SoC of battery are concatenated together to feed as input to a three layer neural network. The hidden layer and output layer value of the neural network is obtained using Eqs. (10) and (11) respectively.

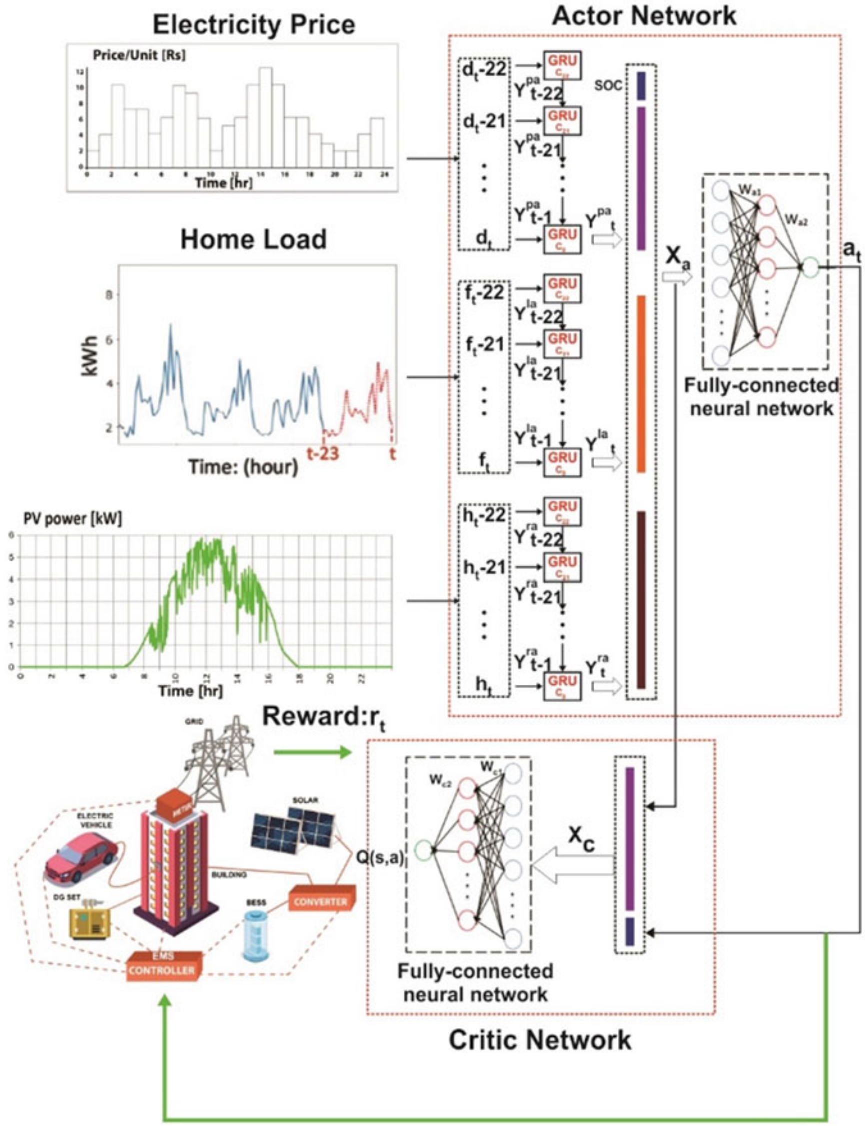


Fig. 4 Deep reinforced learning based building energy management system

$$h_a = relu(W_{a1} * x_a + b_{a1}) \tag{10}$$

$$o = \sigma(W_{a2} * h_a + b_{a2}) \tag{11}$$

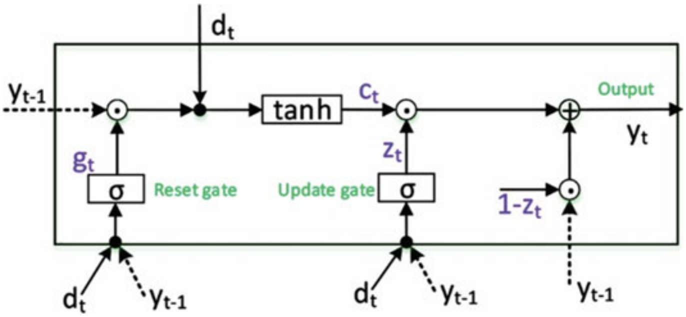
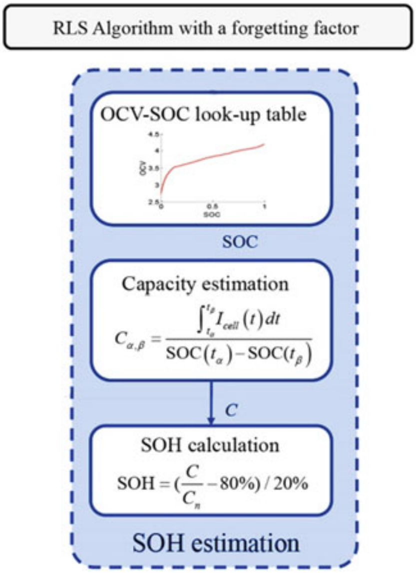


Fig. 5 GRU cell information flow

Fig. 6 RLS alogorithm schematics



$relu$ represents rectified linear activation function and W_{a1}, W_{a2}, b_{a1} and b_{a2} are weight and bias terms. The output is scaled to remain within 0 to $e_{\max}$ to get a_t such that consumption from utility grid is within sanctioned limits.

(2) Critic Network: The critic network concatenates the output of three GRU networks $\left(y_t^P, y_t^L, y_t^S\right)$, SoC of battery, output of actor network a_t and reward r_t calculated from Eq. (1) together. Concatenated output acts as input to a three layer neural network. The neural network's output and hidden layer value is computed with Eqs. (12) and (13).

$$h_c = relu(W_{c1} * x_c + b_{c1}) \tag{12}$$

$$oc = \sigma(W_{c2} * h_c + b_{c2}) \tag{13}$$

The output oc is taken as $Q(s, a|\theta)$ and W_{c1}, W_{c2}, b_{c1}, b_{c2} are weight and bias terms.

B. Training Algorithm

Training provided to the deep RL model is in accordance with deep deterministic policy gradient to get optimal actions. Two additional target networks are considered along with actor and critic network for training purpose. The target networks are same as actor and critic network and their initial parameters are obtained from the main networks. The action a_t is initially obtained by randomly sampling the uniform distribution $U(-e_{\min}, -e_{\max})$ till certain number of iterations in training episode. This phase is referred as pretrain phase, after which the main actor network is considered for calculating action a_t while considering exploration noise as well. Reward r_t is calculated using the selected action and next state s_{t+1} is attained by the problem. A replay buffer D stores the transition (s_t, a_t, r_t, s_{t+1}) from which a batch of transitions $F = \left(s_j, a_j, r_j, s_{j+1}\right)_{j=1}^{\mathrm{F}}$ is randomly sampled. The loss function is minimized with transition batch for updating the parameters of critic network $\left(\theta^Q\right)$. In Eq. (14), $y_j = r_j + \gamma Q'\left(s_{j+1}, A'\left(s_{j+1}\middle|\theta^{Q'}\right)\right)$ where A', Q' are target actor and critic networks respectively. And the sampled policy gradient is used for updating parameters of actor network. Further, these parameters of main network are slowly tracked by target network parameters. The network uses 300,000 episodes for training wherein each episode comprise of 24 time steps. The pretraining phase is of 8000 episode. SoC of battery is a state variable of the energy management problem whose accuracy will affect the performance of energy management strategy [4].

$$L_c = \sum_{j=0}^{\mathrm{F}} \left[y_j - Q\left(s_j, a_j\middle|\theta^Q\right)\right]^2 \tag{14}$$

4 Battery Management System

BMS performs protection of battery against over voltage, overcurrent, undervoltage, short circuit and over temperature. It monitors the cell voltages and calculates battery SoC and SoH. Variations in SoC of battery directly affect the life of battery. Longer the life of battery lesser will be cost of system over time. Thus, BMS should accurately measure battery SoC and communicate with energy management system. The calculation of SoC depends on the capacity of battery which keeps degrading with time [5]. Battery SoH reflects the instantaneous capacity of battery. For accurate SoC estimation simultaneous online SoH estimation is implemented in the BMS in this paper.

Open circuit voltage (OCV) method, coulomb counting, neural networks etc. are some of the algorithms used for SoC estimation [6]. In this paper, SoC estimation is performed using unscented kalman filter (UKF) which integrates coulomb counting and OCV method. Since, it does not needs calculation of Jacobian matrices like extended kalman filter method, it gives higher accuracy. Capacity of battery required for UKF method is updated with SoH calculations [5].

SoH of battery is often calculated using approaches based on degradation model, incremental capacity analysis, differential voltage analysis etc. [5]. However, empirical models used in most of the approaches are calibrated by life tests often lead to erroneous results due variation between cells and their environment. Recursive least square (RLS) algorithm with forgetting factor [5] is used for estimating battery (OCV) and internal resistance. Battery capacity is found using variation in SoC obtained from OCV-SoC relation and accumulated charge in a certain time interval.

5 SoC Estimation algorithm

The SoC estimation uses second order equivalent model in UKF algorithm for higher accuracy. Since accuracy of battery model affects the accuracy of Kalman Filter algorithms. However, equivalent model should not be too complicated to implement practically.

The second-order RC equivalent model being practically implementable is selected as shown in Fig. 7. The model consists of OCV as internal open circuit voltage and R_0 is internal ohmic resistance of the battery. The charge transfer, diffusion, polarization process and other factors are represented by R_1, C_1 and R_2, C_2 parameters.

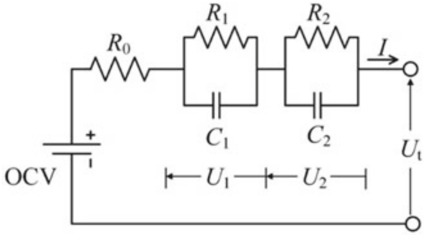
The model characteristics are described by equations.

$$U_1 = IR_1\left[1 - \exp(-t/\tau_1)\right] \tag{15}$$

$$U_2 = IR_2\left[1 - \exp(-t/\tau_2)\right] \tag{16}$$

$$U_t = OCV(SoC) - IR_0 - U_1 - U_2 \tag{17}$$

Fig. 7 Equivalent circuit model



where, I is the discharging current and U_t is the terminal voltage. U_1 and U_2 are the voltages across capacitors C1, C2 respectively. The value of $OCV(SoC)$ can be obtained from look up table. The $\tau_1 = R_1C_1$ and $\tau_2 = R_2C_2$ are time constants. Model parameters are adopted from [5]. They can be obtained using Hybrid Pulse Power Characteristic (HPPC) Tests [7].

Using Eqs. (15)–(17) state space model can be built as follows:

$$SoC_{k+1} = SoC_k + \frac{-\Delta t}{Q_a 3600}\eta I_k + W_1 \tag{18}$$

$$U_{1,k+1} = U_{1,k}\exp\left(\frac{-\Delta t}{\tau_1}\right) + R_1\left(1 - \exp\left(\frac{-\Delta t}{\tau_1}\right)\right)I_k + W_2 \tag{19}$$

$$U_{2,k+1} = U_{2,k}\exp\left(\frac{-\Delta t}{\tau_2}\right) + R_2\left(1 - \exp\left(\frac{-\Delta t}{\tau_2}\right)\right)I_k + W_3 \tag{20}$$

$$U_{t,k} = OCV_k(SoC) - U_{1,k} - U_{2,k} - R_0 I_k + V \tag{21}$$

U_1, U_2 and SoC are states of the model with current I as input and U_t being the output. W_1, W_2 and W_3 are process noise and sensor noise is denoted by V are considered to be mutually uncorrelated random processes. Q_a represents the battery capacity.

UKF algorithm works with sigma points, calculates and updates their mean and covariance iteratively. These sigma points are propagated through nonlinear model function. And using feedback from output measurements optimal estimate of state variables is obtained.

The new state vector for UKF implementation having dimension $L = 7$ is $X = [U_1, U_2, SoC, W_1, W_2, W_3, V]$ with mean $\overline{X}$ and covariance P_X. The sigma points with their weights are as follows:

$$X_0 = \overline{X}$$

$$X_i = \overline{X} + \left(\sqrt{(L+\Lambda)P_X}\right)_i i = 1, 2, \ldots..L \tag{22}$$

$$X_i = \overline{X} + \left(\sqrt{(L+\Lambda)P_X}\right)_{i-L} i = L+1, \ldots 2L$$

$$\alpha_0^m = \frac{\Lambda}{L+\Lambda}, \alpha_0^c = \frac{\Lambda}{L+\Lambda} + 1 - \alpha^2 + \beta \tag{23}$$

$$\alpha_i^m = \alpha_i^c = \frac{1}{2(L+\Lambda)}$$

Parameter controlling spread of sigma point is controlled by $\Lambda = \alpha^2(L+k) - L$. In this paper $\beta = 2$ and $\kappa = 0$. α^m and α^c are weighing factors of mean and covariance of sigma point. Update the sigma points $X_{(k-1)i}$ through Eqs. (18)–(20) to get X_{ki}. $\hat{X}_k^-$, P_{xk}^- are mean and covariance of propagated state vector.

$$\hat{X}_k^- = \sum_{i=0}^{2L} \alpha^m X_{ki} \tag{24}$$

$$P_{xk}^- = \sum_{i=0}^{2L} \alpha_i^c \left(X_{ki} - \hat{X}_k^-\right)\left(X_{ki} - \hat{X}_k^-\right)^T$$

Propagate estimated sigma points X_{ki} through Eq. (21) to get Y_{ki} and get estimated output mean $\left(\hat{Y}_k^-\right)$ and covariance matrices $\left(P_{yk}, P_{xyk}^-\right)$.

$$\hat{Y}_k = \sum_{i=0}^{2L} \alpha_i^m Y_{ki} \tag{25}$$

$$P_{xy} = \sum_{i=0}^{2L} \alpha_i^c \left(Y_{ki} - \hat{Y}_k\right)\left(Y_{ki} - \hat{Y}_k\right)^T$$

$$P_{xyk}^- = \sum_{i=0}^{2L} \alpha_i^c \left(X_{ki} - \hat{X}_k^-\right)\left(Y_{ki} - \hat{Y}_k\right)^T \tag{26}$$

Kalman gain matrix (K_k) is obtained using covariance matrix.

$$K_k = \frac{P_{xyk}^-}{P_{yk}}$$

$$\hat{X}_k^+ = \hat{X}_k^- + K_k\left(y_k - \hat{Y}_k\right) \tag{27}$$

$$\hat{P}_{xk}^+ = \hat{P}_{xk}^- + K_k P_{yk} K_k^T$$

$\hat{X}_k^+$ and $\hat{P}_{xk}^+$ are updated mean and covariance of state vectors estimates.

6 SoH Estimation Algorithm

When a battery is fresh its capacity is 100% the battery is considered to have 100% SoH. However, as battery degrades to a lower limit such as 80%, SoH is considered to be 0%.

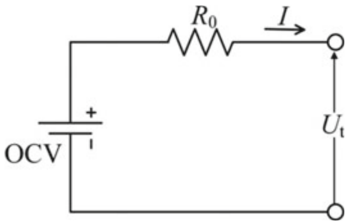


Fig. 8 R_{int} model

$$SoH = \left(\frac{C}{C_n} - 80\%\right)/20\% \tag{28}$$

where C_n is the initial capacity of battery when it is freshly manufactured and C is the instantaneous battery capacity. The instantaneous battery capacity could be calculated with variation in SoC over certain time interval and the accumulated charge ΔAh in that interval as given in Eq. (29).

$$\Delta SoH = \frac{\Delta Ah}{C} \tag{29}$$

$$C_{a,b} = \frac{\Delta Ah}{C_{a,b}} = \frac{\int_a^b I_t(dt)}{SoC(t_a) - SoC(t_b)} \tag{30}$$

Here a and b are two time instants and OCV-SoC lookup table is used to get $SoC(t_a)$ and $SoC(t_b)$ using estimated OCV at a and b instants. In this paper RLS algorithm with forgetting factor is used to get OCV estimation. The R_{int} model as shown in Fig. 8 is used for OCV identification. The R_{int} model is described by equation.

$$U_{tk} = OCV(SoC) - IR_{int}$$

$$y_k = U_{tk} \tag{31}$$

$$\varphi = \left[\, 1 \; -I_k \,\right]^T$$

$$\theta_k = \left[\, OCV_k \;\; R_{int,k} \,\right]$$

where U_t is the terminal voltage as system output and OCV and R_{int} are parameters to be identified denoted by parameter vector θ. The RLS algorithm with forgetting factor is implemented using the following equations:

$$y_k = \varphi_k^T \theta_k \tag{32}$$

$$e_k = y_k - \varphi_k^T \hat{\theta}_{k-1} \tag{33}$$

$$K_k = \frac{P_{k-1}\varphi_k}{\lambda + \varphi_k^T K_k \varphi_k} \tag{34}$$

$$P_k = \frac{P_{k-1} - K_k \varphi_k^T P_{k-1}}{\lambda} \tag{35}$$

$$\hat{\varphi}_k = \hat{\varphi}_{k-1} + K_k e_k \tag{36}$$

Here y_k being the system output with e_k prediction error. φ_k and θ_k are measurement vector and parameter vector respectively. P_k is covariance matrix and K_k represents update gain with λ forgetting factor.

The combination of UKF and RLS algorithm is implemented in BMS to get accurate SoC and SoH for BESS. Using reinforced learning algorithm the consumption of building is reduced especially during high price duration. Studying the performance of reinforced learning algorithm with EV charging station integrated. It was found to have less operating cost than the existing energy management strategy. Also entire solar generation was found to be consumed.

7 Conclusion

The intelligent optimal energy management algorithm based on deep reinforced learning is found to reduce the operating cost of building. The uncertainty associated with solar generation and also of load due to integration of EV charging station is considered in the algorithm. The simultaneous SoC and SoH estimation algorithm in BMS ensures safe operation and long life of BESS. The consumption of solar generation is also optimised. The operation DG at maximum efficiency increases overall efficiency of system and helps in reducing pollution. The SoC and SoH estimation algorithm being computationally less intensive is suitable for EV batteries as well.

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Assessment of Charging Technologies Currently Used for Electric Two and Three Wheelers in India

Chandana Sasidharan and Shyamasis Das

Abstract The commercial application of electric two-wheelers (e-2Ws) and electric three-wheelers (e-3Ws) with lithium ion batteries is growing in India. Hence, charging infrastructure for these electric vehicles (EVs) would be essential. Currently, there is no standardization of charging practices worldwide for these EVs. In view of this, an investigation is done to understand how the e-2Ws and e-3Ws in India are currently being charged. The paper presents an overview of the charging technologies associated with e-2Ws and e-3Ws with advanced batteries in the Indian market. Manufacturers, fleet operators and swapping service providers are consulted to study charging of the e-2W and e-3Ws. The study concludes that for e-2Ws and e-3Ws with battery size less than 5 kWh, the charging requirement can be met through 230 V, 16 A (3.3 kW) outlets. The paper also finds that portable chargers serve the purpose of on-board chargers in this segment. While planning the charging of these vehicles, the thermal management of the batteries should be taken into account. Detachable batteries make swapping an equally practical option for e-2Ws. In the case of e-3Ws the weight of the batteries should be managed to facilitate swapping. To estimate charging power for swapping a thumb rule of half of battery capacity can be used. The total power demand at the swapping station will depend on the number of batteries.

Keywords Electric vehicle charging · Two-wheeler · Three-wheeler · Battery swapping · India

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1 Introduction

India exhibits certain preferences in the choice of vehicles for transport, differentiating it from the motorised transport in the rest of the world [1]. The current vehicular landscape in India is dominated by two and three wheelers, which constitute 80% of the total number vehicles [1, 2]. Two wheelers, the largest share of vehicles in India, enjoys the privilege of being a preferred mode for personal and commercial transport. Three wheelers, on the other hand, are commercial vehicles for passenger and goods transport [3]. Electrification of two and three wheelers is recognized as a low hanging fruit for clean mobility in India in based on the market readiness and emission reduction potential [4].

One of the distinguishing factors of electromobility in India, is also the significant share of electric two wheelers (e-2Ws) and electric three wheelers (e-3Ws). Two and three wheelers together represented 99.5% of sales of electric vehicles (EVs) that happened in FY 2019 in India [5]. The upward trend of e-2W and e-3W adoption is expected to continue with the right policy elements focusing the upfront cost reduction. Government of India announced demand incentives for 10 lakh electric two wheelers and 5 lakh electric three wheelers under the phase II of Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme [6].

Not surprisingly, the e-2W and e-3W segment has generated a lot of interest among manufacturers and entrepreneurs. There is a massive impetus for commercial adoption for these vehicles for passenger and goods transport in India. Pilot programs proved that these vehicles offer advantages in terms of total cost of ownership to fleet operators [7]. While some fleet operators offer transport services with fully electric fleets [8–10], where as many others are currently electrifying a share of their transport vehicles [11–13]. The key factor for any successful commercial application of electric vehicles is planning their charging. Quite a few charging serving providers have made their presence in market focusing on this particular segment [14, 15].

The e-2Ws and e-3Ws are a distinct class of electric vehicles with their own set of advantages and challenges when it comes to charging. A key characteristic feature that demarcates e-2Ws and e-3Ws from the other classes of electric vehicles is their smaller battery size. Additionally, the smaller size of batteries enable battery swapping as a supplementary possibility with this vehicle segment. But there is no standardization of charging practices worldwide for e-2Ws and e-3Ws. This is primarily because there are no standards for electric two-wheelers and three-wheelers design. Moreover, the e-2Ws and e-3Ws generally have no active cooling mechanism and the charging rates of these batteries are often limited by the thermal management capability.

The e-2Ws and e-3Ws typically employ either of the two battery chemistries-Lithium Ion or Lead Acid. Initially Lead Acid batteries were common in this segment. The recent trend in the EV industry is to adopt Lithium Ion based battery packs in the commercial use cases. Moreover, only electric vehicles with advanced chemistries such as Lithium Ion are eligible to receive the demand incentives under FAME II [6]. The relatively lower charging time and increased cycle life are supporting factors for in the uptake of Lithium Ion batteries for these vehicle segment.

In view of this, an investigation is done to understand how the e-2Ws and e-3Ws in India using Lithium Ion chemistries are currently being charged. The paper presents an overview of the charging technologies associated with the e-2Ws and e-3Ws with advanced batteries in the Indian market. Manufacturers, fleet operators, swapping service providers and battery pack manufacturers are consulted to understand the details of the battery and charging of the e-2W and e-3W models. The results from the case studies showcasing commercial application of e-2Ws and e-3Ws are analysed to derive the key aspects for charging for this EV segment. This study will help planning of charging infrastructure for e-2Ws and e-3Ws.

2 Charging Aspects of Electric Two Wheelers

The commercial application of electric two wheelers are found in both passenger and good transport. There are limited e-2W models which are custom built for logistics operation [8]. The e-2Ws mostly used in commercial operation are mostly electric equivalents of scooters. A popular classification of the e-2Ws is based on their speed of travel. There are two sets of e-2Ws: Low-Speed vehicles: maximum speed of 25 kmph and High-Speed vehicles: maximum speed above 25 kmph. However, the stakeholder consultation reveals that the difference in speed of travel does not necessarily translate to changes in battery.

On the other hand, one of the major observations from the stakeholder consultation for e-2Ws is about the configuration of batteries. The batteries in these vehicles are either fixed or detachable as shown in Fig. 1. The battery configuration has an impact on the charging technology decision as the detachable batteries enable swapping operation. In terms of battery swapping, the depleted batteries are removed and replaced with a fully charged battery. Hence for the purpose of studying charging technologies, a better classification is.

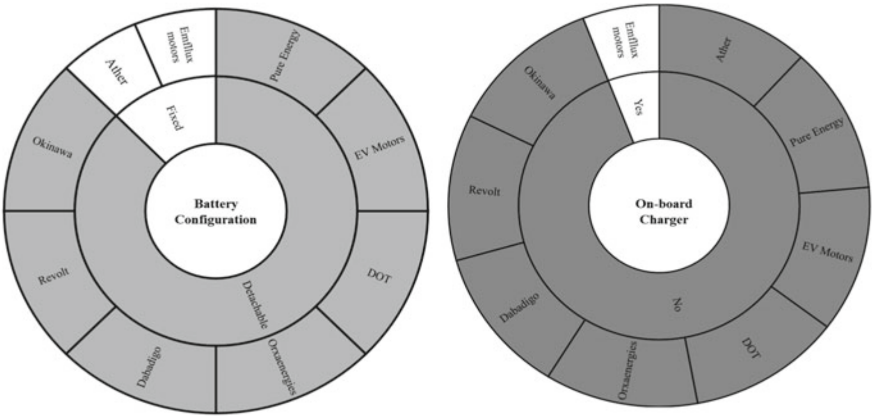


Fig. 1 Details of battery configuration and on-board charger in surveyed electric two wheelers

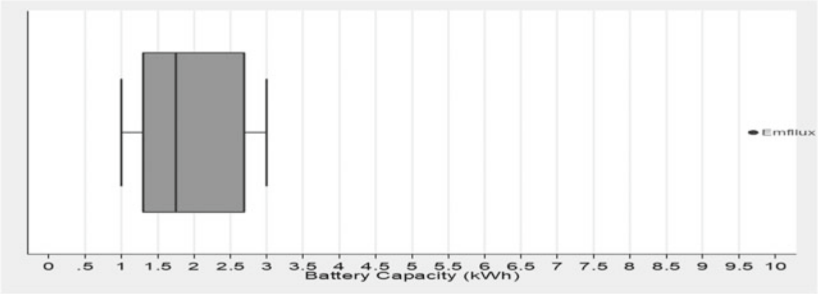


Fig. 2 Battery capacity of surveyed electric two wheelers

- Two wheelers with fixed batteries, where in plugging- in of the vehicle is the only possibility to recharge depleted battery
- Two wheelers in detachable batteries where both plug-in charging and battery swapping are equally possible.

The second key observation from the stakeholder consultation is that on-board chargers is not a common technology for charging this vehicle segment. There were very few vehicles with on board chargers among the surveyed as shown in Fig. 1. However most of the manufacturers provide portable chargers which perform the same function as the on-board chargers. The third most significant finding from the stakeholder surveys is about the battery sizing in these vehicles. The charging energy needs for e-2Ws would depend on the battery capacity, and the battery voltage determines the charging voltage. A mapping of battery capacity for e-2Ws is presented in Fig. 2. The major findings related to battery sizing are stated below.

- The battery capacity for e-2Ws surveyed ranged from 1 to 9.7 kWh. The most common battery capacity is around 1.75 kWh (refer to Fig. 2)
- The voltage of the battery packs is not the same for all vehicles in this segment. Generally, it varies between 48 and 72 V
- The typical weight of battery for these vehicles is 15–16 kg

3 Charging Aspects of Electric Three Wheelers

The e-3Ws aid in passenger and goods transport. Most e-3W models in commercial use are e-rickshaws, e-autos, e-loaders or e-cargo vans. In comparison with the e-2Ws, the penetration of Lithium Ion batteries is relatively new in the e-3Ws segment. However, there is an increasing trend of retrofitting of Lithium Ion batteries in the e-3W segment. The change in electro chemistry of batteries has reduced the charging time and improved the operating hours.

The first observation from stakeholder consultation of e-3Ws is that the battery capacity is not the same for passenger and goods vehicles. Similar to e-2Ws, the e-3Ws also have fixed or detachable batteries. However, when it comes to e-3W batteries the capacity is determined by the application. And battery capacity, along with the battery chemistry determines the weight of the battery. And the weight of the battery is of prime consideration when it comes to swapping operation.

The highlights from the stakeholder consultation for e-3Ws are as follows:

- The e-3Ws are designed with both fixed and detachable batteries (refer to Fig. 3)
- On-board chargers are not a common occurrence in this segment (refer to Fig. 3)
- The e-3Ws passenger transport operation have batteries between 2.8 and 3.4 kWh. The average capacity is 3 kWh. (refer to Fig. 4)
- The goods carriers e-3Ws have batteries between 2.7 and 7 kWh. The average capacity is 4.75 kWh. (refer to Fig. 4)
- The battery pack Voltage is between 48 and 72 V.
- The typical weight of the batteries is between 35 and 50 kg.

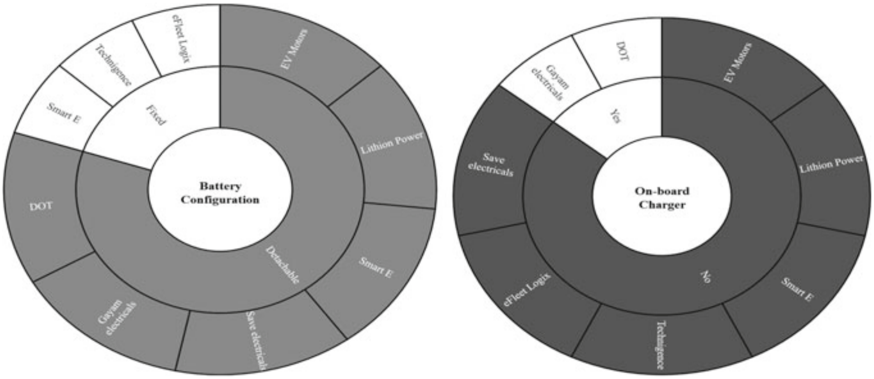
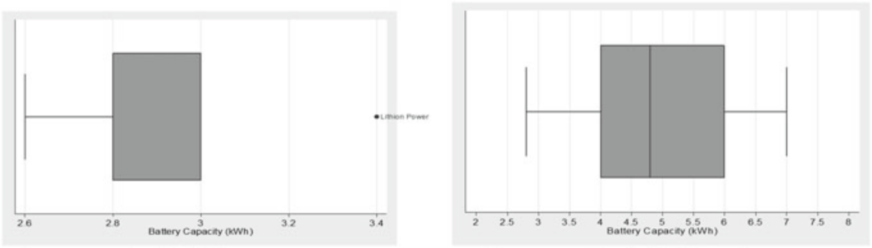


Fig. 3 Details of battery configuration and on-board charger in surveyed electric three wheelers



Battery capacity of e-3W for passenger transport

Battery capacity of e-3W for goods transport

Fig. 4 Battery capacity of surveyed electric three wheelers for passenger and goods transport

4 Case-Studies on Charging and Swapping

The research team interacted with the commercial fleet operators and charging service providers in the segment. The key findings from selected case studies from logistics and passenger fleet operation is presented in this section. The use cases studied include both plug-in charging and swapping operation for two wheelers and three wheelers.

A. Charging and swapping of electric two-wheelers

For e-2Ws in commercial operation often the fleet operators also provide the charging service. It is interesting to see that in India a vehicle manufacturer has also turned to charging service provider. The charging behaviour associated with passenger transport shows that both swapping and charging a suitable-options as shown in Table 1. Bounce, vehicle rental service provider has tied up with local convenience store owners for swapping. eBikeGo, one of the commercial fleet operators also suggested that they prefer e-2Ws with detachable batteries, as it is possible to swap with spare fully charged batteries in case of emergencies, instead of waiting for the vehicle to charge.

Table 1 Summary of case studies on electric two wheelers

Stakeholder	Ather energy	Bounce	Dabadigo	DOT	eBikeGo
Category of stakeholder	Electric vehicle manufacturer and charging service provider	Vehicle rental service provider	Electric vehicle rental service provider	Electric vehicle logistics fled operator	Electric vehicle passaiger and logistics fleet operator
Vehicle segment	Electric two wheelers	Electric two wheelers	Electric two wheelers	Electric two wheelers	Electric tw o wheelers
Commercial segment	Passenger	Passenger	Passenger	Goods	Passenger and Logistics
Type of solution	Charging	Charging and swapping	Swapping	Charging	Charging
Battery capacity	2.4 kWh	Not available	1.2 kWh for three wheelers	1.5/2/3 kWh for two wheelers	1.7 kWh
Type of charging	DC charging	Swapping	Assisted swapping	AC charging	AC charging
Capacity of charger	2.5 kW	NA	6 kW for 10 batteries	Not available	Not available
Charging time	Not available	1–3 h	2 h for one charge	2–4 h	Not available
Charging cycle	Not available	NA	2 charges in a day	1 charge in a day	1 charges in a day

The reported charging time for vehicle batteries for charging and swapping is in the range of 1–4 h. Most of the plug-in charging is AC charging with portable chargers. The portable chargers are typically plugged into regular 230 V, 16 A AC outlets for charging. However, Ather Energy provides DC charging with fixed chargers. In case of swapping, the battery charging is done within 2 h. It is also observed that if battery capacity of the e-2W is more, it is possible to sustain the operation with one charge cycle.

B. Charging and swapping of electric three-wheelers

For commercial operation of e-3W fleets, the fleet operators set up captive charging facilities or tie up with a swapping service provider (refer to Table 2). In case of the electric three wheelers, the operational characteristics and the weight of the battery are the parameters that determine charging or swapping. The operating pattern of the vehicles could be such that they ply on the road the entire day. An alternate possibility is that the operation stops mid-day, where the vehicles retire to the service hubs. The latter type of operation presents a case to undertake opportunity charging for the fleet.

The weight of the battery is the biggest consideration for swapping. The specific energy density of Lithium Ion batteries used in e-3Ws is approximately 100 Wh/kg

Table 2 Summary of case studies on electric three wheelers

Stakeholder	e-fleet logix	Gayam motors	Litbion power	Smart E	Sun mobility
Category of stakeholder	Electric vehicle logistics fleet operator	Equipment manufacturer and swapping service provider	Electric vehicle swapping service provider	Electric vehicle passenger fleet operator	Electric vehicle swapping service provider
Vehicle segment	Electric three wheelers	Electric three wheelers	Electric three wheelers	Electric three wheelers	Electric three wheelers
Commercial segment	Logistics	Logistics	Logistics	Logistics	Passenger
Type of solution	Charging	Swapping	Swapping	Charging	Swapping
Battery’ capacity’	4.8 kWh for three wheelers	4 kWh for three wheelers	3.4 kWh for three wheelers	2.8 kWh	2 × 1.5 kWh battery’ pack
Type of charging	AC charging	Assisted swapping	Assisted swapping	AC charging	Automated swapping
Capacity of charger	2 kW	2 kW	15 kW for 9 batteries	2 kW	Not available
Charging time	2–4 h	2–3 h	2 h	2–2.5 h	1 h
Charging cycle	2 charges in a day	2 cycles in a day	Not available	1.5 charges in a day	Not available

[16]. This means that a 1.5 kWh battery weighs around 15 kg, which is easier for a single person to lift without assistance.

One way to plan the swapping operation is to use multiple battery packs of 1.5 kWh. This is the strategy adopted by Sun Mobility to set up automated swapping solution. They provide two battery packs of 1.5 kWh for e-3Ws for passenger fleet.

Alternately, swapping operation can be planned for bigger batteries where every swapping station has an assistant who will assist in the vehicle driver in lifting the battery. Lithion Power provides assisted swapping solution for e-3W passenger vehicles with a 3.4 kWh battery which weighs around 35 kg. Gayam Motors employ a similar assisted swapping model for their logistics operation.

It is already observed that the batteries of the e-3W goods carrier vehicles are of higher capacity than the e-3W passenger vehicles. This makes the good vehicles batteries heavier, and making the swapping operation tricky. The case studies show that as the vehicle batteries get heavier, the logistics fleet operators prefer plug-in charging to swapping. Another reason supporting the choice of plug-in charging over swapping is the window of opportunity charging at mid-day arising from the operational pattern.

Most common mode of charging is using portable chargers are plugged into 230 V, 16 A (3.3 kW) outlets for plug-in charging. The reported charging time for these vehicle batteries is in the range of 2–4 h. In the case of battery swapping also charging of the batteries is planned in 2 h. Only reported case for faster charging of batteries is by Sun Mobility in their swapping operation, where the batteries are charged within an hour in an air- conditioned environment.

The case studies also reveal that in case the batteries are charged within 2 h at a swapping station, a thumb rule half of the battery capacity is useful. However, the total power demand for a swapping facility will depend on the number of batteries that needs to be charged. The charging of the batteries can be performed using individual chargers or stack chargers.

5 Discussion and Conclusion

The paper provides an overview of the charging aspects associated with e-2Ws and e-3Ws powered by lithium-ion batteries in the Indian market by studying the vehicle models and their commercial operation. It is found from the stakeholder consultation that e-2Ws and e-3Ws have fixed or detachable batteries, which can be charged inside or outside the EVs. Both fixed and detachable batteries can be charged inside the EVs with fixed or portable chargers. The second possibility is to remove the depleted battery from the EV and re-charge it in a controlled environment using a battery charger. Thus, the two applicable charging technologies are plug-In charging and battery swapping. The selection of charging or swapping options for this EV segment requires the following key considerations:

- **Battery capacity**: The common battery capacities for e-2Ws currently available in the market are between 1.25 kWh and 2.75 kWh. In case of passenger e-3Ws, the capacities range from 2.8 kWh to 3 kWh. The batteries of e-3W goods carriers are between 4 and 6 kWh. Thus, the average battery capacities for e-2W, e-3W passenger and e-3W goods vehicles are 1.75 kWh, 3 kWh and 4.75 kWh respectively.
- **Charging power**: The most observed cases of e-2Ws and e-3Ws, time taken for charging is between 2–4 h. 0.25 and 0.5 kW chargers can charge a 1 kWh battery in 2 h and 4 h respectively. Considering the average battery sizes, the charger power needed for these vehicle segments is between 0.5 and 2.5 kW. It is possible to charge these vehicles from a 230 V, 16 A socket (3.3 kW). In case of swapping, a thumb rule of half of battery capacity can be used to estimate charging power for individual battery pack in 2 h.
- **On-board or portable charger**: Typically EVs have on-board chargers, and it is possible to plug it into any suitable plug outlet to charge. Quite often the e-2W and e-3W segments do not have on-board chargers. Alternately, portable chargers are often provided by the manufacturers along with the e-2Ws and e-3Ws which can serve the same purpose.
- **Thermal management of the battery**: The e-2Ws and e-3Ws generally have no active cooling mechanisms. Charging of the batteries produce heat, and the charging rate of these batteries are often limited by the thermal management capability. This is particularly important considering the tropical climatic conditions in India. There are only a few EVs which can be charged until 80% of battery capacity under an hour.
- **Battery voltage**: Chargers are designed to cater to the required battery voltage. 48 V batteries need chargers that can provide 48 V output, and 72 V batteries need chargers that can provide 72 V output. Charging a low voltage battery with a high voltage charger could damage the battery. Hence, the chargers for this segment are Low Voltage chargers.
- **Battery weight**: The weight of the battery pack is of prime importance when planning swapping operation. A 1 kWh battery pack weighs approximately 10 kg. The e-2W battery packs being of smaller capacity are typically lighter than the e-3W battery packs. Hence, challenge arises for swapping of heavier e-3W batteries. It is possible to split the battery bank into individual battery packs which can be easily lifted by a single person. It is also possible to manage the swapping in the passenger segment with an assisted two-person operation in the swapping station.
- **DC charging**: DC plug-in charging of e-2Ws have gained attention from manufacturers as it allows charging at faster rates in comparison with the plug in AC charging. Nevertheless, the maximum charging rate for this type of charging is subject to the thermal management capability and ambient temperature conditions. In the case of e-3Ws the faster charging is achieved only by removing the batteries and charging in air-conditioned environment.

The study concludes that for e-2Ws and e-3Ws with battery sizes less than 5 kWh the charging requirement can be met through 230 V, 16 A (3.3 kW) outlets. The paper also finds that portable chargers can serve the purpose of on-board chargers in this segment. While planning charging of these vehicles the thermal management of the batteries is an important factor. Detachable batteries make swapping an equally practical option for e-2Ws. In the case of e-3Ws the weight of the batteries should be managed to facilitate swapping. In case of battery swapping, a thumb rule of half of battery capacity can be used to estimate battery charging power. The total power demand at the swapping station will depend on the number of batteries.

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Energy Storage—The New Era of Power Sector

Debmalya Sen

Abstract The new era of the energy sector encircles around alternate sources of energy, the truth in the phrase has now been well understood and accepted by even the toughest critic of change. The revolution in the energy sector started way back in the last century but it was more dispersed in nature. Also, the need of an alternate source of energy was not felt then with the abundance of fuel sources like coal and gas. The world became conscious of the emissions from coal-based power generation but was quiet as it did not have a strong enough substitute to support their concern. With the invent of renewables the world for the first time found a voice to raise concern. For the first time there was someone who had the potential to reduce the dependency on coal for power generation. Renewables being agile, compatible and flexible in design brought about changes in the otherwise rigid power sector. The sector which was overtly a B2B industry started to open. Industry started to talk about decentralization of power, decarbonization of grid and concepts like open access, distributed generation to name a few. The period between 2008 to 2015 saw many new types of technologies coming up and giving more options of generating power commercially. The paper is an effort to describe the development of the power sector, its concerns, the enablers and the way forward.

Keywords Electric vehicle · Batteries · Renewables · Power sector · Capacity · Grid · Reliability · Curtailment · Storage · Generation · Forecasting and scheduling · Power and energy density

1 Introduction

Sector Status Quo: The Indian power sector present generation Capacity is 346 GW (59%—Coal) of which 46% of generation capacity is catered by private sectors. The Capacity Factors range from 74%—Central; 59%—State and 54%—Private players. The Renewables Capacity is around 72 GW which is around 8% of total capacity.

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Solar Installed Capacity as on date is 27 GW (87% utility scale, 13% rooftop) and that for wind is 34 GW. The pumped hydro part is quite insignificant as on date because of many hurdles being faced due to land acquisition and selection issues. Statistics shows that around 85% of the hydro potential is unexplored. India's energy consumption rate is growing at a CAGR of 6–8%, with daily peaks ranging 150–170 GW. In 2018, renewables pumped 78,537 million units into grid.

Along with the increase in renewables in the grid, the reserve margin in grid increased from 51% in 2011 to 725 in 2017 (lower utilization of thermal plants due to increased RE penetration). The DG Capacity as on date: 80 GW (~4.7 billion ltrs. of diesel). Along with the increase in renewables in the grid, the grid inertia has been decreasing too, which makes the grid vulnerable while being grid. In order to make this responsible, storage plays a very big part. The storage market has been growing to compliment this growth. At present the energy storage market is around 20 GWh, with 5.3 GW of large-scale energy storage projects announced in 2018 alone.

2 Government Commitments

Government of India has been actively promoting the Greening of Grid revolution. It has placed ambitious targets from time to time from 225 GWs of Renewable capacity by 2022 to 30% of vehicles manufactured as EVs by 2030. India also made commitment in Paris Agreement to reduce GPD's emission intensity by 33% by 2030 from its level in 2005 and promotion of indigenous manufacturing and development of skills—Make in India. With policy frameworks like FAME I and now FAME II and also encouragement and incentives on local manufacturing, the Government has made clear its intent. All these has given a clear indication to market on the way forward in the power sector.

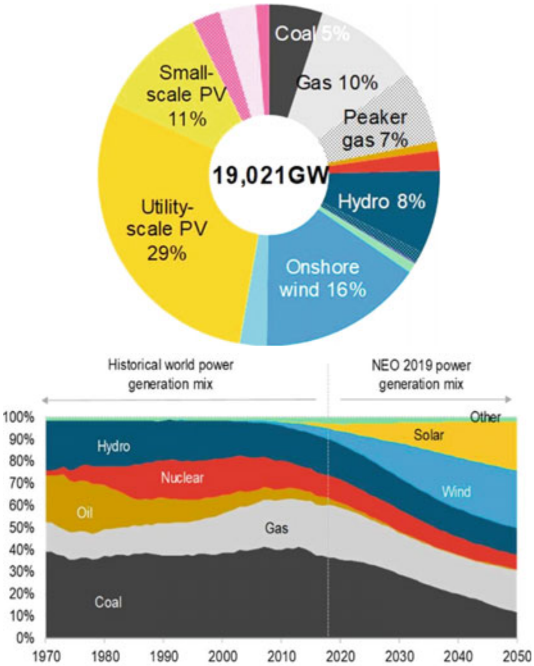
3 Market Projections

The year 2018, have seen some ups and downs in terms of Renewables capacity addition in India. While the main reason has been the fluctuations of the Indian rupee against the US dollar, anti-dumping duty which was imposed on solar panels also dampened the industry sentiments.

The year 2019 promises to bring back the growth to track with around 50% more addition of RE capacity forecasted. Predictions claim that India will be 50% non-fossil fuel generation nation by 2030 with diversity in grid increasing to 5% and by 2050, 75% of India will be powered by Renewables. The predictions state 620 GWs of Renewable capacity by 2027 which will be 44% of grid (Wind—75 GWs by 2025; Solar—150 GWs by 2025) (Fig. 1).

The increasing percentage of renewables in the grid also will increase the ramping rate requirements.

Fig. 1 Global energy trend



Studies predict 150 MW/min for 40 mins at present to 340 MW/min for 3–4 h by 2025 increase in ramping rates. Amongst usage and demand, AC usage is projected to increase significantly—24% of total energy consumption demand.

Potential of the storage market as per report is more than 300 GWh by 2030 growing at a CAGR of 21% from 2017 to 2025. The world has seen a steep decline in battery prices, Battery prices have decreased 85% from 2011 to 2018, at present battery prices are around USD150/ KWh, further 30% reduction expected in 2 years' time, almost reaching USD100/KWh by 2030. Figure 2 shows how the price has fallen for battery packs from 2011 to 2018. The price drop mainly attributes to the economies of scale for each manufacturer crossing the 5 GWh mark by 2015.

India battery storage market will be around 90 GWh by 2025. One of the main demands here will come from Inverters (16%) but overtime with more stability and reliability of grid the inverter market will decline. Top 5 applications in terms of MWh potential in the battery market, will be EVs (51%), Inverters (16%), telecom (10%), UPS (7%) and thermal storage. EVs to share 51% of battery market resulting to total requirement of 200 GWh (total sale of EVs to be 17.8 M by 2025)

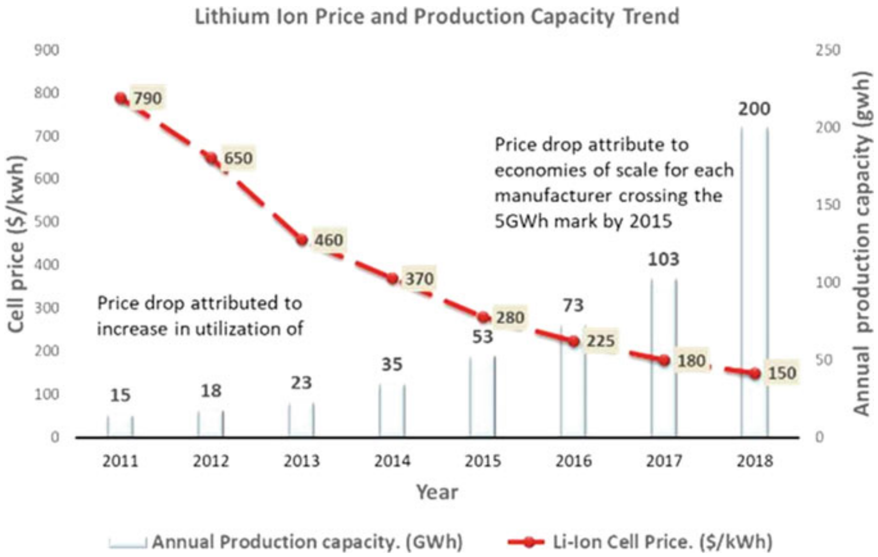


Fig. 2 Battery price and manufacturing capacity trend

4 Concerns

- Grid Reliability—Percentage increase of renewables in grid also increases variability in grid. As renewable power is cheaper and due to mandate to consume 100% of renewable generation by the DISCOMs it leads to the conventional plants being shut down. But what happens due to this is that the inertia of the grid reduces a lot and there is fear of grid blackouts in case renewable generations doesn't meet forecast.
- The Duck Curve Issue—Solar generation shuts off in evening, which will create a huge instant demand, which will lead in very high ramping rates. Coal plants will not be able to cater to this demand. Gas plants can, but power price from gas plants are very high due to non-availability of cheap domestic gas supplies (Fig. 3)
- Stringent Forecasting and Scheduling Regulations—In order to make the grid reliable, grid has come out with F&S regulations with penalties on defaults. Renewable with variability thus will find it challenging to adhere to schedule with resource assessments not yet matching >90% accuracy levels. Discussions are also going on to convert the 15 min blocks to 5 min blocks (Fig. 4)
- Curtailment and Load Shedding—There has been a substantial gap between the expansion of renewables and in connection to it expansion of sub-stations to cater the load. This has resulted in maximum of the substations operating at near full capacities or even being over loaded. This leads to huge curtailment and load shedding's whenever wind speeds increase. A study was carried out in an operational windfarm to understand the magnitude of this loss, the Fig. 5 shows

Source: NLDC SCADA data, CAGR assumed: 8%

Fig. 3 Duck curve

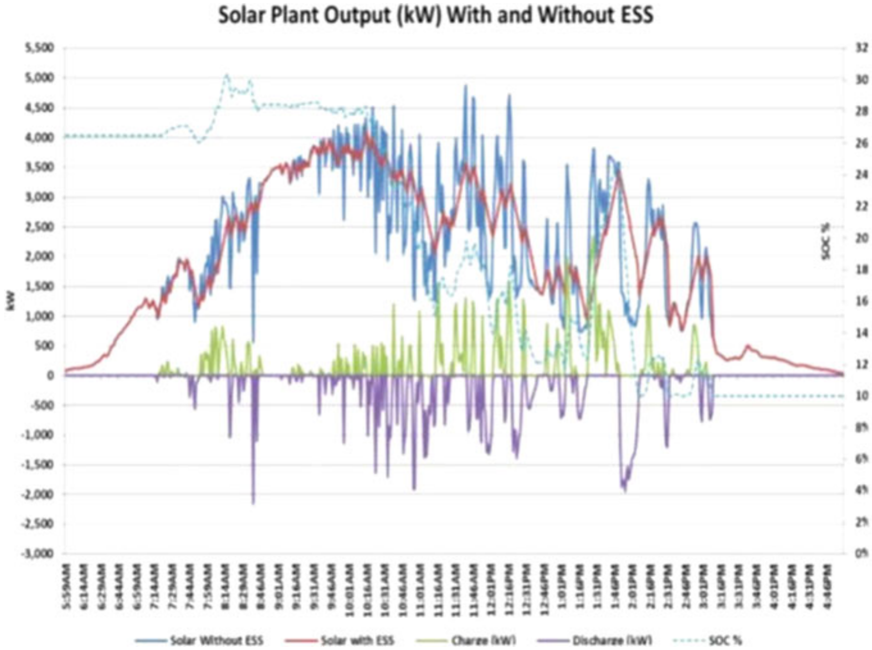


Fig. 4 RE output—with and without ESS

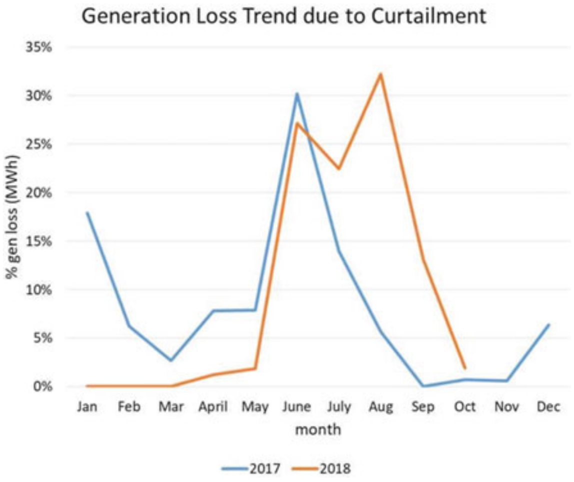


Fig. 5 Loss observed due to curtailments in an operational windfarm

the amount of revenue loss incurredjust in the high wind months. This is more pronounced in the wind sector than the solar sector. This eventually leads to huge revenue loss for the utilities and builds in huge inefficiencies to the system.

5 Energy Storage—The Enabler

The Technology: Energy storage has various forms, in terms of mechanical storage, we have pumped hydro, compressed air energy storage and flywheels. In terms of electrochemical storage technologies, we have batteries, flow batteries and fuel cells. While there have been significant developments on many of these technologies, some of them have faced challenges in deployment (pumped storage—land issues), some have faced cost issues. Of all this one technology that has come forward and has been pronounced in deployment is Batteries (Fig. 6).

Batteries are like a one stop solution to many of the concerns illustrated earlier. Batteries have many characteristics, some has very fast discharge rates, some has very long cycle life, some has very high energy density, while some are much more efficient. Depending upon the application therefore when batteries are selected, they can solve many problems. For examples, when used in energy applications, where we need these batteries to store energy for long, we need to look at such chemistries which can give us long cycle life (flow batteries), whereas when looking for power applications, we will need batteries which can discharge energy very fast while being compact, so in such cases we will have to look for more efficient and higher power density batteries. So, batteries which needs to be deployed in grid storage and EVs will be contrasting in nature (Fig. 7).

One of the various chemistries which everyone is talking about today is Lithium Ion batteries which has an efficiency of around 95% and has a good mix of attributes

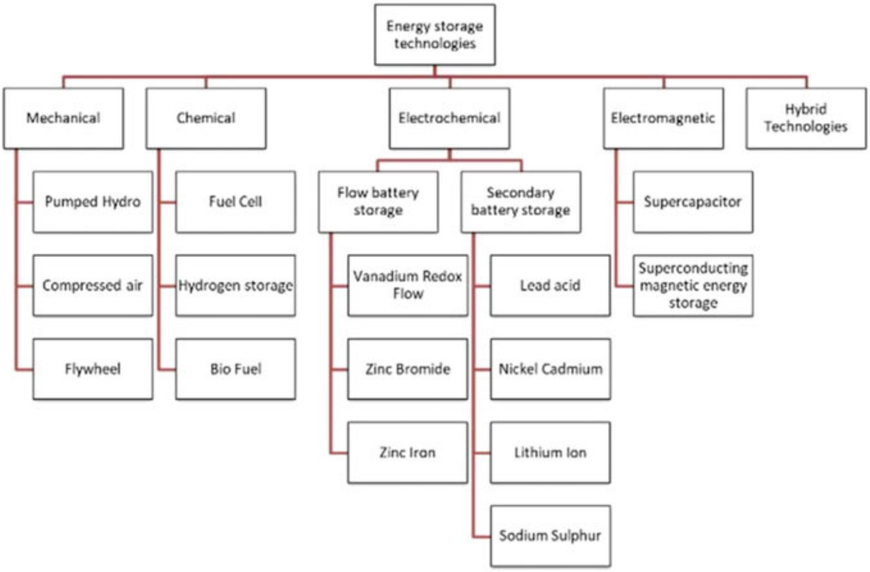


Fig. 6 Storage technology bifurcation

while also being easy on economics when compared to the other technologies. At global level of all batteries that are being deployed 82% is lithium ion batteries as on date. Researchers and industry experts warn that post 2020, cadmium which is a key ingredient in Li-Ion batteries can cause an issue in mass production and thus research is ongoing for more viable technologies going forward like Lithium air batteries, zinc battery systems, molten salt batteries, flow batteries and solid-state batteries like lithium garnet batteries. The economic and technological compatibility of these however needs to be seen with time.

It should be understood here that each of the technologies even under lithium ion suits different applications, based on what kind of application the batteries are to be used, the selection should b decided upon. The below table gives a snapshot to show which chemistry is suitable for what application based on power/energy/volume/discharge time/weight etc. (Fig. 8).

Concerns with lithium ion as on date are its cost and performance eat high temperatures. Though the cost of these batteries has reduced 85% w.r.t 2011, but still they need to reduce further to make economical sense and stand competition with other competing technologies. Also, a concern has been temperature tolerance, in countries like India where temperatures are quite high, performance of such batteries remains a concern. There also has been issues like potential short circuits, formation of reactive product layer and restriction in achieving higher energy density. But there has been challenges to address all these with alternate technologies as this will lead to increase in cost and maintenance which overall will increase the LCEO of such technologies. So, it will be fair to say that in terms of cost benefit analysis as on date

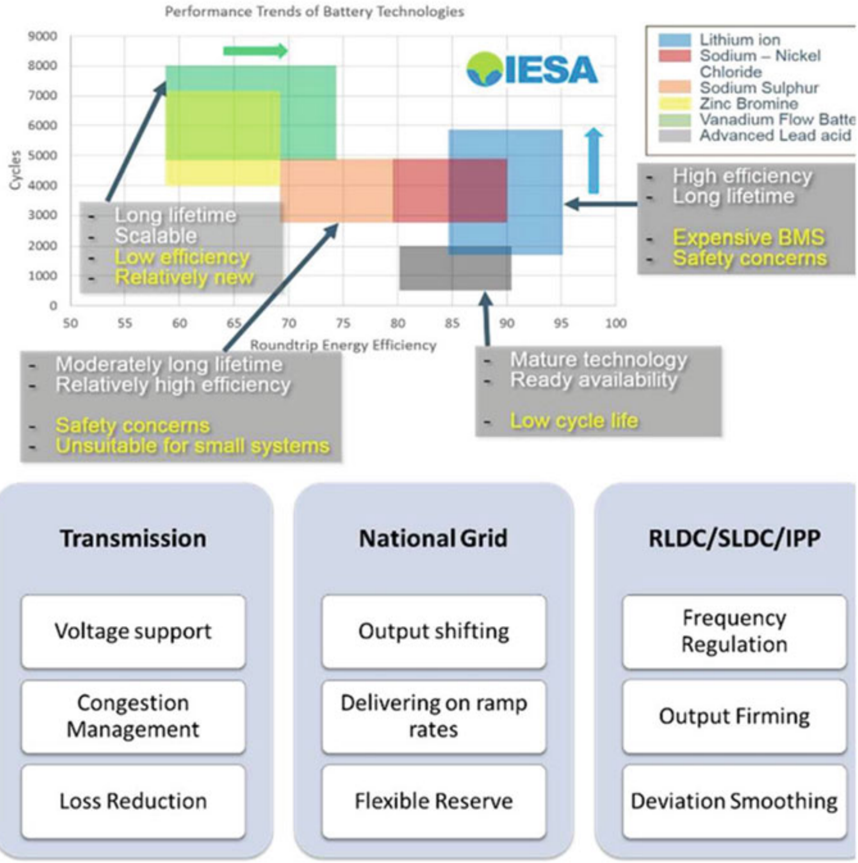
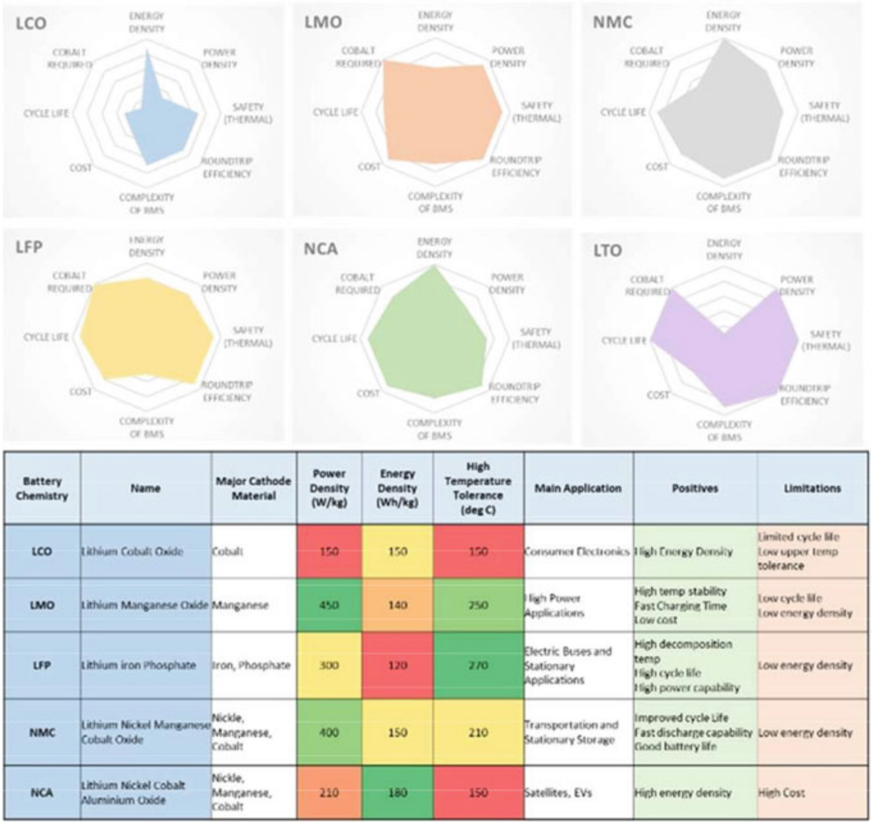


Fig. 7 Storage applications

lithium ion batteries remains the most adaptable and compatible technology in the energy storage arena.

Benefits from Storage: Issues like duck curve formation which will need very high ramping in the early evening hours can be well managed by batteries, so can batteries be used to manage the load from renewables, where it can be used to smoothen out the load curve and take care of sudden fluctuations. Batteries can even be helpful for utilities to adhere to the F&S regulations better where batteries can store excess energy in blocks of excess generation and discharge the deficient energy in blocks of under generation. This can also help in absorbing the energy which otherwise would have been curtailed in high RE resource seasons due to over loading of sub stations.

Multiple Application Deployment: What is of paramount importance here is proper sizing of these batteries and choosing the most appropriate technology of battery based on its application.



Battery Chemistry	Name	Major Cathode Material	Power Density (W/kg)	Energy Density (Wh/kg)	High Temperature Tolerance (deg C)	Main Application	Positives	Limitations
LCO	Lithium Cobalt Oxide	Cobalt	150	150	150	Consumer Electronics	High Energy Density	Limited cycle life Low upper temp tolerance
LMO	Lithium Manganese Oxide	Manganese	450	140	250	High Power Applications	High temp stability Fast Charging Time Low cost	Low cycle life Low energy density
LFP	Lithium iron Phosphate	Iron, Phosphate	300	120	270	Electric Buses and Stationary Applications	High decomposition temp High cycle life High power capability	Low energy density
NMC	Lithium Nickel Manganese Cobalt Oxide	Nickle, Manganese, Cobalt	400	150	210	Transportation and Stationary Storage	Improved cycle Life Fast discharge capability Good battery life	Low energy density
NCA	Lithium Nickel Cobalt Aluminium Oxide	Nickle, Manganese, Cobalt	210	180	150	Satellites, EVs	High energy density	High Cost

Fig. 8 Li Ion chemistry segregation and application

Various test labs are being developed to make batteries much safer and more reliable. Also, what needs attention is development of ancillary industries, as deployment of batteries to only address one issue will not make the deployment economically viable. Deployment must be made with multiple applications kept in mind. Let's discuss its deployment in a solar farm. Solar irradiance is more during March to June post which the irradiance level decreases, so during the lean periods the batteries will almost be idle, this is a time when these batteries can be used for other ancillary services. This further will need the policies to be developed in a much more favorable way for the open access market to develop.

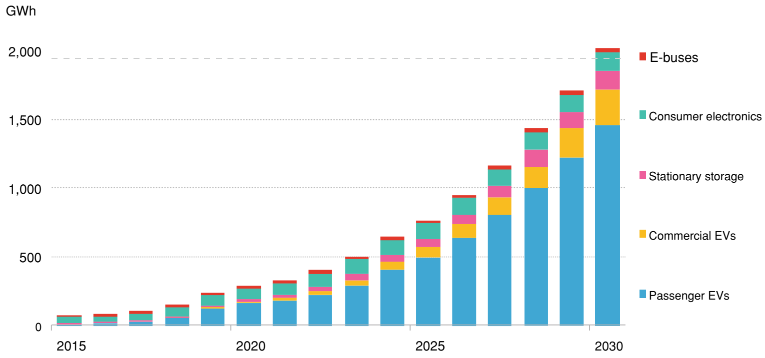


Fig. 9 Battery long term demand forecast

6 Conclusion

As seen, batteries are the way forward and its now upon us as to how we take advance of this opportunity and ensure we take the first mover advantage on the same. Indigenous manufacturing of batteries will be the key to hold the sustainability edge in this market and the government is taking small steps to realize the same. Policy clarity, incentives to motivate the manufacturing industry and investing sufficiently on R&D will be the key to success going forward. If these fall in line without much procrastination then the below benefits will too fall in, namely:

Battery pack Cost—Decrease
Cycle Efficiency—Increase
Promoting Indigenous Manufacturing—Low dependency on import
Battery recycling and better end of life use
Agile Net Metering and Open access Policies
Strategic Partnerships between developers and IPPs
Beyond Li-Ion—development of more efficient technologies.

Overall the future of technology looks promising with many options congregating in the power sector. It's a challenging and competing environment where the technology which remains agile, compatible, trailable, convenient and customer oriented will lead and maintain the sustainability edge going forward (Fig. 9).

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Preventing Water Pollution Using AMI and IoT

Dinkar Kumar Verma

Abstract Reports say that 80% of India's surface water is polluted and the reason being, industrial sewage and residential sewage that gets into water bodies (lakes, rivers, sea) unchecked. Government has defined regulations for the Industrial sewage recycling; however, it is the major contributor to water pollution as there is no monitoring system in place or it is not capable enough. The paper discusses about mechanism where automated and continuous monitoring system can be put in place to keep track of pollutants discharged by various industries and municipal corporations which eventually would enter the water bodies. We discuss how various IoT based sensors could be strategically placed at sewage outlets of industries and connected to centralized servers which monitors the pollutants at the source of its creation. Identify the kind of pollutants that an industry discharges and setup IoT sensors to detect those. The system raises alarm when the pollutants go above a threshold and could automatically block the sewage outlet if goes above the defined norms. This could be also be used to reward or fine a company based on amount of water pollution created by them. The mechanism discussed can control the water pollution at the very source of pollution, i.e. where it is created, and automatically ensure that industries follow the government norms. This would help us bring down the recycling cost or water bodies cleansing cost drastically.

Keywords Wastewater · Water pollution prevention · Pollution monitoring unit · Pollution prevention and control system · Sewage treatment · Industrial water pollution

1 Introduction

Water pollution is one of the most critical problem that the environment is facing today. If not controlled aggressively, the time is not far when all the water bodies on earth (lakes, ponds, rivers, seas, oceans etc.) will be contaminated to such an extent

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that it would be of no use or it would become a very expensive affair to clean it. (e.g. Namami Gange Program has a budget of INR 20,000 Crore [1]). It's estimated that around 70% of surface water in India is unfit for consumption. Every day, almost 40 million liters of wastewater enters rivers and other water bodies with only a tiny fraction adequately treated [2].

2 Abbreviations and Acronyms

AMI:	Advanced Metering Infrastructure
IoT:	Internet of Things
PPCS:	Pollution Prevention and Control System
PMU:	Pollution Monitoring Unit
SR valve:	Sewage Release Valve
MSCTP:	Municipal Sewage Collection and Treatment Plant
BOD:	Biological Oxygen Demand
COD:	Chemical Oxygen Demand
TOC:	Total Organic Carbon
TSS:	Total Suspended Solid

3 Impacts of Water Pollution

Water pollution has a huge impact on biodiversity and economy. Places where people are directly dependent on the water bodies (like lakes, ponds and rivers) for their day to day use have a very high health risk. Polluted water does not allow any aquatic life to flourish in it and also has a huge impact on the quality agricultural products and on the health of farm workers and consumers [3]. This also causes soil pollution. Lack of water, sanitation and hygiene results in the loss of 400,000 lives per year in India. Health Cost relating to water pollution in India estimated to be INR 470–610 Billion per year, most associated with diarrheal mortality and morbidity of children under five and other population morbidities. Cost of Environmental degradation is in India estimated to be INR 3.75 Trillion [2].

4 Sources of Water Pollution

Water is a universal solvent and can dissolve more substances than any other liquid. Toxic substances in form of sewage from factories, farms, household wastewater, pharmaceutical companies, dump from mining companies etc. get into water bodies there by creating pollution [4]. There could be many more indirect sources of water pollution but the major being, untreated or polluted water with various pollutants above the specified limit entering the water bodies. THE ENVIRONMENT (PROTECTION) ACT, 1986 very well defines how pollution can be controlled which includes water pollution as well [5]. The Environment Protection Act has a provision of manual inspection of sites. Despite this, water pollution is a matter of concern which is at an alarming stage because the manual inspection happens occasionally or very rarely. It is also a fact that manual inspection is highly susceptible to corruption. This allows the factories to dump untreated water into water bodies to such an extent that “Burning Lake” in Bengaluru makes an international news and “Frothing Yamuna” is national headlines [6].

5 IoT Based Pollution Prevention & Control SYSTEM (PPCS)

The solution is to upgrade the existing infrastructure to use the technology to provide continuous monitoring and control of the pollutants being discharged by various sources, right at its source of creation. The pollution monitoring unit (PMU) continuously checks for pollutants present in the sewage if it is above the maximum allowed limit, as per policy. Let us understand the solution with help of some diagrams.

5.1 Setup at a Factory

(1) *Entities Involved*

Figure 1 shows a setup which can be installed at any factory where a Water Utility Company supplies water to the factory (AMI). It shows 10 entities numbered 1–10 and defines each entity.

- Factory (manufacturing, pharmaceutical or any) uses water and releases sewage or polluted water.
- Water Meter monitors the water consumed by the factory. The meter has communication and processing capabilities and can be controlled remotely (to start / stop water supply) by the Water Utility company’s server or AMI server.
- The PPCS server has the required communication medium support and capability to receive and process the data sent by PMU and take actions based on it. The PPCS server could be setup by municipal authorities or could also be operated by Water Utility Company as an added functionality to AMI server, which communicates with all the water meters, monitors water consumption, processes billing and other functionalities. The AMI server and PPCS server could either be operated by one or more authorities. PPCS server is capable of remotely controlling the SR valve at PMU and the AMI server is capable of remotely controlling the water meter.

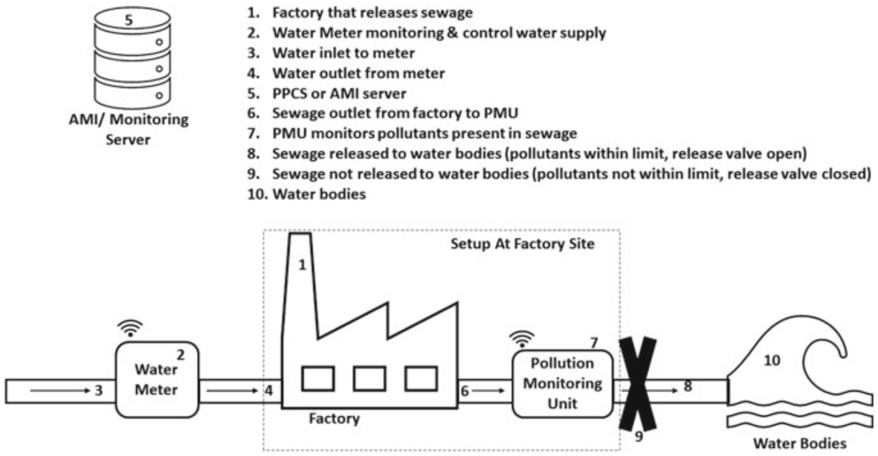

Fig. 1 Setup at any factory (With Water Utility Company)

PPCS server manages multiple PMU installed at different factories. In Fig. 1, only one factory is shown for easier understanding. The PPCS server is configured with different profiles for different factories based on the kind of pollutants a factory releases and permissible limits of those pollutants.

- PMU receives all the sewage discharged by the factory. This unit is supposed to be installed at the factory premises. This unit has a SR valve which can be remotely controlled by the PPCS server. This valve is always closed so that no sewage is discharged without inspection. PMU has communication module along with required sensors installed and the kind of sensors installed would depend on the kind of pollutant released by the factory. For example, Printing Industry releases Heavy Metals, so sensors to detect those (e.g. optical sensors) could be installed [7]. The sensor could be electrochemical sensors or optical sensors or any other sensor [8]. The pH value of water or sewage being discharged would be one of the important parameters to be monitored. The PMU continuously monitors the amount of pollutants being released by factory and sends the data to the PPCS server, either directly or via the water meter, based on the kind of communication mechanism used. PPCS receives the data and based on the pollution level the PPCS server remotely opens the SR valve or keeps it close so that the pollutants above permissible limits are not discharged to water bodies. A high-level architecture of PMU is shown in Fig. 3.
- In Fig. 1 Entity 8 represents open state of SR valve so that sewage within permissible limits are released into water bodies
- In Fig. 1 Entity 9 represents closed state of SR valve so that sewage above permissible limits are not released into water bodies. And this sewage may need further treatment before being released. In this case the sewage must be diverted to treatment plant once again. (As shown in Fig. 2)

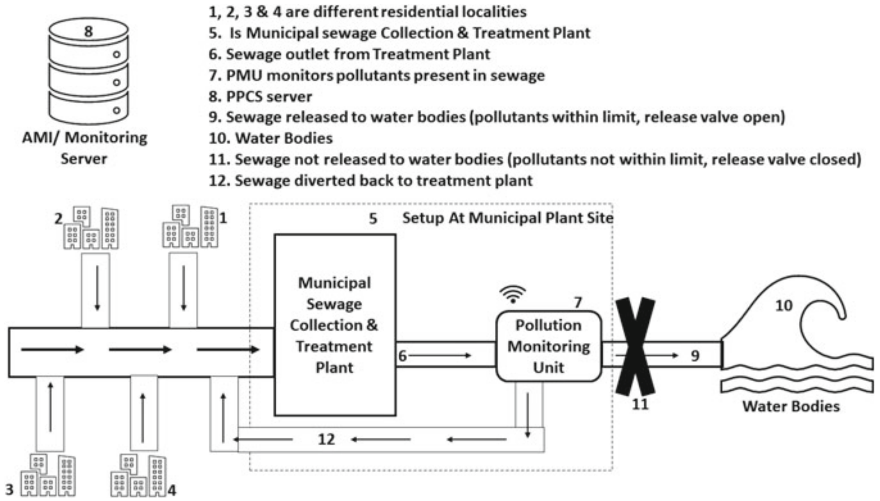

Fig. 2 Setup at Municipal or Local Sewage Collection & Treatment Plant (Factory without water Utility)

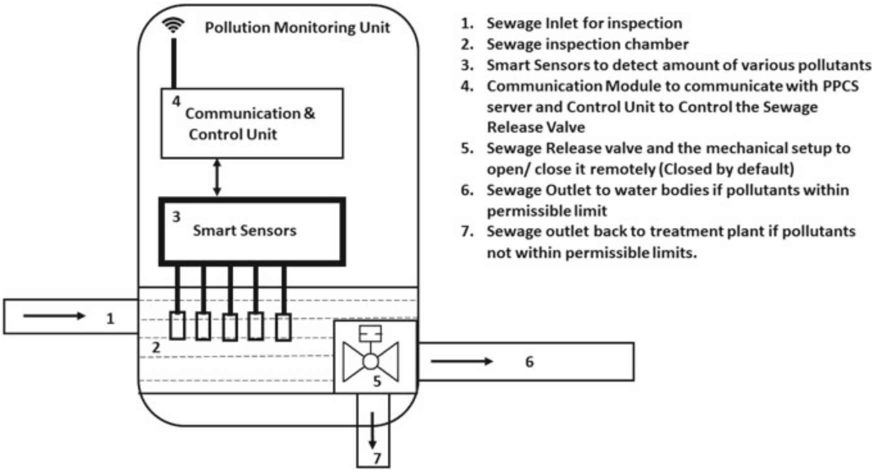

Fig. 3 High Level Architecture of PMU

5.2 *Setup at Municipal or Local Treatment Plant*

(2) *Entities Involved*

Figure 2 shows a setup which could be installed at any municipal or local sewage treatment plant which collects sewage from various localities or entire city. The setup could be used at any factory where there is no Water Meter installed and no AMI support.

- Figure 2 shows 4 different localities from where household sewage and sewage from other sources are generated. It could be sewage from residential or commercial buildings.
- MSCTPs is a municipal or locality-based sewage collection and treatment plant which treats sewage collected from the entire city or localities and then releases it to water bodies.
- PMU is installed at the premises of treatment plant and it supports all the functionalities as described for Fig. 1. This unit continuously monitors and sends pollution data to the PPCS server and receives control commands from server either to open or close the SR valve.
- PPSC server setup by municipal or government authorities or any other authorized body. PPSC server can receive data from multiple PMUs installed at different sewage treatment plants and is also capable of remotely controlling SR valve at PMU.
- In Fig. 2 Entity 9 represents open state of SR valve so that sewage within permissible limits are released into water bodies
- In Fig. 2 Entity 11 represents closed state of SR valve so that sewage above permissible limits are not released into water bodies. And this sewage is diverted back to treatment plant as shown by Entity 12 in Fig. 2.

Similar IoT enabled PMUs could be installed at major sewage collector drain junctions and release of sewage further could be controlled based on the pollution level of sewage.

5.3 PMU (Pollution Monitoring Unit)

The diagram above shows a high level architecture of the PMU which could be installed at any factory or municipal or local sewage treatment plant.

- Sewage released enters the PMU via the sewage inlet.
- It is collected in the sewage inspection chamber where a set of smart sensors are inserted to detect the quantity of different pollutants present in the sewage. As mentioned earlier, the kind of sensors placed would depend on the kind of pollutants the factory or municipal sewage treatment plant disposes [9].
- Once the smart sensors have the pollutants data, the communication module picks it up and sends it to the PPCS server.
- The PPCS server process the data, compares it against the configured profile of pollutants permissible limits and sends a control command (open/ close) to PMU.
- The communication module receives the control command. The control module acts based on the command received. It takes appropriate action to open the SR valve if the pollutants are within permissible limits. If the pollutants are not within

permissible limits, the control unit keeps the SR valve closed and opens the sewage outlet back to treatment plant and does not allow sewage to be released to water bodies, there by preventing pollution right at the source.

5.4 Water Pollutants and Sensors

Quality of wastewater is measurement of parameters like BOD, COD, TOC, TTS, global N, total P, nitrate, nitrite, ammonia, orthophosphate, anionic detergents, sulphate, pH, conductivity, presence of pollutants like asbestos, oils, petrochemical, metals like Lead, Mercury etc. [9, 10]. All these and various other pollutants enter water bodies via various sources like household sewage, sewage discharge from treatment plants and industrial waste. Figure 4 shows a some of the pollutants discharged by some of the industries [11]. Based on the type of pollutants discharged by a factory or sewage treatment plant, number of sensors could be installed at the PMU. Combination of different types of sensors like potentiometric sensors, voltammetric sensors to detect various contaminants present, optical sensors to detect the presence of metal, chemical sensors to detect presence of other chemicals and other toxic substances [8, 12].

EXAMPLES OF HAZARDOUS WASTE GENERATED BY INDUSTRIES AND BUSINESS:	
WASTE GENERATOR	**WASTE TYPES**
Chemical Manufacturers	Acids and Bases Spent Solvents Reactive Waste Wastewater Containing Organic Constituents
Printing Industry	Heavy Metal Solutions Waste Inks Solvents Ink Sludges Containing Heavy Metals
Petroleum Refining Industry	Wastewater Containing Benzene & Other Hydrocarbons Sludge from Refining Process
Leather Products Manufacturing	Toluene and Benzene
Paper Industry	Paint Waster Containing Heavy Metals Ignitable Solvents
Construction Industry	Ignitable Paint Waste Spent Solvents Strong Acids and Bases
Metal Manufacturing	Sludges containing Heavy Metals Cyanide Waste Paint Waste

Fig. 4 Industries and Pollutants Discharged

6 Stakeholders

For the implementation of this idea we need involvement from various stake holders.

- Relevant Government Ministries to come up with laws to install IoT enabled Pollution Monitoring Unit at all factories, commercial buildings sewage treatment plants etc.
- Municipal Authorities to host and manage Pollution Control Servers.
- Industry experts to identify which sensors to be used for which kind of factory and released pollutants.
- Water Utility companies to provide required AMI infrastructure and support.
- IoT Industry to setup servers and other required infrastructure.
- Experts from chemical and sensors industry to come up with more different sensors to detect various pollutants.
- All the factories, municipal and local sewage treatment plants and any entity that produces wastewater.

7 Advantages

The PPCS offers lots of advantages compared to the conventional methods of dealing with water pollution. A few, are as follows: -

- Restricting the pollutants at the source of its creation preventing water pollution and avoiding huge cost associated with cleaning water bodies.
- Automated and continuous process which is more reliable.
- Realtime data available as to who is contributing to how much of pollution and this data could be used in many ways to reward/ fine and used for analytics
- Notifies whenever pollutants go above a limit so that necessary actions can be taken.
- Improved biodiversity, aquatic life, reduced health risk and reduced health care expenses.
- A lot of data related to water pollution, pollutants, type of chemicals used in industries etc. can be collected and used for Data Analytics which can enable us to take better decisions.
- Other economic benefits.

8 Challenges

The challenges associated with PPCS are as follows.

- Lifetime of sensors available in market used to identify various pollutants are around 2–3 years, so it needs to be replaced.
- Regular maintenance of sensors to be done.

- Precision of chemical sensors reduces with usage.
- We do not have exhaustive list of sensors to identify each kind of pollutants.

9 Conclusion

The mechanism can be used to prevent water pollution right at the source of its creation. With the right laws in place and with right sensors placed at every sewage source the water pollution can be prevented instead of spending millions in cleaning up programs for the water bodies after its polluted. Since the process is automatic, continuous and has all the data recorded, it ensures that all the factories and treatment plants are more accountable to the amount water pollution created by them.

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Importance of Smart Grid Development in India

Arup Sinha

Abstract The purpose of this paper will explain the importance of Smart Grid Development in India The paper will throw the light on various problems and challenges related to electricity grids that are faced in India and the solution to manage those problems by adopting the vision of a “Smart Grid.” The essence of this vision is “a fully- automated power delivery network that can ensure a two-way flow of electricity and information between the power grids and appliances and all points in between”. The paper also will provide the overview on the three key technological components of Smart Grid that includes Distribution Automation (DA), Advanced Metering Infrastructure (AMI)). Focusing in on the role of the above three key components of Smart Grid, this paper will lay out the Introduction on the factors that are pulling and pushing the utilities to change the way they operate in order to improve the current services. The flow then involves the explanation on Moving beyond AMI to Adopt Smart Grid Vision which includes the overview of all the key components of Smart Grid and thus focusing on the requirement to make the electricity grid “Smart” and revolutionizing the electric power networks. The further explanation is on the Ongoing and Future Projects on Smart grid in India. Finally, the paper will conclude with the benefits and suggestions for the key stakeholders for Smart Grid Development that will explain the demand for Smart Grid capability in India.

Keywords Smart Grid · AMI (Advanced Metering Infrastructure) · Distribution automation · AT & C (Aggregated Technical and Commercial) Loss

1 Introduction

The significant increase in the tariff of electricity is experienced by throughout all states in India due to high AT & C (Aggregated Technical & Commercial) loss in Distribution sector. This has resulted for the interest in Advanced Metering Infrastructure i.e. AMI by utilities which involves Demand Response programs through

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which the customers can lower their monthly electricity bills. Often the areas in this region are facing the outage problems especially when the demand is high. The population in country like India is large and so is the demand for electricity. These are some of the reasons that utilities are now actively considering the AMI investments. The utilities have many ongoing pilot programs to consider the effectiveness of new pricing structures enabled by AMI.

AMI involves many features/ways to manage the peak loads like:

- Demand Metering which is a billing method in which the customer is charged for the normal energy usage plus an additional charge for the peak usage.
- Time of Use Metering which is again a billing method where the utility varies the price of electricity during different periods of a 24-h day depending on 'ON' peak and 'OFF' peak hours.

The other major benefits of AMI are:

- Automated Meter Reading
- Remote Disconnection and Reconnection of Meter
- Outage Management
- Call Center Integration
- Theft Detection
- Distribution Automation
- Revenue Protection

The internal factors are "pushing" the utilities to change the way they operate in order to improve current services.

The factors include:

- Grid Performance
  - Reliability
  - System Efficiency
  - Safety
  - Security

The external demand drivers are "pulling" the utilities to offer new services. The drivers include:

- Demand-side Management
- Value-Added Services
- Customer Service Quality
- New forms of Generation
- Distributed Generation and Storage
- Intermittent and renewable Generation

2 What is Smart Grid

Smart Grid is the modernization of the electricity delivery system so that it monitors, protects and automatically optimizes the operation of its interconnected elements—from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices. Smart grid is the integration of information and communications system into electric transmission and distribution networks. The Smart Grid in large, sits at the intersection of Energy, IT and Telecommunication Technologies.

The smart grid (Refer Fig. 1) delivers electricity to consumers using two-way digital technology to enable the more efficient management of consumers' end uses of electricity as well as the more efficient use of the grid to identify and correct supply demand-imbalances instantaneously and detect faults in a "self-healing" process that improves service quality, enhances reliability, and reduces costs. The emerging vision of the smart grid encompasses a broad set of applications, including software, hardware, and technologies that enable utilities to integrate, interface with, and intelligently control innovations.

Some of the enabling technologies and business practice that make smart grid deployments possible include:

- Smart Meters

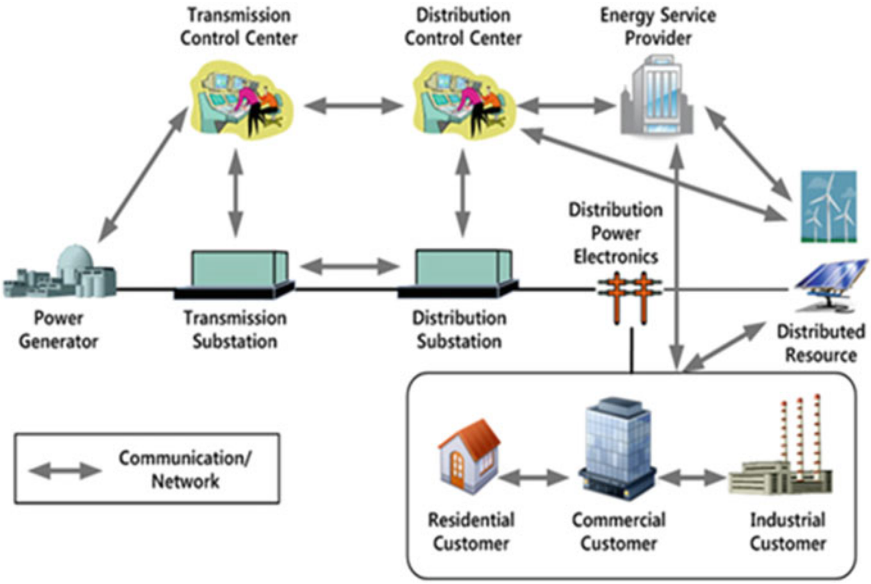

Fig. 1 Typical structure of smart grid

- Meter Data Management
- Field area networks
- Integrated communications systems
- IT and back office computing
- Data Security
- Electricity Storage devices
- Demand Response
- Distributed generation
- Renewable energy

3 Objective of Smart Grid Development for Power Distribution Utility In

Key objectives of Smart Grid Development

- Self-healing: The grid rapidly detects, analyzes, responds, and restores
- Empowers and incorporates the consumer: Ability to incorporate consumer equipment and behavior in grid design and operation
- Tolerant of attack: The grid mitigates and is resilient to physical/cyber-attacks
- Provides power quality needed by 21st-century users: The grid provides quality power consistent with consumer and industry needs
- Accommodates a wide variety of supply and demand: The grid accommodates a variety of resources, including demand response, combined heat and power, wind, photovoltaics, and end-use efficiency
- Fully enables and is supported by competitive electricity markets.

4 Main Drivers for Smart Grid

Following are the key drivers for smart grid development in India.

4.1 Environment

Smart Grid development is happening at a very fast pace because of the broad interest of policy makers and utilities in decreasing the adverse effect that energy usage has on the environment. Smart Grids uses technology to drive efficiencies in transmission, distribution, and consumption. As a result, fewer generating plants, fewer transmission and distribution assets are required in order to cater the growing demand of electricity. With the possible expectation of wind farm sprawl, landscape preservation is one of the evident benefits. Since maximum generation today results in emission of greenhouse gas, Smart Grids reduces air pollution and plays a significant role in combating global climate change issue.

Smart Grids has the capability to accommodate technical difficulties of integrating renewable resources like wind and solar to the grid, providing further reduction in greenhouse gas emissions.

4.2 Aggregated Technical & Commercial (AT & C) Loss Reduction

In response growing concern about AT & C loss across all power distribution utilities in India, Smart Grid Technology will contribute to reduce the losses to achieve the target goal of AT &C loss around 15% across all utilities against presently 30 to 35%. It will do by collecting data through AMI (Advance Metering Infrastructure), cleansing and analyzing the data through MDM, developing energy audit mechanism to identify the loss prone areas, and finally reduce the losses by applying effective energy conservation measures.

4.3 Consumer Price Signals

Smart Grid aims to create an understanding among consumers that pricing of electricity varies significantly during the day. Facilitating consumer readily accesses it and which will influence their behavior, encourage initializing the wiser use of energy.

4.4 Integration of Renewable Energy Sources

The two most common form of commercial renewable energy available in India are Wind and Solar. Both are intermittent and tend to be geographically dispersed than conventional generation. In this case smart grid will help the utility to deal with this nonconventional energy sources, especially when these resources are becoming prevalent in India.

4.5 Utility Operations

Smart Grids can assist the utilities, as the principal focus of the utilities is to improve business processes. Many utilities have an extensive list of projects that they would like to fund in order to improve the customer service or to ease workforce's burden of repetitive work. Calculating Smart Grid benefits by the cost/benefit analysis it puts emphasis in favor of the change and can also significantly decrease settlement/payback periods.

Mobile workforce group and asset management group work collectively to organize assets and then maintain, renovate, and replace them. Thus, results in increased productivity and fuel saving from superior methods.

Similarly, Smart Grid provides customers with real time information and encourages them to do online payments, thus lowering billing costs. Utilities can include these cost and service improvement in the list of Smart Grid benefits.

4.6 Theft Control

This is not an issue in developed countries like US, but in developing countries like India, where people have a little insight of the grid and higher poverty rate, power theft is quite common. With development of Smart Grid, power theft can be controlled to a greater extent, thereby improving the efficiency of our distribution system. Thus, grids will provide higher quality and reliable.

5 Need for Development of Smart Grid Beyon AMI and DA

Metering was all about "Feeding" utilities commercial processes that include metering, meter reading, billing and clearing. Utility networks are "One-way" networks and the last mile is still "BLIND". This paper focuses on this "last mile" i.e. the growing urgency to make the Electricity Grid "SMART." We are in transition phase today. The major challenges in this region are:

- Quality, security and reliability of supply
- Cross-border power trading and grid services
- Ambitious energy policies & environmental goals
- Electric vehicles
- Real time and variable pricing
- Growing expectations from consumers

As power failures occur relatively in India, as compared to developed countries, there's been an urgent need to renovate the country's power network and since 2005 the research projects and government policies focusing on smart grid and next generation electric networks have been carried out. The above challenges can only be met if we move towards the future vision of electricity system and making our electricity network "Smart". The user specified quality, security and reliability of supply for the digital age can be achieved. Harmonized legal frameworks facilitating cross-border trading of power and grid services, extensive small and distributed generation connected close to end customers etc.…all can be achieved. But all this is very far until and unless we move our approach towards Smart Grid.

Smart Grid is a One System combination of Advanced Metering Infrastructure (AMI), Distribution Automation (DA) and Energy Management (EM). It is a secure, scalable, interoperable, intelligent and proven system with the path to future enabling applications for Smart Grid today. In a Smart Grid system, consumer's information is received by the electric power company in order to provide the most efficient electric network operations.

5.1 Advanced Metering Infrastructure (AMI)

AMI is architecture for automated, two-way communication between a utility's smart meter with an IP address and a utility's head end systems. The goal of an AMI is to provide utility companies with real-time data about power consumption and allow customers to make informed choices about energy usage based on the price at the time of use. AMI differs from traditional Automated Meter Reading (AMR), it enables two-way communications with the meter. It involves the intelligent use of Demand/Response system where the end customers are aware of the pricing rates of electricity when the demand is high or low and the customers can use their electric appliances accordingly.

5.2 Distribution Automation (DA)

DA System provides tools for the distribution power network's security, economical operation. It guarantees power quality, perfecting facility management as well as increasing working efficiency and providing a series of solutions for the distribution automation system. The system supplies the function of power grid monitoring, control, failure management, and power balance and charge management. It improves reliability with real-time monitoring and intelligent control. This system is basically head-end network management software.

It provides network speed enhancements. Improving efficiency and reliability of a distribution network is a critical goal for many utilities. Two-way communications with the protection and control devices on the distribution portion of the smart grid is fundamental to achieving those energy efficiency and reliability goals. Distribution Automation (DA) devices themselves are evolving to be more robust and reliable, offer higher computing power, and act as a source of planning data. And given utilities' continual focus on improving energy efficiency and power reliability, matching these improvements with real-time communications is a key. Understanding the status of devices like switches and reclosures, capacitor banks, voltage regulators and transformers in real time enables much faster outage detection and notification and improves fault location and isolation. It also increases energy efficiency through better capacitor and voltage control and improved asset management. Many analysts believe DA is the secret to making the Smart Grid pay for itself.

6 Barriers for Smart Grid Development in India

6.1 Policy and Regulation

The current policy and regulatory frameworks were typically designed to deal with the existing networks and utilities. To some extent the existing model has encouraged competition in generation and supply of power but is unable to promote clean energy supplies. With the move towards smart grids, the prevailing policy and regulatory frameworks must evolve in order to encourage incentives for investment. The new frameworks will need to match the interests of the consumers with the utilities and suppliers to ensure that the societal goals are achieved at the lowest cost to the consumers.

Generally, governments set policy whereas regulators monitor the implementation in order to protect the consumers and seeks to avoid market exploitation. Over the last two decades, the trend of liberalized market structure in various parts of the world has focused the attention of policy- makers on empowering competition and consumer choice. The regulatory models have evolved to become more and more effective to avoid market abuse and to regulate the rates of return.

Moving forward, the regulatory model will have to adopt the policy which focuses much on long term carbon reduction and security of supply in the defined outcomes and they need to rebalance the regulatory incentives to encourage privately financed utilities to invest at rates of return that are commensurate to the risk. This may mean creating frameworks that allow risk to be shared between customers and shareholders, so that risks and rewards are balanced providing least aggregate cost to the customer.

6.2 Business Scenario

Most examples result in negative business cases, undermined by two fundamental challenges:

High capital and operating costs: Capital and operating costs include large fixed costs linked to the chronic communications network. Hardware costs do not cause in significant growths in economies of scale and software integration possess a significant delivery and integration risks.

Present Regulatory framework: When calculating the benefits, organizations tend to be conservative in what they can gather as cash benefits to the shareholders. For example, in many cases, line losses are put on to the customer and as a result any drop in losses would have no net impact on the utility shareholder. The smart grid benefits case may begin on a positive note but, as misaligned policy and regulatory incentives are factored in, then investment becomes less attractive. Therefore, regulators are required to place such policies and regulations in place which could provide benefits both to the utilities and the consumers. Therefore, the first factor to be considered is to provide incentives to the utilities in order to remove inefficiencies from the system. They should be aptly remunerated for the line losses on their networks.

On the budget side of the calculation, there is none, avoiding the fact that smart technologies are expensive to implement, and at the present level it is right factor in the risk associated with delivery. But the policy makers and regulators can mitigate that risk by seeking economies of scale and implementing advanced digital technologies.

6.3 Technology Maturity and Delivery Risk

Technology is one of the essential constituents of Smart Grid which include a broad range of hardware, software, and communication technologies. In some cases, the technology is well developed; however, in many areas the technologies are still at a very initial stage of development and are yet to be developed to a significant level as per requirement of utility Industry in India. As the technology's advances, it will reduce the delivery risk; but till then risk factor must be included in the business situation.

On the hardware side, speedy evolution of technology is seen from vendors all over the world. Many recently evolved companies have become more skeptical to the communications solutions and have focused on operating within a suite of hardware and software solutions. Moreover, the policy makers, regulators, and utilities look upon well-established hardware providers for Smart Grid implementation. And this trend is expected to continue with increasing competition from Asian manufacturers and, consequently, standards will naturally form, and equipment costs will drop as economies of scale arises and competition increases.

On the software and data management side, the major challenge is to overcome the integration of the entire hardware system and to manage high volume of data. With multiple software providers come multiple data formats and the need for complex data models. In addition, the proliferation of data puts stresses on the data management architecture that are much similar to the telecommunications industry than the utilities industry. Many of these issues are currently being addressed in pilots such as Smart Grid task force and, consequently, the delivery risk will reduce as standards will be set up.

6.4 Lack of Awareness

Consumer's level of understanding about how power is delivered to their homes is often low. So before going forward and implementing Smart Grid concepts, they should be made aware about what Smart Grids are? How Smart Grids can contribute to low carbon economy? What benefits they can drive from Smart Grids? Therefore: Consumers should be made aware about their energy consumption pattern at home, offices…etc. Policy makers and regulators must be very clear about the prospects of Smart Grids. Utilities need to focus on the overall capabilities of Smart Grids rather than mere implementation of smart meters. They need to consider a more holistic view.

6.5 Access to Affordable Capital

Funds are one of the major roadblocks in implementation of Smart Grid. Policy makers and regulators must make more conducive rules and regulations in order to attract more and more private players. Furthermore, the risk associated with Smart Grid is more; but in long run it is expected that risk-return profile will be closer to the current situation as new policy framework will be in place and risk will be optimally shared across the value chain. In addition to this, the hardware manufacturers are expected to invest more and more on mass production and R&D activities so that technology obsolescence risk can be minimized and access to the capital required for this transition is at reasonable cost.

6.6 Skill and Knowledge

As the utilities will move towards Smart Grid, the and twelve years industrial experience in power generation re will be a demand for a new skill sets to bridge the gap and to have to develop new skills in analytics, data management and decision support. To address this issue, a cadre of engineers and managers will need to be trained to manage the transition. This transition will require investment of both time and money from both government and private players to support education programs that will help in building managers and engineers for tomorrow. To bring such a change utility have to think hard about how they can manage the transition in order to avoid over burdening of staff with change.

6.7 Cyber Security and Data Privacy Skill:

With the transition from analogous to digital electricity infrastructure comes the challenge of communication security and data management; as digital networks are more prone to malicious attacks from software hackers, security becomes the key issue to be addressed.

In addition to this; concerns on invasion of privacy and security of personal consumption data arises. The data collected from the consumption information could provide a significant insight of consumer's behavior and preferences. This valuable information could be abused if correct protocols and security measures are not adhered to.

If above two issues are not addressed in a transparent manner, it may create a negative impact on customer's perception and will prove to be barrier for adoption.

7 Solutions for Overcome Barriers for Smart Grid Development in Inmdia

Despite the challenges mentioned above, there are a number of steps that can be taken to speed up the implementation of smart grid technologies. Foremost step that is required to be taken is that policy-makers and regulators need to restructure the economic incentives and align risk and reward This paper focuses on explanation of smart grid with the short description on AMI and DA, and is the major part for smart grid AN can be integrated with smart grid. Across the value chain. By building the right economic environment for the private sector investment and focusing more broadly about the way that social value cases are created and presented implementation would become much easier. By analyzing these solutions in bigger environments i.e. in cities, the entire industry will learn what it takes to implement smart grids successfully and will result in developing an industry that is set to booming the coming periods.

7.1 Forming Political and Economic Framework

Policy makers and regulators must implement a framework which optimally spread the risk over the whole value chain i.e. to guard the investors from risk and to yield the result at lower cost to the customers. They must form a robust incentive model in order to attract more and more private investment. Also rate of return should be based on the output generated. Rewards and penalty mechanism should be considered in order to monitor the performance of the utilities and to encourage them to deliver the outcomes in the most efficient manner.

Technological and delivery risk associated with Smart Grid are significant. And this can be overcome over a due course of time as more issues arise and are addressed. Risks associated with Smart Grid must be shared by every member across the value chain. While making the framework regulators must consider how much of that risk a utility can pass on to the contractors, suppliers and consumers. By maintaining the proper balance, there will be an improved alignment of the incentives. And further they must tackle numerous policies disputes and recommend potential solutions.

7.2 Moving Towards a Societal Value System

The major challenge for the transition from analogous to digital infrastructure will be to move from utility-centric investment decision to societal-level decisions which determine wider scopes of the Smart Grid. This would help in the accelerated adoption of Smart Grid Technology by the society.

7.3 Achieving Greater Efficiency in Energy Delivery:

Smart Grid Technology should consider building greater efficiency into the energy system which would result in reduction of losses, peak load demand and thereby decreasing generation as well as consumption of energy. New regulatory framework which incentivizes utilities for reducing the technical losses would help utilities to perform more efficiently.

7.4 Enabling Distributed Generation and Storage

Smart grids will change where, when, and how energy is produced. Each household and business will be empowered to become a micro-generator. Onsite photovoltaic panels and small-scale wind turbines are the predominant examples; developing resources consist of geothermal, biomass, hydrogen fuel cells, plug-in hybrid electric vehicles and batteries. As the cost of traditional energy sources continues to rise and the cost of distributed generation technologies falls, the economic situation for this evolution will build.

7.5 Increasing Awareness on Smart Grids

There is an imperative need to make the society and the policy makers aware about the capabilities of a Smart Grid. The main step is to form a perfect, universal description on the common principle of a smart grid. Beyond agreement on a characterization, the matter also needs to be debated more holistically as a true enabler to the low-carbon economy, rather than as an investment decision to be taken within the meeting room of distinct utilities. The importance of consumer education is not to be underestimated. The formation of user-friendly and state-of-the- art products and services will play a significant role in convincing the society about Smart Grids.

7.6 Creating Fresh Pools of Skilled Resources

Successful implementation of the smart grid will require many highly skilled engineers and managers. This paper focuses on explanation of smart grid with the short description on AMI and DA, to those mainly those who are trained to work on transmission and distribution networks. As a result, to on-job training and employees' development will be vital across the industry. Simultaneously, there is a requirement for investment in the development of relevant undergraduate, postgraduate and Vocational training to make sure the availability skilled work force.

7.7 Addressing Cyber Security Risks and Data Privacy Issues

Smart Grid success depends on the successful handling of two major IT issues:

- Security
- Integration and data handling

With increase in computers and communication networks comes the increased threat of cyber- attack. The Government should look into this matter because consumer's consumption data can be misused by the utilities and the third party. Utilities must give assurance to the consumers that their valuable information is handled by authorized party in ethical manner. The government must adopt high standard level in order to withstand cyber-attacks.

8 Potential Benefits of Smart Grid for Utility Industry in

The smart grid promises to change the power industry's entire business model and its relationship with all stakeholders, involving and affecting utilities, regulators, energy service providers, technology and automation vendors, and all consumers of electric power.

The smart grid envisages providing choices to every customer and enabling them to control the timing and amount of power they consume based upon the price of the power at a particular moment of time.

Some basic benefits of a smart grid are:

- Peak load Reduction: TOD price signals have unique potential for India.
- AT& C loss reduction: This is a major commercial and regulatory consideration. DICOMS may consider communication technology.
- Self-healing: A smart grid automatically detects and responds to routine problems and quickly recovers, minimizing downtime and financial loss.

  - Consumer motivation: Smart grids give consumers visibility into pricing offers an opportunity to control usage
  - Improved power quality. A smart grid helps provide power free of sags, spikes, disturbances and interruptions.
  - Accommodation of all generation and storage options: Enables interconnection to distributed sources of power and storage
  - Optimized assets and operating efficiently: Lowers need for construction of new infrastructure and enables sale of more power through existing system.

However, in nutshell following are the direct benefits to power utility as well as to consumer in India:

- Reduced generation operation costs
- Deferred generation capital investments
- Reduced ancillary service cost
- Deferred transmission capital investments
- Deferred distribution capital investments
- Reduced equipment failures
- Reduced distribution maintenance costs
- Reduced distribution operations costs
- Reduced electricity theft
- Reduced electricity losses
- Reduced electricity cost to consumers
- Reduced major outages
- Reduced restoration costs
- Reduced momentary outages
- Reduced, SOx, NOx emissions

9 Recommendation for Smmart Grid Development in India

Suggestions to main stake holders to promote and support the Smart Grid initiative in India as follows:

E1 Regulators:

- Create a regulatory framework which aligns incentives of each member in the value chain.
- Allocate risk and reward efficiently.
- Consider both utilities and customer while making policies.
- Adopt output based regulatory system (Reward/Penalties) which stresses on utilities to perform better.

E2 Utilities:

- Adopt more holistic approach about Smart Grids, so that they can convey its future benefits to the customers.

- Reduce the risk of technology obsolescence by R&D activities.
- Undertake large scale pilot projects and analyze the benefits.
- Transformation from utility-centric investment decision to societal-level decisions.

E3 Vendors:

- Required to play important role in policy making process
- To help utilities to adopt flexible design and compatibility of Smart Grid fast.
- To convince customers about the acceptance of changing trend by product and service offering.

E4 Customers:

- Plays critical role by demanding for more flexible service.
- To encourage more players to enter in this field and in order to make the market competitive
- To help utilities and regulators to set goals and make conducive policies.
- To increase the awareness in society.

10 Conclusion

This paper discusses about the smart grid initiatives in India, Issues, Challenges and benefits. The paper discusses the need for smart grid technology to minimize the AT & C losses which is a burning issue across all power distribution utilities in India. The authors have highlighted some aspects of various key areas related as to smart grid initiative for Indian Power distribution utility like AMI, DA etc. Highlights the various barriers for smart grid development in India. Finally elaborate the benefits as well as suggestions to key stake holders to promote the smart grid technology grid for the utilities as well for the consumers, and obviously benefit to the Indian economy. Further, because of growing environmental concerns, it is suggested that Indian power grids need to become far more flexible than they are today, accommodating distributed power generation from renewable sources and use several energy-efficiency techniques.

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Blockchain Based Peer-to-Peer Power Trading Platforms

Gopal Bhageria

Abstract This electronic document is about Peer to Peer Power Trading Platform built on top of Blockchain technology.

Keywords Blockchain · Chain code · Smart contract · Energy trading

1 Introduction

Distributed Energy Resources (DER) is becoming a prevalent way of producing energy in some of the regions in the USA and globally. Technology is making it possible to move away from a small number of bulk generation units serving power to a large number of consumers to distributed generation in small amounts but able to sell it in the neighborhood. The DER through the solar, wind or, combined heat and power (CHP) requires new capabilities in the grid such as trust among the DER generators, maintaining the reliability of the grid, improved security, and privacy in the new grid. The paper explains a way to establish trust among DER producers and work with each other through a distributed energy marketplace that provides transparency and immutability using blockchain technology. We have outlined how energy producer can list their excess power in the market that can be bought by consumers through the bidding process. This whole process of energy exchange is implemented in an open-source Blockchain project called Hyperledger Fabric. With this platform, DER producers and consumers can exchange energy and complete the financial transactions, thereby increasing the adoption of the DER.

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2 Backround

2.1 Background of the P2p Energy Trading

The current energy generation, transmission, and distribution model are built to cater to bulk energy generation after that stepping up the voltage for long-distance transmission then finally stepping down for distribution. This model has lasted for more than 100 years but with the advancement in technology and growing concern over the impact of environmental pollution by bulk generation, such as coal-fired plants and nuclear power plants, have raised public awareness. This awareness has found a solution in the form of a DER where the consumer can generate his own power and possibly sell the excess energy to someone who needs it. The price of the energy will be driven by demand and supply and availability of options. On a hot summer day when utilities are struggling to meet the peak demand, solar panel generates the maximum, thereby improving the supply to meet the higher demand hence managing the price increase as well.

The concept of having local generation and energy trading at the local level will revolutionize the energy industry and how we currently source our energy needs. However, to make this model a success, multiple innovations needed across the whole value chain. One of the critical aspects of energy trading is the association of trust among the participants. Since promises to buy/sell energy, actual energy transaction and payment settlement will happen at different times. Therefore, we need a way to enthuse trust among the participant; otherwise, the seller will be averse to selling energy, and the cost of the operation may become too high. Manual interventions will also not improve the situation. Therefore, we see the need for a platform that can facilitate the transaction in a manner that can increase trust among the participants.

2.2 Innovations in Energy Trading

The proposed solution to facilitate energy trading in the local community address the requirement of trust among the participants and provides a platform for the participants to publish excess energy, a commitment by buyers for purchasing, reconciliation after the actual energy exchange followed by settlement of the money to conclude the transaction. We have used the Hyper-Ledger-Fabric based Blockchain technology to implement the solution. One of the core components of the solution is a series of chain codes. A chain code is the ’smart contract’ that runs on peers and creates transactions. More broadly, it enables users to create transactions in the Hyperledger Fabric network’s shared ledger and update the world state of the assets. In the chaincode, we embed the logic of a smart contract, which is agreeable to all the participants. As regulators are taking note of blockchain technology, the smart contract could become a legally binding contract.

This project will help the community and enable peer-to-peer energy exchange, which will encourage the adoption of renewable energy and reduce the carbon footprint. Now an energy consumer is not only the consumer of the energy but also the producer hence qualified as prosumer.

3 Why Blockchain

Blockchain is a decentralized platform for such peer to peer business activities wherein the transactions happening among the peers remain secured in all aspects, as the blocks in the Blockchain are immutable and the transactions, once processed to the chain, cannot be edited, so there are no chances of data integrity to be compromised. It shows the property of provenance that helps in building a system that can be traceable, i.e., the transactions taking place can be visible to all the peers that are in the particular chain; this brings transparency and trust among the peers, this can also help the users to get to know about the previous transactions of the particular user [1]. Blockchain provides the provenance of a historical record for any transaction. Data provenance systems track changes that are made to data, where data originates and moves to, and who makes changes to it over time. In other words, data provenance is "showing your work" in a database. This historical record of information can then be trusted for data validation and audit purposes.

The main advantages of P2P energy trading are:

- no middle man—people make deals on their terms
- everyone saves money—improved operational efficiency hence less costly
- transparent dealings directly with other consumers
- trust is never an issue in this network and can be done easily with all valid proof
- maintains historical transaction and integrity of the data is maintained

3.1 Hyperledger Fabric

The proposed model is developed on the Hyper ledger fabric managed by Linux Foundation. Hyperledger Fabric is an open-source enterprise-grade permissioned distributed ledger technology (DLT) platform designed for use in enterprise contexts that delivers some key differentiating capabilities over other popular distributed ledger or blockchain platforms. Hyperledger is an enterprise-graded permissioned distributed ledger platform designed for enterprise context [2]. The fabric has a highly modular and configurable architecture, enabling innovation, versatility, and many more. Instead of Smart contracts, fabrics call these functions "chaincode" that gains trust from the Blockchain and underlying consensus among the peers. Smart contracts are essentially transactions that are only completed after certain conditions are met. For example, if a buyer wanted to buy power at 15¢ per kWh, the smart contract would only activate when a seller was willing to meet a condition and deliver the power. Thanks to the Blockchain, we can now increase efficiency and reduce the costs of buying and selling electricity. Combining the capability of Blockchain with data originating from smart inverter data and possibly meter will revolutionize the energy is distributed and consumed. Our platform can automatically reconcile demand and supply in real-time to better balance the grid. While the technology is still in its early days, its potential is for disruption is evident.

(1) *Blockchain Energy Eco System*

Not surprisingly, technology firms are leading the development of blockchain applications for energy. Some, like Siemens, have invested in companies that are already developing blockchains. Others are developing their own blockchain products. We at SUJOSU Technology have implemented a Blockchain-based power trading that includes hooks for integration with smart inverters and smart meter and financial reconciliation.

(2) *How will it work?*

Initially, the producer would sell his energy at a less than optimal price to a broker company, which would then make a profit by selling this energy to a much higher price to the end consumer. In our project, the producer and consumer directly agree on the price. The result of the agreement is a lower price for the consumer and a higher price for the producer than if he had sold it to a broker company. This way, the consumer incurs electricity cost savings while the producer becomes more profitable and can break even much faster on the costs of his production assets. This makes it easier for other consumers to purchase electricity based on the renewable energy source of their choice. Also, the prices of electricity can be lower than those of conventional energy suppliers.

4 Our Solution

4.1 Overall Solution

The overall solution of our Blockchain platform is depicted below.

Our platform has three key capabilities.

- The first key capability is to allow the prosumers to trade energy among themselves through blockchain-backed web/mobile interaction.
- The second key capability is the ability to analyze the data generated through the platform and develop insights that can be used by multiple parties including utilities, regulators, solar providers etc.
- The third key capability is to integrate with solar inverter data providers or utilities smart meter through IoT (Internet of Things) integration using REST based interface that talks to our Blockchain platform (Fig. 1).

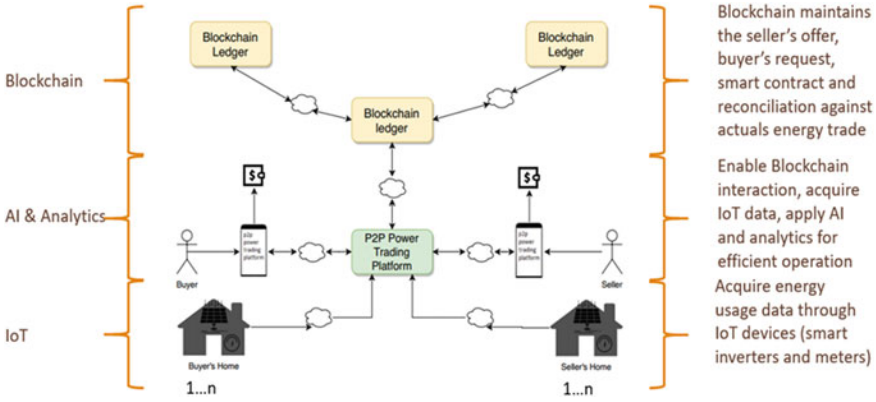


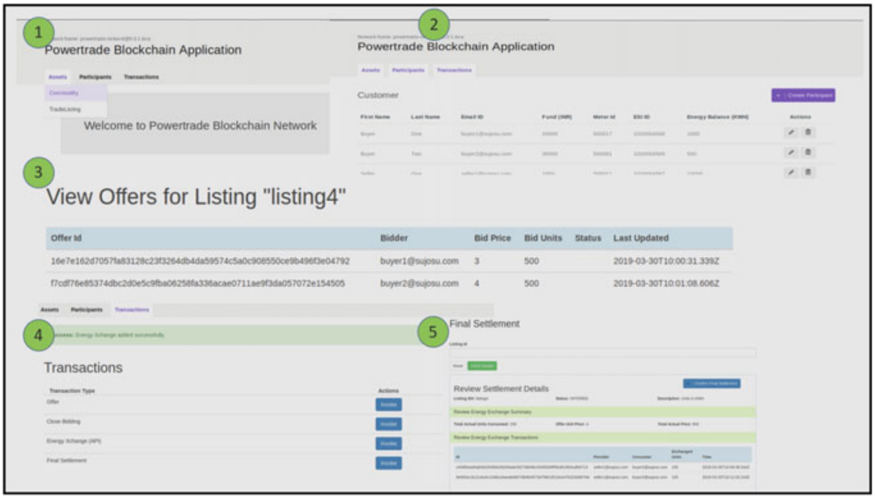
Fig. 1 Solution architecture of P2P energy trading platform based on Blockchain

We have implemented a simple User Interface for testing the platform where prosumers can register and login to the system, creating energy assets, listing the asset for future data/time consumption with the rider of the minimum expected price. Consumers, on the other hand, can bid for the available published listing by putting their own price point. A consumer with the highest purchase price wins the bid, thereby coming to an agreement with the seller to agree to his terms through chaincode. If, for some reason, the production of the energy is below the committed value, then there can be added penalty or compensation in terms of preferential bidding or discount coupon for the buyers. There can be multiple innovations that can lure market participants into continuing to participate in the p2p energy trading ecosystem (Fig. 2).

After the energy consumption, data from smart inverters and smart meters will be reconciled to calculate actual energy provided and consumed by the prosumers of the system. This data will then be used for the purpose of invoicing and financial settlement.

4.2 Challenges

There are several questions that need to be answered before the mainstream adoption of the Blockchains in the energy industry. The maturity of the distributed consensus mechanism is still an ongoing research effort, which is crucial to achieving these objectives. However, a solution that combines all desired characteristics cannot yet be achieved without significant trade-offs. PoW (Proof Of Work) algorithms are more mature and secure but on the other hand, are also slow and very energy-intensive. As a result, blockchain developers are increasingly moving towards PoS (Proof Of Stake) schemes that are energy-efficient, faster, and more scalable. Early adopters of



View Offers for Listing "listing4"

Offer Id	Bidder	Bid Price	Bid Units	Status	Last Updated
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f7cdf76e85374dbc2d0e5c9fba06258fa336acae0711ae9f3da057072e154505	buyer2@sujosu.com	4	500		2019-03-30T10:01:08.606Z

Transactions

Fig. 2 Platform UI for illustration

blockchain technologies face the challenge of selecting the right consensus mechanism and system architecture without having a clear long-term picture of the advantages and downsides that each approach has to offer.

Resilience to security risks stemming from unintentionally bad system design or malicious attacks is highly likely. Blockchains face additional risks such as possible malfunctions at the early stages of development due to a lack of experience with large-scale applications. Blockchain ecosystems rely heavily on coding new algorithms, a procedure that can be prone to errors.

Security issues are still highly likely before the technology becomes mature, resulting in bad publicity and delays in acceptance from consumers. With respect to cyberattacks, Bitcoin, the oldest blockchain implementation, has proved to be relatively resilient, but other platforms such as Ethereum, Crucially, vulnerabilities in terms of cyber securities often come from peripheral applications, such as digital wallets or smart contracts have been the target of serious attacks in the past.

4.3 Conclusion

In this paper, we summarized how the blockchain transaction could help in solving such a vast power issue and help in wastage of power and help more consumers to be benefitted from it. We have talked briefly about our platform that can bringing trust in the system and enable prosumers to trade energy and make the whole system efficient.

Acknowledgements I would like to acknowledge our developers (Mr. Suresh P., Mr. Bikash Sen, and Ms. Shraddha Mishra), who helped build and deploy the platform and research work for this paper.

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Explainable Artificial Intelligence (XAI): Towards Malicious SCADA Communications

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Abstract Critical infrastructure Supervisory Control and Data Acquisition (SCADA) systems have been designed to operate on closed, proprietary networks where a malicious insider posed the greatest threat potential. There is an emergence of new threat scenarios of command and data injection. Multiple machine learning methods have been used to predict instances of command and data injection attack scenarios. The models often lack transparency. The black-box nature of these systems allows powerful predictions, but it cannot be directly explained. Understanding the reasons behind predictions is, however, quite important in assessing machine decisions, predictions and justify their reliability. More an attack is threatening the more explainable it should be. We need to explain attacks on both a local and global scope to get complete transparency against the attack. We will apply global interpretability methods like Partial Dependence Plots(PDP), Individual Conditional Expectations (ICE), Decision Trees to explain the whole logic of a model. For more menacing attacks we use local interpretability methods like Local Interpretable Model-Agnostic Explanation (LIME) to explain the reasons for specific decisions a model is taking.

Keywords SCADA · Machine learning · PDP · LIME · ICE

1 Introduction

The increasing complexity of Artificial Intelligence methods leads to increase in difficulty to interpret its decisions. So, Explainable Artificial Intelligence(XAI) [1] refers to various methods and techniques to help humans interpret the decisions made by the machine learning models. It helps us understand on what grounds our model is making the decision and if it is connected with prediction. For example, if a model is giving more importance to snow than other features in identifying a wolf's image, we will get to know our model is flawed as it fails to generalize. So, we can then add more wolf images with non-snow backgrounds.

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Many techniques are in use by XAI to make interpretability easier. One of them is Partial Dependence Plots(PDP) which shows dependence between all pairs of features and target. This helps us to interpret the importance of each feature on each. PDP can show whether the relationship between the target and a feature is linear, monotonic or more complex.

Another method is used is Local Interpretable Model-Agnostic Explanation(LIME). LIME helps us explain individual prediction by permuting it and finding the patterns. It is one of the few methods that works for text, images and tabular data formats. It is implemented in Python and R.

Supervisory Control and Data Acquisition (SCADA) system consists of a number of Remote Terminal Units (RTUs) which via a communication system connect to master station collecting field data. The station displays the data and allows control tasks to be performed. We try to interpret a set of machine learning algorithms in terms of their ability to identify various attacks when analyzing remote terminal unit (RTUs) serial communications in a gas pipeline system [2]. The RTU data used in this set of experiments was developed by the Mississippi State University's Critical Infrastructure Protection Center [3], and includes examples of benign RTU transactions and variants of command and data injection attack transactions generated specifically for critical infrastructure protection research.

2 Types of Interpretability

The explainable AI methods can be broadly classified into according to the following parameters [4].

2.1 *Complexity of Interpretability*

The complexity of a machine-learning model is directly related to its interpretability. An inverse relationship exists between the accuracy and interpretability of AI methods. The negative correlation between the two is as follows: the greater the interpretability, the lower the accuracy and vice versa.

2.2 *Scope of Interpretability*

This classification of interpretation talks about if the interpretation method explains a single prediction or the entire model behaviour. We distinguish between two sub classes:

(1) Global Interpretability

Global interpretability is all about being able to explain and understand model decisions based on conditional interactions between the dependent (response) variable(s) and the independent (predictor) features on the complete dataset. It involves understanding of the whole logic of a model and follows the entire reasoning leading to all the different possible outcomes.

(2) Local Interpretability

Local Interpretability involves understanding prediction decisions for a single datapoint, focusing specifically on that datapoint and looking at a local feature space around that point, and trying to understand model decisions for that point based on this local region. This is used to generate an individual explanation, generally, to justify why the model made a specific decision for an instance.

2.3 Model Dependency

Another important way to classify model interpretability techniques is whether they are model agnostic, meaning they can be applied to any types of ML algorithms, or model specific, meaning techniques that are applicable only for a single type or class of algorithm.

(1) Model Specific

Model-specific interpretability methods are limited to specific model classes.

(2) Model Agnostic

Model-agnostic methods are not tied to a particular type of ML model. In other words, this class of methods separates prediction from explanation. They are usually used to explain predictions post the prediction stage.

3 Evaluation Approach

The focus of the evaluation is to understand the prediction of machine learning methods applied. We applied four XAI methods: PDP on Gradient Boosting Regressor, LIME on decision tree classifier, ICE using Random Forest and Decision Tree using Gini index. Each method [5] was applied in isolation on a dataset.

3.1 Machine Learning Methods

The methods used were:

(1) Gradient Boosting Regressor

Gradient Booster acts as an additive model to regression in a forward stage-wise fashion. Negative gradient of the given loss function is fitted by a regression tree in each stage.

(2) Decision Tree Classifier (C4.5)

It is the extension of the ID3 algorithm where at each node it chooses an attribute to split the sample data according to the Information Entropy. It can handle both continuous and discrete attributes and can also perform post-pruning.

3.2 XAI Methods

(1) Partial Dependence Plots (PDPs): It helps us identify features which have marginal effect on the outcome of the models. The partial dependence function for regression is as follows [6]:

$$\hat{f}_{xs}(xs) = E_{xc}\left[\hat{f}(x_S, x_C)\right] = \int \hat{f}(x_S, x_C)d\mathbb{R}(x_C) \tag{1}$$

where

x_S = features to be plotted

x_C= remaining features

$\hat{f}$ = Machine Learning Model.

x_s and x_c together make a feature set.

(2) Local Interpretable Model -Agnostic Explanation (LIME): It is trained to approximate the prediction of black box models [7] and helps explain individual prediction. The local surrogate models with interpretability constraint can be expressed as follows [8]:

$$\text{explanation}(x) = \arg\min_{g \in G} L(f, g, \pi_x) + \Omega(g) \tag{2}$$

where

x = an instance

f = original model

g = predicted model
$\Omega(g)$ = model complexity

(3) Individual Conditional Expectations (ICE): It is a linear plot consisting of only one line depicting changes in prediction with respect to changes in features. It is a global method [9] as it does not depend on a specific instance, but on the overall average. An ICE plot [10] visualizes the dependence of the prediction on a feature for each tuple separately, resulting in one line per tuple.

(4) Decision Tree: Decision Trees [11] can be converted to decision rules where the outcome is the contents of the leaf node of the decision tree, and the conditions along the path form a conjunction in the if clause. The Gini index is a simple probabilistic measure of deciding splitting points for features. More the Gini index less the probability of getting selected as a splitting attribute [12].

$$Gini(D) = 1 - \sum p_i^2 \tag{3}$$

4 Results

The input features of the dataset are shown in Table 1. Each instance of dataset represents communication with SCADA. Output is either an attack (represented by 0) or not an attack. (represented by 1).

4.1 PDP Plots

As we can see in Fig. 1. PDP plot is linear. As the value of CommandResponse becomes 1.0 the target value decreases to zero which means probability of attack

Table 1 Feature description

Feature name	Description
Pipeline Pressure(PSI)	It is gas pipeline pressure value in pounds per square inch (PSI)
Setpoint	The Setpoint Value
Invalid data length	The transaction is comprised of a response with a data element of an invalid size
Data length	Length of the response data for this transaction
Control scheme	An indicator of whether control is accomplished through the solenoid
Control mode	An indicator of whether the RTU unit is in auto control mode or off
Solenoid state	A binary indicator of whether the solenoid is on or off
Pump state	A binary indicator of whether the pump is on or off
Invalid function code	A binary indicator of whether the function code is invalid

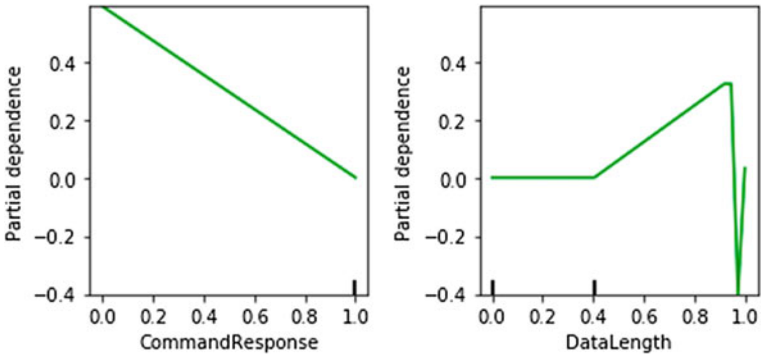


Fig. 1 CommandResponse and DataLength

increases whereas the DataLength doesn't affect target value till it becomes 0.4 and then it shows fluctuation when its value is around 1.0.

Similarly, as we can see in Fig. 2, When Data Length is invalid (i.e. value of InvalidDataLength is 1) the target value increases and hence chances of attack occurring are less. When pipeline pressure increases from zero to one chances of attack is increasing.

Finally, as you can see in Fig. 3, there are attacks when PumpState is OFF (i.e. value of PumpState is 0 or 1) and the probability of attack decreases when the pump state is ON.There is less probability of an attack when SolenoidState is OFF. Chances of attack increases when the state become ON.

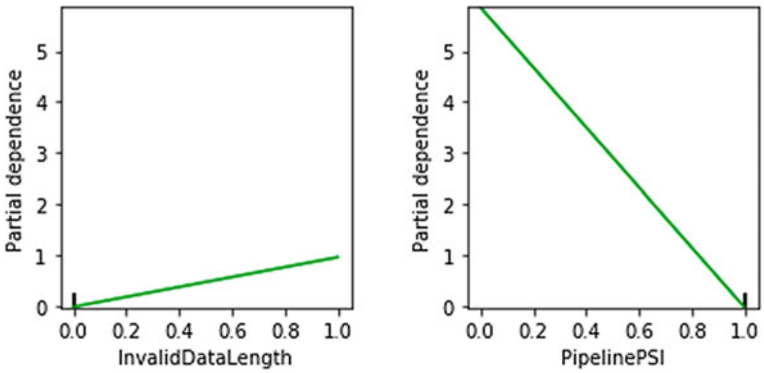


Fig. 2 CommandResponse and DataLength

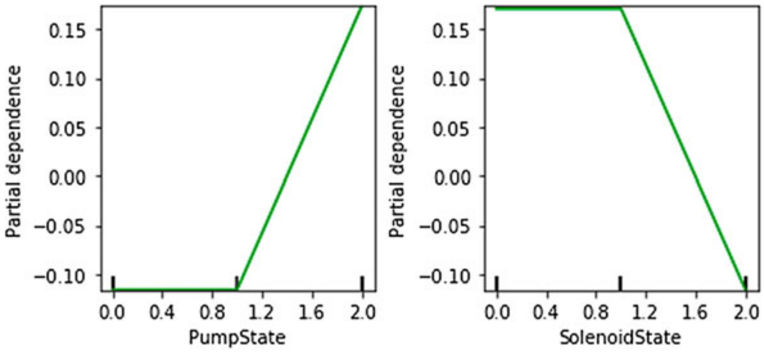


Fig. 3 PumbState and SolennoidState

4.2 Lime

We show the result of LIME on some of the positive and negative instances (attack and no-attack) of the dataset. Figure 4 and 5 represent instances of no attack. For the instance in Fig. 4, PumpState value has the most effect (0.15) for classifying it as no attack when it's OFF. Similarly, instance in Fig. 5 is classified as not an attack due to PumpState. Figure 6 and 7 represents instances of an attack. For instance in Fig. 6, PumpState plays an important role(has an effect of 0.19) to classify it. Same is the case for instance in Fig. 7.

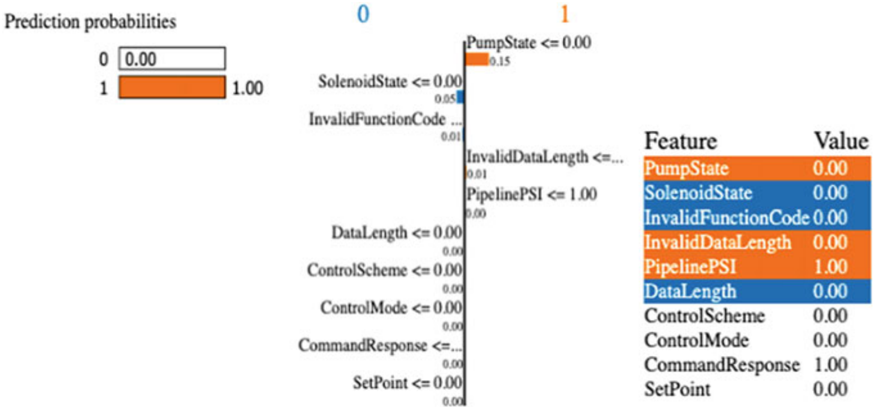
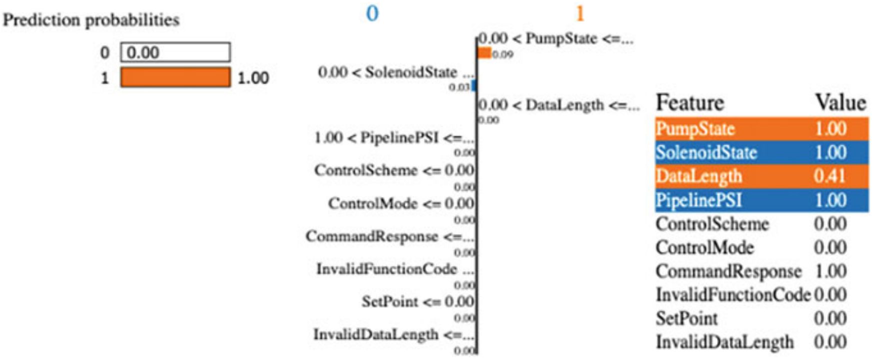


Fig. 4 Example of no attack

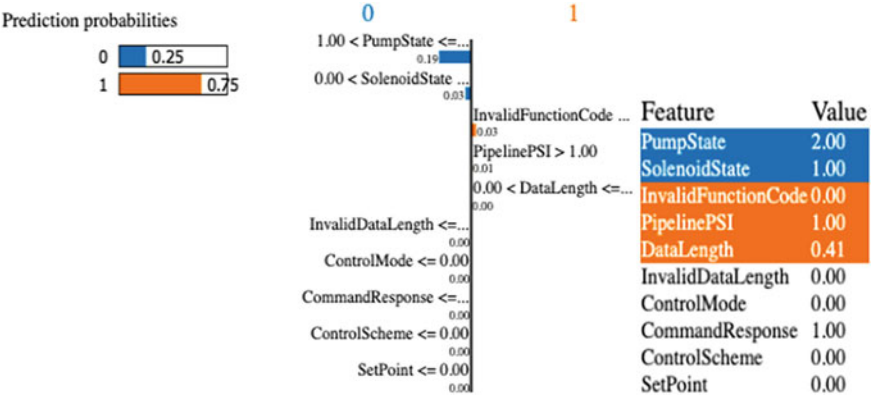


Feature	Value
PumpState	1.00
SolenoidState	1.00
DataLength	0.41
PipelinePSI	1.00
ControlScheme	0.00
ControlMode	0.00
CommandResponse	1.00
InvalidFunctionCode	0.00
SetPoint	0.00
InvalidDataLength	0.00

Fig. 5 Example of no attack

Feature	Value
PumpState	2.00
SolenoidState	1.00
InvalidDataLength	0.00
PipelinePSI	1.00
DataLength	0.41
ControlScheme	0.00
ControlMode	0.00
CommandResponse	1.00
InvalidFunctionCode	0.00
SetPoint	0.00

Fig. 6 Example of attack



Feature	Value
PumpState	2.00
SolenoidState	1.00
InvalidFunctionCode	0.00
PipelinePSI	1.00
DataLength	0.41
InvalidDataLength	0.00
ControlMode	0.00
CommandResponse	1.00
ControlScheme	0.00
SetPoint	0.00

Fig. 7 Example of attack

4.3 Individual Conditional Expectations (ICE)

The output value 0 in ICE plots indicates an attack is detected in the SCADA communication and value 1 indicates that no attack was detected. Each line in the ICE plots represents a tuple and the graph indicates the change in output value with respect to the feature value.

From Fig. 8 we observe that in ICE plot for CommandResponse, the output value in most cases indicates no attack (indicated by dark line). For some observations we have attack and in few observations, the chances of attack decreases as the CommandResponse value increases, indicating we have registered a response.

Figure 9 shows that the output value for ICE plot for InvalidFunctonCode is not dependent on the value of Invalid-FunctionLength. In the ICE plot for PipelinePSI, for just about all cases, the chances of attack on SCADA communication reduces with an increase in PipelinePSI value.

Finally in Fig. 10 the ICE plot for PumpState indicates that no attack takes place in the majority of the cases. In fact, the chances of attack in sparingly few cases reduces after the value of PumpState crosses 1, indicating it is switched on. ICE plot for SolenoidState also shows a similar pattern, practically all the value show a safe

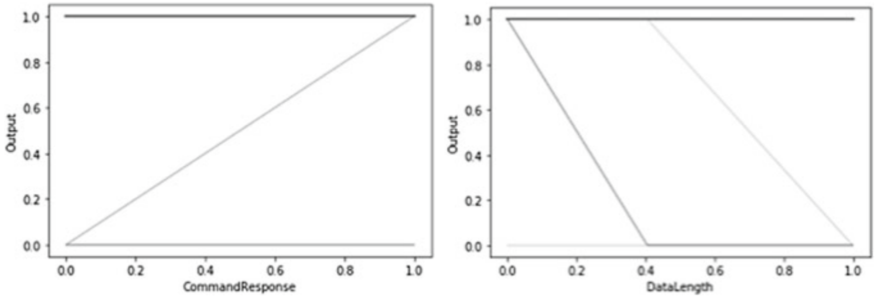


Fig. 8 CommandResponse and DataLength

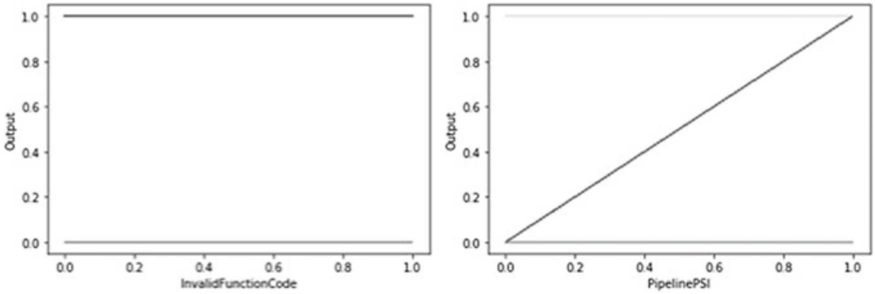


Fig. 9 InvalidFunctionalCode and PipelinePSI

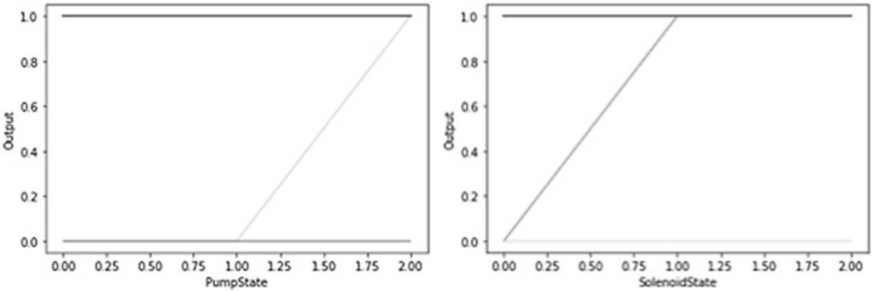


Fig. 10 PumpState and SolenoidState

communication irrespective of the SolenoidState value but in a few cases as the value of SolenoidState falls below 1 indicting switched off state for solenoid, the chances of attack increases.

4.4 Decision Tree

As we can see from Fig. 11, splitting on PumpState results in the most pure partition of the dataset i.e. each part after the split corresponds to only a specific class of target value. From this tree some of the rules that we can interpret are:

$$if(PumpState) \geq 1.5 \wedge SolenoidState \geq 1.5 \Rightarrow Label = Good$$

$$if(PumpState) \leq 1.5 \wedge CommandResponse \leq 0.5 \Rightarrow Label = Attack$$

5 Conclusion

The application of XAI methods to SCADA data demonstrates their promise in addressing interpretability problem in the machine learning domain about understanding why it classified a session as an attack. So, we came to know about the features responsible for high probability of an attack. Knowing this can help make future SCADA communications secure.

We see this work as a basis for applying different XAI methods to domain like SCADA communications and push use of more complex XAI methods in future.

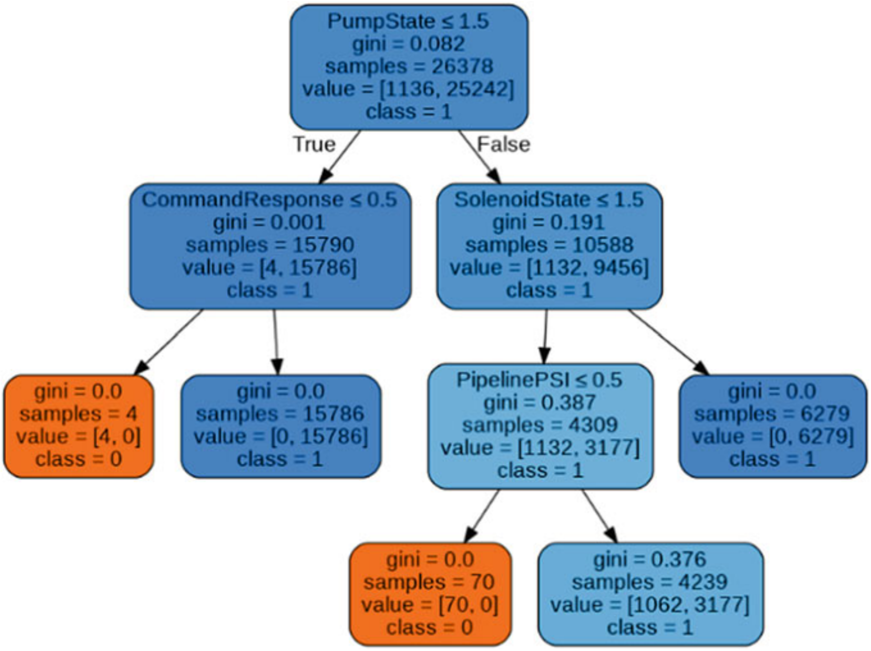


Fig. 11 Decision Tree

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Energy Optimization and Sharing in Smart Grid with Renewable Energy System Using Cyber Physical System

R. Karthikeyan, A. K. Parvathy, and S. Priyadharshini

Abstract The recent development in Micro smart grid technology has improved energy efficiency and renewable energy utilization rate to serve local load with dispersed resources. We Propose a Hierarchical Household Load priority Load scheduling algorithm using cyber physical controller for Hybrid Energy Management in micro Smart Grids to maximize the utilization rate of the Renewable energy resources connected to the system. The Household appliances are connected to bundle with different priority according to the energy consumption pattern and the customer sophistications. The inclusion of energy storage systems in microgrids provides the energy management with additional degrees of freedom, and therefore, makes the microgrid more flexible to the changeable situations. This paper focuses on implementing adaptable energy management system for microgrids in order to coordinate generation, demand, and storage, as well as compensate the effects of the variability of renewable energy generators and load fluctuations, in view of the user necessities. The considered hybrid energy systems comprise of renewable sources (solar photovoltaic and wind turbine), conventional systems (utility grid connection), battery-based energy storage systems and loads. In this work, a modular structure of energy management system is introduced in order to conduct the function of optimizing the energy dispatch of distributed resources. The Scheduling of the appliance are done according the priority and the availability of the renewable resources such as Photovoltaic Cells and Wind energy added to the grid. The proposed scheduling algorithm used Minority Game Technique to improve the utilization factor of the renewable resources. The System further uses Non- Intrusive Load monitoring is essential to

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obtain specific power consumption by individual appliances which will be used to allocate priority during the load scheduling.

Keywords Smart Grid · Load Scheduling · Non-Intrusive · Renewable Resources · Hybrid Energy Management · Cyber Physical System

1 Introduction

Management in households have more gained more attention in recent years due to the continuous increase of energy demand and change in the consumption pattern of the users. A Smart Grid [1] is an evolved structure where the system manages the electric demand, in sustainable, economical and reliable manner. It uses two way communications between the generation and the consumer to dynamically respond to the demand and change in energy consumption pattern. Micro Grid is part of the Smart grid with low voltage network that is developed by interconnecting the renewable energy plants and storage network to govern the load in an apartments or dwellings. In modern micro grid technology renewable energy such as windfarms and solar cells are added to improve the efficiency of the system which increases the complexity and challenge to powergrid at various Levels [2]. In micro grid infrastructure uses demand side management technology to integrate the various renewable resources and schedule the load by maximizing the usage of the renewable sources. Demand side management technology can shift the workloads from consuming power during the peak time to off-peak time for load balancing and expense reduction [3] which is an essential property of smart homes in microgrids. Some of the common components in a smart home includes household appliances (Such as washing machines, refrigerators, personal computers, ovens, water heaters, air conditioners and juicers), energy storage components i.e. battery, renewable energy such as Photovoltaic (PV) array, Windmills (PMSG).

The main objective of the system is to reduce the electric charges paid to the power supplier by increasing the utilization of the renewable resources produced at the site and to reduce the Peak time demand. Scheduling algorithm is designed to forecast the demand and schedule the load according to the availability of the load. Automatic residential consumption scheduling algorithm [4] was designed by combining a real time tariff with inclining blocking rates. The three step control [5] methodology helps in effective managing the cooperation between energy production, consumption and storage. A swarm optimization technique is proposed [6] for effective coordination and optimal scheduling of residential resources to improve the advantages of smart home services.

The Paper focus on Cyber physical system (CPS) [7] it is tight integration of physical process and digital computing system. The major issue in the CPS are sensing and controlling the real time physical system. Other major applications of CPS are in medical system, traffic control and Smart Building etc. [8] The proposed algorithm aims in reducing the peak to average ratio, total energy usage and electric charges by maximizing the usage of the renewable resources. The proposed model can control the all the major household components effectively in the real time environment by considering the comfort level of the user and the priority of the household components. The scheduling of the components is done by also considering the renewable resource available and the state of charge of battery. This Paper is organized as follows Sect. 2 describes the setup of smart energy automation with renewable energy integration. The Sect. 3 presents the system objective and Sect. 4 explains NILM technique and Sect. 5 describes the load scheduling feasibility. Section 6 explains the mathematical modeling of power calculation for each appliance and Sect. 7 describes the feasibility analysis of the proposed system. The reliability of the system is explained with case study in Sect. 8 and conclusion is given in Sect. 9.

2 Setup of Smart Energy Automation with Renewable Energy Integration

Scheduling of appliances has proved to be efficient way of reducing house loads and energy usage. All the appliances in the household are not schedulable; the customer comfortless has to be taken before deciding the scheduling. The appliances such as HVAC and indoor lighting can be connected with the sensors to decide on the priory of the load and to make consumption more efficient. The grid must be customer oriented and has to operate on business principles where customer will have maximum information about the grid availability and gives the customer more choice to operate. This information's will help consumer to choose when to use electricity to save cost on electricity bills.

The Fig. 1 shows the proposed system layout in that system the whole load is divided in to bundles where each bundle consists of various house hold equipment's. These bundles where connected to AC grid by using the Access point through a computer controlled switch. This enables the controller to power on or off the bundle. Major house hold equipment's such as Refrigerators, AC consume a large portion of the total energy utilized by the system; some of these can be scheduled without affecting the customer priority and reducing the energy utilization.

Primary Controller: The processor has three main objectives first, it communicates with other appliances to obtain the status and to coordinate them. Second processer serves as a gateway for the customers to control the appliances and cyber physical controller to get the status of the system. Third the Master controller has to execute the schedule the all the appliances based on the priority and Hierarchical algorithm. The Project uses the Microchip 30 MIPS dsPIC30F Digital Signal Controller which makes it access large amount of data from the each nodes and process it.

Communication in between Notes: The system uses both wired and wireless modes of communication. The Primary controllers are connected with the cyber physical through Ethernet control and all the appliances inside the buildings are controlled by Using Wi-Fi. The main advantage of Wi-Fi is easy implementation

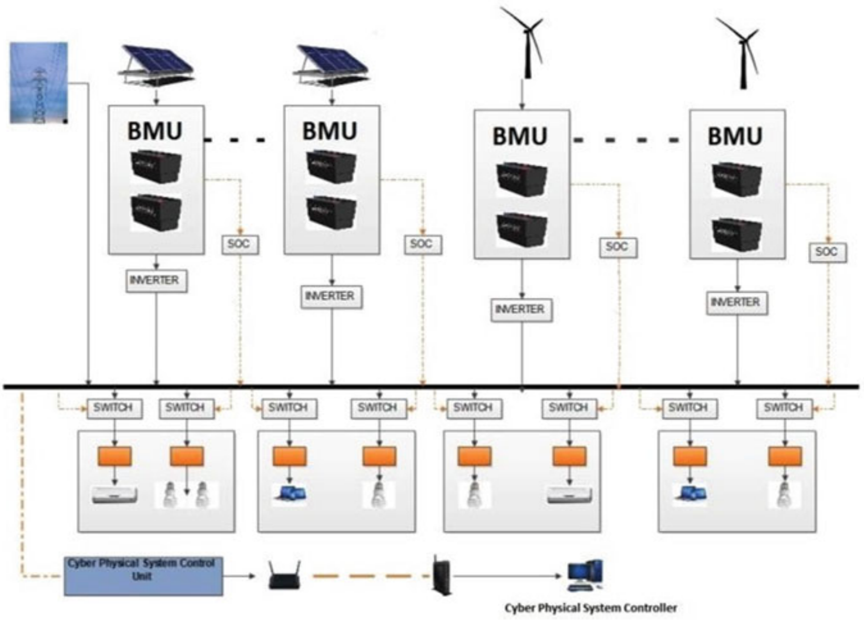


Fig. 1 Setup of Home energy Automation with Renewable Integration

and almost all the buildings are now covered with Wi-Fi signals, so it will reduce the installation cost and large data can be handled.

User Interface: Each Primary controller in the Building is connected with the PC of the customer for modifications in the priority of the appliances and for monitoring the system. Further master controller displays all the parameters to the customers by using a LCD display. Further the customer can also remote user interface in the web page to control the system.

Sensor Interface: The system has many sensors to collect real time data of power consumption by various appliances for finding the non-intrusive load monitoring. Further this system has temperature sensor in the buildings and to measure the state of charge of battery. The data collected by these sensors are passed to the master controller by using Wi-Fi.

Load Connection: All the Loads are connected with a computer controlled relay for scheduling according the availability of power in system and priority of the appliances.

The PV generation works by photovoltaic effect where a semiconductor converts the luminous energy to electrical energy, the generation rate depends on the illumination from the sun. The output of PV is nonlinear due to the variation in the environmental effects such as temperature and light intensity.

$$P_{pv}(t) = A_{pv} \times \rho \times SI(t) \tag{1}$$

where the A_{pv} is the total surface area of the solar panel, ρ is the specific resistivity of the panel and $SI(t)$ is the specific irradiance of the sun in the location with respect to time (t).

The model of wind power generation (WT):

The wind energy converts the kinetic energy from wind movement and converts it to torque in the wind turbine blades which drives the hub and gear box connected the prime mover of the generator to produce electricity. The output of the wind turbine depends on the velocity of the wind.

$$P_{mw}(t) = 0, if V < V_C or V_f > V_o \tag{2}$$

$$P_{mw}(t) = P_{rated}, if V_r \leq V_f \leq V_{co} \tag{3}$$

$$P_{mw}(t) = P_{rated} \times \frac{V_f - V_{ci}}{V_r - V_{ci}} if V_{ci} \leq V_f \leq V_r \tag{4}$$

The power output of the micro wind turbine $P_{mw}(t)$, depends on the velocity of the wind. Where V_C the cut in wind speed or the threshold wind speed is required to generate the wind power and V_o is the cutout wind speed where wind mill is not allowed to operate beyond the limit to the safeguard the turbine form mechanical insatiability. The terms V_f and V_r are the forecast wind speed and Rated wind speed respectively.

The model of energy storage system (ESS):

The battery energy storage system is used to increase the stability of the system by saving the energy during the surplus generation and satisfying the needs by discharging during the demand. The state of charge (SOC) indicates the battery capacity available in the storage system so based on the available source the load can be scheduled.

$$P_{Bch}(t) \leq P_B^{Cmax} \times C(t) \tag{5}$$

$$P_{BDis}(t) \leq P_B^{Dmax} \times D(t) \tag{6}$$

$$C(t) + D(t) \leq 1 \tag{7}$$

$$\begin{aligned} Ncap_B \times SOC_B(t) =& Ncap_B \times SOC_B(t-1) \\ &+ \left[\frac{P_{Bch} \times dt}{e_c} - (e_d \times P_{BDis}(t) \times dt) \right] \end{aligned} \tag{8}$$

$$Ncap_B \times SOC_B(t) = Ncap_{Bi} + [\frac{P_{Bch} \times dt}{e_c} - (e_d \times P_{BDis}(t) \times dt)] \tag{9}$$

$$\frac{P_{Bch}(t) \times dt}{e_c} + (Ncap_B \times SOC_B(t-1)) \leq Ncap_B \tag{10}$$

C (t) and D (t) State of the energy storage system in t for home C = 1 during charging and D = 1 during discharging. Equation 8 is used to determine the capacity of the Energy storage during the discharge. Where $P_{BDis}(t)$ is the Discharge power from battery in t [kW] and $Ncap_B$ is the Battery nominal capacity [kWh].

3 System Objectives

Depending on the customers objectives such as energy consumption, utilization of renewable reouces,CO_2 emission and peak load scheduling are considered for optimized scheduling.

Renewable energy utilization: The main objective of the current model is to maximize the utilization rate of the renewable energy and reduce the consumption from the power grid which lowers the energy cost and CO_2 emission.

Energy Cost: The total energy cost represents the cost of electricity consumption, where the energy cost is reduced by optimized scheduling and using renewable resources.

$C0_2$ Emission Cost: Thermal and gas or diesel fired power plants are the main source of the CO_2 emission in the power industry, the proper furcating of the loads can reduce the carbon footprint. The cost includes the carbon footprint by the customer by utilizing power from the grid. The Emission cost can be reduced by utilizing renewable resources effectively. The cost includes carbon footprint of the customer

Peak load Factor: The demand for power is usually higher during the peak hours and scheduling of house hold appliances during such time is a great challenge since the algorithm must consider the customer priority and also the objective of the system. The scheduling of appliances during the hot afternoons of summer [9] is a great challenge.

Optimization: For the optimized scheduling all the objectives are considered simultaneously with different priority given by the customer.

$$\mathrm{O} = \mathrm{AO}_1 + \mathrm{BO}_2 + \mathrm{CO}_3 + \mathrm{DO}_4 \tag{11}$$

where O_1, O_2, O_3, O_4 are objectives and A, B, C, D are the priorities given to each objective respectively.

4 Non-intrusive Load Monitoring (NILM)

The Technique was proposed by Hart [10] in 1992 to disintegrate the total electrical load by monitoring the appliances specific power consumption pattern. The sensors are fixed in main electric panel to calculate the total power utilized by the building. The sensors are fixed at each bundle to calculate the power consumed at each bundle and sensors are further fixed across the major appliances such as Refrigerators, Air conditioners etc. This problem is formulated as

$$\mathrm{P(t)} = \mathrm{p1(t)} + \mathrm{p2(t)} + \cdots + \mathrm{pn(t)} \tag{12}$$

where P(t) is the total power consumption and pi is the power consumption of individual appliances where n is the total number of active appliances within the time period t.

5 Load Sheduling Feasiblity

In our proposed method the priority is dynamically allocated so that the house hold equipment's can be scheduled according to the parameters such as customer priority, Activity Level, renewable resource availability and battery SOC. The whole household equipment's are classified in to three priority stages as High, low and medium. Different appliances have different time limits with dynamic priority where the time limit can be prescribed by the customer or manufacture of the products. The appliances are classified with priority according to the energy consumption and customer satisfaction.

A. *Customer Priority*

The scheduling pattern of the residential system first depends on the customer preferences and also depends on the energy saving aspects. In the dynamic priority scheduling technique the house hold equipment's are scheduled according to the renewable resource availability and the load demand the time period. The system also includes factor such as desired room temperature of the customer and maximum deviations that the customer will accept.

B. *Activity Level*

In the residential application the load curve for the load depends on the season and days such as weekdays and weekends. For a perfect scheduling of electrical appliances the activity level of the each bundle in the system must be monitored for every hour and plotted. The measured data for the weeks or months can be used to forecast the demand for each day. The load curve of the each house hold equipment's does not remain for e.g. the load curve of the refrigerator will not be same as the printer or microvan connected to the bundle.

Table 1 State of charge of 12 v Lead acid Battery

S. no	Open circuit voltage	Charge (%)
1	12.73	100
2	12.62	90
3	12.50	80
4	12.37	70
5	12.24	60
6	12.10	50
7	11.96	40
8	11.81	30
9	11.66	20
10	11.51	10

C. *Renewable resource availiablity*

The energy production using the renewable resource like solar and wind are generally fluctuating and affects the reliability of the system. The output of the renewable resources depends on the weather forecast information's for E.g. If the wind speed for a day is obtained the windmill generated for day can be calculated so that the algorithm can schedule a part of load to the wind energy source.

D. *State of Charge of Battery*

SOC determination based on the open circuit voltage [11] is direct measurement method and efficient method for determining the performance and life of the battery. Table 1 explains the relation between the open circuit voltage and state of charge of battery for 12 V lead acid batteries. The proposed system uses the Li-ion battery where there will be voltage drop during the discharging in the linear or nonlinear way. The voltage is also affected by the current, temperature, discharge rate and age of cell.

6 Mathematical Formulation

The objective function of the system is modeled with time horizon T with t time steps.

$$\min f(Cost) = \sum_{t=1}^{T} \left\{ \left[((P_g(t) \times dt\right) \times Cg(t)) \right\} \tag{13}$$

The mathematical formulation with weights is represented for sensitive analysis where

$$minf(cost) = w\left[\sum_{t=1}^{T}\sum_{i=1}^{I} C_i(P_{t,i}) + \sum_{t=1}^{T} C_r(Pr_t)\right] + (1-w)\left[\sum_{t=1}^{T}\sum_{j=1}^{J}[y_{j,t} - \tau_{j,t}x_{j,t}]\right] \quad (14)$$

In the Eq. (12) the objective function is added for sensitive analysis where $wandw - 1$ are weights where the condition need to be satisfied for choosing weights

$$w + (1 - w) = 1 \quad (15)$$

The equation (14) guarantees the balance between the generation and demand.

$$P_g(t) + P_{pv}(t) + P_{mw}(t) + P_{Bdis}(t) = P_L(t) + P_{Curtail}(t) \quad (16)$$

$$0 \leq P_g(t) \leq P_g^{max}(t) \quad (17)$$

The equation (16) represent the limits of power produced by the PV system during the day where $P_{PVmax}t$ the maximum allowed PV power in t *and* $P(t)$ is the power produced at the instant.

$$0 \leq P_{pv}(t) \leq P_{pv}^{max}(t) \quad (18)$$

PW_{max} is the maximum allowed power that can be generated by the wind mill at the rated wind speed.

$$0 \leq P_{mw}(t) \leq P_{mw}^{max}(t) \quad (19)$$

$$SOC_{Bmax} \leq SOC_B(t) \leq 1 \quad (20)$$

The excess energy from each home is shared between the other homes and stored in battery for critical loads. The customer sets the priority to each load in system with positive integers from 0 Which helps during scheduling of loads. The cost of each customer is given by $C(\theta, X)$, where the customer consumption decreases by X MW. The mathematical formulation in the Eq. 17 is the summary of the cost function of the customer, where K_1 and K_2 are the cost co-efficient. θ Refers to type of customers based on the willingness to schedule the electric power during the demand to gain the incentives. where θ toggles between 0 and 1, when $\theta = 0$ is for least willingness for scheduling and $\theta = 1$ is for the most willingness to schedule the load.

The cost function for all conditions is given as

$$C(\theta, X) = K_1X^2 + K_2X - K_2X\theta \quad (21)$$

$K_2X\theta$ is used to sort the customer based on the value of θ, as θ increases the margin cost decreases. The customer with most willingness will have least marginal cost and marginal benefit.

$$\frac{\partial C}{\partial X} = 2K_1X + K_2 - K_2\theta \tag{22}$$

7 Feasibility Analysis

The proposed algorithm initially schedules the appliances according to the priority status and forecasting of load demand. The sample house hold appliance priority is given in Table 2. The Fig. 2 explains the flow of proposed algorithm. The signal is sent to the master controller when the customer turns on the appliance. The controller checks the status of availability and turns on the appliance based on the availability of supply and priority of the load. When there is enough power is available under the limit the request is accepted if not the controller checks the priority of the appliance, if the priority is high the load is limitedly turned on.

If power available for the home is already filled then the controller stops the other schedulable loads and satisfies the power limit. The power generated by Solar and wind are used as primary sources for the each home. When power generated by one home is not completely utilized the primary energy generated in other home will be share to other homes to compensate their demand. The system imports the excess power from the grid to compensate the demand of the system. This method will solve the peaking in the grid and increase the utilization factor of the primary source. The aim of the project is to flatten the demand curve of the customer for each time slots and to consume maximum power in the allotted time slots. The each home connected to the grid has maximum power that can be consumed.

Table 2 Sample house hold equipment's priority

Devices	Energy consumption pattern	Energy consumption (Watts)	Eligible for scheduling	Priority
AC	Continuous	2000	Yes	Medium
Water Heater	Periodic	3000	Yes	Medium
Fridge	Continuous	265	No	High
Washing Machine	Flexible and Periodic	330	Yes	Low
Fans	Continuous	75	Yes	Low
Light CFL	Periodic	11	No	High
Personal Computer	Instantaneous	75	No	High
Printer	Instantaneous	100	Yes	Low
LED Tv 40 inches	Instantaneous	110	No	Medium
Hair dryer	Periodic	1250	Yes	Low

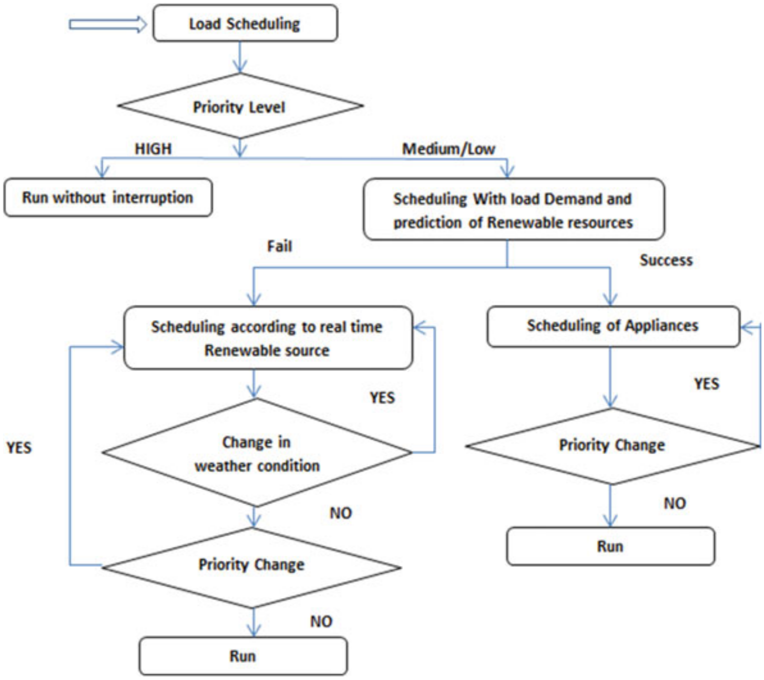


Fig. 2 Flow Diagram of Proposed Scheduling algorithm

8 Case Study

The real time prototype is being developed in the Hindustan university campus in Chennai, India which is funded by the MNRE, India. The system consist of 3 homes with solar panel capacity of 2KW,2KW and 1 KW respectively and each system has its MPPT controller, Inverter and Battery system separately. In this section simulation results are discussed by applying proposed model is discussed. A community of 5 homes is taken and power is generated by using installed solar and wind mills are added as primary sources for each homes. Connection are made such that when the generation is excess in one home can be shared with other home to reduce the power purchased from the grid and to reduce the peaking in the grid. In this no power is sold to the utility and excess power is saved in the battery (Fig. 3).

The system further uses MIPS dsPIC30F at each Prosumer Node as Slave unit along with Lumisense IoT board to upload all the data such as Power consumed, Battery status , battery temperature, voltage, current and status of sharing to the master controller through cellular communication. Each IOT board is equipped with SIM900 GPRS modem to activate internet connection also equipped with a controller to process all input UART data to GPRS based online data. The data is collected from the Energy meter connected to the each Prosumer Node. The System Uses indigenous Made ICD Meters for Both AC and DC measuring applications. Which

Fig. 3 Solar Panel 5KW installed in the Campus and 1KW Wind Mill PMSG installed

Enables us to get the real time data for Monitoring purpose. ICD make DC ENERGY METER (DEM 9004F) is used for measuring the solar panel output to the battery soures with the operating range of 0–800V DC and current range of 0–999.9 A. The meter has PC Interface Optically isolated RS485 communication provided by the MODBUS—RTU which enables us to directly port the data in to system. Further Each Prosumer is connected with ICD SEM 9510 (Single Phase Energy Meter) meter with the Wide range of input voltage and Whole current operation (5A and 10A Ib with 600% operating range). It has Accuracy class 1.0 as per IS 13779, IEC 62053 and Accuracy class 0.5 as per IS14697, IEC 62053 operated meters). The Data Collection through Optical Port/IrDA with IEC 62056-21 protocol (standard) and Data Collection through Optical Port with DLMS (Optional) Isolated RS232/RS485 with MODBUS RTU protocol. Both AC and DC Meter connected in the system are directly capable of porting data to the system and all the data are processed and uploaded to the cloud each minute to get the Realtime scheduling of the system. The system is totally controlled by the cyber physical master controller and all the decisions for scheduling is done based on the energy available in the storage system and based on the availability of the Renewable energy sources. The System is taken care to Reduce the system reliability for the Grid and improve the utilisation of the renewable energy to reduce the electricity bills and for quick recovery of the solar return. The Project further uses the ZigBee (cc2530) is a true system on chip (SoC) solution for IEEE 802.15.4 applications for collecting the panel temperature. The solar panel temperature is collected to access the performance of solar panels at various temperature to further study the performance of panels. Battery Temperature is measured by NTC sensor attached to Cathode terminals of the battery to monitor the health of the battery and the data of battery charging and discharging status and SOC of the system along with temperature of the each battery is uploaded to the cloud sytem to monitor and schedule the sytem.

The power rating of various appliances is collected and averages of these appliances are used in this research. The household appliances are classified as schedulable and non-schedulable. The proposed algorithm is tested with a case of both priority scheduling and non-priority scheduling technique conditions. The sample house hold equipment is listed with user priority and load consumed by each load in a day is calculated using NILM technique for scheduling in Fig 5 and energy yield is calculated for the year by solar module for scheduling of load is shown in Table 2 and Fig 4. The shadow loss and other losses such as non-alignment of panels were taken in to account for energy yield calculation. The Chennai solar irradiation values were taken from NREL Website. For the case study the system Figure 5 explains the scheduling with priority and non-priority if the system in a graphical way (Figs. 6, 7, 8 and 9).

Without priority scheduling the appliances switch on at random times according to the user needs so the total energy utilized increases. With the priority scheduling the usage of grid supply is reduced thereby increasing the utilization rate of renewable resources. The peak demand of the system is reduced by compensating the energy demand by using the renewable energy and scheduling of loads with their priority.

Fig. 4 Battery Storage System and MPPT System with Charge Controller

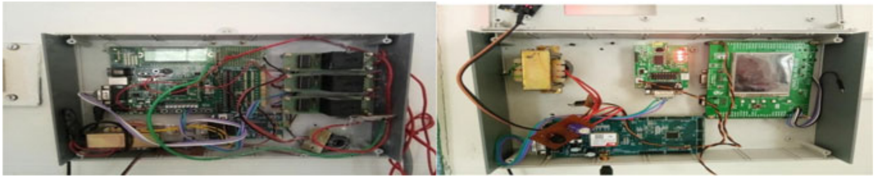
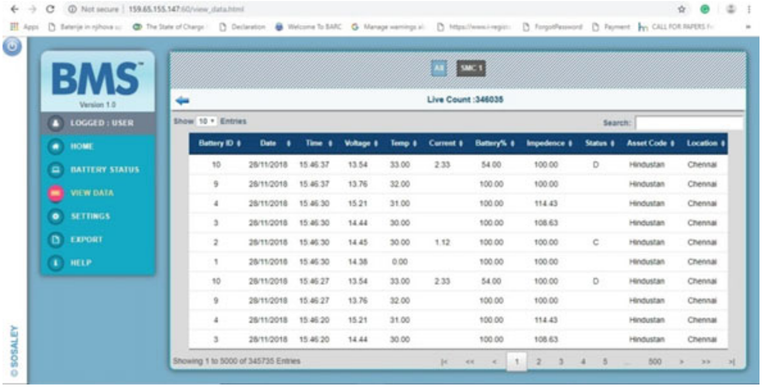


Fig. 5 Smart Meter Setup Both AC and DC with MCB and BUSBAR AC for Sharing and Controlling

Fig. 6 Master and Slave Control Board with Microchip Controller and IOT board

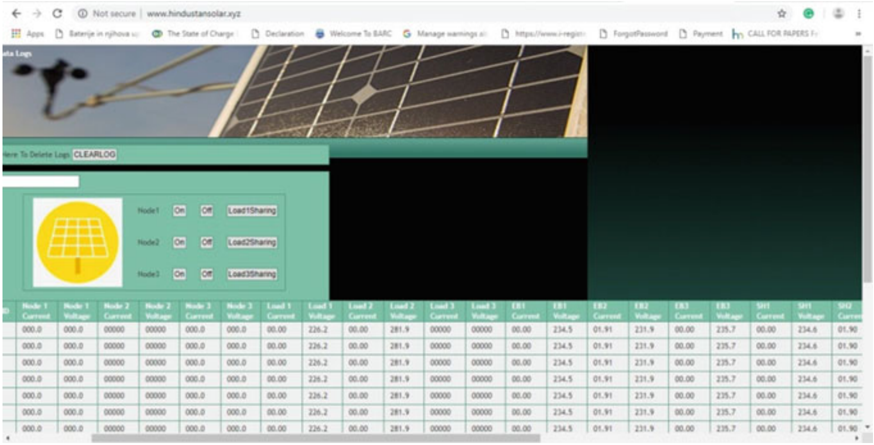


Battery ID	Date	Time	Voltage	Temp	Current	Battery%	Impedence	Status	Asset Code	Location
10	28/11/2018	15:46:37	13.54	33.00	2.33	54.00	100.00	D	Hindustan	Chennai
9	28/11/2018	15:46:37	13.76	32.00		100.00	100.00		Hindustan	Chennai
4	28/11/2018	15:46:30	15.21	31.00		100.00	114.43		Hindustan	Chennai
3	28/11/2018	15:46:30	14.44	30.00		100.00	108.63		Hindustan	Chennai
2	28/11/2018	15:46:30	14.45	30.00	1.12	100.00	100.00	C	Hindustan	Chennai
1	28/11/2018	15:46:30	14.38	0.00		100.00	100.00		Hindustan	Chennai
10	28/11/2018	15:46:27	13.54	33.00	2.33	54.00	100.00	D	Hindustan	Chennai
9	28/11/2018	15:46:27	13.76	32.00		100.00	100.00		Hindustan	Chennai
4	28/11/2018	15:46:20	15.21	31.00		100.00	114.43		Hindustan	Chennai
3	28/11/2018	15:46:20	14.44	30.00		100.00	108.63		Hindustan	Chennai

Fig. 7 Realtime Battery Monitoring System Website Snapshot

9 Conclusion

The paper presents controlling of load in smart grid using CPS. The hierarchical based Priority scheduling helps in controlling of peak demand in house hold equipment's effectively without disturbing the user comfort. The algorithm is simulated by using the case study where the appliances are switched on during the availability of



Node 1 Current	Node 1 Voltage	Node 2 Current	Node 2 Voltage	Node 3 Current	Node 3 Voltage	Load 1 Current	Load 1 Voltage	Load 2 Current	Load 2 Voltage	Load 3 Current	Load 3 Voltage	EB1 Current	EB1 Voltage	EB2 Current	EB2 Voltage	EB3 Current	EB3 Voltage	SH1 Current	SH1 Voltage	SH2 Curre
000.0	000.0	00000	00000	000.0	000.0	00.00	226.2	00.00	281.9	00000	00000	00.00	234.5	01.91	231.9	00.00	235.7	00.00	234.6	01.90
000.0	000.0	00000	00000	000.0	000.0	00.00	226.2	00.00	281.9	00000	00000	00.00	234.5	01.91	231.9	00.00	235.7	00.00	234.6	01.90
000.0	000.0	00000	00000	000.0	000.0	00.00	226.2	00.00	281.9	00000	00000	00.00	234.5	01.91	231.9	00.00	235.7	00.00	234.6	01.90
000.0	000.0	00000	00000	000.0	000.0	00.00	226.2	00.00	281.9	00000	00000	00.00	234.5	01.91	231.9	00.00	235.7	00.00	234.6	01.90
000.0	000.0	00000	00000	000.0	000.0	00.00	226.2	00.00	281.9	00000	00000	00.00	234.5	01.91	231.9	00.00	235.7	00.00	234.6	01.90
000.0	000.0	00000	00000	000.0	000.0	00.00	226.2	00.00	281.9	00000	00000	00.00	234.5	01.91	231.9	00.00	235.7	00.00	234.6	01.90
000.0	000.0	00000	00000	000.0	000.0	00.00	226.2	00.00	281.9	00000	00000	00.00	234.5	01.91	231.9	00.00	235.7	00.00	234.6	01.90

Fig. 8 Realtime Solar and wind System Controlling and Monitoring Website Snapshot

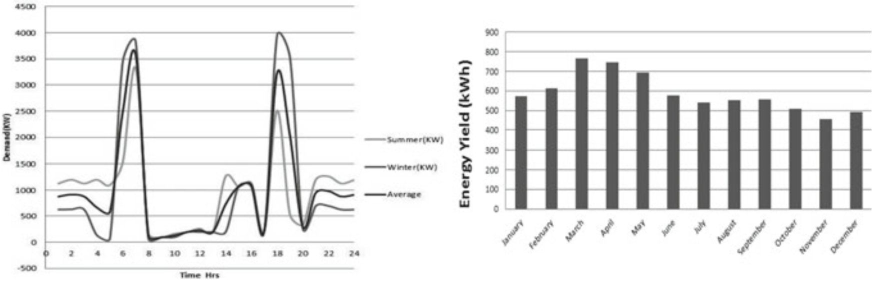


Fig. 9 Energy demand in each home during summer and winter season

renewable resources and only high priority load are switched on during the absence of renewable resources. Therefore, a scheduling scheme was proposed to residential households that would help consumers in saving money spent on electricity bill. The effective forecasting of availability of renewable resources and demand the efficiency of the algorithm can be improved.

Acknowledgements This work is supported by the Ministry of New and Renewable Energy (MNRE) Grant funded by the Indian government.

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Quantum Computing and Grid Security

Kshama M. Joshi, Tanmay Dalal, and Prakhar Chaudhary

Abstract Utilities Power grid is a critical artery of everyone's lives. It has an inherently complex design in that it encompasses several systems, devices, networks that are interconnected and the data of these power transmission and distribution systems is controlled in cyberspace. Like all systems, this one too is vulnerable to attacks—either manual or cyber. As a result, there is a need to know how Utility Companies would create a strategy to provide a response and thus recover from simulated coordinated cyber and physical security threats and incidents. In this paper, we have detailed out the following—Analysis of recent grid attacks—Nature and pattern of attacks. Reasons—Security Vulnerabilities, Advent of Quantum Cryptography. Threat Vectors—Cyber Attacks, Control System malfunctions. Impact of Threat Vectors—Outages, demand supply imbalance, leakage of sensitive information. Detailed Approach to Secure the Grid—Plan Ahead—Assess the Situation and Identify what is at stake. Get Support—Get the Software and Infrastructure Capability in place. Resolve—In Time and Appropriate response and restoration. Further, this details out how grid attacks can be prevented using application and network level security with possible use of Quantum cryptography. It explores options to prevent hacking of messages between 2 separate nodes of the grid using dynamic encryption. Finally, we conclude with how the market forces are far more vigilant now than in the past and how they are gearing up to be a resilient system in the face of grid cyber threats.

Keywords Cyber attack · Quantum · Threat vector · Cryptography

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1 Introduction

In the past decade, Utilities Industry has witnessed rapid deployment of technologies, amongst them, the Smart Grid, with an end goal aimed at improving the reliability and efficiency of operations. The Grid is complex in that it encompasses several systems. However, with technology at its helm, maintaining confidentiality, integrity and availability of data is of paramount importance. Unfortunately, these are the very parameters which are vulnerable and can be compromised with the advent of Cyber-attacks. The Accenture's Digitally Enabled Grid survey reveals that distribution business executives cite interruptions to supply as their greatest cyber-attack-related concern, closely followed by potential impacts on customer and employee safety [1].

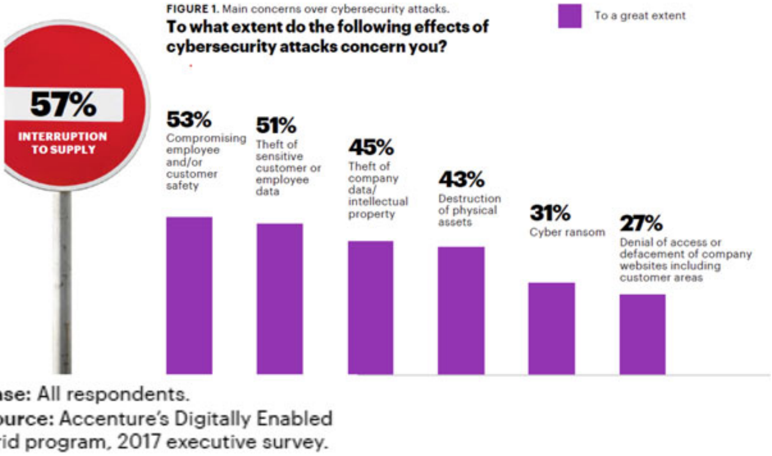


FIGURE 1. Main concerns over cybersecurity attacks.
To what extent do the following effects of cybersecurity attacks concern you?

Base: All respondents.
Source: Accenture's Digitally Enabled Grid program, 2017 executive survey.

The Siemens and the Ponemon Institute conducted a survey in Oct-2019 on—"Are Utilities Keeping Up with the Industrial Cyber Threat? Assessing the Operational Readiness of the Global Utilities Sector" [2]. The survey results show that risk is worsening, with potential for severe financial, environmental and infrastructure damage. Industry-wide, readiness is uneven and has common blind spots. In particular, the report highlights the unique cybersecurity requirements for OT, and the importance of distinguishing between security for OT and security for Information Technology (IT). This remains a major challenge for many organizations across the industry..

1.1 Grid Attacks Across the Globe

Between 2007 and 2019, countries across the globe have witnessed major attacks on the grid, causes of which are still being investigated. To list a few [3]–

On September 26–27, 2007, a cyber-attack caused major disruptions affecting more than three million people in dozens of cities in the Brazilian state of Espírito Santo.
On December 23, 2015 Ukraine power grid cyberattack left 230 thousand people without power for 1–6 h.

Between May 2017 and March 2018, India has also experienced attacks as below–

November 2017 Malware attack on THDC Ltd's Tehri dam in Uttarakhand.
May 2017 ransomware attack on West Bengal State Electricity Distribution Co. Ltd (WBSEDCL).
February 2018 attack on a Rajasthan discom website.
March 2018 attack on Haryana discoms in which the commercial billing software of the highest paying industrial customers was affected.
On March 7, 2019 Venezuela was affected by the first in a series of concurrent, nation-wide blackouts.

If the nature and pattern of these attacks is analyzed, it becomes difficult to rule of the possibility of hackers/hactivists and terror organizations doing this with malicious intent.

1.2 Grid Attacks Threat Vectors

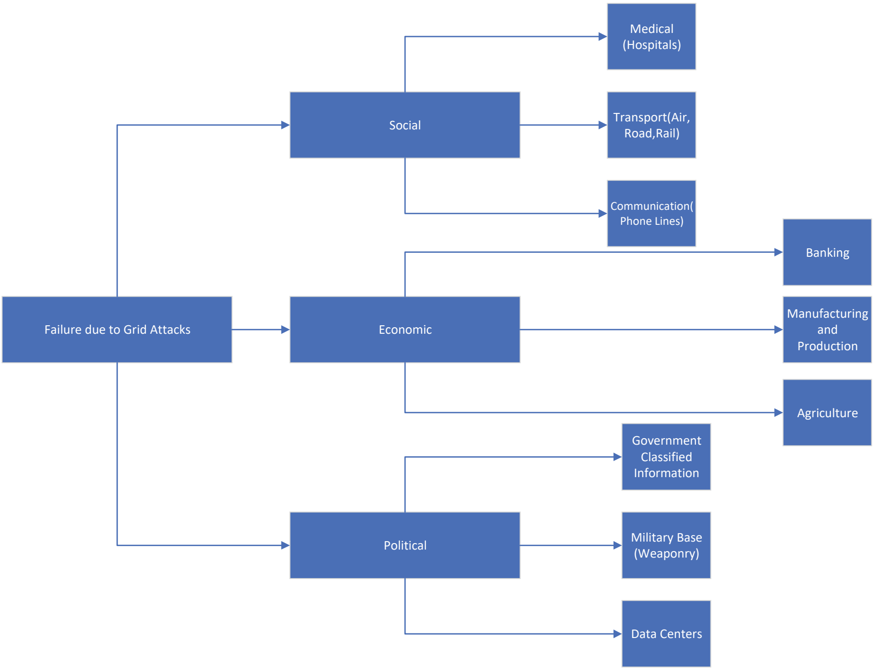
Any attack on the grid is an obvious intrusion into the Power Grid and aiming at complete chaos. The hackers can enter into the systems by using decades old tactics including but Not limited to–

(a) attacking smaller, less secure companies, like ones that make parts for generators or sell software that power plant companies use
(b) "Spearphishing"—this entails sending emails from a compromised account that the receiver trusted and had interacted with before, to get the person receiving the email to reveal confidential information
(c) Waterholing—alter websites that people in the energy industry regularly visit, so that those websites could collect information, like logins and passwords
(d) Email with attachments—having users open emails containing Control process documents which were malicious
(e) Overwhelm the Utilities Telephone Networks—the hackers are aware of whom they are hitting and hence pair it with a flood of telephone calls to overwhelm the utilities' phone networks and hamper restoration.

While all the above may Not mess the power generation in its entirety, the fact that intruders are watching and recording data from energy generation systems is enough of a concern.

1.3 Impact of Threat Vectors

The loss of power will certainly have cascading impact on the day to day work matters. The impact is not just social but extends to Political and Economic areas equally. Socially, it affects key areas like hospitals (X ray machine, ventilators), transport (rail and road), communication (phone) facilities. Lack of power would directly lead to lack of water supply exposing people to serious health hazards all in a matter of a few hours. Economically, it will cause failure of payment systems in Banking, down time of manufacturing and production resulting in huge revenue losses and heavily impact Agriculture as it is nowadays dependent on machines such as irrigation pumps for farm production. Politically, this could lead to security system to be disabled, thus affecting military bases, weaponry and classified information.



1.4 Approach to Securing the Grid—Identify What is at Stake and Plan Ahead

To secure the grid, it is first and foremost essential to Plan ahead. It needs an assessment of what is at stake, like some obvious pain areas that are susceptible to attacks on a Smart Grid as below.

- Generation Side—
  A delay in the transmission of message in case of trip protection at generation stations thus causing damage to the power equipment. Using decade old security techniques to control and operate the SCADA Systems which can be relatively easily hacked.
- Transmission Side—
  At the heart of the load dispatchers is the SCADA system and any undue infiltration at this center will put the power transmission at stake.
- Distribution Side—
  A single system has millions of conventional and smart meters responsible for power distribution. A conventional meter is susceptible to tampering using manipulation techniques. Intelligent Electronic Devices like Smart meters can be operated from distant remote locations. Thus, there is a possibility that an infiltrator can compromise this data.

Per Accenture High Performance Security research, 2016 [1], it is apparent that fewer than 40% of utilities have methods, tools and skills comparable to the highest level of performance.

RESILIENCE READINESS

27%	39%	37%
Design for protection of key assets	Maintaining resilience readiness	Cyber-incidence recovery

RESPONSE READINESS

24%	30%	38%
Ensure stakeholder Involvement	Protection and recovery of key assets	Cyber-response plan

Base: All utility respondents.
Source: High performance security research, Accenture 2016.

This means having a robust response plan, strong cyber-incident communications, tested plans for the protection and recovery of key assets and the grid, effective cyber-incident escalation paths and the ability to confirm solid stakeholder involvement are All extremely imperative.

1.5 Get the Right Support

In order to counter these threats, it is necessary for IT, OT and System operations to work together. While researching the ways to do this, one field of Science that is becoming increasingly relevant is that of Quantum Physics/Quantum computing.

Researchers at the Los Alomos National Laboratory think they have a patch: quantum-encrypted power stations. Let us look at how this can help resolve the issue in the next section.

1.6 Support: Quantum Computing for Grid Security:

Let us begin by looking at a research done in Feb-2019.

In February 2019, researchers at the Oak Bridge National Lab tested this by using lasers, electronics, and extremely sensitive detectors from Oak Ridge National Laboratory, Tennessee, down to Chattanooga. Further, these machines were integrated with a Utility Company—in this case—EPB's—unused optical fiber. Along with this equipment, a protocol known as quantum key distribution, or QKD was used to send and receive a series of numbers as a key. The QKD concept is used because of its inherent feature to prevent any tampering of numbers. The way it works is [4]: The sender beams single infrared photons oriented in different directions—polarizations—that correspond to 1 s and 0 s. A receiver measures those orientations. Then, the sender and receiver compare some of their numbers. In quantum mechanics, if you measure a photon's polarization, you instantly alter it from one state to another. If a hacker had tried to intercept the photons, they would have introduced a telltale statistical error in the numbers, and you would know that the connection was not secure. Per cybersecurity experts at the National Institute of Standards and Technology—QKD gives you the confidence that the key has not changed from when it was sent. If the statistics look good, the message between the grid nodes can be deciphered by the sender and receiver. One of the major differences between this and the conventional security method is that the latter guarantees security based on the assumption that the encryption algorithms cannot be cracked fast enough in a reasonable amount of time. The researchers think that a utility company could use quantum-encrypted data to communicate with their hardware. For someone to intercept or change a quantum-encrypted data stream, they'd have to defy quantum mechanics. This comes with its own challenges—one being deploying any new technology on the grid is difficult—the grid being a slew of interconnected devices such as transformers, switches, and sundry parts installed over various years. The other being getting the technology to work over long distances. You can send a photon only about 100 miles through fiber-optic cable before its quantum properties change too much to recover its information. In the Chattanooga demo, the physicists extended the distance by converting the quantum signal to classical bits. They then fed those classical bits into a different quantum encryption system, which could reproduce the key and transmit it farther. This means that you could put various encryption machines inside various power substations and use them as relays to secure wider swaths of the grid. In order to communicate with the substation hardware, you'd need to know what the key is. The system would prevent a hacker from measuring and duplicating the key, which is one way of keeping them from gaining access to the hardware.

1.7 Quantum Safe Encryption Implementations

As mentioned in the above section Quantum Computing research is helping beef up the Grid Security. Per Research and Markets.com Smart Grid Security market worldwide is projected to grow by US$4.8 Billion, driven by a compounded growth of 9.9%. Utility Companies are already looking at implementing Quantum Safe Encryptions. In the Sultanate of Oman, ABB is in the process of installing a high-reliability grid communications technology solution. This will protect the critical digital electrical infrastructure for the Oman Electricity Transmission Co. (OETC).

It will be among the first in the world to feature a Quantum-Safe encryption card which provides best-in-class, end-to-end encryption for mission-critical utility networks.

It uses a method that incorporates the physical properties of light to generate truly random encryption keys ensuring uncompromising real-time performance and Quantum-safe security. The secure key generation mechanism and implemented crypto-agility is termed “quantum-safe”. Crypto-agility facilitates system upgrades and evolution without having to make significant changes to the system’s infrastructure.

Companies like IDQ offer Quantum-Safe Security Solutions for Protecting Critical Infrastructure.

IDQ’s Centauris network encryption platform offers “set & forget” functionality to ensure that the encryption does not place an additional burden on the network team. In addition, state-of-the-art security features meet even the most stringent regulatory requirements. FIPS and Common Criteria level security certifications ensure both physical protection of the appliance as well as best-practice encryption key management processes and access controls.

1.8 Challenges in Quantum Encryption Implementation

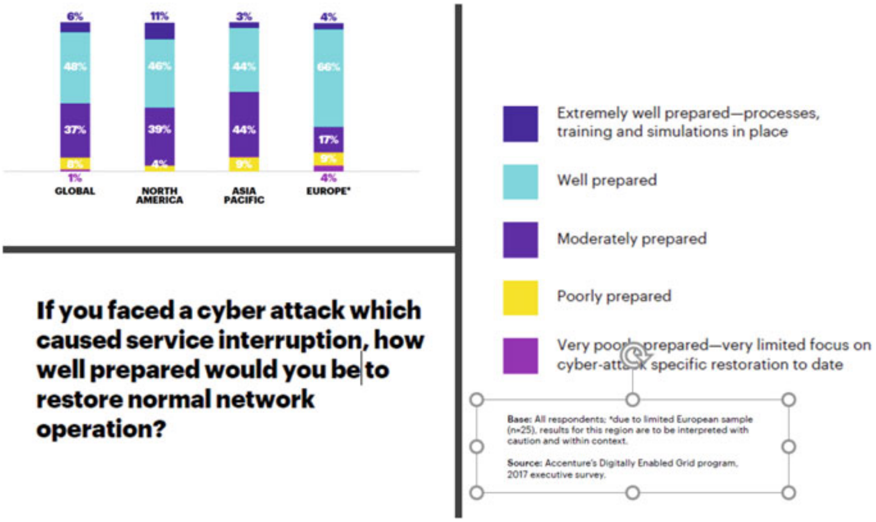
While solutions around Quantum Computing and Encryption are being researched and worked upon in full force, there are certain challenges lurking in the background. A new report on the “progress and prospects” of quantum computing put together by the National Academies of Sciences, Engineering, and Medicine (NASEM) in the US in 2019 [5] says that work should start now on putting together algorithms to counter cyber-attacks. This report highlights certain risks and challenges in implementing Quantum Cryptography. Some of the Technical risks include–

- Qubits cannot intrinsically reject noise—Quantum which works on the principle of qubits—which can be any combination of one and zero, cannot readily reject small errors (noise) that occur in physical circuits.
- Error-Free QC Requires Quantum Error Correction—Quantum Error correction algorithms are quite resource intensive.

- Large Data Inputs Cannot Be Loaded into a QC Efficiently—The amount of time needed to create the input quantum state for large inputs would typically dominate the computation time, and greatly reduce the quantum advantage.
- Quantum Algorithm Design Is Challenging—Developing Quantum algorithms leveraging interference and entanglement are challenging.
- Quantum Computers Will Need a New Software Stack—Research is needed to develop new software tools
- The Intermediate State of a Quantum Computer Cannot Be Measured Directly—A quantum state cannot simply be copied, it can bring computation to a halt.
- Despite of all these challenges, Quantum computing will have a major impact on cryptography, and hence Utility Companies and Governments cannot afford to have their classified information decrypted in the future, even if that future is 30 years away. For this reason, there is a need to begin the transition to post-quantum cryptography as soon as possible.

1.9 Resolve and Respond

The Siemens and the Ponemon Institute conducted a survey in Oct-2019 on—"Are Utilities Keeping Up with the Industrial Cyber Threat? Assessing the Operational Readiness of the Global Utilities Sector". The "Readiness" quotient in this Survey metioned that the Industry is Uneven in this area due to factors like Technical Capabilities to identify threats and internal organization failures to name a few. Accenture Digital's survey in this area also demonstrates the varying degrees of confidence [1].



Base: All respondents; *due to limited European sample (n=25), results for this region are to be interpreted with caution and within context.

Source: Accenture's Digitally Enabled Grid program, 2017 executive survey.

To counter this lack of readiness, Grid Cybersecurity must become a core industry capability, one that protects the entire value chain/extended ecosystem end to end. Developing this new capability will take continuous innovation, a practical approach to scaling, and collaboration with partners to maximize value. While there is no single path forward, every distribution company should make several steps to improve resilience and cyber-attack response. To list a few—

- Security Operations Center (SOC)
  Distribution businesses can create and leverages an SOC to provide a response based on changing threat actors.
- Leverage Experience from other Sectors
  Taking Experience from other sectors like Financial services and Retail, security should be embedded in the design requirements. Each new substation, AMI deployment, IoT device installed or smart grid deployment initiatives should have security embedded at the earliest stage.
- Simulate an Attack to improve preparedness
  Distribution companies should simulate how to manage false data streams and regain control over hijacked grid parts.
- Investigate a platform approach to cybersecurity capabilities
  Look to platform-based models and technology solutions that could help address common cybersecurity challenges.
- Share threat information
  There are likely to be common threats faced by distribution businesses. Intelligence and information sharing are vital practices that can help create situational awareness of the current risk environment. External cyber specialists could be employed to help create the situation awareness in the absence of information sharing between utilities.
- Develop security and emergency management governance models
  Each distribution business needs to consider its organizational and operational context in order to devise a cybersecurity governance model.
- Cadence with Security Governance Teams
  Regular cadence with National security and intelligence officials, private-sector cyber response and legal experts is necessary to create an effective response.

With these resilient techniques, Utilities across can develop a much stringent and proactive response to cyber threats.

As is, Utilities are extremely well versed at restorations following inclement weather or standard asset failures. Hence, there is no reason why they cannot equip themselves to identify and restore post a cyber attack. Nations and their Governments are rigorously putting together teams to conduct seamless and concentrated effort in this area. In India, the power ministry has asked all power companies to nominate a senior officer as their chief information security officer, who will coordinate cybersecurity related issues with the National Critical Information Infrastructure Protection Centre (NCIIPC) that was created under National Technical Research Organisation for taking all measures for protection of critical infrastructure in India.

NCIIPC prevents cyberattacks against critical infrastructure, minimises vulnerabilities to such threats and reduces damage and recovery time when such attacks take place.

The U.S. Department of Energy has announced awards of up to US$28 million to support the research, development, and demonstration (RD&D) of next-generation tools and technologies to improve the cybersecurity and resilience of the nation's critical energy infrastructure, including the electric grid and oil and natural gas infrastructure.

2 Conclusion

Now and in the forthcoming years as Utilities increasingly embrace emerging technologies and continue to provide their services, there is a need to work together to address challenges arising from cyber threats. To further diversify energy supply and delivery, Utilities across can collaborate in research and in integrating their efforts towards reliable and secure systems.

While Cyber attacks on the grid can be an imminent threat in a future not far from now, nation states need to tackle this beast for a "Power" ful future.

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Secured Automatic Meter Reading for Implementation of SAMAST Framework in India

Dodla Sidhartha, Lagineni Mahendra, Katta Jagan Mohan, R. K. Senthil Kumar, and B. S. Bindhumadhava

Abstract The next level of the smart grid contains essential components like advanced Interface Energy Meters (IEMs), which play a major role in SAMAST (Scheduling, Accounting, Metering and Settlement of Transactions in Electricity) implementation in India. Automatic meter reading (AMR) is one of the very important modules considered in the implementation of the SAMAST Framework in India. As per SAMAST guidelines, all IEMs data should be available at corresponding State Load Dispatch Center (SLDC) in defined periodic intervals. Various communication mediums like PLCC, Fiber Optics, VSAT, and GSM/GPRS/3G/4G are used to transfer data from substation IEMs to the control center. Communication between the IEMs and Control center is vulnerable for various attacks like Meter spoofing attack, Authentication attacks, Man-In-The-Middle (MITM) attacks, Reply attacks, De-pseudonymization attacks, etc. These attacks on communication have a cascading effect on other modules of SAMAST such as scheduling, forecasting, accounting, and deviation settlement of the transactions. The proposed solution helps to achieve high-secure data communication between IEMs and control center by retaining interoperability and also addresses various attacks by using various security suites of DLMS/COSEM High-Security mechanism without compromising the availability, integrity, and confidentiality of the data.

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Keywords Interface energy meter · Automatic meter reading · DLMS protocol · Communication security

1 Introduction

India has achieved 'One Nation—One Grid—One frequency', with this the grid reliability and management have improved significantly along with the frequency profile, but several building blocks of developed grid are yet to be put in place. One of them is Scheduling, Accounting, Metering and Settlement of Transactions (SAMAST) in electricity [1]. The electricity act on open access allows large users of power to buy cheaper power from the open market from anywhere in India instead of being forced to buy electricity from their existing electric utility monopoly. Initially, open access was limited to inter-state power transactions, now it is extended intra-state as well. This implies that load dispatch centers are required to maintain the records of open access approved energy transactions and actual physical energy flow. The physical flow of energy is measured by energy meters, those are installed at various state interface points. The metering/automatic meter reading (AMR) module of SAMAST helps to read energy flows from the interface point's energy meters. Based on scheduled data and measured data from meters, schedule deviations can be calculated, which can be used for deviation settlements. Figure 1 shows the typical infrastructure of SAMAST implementation [1, page 75]. Data Concentrator Unit (DCU) is a communication device, which collects data from substation meters and sends to the control center over OFC/GSM/GPRS/3G/4G and also executes the commands received from control center simultaneously. Figure 2 represents data flow among the SAMAST modules. Thus, Scheduling, Accounting, Metering and Settlement of Transactions in electricity (SAMAST) is indispensable as it solves the puzzle—"Who" pays to "Whom" and for "What?" [1]. Meter data is one of the very important data sources, which can be used for load forecasting [2], renewable energy forecasting, online energy accounting and transmission loss calculations, and energy scheduling [3] and deviation settlement and assessment [4]. So the need for secure and reliable meter data communication is essential in the SAMAST implementation.

The rest of the paper is organized as follows. Section 2 discusses meter communication protocols. Section 3 discusses the vulnerabilities of meter data communication protocols. Section 4 discusses the secure meter data communication for SAMAST implementation and finally, Sect. 5 ends with the conclusion.

2 Meter Data Communication Protocol

Majorly used meters in the power system are classified into 3 categories. Class A meters are used for Energy accounting and audit Metering purposes, Class B meters are used for Boundary/Bank/Ring/availability based tariff metering purposes

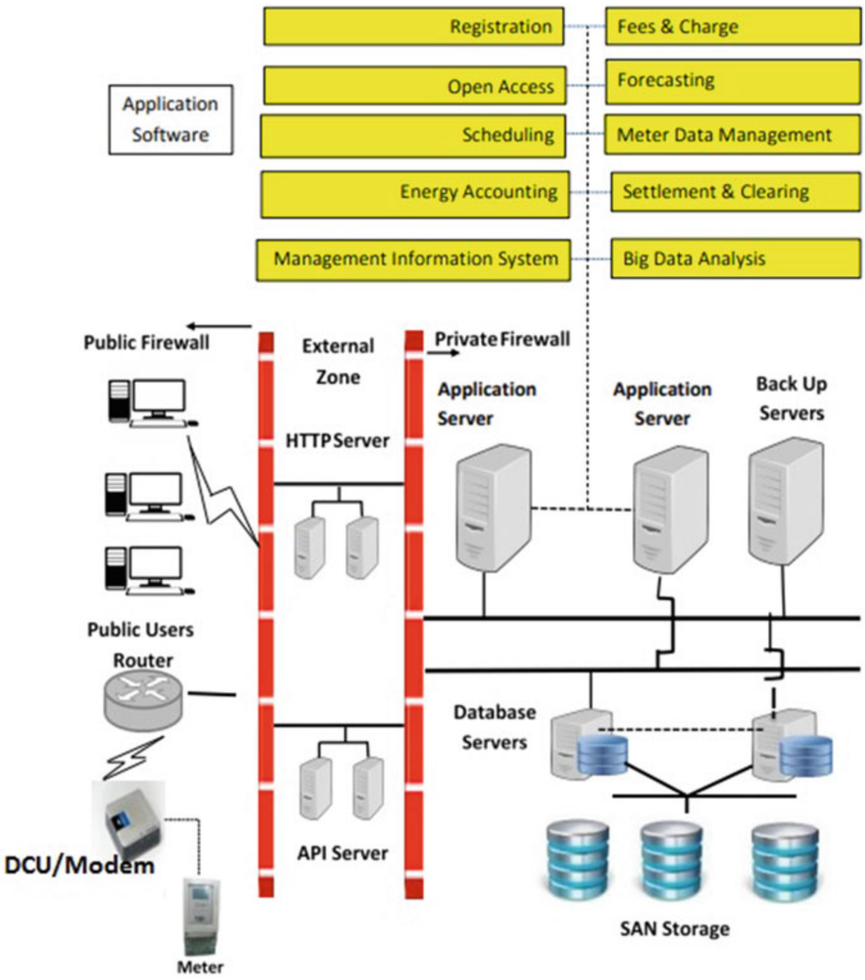


Fig. 1 Typical infrastructure of SAMAST implementation

and Class C meters are used for high voltage (HV) and low voltage (LV) consumer metering purpose [5]. Widely used open and standard meter communication protocols are MODBUS, IS 15959 and Device Language Message Specification (DLMS).

2.1 MODBUS

MODBUS is one of the widely used meter communication protocol in the Indian power sector. MODBUS [6, 7] protocol available in 2 variants based on communication mode, one MODBUS serial and another is MODBUS TCP. Instantaneous and

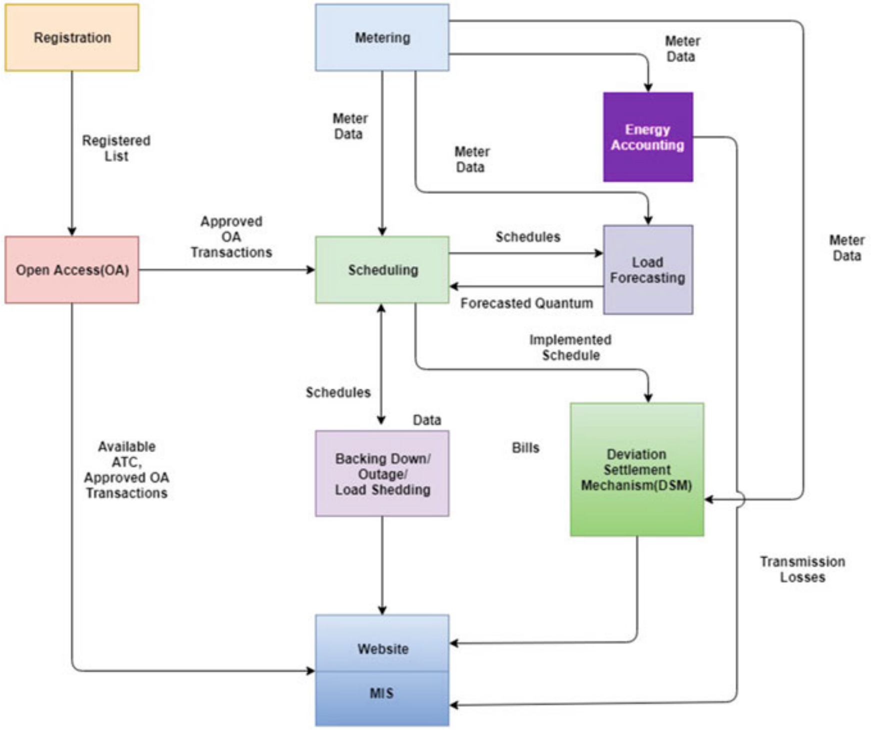


Fig. 2 SAMAST data flow diagram

load profile parameters are updated in input registers and holding registers of meter as per MODBUS standard and these parameters can be retrieved from MODBUS clients.

2.2 DLMS—Device Language Message Specifications

DLMS/COSEM (Companion Specification for Energy Metering) is an interface model and communication protocol for meter data exchange. The three-step approach (Modeling, Messaging, and Transporting) is followed in DLMS/COSEM [8]. DLMS/COSEM communication between Meter (server) and client consists of 3 phases i.e. Application association (AA) establishment, data exchange, and AA Release. During association establishment phase authentication and access right to various objects will be decided between server and client. No security, Low-Level Security and High-Level Security three different kinds of authentication mechanisms are available with various authentication levels.

3 Vulnerabilities of Meter Data Communication Protocol

3.1 MODBUS

Vulnerabilities of TCP variant of MODBUS plain text protocol [14, 16] is discussed in this section. MODBUS meter data communication is vulnerable for the attack on its

(1) *Confidentiality*: MODBUS protocol is a plain-text protocol, so it is easy to understand and intercept the meter data by an eavesdropper.
(2) *Integrity*: Attacker, who successfully launches a man-in-middle attack; with the knowledge of protocol information can modify/tamper the meter data as MODBUS is open protocol.
(3) *Authentication*: As a protocol, it has no provision of authentication mechanism, so an attacker can access meter data and also can change the time of meter using holding registers control command.

3.2 DLMS/COSEM—Server Authentication Vulnerabilities

This section discusses the Vulnerabilities of TCP variant of DLMS protocol. As per protocol, an association is the first step of meter data communication. Authentication happens during the association connection establishment phase as shown in Fig. 3 [8]. DLMS/COSEM authentication mechanisms and vulnerabilities are discussed below.

(1) *DLMS—No security authentication*: In DLMS—no security authentication mechanism, the client doesn't require any authentication for association establishment. Due to this any unauthorized client/attacker can establish association and access the meter data. But in this mechanism, the client is allowed to access only some basic information like meter details and the manufacturer details.
(2) *DLMS—Low-level security authentication*: In the Low-Level Security (LLS) of DLMS/COSEM, the server requires the client to authenticate itself by supplying the password known by the server. Here the clients provide the secret password in plain text format to the server during the association establishment. If the password is valid then the server accepts the association connection. Meter data communication can be captured using various network traffic monitoring software and can retrieve the secret password. This secret password can be used by an attacker for association establishment and meter data exchange. In another way, an attacker can gain the secret by using a brute force attack. Once the attacker gains access can get all instantaneous profile, block profile and load profile of meter and can also reset the profile data.
(3) *DLMS—High-level security authentication*: In this case, meter and client have to authenticate each other for the association establishment. This mutual

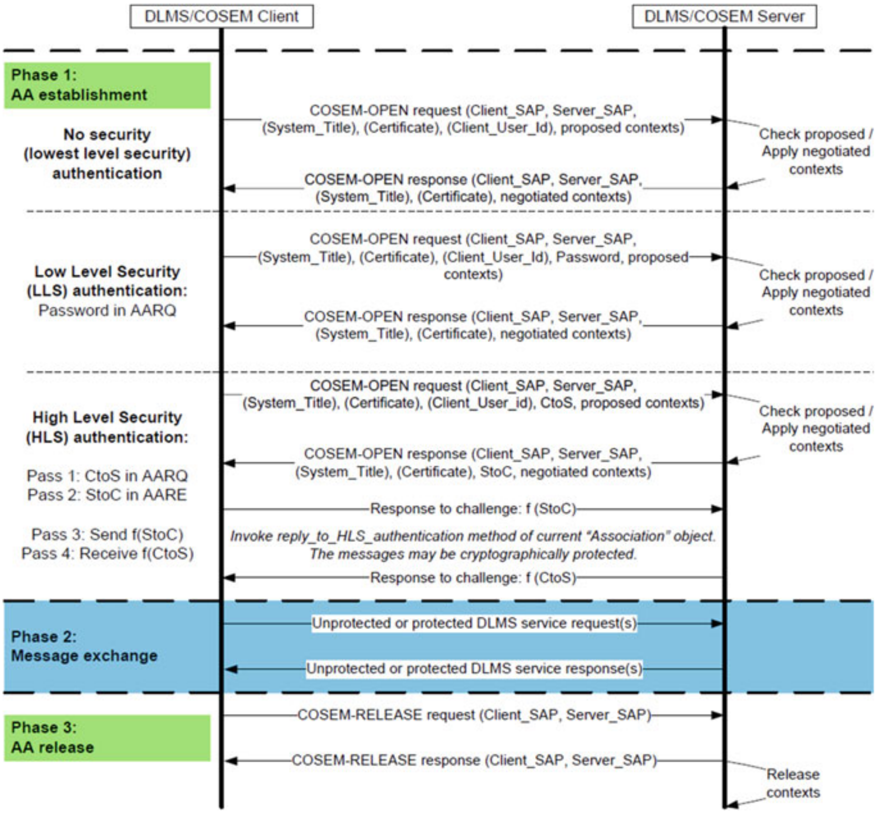


Fig. 3 DLMS/COSEM authentication mechanisms

authentication is a 4-pass challenge-response process as shown in Fig. 3 [8]. As shown in Fig. 4 attacker can authenticate himself with meter, with the help of a co-ordinated mechanism with MITM server (Man-in-Middle-attack

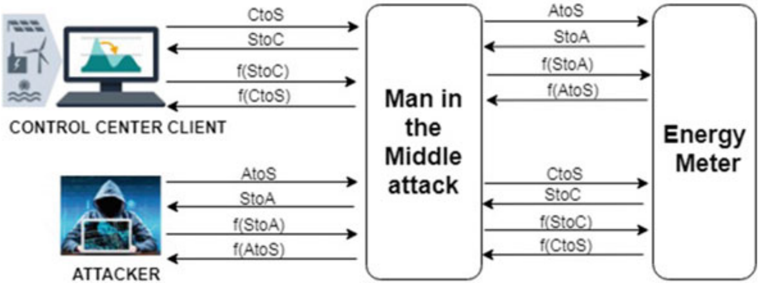


Fig. 4 Meter authentication by an attacker

system). The attacker sub-system (MITM) helps in swapping the messages of an attacker and legitimate clients during the association establishment phase.

Once the connection resets, the legitimate client loses the connection. At that time client initiates the association with challenge message (CtoS), at the same time attacker also initiates the challenge (AtoS). The attacker subsystem (MITM) swaps the challenges of an attacker and legitimate client messages and forwards to meters. As the meters also send a challenge for authentication, the MITM system swaps the meter challenge messages and forwards to the client and attacker. Similar way the client and attacker responses also swapped by MITM and forwards to the meter. Thus the attacker authenticates and the legitimate client fails in the authentication process. Once an attacker gains the access, MITM system can go out of the communication. An attacker can access all instantaneous profiles, block profiles and load profiles information and also able to tampers the meter data where an attacker can change the date-time of the meter. If wrongly sets the time by an attacker, all recorded data by meter goes meaningless.

3.3 DLMS/COSEM—Client Authentication Vulnerabilities

In this case, the attacker spoofs the meter IP and acts as a meter and can perform a replay attack based on information gathered earlier from the meter.

(1) *DLMS—no security authentication*: In DLMS—no security authentication profile, the meter doesn't require any authentication for association establishment. Due to this any unauthorized server/attacker can establish an association with the client and sends as the meter data.

(2) *DLMS—Low-level security authentication*: In DLMS low-level security authentication profile, the meter doesn't require any authentication for association establishment. The client only requires to authenticate with the server. Due to this any unauthorized server/attacker can authenticate the client without checking the secret password and can establish an association, and sends the meter data (reply) to the legitimate client.

(3) *DLMS—High-level security authentication*: The meter data is communicated to the main and backup control center, where more than one client can communicate with the meter. As shown in Fig. 5 [9, 10] attacker can authenticate by swapping the messages of client1 and client2 challenge-responses during the association establishment phase. By using this process attacker can authenticate with 2 clients for all authentications mechanisms. Once an attacker authenticates with clients acts as a meter for the clients and the attacker can send a reply attack.

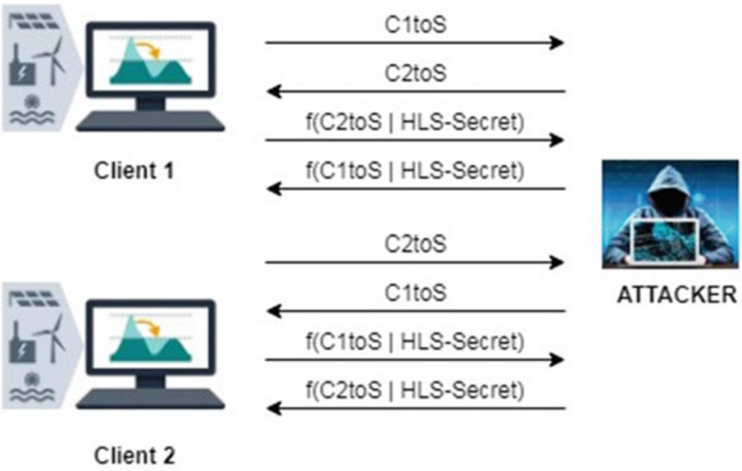


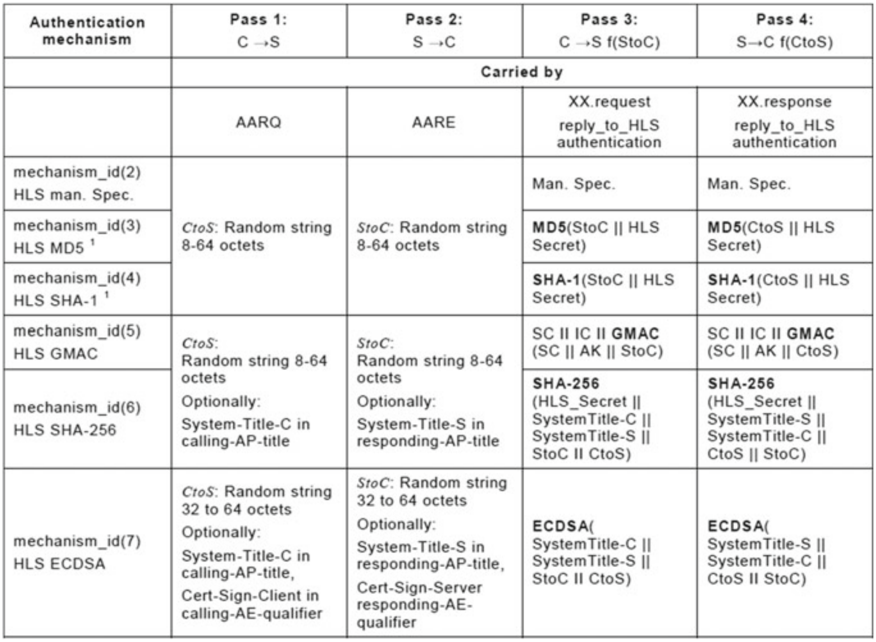
Fig. 5 Client authentication

3.4 DLMS/COSEM—Data Exchange Vulnerabilities

In the DLMS/COSEM, the application association plays an for connection establishment with meter. Here, the LLS and HLS play an important role for data accessing. In the LLS the data can be accessed by providing the secret password to the meter either by using the ciphered and non-cipher mode. In non-cipher mode, the acquired data is monitored using the network monitoring tools, where it is easy to access for the data sniffing. In the LLS if the AA is done using the ciphering mode then the xDLMS packet is ciphered using authenticated encryption with AES-GCM method, but the secret password is still kept in the plain text mode. In the case of HLS, the AA is a 4 pass model as shown in Figs. 3 and 6 where the challenge for both the client and server is passed through the first two steps where the critical information is exchanged. And in the next steps based on the security mechanism, the challenges are solved.

4 Proposed System: Secured Automatic Meter Reading System

As shown in Fig. 1, Data Concentrator Unit (DCU) plays a major role in transferring substation meter data to the control center. The meter data is majorly transferred over OFC/Wired-Internet/GSM/GPRS/3G/4G, this communication is more vulnerable for various attacks as discussed in the previous section, based on meter supporting protocol. DLMS/COSEM standard discusses majorly various authentication mechanisms no security, Low-Level Security (LLS) and High-Level Security



Authentication mechanism	Pass 1: C →S	Pass 2: S →C	Pass 3: C →S f(StoC)	Pass 4: S→C f(CtoS)
	Carried by			
	AARQ	AARE	XX.request reply_to_HLS authentication	XX.response reply_to_HLS authentication
mechanism_id(2) HLS man. Spec.	*CtoS*: Random string 8-64 octets	*StoC*: Random string 8-64 octets	Man. Spec.	Man. Spec.
mechanism_id(3) HLS MD5 [1]			**MD5**(StoC || HLS Secret)	**MD5**(CtoS || HLS Secret)
mechanism_id(4) HLS SHA-1 [1]			**SHA-1**(StoC || HLS Secret)	**SHA-1**(CtoS || HLS Secret)
mechanism_id(5) HLS GMAC	*CtoS*: Random string 8-64 octets Optionally: System-Title-C in calling-AP-title	*StoC*: Random string 8-64 octets Optionally: System-Title-S in responding-AP-title	SC II IC II **GMAC** (SC || AK || StoC)	SC II IC II **GMAC** (SC || AK || CtoS)
mechanism_id(6) HLS SHA-256			**SHA-256** (HLS_Secret || SystemTitle-C || SystemTitle-S || StoC II CtoS)	**SHA-256** (HLS_Secret || SystemTitle-S || SystemTitle-C || CtoS || StoC)
mechanism_id(7) HLS ECDSA	*CtoS*: Random string 32 to 64 octets Optionally: System-Title-C in calling-AP-title, Cert-Sign-Client in calling-AE-qualifier	*StoC*: Random string 32 to 64 octets Optionally: System-Title-S in responding-AP-title, Cert-Sign-Server responding-AE-qualifier	**ECDSA**(SystemTitle-C || SystemTitle-S || StoC II CtoS)	**ECDSA**(SystemTitle-S || SystemTitle-C || CtoS II StoC)

Fig. 6 HLS authentication mechanisms

(HLS). In HLS also 5 varieties of authentication mechanisms are available as shown in Fig. 6. Coming to the data exchange portion, in no security profile data communication is in plain text format. In LLS and HLS profile data communication can be either ciphered or without ciphered. As shown in Table 1, three security suites are available; some of these authentication mechanisms and security suites are vulnerable as discussed in previous sections. DLMS HLS Security suite-2 is strongest among all other security suites. In Proposed system as shown in Fig. 7 DCU is added with protocol conversion to protocol DLMS HLS Security Suite-2 and transport layer security.

4.1 Protocol Conversion

As shown in Fig. 7, MODBUS, No Security, LLS and HLS with different security suite meters are present at substations. Field meters protocol is converted to the DLMS security suite-2 profile, as it is strongest in DLMS versions. This module helps in meter data up linking to DLMS security suite-2 and reversely client requests are downlinking to meters appropriate protocols and suites.

Table 1 DLMS/COSEM security suites

Security suite id	Security suite name	Authenticated encryption	Digital signature	Key agreement	Hash	Key-transport	Compression
0	AES-GCM-128	AES-GCM-128	–	–	–	AES-128 key wrap	–
1	ECDH-ECDSA-AES-GCM-128-SHA-256	AES-GCM-128	ECDSA with P-256	ECDH with P-256	SHA-256	AES-128 key wrap	V.44
2	ECDH-ECDSA-AES-GCM-256-SHA-384	AES-GCM-256	ECDSA with P-384	ECDH with P-384	SHA-384	AES-256 key wrap	V.44

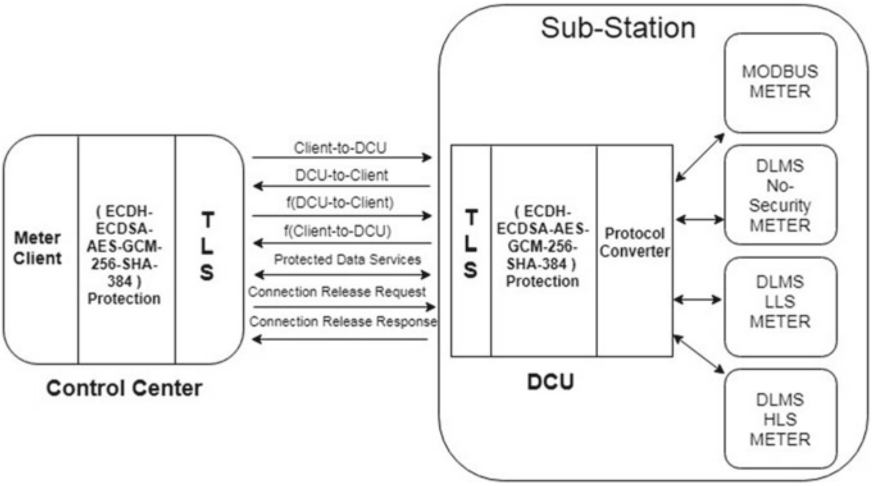


Fig. 7 Secured automatic meter reading system

4.2 DLMS Security Suite-2

DLMS Security Suite-2 provides decent secure meter communication. In Fig. 8 shows the structure of DLMS HLS security suite-2 ciphering of extended DLMS messages (APDUs) [11, 12]. As per security suite-2, authenticated encryption is based on AES-GCM-128 [11]. In Fig. 9 shows the structure of DLMS HLS security

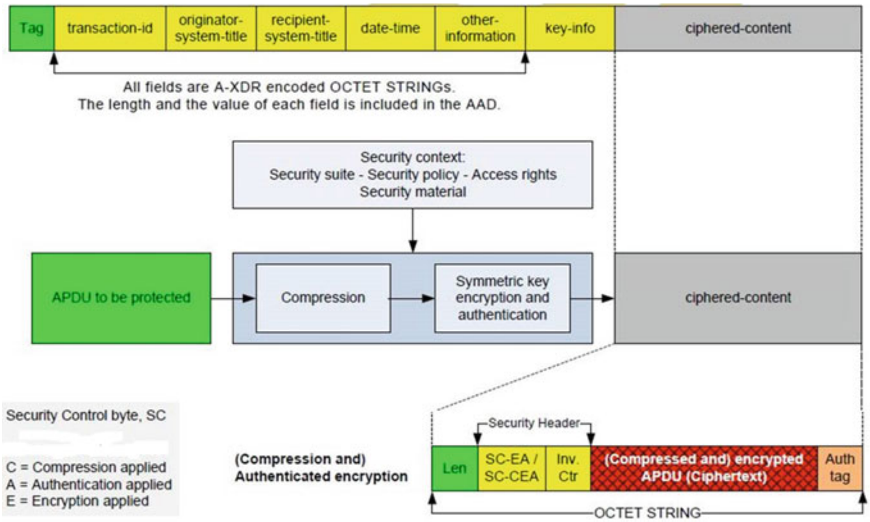


Fig. 8 Structure of HLS security suit-2 ciphering APDU

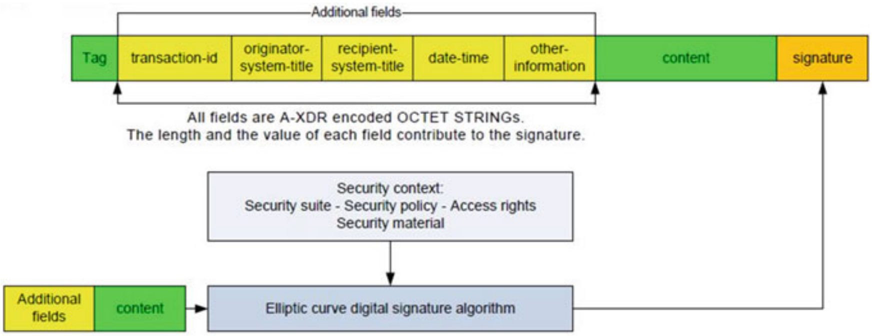


Fig. 9 Structure of ECDSA-signing APDU

suite-2 signing of messages (APDUs) [11] are using Elliptic curve digital signature (ECDSA P-384) But subparts of these messages are still in plain text vulnerable for attacks.

4.3 Transport Layer Security (TLS)

Sub-part of DLMS HLS security suite-2 messages are in plain text format. TLS [15] protocol helps in providing the extra protection layer which helps in message confidentiality, Authentication, and integrity of messages.

5 Conclusion

Automatic Meter Data Reading (AMR) plays a very important role in SAMAST implementation in India. AMR helps in efficient accounting of electrical energy injected/drawn by each stakeholder and helps to improve discipline in the grid system. Meter data used for efficient implementation of load/renewable forecasting, scheduling, energy account, and deviation settlement mechanism (DSM) calculation. So secure and reliable meter data reading plays a very important role in the efficient management of the power grid.

Widely used standard and open meter communication protocols and its vulnerabilities are discussed in this paper. The proposed system is based on protocol conversion of meter data to DLMS/COSEM HLS security suite-2 and adding extra security using transport layer security. The proposed system helps in secured meter data communication between substations and control center by retaining interoperability.

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Enedis IoT Smart Grid Solutions for More Efficiency

Laurent Karsenti and Réda Khellou

Abstract Enedis has established a smart grid roadmap in France (also called Road 22) with two main objectives to achieve by 2022:

- Modernising network management processes and infrastructure, with predictive maintenance solutions such as big data, analytics, monitoring of primary substations, and the improvement of its quality of service using new sensors, more data and smart automation.
- Providing assistance to electric power system stakeholders and regional territories in French energy transition, with innovative grid connection solutions and processes/automations for facilitating the Renewable Energy Sources integration.

This paper presents the impact of the IoT on Enedis Smart Grid Strategy, describes several IoT solutions developed by Enedis and gives some use cases based on IoT solutions. Due to smart metering (more than 23 million of Linky smart meters have been already deployed in mid-December 2019) and other connected objects, Enedis is now able to know what happens on its network in real-time.

Keywords IoT · Smart grid · LPWAN · UNB · Sensors · SAIDI · Big data

1 Introduction

Enedis has launched around ten projects concerning Internet of Things (IoT) solutions in its smart grid roadmap (cf [1]), with around a hundred of partners (and particularly start-ups) in an open innovation approach. After proofs of concept, the industrialisation of the best technical and economic solutions has been decided. Due to smart metering (35 million of Linky smart meters have been deployed at the end of 2021) and other connected objects, Enedis is able to know what happens on its

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network in real-time. Some of the IoT solutions developed, tested and deployed by Enedis are listed below:

- Linky smart meters' roll out, launched from 2015 to 2021, allows Enedis to anticipate, detect, localise and identify a wide variety of incidents on its MV and LV networks,
- Fault Indicators, using Linky communication but also LPWAN/UNB technologies such as LoRa or Sigfox, are remotely transmitted to the SCADA allowing operators to operate the network remotely and to localise the MV faults better, and hence to optimise the SAIDI,
- Flood sensors, pole sensors, lightning arresters sensors are useful to detect incidents and to operate the network better with SmartConnect* platform data.
  - *SmartConnect platform is based on open source products, and allows, with multiple protocols and networks, to collect data, enrich it, transfer this smart data to man machine interface and hence to supervise the connected objects.
- Connected gensets used for supplying customers during works or outages and communicating with the SmartConnect platform allow to optimise the genset fleet management as well as the SAIDI.

Moreover, maintenance in France is to become more predictive and adapted to each kind of equipment, based on its health index. Sensors in primary substations, with data monitoring combined to big data models will help optimise maintenance operations. Enedis has a large fleet of sub-station power transformers. To improve its reliability and minimise the downtime of these strategic grid components, Enedis has decided to deploy a large number of on-line monitoring systems in an innovative and cost effective way.

Some of the above described solutions, which are industrialised, are proposed worldwide by EDF International Networks—the subsidiary that promotes Enedis know-how and expertise abroad

2 The Technologies

Several technological factors help for a large-scale development of smart objects, especially the telecommunication infrastructure, the hardware/sensors and the software/Data analytics (see Fig. 1).

More detailed information about these different technologies will be given in the chapters below.

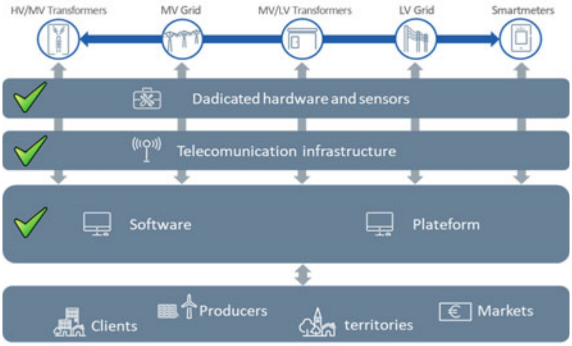


Fig. 1 Technological items for a smart grid

2.1 *Telecommunication Infrastructure*

Enedis uses new telecommunication technologies and standard that are more resilient, more robust and low cost, we will focus on:

- Power-Line Communication (PLC)

PLC has been developed to meet the industry's need for a powerline communications standard that will enable the smart grid vision. PLC facilitates high-speed, highly reliable, long-range communication over the existing powerline grid. With the ability to cross transformers, infrastructure costs are reduced and by supporting IPv6, the G3-PLC standard will support powerline communications in the future.

Enedis use G3-PLC to operate the Linky Smart Meter (see Fig. 2):

- Low-Power Wide-Area Network (LPWAN):

LPWAN is wireless technology with the characteristics such as large coverage areas, low bandwidth, possibly very small packet and application layer data sizes and long battery life operation. Thus, LPWAN has a number of benefits that are adapted to industrial communication such as power efficiency, reliability, wider deployment and cost saving.

Enedis is using two standards -LoRaWAN and Sigfox- which are both based on Ultra Narrow Band (see Fig. 3).

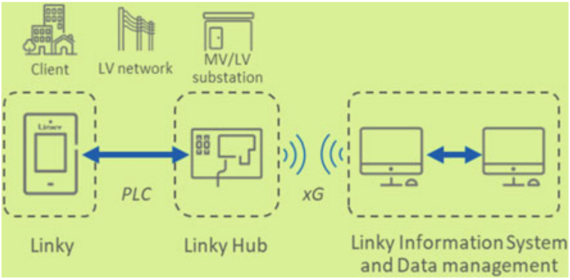


Fig. 2 Linky Smartmeter infrastructure

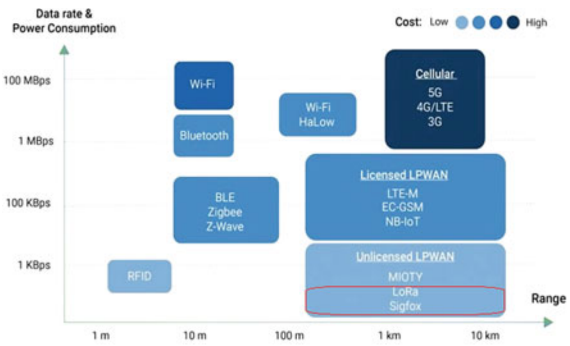


Fig. 3 Range and Data rate of different wireless technologies

Fig. 4 lightning arrester sensor, fault detector, smart genset, and flood detector

2.2 *Hardware/Sensors*

A smart device consists of with three main parts: a sensor to measure up different physical size (pressure, temperature, position, level…), a microcontroller with an embedded firmware to calculate the information and its periodicity (on event, timer…) and finally the modem to send the data on the compatible telecom network.

Enedis use different types of smart devices (see Fig. 4).

2.3 *Software*

Enedis develops SmartConnect, its dedicated connected object software platform to follow the implementation of connected objects, from Proof of Concept to industrialisation, based on open source, multi-protocol and multi-network solution.

SmartConnect aggregates the bulk of data from connected objects used by Enedis. The system consists of three technical components:

- The web interface
- The mobile app
- The server-side data treatment and service provider.

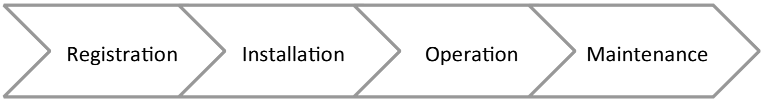


Fig. 5 SmartConnect process

SmartConnect offers software-based management of the connected objects lifecycle to its users (see Fig. 5):

- Registration

The registration phase consists of recording the object with the telecom operator (provisioning) and the SmartConnect platform through its web interface.

- Installation

Connected object installation is performed through the mobile app, enabling a technician on the field to link a connected object to the relevant electricity network infrastructure. This phase does not require any particular telecommunications or IT skills from a technician (see Fig. 6).

- Operation

Object data is generated as follows:

– Connection to operator to extract object data
– Convert object data to business information
– Business rules treatment
– Rendering of information through the web application and transfering of data to the SCADA system

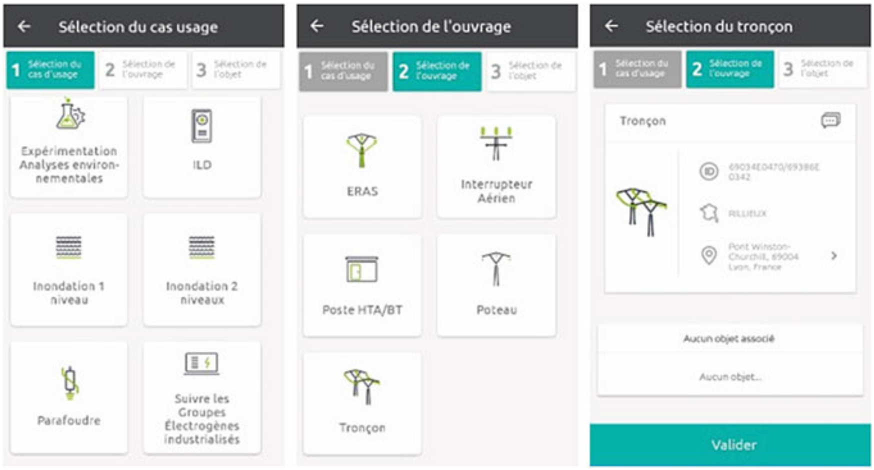


Fig. 6 SmartConnect mobile app

- Maintenance

SmartConnect implements monitoring of the communication chain to detect any object, network or system malfunction.

3 The Use Cases

In the following chapter, we will focus on some Enedis' use cases deployed in the field (cf [2–4]).

3.1 Flood Detector

The flood detector helps Enedis know if there is a risk of rising water level in a MV/LV station to plan the intervention in the field better and enhance the security of Enedis' works.

- How it works:

- For what purpose:

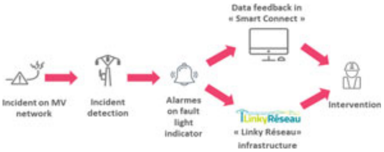
– Contribute to the safety of electrical works
– Limit the impacts of power cuts
– Facilitate the management of the crisis with external actors, by a precise communication of the operations
– Ensure better planning and mobilisation of teams to rehabilitate the structures.

3.2 *Fault Detector*

MV network operations rely on network equipment that enables supervision and control with remote signals and remote controls. Strategic points on the MV network are instrumented with fault detectors and remotely controlled switches, whose information is telesignaled. In case of an incident, this data can be used by the Control Room Operator to diagnose, locate, and isolate faulty sections of the network, in order to restore supply to the highest number of grid users within the shortest outage time. Such operations are usually performed by telecontrol automatisms. They can be complemented by manual control switch operations done by field operators with the help of non-remote fault indicators.

The new telecommunication technologies allow Enedis to make fault detectors communicating with a minimum of investment, either via IoT technologies using "SmartConnect" interface or with PLC/xG technologies with "Linky Réseau[1]" infrastructure.

- How it works:



- For what purpose:
  - A better and faster location of MV incidents
  - An optimisation of hand-operated actions
  - A reduce of cut-off time (SAIDI).

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[1] LinkyRéseau: is a set of solutions that aims to take advantage of the Linky communication network to manage the distribution networks better.

3.3 Lightning Arrester

Lightning arrester helps Enedis protect electrical equipment against high transient overvoltage and also find the fault location on the MV networks.

This device measures and analyses conduction current flowing through the earth cable, downstream from the arresters.

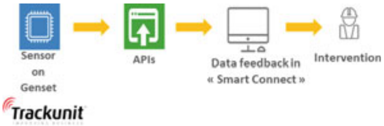
- How it works:

- For what purpose:
- Improved responsiveness by making it easier to locate faulty surge arresters
- Decrease in equipment sollicitation during faults location
- Customer perceived quality (average cut-off time).

3.4 Connected Genset

The connected Genset will allow a real-time view of its positioning and its state of operation from the local to the national mesh.

- How it works:



- For what purpose:
  - Improve the management of Genset's fleets, via their geolocation (transport, delivery, etc.) and the knowledge of their operating status (engine running, breaker position, fuel level), in scheduled work situations and during episodes of crisis
  - Optimize maintenance of Gensets, by monitoring hours of operation

3.5 HV/MV Transformers Monitoring Systems

The system is called AGATH (Appui à la Gestion Avancée des Transformateurs HTB/HTA) and is based on various sensors (pressure, temperature, hydrogen…) in order to detect anomalies, anticipate failures, and optimise their operations (cf [4]).

In the long run, the system makes it possible to go from preventive maintenance to predictive maintenance.

- How it works:

- For what purpose:
  - Reduction of the number of incidents on transformer
  - Optimisation of the life of the transformers,
  - Better knowledge of the transformers health index, in an individual as well as fleet approach,
  - Adaptation of our maintenance policy for these works.

4 Conclusion

Enedis has started the industrialisation of Smart Grid solutions, by capitalising on lessons learned from first demonstrators before the end of all demonstrators in which Enedis has participated. The French DSO is already implementing its Smart Grid roadmap through Road 22 and has rolled-out first industrialised solutions, using a three-step approach (R&D, experiments, roll-out), and in particular **IoT solutions** for better efficiency.

This approach is dynamic since the duration of each step may change from one solution to another, according to its simplicity/complexity of implementation. Moreover, new solutions may constantly appear and become part of the industrialisation process. Enedis Smart Grid roadmap has been continuously enriched by new use cases and new solutions. Among new solutions, the use of flexibility levers based on IoT sensors or equipment to solve network constraints is currently tested in local experiments.

Besides, the industrialised technical solutions constitute a pillar for smart grid offers to customers (producers, consumers, prosumers, and customers with storage).

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Voice of the Customer—What the Digital Customers Wants?

Manish Ahuja

Abstract This paper will give brief idea Companies which will target to adopt new digital ways will hold their position in the market based upon the adopting new digital tools like facebbok, twitter, you tube etc. These organisation has to train their workforce also to learn these new digital medium in this fast pace perfect competition market.

Keywords Digital customer · Transformation · Consumer behaviour · Always connected · Traditional buyer

Digital transformation is forcing companies to change their business models and adapt to the new market reality and Look the various ways to serve your customer. This Change is not driving through companies that are driven by **the customer**.

Due to busy schedule of life today, customers expect relevant content in relation to what they like related to i.e. purchase of new item, going for vacation, reading the news of particular category like political, fashion, sports etc. i.e. customised news.

It is true that for a particular human being to understand the customer expectations based upon their daily activities is not simple task since at larger scale such type of tracking and understanding the habits of requires a digital interface. So concept of "always-connected" customer, through technology to deliver customer expectations is becoming popular day by day.

In large scale of perfect competition market Voice of customer is playing a large scale role to drive the business of companies even if in monopoly companies product like electricity digital interface of customers like facebook and twitter is forcing the organisations to improve their performance standards to meet the customer requirements.

Digital interface has also helped the organisation top employee to understand the pulse of customer in a small interval of time and look for internal structure too.

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Digital transformation is the integration of digital technology into all areas of core business, resulting in fundamental changes in how a business operates, improves and give value to deliver to their customers.

Digital technology is effecting the customers upto so that even the political parties are now using same to show to customer what they have done in local areas and national level to their customer.

Digital customers who are highly engaged with the companies only wants to purchase their products and brands which they like they even do not want to shift to new competitor market product easily without using them.

Referring a product to family friends has become easy and click on the button which earlier was depend upon the physical interaction.

Digital technology has transformed consumer habits in urban areas and now it is changing same in rural areas too as mobile devices and less costly internet.

Mobile devices, apps, machine learning, automation and much more allow customers to get what they want almost exactly at the moment they need it.

Traditional buyer is changing with new buyer along with new habits of digital arena. Traditional cold calling behaviours is changing with social selling.

Now a days Instead of waiting for the customer to contact organisation, organisations are reaching to consumers building a relationship.

Traditional offline marketing activities, such as direct mail, billboards and TV ads is losing their grounds due to low response rate.

Organisations are now focusing on highly targeted messages, which can only be achieved through a data-driven marketing strategy. New digital channels like search engine marketing, account-based marketing and email marketing strategies.

Digital is about being proactive in the way to use a wide range of channels to seek out support. Social media, reviews sites, forums, and communities are all now part of the customer service eco-system.

Digital Transformation is also forcing companies to advance and train their workforce to adopt new digital ways. Adopting a digital ways means complete overhaul of company working style and pattern to deliver their results to customer.

It is proved that people like previlage service like organisations send their product and service advertisement to consumers.

- By their name,
- Its purchase history,
- Like to give feedback on their past purchases.

Consumer goods, “telecommunications”, “media” and “trade” are amongst the digital leaders and already produce a significant portion of their sales with digital products and services or through digital sales channels.

Now a days India is facing some problems like Air Pollution and water pollution /water unavailability (maximum usage of ground water) which is requiring for large scale of agriculture revolution at farmer level in India.

Apart from consumer durable industry how we can utilise digital technology to provide the basic amenities to large population of India using the concept of circular economy i.e. development and usage of product in manner which gives its optimum utilisation in environment friendly way.

Digital interface can be better utilized to make people aware about the current problems of living and its solutions which is implementable at ground level. Apart from that various govt. schemes and its proper usage may inform to all consumers so that they can be better aware about the schemes.

Technology has empowered customers to get what they want, whenever they want, and how they want it.

Those companies that can offer immediacy, personalization and accessibility to their customers will win out in the long-run.

Understanding the consumer behaviour. Previous correspondence, purchase history and their behaviour is the key to retain the consumer.

This focus on customer expectations helps to rethink business models or services to make competitive in the industry. Digital Literacy and voice of customer will play Vitol role in such models.

Till Now pvt. sector is utilising the digital media more effectively in India, government has to use this digital services to provide the various services like health care services to poor people, getting admission to children, Electricity connection to consumers, Automatic meter reading of consumers of gas and electricity meters, Sewerage cleaning services using Robert along with digital media interface, Segregating the waste, Removal of Mud from water, Revenue collection etc. as a part of Ease of Doing Business.

As a part of development of governance in rural and urban areas digital customer can play important role by providing the inputs to all utilities and govt. authority to make a peaceful environment in the country for proper growth of each human being.

Till Now in the industry consumer is looking for some services in digital arena are related to their preferences and perception but as times moves on voice of digital customer will move towards beyond their personal needs to peaceful environment of society using the concepts like circular economy.

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Mobility Solutions for Redressal of Power Failure Complaint in Mumbai Distribution

Mayank Kandpal and Mahesh Rajole

Abstract AEML is a technology-driven organization and has incorporated modern-day technologies in its day to day processes to reinforce customer satisfaction. Communication technology like Mobile phones has evolved to be smart computers (smartphones) supporting a wide range of information services that can be accessed anytime and from anywhere. Smartphone has revolutionized the way we eat, shop and travel. As part of Digital transformation, AEML has introduced a GIS-based Android application for the field crew to minimize power outage duration and a new alternative to the traditional way of outage management. In this paper, we discuss the use of GIS-based mobile application for expeditious redressal of consumer's power failure complaints. Complaints are auto-assigned to respective field crew as per their attending area and geographical location. Mobile Application facilitates field crew with the shortest possible route to reach the predicted abnormality location. After site investigation, real-time abnormality details are updated by the field crew. The Use of a mobile application increases the productivity of our crew by providing a holistic view of consumer power failure complaints. Also, real-time updation of complaints ensures the correctness of abnormality related details for further data analysis.

Keywords Mobile technology · GIS · Data acquisition

1 Introduction

Adani Electricity Mumbai Limited (AEML) serves over 3 million consumers spread across 400 km^2. in Mumbai and its suburbs meeting close to 2000 MW of power demand with 99.99% reliability, which is among the highest in the country. AEML provides excellent customer care services with the help of advanced technologies.

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In case of any power outage immediate supply restoration is a prime responsibility of utility. We are ready with a risk management plan to face any abnormalities.

Whenever there is a power interruption consumers can lodge a complaint at AEML call center using a toll-free number.

To handle the inflow of consumer complaints we have 18 complaint handling centers at strategic locations manned with shift-engineers 24 * 7, 365 days. Shift-Engineer at these locations manages complaints registered at Call center through Outage Management system (OMS) Software. Scrutinize complaint and pass on to Complaint attending field crew (Fuseman) for site investigation and resolution.

2 Complaint Attending Legacy Process

A. *Shift-Engineer role*

1. Shift-Engineer receive No Supply Consumer Complaint in OMS
2. Shift-Engineer segregates complaint region-wise, assigns complaints in OMS and passes complaint details to fuseman.
3. After the complaint is attended, fuseman informs shift-engineer all the relevant details regarding abnormity. Shift-engineer enters the information manually in the Outage Management System (OMS).

B. *Fuseman role*

1. Fuseman receives a complaint from shift-engineer over mobile or through print out.
2. Fuseman note down complainant address, telephone number, and type of complaint.
3. Fuseman visit site, identify the problem, restore supply wherever possible and report the abnormality details to shift-engineer over the phone or in-person

3 Drawback of Legacy Process

1. It takes time to segregate complaint region wise and assigning to respective fuseman.
2. Interruption to fuseman while attending complaints or driving vehicle when a shift engineer calls for passing complaints.
3. While on-site it is difficult for fuseman to note down complainant address and other required details.
4. It is inconvenient to note down the complaint details, during the monsoon season.
5. Locating the complainant address is difficult.
6. Tracing of electric feeding becomes difficult for fuseman in new areas.

7. Shift engineer calls for follow up for already given complaints that interrupt fuseman's activity.
8. No real-time mechanism for report punching, shift-engineer has to punch reports manually.

4 Solution Devised

To overcome the challenges of the legacy system we devised Smartphone-based **OMS Mobile Application** for management of No supply consumer complaints.

Fuseman will be equipped with OMS APP enabled smartphones for attending complaints.

OMS App will acquire input from OMS Desktop client for consumer complaints, the same will be viewed by fuseman and updation in OMS App will be reflected in OMS desktop software.

The system will auto-assign complaint directly to OMS App as per their respective region, the details of the complaints can be viewed by fuseman along with network/route details. This would reduce assign time and minimize navigation time.

After attending the complaint, fuseman will directly punch the report in OMS App, the same will be updated in OMS Desktop software and readily available for any further query.

Manual intervention will be minimized as all the updates will be directly done on Oms App. Also, there is functionality to capture the signature of a consumer on the OMS app for any future reference.

5 Development of Solution

For successful implementation of mobile application following strategies were implemented

1. Existing GIS Region bifurcation
2. Auto assigning Logic
3. Offline Working of App

1. *Existing GIS Region bifurcation*

In the legacy process, Shift-Engineer segregates the complaint and assigns it to respective Fuseman. This is a very time-consuming task. To facilitate the App to auto-assign as per Fuseman region we have bifurcated the existing region (Fig. 1).

2. *Auto assigning Logic*

The regions were bifurcated as per fuseman Complaint attending area.

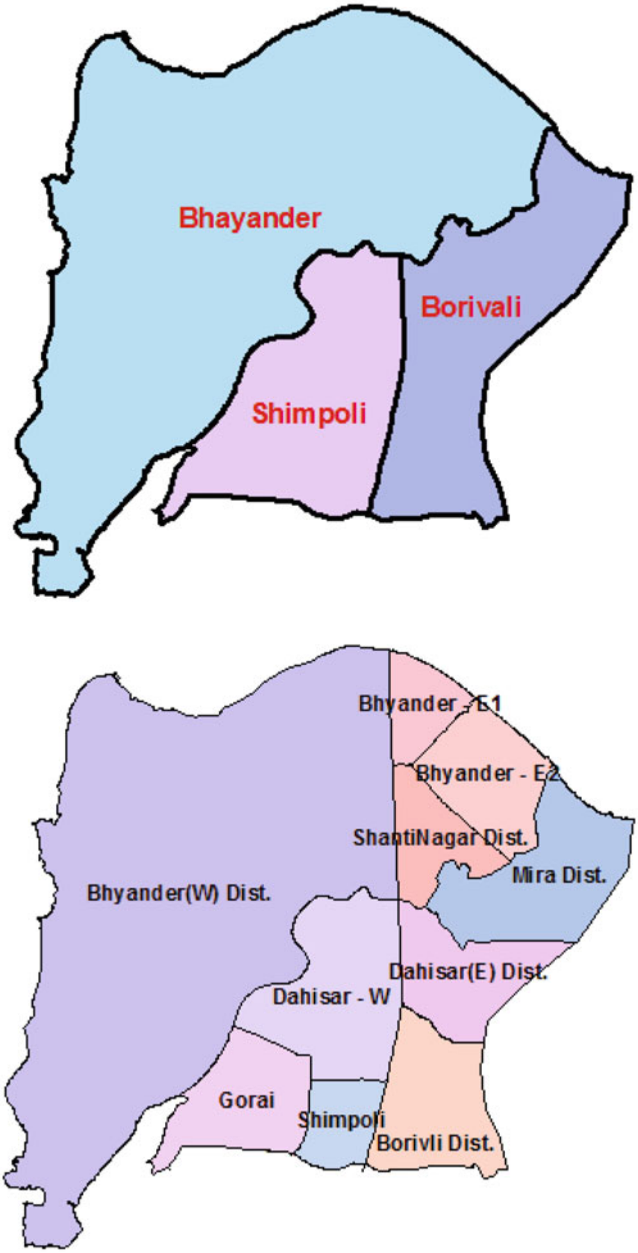


Fig. 1 Sample division region bifurcation before and after

During the normal period one region is allocated to one fuseman, but during Monsoon season due to higher complaint load one region might have multiple fuseman.

Also, during the winter season, there is a provision in app by which, multiple regions can be looked after by one fuseman.

The following scenario will arise for Auto assigning of complaint.

A. *Single Login in one or Multiple regions*

  (a) Fuseman will select region while login (one or multiple regions). The same can be viewed by shift-Engineer in OMS desktop client.
  (b) In order to know the location of fuseman, functionality to Auto turn-on GPS while starting the app is incorporated. If GPS is turned off manually, various features of the mobile App will not work as desired.
  (c) After the complaint is assigned by fuseman in app same will be reflected in a Shift-Engineer portal.
  (d) Only one complaint at a time can be assigned by Fuseman.

B. *Multiple logins in one region*

  i. Assign of a new complaint
  If in a region
  Total no of $(FM_i) > 1$
  $C(FM_1)_2 > C(FM_2)_2$
  then the complaint will be assigned to $\mathbf{C(FM_2)_2}$
  Where:
  FM_i = ith Fuseman in a Region
  $C(FM_i)$ = Complaint count of ith Fuseman
  $C(FM_i)_n$ = Complaint count of ith Fuseman for n previous days.
  ii. When First fuseman (FM_1) is logged in with one Complaint assigned to him plus additional complaints already available in his mobile app, and suppose if Second Fuseman (FM_2) logs in the same region, **reshuffling** of the existing complaints available with FM_1 will be done between FM_1 & FM_2 (reshuffling logic explained below)
  iii. Reshuffling logic
  Logic is devised considering buffer area of Fuseman and complaints.

Buffer Definition

If the complaint is assigned to FM, then Area “A” with center “C” is considered as a buffer.

If the complaint is not assigned to FM, then fuseman location “F” is considered as the center for Buffer area “A” (Fig. 2).

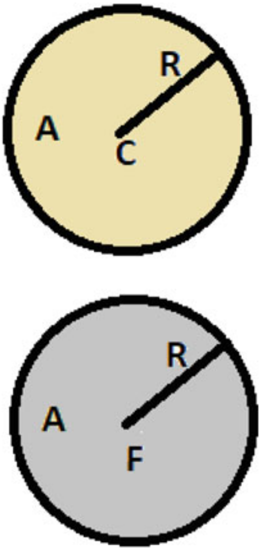


Fig. 2 Buffer area for assigned and non assigned complaint

Where C = Assigned-complaint location
R = radius of buffer
A = Buffer area with center C and radius R
F = Fuseman location in case no complaiant assingned to him

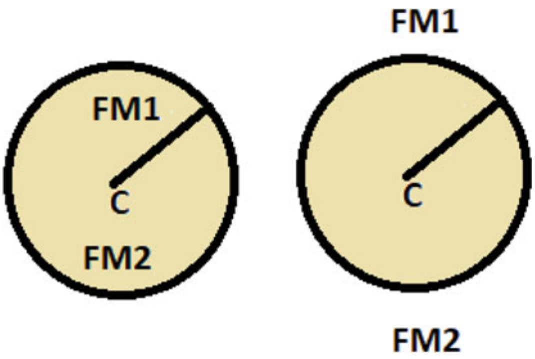
Following is the logic for reshuffling

(a) Check new created complaints in the buffer (say buffer with R = 250 m) of the crew assigned complaint of FM_1. Number of Complaints not in FM_1 assigned -complaint-buffer passes to FM_2.
(b) If all complaints in FM_1 buffer, no reshuffling.
(c) If newly created complaints are not in the buffer of crew assigned complaint in FM_1, check newly created complaints in the buffer of FM_2.
(d) If all complaints in FM_2 buffer, pass created complaints to FM_2.
(e) If newly created complaints are not in the buffer of the crew assigned complaint both in FM_1 and FM_2 location, then check created complaints of FM_1 in FIFO (based on registration time).
(f) Calculate the distance of each created complaint from the location of FM_1 and FM_2. The created complaint will pass to the nearest (minimum distance) FM.

iv. New **complaints** registered post reshuffling activity:

  (a) If a complaint is in the buffer of both FM_1 and FM_2 (as shown in left side Fig. 3) or, if complaint is not in the buffer of both FM_1 and FM_2 (as shown in right side figure above), then FM Count Threshold (CT) will be checked for passing new incident.

Fig. 3 Multiple fuseman within and outside buffer area



Where
CT = Count threshold
Predefined (CT) = CT defined manually to check logic
$CT = |C(FM_i) - C(FM_{i+1})|$
then the threshold will be met when
CT >= Predefined CT
Then New complaint will be passed to FM with fewer numbers of Complaints
Else If
CT < predefined CT
consider FM nearest to the Complaint

(b) e.g 1:
Predefined (CT) = 4
$C(FM_1) = 12$
$C(FM_{2)} = 17$
CT = 12 − 17 = 5 >= 0.4 (predefined CT)
then
New complaint will be passed to FM_1 (as he has fewer numbers of Complaints).
e.g 2:
Predefined (CT) = 4
$C(FM_1) = 17$
$C(FM_{2)} = 16$
CT = 17 − 16 = 1 < 0.4 (predefined CT)
then consider nearest FM, based on Complaint location and FM location

(c) **Note**: Count Threshold (CT) criteria will be overridden by Distance Threshold (DT) criteria in case the distance of FM with fewer Complaints is more than certain pre-defined distance limit.

(d) **Distance threshold (DT)**
Predefined(DT) = DT defined manually to check logic
$DT = |D(FM_i) - D(FM_{i+1})|$
Where

$D(FM_i)$ = Distance of ith FM from New complaint
e.g.
Predefined (DT) = 1000
$D(FM_1) = 400$
$D(FM_1) = 1500$
DT = 1500 – 400 = 1100 >= 1000 (predefined DT)
Then pass complaint to FM nearest to complaint

v. If coordinates of the supply point of the consumers are not found in GIS, then this type of complaints are defined as **location call**. Location calls will be passed to FM with minimum complaints.

3. Offline Working of App

After attending a complaint Fuseman will input the defect details in OMS APP e.g. for Main Line network fault: Feeding substation, Feeding Pillar, Feeding Circuit, Cable Size, Fault type, etc. details are available in the dropdown list.

For this, seamless data connectivity is required.

Data network is the heart of the OMS app. In the absence of proper data network, complaints cannot be updated in the OMS App. To overcome this drawback, we developed offline APP. With the offline app in case of no data network, all the required fault details are stored in mobile locally and when the network connectivity resumes all the details get updated in the central server. As we can see from Fig. 4 App penetration increased drastically after offline implementation.

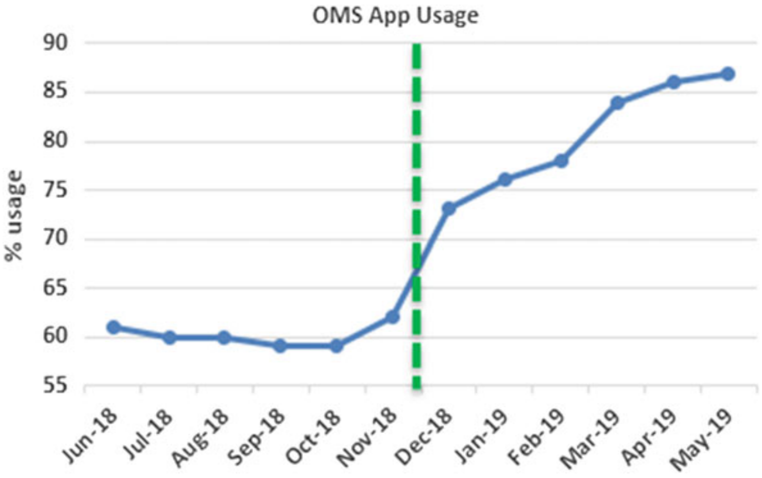


Fig. 4 Usage statistics before and after Offline implementation (offline feature was introduced on Dec 2018)

6 Benefits

1. Connects the shift engineer and the fuseman with collaborative mobile tools, that improve the experience for everyone.
2. Shift Engineers benefit from real-time updation of fault on the field, while the crew receives complaint notifications across multiple regions with the elimination of administrative paperwork and easy access to the information, they need to do their jobs.
3. Complaints details will be displayed in a similar fashion as they are on the complaint form.
4. Data validation is incorporated in the OMS App to avoid any error.
5. No need to carry a complaint form to write complaint details.
6. Complaint form getting wet during monsoon will be avoided.
7. Fuseman can select the complaints from the list, to see the details of the complaints to be attended.
8. Linesman can call the consumer, directly from OMS Mobile Application.
9. Facility is available to find the location of the consumer and to trace Electric feeding on OMS Mobile Application using GIS.
10. Shift engineer follow up calls will be reduced and no need to write or remember a report of a complaint.

7 Conclusion

Implementation of mobility solutions in the service sector will improve the efficiency of the service provider. Adoption of new technology enhance consumer satisfaction by minimizing redressal time.

Blockchain Technology Application to DER-Implementation Strategy for India

Madan Sachdeva and Narendra Singh Sodha

Abstract Government of India (GoI) is encouraging development of Micro Grids with Distributed Energy Resources. Consumers are becoming 'Prosumers' by generating electricity locally with an option of feeding it back to the Grid. ICT & Automation Systems implementation in Power Distribution Sector is now moving fast. Conventional & RE players are performing numerous energy transactions (public, private & prosumers) which are cumbersome and complex. Under such scenarios, Blockchain based systems allow for parties to transact directly and instantaneously among themselves, with transactions secured by a cryptographic verification process making visible all energy transactions open to its members affording clear visibility & certification of each transaction at market rate. These transactions on "blockchain" ledger of each participant in the system holds and identical & immutable copy. Blockchain in Energy System is still at infancy and development of improved platforms is progressing. Blockchain enabled peer-to-peer (P2P) trading of Renewable Energy in the city allowing both Utilities and Consumers to produce and sell electricity is required in India. This paper intends discussion on induction of Blockchain in DER globally including Pilot projects with a Microgrid in Israel and a Grid operator in Cyprus with viewpoints of international experts. Strategy to introduce Blockchain Technology in DER, which is still at infancy stage in India, shall be discussed.

Keywords Prosumers · P2P · Microgrids · Blockchain · DER · Blockchain ledger · User Cases

1 Introduction

Emerging Technologies i.e. Internet of Things (IoT), automation, Virtual reality and Artificial Intelligence (AI), Machine learnings (ML), cloud platforms, advance analytics, etc. call for transformation of current enabling environment for global

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environment management and this also calls for protective collaboration among policymakers, Regulators, scientists, engineers, civil society, technology experts and investors. The 'Fourth Industrial Revolution for the Earth series' Project [1] looks at Blockchain and the Planet in addition to its earlier contribution towards 'Transforming ocean management', 'enable sustainable cities and 'build an inclusive bioeconomy that preserves biodiversity', as well as examining how AI &ML could be harnessed to address economic, social and governance challenges related to Earth systems. Blockchain could be a real game changer for 'blended finance' investment in projects seeking to deliver the UN's.

Sustainable Development Goals. A platform could efficiently facilitate the complexity of such transactions where different types of funding, traditional and nontraditional assets, and multiple stakeholders with multiple requirements are involved.

FICCI, India [2] Report envisions Blockchain as the next innovation to make Indian City Smarts. The Report further explore multiple uses of the blockchain technology in the smart city domain and explains the prerequisites for the adoption of a blockchain-based solution and the way forward.

2019 Annual Global Power & Energy Blockchain Conference [3] deliberated blockchain role by Peers involved in the planning and implementation from US, Canada and Overseas in transformation currently underway in the Utility Industry of Blockchain technology to solve over a dozen different problems and new opportunities.Blockchain applications and platforms are becoming widely known, starting with Bitcoin, which pioneered cryptocurrency (and crypto-assets), followed by Ethereum, which as a platform for building decentralized applications through smart contracts has inspired a whole new 'token economy.' Seven more crypto currency are in vogue. The emergence of applications in voting, digital identity, financing and health and emerging Environment and DER illustrate how blockchain can potentially be used to address global challenges and offer potential to support global efforts to advance environmental sustainability.

2 Blockchain

2.1 What Is Blockchain

Blockchain—A revolutionary and highly disruptive technology for future energy transactions. As an 'Emerging Technology' of on-going 4th Industrial Revolution, has its features viz. distributed and immutable ledger and advanced cryptography, which enable the transfer of a range of assets among parties securely and inexpensively without third-party intermediaries. It is also democratized by design (unlike the platform companies of today's internet) allowing participants in the network to own a piece of the network by hosting a node (a device on the blockchain). Blockchain more than just a tool to enable digital currencies, at its most fundamental level, is a new decentralized and global computational infrastructure that could transform many existing processes in business, governance and society. This architecture can be harnessed to facilitate P2P payments, manage records, track physical objects and transfer value via smart contracts.

2.2 Eminent Players Across Blockchain Technology in Energy Market [4]

Infosys limited, Power Ledger, Accenture, Drift, Alliander, Grid Singularity, SAP, Oracle, Grid+, Greeneum, LO3 Energy, Conjoule GmbH, WePower, EnergiMine, Sun Exchange, Solar Coin, Vector, Komgo (Switzerland based alliance), Energy Web Foundation (EWF) (RMI+ Austria based Blockchain start up Grid Singularity) etc.

2.3 Emerging Blockchain Game Changers

(i) See-through supply chains
(ii) Decentralized and sustainable resource management
(iii) Raising new sources of sustainable finance
(iv) Incentivizing circular economies
(v) Transforming carbon (and other environmental) markets
(vi) Next-gen sustainability monitoring, reporting and verification
(vii) Automatic disaster preparedness and humanitarian relief
(viii) Earth-management platforms
(ix) Regulatory reporting and compliance.

2.4 Global Initiatives in Harvesting Blockchain and Use Cases

2.4.1 Global Initiatives in Harvesting Blockchain

Jerry Wall [5]. The Cyber Space Management Bureau, China's cyber-related regulatory agency, as per their notification of March 30 released a list containing 197 (viz. IT Cos Tencent, Alibaba, and Baidu: financial institutions China Zheshang Bank and insurance company Ping An), approved blockchain registered service providers. This list included two virtual currency projects viz. VeChain (VET),crypto project focusing on blockchain-enabled supply chain management services and ParcelX (GPX), crypto-based parcel delivery service for operation commercially within China.

EWF [6] has been established to bring together the energy and blockchain community. EWF with its nearly 100 affiliates viz 'Iberdrola', 'Total' and German utility 'EnBW' provide an open source and scalable blockchain platform designed especially for the operational, regulatory and market requirements of the energy industry and help develop relevant applications and serve as influential mediums to thrust this emerging tech towards full-scale deployment. The initiative is expected to fuel the growth of not only inter-trading main players, viz. 'Ledger', a specialist in security & infrastructure solutions and blockchain applications, to develop blockchain for energy market solutions.

Deloitte [7] has prototyped a platform suitable to support the entire end-to-end process with a digital ledger technology such as blockchain, which provides the real-time speed and efficiency, tamper-proof reliability, traceability, and transparency to allow companies to share information on a common platform without fear of having their sensitive business-critical information compromised. Such a platform could become even more important as connected devices are increasingly used to capture real-time data and artificial intelligence predicts and reacts to demand all without the need for human interaction. It is also engaged in proto typing for a blockchain based regulatory platform.

Blockchain [8] Swiss Bank UBS teamed up with German power company Innogy (RWE) and automotive technology company ZF, in 2016, to create Blockchain-based 'eWallets' for electric cars that will enable car owners to pay on-the-go for EV charging, parking fees, toll fees and receive car-sharing fees in the evolving sharing economy. In early 2017, Innogy partnered with California based 'the Oxygen Initiative' to roll out the technology.

Blockchain [8] BTL, in 2017 in Austria, launched a pilot with Wien Energie for Whole Sale trading with two other utilities. Similarly, Qiwi, a Russian payment system operator launched a pilot to track energy transactions using Blockchain technology in partnership with Tavrida Electric.

Chilean National Energy Commission (CNE) [9], in April 2018, announced having launched a blockchain focused on energy and Govt Dept. to use Ethereum blockchain to record, store and track energy data with a view to avoid intentional manipulation or unintentional mistakes/presentation and make the transparency of public blockchain to reduce chances for monetary or data exploitation.

WPED Contributor et al. [11], In Germany, Blockchain based Energy platform-Swytch, as a part of large scale pilot program aims to distribute approx.3.5GW of wind, solar hydro and biogas power capacity enough to power over half a million homes, working between energy companies but also among consumers and at microgrid levels.

Danahy et al. [12], For grid balancing, London-based energy tech company 'Electron' has been awarded substantial funding from the UK's Energy Entrepreneurs Fund to demonstrate blockchain capability to transform the market for electricity-grid balancing. Electron's platform leverages blockchain technology allows multiple parties to co-ordinate and share the value of a single consumer's action.

Danahy et al. [12], ‘Verv’, a home energy assistant, in UK, claimed 1st launch of a blockchain-powered P2P energy trading pilot at a housing estate (40 participating flats) in Hackney, London including community battery storage for storage, sharing and trading of energy. The project supported thru government grant funding to support UK industry regulator Ofgem, which is currently researching the potential for blockchain within its “regulatory sandbox” (a platform allows innovators to trial innovative business propositions that will benefit consumers without being subject to all of the usual regulatory requirements).

Colthorpe [13], TEPCO, Japan launched TRENDE-next Generation P2P Electricity system in May, 19 in conjunction with Toyota and University of Tokyo using a blockchain ledger to trade electricity from homes, business and EVs, all connected to local grid. The capacity and real-time energy exchange markets are expected to open in 2020.

2.5 Global Blockchain Use Cases

BAS Nederland was the first energy company in the world to accept bitcoin bill payment in 2014 followed by ‘Enercity’ in Hannover, ‘Elegant’ in Belgium and ‘Marubeni’ in Japan. Bankymoon in South Africa launched a social innovation project that enables anyone to “send” electricity, water and gas to anybody else in the world, from anywhere, by topping their utility meters [8].

First blockchain-enabled community microgrid (Trans Active Grid-5 homes on either side of President Street) allowing energy transactions among each other took place in April 2016 in Brooklyn, New York [8, 12]

Deshmukh [6], Greeneum blockchain powered sustainable platform thru one of EWF affiliate has displayed the ability of blockchain technology to promote the investment in renewables by global contributors confirming ongoing pilot projects with a microgrid in Israel and with a grid operator in Cyprus.

Sun Exchange, in South Africa, connects investors to businesses and communities who need access to affordable electricity [8].

Wanxiang, in China, is planning to invest $30billion in a Blockchain backed Smart City Project [8].

Power Ledger, startup in Perth, Australia, is working on multiple projects across the region [8].

Vandebron, in Netherlands, in a pilot project to work with customers owning EV to make the capacity of their car batteries available to help the grid operator balance the grid while protecting the battery life. The Blockchain will enable each car to participate by recording its availability and action in response to signals from the grid operator [8]

Enedis (In 2017) working with the French start-up Sunchain and the Depart. Council of Pyrénées-Orientales, launched one of the first P2P energy sharing projects in France. The project, DIGISOL, explored the use of blockchain technology to share solar energy between individuals within the same building (collective autoconsumption) [10].

Electrify (Sept 2019)—Singapore-based retail electricity marketplace [14] launched a pilot to test the commercialization of its blockchain-enabled P2P trading of renewable energy in the city, which allows participation both utilities and prosumers to produce & sell electricity and many more.

Start-up ME SOLshare is developing Blockchain platform connecting homes to trade excess energy from rooftop solar panels in Bangladesh [15].

2.6 Blockchain Harvesting in India

Economic Times [16], Though the Panel under 'The Committee of2nd Nov.2017 under Economic Affairs Secretary (Chairman) with Secretary (Electronics and IT Ministry), Chairman (SEBI) and Deputy Governor (RBI) as its members to study the issues related to virtual currencies, etc. in its draft report on private cryptocurrencies, given the risks associated with them and volatility in their prices, recommended banning them and imposing fines and penalties for carrying on of any activity connected with them in India yet mentioned as virtual currencies & its underlying technologies are still evolving, the committee has proposed setting up of a Standing Committee to review the issues as and when required. Finance Ministry Statement highlighted the positive aspect of applications of distributed-ledger technology (DLT) in India especially in financial services.

Nasscom has come forward to engage with the GOI in convincing them how DLT is of use to India to improve transparency and infuse Regulation cryptocurrency instead of total ban.

FICCI, India [7] Report envisions Blockchain as the next innovation to make Indian City Smarts. The Report further explore multiple uses of the blockchain technology in the smart city domain and explains the prerequisites for the adoption of a blockchain-based solution and the way forward.

UMA GUPTA [17], Amtronics of Qamronics India (Amtronics India and the State-owned Assam Electronics Development Corp Ltd., AMTRON) announced that Assam Tech City Facility in a joint venture with US Quantum Materials Corp's (QMC) technology to develop, manufacture and commercialize quantum dots is likely to begin producing quantum dots in Q1, 2020 as also Assam facility will develop thin film and quantum dot solar cells, solid state LED Lighting, etc., QMC intends to upgrade the reactors at Tech City to connect them to its.

QDX Ledger blockchain platform embedded with anti-counterfeit applications. This will allow the volume of quantum dot production, which is expected to be higher than originally budgeted, to be monitored and appropriate royalties recovered.

Impact PPA has mentioned be in dialogue with GOI (Indian Minister of Small and Medium Enterprises) to set up the Project 'Harit Khadi' for providing the renewable energy generation and blockchain technology (Power Ledger-Distributed Ledger

Technology Platform) to create more jobs thru restarting the Cotton Process industries deploying sizeable women work force. Tangirala [18] mentioned that tools for accessing Impact PPA platform (Ethereum based technology) are open and available for any project anywhere in the world.

Bester [19] More than 15 cryptocurrency operating in the country and over US$3.5 billion invested in India and an estimated 5million traders have invested in cryptocurrency and blockchain via regulated banking channels.

3 Standards on Blockchain

3.1. In December 2018, the French Accounting Standards Authority established a regulation that defines the accounting rules applicable to Initial Coin Offerings (ICO; a highly popular approach to raise capital in the blockchain space) issuers, ICO investors, and organizations that hold any type of crypto currency or crypto-asset. However, several issues such as intellectual-property, data privacy, and enforceability of contracts remain to be addressed

3.2. In 2007, US Congress passed the Energy Independence and Security Act that entrusted NIST with primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of smart grid devices and systems. To harness the potential of Blockchain, State of Illinois has established a Legislative Blockchain and Distributed Ledger Task Force

4 Way Forward for Enabling Blockchain in India

4.1. Constituting a Committee on disrupting'Blockchain Technology on Energy Transactions (retailer, bulk, storage)'comprising NASCOM& FICCI (at 2.5), Min of Finance, Institutions (Financial & Technical Regulatory), Council of Scientific& Industrial Research (DST), ISFG, Min of New &Renewable Resources, MoP, etc.

4.2. DST plans to set up 15 Centers (SATHIs) [20] with high-end science and technology infrastructure and these hubs can help Startup including Blockchain Forum India [18] & Blockchain Lab. similar to Rocky Mountain Institute, USA with the aim of accelerating new Blockchain applications such as distributed ledger solutions and associated use-cases.

4.3. For People living below poverty line & remote villages, use blockchain making access Impact PPA platform [18] encompassing prepaid energy solutions thru small -scale mobile money installments.

4.4. Deploying blockchain to track electricity generating assets including DER, EV charging, P2P transactions, India to pursue on-going Use Cases at 2.5.2 as also take a que from Use Cases at 2.5 enabling blockchain technology Pilot Projects in ‘off grid rural areas’, ‘localized microgrids’, ‘SV roof top owners’ for P2P transactions, etc. for energy transactions enshrining regulatory reporting & compliance and security measuresamong the participants.

5 Conclusion

5.1. Blockchain is a breakthrough trust mechanism that can remove the need for costly intermediaries and enable an unprecedented level of transparency, coordination, and information sharing across the energy industry—while at the same time allowing companies to retain control over sensitive information that gives them a competitive advantage in the marketplace

5.2. Many pilot projects on energy transactions among SV owners, P2P, microgrids are operative in numerous countries but awaiting break thru in big projects wanting regulatory frameworks, clear legal definitions and current level of uncertainty.

5.3. India is enabling DER (KW to MW) scattered all over the country and harness green energy blockchain technology incorporating regulatory frame work and becoming 1st to export technology platforms to other countries similar to small & medium public EV careers

5.4. Recommended to set up a Committee comprising GoI (Mo Finance, Min. of New & Renewable Energy, MoP, DST), Regulatory Institutions (Financial & CERC), PSUs (NTPC, PGCIL, PFC, REC), National Forums (ISGF, Blockchain Forum India, FICCI, NASSCOM, IEEMA).

5.5. International Cooperation (SARACC, USA, EU, China) enabling implementation of block chain technology in the energy distribution, accounting, flattening peak demand, EVs including regulatory framework, security; etc. thru sharing of each other experience (platforms, loss reduction, efficiency improvement, etc.)

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Vehicle to Grid Integration in Context of India

Moreshwar Salpekar

Abstract India uses fossil fuels to generate power. With advent of Electric Vehicles, more electricity will need to be produced to meet the demand. This will require more power generation. This will also mean more pollution if fossil fuels are used to generate the electricity. As per research, there are lot of cases where vehicles are not run for full day i.e. are idle for most of the time. Idle electric vehicles can be used to supply electricity to grid or even buildings or house effectively decreasing the demand from grid. However, the vehicle must have enough State of Charge (SoC) when needed. However, discharging and charging battery frequently can lead to lowering the useful life of battery (i.e. State of Health or SoH). This paper looks at the scenario of vehicle to grid integration. It gives the circumstances under which electric vehicles can supply electricity back. It proposes a system and associated protocols for such transfer. The proposed protocols attempt to ensure that the SoH of battery does not deplete much in percentage terms and SoC is always enough for at least one drive.

Keywords Electric vehicles · Protocol · Charging

1 Introduction

Electric Vehicles are supposed to help in reducing pollution. However, with increase in number of vehicles, the electricity demand will go up which will require increase in production. However, the production is unlikely to keep up with demand. India produces most of electricity from thermal sources implying increasing pollution with increased demand. From [1]:

> As of 31st Oct 2019
> total installed capacity 364960.14 MW
> total thermal installed capacity = 229401.42 MW
> total thermal installed capacity = 62.86% of total capacity

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As per ASSOCHAM and Ernst Young Study [2], the overall electricity demand from electric vehicles (EVs) in India is projected to be around 79.9 gigawatt hours (GWh) by 2020 and is expected to reach 69.6 terawatt hours (TWh) by 2030 which implies increase of 870.09% between 2020 and 2030.

The solution is to replace the thermal sources with non-thermal sources such as wind power and solar power to name a few. However, this will take time and may not result in demand–supply match.

On the other hand, electric vehicles are unlikely to be used for full day even when fully charged. Therefore, these can be used to supply electricity back to grid, building or home as the case may be. The duration for which the vehicle supplies electricity to grid may be treated as load-shedding period for the home or building. In case of supplying power to grid, the vehicle owner can be compensated according to the supplied electricity. The requestor may request electricity, or the vehicle may supply electricity without any request. In case, the vehicle supplies without request, care needs to be taken to ensure that the supply from vehicle does not result in overcurrent condition. The below sections give the protocol for the scenario where the requestor raises a request for electricity supply.

2 The Electric Vehicle Subsystems

A. *Block Diagram*

The Block Diagram is given in Fig. 1.

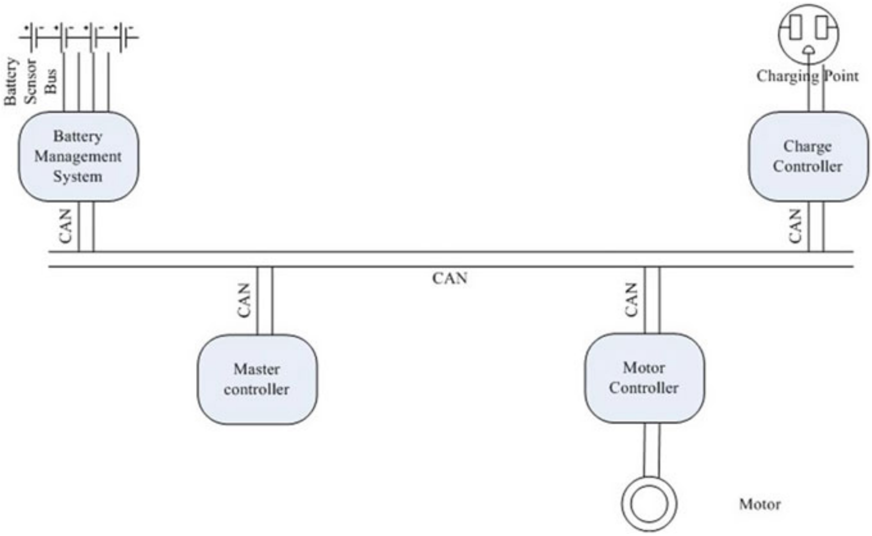

Fig. 1 Electric vehicle subsystems and their interconnections

B. *Explanation of Block Diagram*

The Electric vehicle subsystems consist of the following controllers (based on [3–5]).

a. Battery Management Subsystem (BMS): Its role is monitor the battery. This includes the output voltage, output current, State of Charge (SoC), State of Health (SoH), cell voltages, cell current, balancing status, and battery temperature. It also performs cell balancing. It sends the measured parameters over the Controller Area Network (CAN) bus.
b. Motor Controller: It monitors the motor for the vehicle. This includes motor torque, demand torque, Rotations Per Minute (RPM), input voltage, input current, and motor temperature. It sends the measured parameters over the Controller Area Network (CAN) bus.
c. Charge Controller: It monitors parameters while charging is in progress. The main parameters to monitor are: Charging Voltage, Charging Current and temperature of charger (shown in figure as charging point). It has sensors to detect whether charging cable is connected or not. It can stop charger output to battery if requested by master controller. It sends the measured parameters over the Controller Area Network (CAN) bus.
d. Master Controller: This coordinates and controls operations of other systems and monitors parameters sent by other subsystems sent over the CAN bus. It can send action requests to other subsystems and act on faults detected by other subsystems.

It should be noted that there is a display (not shown) which shows the parameters relevant to the user of the vehicle. This display may be controlled by the master controller or a separate display controller.

This electric vehicle system can be used to supply power to electric vehicles as given in next section.

III. *Supplying Power to Grid/Building/Home*

As stated above, electric vehicles can be used to charge vehicles. However, the charging process needs to use a protocol to start, stop and monitor/control the electricity supplied be vehicle. It is assumed that the vehicle is connected to a bidirectional power plug capable of taking in the supplied power (voltage and current) and can also be used to charge vehicle.

There are two types of supply protocols:

Manual: The user controls the start/stop of supply
Automatic: the system is defined to start/stop supply.

IV. *The Parameters*

The parameters relevant for the purpose of the protocol are [3–5]

SoC, SoH, Output Voltage, Output Current, faults and temperatures.

For all practical purposes.

SoC and SoH are expressed in percentage. The actual SoC of vehicle is

$$\text{Actual SoC } (\text{SoC}_\text{A}) = \text{SoC}_\text{V} * \text{SoH} \quad (1)$$

where SoC_V is the SoC reported by the vehicle and does not include the SoH.

The BMS reports the output current when a load is connected to battery else output current is zero. The User end of the system has to compute the output power as it is aware of the load. Therefore, maximum current output possible from battery is sent to requesting controller.

E. *The Packets*

The general packet structure proposed is

Packet Type: Handshake User Handshake Vehicle, Request, Data, ACK (ACKnowledge) and NACK(NoACKnowledge) which are the Responses.

Payload: It contains additional request as per packet type. For data packets, it contains parameters. For Request, it contains details of request.

CRC: The Cyclic Redundancy Check (CRC) field will be added to check the integrity of data. On failure of CRC check, the recipient of packet will discard the packet and send NACK.

Options are given in [6]

CRC-32-Castagnoli polynomial: $x^{32} + x^{28} + x^{27} + x^{26} + x^{25} + x^{23} + x^{22} + x^{20} + x^{19}x^{18} + x^{14} + x^{13} + x^{11} + x^{10} + x^{9} + x^{8} + x^{6} + 1$ (it is even parity and primitive polynomial).

CRC-8-AUTOSAR: $x^{8\,+}\,x^{7\,+}\,x^{5\,+}\,x^{2} + x + 1$ (it is primitive and even parity polynomial).

F. *How will the Protocol Work?*

It is assumed that protocol operates in manual mode. The user end has a switch to start reception. The below diagram gives the assumed system (Fig. 2).

It is further assumed that user end part is calibrated with maximum voltage and current and the lower threshold for SoC of vehicle.

Request and Data packets are always followed an ACK/NACK as the case may be.

The steps are

1. Electric Vehicle is connected to plug and the controllers in vehicle subsystems are on.
2. User Switches on the user end part of the subsystem.
3. The user end controller does a handshake with electric vehicle master controller to verify its online presence (using Handshake User and Handshake Vehicle packet types.
4. User end controller sends request for initial parameters.

    4.1. Electric Vehicle Master Controller sends initial data.

5. User end Controller verifies

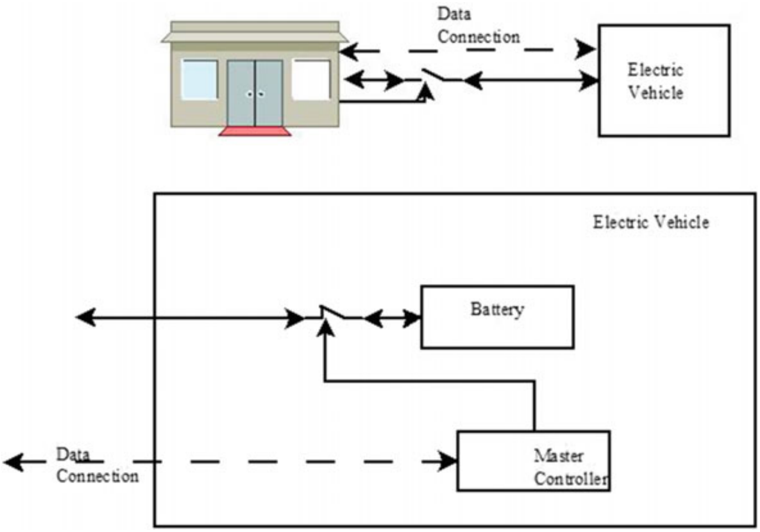

Fig. 2 Connecting vehicle to building/home

   5.1. Actual SoC (computed using Eq. (1)) is above threshold.
   5.2. Voltage is above expected voltage and current required is less than or equal to the maximum current that can be drawn from battery.
   5.3. Output Power possible from electric vehicle battery meet

6. If verification fails, a message is displayed on screen at user end and protocol stops
7. If verification succeeds, the user end controller sends request for electricity output.

   7.1. The Vehicle master controller enables path from battery of vehicle to the user end input.
   7.2. Vehicle master controller keeps sending the measured parameters

8. If the user end microcontroller detects Actual SoC is approaching lower threshold

   8.1. If it is 20% above threshold, first warning is displayed
   8.2. If it is between 10 and 20% above threshold, 2nd warning is displayed
   8.3. If it is 5–10% above threshold, audio visual warning is given
   8.4. If it is 0–5% above threshold, the user end controller sends a stop request to vehicle master controller
      8.4.1 Vehicle master controller stops supply by disabling output
      8.4.2. Vehicle master controller sends a response acknowledging stop
      8.4.2. Vehicle master controller sends the last data reading

9. In case current output or voltage output approaches the lower threshold or exceeds the acceptable high threshold, the user end controller sends a stop request to vehicle master controller
    9.1. Vehicle master controller stops supply by disabling output
    9.2. Vehicle master controller sends a response acknowledging stop
10. In case of switch off, the user end controller sends a stop request to vehicle master controller
    10.1. Vehicle master controller stops supply by disabling output
    10.2. Vehicle master controller sends a response acknowledging stop.

G. *Emergency Cases*

There are few emergency cases that need dealing

1. Vehicle ignition is started without user end system switching off. In this case, the vehicle controller:
    1.1. Disable motor so that vehicle cannot be moved. This is safe from damage point of view.
    1.2. Inform the User end controller that vehicle has been started so that it can initiate a proper switch off.
2. Vehicle master controller detects a fault.
    2.1. The master controller switches off output and the problematic subsystem (in case the subsystem has not already switched itself off).

H. *Supplying to the Grid*

The electricity grid can accept electricity the vehicle has to offer. The above protocol can be applied to vehicle to grid supply. However, in this case

a. The vehicle information must be sent to billing centre for bill adjustment. This must have the vehicle owner details. This information must be transmitted using a secure protocol.
b. The vehicle must be connected to a point where the electricity can go to the grid.

The protocol is same as above except

1. New Packet Types: User Identification Data and User Identification
2. Data Packet Payload:
    a. Information about grid request
    b. Information about user data
    c. Bill details having supplying point identification number (each supply point has unique ID) and amount of electricity supplied back to grid.

3 Revenue Model

There are multiple revenue models available. One such business model is outlined in [7].

It should be noted here that (as per [7]).

- Delhi Electricity Regulatory Commission (DERC) in its tariff order in 2017 introduced a separate tariff for EV charging which is substantially lower than the commercial tariff—Rs. 5/kWh for charging from HT supply and Rs. 5.5/kWh for charging from LT supply. Also, there is no minimum monthly charges for capacity. This was intentionally kept lower in order to promote EV rollout as well as creation of EVSE ecosystem.
- In 2018, Karnataka and Maharashtra State Electricity Regulatory Commissions have also introduced separate tariffs for EVs while DERC retained the 2017–18 tariff for 2018–19.
- Separate tariffs for EVs all across the country in the coming years which will be variable based on time of use (ToU).

As per ISGF white paper [7] in Table 4 (Capex and Opex of a typical EVSE Setup).

Maximum Power sold to EVs per Day, assuming 20 h/day operation is 842 kWh and the associated Capex is 1,170,000.

The Opex is 215,000 + EVSE Management Software Fee in First Year and 65,000 + EVSE Management Software Fee from second year onwards.

For revenue model, two scenarios are considered in [7] in Table 5 (Revenue Projections from a typical EVSE Setup)

Scenario-A: Margin of Rs. 2 on electricity tariff.
Scenario-B: Margin of Rs. 3 on electricity tariff in Years 1 and 2; margin of Rs. 2.5 in Years 3 and 4 and margin of Rs. 2 from Year 5 onwards.

The opex and revenue calculated for above models is

- Total Opex Scenario-A 576,040 and Net Revenue: Scenario-A 434,360
- Total Opex Scenario-B 626,560 and Net Revenue: Scenario-B 889,040

Further study and research work is going on for more revenue models so that EV charging business is profitable enough to sustain it.

4 Conclusion and Further Work

Electric vehicles will increase electricity consumption. This increased demand can be met by increasing electricity generation. However, when using thermal power, pollution is likely to grow. Renewable and clean energy sources must be used to counter this. This will require more power plants, which will take time to setup.

Electric vehicles can be used to supply electricity to homes/buildings and grids. The transfer must be initiated using protocols so that supply process can be controlled, and supplier gets the credit in monetary and/or electricity terms. The aforementioned protocol aims to achieve this.

As a future work, better security and safety design can be incorporated into the protocol. This can be done using added information in protocol. By adding new packet types, the protocol can be extended to inform the vehicle owner, maintenance units about current status such as fault in vehicle, low SoC, low SoH to name a few. This can help owner plan better.

More research work is required on revenue models. All states of India are yet to release their electricity tariffs for electric vehicles. As past experience shows, the tariffs may be revised once the promotion phase is over and hence the above revenue calculations and Opex and Capex may change.

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Smart Grid and Utility Challenges

P. T. Seenath Beevi, R. Harikumar, and M. L. Aravind

Abstract Information environments have grown piecemeal in almost all utilities. Each system is implemented with a vertical view of its function. This includes the typical supervisory control and data acquisition (SCADA) and Geographic Information Systems (GIS), which are the building blocks of smart grid. These systems which when integrated can provide real-time SCADA data on a geographic view of the electrical network, adding value to both. Both applications are geographically referenced database sets and have become the key operational tools of the electricity distribution business. KSEBL (Kerala State Electricity Board Ltd.) had developed a GIS system which was not able to act as a base for the SCADA integration as it is not compiled to meet the requirements of the integration. The challenge was to make it a structured model and design both in terms of database and electrical device design. The scope is for developing a middleware GIS solution for filling the gaps for integration with the existing system including network updates, to meet the requirements of the new system. The 11 kV networks and components are to be mapped into the Middleware application. The middleware application developed shall be in line with the IEC 61968 which is the international standard for SCADA Integration. Network Adapter makes use of this configuration and exports feeders in CIM XML format. Creating interoperability between the two systems will add value to both systems by extracting the optimum usage and availing the maximum benefits and there by technically creating the platform for smart grid implementation.

Keywords DG—Distributed Generator · SCADA—Supervisory Control and Data Acquisition · OMS—Outage Management system · MDMS—Meter Data Management System · CIM—Common Information Model · R-APDRP—Restructured Accelerated Power Development Reforms Programme

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1 Introduction

Electricity is the modern society's most convenient and useful form of energy. Without it, the present social infrastructure would not at all be feasible. The increasing per capita consumption of electricity throughout the world reflects growing standard of living of the people. The per capita consumption of Electricity for India is increasing day by day. The optimum utilization of energy can be ensured by an effective Electrical Grid (Transmission, Sub transmission and Distribution network) system. One of the greatest achievements in the 20th century is the traditional electrical grid.

The traditional distribution grid is a radial network with centralised generation and the power flow is unidirectional. The Generation points are limited and mainly include Hydro, Thermal, and Nuclear sources. The power can be transmitted through transmission, sub-transmission and Distribution lines to the end customers. So, there is transmission and distribution losses in the system, it is nearly 18% in state average and nearly 30% in national average. According to the 2011 census, 70% of Indian population are living in the rural areas, so the reduction of technical losses involved lot of investment.

The emission of green house gases and deforestation associated with large space requirement are main issues that have a negative impact on environment. As per the renewable energy policy, at least 10% of the total generation has to be borne from renewable energy sources like small hydro, wind, solar, etc., which make the utilities to encourage more DG's from renewable sources. These are to be centralised or distributed. In centralised type, renewable sources fail to address the Transmission and Distribution losses. There is a large gap between the power demand and power availability due to the increased demand. To cope up with the gap integrated renewable energy sources are the alternate options. The liberalisation of energy markets and awareness about green house gas emissions has increased the use of distributed generation (DG). So, DG integrated distribution network management should have given top priority considering future grid and the grid visibility.

The rapid proliferation of distributed and renewable generation, the 21st century grid will have numerous points of power injection as well as millions of point of power consumption, so the consumers become the prosumer. The grid management is important due to the increasing number of intermittent energy sources. Most of the critical power applications, there is a need to maintain minimal operating capability under minimal fault conditions. To provide 24 × 7 quality and reliable electric power to the customers leads the importance and evolution of the smart grid (SG). The traditional electric grid will need to build additional layers of automation, communication and IT system to transform it to a smarter grid. Supervisory Control and Data Acquisition systems (SCADA) with energy Management Systems (EMC) and Distribution Management Systems (DMS), Enterprise IT network covering all substations and all field offices with reliable communication systems, Enterprise Resource Planning (ERP)/Asset Management systems, Geographic Information System (GIS),—mapping of Electric network assets and consumers, modernization of substations with modern switchgear and numerical relays, AMI with MDMS, Billing and Customer Care system, automation of distribution network and substation, outage management system (OMS), renewable integration, Electrical Vehicle integration, etc. are the building blocks for SG implementation. That is Electrical Grid with automation, communication and IT systems that can monitor power flows from points of generation to points of consumption and control the power flow or curtail the load to match generation on real-time basis. Various types of outages and faults occur in the distribution network, which created consumer dissatisfaction. This will be avoided and the substantially improve system average duration index.

This paper is focussed on the challenges to be faced by the utilities in implementing smart grid. SCADA refers to the combination of telemetry and data acquisition which is one of the leading building blocks of Smart grid. The other major applications are MDMS application, Customer care centre (CCC) application, Advanced metering Infrastructure (AMI), Billing Application, etc. Smart Grid is characterized by the integration of communication networks and IT infrastructure with the power and energy layer. That is seamless integration of different types of bulk energy sources, distributed energy sources, transmission and distribution systems, communication systems, and measurement systems. The communication network shall provide reliable medium for two way communication between various nodes. All the IT systems and SCADA systems require the need for a reliable and secure private communication network. As per economy, advanced RF based network technologies are available, but considering Cyber threats, etc. more inception standards has to be adopted for data security. A communication protocol is a standard rule, so as to enables devices to be able to speak to each other. If devices use different protocols they will not be able to share data with each other. The automation of control systems of substations in the power utility uses a variety of standards and protocols. The most frequently used for SCADA are IEC60870, DNP3 and IEC61850 protocols.

Major challenges faced by the utilities in implementing smart grid and mitigation of these challenges. Integration of SCADA with major applications GIS, CCC, etc., connectivity issue, huge investment, data storage, its management and analysis, development of middle ware GIS application. Utilities in India implemented IT enabled applications as part of Re-stretchered Accelerated Power Development and Reforms programmes (R-APDRP) introduced by Ministry of Power, Govt. of India. Subsequently, as part of same scheme, SCADA/DMS project implementation through a separate vendor. So, the integration of these two systems become a great challenge. Utilities throughout the planet face unprecedented changes. New tools and technologies are required for capital-intensive companies to remain competitive in the marketplace.

2 Objectives

This paper focussed on the challenges faced by the utilities in implementing smart grid and mitigation of these challenges.

- SCADA GIS integration.
- SCADA—CCC integration
- Integration of other major building blocks
- Connectivity Issue
- Huge Investment
- Big data storage, Management and analysis
- Middleware GIS application
- Power quality issues

Utilities in India implemented IT enabled applications such as GIS, CCC, MDAS,etc. as part of the central scheme R-APDRP which was introduced by Ministry of Power, Govt. of India. Subsequently, as part of same scheme, SCADA/DMS project implementation tendered through a separate vendor. So, the integration of these two systems become a great challenge. Utilities throughout the planet face unprecedented changes. New tools and technologies are required for capital-intensive companies to remain competitive in the marketplace.

3 SCADA/DMS System with GIS Integration Challenges and Mitigation

Better use of GIS data is one of the key areas of focus for utilities. Improved hardware, software, and networking technology have created opportunities for the utility industry to build and benefit from more comprehensive and high technical GIS implementation. GIS software has evolved from their foundation in map production to advanced analysis tools for planning and operations and integration to real time systems. GIS products are commonly used by utilities for marking facilities location, and engineering applications like planning and development etc. The GIS middleware application thus developed shall be in line with the IEC 61968 which is the international standard for SCADA Integration. GIS integration to the complete requirement will enable utilities to use maximum DMS features of the SCADA/DMS system. Many utilities information environments have grown piecemeal, with each system implemented with a vertical view of its function. This includes the typical SCADA and geographic information systems (GIS)-systems which when integrated, can provide real-time SCADA data on a geographic view of the electrical network, adding value to both. SCADA and GIS have become the key operational tools of the electricity distribution business. Creating interoperability between the two systems adds value to both SCADA and GIS, providing tools that allow us more significant information in the control room.

Network Adapter is an interface between the ArcFM Solution and third-party modelling and planning applications or analysis engines. Network Adapter provides tools for extracting a model from the GIS and loading the data to an analysis engine via XML. Network Adapter also extracts results from the analysis engine and displays them in any ArcFM Solution application, including ArcFM Enterprise GIS, ArcFM

Designer, and Responder. Thus, as feeders are modified, planners can quickly analyze the feeder with the analysis software and display the results in a GIS environment. Network Adapter eliminates the need to maintain data in two separate systems. The corporate GIS database becomes the system-of-record for all network information.

This implementation of Network Adapter is accessed through an executable file in the ArcFM Solution or Bin directory. It allows you to export a particular feeder (or multiple feeders) from a geo-database using a Common Information Model (CIM) XML format. The geodatabase schema from which the feeder is exported is specified during configuration.

If configured properly, Network Adapter will export feeder information to CIM. When Network Adapter opens, it reads the geo-data-base and populates the top window with the feeders available in that database. Geo-data-base need to configured with the feeder manager. The configured feeder will be able to export using the CIM to DMS export configuration script. When Network Adapter opens, it reads the geo-database and populates the top window with the feeders available in that database.

3.1 CIM XML as GIS—SCADA Integrator

In electric power transmission and distribution, the Common Information Model (CIM), a standard developed by the electric power industry that has been officially adopted by the International Electro technical Commission (IEC), which aims to allow application software to exchange information about an electrical network. The CIM models the network itself using the ’wires model’. This describes the basic components used to transport electricity. The standard that defines the core packages of the CIM is IEC 61970-301, with a focus on the needs of electricity transmission, where related applications include energy management system, SCADA, planning, and optimization. The IEC 61970-501 and 61970-452 standards define an XML format for network model exchanges using RDF. The IEC 61968 series of standards extend the CIM to meet the needs of electrical distribution, where related applications include distribution management system, outage management system, planning, metering, work management, geographic information system, asset management, customer information systems and enterprise resource planning.

4 Methodology

KSEBL (Kerala State Electricity Board Ltd.) had developed a GIS system which was not able to act as a base for the SCADA integration as it is not compiled to meet the requirements of the SCADA–ADMS. Data is unstructured illogical modelled as far as SCADA integration is concerned. The challenge was to make it structured model and design (both database and electrical device design). The following Methodology was adopted to capture the needs of KSEBLs requirements.

4.1 Gap Analysis of the Existing GIS System and GIS Database

During the initiation of the project, a detailed study of the existing GIS database has been conducted to analyse the gaps in already implemented GIS software. During this phase, the ultimate deliverable configuration was collected from the Utility, and was taken as the input for final CIM XML generation. In the evaluation stage the existing GIS data, SCADA–ADMS requirements, data model etc. were evaluated and further cross-matched with the network single line diagrams and existing GIS data. The identified issues are:

- Existing GIS data was not complied to meet the Utility GIS (AM/FM) standards for SCADA Implementation (GIS data collection was carried out without considering the future SCADA Integration).
- Facilities changes over time as delta changes were not properly updated.
- Assets are considered geographically more important in utility.
- RMU was marked as a point in existing GIS, it is a container and it will have load break switches, fault passage indicators circuit breakers, bus couplers and earth switches inside it. The network should have all the components of the RMU defined properly so that connectivity can be configured with switching and regulating controls.
- Non-uniformity of the input data for the three towns.

  All these issues were resolved as follows

- Existing GIS data need to be converted into a utility-based logical mode based on ArcFM electrical geo-database.
- An interface to be evolved for incorporating missing and future data. In this project, created templates for the Ring Main Unit, so as to complete the connectivity without any missing information in the configuration.
- A middleware application to be designed to convert the network database to CIM XML based on IEC 61968 Standards.
- The input data should be examined and the validity of the data is finalized.

4.2 Design and Develop AM–FM Electrical Utility Network Model—Compatible to Work with Existing SCADA

Based on the inputs from gap analysis an enterprise database model will be designed that can serve the current needs of the Utility. All the models, subtypes of the electrical components, domain configuration, building the table relationships, network tracing model, snapping configuration, QA Model, flow model, etc. will be designed.

5 Template Design for Electrical Network Asset Internal Drawing for New and Missing Network Components Required for SCADA

During template design phase internal structure of the RMUs, Feeder Pillars, etc. will be designed. This will be available for the user as system favorites and can use the same for missing and new data capture in the future.

6 Extract Transform and Load—GIS Data to Utility Network Model

In this phase, the existing data attributes are transformed to the enterprise utility compatible subtype and domain values and extract the data from source shape files and load into the enterprise database. This will be done using automated tooling which will be designed after the design and development of enterprise Utility database. The attribute data were descriptive and data size is huge but no logical attribution. The existing data attributes were descriptive, so that each of the data has to be represented in domain values to describe the values of a field type which is used to ensure attribute integrity and is transformed to an enterprise utility database.

7 Incorporating Missing and New Data

Missing and new data were incorporated after getting the location, connections and attribute data, using the templates designed. The overall view of the design and configuration of the methodology is illustrated in Fig. 2. The SCADA DMS System

```
Initializing phase validation.
Initializing Voltage validation.
Initializing GetRelationships
Initializing GetFeatures
Initializing TraceFeeders
Tracing feeders...
Reading attributes and geometry...
Getting relationships...
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Fig. 1 Network adapter

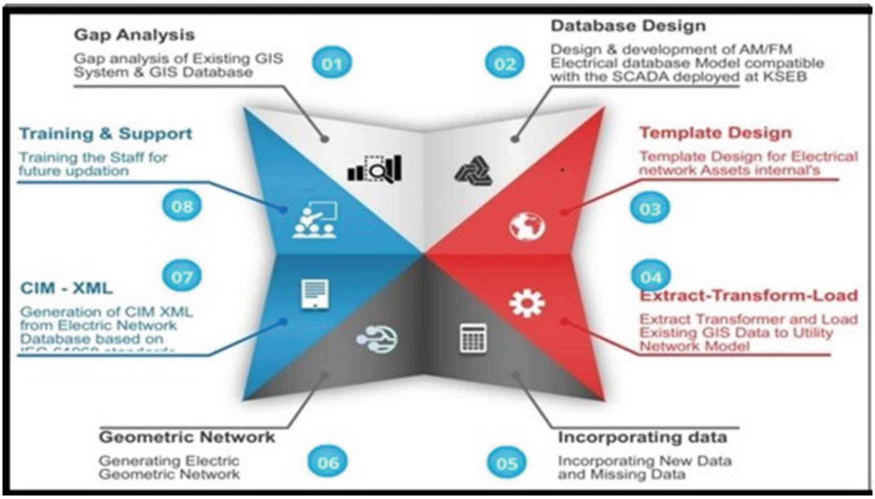

Fig. 2 Methodology

with Geo referenced displays of all network assets along with their connectivity in Trivandrum city is in Fig. 3.

8 Result

- To achieve an improved interoperability between Planning and Operations.
- To have a single source of data to avoid and process optimization.
- To have a fast and clear view of the current state of the network.
- To highlight deviations to the normal state, to easily locate network faults and subsequently restore the network.
- The middleware solution was developed for the integration of SCADA–ADMS system with GIS system and the smart grid implementation should be smooth. The Fig. (1) shows the network adapter and the Figs. (4, 5 and 6) are the component internal views and the connectivities and operation mode.

9 Conclusion

The Creation of intelligent network models are typically high labour-intensive and normally requires a highly skilled technician or engineer. Operating the analysis model from the AM/FM-GIS database can result in reduced labour and improved analytical models. Continuous data upgrade is needed so that any modification in one system match with the other. A robust database is to be evolved over a while, so that any modification can be incorporated much easier and implementation can be effort-

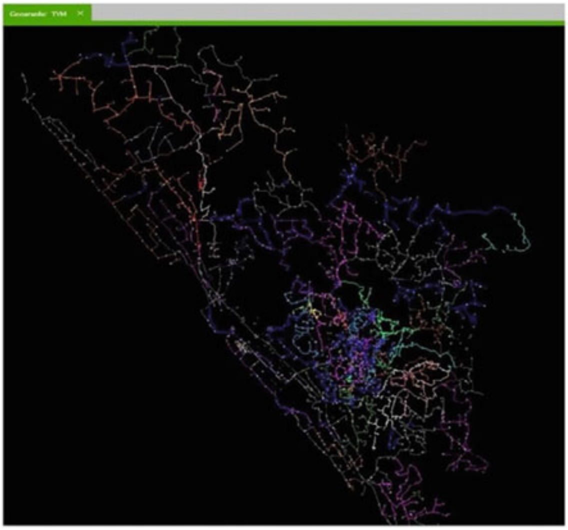

Fig. 3 A SCADA DMS system with Geo referenced displays of all Network assets along with their connectivity

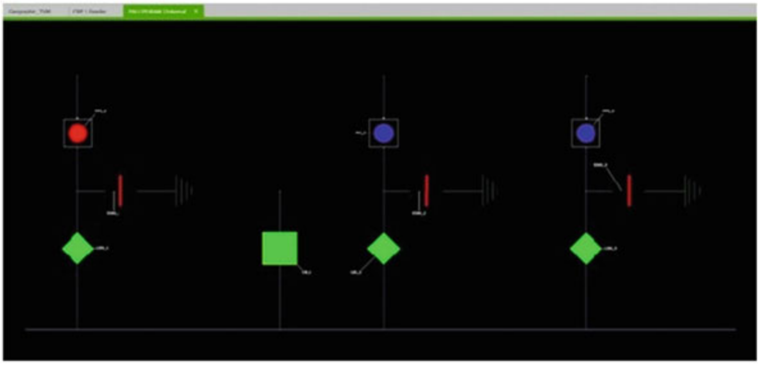

Fig. 4 RMU operation internal diagram

less. Continuous upgrade of the network is essential for the SCADA to work more efficiently and the utility will get the maximum advantage of the implementation. In this paper it was tried to customise the GIS application by populating the existing GIS developed as part of IT project with RMU internal and connectivity collected through separately to have an updated new solution that can be directly integrated to the SCADA system.

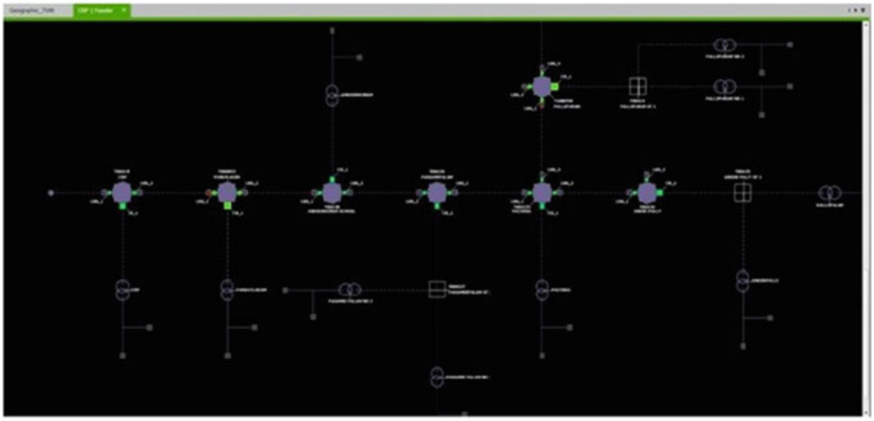

Fig. 5 RMU operation view

Fig. 6 Schematic representation of Feeders and RMUs possible from the connectivity and coordinate information brought about by the CIM XMLs

10 Limitations

The limitation of this systems are the network field updations will be in the GIS application. So these to be updated into the new middleware solutions. The developed system is scalable and having capability to integrate the GIS application.

11 Future Scope

The developed middle wear application should be scalable and to be implemented to other cities.

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India Moving Towards Solar Energy

Purnima M. Gupta

Abstract A milestone in India's journey towards solar energy was the launching of India's National Action Plan On Climate Change in 2008. The 12th five year plan recognized the necessity of moving to a low carbon growth and suitable strategies were covered for specific sectors of power, transport, industry, buildings and forestry. At present, the renewable share in total energy is about 2.2% only. The acceleration of the renewables in India and enhancing that share will bring India closer to the fulfilment of its Intended Nationally Determined Contributions (INDCs) under the Paris Climate Change Agreement. At the UN climate action Summit, New York, held on 23rd September 2019, Prime Minister announced that India expects to increase the share of non-fossil fuel in its energy use. By 2022, India plans to increase renewable energy capacity beyond 175 GW and later to 450 GW. This paper argues in favor of a higher share of 5% of renewables in the total energy use in India and outlines measures to meet the challenges of making available solar energy at an affordable cost to the large masses. The cooperation of Indian enterprises must come forward. This will secure twin dividends of poverty reduction and clean energy usage.

Keywords Solar energy · Preferential tariffs · Electricity act · Solar energy storage · Climate change

Solar energy is one of the cleanest forms of renewables. In the past decade, the Indian government has taken many initiatives towards increasing the contribution of solar energy in the total energy needs of India. Indian leadership has promoted the cause of solar energy within and outside the country at global fora. The realization that fossil based energy causes climate change has led to a shift towards producing cleaner energy. At the Paris Climate Change summit in 2015, India, along with France, took the initiative to set up an International Solar Alliance of sunshine rich countries to promote the production and use of solar energy. The ISA has formally entered into force and acquired the status of an international organization. According to the UNFCC, "The Alliance, which is headquartered in Gurugram, India, aims to deploy over 1,000 Gigawatt of solar energy and mobilise more than USD 1,000 billion into

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Table 1 Targets for solar energy

Rooftop scheme	40 GW
Entrepreneurs' scheme	20 GW
Already planned	10 GW
State policy	10 GW
Public sector	10 GW
Private sector and independent power producers	5 + 5 GW

Source India Surging Ahead, Ministry of External Affairs, Government of India, 5.5.2017

solar power by 2030, facilitating and accelerating the large-scale deployment of solar energy in developing countries in order to meet soaring energy demand and help fight climate change."[1]

The 12th five year plan 2012–17 recognised the need to move to a low carbon growth path. Accordingly, suitable strategies were covered for specific sectors of power, transport, industry, building and forestry. India's solar potential is 750 GW. National Solar Mission envisages 100 GW of solar energy by 2022 as follows (Table 1):

The National Action Plan on climate change (2008) culminated in the National Solar Mission for 20,000 MW grid connected power generation capacity using solar energy. The targets for solar energy have been increasing subsequently. "New India" set a goal of 175 GW renewable energy consisting of 100 GW of solar energy.[2] The share of renewables is only 2.2%. It is advisable to increase this share to 5% with a pro rata increase of solar share in renewables. India has abundant sunshine to generate solar energy.

The legal framework for giving a push to solar energy is in place in India. The renewable energy as a nonconventional source of energy generation is provided for in section 86 (1) (E) of The Electricity Act 2003. The tariff policy, 2006, recognized that preferential tariffs determined by the appropriate Commission (Central Electricity Regulatory Commission And State Electricity Regulatory Commissions CERC/SERC) will be fixed for procurement by the distribution companies.[3] The preferential tariffs were an incentive to tap into solar energy. In January 2011, the Ministry of Power amended these provisions so that "the SERC shall also reserve a minimum percentage for purchase of solar energy from the date of notification in the official Gazette which will go up to 0.25% by end of 2012–13 and further up to 3% by 2022".[4]

There was a policy thrust towards renewable purchase obligation (RPO) including solar energy. Regulation for purchase of solar energy ensured that investment in solar

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[1] https://unfccc.int/news/international-solar-alliance-enters-into-force.

[2] *Strategy for New India@75*, NITI Aayog, Government of India, November 2018.

[3] *Tariff Policy*, Ministry of Power Resolution, the Gazette of India Extraordinary, New Delhi, 6.1.2006.

[4] *Ministry of Power Resolution*, the Gazette of India Extraordinary, New Delhi, 20.1.2011.

developers gets adequate support. There is variation in solar potential across the states. Some states have insufficient solar availability. The amendment in the Electricity Act 2003 provides for renewable energy certificates (REC). It was suggested that through the RECs, the obligated entities may meet their RPO. The REC is an additional source of income for the solar power developers that may facilitate recovering the cost of production. The sale and purchase of RECs is by the power exchanges with the approval of CERC.

Solar plants are relatively more capital intensive than other power plants. The growth of solar developers is dependent on adequate capital investment, easy availability of land and incentives by the government at different levels. The Ministry of New and Renewable Energy extends 30% subsidy for initial capital investment. Apart from this central government initiative, the states and union territories also have diverse kinds of schemes to propagate solar energy. As energy is concurrent subject under the Indian constitution, encouragement to solar energy exists within the central and the state government and their agencies. However, the potential solar developers of solar PV plants may be reluctant to seek government subsidies due to the bureaucratic problems, delays and uncertainty in fund disbursement.

Once the solar power plant is installed, the tariff level determines the market dynamics. The solar power developers are driven by business instincts and view all aspects through their commercial lens. Installing a solar plant is profitable once the tariff rates are competitive. The tariffs have fallen to Rs. 2.44 per unit. Thus, solar energy is becoming more affordable. While the explicit costs for solar energy are falling, there are L implicit costs as well. The cost of storage of solar energy when sunshine is absent have to be added. Technological advancements in storage are needed so that daytime surpluses of sunshine are stored and released after sunset. The National Solar Mission needs to work on efficient and affordable storage systems. This will facilitate competitiveness in solar tariffs. Once the solar developers are convinced about the market profitability, the investment will follow.

The Indian government has pushed for solar energy in the state, central government and global levels. Delhi government has a Mukhyamantri solar power scheme. A 30% subsidy is being given by the Delhi government for projects upto December 2019. Future projects are going to receive a lower subsidy of 20%. At the central government level, policy on solar energy is translated into planning targets up to 2022. India is surging ahead in solar energy.

The acceleration of the renewables in India and enhancing that share will bring India closer to the fulfilment of its Intended Nationally Determined Contributions (INDCs) under the Paris Climate Change Agreement (2015). At the UN climate action Summit, New York, held on 23rd September 2019, Prime Minister announced that India expects to increase the share of non-fossil fuel in its energy use. By 2022, India plans to increase renewable energy capacity beyond 175 GW and later to 450 GW. The cooperation of Indian enterprises is needed to achieve these ambitious targets. This will secure twin dividends of poverty reduction and clean energy usage.

Hybrid Microgrid Set up in Laboratory for Practical Alimentation of Electrical Engineering Students

Rahul Singh, Mohammad Saad Alam, Furkan Ahmad, M. S. Jamil Asghar, and Yasser Rafat

Abstract In recent years, renewable energy source based Microgrid are getting immense consideration due to its capabilities to overcome the Green House Gas (GHG) emission. Thus, in addition to the utilization of renewable energy sources and proper monitoring of Microgrid, we need such type trained engineers who have betters understanding about microgrid since their college days. Ministry of Human Resource Development (MHRD) India is investing a huge amount of money and trying to produce good quality engineers by opening many training centres and also by offering reputed educational institution of India to come forward to assist. Research Question: How can we educate our electrical engineering students so that they can easily learn during their course work and have good technical skills as well as practical knowledge? Methodology: To nourish and have good practical knowledge about hybrid microgrid system for electrical engineering students, we set up a hybrid microgrid system in laboratory in which we took combination of Solar PV panel, solar emulator, wind emulator, battery bank, fuel cell, AC/DC converters, DC/AC inverters and grid power where our students can do different experiments based on hybrid microgrid system.

Keywords Microgrid · Solar emulator · Wind emulator · Solar PV panels · Battery bank · Fuel cell · Voltage Source Converters (VSC's) · DC/AC converters

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1 Introduction

Practical knowledge always offers the real world experience of gained theoretical knowledge to the students and that is why the good institutions have their own laboratory to experience the factual information. According to the report of Economics times, 94% of engineering students of IT sectors in India are not suitable for hiring due to lack of practical knowledge and good technical skills [1]. This is really a big issue and also a reason of motivation to work in these area to resolve such type of problem by practical knowledge. The importance of laboratory practice for engineering students has been very crucial for decades. Several institutes understood and providing laboratory education [2–7], because in laboratory setup we learn, analyze and try to resolve the practical issue of the real world. The demand of electricity is increasing day by day and we have a very limited amount of conventional resources and with the current mining rate, the coal will be available for 110 years, oil will be in 52.5 years and natural gas will be available for 54.1 years [8]. So engineers are looking for those environmentally friendly resources which can fulfil our demand for a long time, that is why continuous research work has been going on to find the best solution. To aware of our engineering students from the real world, we have to set up new laboratories and recent technology based experiments. With the help of experimental exercise, educators can directly involve and teach their students in a practical way and also encourage them to understand the essence of knowledge. According to the educational reformer John Dewey [9], learning is incomplete only with bookish knowledge and lectures, but it is substantiated with familiarization of explanation to the students. International engineering learning activities were also helping students to improve their talents, including technical and professional skills. [10–14] so that, when these engineering students go in their professions, they could help their society to come out of the gloom. The microgrid is a clump of distributed energy resources and systematized loads within specified electrical conditions [15]. Due to advancement in technology, engineering practice is increasing globally very fast [16], and such engineers who have specialized abilities, attitudes and awareness to lead in a competitive world [10, 17, 18]. This creates a challenge for engineering educators, to prepare engineering students technically sound and very effectively in a global context [16].

To operate and controlling purpose of the power sectors we need such type of engineers who have good technical skills and are well-trained during academics so that they can groom very fast in any organization. In higher education, China, there is Ministry of Education's proposal which provides a learning platform named "A Plan for Educating and Training Outstanding Engineers" at the international level to develop the abilities and proficiencies of engineering students [19]. The government of India is more concern about unskilled engineers, so they are providing many platforms to cognize technical information and gain practical experience through industries and technical reputed educational institutions. The lectures and learning activities were designed in such a manner to help students to make them more efficient, knowledgable and experienced with good abilities [19]. In 1984 Kolb [20] suggested the effective learning cycle which was divided in four stage, which state that at first we should solidify our experiences followed by observation of things and then that should be reflected to lead us to develop intellectual concept which further applies in upcoming situation and we will have the better concept arise again. Kolb's cycle is also being used in many areas and different courses, engineering is one of them [21, 22] where lab exercises are very important. On the basis of all information and expertise views, a survey is performed to calculate the building's load at Aligarh India and to design and experience real-world microgrid system in the laboratory, a hybrid microgrid has been set up in C.A.R.E.T. AMU India. In our setup, we took a combination of solar PV panels, solar PV emulator, wind emulator, battery bank, Fuel cell and the power grid. Term Emulation is used for simulation practices which involve hardware platform. In an elementary word, emulation is a hardware level simulation which provides a fast configurable testing platform to perform in real time. An emulator is similar to Hardware-In- Loop simulation concepts. This setup will help our students and trained them for a better understanding of technical, social, educational as well as economic aspects of microgrid role in the power system.

We have seen an introduction in Sect. 1, in Sect. 2 there is description about the laboratory infrastructure, in Sect. 3 technical details of each component of the installed system has been discussed, in Sect. 4 mode of operation of the system has been discussed and finally conclusion is discussed in Sect. 5.

2 Laboratory Description

The software-based simulation make easy and opened new paths in the education system and help students a lot to understand the complex model and working of the microgrid system in a simple way but when it comes to the physical understanding and familiarization with the application of a system, our engineering students' incompetent due to lack of practical knowledge and the less familiarization with real hardware system. So, to improve the skills and knowledge of our students, we set up a hybrid microgrid system in the laboratory. An attracting feature of the microgrid is its flexibility to operate in two modes Islanding mode and grid- connected mode just by disconnecting and connecting from the main grid.

Of the many renewable and free available alternatives, wind energy and Solar Photovoltaic has emerged as one of the most established and affected technologies. However, the output of wind energy conversion system (WECS) and Solar PV system is dependent on environmental conditions which are capricious by nature. But due to the development of reliable and efficient control schemes, WECS and Solar PV has been a major area to concentrate. Fig. 1 shows the hybrid microgrid system in which different load and source components are represented as blocks. For the successful deployment of solar PV panels in hybrid microgrid system, as an engineering student, we must know that the solar irradiance data of a particular location. The solar irradiance data of the specified location of Aligarh, India is 5.27 kWh/m2/day [23]. In our hybrid microgrid system, we took two energy generating sources which are solar

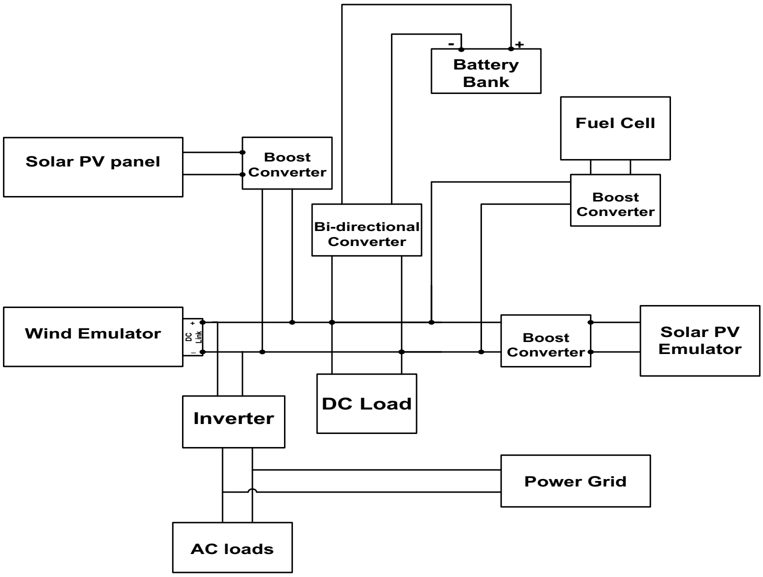

Fig. 1 Hybrid microgrid system with different type of loads

energy based and wind energy based. In solar energy based generating sources, we took solar PV emulator integrated with boost converter and wind emulator whose output is converted DC to make common dc link. We also took the solar PV panel integrated with a boost converter to take real- time power generated value. To provide uninterrupted power, when we don't have enough power generated by our microgrid system and no power is available in power grid, we took Battery Bank and Fuel Cell as power backup which plays a key role to feed our loads and make our system reliable.

3 Components Detail

In this section, every components and detail of hybrid microgrid have been discussed briefly which was used to set up our educational laboratory. The system resides solar PV panels, solar PV emulator, wind emulator, a boost converter, battery bank and Fuel cell.

A. *Rooftop PV panels*

In our Rooftop Solar PV System, we installed a single solar panel of 320 Wp at the roof, which is one of the sources in the Hybrid System to take the real-time solar PV power generation. Rooftop Solar PV panel output is connected to boost converter and converter lift and regulate the voltage from 35 to 150 V to fed the DC Link. By using the solar PV inverter, the power is stored in a battery for power backup and surplus power is delivered into the power grid [24] (Fig. 2 and Table 1).

B. *Solar PV emulator*

The PV Emulator has internal programming to set Open circuit voltage (Voc) and short-circuit current (Isc) and the user can select solar PV panel of their choice on the basis of solar irradiance level and ambient temperature. The output power of solar PV panels is hard to predict because of dependency on natural parameters which is dynamic and complex in nature. For a specified panel, location, position of the sun, time and year PV emulator the average data to estimate the response the output

Fig. 2 Solar PV panel with converter

Table 1 Solar PV panel and boost converter details

S. no.	Component	Specification
1.	PV panel • Peak power (Wp) • Maximum voltage • Maximum current • Open circuit Voltage(Voc) short • Circuit current (Isc) • Module efficiency (%) • Temperature range • Panel type	320 W 37.65 V 8.5 A 45.96 V 9.03 A 16.67% −45 to 80 °C Poly crystalline
2.	Boost converter • Input voltage • Input current • Output voltage • Output current • Switching frequency	35 V 8.5 A 150 V 3 A 20 kHz

Fig. 3 Solar PV emulator

of solar panel in a practical way, then assured the response of PV emulator should matches to actual PV panel within all range and conditions. The actual measured climatological data of specified location is used to simulate I-V curve and then further use to assure the other parameters such as MPPT, the efficacy of MPPT tracking, tracking algorithm of PV inverter, PV inverter efficiency, overall efficiency of system and response of different varieties of solar panel in varying weather conditions. There is no requirement of external setup for data acquisition and data monitoring (Fig. 3).

The output characteristics can be shown in LCD of emulator and software application presents the user with tables, plots and simulation parameters. The specification Solar PV emulator is given in the table (Table 2).

The key features of Solar PV emulator:

- There are four channels provided in the emulator with 0–50 V and 8 A each.
- All channels have the capability to operate in series, parallel and can be used independently according to desirable voltage and current.
- The emulator has a fast transient response for any type of selected panels for simulation purpose.
- The emulator has the ability to work without a connection to computer or internet at standalone mode.
- Emulator provide the free facility of "cloud-based application" software for observing and examining all simulation details
- There is no any issue related to downloading, updating, installing, and troubleshooting in cloud-based application
- Controlling of the emulator is so easy that user can control even with an android tablet which has recently updated browsers

Table 2 PV emulator details

No. of channels = 4		
Input	Supply voltage	230 V AC,50 Hz
	Short circuit current/channel	0–8 A
	Open circuit voltage/channel	0–50 V DC
	Max. Output power/channel	400 W
Output	Maximum channels in series/parallel	4
	Maximum absolute voltage at output	200 V DC
	Voltage slew rate range	0.01 V/ms−2 V/ms
	Current slew rate range	0.01A-1A/ms or INF
	Modes of operation	Fixed mode, Table mode, Simulator mode
	Connector at output	Banana type
Physical box	Number of leads in the output connector	4
	Operating environment	Indoor use

- Manual controlling over I–V curve for a specific condition and a wide range of selection of panels of a different manufacturer.

C. *Wind emulator*

Wind turbine emulator copies the technical behaviour of the actual wind turbine under certain precise manner. At the specified operating parameters of wind speed and pitch angle, the wind emulator simulates the actual operating conditions of the wind turbine in real time at the hardware level. The dynamic and steady-state behaviour of the wind turbine can be easily tested on the wind emulator. Engineering students can easily learn about different characteristics of the wind turbine such as wind speed, Torque/turbine speed and Power/turbine speed and about those factors which affect these characteristics (Fig. 4 and Table 3).

D. *Fuel cell*

Like a battery, the fuel cell is also used as power backup which is an electrochemical device and which converts chemical energy into electrical energy. Similar to battery a fuel cell has also different units which are composed of a number of stacked cells and cathode and the anode of each cell in the stack is separated by the proton exchange membrane (PEM).

The functions of PEM to work as an insulator between the nearby “half cells” and also to provide a path for migration of hydrogen protons which was created

Fig. 4 Wind emulator

during the process. From each cell of anode side, hydrogen is fed and air or oxygen is fed from the cathode side of the system. In the cell stack, the oxidation–reduction reaction takes place in which hydrogen is oxidized, oxygen is reduced, and electron flow which so electrical power generated and most importantly, the by-product of this electrolytic reaction is water. In the each cell of stack, reaction takes place as long as hydrogen fuel is available. An electron released from each cell is pumped by the preceding cell which gives a voltage or pressure overall, and this will be equal of each cell voltage multiplied by the number of cells which are in series in the stack (Fig. 5 and Table 4).

E. *Battery bank*

Battery bank is also coupled to the common DC Link through the output of bidirectional Converter, a Rooftop Solar PV acts as a DC Source which output is connected to input of boost converter and output of boost converter is connected to common DC Link (Fig. 6).

In the system, the Battery Bank act as a sink when it is not fully charged and as a source when power is not available to fulfil the load demand then power is being supplied by the battery.

The specifications of Battery bank and bidirectional converter are given in table (Table 5).

4 System Operation Mode

The ability of the hybrid microgrid system is that it can operate in two modes (1) Stand-alone mode or off-grid mode and (2) Grid-connected mode or on-grid mode.

Table 3 Wind emulator details

S. no	Component	Specification
1	DC motor • Output power • Nominal field voltage • Nominal armature • Speed at rated voltages	3.5 kW (5HP) 220 V DC 220 V DC 1500
2	DC drive • Input voltage • Input current • Output voltage • Output current • Switching frequency	230 V 13 A 200 V 15 A 20 kHz
3	Buck converter after generator • Input voltage • Output voltage • Output current • Switching frequency	450 V 150 V 10 A 20 kHz
4	Gear box • Gear ratio	2:1
5	Induction generator • Type • Output power • Line to line voltage	Squirrel cage (self excited) 1.2 kW 415 V AC
6	Tacho-generator • Input voltage • Speed encoding	24 V DC 10 V DC for 1500 RPM
7	AC excitation capacitors • Connection • Capacitance	Delta 50 μF AC
8	Control card • Technology • ADC inputs • PWM ports	FPGA Available Available
9	Sensing board • 4DC voltage sensors • 3DC current sensors	
10	Pull-UP card for inverter gate firing	8 PWM signals
11	Bridge rectifier • Rating • Capacitor	10 A, 400 V 3300 μF, 450 V

(continued)

Table 3 (continued)

S. no	Component	Specification
12	Three phase inverter • 3 Leg inverter • Maximum input voltage • Output voltage • Output current • Switching frequency	150 V DC 112 V AC 25 A 10 kHz
13	Step UP power transformer • Connection • Rating	Delta to star 5000 VA
14	Measurement • DC link voltage voltmeter • Armature voltage voltmeter • Field voltage voltmeter • Battery voltage voltmeter • Rectified voltage voltmeter • Battery current ammeter • Tachometer	0–1000 V 0–1000 V 0–1000 V 0–200 V 0–1000 V 0–10 A 0–2000 RPM
15	Three phase LC filter • Inductor • Capacitor	3 mH, 10 A 10 μF, 400 V
16	Protection • AC and DC MCBs	

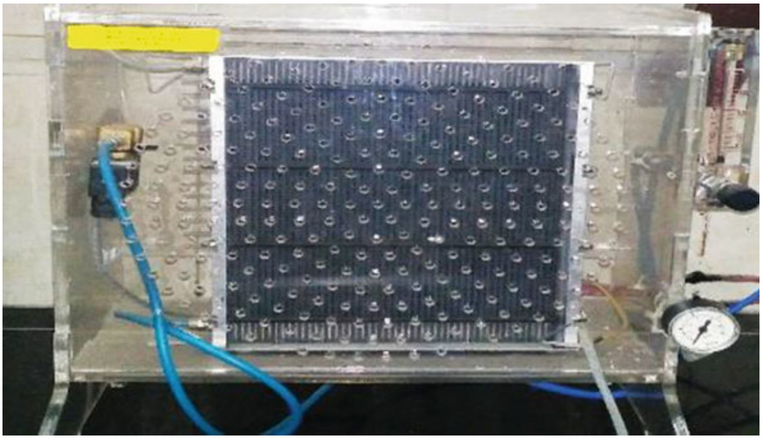

Fig. 5 Fuel cell

Table 4 Fuel cell specification

S. no	Components	Specifications
1	Type of fuel cell	PEM
2	Number of cells	48
3	Rated Power	1000 W
4	Hydrogen supply valve voltage	12 V
5	Purging valve voltage	12 V
6	Blower voltage	12 V
7	Reactants	Hydrogen and air
8	External temperature	5–30 °C
9	Max. stack temperature	65 °C
10	Hydrogen Pressure	0.45–0.55 bar
11	Stack weight	4000 g(±100 g)
12	Controller weight	400 g(±30 g)
13	Dimension	(23.3 × 26.8 × 12.3)cm
14	Flow rate of gas at max output*	13 L/min
15	Start-up time	≤30S
16	Efficacy of stack	40% @ 28.8 V
17	Minimum voltage shut down	24 V
18	Maximum current shut down	42A
19	Maximum temperature shut down	65 °C

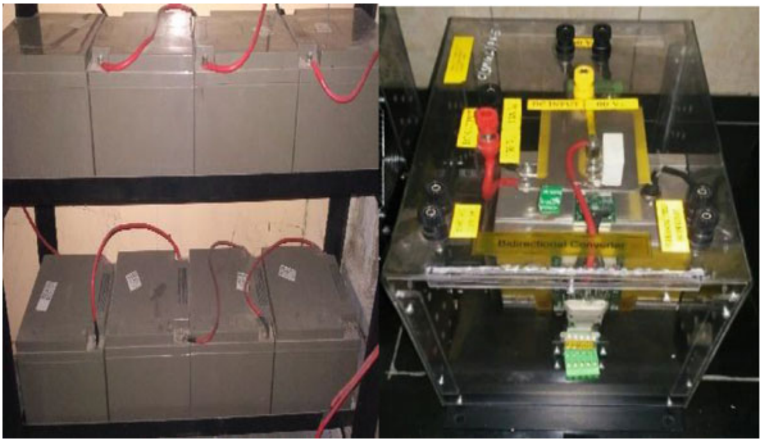

Fig. 6 Battery bank with bidirectional converter

Table 5 Battery bank and bidirectional converter

S. no	Component	Specification
1	Battery bank • Voltage • Capacity • No. of batteries • Battery type	12 V 24 Ah 8 in series Lead acid sealed battery
2	Bidirectional converter • Converter input voltage • Output voltage • Output current • Converter switching frequency	105 V (Battery Side) 150 V (Inverter Side) 10 A 20 kHz

The network can be connected more than one energy source just by controlling and interfacing the specific on-off switches [13, 25, 26].

In stand-alone mode, the microgrid is separate from the main grid and both types of load can be get supplied either AC or DC. In the on-grid mode, the microgrid is connected through the bidirectional converter to power grid [27]. The detail about the system is explained below.

A. *Stand-alone DC/AC system*

In stand-alone Hybrid System, Solar PV emulator and a Rooftop solar PV acts as a DC source, which is coupled to DC link through boost Converter. A Wind Turbine Emulator with a three-phase rectifier also acts as a DC source which is coupled to DC link with a buck Converter. Battery power Bank is also connected to the DC Link through the bidirectional converter and similarly, Fuel Cell also acts as a DC source which is connected through Boost Converter with DC link. All these DC sources connected at DC link makes a DC Microgrid. We can supply power to DC load by connecting load through a voltage regulator with a DC link. To supply power to AC loads, first, we use an inverter to convert AC into DC and then fed to AC load.

B. *Grid-connected system*

Schematic diagram of solar PV emulator and wind emulator system based DC microgrid in a grid-connected mode including the battery storage and fuel cell has been shown in Fig. 1. The DC microgrid system or comman DC link is connected to the power grid through voltage source converter (VSC). Grid-connected based VSCs play an important role in synchronizing DC microgrids with the AC grid. The DC voltage of wind and Solar PV (Photo Voltaic) system is connected to common dc link and then DC link interfaces with the grid through VSC (or inverter) and supplies wind and solar power to the power grid. In the proposed system again two combinations are there in which one system is with battery and another system is without battery. In without battery system, grid maintains the DC link voltage and grid bear all switching losses. VSC synchronizes DC microgrid with the power grid and supplies all wind and solar power to the grid while in the battery system, grid maintains the DC link voltage. VSC synchronizes DC microgrid with the power grid and supplies battery power along with all wind and solar power to the power grid and bidirectional converter control can charge or discharge the battery.

5 Designed Experiments

In this manuscript, various exermients depends on various possibale combination of available power generating components are designed.

1. To Demonstrate the Fixed Mode, Table Mode and Simulated Mode of Solar PV Emulator with all the three configurations (Independent, Series and Parallel).
2. To demonstrate I–V curve of a Switched Mode Power supply with varying load.
3. To demonstrate the I–V and P-V characteristic of a Solar PV module with varying radiation and temperature level.
4. To demonstrate the I–V and P-V characteristics of series and parallel combination of PV modules.
5. To show the effect of variation in tilt angle on PV module power.
6. Workout power flow calculations of standalone PV system with DC load and battery.
7. Workout power flow calculations of standalone PV system with AC load and battery.
8. Workout power flow calculations of Grid Connected PV system with AC and DC load.
9. Perform experiment with MPPT algorithm on Solar PV Emulator and observe the Vm, Im, Pm and duty cycle at which MPP occurs.
10. Plot the Torque v/s Speed and Power v/s Speed characteristics of the turbine at different wind speed and load configuration.
11. Plot the torque v/s speed and power v/s speed characteristics of the turbine at different pitch angle and load configuration.
12. Plot the Cp-λ curve for a particular pitch angle.
13. Evaluate Charging and discharging characteristics.
14. Using Battery Bank in Constant Voltage and Constant Current mode for charging application.
15. Study the buck and boost mode of operation of bidirectional converter in the battery back-up system, during the
    (a) Load is greater than wind turbine generation (i.e. Battery discharging).
    (b) Load is less than wind turbine generation (i.e. Battery charging).
16. Study of system performance with two renewable sources (wind and solar) connected together to form a DC micro grid with battery as the energy storage device.
17. Study of the integration of DC micro-grid to the main AC grid using a 3-phase inverter.

18. Study the operation of DC micro-grid under various load conditions by applying various DC and AC loads.
19. Study 3 phase inverter operation for an isolated Wind Turbine Emulator and PV Emulator system in stand- alone mode.

6 Conclusion

The hybrid microgrid experimental setup in the laboratory for training and nourishing our engineering students which will help them to increase their technical skill and practical knowledge. We took a different type of generating sources like a solar emulator, wind emulator, PV panels and different power back-ups like fuel cell and battery storage in our system. This microgrid can operate in both mode, such as stand-alone mode and grid-connected mode for both type of loads such as AC and DC, according to availability of power and by taking the different combination of generating sources and energy storage system further we can analyze an efficiency of different type of microgrid system and can get the best combination.

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AGC in a Deregulated Interconnected Power System with STATCOM and Energy Storage System

Rachakonda Shri Rama Akshay and Rajesh Joseph Abraham

Abstract This paper presents load following in a two area power market incorporating a STATCOM with a Battery Energy Storage (BES). The STATCOM with BES operates in parallel with the generating units in both the control areas. The bilateral contract violation has been defined using a DISCO participation matrix and Area Contract Error participation factors. The appropriate control action is taken by an integral controller to minimize the frequency error. The integral gain values are optimized by Genetic Algorithm (GA). The dynamic performances of the system with and without STATCOM and BES are obtained by using MATLAB/ SIMULINK simulations and are presented in this paper. The results show improvement in the dynamic performance of the system in terms of lesser overshoot and faster settling time.

Index Terms Bilateral contract violation · Grid connected converter · Deregulation · Genetic algorithm · Area control error · DPM

Abbreviations

f	Nominal system frequency (Hz)
Δf	Deviation from nominal frequency (Hz)
$B1$, $B2$	Area Frequency Bias factors
K_{i1},K_{i2}	Controller Integral Gains.
$R1$, $R2$	Governor speed regulation parameters
T_{Gi}	Generator time constants (sec)
T_{RHi}	Reheat turbine time constants
K_{p1},K_{p2}	Power System Gains
T_{p1},T_{p2}	Power System time constants (sec)
T_{12}	Synchronizing Coefficient
P_{R1}, P_{R2}	Rated area capacities

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apf_i	Area participation factors
P_{Ti}	Turbine power output deviations (pu MW)
P_{Mi}	Generator power output deviations (pu MW)
P_{tie12}	Tie line power change (pu MW)
P_{D1}	Power disturbance in Area 1
P_{D2}	Power disturbance in Area 2
cpf_{ij}	Contract Participation Factors

1 Introduction

In an interconnected power system, maintaining frequency within standard limits is essential for its normal operation. The imbalance between generation and load demand causes frequency instability due to which the frequency can't be retained to its nominal value. The frequency reduction in a power system leads to increased magnetizing currents in transformers and induction motors, thus demanding more apparent power. This prompts further load demand and drop in frequency. To operate power system in normal state, generation is controlled to meet the gap in demand and generation. The control is of hierarchical nature. The primary control is done by governor and turbine set. The load demand can be shared by one or many generators while maintaining the system frequency under nominal value. This control is suitable for a single area where all the generators are in unison. In a multi area interconnected system, a secondary control known as Automatic Generation Control (AGC) controls the generation economically by opting suitable Area Participation Factors (apf). The emergency control is taken as a last resort; it is achieved by under frequency relays which results in load shedding. In this structure the large utilities holds the authority on tariffs and power availability [1]. The lack of competition and a limited number of market players left customers with no options to choose service providers. Thus, customer is obliged to pay for the inefficiency and financial loss of the utilities. In order to increase competition and provide customers with more options deregulated power system is opted. In deregulated power system new entities emerged such as GENCOS (GENeration Companies), TRANSCOS (TRANSmission Companies), DISCOS (DIStribution Companies), ISOS (Independent System OperatorS), RESCOS (Retail Energy Service CompanieS) etc. [2, 3]. In a deregulated power system, a customer in a particular area has independence to select GENCOs from different area. This retail service is provided by RESCOS. ISOS controls and monitors the the power flow and transaction between the GENCOS and consumer.

In a deregulated power system the power flow in the grid largely depends on the power transfer capability of trans-mission line [4]. To utilise transmission line with its full capacity FACTS device were introduced. The FACTS devices are capable of damping power oscillations, compensate active and reactive power [5]. Recent developments in Energy Storages such as Battery Energy Storage (BES), Super Magnetic Energy Storage (SMES), Flywheel Energy Storage and Ultra Capacitors have led to improve the frequency stability of the power system [6] using Sine–Cosine algorithm (SCA). Genetic Algorithm (GA) provides robust search in complex search spaces than SCA [7, 8]. GA is a random search methods which follows probabilistic rules.

In this paper, STATCOM with Battery Energy Storage is applied to a deregulated power system. The controller gain parameters are obtained by GA. The section II presents converter modelling. The controller tuning by GA is presented in section III. Bilateral contract violation case is considered in this paper and presented in section IV. The simulation results obtained by MATLAB/SIMULINK is presented in sect. 5.

2 Grid Connected Converter Model

A GCC constitutes an active power source (battery) and a STATCOM. STATCOM is a shunt connected FACTS device which injects current in the transmission line to regulate volt-age and reactive power. The model and control of STATCOM in a power system for voltage support is presented in [9]. If an active power source is connected with STATCOM then it is possible to exchange active power with power system [10]. The dynamic model is used to analyse small signal stability in [11–14].

If an active power source is connected with STATCOM then it is possible to exchange active power with power system [10]. The dynamic model is used to analyse small signal stability in [11–13] and [14]. A linear time invariant model is derived and frequency control is achieved by a current controller to improve the frequency oscillations. In this paper, the STATCOM and BES is modeled as LTI transfer function and the parameters are given in (Tables 1 and 2).

In Fig. 1, the schematic diagram of grid connected converter is shown in which a BES is operating along with a STATCOM. The STATCOM with BES is modeled as a gain (K_{GCC}) and time constant T_{GCC} in Fig. 2. The droop logic is used to obtain active power reference. The relation between active power and frequency is given by droop logic as

$$\frac{\Delta f_1}{f_{no\min al}} = \frac{\Delta P_{active}}{P_{ratedactive}} \tag{1}$$

Table 1 Genetic algorithm parameters

Population	100
Number of iterations	100
Crossover rate	0.8
Elite count	10
Initially penalty	10
Penalty factor	100

Table 2 Thermal system and GCC parameters [21]

Rated area capacities (P_{R1}; P_{R2})	1200 MW
Generator gain constants(K_{p1}, K_{p2})	120 Hz/pu
Generator time constant (T_{p1},T_{p2})	20 s
Turbine time constant (T_{T1},T_{T2})	0.3 s
Governor time constant (T_{G1},T_{G2})	0.08 s
Speed regulation (R_1, R_2)	2.4 Hz/pu
Frequency bias constant (B_1,B_2)	0.4251 MW/Hz
Synchronizing coefficient (T_{12})	0.0866 MW/rad
GCC gain (K_{GCC})	0.033 pu MW/Hz
GCC time constant (T_{GCC})	0.01 s

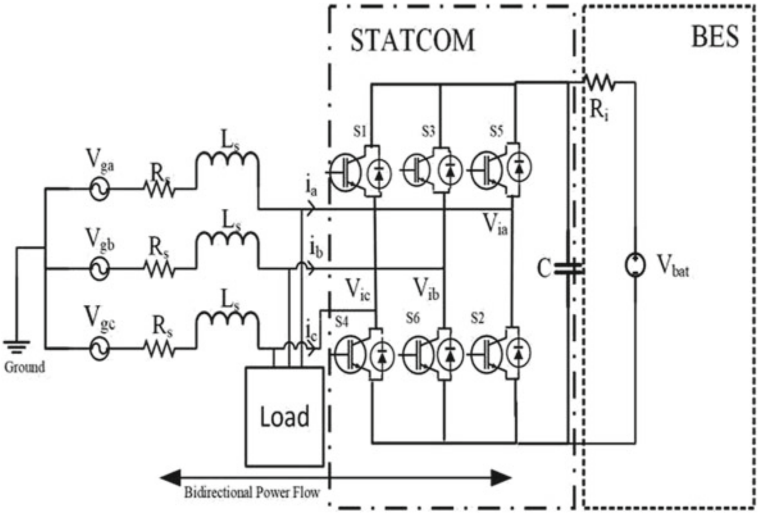
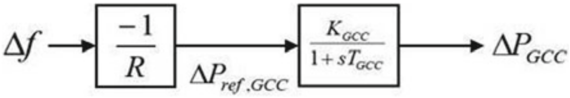


Fig. 1 Schematic diagram of grid connected converter

Fig. 2 Grid connected converter



3 Genetic Algorithm Tuning

The goal of optimization algorithms is to try to find the best solution available. The optimization methods are generally classified as deterministic optimization or stochastic optimization [15]. It is better to use deterministic methods when the system data is known accurately. As in most of the cases the system data is prone to vary, the stochastic algorithm are preferred. Another advantage of stochastic algorithms are that they are governed by probability distributions and the likely result can be estimated. For bounded search space the stochastic algorithms are more robust [16, 17]. Genetic Algorithm begins with producing a random set of individuals (population) [18]. These sets are initial solutions for the optimization problem. The fitness of each candidate in population is calculated by a fitness function. In GA, the populations are encoded firstly. Different encoding techniques are available such as binary encoding, permutation encoding, value encoding and tree encoding. This process breaks the decimal or real value into a string of bits known as chromosomes and each bit is called gene.

$$\frac{\Delta \mathrm{P_{GCC}}}{\Delta f} = \frac{\mathrm{K_{GCC}}}{1 + \mathrm{sT_{GCC}}} \tag{2}$$

The execution of algorithm is faster with binary encoding than working with decimal values. The fitness of each candidate is evaluated with the fitness function. GA selects the fittest of the candidates for breeding next generation population. To choose a selection strategy, the time taken for optimization and the size of population has to be considered. The comparison between available strategies such as linear rank based selection, tournament selection or roulette wheel based selection is presented in [19]. The selected candidates undergo crossover operations. A crossover operator recombines the genes of a pair from the selected candidates. Depending on the location of the crossover points the crossover over operation is classified as single point crossover, two- point crossover and uniform crossover [20]. The number of candidates to be generated from crossover is predetermined by crossover rate. When the crossover is completed, some random candidates are selected and their genes are inverted, this is a mutation operation in which from a selected site a gene is changed. The new population is again tested for their fitness and this iteration continues until the stopping criteria is met. The fitness function is given as

$$J = \int (\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tie12}^2) dt \tag{3}$$

In this paper MATLAB/SIMULINK optimization toolbox is used to obtain integral gain constant and minimize the above function. The GA parameters used are given in Table 1.

4 Deregulated Two Area Power System with GCC

A STATCOM and a BES operates in parallel with two thermal reheat generating units in area 1 and in area 2. The deregulated power system model with GCC is depicted in Fig. 3.

In this paper we consider a case where DISCOMs and GENCOs in area 1 are in a bilateral contract violation with GENCOs and DISCOMs in the area 2. Under

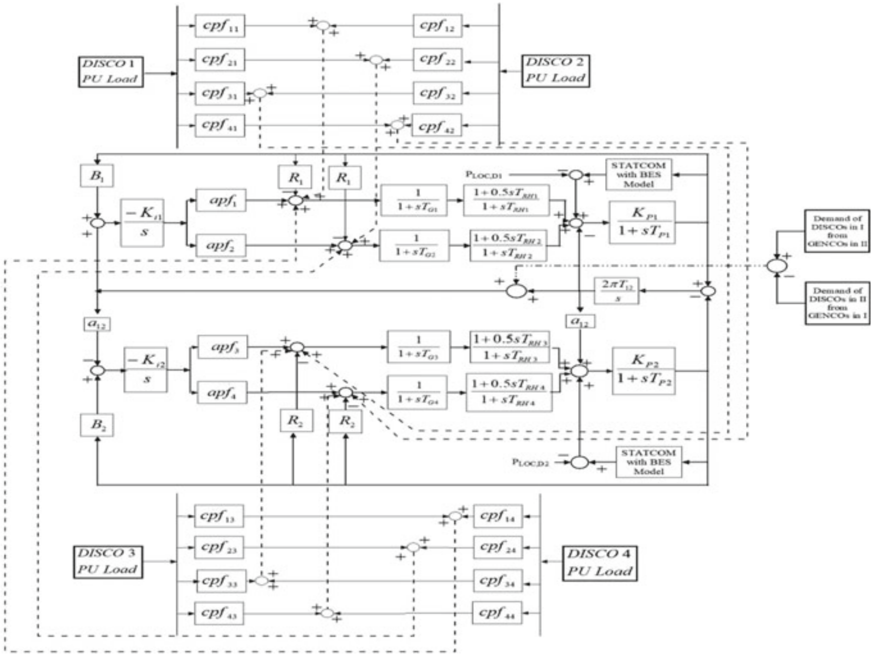


Fig. 3 AGC block diagram with GCC in area 1

this scenario, a DISCOM can contract load from GENCOs of its own area as well as, GENCOs of other areas. ISO supervises the contracted power flow, for which operator has to control ancillary services.

The generation from each GENCO depends on the load contracted with individual DISCOM. The contracted load from each DISCOM is estimated from a DISCO Participation Matrix (4). Contract Participation Factor (cpf_{ij}) is the contracted load between ith GENCO and jth DISCOM.

$$\mathrm{DPM} = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix} \tag{4}$$

The power generated by each GENCO is given from Eqs. (5–8).

$$P_{M1} = cpf_{11}P_{L1} + cpf_{12}P_{L2} + cpf_{13}P_{L3} + cpf_{14}P_{L4} \tag{5}$$

$$P_{M2} = cpf_{21}P_{L1} + cpf_{22}P_{L2} + cpf_{23}P_{L3} + cpf_{24}P_{L4} \tag{6}$$

$$P_{M2} = cpf_{21}P_{L1} + cpf_{22}P_{L2} + cpf_{23}P_{L3} + cpf_{24}P_{L4} \tag{7}$$

$$P_{M4} = cpf_{41}P_{L1} + cpf_{42}P_{L2} + cpf_{43}P_{L3} + cpf_{44}P_{L4} \tag{8}$$

Unlike conventional power systems, where AGC maintains zero deviations in tie line power flow, the change in tie line power flow is maintained at scheduled value in deregulated environment as.

$P_{tie12\ scheduled}$ = Demand of DISCOs in area 2 from GENCO in area 1–Demand of DISCOs in area 1 from GENCO in area 2.

Scheduled tie line power and frequency bias forms Area Control Error (ACE). The control action is taken by an integral controller. The load sharing of individual generator is then decided by Area Participation Factor (apf). Each DISCOM demands 0.1 pu from the GENCOs.

From above equations $P_{M1} = 0.105$ pu MW, $P_{M2} = 0.045$ pu MW, $P_{M3} = 0.195$ pu MW and $P_{M4} = 0.055$ pu MW.

For $apf_1 = 0.75$, $apf_2 = 0.25$, $apf_3 = 0.5$ and $apf_4 = 0.5$.

$$DPM = \begin{bmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{bmatrix}$$

5 Simulation Results

The simulation results for the bilateral contract violation case is presented using above DPM in Figs. 4, 5, 6, 7, 8, 9, and 10. The deviation in frequency of area (f_1)

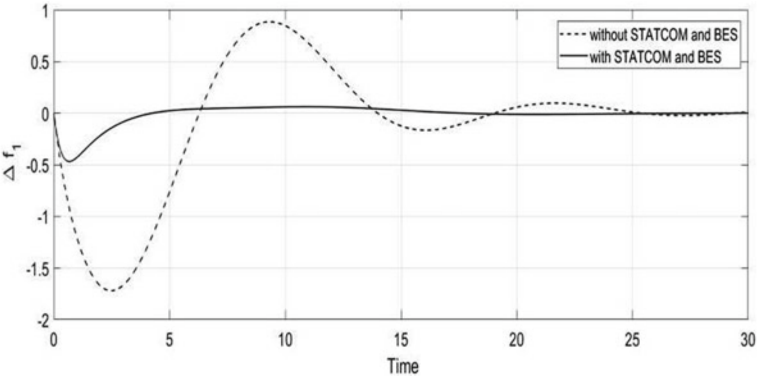


Fig. 4 Deviations in Frequency in Area 1

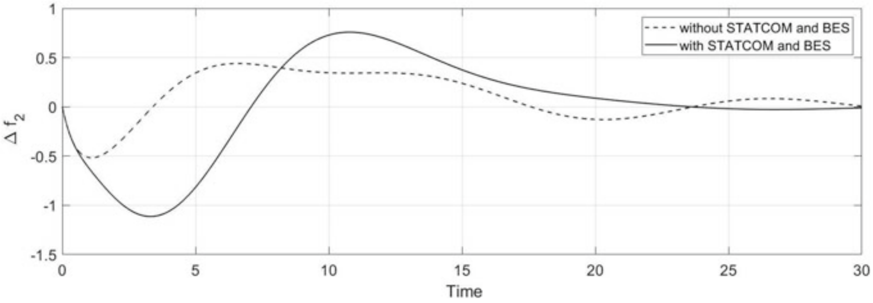


Fig. 5 Deviations in frequency in area 2

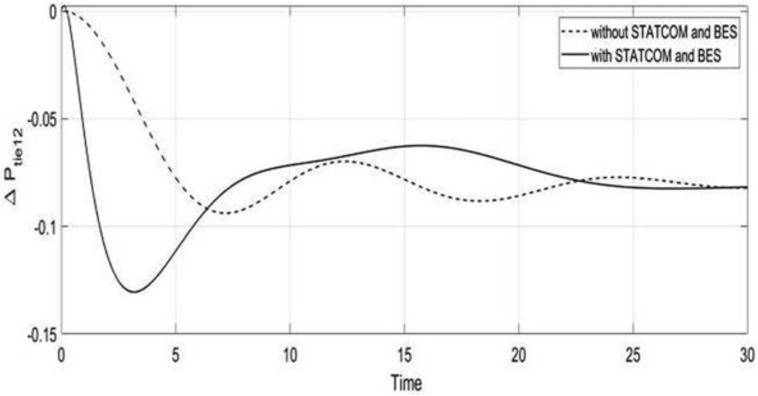


Fig. 6 Deviations in tie line power

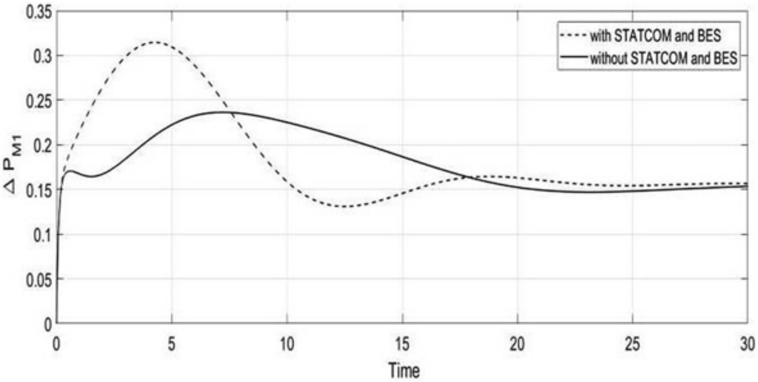


Fig. 7 Deviations in power generated by unit 1 in area 1

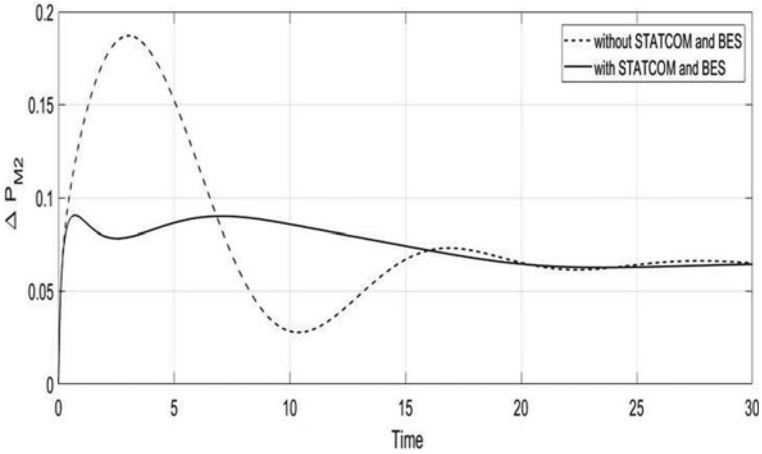


Fig. 8 Deviations in power generated by unit 2 in area 1

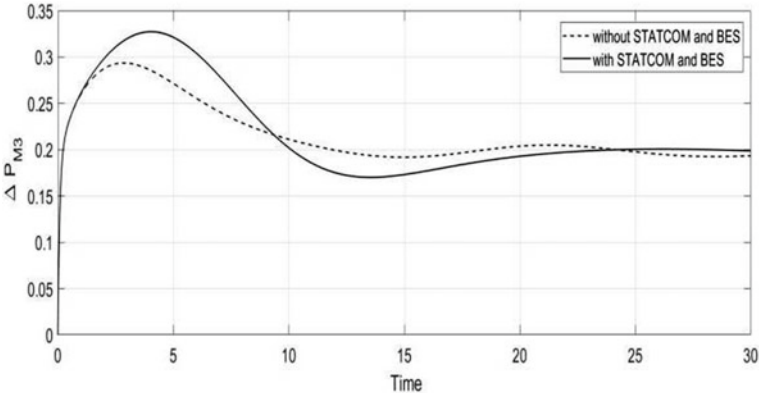


Fig. 9 Deviations in power generated by unit 3 in area 2

and area 2 (f_2) are presented in Figs. 4 and 5 respectively. The GCC in area 1 and area 2 delivers the power to load thus effectively damping the frequency oscillations quickly. Fig. 6 is the deviations in scheduled tie line power flow ($P_{\text{tie12 scheduled}}$). Figs. 7 and 8 depict the change in generation by units 1 and 2 (P_{M1}, P_{M2}) in area 1. The expected change in power generated by unit 1 in area 1 can be calculated by (5) as, $P_{M1} = 0.5 \times 0.1 + 0.25x0.1 + 0x0.1 + 0.3x0.1 + 0.5x0.1$. The deviation in power generated by unit 1 and unit 2 in steady state are 0.155 pu MW and 0.095 pu MW respectively. The deviations in power at steady state is then calculated as per equations (12–15). Figs. 9 and 10 show the change in power generation (P_{M3}, P_{M4}) in area 2, when each DISCOM is demanding 0.1 pu MW power. The steady state power deviation of unit 3 and 4 are 0.195 pu MW and 0.055 pu MW.

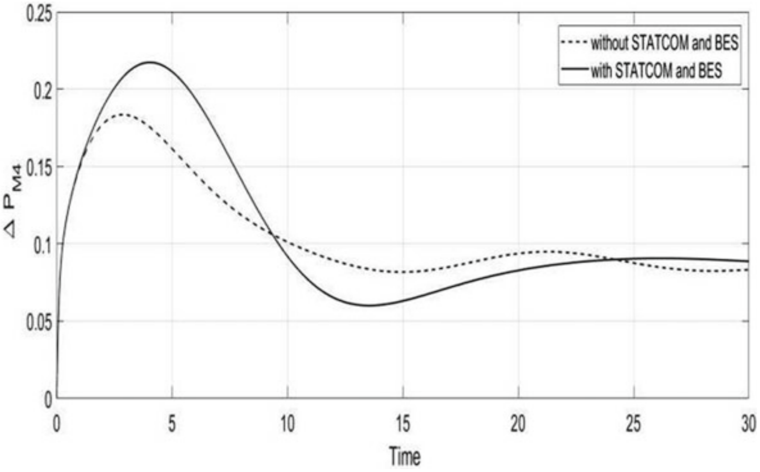


Fig. 10 Deviations in power generated by unit 4 in area 2

6 Conclusion

In this paper, the dynamic responses of a two area deregulated power system under bilateral contract violation, incorporating a STATCOM and BES is presented. The results show improvement in the transient frequencies and power deviations with STATCOM and BES operating in parallel to the generating units in area 1 and area 2. The analysis of the two area deregulated power system is done by LTI modelling and the non linearities are neglected. GA searches the fittest integral gain values to optimize the cost function. Results using MATLAB/ SIMULINK show faster settling of deviations and lower overshoots in the responses with STATCOM and BES.

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Critical Infrastructure Asset Discovery and Monitoring for Cyber Security

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Abstract With ever growing cyber threats on critical infrastructures, need of deploying the security measures to protect these should be of utmost priority. However, without knowing about the assets in the network and what needs to be secured, all the threat modeling activities, strategies or mitigation/remediation activities will be incomplete or ineffective. Hence the critical infrastructure asset discovery and monitoring is a vital part for providing security. But unlike IT networks where asset discovery is automated, critical infrastructures often perform asset discovery and management manually which leads to incomplete and inefficient asset tracking and management over time and makes it ineffective in quick identification and response to potential threats. An automated approach for asset discovery and management is significant to secure critical infrastructures from cyber security incidents and other threats. This paper proposes an automation methodology for asset discovery, managing and monitoring. The solution is compliant to several NERC-CIP requirements and NCIIPC guidelines. It involves identification and real time monitoring of the critical assets connected to the network, baseline network behavior, maintain repository of asset details, compliance check adhering to policies and generates real time network map for visualization in the Purdue model for the better management of the assets. And it also generates incidents compatible with third party SOC/SIEMs. The solution helps to reduce the risk of cyber security incidents in critical infrastructures.

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1 Introduction

Critical infrastructures such as power grids are the key assets for a nation to function. These critical and massive infrastructures are monitored and controlled by Industrial Control Systems (ICSs). ICS is a general collective term for information systems used to control industrial processes such as power transmission and distribution. ICS is a network of hardware and software components built to electronically manage tasks efficiently. The evolution of Information Communication Technologies (ICT) made it feasible and convenient to control critical infrastructures (CIs) remotely using ICS. As a result, ICS and ICT systems have converged. This strong correlation between ICS and ICT comes at the cost of increased complexity, and as a consequence increased risks of accidental faults and targeted cyber attacks [1]. The impact of an ICS incident can be far greater, causing not only disruption to business operations and services but also potential damage and destruction of equipment, and injury to people. With the superposition of ICT over the ICS, confidentiality, integrity, accountability and availability of the system have become critically important in today's scenario.

From the year 2010, researchers detected malwares [1] such as stuxnet, duqu, night dragon which targets critical infrastructures. These worms infected regular operations of the system. The attacks on Ukraine's power industry shows that the attacker could also control the devices using resources at the control center. These incidents show the importance of mitigation of threats at early stages. This, in turn, emphasizes the need for deep visibility of the system to manage and monitor assets across the facility which helps knowing what system assets (including DCSs, PLCs, controllers, network devices) lie within the facility and the assets that can compromise the system can be monitored and protected.

According to survey respondents, increased visibility into control system cyber assets and configurations is the top initiative organizations are budgeting [2] these days, in order to properly secure an existing ICS installation. The deep visibility into the system helps in thorough understanding of the system to quantify the risk and establish an adequate defence strategy. But what does "visibility-into-system" mean?. The answer is having complete knowledge of the network topology, along with all the computing devices in the system that can compromise the system and configuration details of each device, such as vendor, model, location, software and firmware version, date of patching, compliant protocols, TCP/UDP ports (if any), etc.. These are the typical tasks performed by the asset discovery and management tools to be adapted into the critical systems. These tools can be compliant to critical infrastructure protection (CIP) guidelines such as NERC-CIP [3] requirements and NCIIPC CIP [4] guidelines.

The paper proposes a methodology for device discovery, management, and security monitoring for ICS. Where it scans for devices in the network, creates repositories of their inventory such as device location in the network, vendor, model, etc., and base lines the behavior of each asset in the network and specifications for threat detection. It employs hybrid (both active and passive) scanning techniques for device and network topology discovery and uses passive monitoring technique for monitoring security events in the network to detect and alert the operator. The alerts generated are compatible to third party SIEM/SOC tools. And the solution is compliant to some of the NERC-CIP and NCIIPC critical infrastructure protection requirements.

Rest of the paper is organized as follows: Section II describes the need for asset inventory and monitoring in ICS, Section III provides an introduction to NERC-CIP and NCIIPC Critical Infrastructure Protection (CIP) compliance standards. Section IV describes methodology proposed for automated asset discovery and monitoring and its use cases. Section V describes how the proposed solution complies with NERC-CIP [3] and NCIIPC [4] requirements. And finally Section VI lists some of the challenges for implementation of the solution.

2 Need for Asset Discovery and Monitoring

It will be virtually impossible to assess risk and apply effective defence without an accurate and up-to-date inventory of assets in the ICS. An automated asset management process [5] is important to maintain the operational safety and reliability of the system, the process allows the managers to maintain good visibility [6] of their computing infrastructure to track changes made to devices, to perform threat mitigation tasks, restore misconfigured devices to a good state, and perform a planned maintenance schedules. Hence supports the ICS owners to achieve safety, security, and financial requirements. These automated asset discovery and monitoring maintain an up-to-date inventory of manufacturer, type, model, location, functions, and current configurations such as current versions of software and firmware running, time of last update, maintenance or replacement, etc. for every hardware and software components in the network.

Asset discovery and management along with security monitoring on each device is essential for ICS networks to meet their security needs. They help organizations to quickly identify assets that require patching, upgrade, replacement, or maintenance, etc. to avoid security risks they pose. Security monitoring on each asset helps to detect malicious anomalies in the network based on the inventory data of particular asset and known network behavior. For example, quick identification of asset that changed its “known-good” present state is essential, to avoid the risk and reduce the impact of the security events caused by the device. Along with repository of asset details, baselining (also called white-listing) of network behavior of each asset is essential to monitor the health of each device to quickly recover from cyber-attacks and unauthorized changes to devices, hence minimizing the impact on operations and security of the system to ensure the security. For example, network traffic from/to an IEC-60870–5-104 protocol compliant RTU should be only on RTU ports 2404 (reserved port for SCADA operations) or 80 (for RTU configurations), traffic on any other TCP ports can lead to suspect an abnormality in the asset and should be immediately detected, alerted and visualized.

3 “NERC-CIP Requirements” and “NCIIPC Guidelines”

The North American Electric Reliability Corporation Critical Infrastructure Protection (NERC-CIP) [3] is a plan consisting of a set of requirements to secure the bulk power systems. To accomplish security across the power sector, NERC has issued a series of Critical Infrastructure Protection (CIP) Reliability Standards that serve as the minimum security requirements [7] for power generation, transmission and distribution enterprises. It includes guidelines for testing and prevention of security issues of critical cyber assets in bulk electric systems. Each standard has a set of requirements covering the electronic perimeter security and critical cyber asset protection, along with personnel and training, security management and disaster recovery planning.

Protection of Critical Information Infrastructure (CII) is of paramount concern to governments worldwide [4]. To address these security threats, the Government of India has notified the ‘National Critical Information Infrastructure Protection Centre’ (NCIIPC) [4] as the nodal agency vide Gazette of India notification on 16th January 2014. NCIIPC released a document listing forty controls and corresponding guiding principles for the protection of CIIs. In view of the dynamic nature of cyberspace and to ensure the continued relevance of these controls, NCIIPC is continuously reassessing these based on ongoing experience as well as feedback from NCII constituents.

4 Methodology for Asset Discovery and Management

Among the many cyber security challenges associated with protecting the critical infrastructure, maintaining an accurate asset inventory register and performing security monitoring of devices are the most challenging. As illustrated in Fig. 1, the proposed methodology requires the Asset discovery and monitoring device to be connected to the ICS network (that is being monitored) through a physical Switch port analyser (SPAN, also called mirroring port) [8] port of an Ethernet switch to observe the traffic on the network. For the discovery and monitoring device to be efficient, it needs complete visibility to entire network traffic, hence the device is preferably connected to a centralized Ethernet switch in each segment of the network as shown in Fig. 1, where there are five asset discovery and monitoring devices connected to SPAN port of Ethernet switches in each segment of the network. Each of these devices perform asset discovery and monitoring on their respective network segment and report their findings about the assets inventory, network topology and security alerts

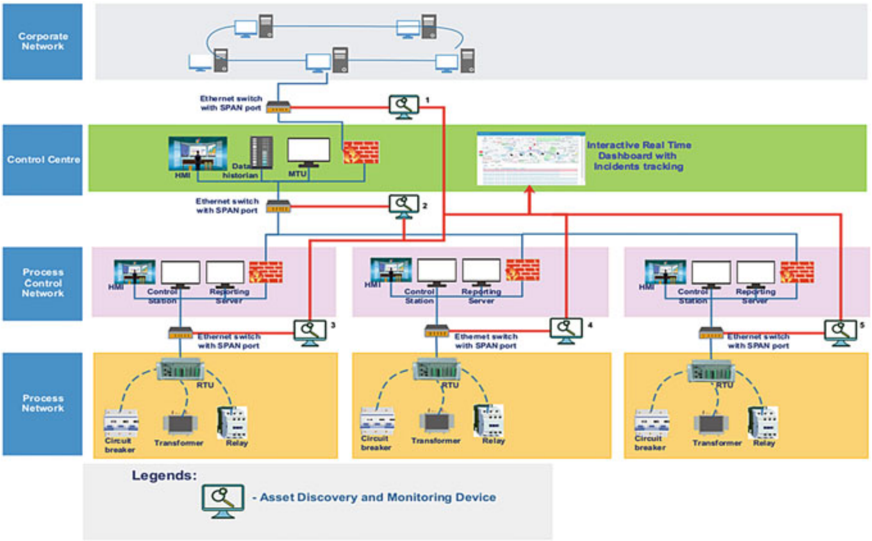

Fig. 1 Proposed methodology mapping to a typical ICS network with purdue model

to a centralized host where all the network and asset details[9] along with security alerts are visualized in an interactive real-time dashboard. The proposed methodology and the dashboard are explained in detail in the further sections. Figure 1 illustrates how the proposed asset discovery and management solution is mapped into a typical ICS network that is being monitored. The asset and network topology discovery can be performed by either active, passive or hybrid scanning methods.

A. *Active scanning and Passive scanning*

Active scanning works by sending additional traffic into the network and monitoring the resulting reply. It requires two way interaction between the scanning device and the network being monitored. Active scanning is very efficient [10] in obtaining device information. By sending packets directly to end devices makes active scanning faster but it may increase the risk of unexpected behavior of connected devices [11] upon receipt of unsupported network packet.

The passive scanning listens to the targeted network for traversing packets and analyzes all or specific types to find asset specifications and topology information. With no additional traffic inserted into the network, passive scanning virtually poses no risk of disrupting the processes, but this method may take more time to collect device data as it needs to wait for traffic from the device and needs visibility to all the network traffic.

B. *Hybrid scanning*

Both active and passive scanning methods have their own advantages and limitations [12]. The active scanner can be used to insert specified packets into the network and the passive scanner to analyze the reply packets. Making best use of both active and passive technologies can enable us to implement a fail safe approach that can maximize the visibility into the ICS environment. Following are some of the advantages of hybrid scanning technology:

(1) It provides deep visibility into the system by scanning silent devices and rogue devices that may have entry points for attacks. And such devices cannot be discovered with passive scanning alone.
(2) Adds clarity, accuracy and reliability to the inventory data with regular data refreshment.
(3) Minimizes the requirement of visibility to complete network traffic for the passive scanner.
(4) Adds flexibility for security managers to choose different approaches to different segments of the network based on the sensitivity of the network.
(5) Allows security managers to choose a fail safe approach to scan any specific device based on a specific detail of the device obtained with the passive scanning.
(6) As it inserts additional traffic into the network only at specified intervals of time, it uses a small portion of the memory and processing power. This gives room for the passive scanner and passive security monitoring.

C. *Proposed Hybrid scanning approach*

The proposed methodology for device discovery is a hybrid scanning [13, 6] method which is a balanced approach with the right mix of both active and passive scanning technologies to achieve maximum visibility without disrupting the critical processes. For hybrid scanning, the methodology employs Simple network management protocol (SNMP) [14] as an active request-packet generator for active scanning, and a passive packet capture to analyse SNMP response and several other protocol packets [6, 15] . In SNMP-enabled hosts, information is saved in management information bases (MIB). The passive scanning method that is aware of the MIBs can parse data that is relevant and produce device and topology information in an effective manner. The useful data found in MIBs can be a list of the network interfaces of the host, IP addresses, subnet masks, whether the host is forwarding packets, default TTL, IP routing tables and other information that can greatly aid the asset and topology discovery effort. The SNMP requests will be sent at regular intervals and the inventory repository is updated dynamically.

Along with the SNMP agents being captured for device specifications discovery, the passive scanning method uses some of the protocols that are an integral part of the basic network operation as a source to gather valuable information about assets and network topology [10]. The protocols include RIP, OSPF, IGRP etc. These protocols are used regularly to exchange messages that contain information about routers or other hosts and their respective subnets to which they are connected. This information is usually adequate to identify the hosts in the network and the respective subnets. The methodology also uses MAC and IP address correlation in passive scanning mode to find, if the host belongs to the same LAN to which the asset discovery and monitoring device is connected. If MAC addresses of two different packets are the same but the IP addresses in the packets are different, then the hosts are part of some other LAN. And it uses Time to live (TTL) value in the IPv4 header to find the network distance between the asset and the asset management device i.e., how many hops away the asset is.

As the devices/assets are discovered, a repository of their inventory details such as vendor, model, asset category, OS type, software and firmware versions, compliant application layer protocols, etc. are maintained and dynamically updated along with the baselined network behavior for each device, such as average packet rate on that device, etc.. This process is referred to as *white-listing*.

D. *Cyber monitoring*

This module of the solution runs along with an asset discovery module in the same physical device. It is a passive monitoring solution [16] that uses the asset inventory and base-lined network behaviors as white listed signatures to detect anomalies in the network such as unknown hosts, change in device configurations, removal of devices, adding new devices, non functional devices, etc.. For example, a vendor implanted malware on RTU triggers on a specific time event to open a tcp port 8080 to open RTU for an unauthorized communication. As the monitoring module captures packets that originated or directed on the RTU port 8080, the port number 8080 is mapped against a list of white listed ports for particular RTU from the inventory, and triggers an alarm about the unauthorized access to an unauthorized port opened on RTU. This found malicious behavior is alarmed and visualized to the operator using an interactive real-time dashboard with alert severity levels.

E. *Real Time visualization*

All assets, their communications and their inventory details along with the network topology including geo locations are visualized using purdue model in an interactive network map referred to as real-time-dashboard, where the user can view the details about the device inventory, how and where it is located in the network, and its behavior pattern. Alerts and alarms will be generated upon violation of baselined white-list rules. These alerts and alarms are visualized as risk prioritized Incidents, Events and Alarms. Where Incidents indicates high risk level alerts, Events and Alarms indicate medium and low risk level alerts respectively. Using real-time-dashboard operators can perform incident tracking, and it can also offer real time data streaming.

F. *Integration with SOC/ SIEM*

Any reported threats/ incidents are reported in the common event format suitable for existing SOCs/ SIEMs. Common Event Format (CEF) is a Logging and Auditing file format from ArcSight [17] and is an extensible, text-based format designed to support multiple device types by offering the most relevant information. Message syntaxes are reduced to work with ESM normalization. Specifically, Common Event Format defines a syntax for log records consisting of a standard header and a variable extension, formatted as key-value pairs.

G. *Use cases*

- Devices will be monitored continuously and reported if any change in device configurations, new devices added to the network, removal of devices, non functioning of devices, deviation in normal behavior of devices, malicious traffic in the network, change in network topology, etc.. The alarms will be generated to notify the operator using a real-time dashboard at the control centre.
- Detects when communication between devices ceases., to help diagnose a broken link or down interface.
- Detects unauthorized communication with devices.
- Detects and raises alarms upon failed or successful remote or local logins into an RTU or the process network. Monitors the function codes sent to RTU and mapps with the whitelisted function codes to detect anomalies.
- Malformed ICS protocol packet sent to master with an advanced level of identity spoofing can be detected as the solution made aware of the utilized control system protocols [18] such as MODBUS, IEC-60870–5-104, etc. Hence the solution is able to detect a wide variety of malformed packets.
- The solution allows incident tracking, where organizations can identify, store, and retrieve incidents over time. It also supports events backtracking to find what are the events that lead to the reported incident, and also provides a log of packets captured during the time of the incident.

5 Compliance to Standards

Following are some of the NERC-CIP [3] requirements under CIP standards, and NCIIPC guidelines that the proposed asset discovery and monitoring solutions would comply with. These NERC-CIP standards push utilities to have more cyber control of their equipment. NERC-CIP [7] meant to prevent an attack that could endanger the bulk electrical systems by ensuring the security of critical cyber assets and thus the electrical reliability. In Indian context, NCIIPC makes guidelines to facilitate safe, secure and resilient Information Infrastructure for Critical Sectors of the Nation [4]. Hence it is necessary for any method that claims ICS security to comply with such security standards.

A. *NERC-CIP requirements*

See Tables 1, 2 and 3

B. *NCIIPC guidelines*

See Tables 4 and 5

Table 1 Requirements Under CIP-002–5.1A

Standard: CIP-002–5.1a - (BES cyber system categorization)	
Requirements (R)	*Functionalities of the proposed methodology to meet the requirement*
R1.1. Identify each of the high impact BES Cyber Systems (electronic or physical list)	Generates an inventory of all active network assets. The inventory includes comprehensive details of each asset, including IP address, host name, vendor and model, OS version, firmware version of all IT/ICS devices, and the device's software information. All assets and their communications along with the inventory details are visualized in an interactive network map
R1.2. Identify each of the medium impact BES Cyber Systems (electronic or physical list)	
R1.3. Identify each asset that contains a low impact BES Cyber system	

Table 2 Requirements Under CIP-005–5

Standard: CIP-005–5–(electronic security perimeters)	
Requirements	*Functionalities of the proposed methodology to meet the requirement*
R1.1 All applicable cyber assets connected to a network via a routable protocol shall reside within a defined ESP	Methodology used in: identifying ESPs, determining which assets are connected to a network and reporting assets violating this requirement
R1.2 All external routable connectivity must be through an identified electronic access point (EAP)	The network map allows you to easily identify and visualize all communication between assets, which helps ensure that all the communication goes through designated EAPs
R1.3 Require inbound and outbound access permissions, including the reason for granting access, and deny all other access by default	Methodology used to perform inbound/outbound network access and security monitoring. The baseline of asset information, along with the information available on the network map, can be used as evidence that only permitted access is occurring in the network. Furthermore, the baseline can be used by the built-in anomaly detection engines. Alos, visualizing this info in real time
R1.5 Have one or more methods for detecting known or suspected malicious communication for both inbound and outbound communication	
R2.1 Utilize an Intermediate system such that the cyber asset initiating interactive remote access does not directly access an applicable cyber asset	Methodology provides evidence that an Intermediate System is used for remote access to applicable assets, and that the communication up to the Intermediate System is through an encrypted protocol. This is visualized on the network map and in the automatically generated network baseline
R2.2 For all interactive remote access sessions, utilize encryption that terminates at an Intermediate System	

Table 3 Requirements Under CIP-007–6

Standard:CIP-007–6 (systems security management)	
Requirements	*Functionalities of the proposed methodology to meet the requirement*
R1.1 Where technically feasible, enable only logical network accessible ports that have been determined to be needed by the Responsible Entity, including port ranges or services where needed to handle dynamic ports. If a device has no provision for disabling or restricting logical ports on the device, then those ports that are open are deemed needed	The solution can be used to automatically identify open ports being actively used by all network assets. Users can filter the map and network baseline per port and/or protocol, to determine which asset is utilizing unnecessary/undesired services. This input can then be used by security administrators to restrict accessible ports and services on network device

Table 4 Controls Under NCIIPC-IC1

Standard:IC1: asset and inventory control	
NCIIPC controls	*Functionalities of the proposed methodology to meet the requirement*
Entire hardware inventory must be clearly marked with uniquely identifying marks (e.g. serial no., model no.) for hardware devices like servers, printers, laptops, desktops, fire alarms, access control devices, etc. Similarly, software inventories can be made listing the product name, version, Serial Number, the device on which it is installed, etc. Periodic audit of the asset and inventory management system should be conducted so as to unravel any flaws in the implementation of the asset and inventory management control. Status Reports of IT Devices may be verified periodically	Generates an inventory of all active network assets. The inventory includes all the network devices and their details such as manufacturer, model, location, current software and firmware version, date of patching, date of installation, compliant protocols, TCP/UDP ports opened (if any), etc

Table 5 Controls Under NCIIPC-OC6

Standard: OC6: asset and inventory management	
NCIIPC controls	*Functionalities of the proposed methodology to meet the requirement*
Asset inventory provides information that is important for day to day system management, CIIs asset tracking, and security incident response. An asset inventory is also important for managing maintenance, servicing, theft prevention, controlling system builds, performing regular audits/reviews, replacing faulty systems and discarding/destroying/auctioning older/faulty systems	Devise a list of authorized software and versions that are required in the enterprise for each type of systems. Devise software inventory throughout the organization covering each of the operating system types in use. The software inventory system should track the version of the underlying operating system as well as the applications installed on it. The software inventory systems is tied into the hardware asset inventory so all devices and associated software is tracked from a single location

6 Challenges

(7) *Limited CPU power of devices:* During active scanning, requests to devices should not hang the operation of devices due to limited CPU power.

(8) *Real-time communications:* Communication systems in the OT networks are very sensitive and extra caution needs to be taken before sending any packet into the network.

(9) *Prior knowledge of the network is required:* SNMP does not have the data frame defined by the protocol, instead it uses MIB. Since each network can have its own MIB, to use this information the asset discovery application should parse many different MIBs. This makes the application complex and processor intensive.

(10) *SNMP needs authentication:* Due to network administrator's strict security practices, SNMP management may not always have authorization and credentials.

(11) Security monitoring needs visibility: The device discovery and monitoring devices need to be installed at multiple locations based on the network architecture for the security monitoring module to have complete visibility to complete traffic in the network.

7 Conclusion

The need to secure Industrial Control Systems (ICS) is a paramount requirement for any critical infrastructure operators, given the widespread and growing risk of cyber threats. This leads to an obvious question, what exactly needs to be protected in the ICS?. Exploring the ways to have a better insight into what needs to be protected has shown us that the visibility into ICS endpoints are inherently poor. And as the security threat is growing, our need becomes clear to have a deep visibility into the system. Hence it is necessary to have efficient asset discovery and management technologies. Among them are the active scanning and passive scanning. Since both passive and active scanning technologies have their own advantages and disadvantages, in this paper we proposed a hybrid scanning method which is a balanced approach with the right mix of both active and passive detection technologies to achieve an efficient asset discovery and monitoring method along with reduced risk of disruption on the ICS. Typically the traffic flow in ICS is not centralized, but since the passive scanners require visibility to all the traffic traversing the network under scanning in order to provide entire network coverage, the passive scanning alone becomes inadequate and signifies the need of hybrid scanning.

Along with device discovery and management, the device inventory details and its legitimate network behavior can be baselined to use them as white listed rule sets to detect anomalous malicious network and device behavior to protect the critical infrastructures. The solution also covers some of the use cases, such as unauthorized devices in the network, unauthorized traffic in the network etc.. Since the solution is tailored towards Indian power sector critical infrastructures, making it compliant to some of the NCIIPC guidelines, and security proven NERC-CIP requirements helps to establish reliable security measures for Indian power sector critical infrastructures.

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Transforming Campuses into Grid Interactive Buildings Using PEER Strategies

S. R. Sanjay Kumar and Ishaq Sulthan

Abstract India is expected to deliver sustained, strong economic growth over the coming decade. Power sector can support this growth by accelerating the deployment of renewable energy (RE) and smart microgrids to replace the inefficient coal-based power plants and to address the rising peak demand of India. These measures need the present grid infrastructure to be modernized in order to manage grid flexibility & power reliability. Major infrastructures in India like Airports, IT Parks, Industries, etc., can help in this grid modernization by incorporating smart microgrids making them as Grid Interactive Buildings (GIBs). GIBs provide ancillary services to the grid in maintaining its frequency & creating a lower, flatter, more flexible load profile. These services can represent as an opportunity for grid operators in greater control of the power system by shaping the power demand. Additionally, GIBs with Time-of-Use (ToU) tariff results in cost savings for both grid operators and consumers. GBCI's PEER (Performance Excellence in Electricity Renewal) is a comprehensive framework that assists campuses in evaluating their power system performance and also provides strategies to achieve further improvements. This paper talks on how PEER credits like Load Duration Curve Optimization, Distributed Energy Resources and Master Controller act as a roadmap for campuses, to become better interactive with the grid and to support grid services.

Keywords Smart microgrids · PEER · Demand response · Load profile · Distributed energy resources · Grid-interactive buildings

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1 Introduction

One of India's major advantage today is that its renewable energy (RE) potential is vast, and it is one of the countries with the largest production of renewable energy. As of October 2019, of the 175 GW RE target of India, 83 GW is already operational, 29 GW is under installation and the remaining is under planning (as per MNRE's October 2019 update). The growing share of RE generation, rise in peak demand and transmission and distribution (T&D) losses are stressing the existing grid. Better integration of these RE sources with the existing grid needs grid modernization, which helps in mitigating the curtailment issues related to the RE generation. ***Smart Grid*** is an approach to modernize the present grid infrastructure by incorporating digital communication & information technology systems and automated control & monitoring infrastructure. This can integrate all types of power generation systems like solar PV, micro wind turbine, combined heat and power (CHP) systems, collectively known as distributed energy resources (DERs), with provisions for storage and can assure better power availability. Smart grid encourages the participation of customers in managing the peak demand. Campuses that are major demand-side entities such as airports, IT parks, manufacturing industries, hospitals, etc. ***contribute to more than 65% of energy consumption in India*** [1]. These infrastructures can support in the grid modernization by the integration of DERs, with technologies like master controller that manage and optimize the generation and demand of a building.

PEER is the world's first certification program that evaluates and improves the power system performance and electrical infrastructure of cities, utilities, campuses and transits. It measures power system performance based on 36 credits classified across 4 categories which are:

- Reliability & Resiliency
- Energy Efficiency & Environment
- Operations, Management & Safety
- Grid Services

This paper details the PEER strategies that provide the campuses with a framework to integrate DERs, master controller and other technologies in order to transform into a GIB.

2 Need for Grid Modernization

The term "Grid Modernization" is a common term used and difficult to define. But, in whatever form grid modernization changes may take, they all are going to solve the problems of our aging grid by:

- Improving reliability & power quality
- Improving safety & resiliency
- Increasing energy efficiency

- Improving consumption behaviors
- Reducing environmental impacts and,
- Reducing grid congestion

This requires a comprehensive transformation of the electricity system design that has remained the same for almost a century. GIBs are one such grid modernization changes that make buildings smarter, more connected to the main grid. They support in reducing grid congestion as they integrate DERs and are more energy-efficient.

3 Defining Grid Interactive Building

Moving towards the future grid, the present centralized, one-way distribution system will get transformed into a distributed, two-way power flow network as illustrated in Fig. 1. Buildings will be incorporated with DERs, electric vehicles, energy-efficient equipments, and monitoring and control systems, that have huge effects on the building's load profile on real-time. In addition to these elements, buildings with a communication infrastructure can interact with the grid to optimize its energy consumption in conjunction with the grid. These buildings are called GIBs. They are connected to the grid, featuring two-way communication of signals between buildings and the grid. These signals may directly control and monitor the loads or may indicate the grid conditions and hourly rate that can trigger the control systems to act accordingly.

GIBs provide options to increase electricity system reliability & energy affordability by integrating DERs and also support various load management programs like load shifting, demand response, ToU, etc. In countries where utilities support net metering, surplus electricity of a building can be sold back into the grid. And in countries with ToU rate structures, building operators can gain advantage by operating efficiently by managing their load based on peak and non-peak hours that help in cost savings. It is a well-known fact that peak demand charges can make up a huge portion of the overall utility bill. For a typical building with occupants, HVAC (Heating, Ventilation and Air Conditioning) systems and electronic/ mechanical equipments, there is a possibility of high variability of demand throughout a day.

GIBs are designed to create lower, flatter, flexible load curves that reduce operating costs for the buildings. For a campus, to transform into a GIB, ***analyzing the load profile is important***. It helps to measure the overall utilization and efficiency of the building's electricity demand and helps in adopting the right technologies to flatten the load profile and optimize the electrical system operation. Two main technologies that can support in this case are:

- **Distributed Energy Resources**: This paves the way to increase the percentage of electricity generated from local renewables and/ or clean generation technologies.

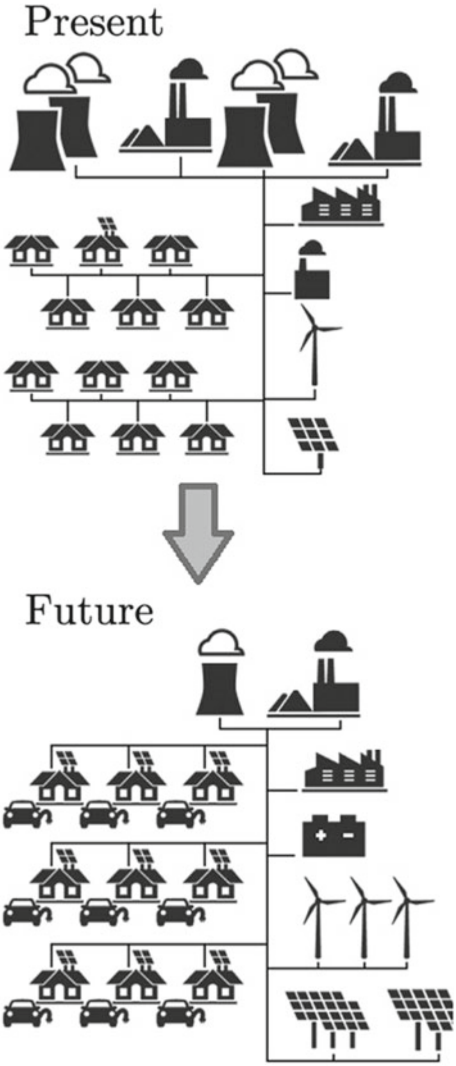

Fig. 1 Grid Modernization—Transformation from a centralized grid to a distributed grid system

- **Master Controller/ SCADA (Supervisory Control and Data Acquisition)**: This promotes adaptability through operational changes that optimize the electricity system in real-time.

These characteristics of GIBs viz. analyzing the load profile and adoption the DERs and master controller, will be discussed below in correlation with PEER strategies.

4 PEER Strategies for Campuses

PEER provides a framework for campuses to transform into a GIB. The PEER credits [2] which provide the strategies that address the above characteristics of GIB are discussed below.

A. *Load Duration Curve Optimization*

PEER credit—Load duration curve optimization details on analyzing the load duration curve. The load duration curve is a graph of the variation in electricity demand. This curve plots the hourly demand, arranged along the x-axis from highest to lowest, for every hour of the year and electricity demand is shown in the y-axis. Figure 2 from [2] provides several typical load duration curves.

Generally, a flat purchased electricity load profile or a nearly straight line is considered the lowest-cost while a load profile with a "peak" much higher than the rest of the curve is generally more expensive to operate. This happens because utility companies have to invest in the infrastructure accounted for the highest demand needed on the electrical grid, so that power can be generated and delivered flawlessly.

For the campuses to analyze their load profile, they can calculate it as a percent of peak with the below-given equation:

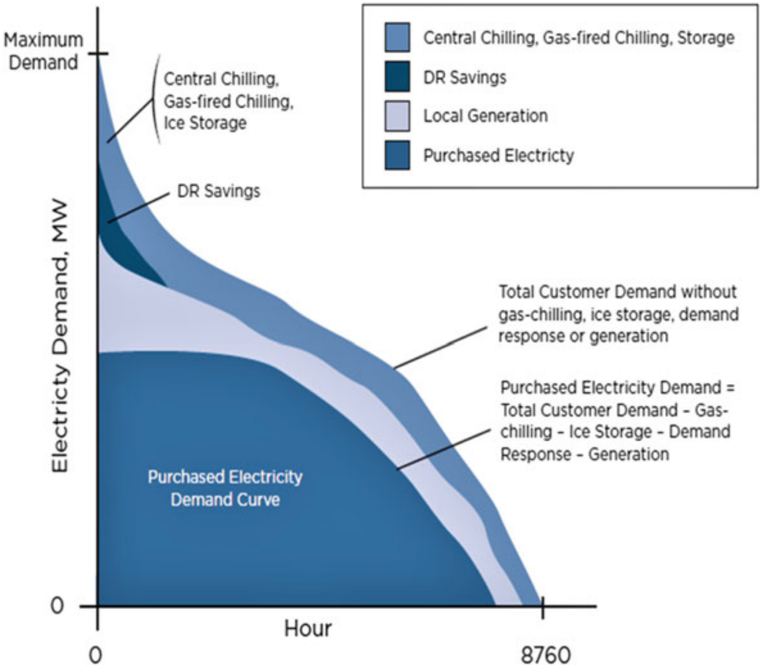

Fig. 2 Example of several typical load duration curves

$$Load\ durationpercentofpeak = \frac{E_{consumed}(kWh)}{D_{peak}(kW) \times 8760} \tag{1}$$

where:

- $E_{consumed}$ = Total annual electricity consumption of a campus in kWh
- D_{peak} = Campus peak annual electric demand in kW
- 8760 = Hours per year

Maximum is the percentage, then flatter is the load profile, which means the peak demand is equal or lesser than the maximum demand of that facility. PEER's intent here is to recognize flat, low-cost load profiles of campuses and encourage investment in solutions that will improve the load profile and lower supply and distribution costs over time.

B. Distributed Energy Resources

Part of the grid modernization plan would include consumers to invest in local clean energy resources and storage systems, collectively known as distributed energy resources. DER is sited close to customer loads that can provide power to all or some of the immediate power needs and can also be used by the system to reduce their peak demand. Examples of different types of DERs include solar photovoltaic, wind turbines, district energy system (DES), energy storage, etc.

Through PEER credit—Distributed Energy Resources, campuses can determine the local generation percentage, which indicates the percentage of campus electrical load served by local renewables and/or clean generation technologies, using which campuses can analyze the excess generation needed to support their peak demand.

Energy storage is gaining ground as an acceptable approach to increase flexibility to maintain an active power balance in the grid [3]. Campuses integrated with local energy storage can provide power to satisfy the ancillary service needs of the distribution grid such as voltage and frequency support and black start support, provided they follow the advanced standard of interconnection (IEEE 1547) [4] with the grid (Fig. 3).

They can also deliver several demand flexibility services like energy efficiency, load shifting, load shedding, etc. Figure 3 illustrates how multiple forms of demand flexibility can combine to reduce and flatten a building's demand and moderate the rate of change of its demand [5].

By shaping demand to take advantage of RE generation when it is available, we can eliminate or at least reduce the peak requirements partially. As an additional strategy, PEER also promotes the integration of the district energy system which supports both the electrical and thermal needs of a building, which may also be advantageous for a GIB.

III. Master Controller

Today's buildings are operated inefficiently with respect to energy overuse and peak time-of-use. Many loads are manually operated and left ON when not needed and

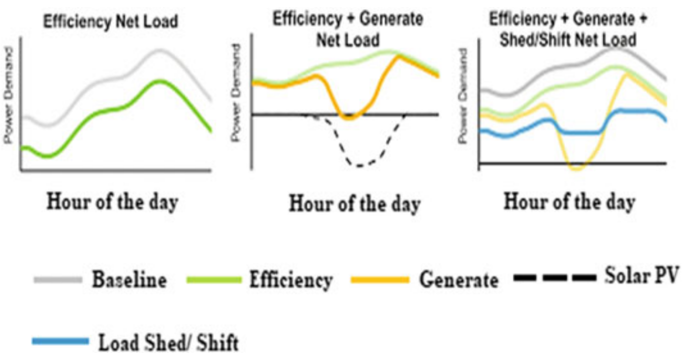

Fig. 3 Load curves of GIBs with different grid services

some spaces are overheated or over-cooled by HVAC systems. Grid modernization focuses on automation and eliminating the use of machines during higher-priced peak periods.

An optimized blend of DERs and load flexibility technologies enabled through smart controls results in a flatter, flexible load profile, which in turn delivers a more resilient and productive building. Smart controls here refers to an information technology-based control and monitoring system, that manages all the energy assets of a building as in [6]. Main elements of this control system should be:

- Host equipment (e.g., redundant servers, GUI (graphical user interface), etc.)
- Communication infrastructure for network and serial communications
- Field devices sufficient to support operation and telemetry requirements.

Master controller, an integrated set of control and management functions for power generation, distribution, and supply, is a collection of these 3 elements which supports the multifaceted nature of distribution automation and the higher-level applications of the load management system.

PEER provides campuses an approach to select/ design a suitable master controller for their facility with certain basic capabilities like - ability to remotely start/stop the local generation and control loads in more than one buildings and also some advanced capabilities like supporting demand response events, ability to detect threats to electrical system, ability to operate in islanding or grid-connected mode etc.

A benefit of having a smart technology is having the ability to access data, detailing how the electrical system functions. To be noted, data is more critical for grid modernization [7], and the master controller needs data to evaluate the utility needs. Master controller optimizes the loads through a coordinated approach to achieve demand flexibility.

Through the master controller, buildings can receive utility price signals and can share the availability of flexible loads with the utility to optimize cost, carbon, reliability and other factors, both when grid-connected and when operating off the grid i.e., islanding mode, thus supporting facility resilience too.

5 Benefits for Campuses

GIBs can provide significant value to utilities, grid operators, building owners and society at large. It supports interoperability and intelligence from building to grid and intelligence across buildings. GIBs provide an untapped source of value and cost savings for building owners. These savings come from:

- Demand reduction & shifting of time-of-use
- Avoided new generation and distribution capacity additions
- More efficient generation sources
- Reductions in T&D losses
- Emission reduction credits & alignment with corporate sustainability goals

With advanced automation schemes such as fault location, isolation and service restoration (FLISR) [8] which includes automatic sectionalizing, restoration and circuit configuration, buildings can attain the most reliable operation of their electrical network and can optimize their energy assets like lighting, HVAC, etc., which is beneficial to both the campus and the grid.

Through PEER certification, campuses can assess their whole electrical infrastructure based on a comprehensive, balanced scorecard of sustainable performance criteria and can invest in the right technology that can help in transforming into a GIB. Campuses can improve their operational process and can reduce operational failures which in turn helps in minimizing the operational cost.

6 PEER Project Case Study

A PEER gold-certified IT park in South India, encompassing three buildings in a 15-acre land, accommodates over 45 leading IT & ITES companies. In the year 2017, this IT Park recorded a peak annual demand of 11 MWs. Prior to the certification, the campus had no DERs and no automated infrastructure to monitor their electrical system and was unaware of the efficiency with which their electrical system is operating. Based on recommendations from PEER, this facility analyzed their electrical system performance and to decrease their electricity demand, they invested in a 530 kW rooftop solar PV system which made them save INR 2.5 million annually.

Also, they upgraded their facility with advanced meters and smart devices to monitor their power interruptions, electricity demand, and power quality events in real-time. This enhanced their power system performance and made their load profile more flexible by controlling their energy assets. These measures made their facility grid-interactive with interoperability and intelligence across 3 buildings.

And, as part of their sustainability initiative, they launched a web portal to share electricity bills and trends with their tenants and have granted third-party access to the portal to track and analyze the electrical system performance, promoting transparency in energy data access.

7 Conclusion

GIBs are essential to balance the electric grid as penetration rises among RE and consumer loads. A modern grid will definitely need an active shaping of consumer loads to align demand with RE characteristics. On the grid side, by supporting the load management techniques like demand response and ToU, buildings provide economic benefits to the grid by reducing their own peak demand. Achieving the benefits from the GIB transformation will be possible only if the national grid operators come up with a policy that will empower, value and engage consumers and private sector through choice, price transparency, direct access to real-time energy usage data, net-metering and payments for ancillary services. Local governments must partner with third parties in these electricity system improvements.

Even though there are barriers to implementation of GIBs like – Investment costs, lack of awareness, lack of promising data and resistance in utility engagement, certification systems like PEER can make the building owners understand the need to invest in this transformation. PEER believes that large infrastructures/ campuses are the keystones for the implementation of GIBs. Campuses can demonstrate leadership and market differentiation by providing societal benefits including lower generation capacity, lower T&D infrastructure costs, which drive capital cost & operational savings for all grid users. Already decarbonization goals are on the rise across the globe and this can’t be achieved without the participation of campuses in the evolution of GIBs.

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Advanced Metering Infrastructure Rollout Strategies & Business Model Adoption: Tata Power-DDL Case Study

Case Study of Tata Power-DDL's AMI Deployment Strategy Across License Area in North and North-West Part of Delhi

Sanjeev Rana, Nitin Marjara, and Amit Bansal

Abstract This Paper showcases different rollout strategies of Advanced Metering Infrastructure (AMI) and Business Models being experimented in India, with a detailed focus on Tata Power-DDL case study. It covers key features such as finalisation of Communication Technology for topology of Delhi, development of Smart Meter vendors for 3rd party communication network, development of business associated for mass deployment of Smart Meters, shortlisting of Meter Data Management System in line with Utility's existing IT/OT system, and Deployment sequence of different element of AMI with probable benefits which can be accrued from this system. This paper also highlights major showstoppers encountered along with probable solutions. National Tariff Policy 2016, which mandate all meters with consumption more than 200 units to be Smart Meters, further reinforced by funding under UDAY scheme and by NSGM to utilities for deployment of Smart Meters as per IS16444, followed by CEA's clarification to have 100% Smart Metering feederwise for loss calculation through AMI, and finally Government of India's policy to convert all energy meters of India from Post-paid to Smart Prepaid / Conventional pre-paid, paved the way for the deployment of Smart Meters in India. Part A of this paper expounds the criteria for selections of deployment strategies with major focus on Tata Power-Delhi Distribution Limited Case study and Part B of Paper will elaborate; probable cost benefits which a utility can avail through AMI deployment.

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Abbreviations

FRTU	Field Remote Terminal Unit
FO	Fiber Optic
SDH/ SONET	Synchronous Digital Hierarchy/ Synchronous Optical Network
OFC/OPGW	Optical Fibre Cable/Optical Ground Wire
IP/MPLS	Internetworking Protocol/ Multi-Protocol Labelled Switching
ADMS	Advanced Distribution Management System
GIS	Geographic Information System
SAP ISU	SAP Industry Solution Utility
SAP CRM	SAP Customer Relationship Management
SAP BCM	SAP Business Communication Manager
ACB	Air Circuit Breaker
LTE	Long-Term Evolution
VPRN	Virtual Private Routed Network
VPLS	Virtual Private LAN Service
QOS	e
LV-PLCC	Low Voltage-Power Line Carrier Communication
ISM	The Industrial, Scientific and Medical radio bands
PoC	Proof of Concept
MDMS	Meter Data Management System
HES	Head End System
LT CT	Low Tension Current Transformer
NCQC	National Competition for Quality Circle

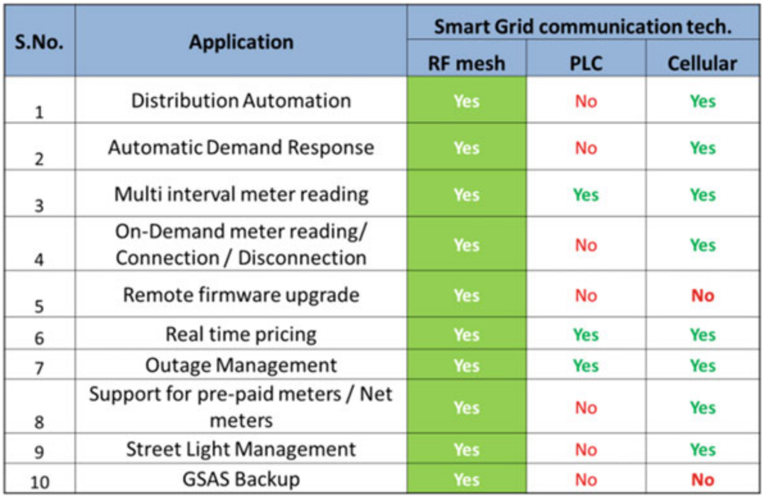
1 Introduction

Tata Power Delhi Distribution Limited (TPDDL) is a Power distribution company that provides electric service for the north and northwest parts of Delhi. TPDDL serves a customer base of about 1.70 million and peak load demand of approximately 2000 MW in an area that spans 510 km^2. Since being privatized in July, 2002 TPDDL has significantly reduced its Aggregate Technical & Commercial (AT&C) losses to record levels in its service area. Losses prior to privatization were close to 54%, as of September 2019 we stand closer to about less than 8%. The decrease in loss levels and subsequent enhancement of the reliability of its network has helped TPDDL incorporate new technologies and innovative systems into its distribution framework. To continue on this journey, as per National Tariff policy 2016 and subsequent approval from Hon'ble DERC, TPDDL started implementation of AMI in its area of operation to empower their customers to manage their energy, improve reliability and operational efficiency.

The paper has been bifurcated in four parts and classified as:

- Unified Communication Network
- Smart Meter Deployment
- Meter data Management System deployment and integration with existing IT/OT applications
- Big Data Analytics

The Project was preceded by PoC with different OEMs in domain of RF, PLC, GPRS and LoRa. As an outcome of PoC it was finalised that RF is best suitable as communication network for topology of Delhi with below mentioned use cases:



S.No.	Application	Smart Grid communication tech.		
		RF mesh	PLC	Cellular
1	Distribution Automation	Yes	No	Yes
2	Automatic Demand Response	Yes	No	Yes
3	Multi interval meter reading	Yes	Yes	Yes
4	On-Demand meter reading/ Connection / Disconnection	Yes	No	Yes
5	Remote firmware upgrade	Yes	No	No
6	Real time pricing	Yes	Yes	Yes
7	Outage Management	Yes	Yes	Yes
8	Support for pre-paid meters / Net meters	Yes	No	Yes
9	Street Light Management	Yes	No	Yes
10	GSAS Backup	Yes	No	No

Findings as concluded in 2013.

2 Challenges

- Sustainable and scalable network for capacity growth
- Cost-effective capacity building for future services (i.e., protection, AMI)
- Adequacy of current network configuration to support future requirements
- Additional WAN capacity required to accommodate multiple AMI hubs
- Media extension to last mile to take care of RF network coverage issues in highly congested areas
- Integration of leased bandwidth, LTE, IoT services and their adequacy to support future requirements
- Cyber security requirements and considerations for encryption, authentication, key management, etc. of Data as well as Devices for various applications
- Sustainable environmental conditions for High end electronic devices Maintaining the Integrity of the Specifications

- Scaling up of Manpower and training them to handle a mammoth task of Smart Meter Installation.
- 3rd Party Smart meter integration with HES on proprietary RF mesh network.
- Customisation of HES and MDMS system as per Indian regulatory requirements.
- Field Tools development for reading and connect/disconnection operations.
- Import lead time for supply of network elements and its allied accessories.
- BIS certification for meter developed for first time as per IS16444, IS15959 Part-2 and Part-3.
- Enhancement of meter testing facilities.
- Ensuing consistency of supply of meters to ensure a consistent pace of deployment.
- Firming up quality of material and deployment in field.
- In-house module developed for billing and Pilferage Analysis due to delay in MDMS deployment.

3 Approach & Methodologies

A. *WAN network*

Due to communications requirement by different upcoming applications, significant growth is expected in the network over the next 5 years. The impact of this growth affects two types of networks:

- The communications backhaul wide-area network (WAN)
- The communications access "last mile" network that consists distribution substations, DA devices, AMI meters and customers, and TATA POWER-DDL offices that are connected by a "last mile" link that eventually aggregates to the data centers.
- Backbone Network Optimization to resolve Convergence issues due to exponential increase of IP/MPLS nodes at different locations for multiple services (ISS, AMI, LDR, Energy Metering, Video Conf. etc.) and presence of large nos. of sites in Access link, there is overutilization (from industry standards) of the WAN network and fast convergence of different services including Media is at High risk. Hence there is a requirement to form a multi-tier hybrid network.

B. *Field Area Network (FAN)*

TPDDL created its own Wide Area Network communication infrastructure. However TPDDL faced challenges for sustaining field applications like DA due to dependency on 3rd party service providers (TSP's). TPDDL evaluated various technologies from different solution providers like Pilot test on LV-PLCC, RF mesh network on 865–867 MHz from 3 different solution providers.

C. *AMI Deployment*

To have complete control of end-end communication TPDDL commissioned Unified Communication network [RF Canopy network in unlicensed frequency band (865–867 MHz)]. Objective was to meet communication requirement of filed applications like Street Light automation, Distribution Automation (FRTU, FPI and other automated devices) across its service area. RF canopy has been designed to support multiple Smart Grid applications like Distribution Automation. The RF canopy network is designed in a way that Field applications data including Smart metering data merge into the nearest IP/MPLS node as shown below:

AMI deployment approach:

For AMI deployment TPDDL evaluated and adopted following strategy:

- Target consumers were identified and mapped in GIS.
- DT meters, IP/MPLS nodes across service area were mapped in GIS
- As per design, the Gap Collectors were installed at sites having IP/MPLS. Metering data is then transported to Control Centre using OFC as backhaul media.
- Consumer clusters were identified using GIS.
- To meet the requirement of Capacity and coverage of RF mesh, Meter deployment is planned in a way that Mesh network form in a natural way.
- Dark pockets identified and additional Network elements were commissioned to enhance coverage. Further network tunnels were created using using repeaters or installing additional Smart meters in a way to strengthen mesh network.

Network coverage maps per collector were generated through software. Quantity and placement were decided considering Throughput, Coverage and maximum no. of Hops for each collector/repeater for each Cluster. Survey reports were generated after carrying out Noise analysis/drive by tests, to finalize the location. Figure 1 below Depicts sample network coverage map:

Network Infrastructure requirement estimation:

A gateway /Data Collector was considered for each pocket /cluster of endpoints. The network element requirements were estimated for 5L Smart meters considering the utilization margin available for future growth of additional endpoints.

Network deployment:

- The Gateway are installed at a minimum height of 8 m above ground level with a minimum separation of 1.5 m between antennas.
- Point to point communication between endpoints is estimated depending on standard power output, antenna, High rise

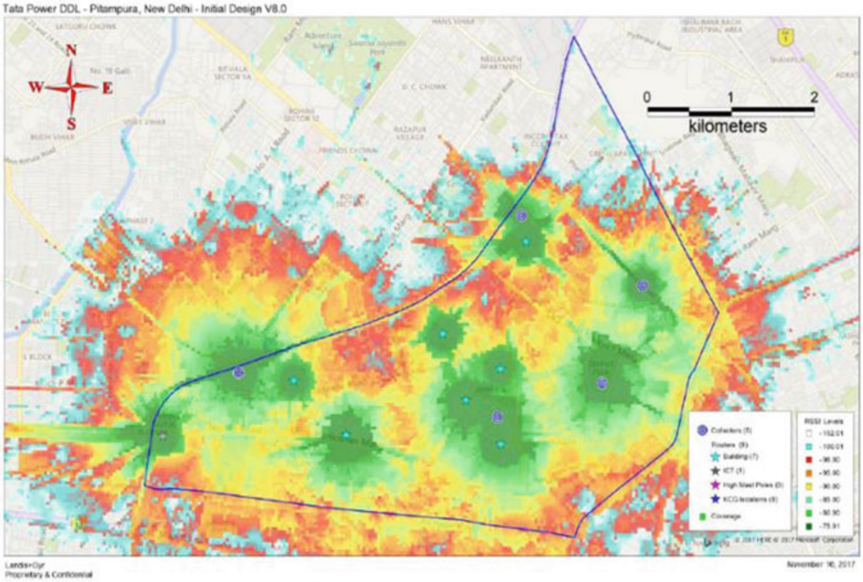


Fig. 1 Network Coverage Map

Total 80 k Smart meters (1 Ph., Whole Current and DT meters) have been installed across TPDDL area. A pictorial representation of the same is as below (Fig. 2).

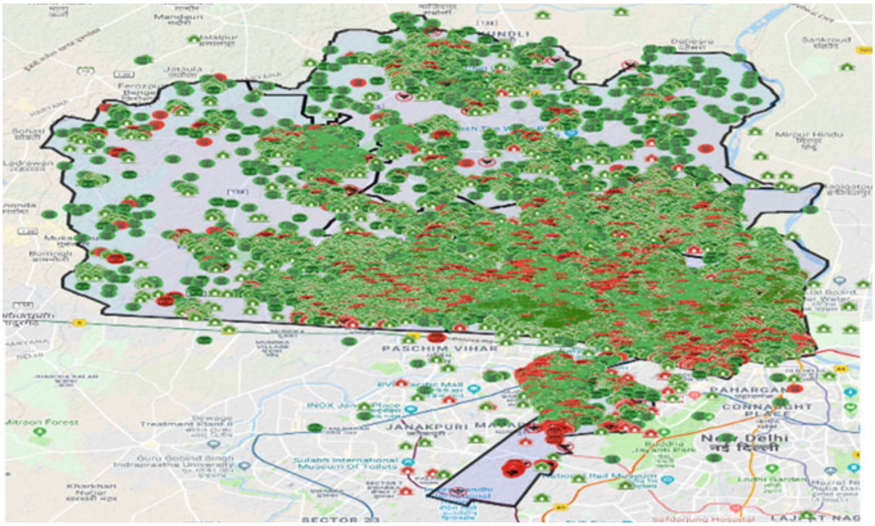


Fig. 2 Smart Meter Communication Status

Green dots are communicating while Red dots are showing non-communicating Smart meters. The non-communication may be a number of reasons like power failure, Pending Security configurations required for registration in mesh network, Weaker communication network etc.

RF Canopy was deployed across TPDDL by installing 61 nos. of Collectors (54 nos. of 3 Radio) & 7 nos. of Single Radio) and 250 + nos. of repeaters.

(1) *Monitoring Deployment on AMI Dashboard:*

The meter manufacture file (MMF) and Customer information file (CIF) associated with the meters via a file import, through integration services, or by manually entering the information into Head End System. The deployment can be monitored through the AMI Dashboard. The endpoint status section of the AMI Dashboard displays a list of all possible endpoint status, and the number of devices in each status shown in Fig. 3.

D. *Meter Deployment*

Smart Meter Deployment activity has become a part of Meter Management Group which introspected the existing process and identified blind spots and bottlenecks. To overcome same host of solutions have been devised to make it a flagship journey as mentioned below:

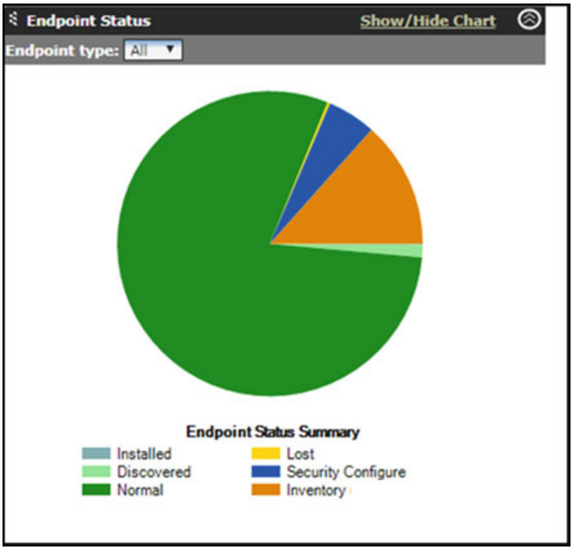
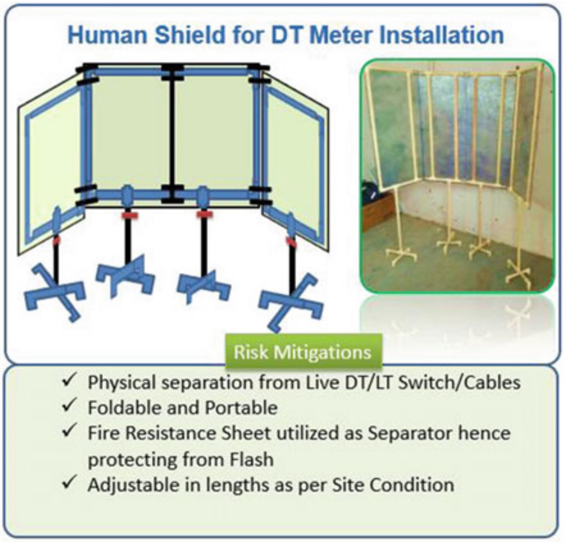


Fig. 3 Endpoint status

1. Employee Engagement:
    a. Skill enhancement of existing teams members to handle smooth deployment of Smart Meters in field and making customer understand the benefits of smart meters to enhance customer satisfaction along with ensuring of safety and quality.
    b. Creating Brand ambassadors by educating cross functional groups across Tata Power-DDL.

2. **Pre-survey of Installations** which will be replaced with Smart Meters so as to improve the working practices and take initiatives to reduce the cycle time. Few initiatives undertaken are listed below:
    a. Online DT meter replacement—Gold Award under National Competition for Quality Circle (NCQC) and Adjudged as Best Business Excellence Award in Tata Power-DDL.
    b. Portable trench was introduced—Gold Award under NCQC.
    c. Human Shield for working near transformer—A shied developed to safe guard the team members from live transformer and hot oil in case of any faulty while working near it.



Human Shield for DT Meter Installation

Risk Mitigations

- ✓ Physical separation from Live DT/LT Switch/Cables
- ✓ Foldable and Portable
- ✓ Fire Resistance Sheet utilized as Separator hence protecting from Flash
- ✓ Adjustable in lengths as per Site Condition

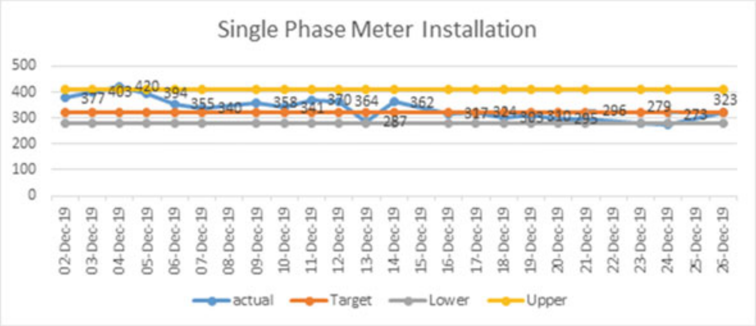
   d. PVC cap for sealing of live end of the cable during replacement of meter in live condition.

   e. Transparent LT CT Meter box with colour coding of different ratings of CT unit to identify mismatch of meter and CT ratio and identification of any tampering in CT meter box.

3. **Extension of Testing Facility**: Testing facility has been extended to cater for testing of additional quantity of meters required for replacement has been established to ensure first time right installation at site.
4. Smart Tools: To embark on the journey of quality, safety and enhanced productivity, Smart Tools have been introduced.
5. Load Centre operating locations for meter installation crew have been added resulting in increasing in productivity, reduce travel time, and better controlling and monitoring as the execution has increased to twice of its regular volume.
6. BA Work force Management and Skill Enhancement: Capacity and Capability of workforce was a major constrain in execution of a labour intensive project of this scale. Major focus was given on selection of BA employees to see that capable workforce is deployed in filed and with correct skill set. Rigorous class room and hands on technical trainings have been done followed

by competency assessment with declaration of workforce in 4 different segments i.e. Diamond/gold/Silver/Bronze. Workforce qualifying in first 3 categories is allowed to work at site.

7. Daily Work Management was introduced to monitor planned versus actuals execution so as to bridge the gaps if any during daily execution.



8. Meeting with IWAs and RWAs have been done in advance and on regular basis to ensure smooth deployment of Smart Meters in field along with customer engagement.

E. *Meter Data Management System*

As an integral part of project MDMS tender was allocated to a work class Business Associate. Evaluation criteria has been finalised to ensure that Business Stability is achieved through operational efficiencies, Reliability and further increasing billing accuracy. Data Analysis was a underlying principle to ensure theft pilferage is curbed.

1. **DT meters are made smart**:

With Smart meter installed on the DT, loading of the transformers will be available on real time basis. Voltages and currents of all the phases can be taken from the meter and MDMS can be configured to provide critical reports such as below.

a. Over loaded transformers
b. Power Quality Parameters
c. Harmonics
d. Phase balancing of Transformers

Utilities are asking for a special feature in meters i.e. DI and DO. DI is used to monitor the status of transformer. Four no of DI have been asked for, which means information of any flaw in transformer will be transmitted to back end server the moment it is generated. DO is used to give the trip command to transformer in case of need. This input given from meter will be monitored by system and decision will be taken on real time basis in auto mode.

2. Outage notification from the meter

Currently OMS is using phone calls received from customers for prediction of the area which is effected with power outage. This application is currently designed to receive 3 to 4 calls at a time and logics are developed around that to identify the affected area. Since number of calls are very low, so these prediction logics are weak and many a times the area effected is not properly demarked. If indexing of customers in GIS is not proper there also results are wrong. With Outage notifications coming in from the meters, all the meters which are powered off sends notifications, so in this case in-spite of prediction actual power failure and actual area effected is knows. So accordingly area staff can be mobilized to restore power from exact location. Secondly consumers can be given perfect time of restoration.

3. Safety concern addressed

At present real time monitoring of feeder shut down and provision of providing Permit to Work on dead network is given by control room operator. At HT level data from SCADA enables operator to actually see that the line is shut down. However at LT level there is no monitoring of network and control room operator is purely dependent up on the feedback given by the field staff. So if field operator is doing some mistake, it is not known to the control room operator and wrong permission can be given. With notification flowing from Smart Meter about the power failure this information can be derived from the notification of the meters that proper circuit is put off and is ready to work up on.

4. Virtual Metering

This is a very beautiful concept in which if we want to know loading of any particular point in electrical network we can mark a virtual meter at that point in system and logic for calculation of load can be done as explained in figure. Similarly if we want to check the loading in terms of current per phase then loading of current of R Phase will be sum total of current of R-Phase of each meter. However this point needs to be taken care of that phase wise matching of each meter should be done.

Use Case

If there are 5000 transformers in HVDS structure then and there if virtual meters are used. Then direct saving in cost:

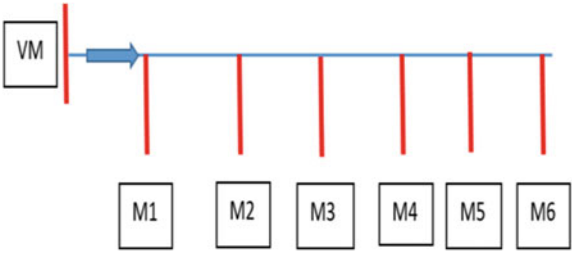
Cost of One Smart Meter: Rs 5000

Count of meters: 5000

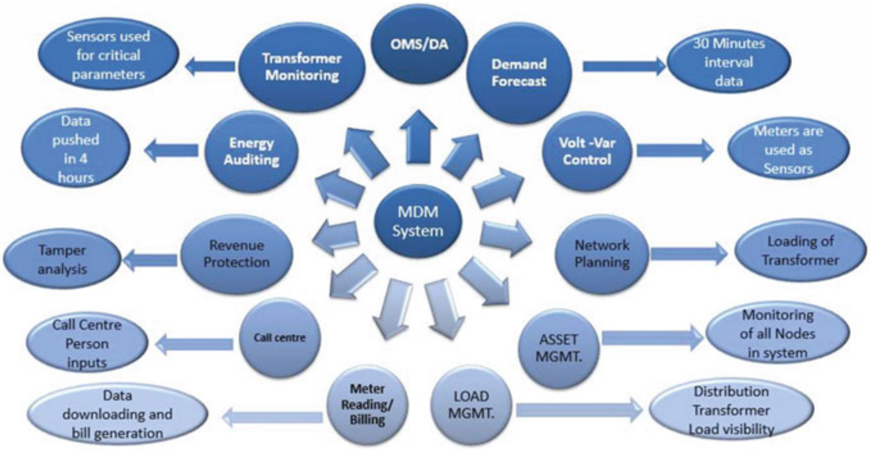
Total cost of infrastructure: Rs 5000 * 5000 = Rs 2,50,00,000

This calculation does not include installation and maintenance charges over the years. In below system VM is a virtual meter at one point in network. Flow of the power is shown by arrow head. M1 to M6 are customer meters.

So KWH (VM) = KWh(M1) + KWh(M2) + KWh(M3) + KWh(M4) + KWh(M5) + KWh(M6)

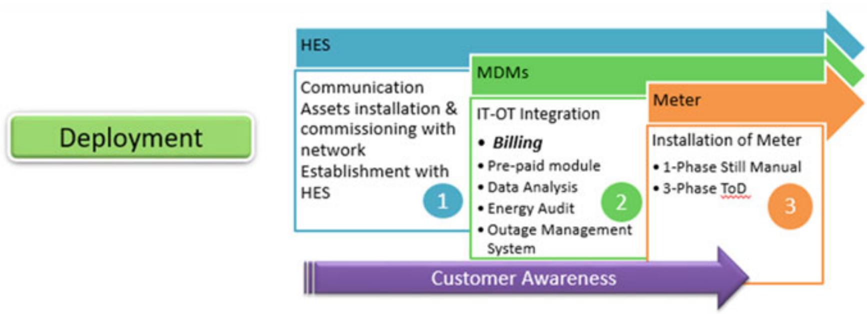


5. Some additional features are mentioned in image below.

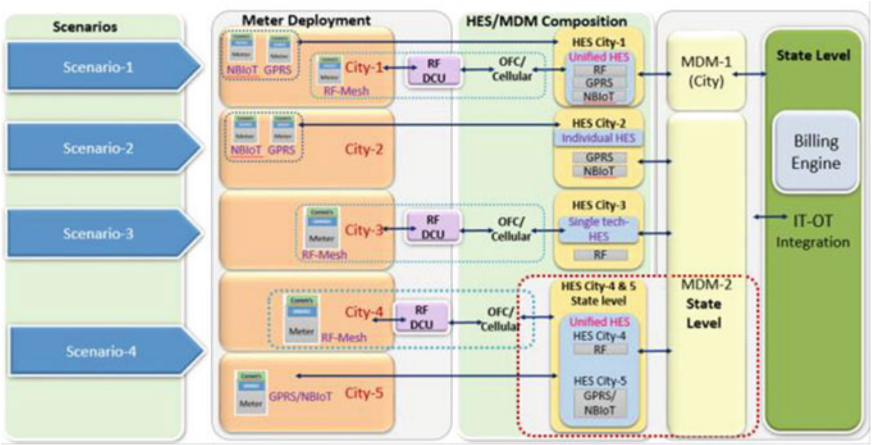


F. Various approaches for selection and deployment of AMI in different demographies

Approaches:



Selection Criteria:



4 Conclusions

This paper presents approaches and methodologies to strategize for AMI Project Implementation and selection of communication technology. It explores different network and communication topologies adopted by utilities. The success of future smart grid applications like.

- Smart metering
- Distribution Automation Infrastructure
- Power Quality metering for Solar systems
- LV Automation system for ACB'S, Feeder Pillar, Service Pillar
- Net metering for roof top Solar
- E-charging: Remote metering

Will largely depend upon communication technology, devices and services. The paper proposes end to end hybrid type of communication infrastructure by deploying mix of technologies based upon geospatial area, density of endpoints, cost effectiveness of solution deployed, and future scalability. Further moving ahead, cyber security will be playing a pivotal role and area of concern for all smart grid deployments.

5 Way Forward

With fast changing communication technology, a modular design is recommended. Further Sub GHz ISM bandwidth in India is only 2 MHz, could be a technology risk considering large no. of deployments. Hence a hybrid of small RF mesh with Optical fiber/LTE gateways or NB-IoT/LoRA network is recommended. The AMI network should be designed to reduce waste and spare bandwidth for DA, DSM in future.

In order to meet data requirements of Smart metering and other applications (having less stringent requirements on Latency and bandwidth), TPDDL is evaluating different technologies Like Leased Carrier Services 4G LTE, LoRa and NB-IoT. The NBIoT architecture is as shown below.

For areas where backhauling on Optical fiber is not feasible other communication technology like 4G LTE or leased bandwidth from telecom operator can be used as backhaul network to the control center. In such cases, a secure MPLS VPN tunnel is provided by the service provider.

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Power Quality Improvement and Performance Enhancement of Permanent Magnet Brush-Less DC Motor

Saurabh Manglik and Anish Garg

Abstract Residential household appliance consumption is one of the highest electricity consumption sector, out of which ceiling fan is second largest power consumption device in the home. This paper provides description of proposed ceiling fan and Government policies to encourage manufacture and use of energy efficient ceiling fans This paper presents a new design development of the Permanent magnet Brushless DC Motor (PMBLDCM) to reduce the power consumption and reduce the harmonic distortions in the power supply, as compared to the market available PMBLDCM fans. Further this paper summarizes the future road map to enhance the use of the Energy efficient Fans for household application with improved power quality design concepts.

Keywords Permanent Magnet Brushless DC Motor (PMBLDCM) · Buck-Boost Converter · Diode Bridge Rectifier (DBR) · Voltage Source Inverter (VSI) · Discontinuous Current Mode (DCM) · Power Factor Correction (PFC) · Digital Signal Processor (DSP)

1 Introduction

Increase in energy demand every year encourages energy planners & policy makers to promote energy efficient appliance at micro to macro level instead of increasing power generation, which in itself has its own limitaions; apart from requiremnt of huge Capital Invetsment. In the past year, India recorded a huge demand of electricity in various consumption categories such as commercial, industrial, residential, agricultural and traction. Residential sector consumption recorded huge demand of 24.20% during fiscal year 2017–2018 [1, 2]. The Residential consumption includes

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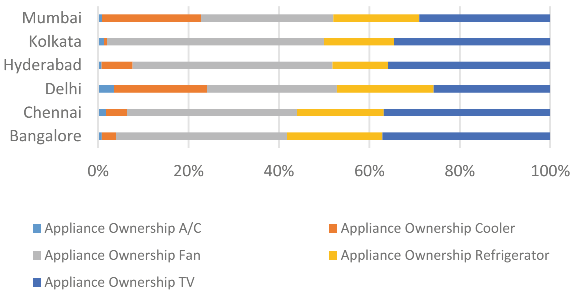


Fig. 1 Appliance ownership in major metro cities of India

refrigerators, air conditioners, washing machines, fans, TVs, water heaters, fluorescent tubes, and incandescent bulbs. Fan is the second largest power consumption in the home, which was recorded through survey of report of various metro cities [3]. Average all India appliance ownership of ceiling fan is 72% as shown in Fig. 1.

Even globally ownership of Fan is a major percentage. Conventional ceiling fan designed with Single phase Induction motor consume about 70–80 W, which is the major chunk of the energy demand in the residential sector.

Therefore, recently in the era of appliances of low power consumption application goods, these are more in demand and are also subsided by government policies. This paper presents modification and design of improved PMBLDCM (Permanent Magnet Brushless DC motor) for ceiling fan with improvement of Energy consumptions and power quality in comparison with market product.

2 Government Policies of Energy Efficient Fans

Government of India has been promoting the use of energy efficient appliances with Bureau of Energy Efficient (BEE). BEE initiated the program Super-Efficient Equipment Programme (SEEP). under this program, ceiling fan has been identified as the first appliance to adopted. SEEP for ceiling fans aims to leapfrog to an efficiency level which will be about 50% more efficient than market average by providing a time bound incentive to fan manufacturers to manufacture super-efficient (SE) fans and sell the same at a discounted price. The goal is to support the introduction and deployment of super-efficient 35 W ceiling fans, as against the current average ceiling fan sold in Indian market with about 70 W rating.

Energy Efficiency Services Limited (EESL) is an energy service company (ESCO) of the Government of India and is the world's largest public ESCO organized a program UJALA Ceiling Fan Distribution Scheme and National Energy Efficient Fan Programme. Under the program of EESL low price and 5 star rated Energy Efficient Fans are Being distributed.

1. Energy Efficient Fan Scheme of EESL:

EESL launched the National Energy Efficient Fan Programme (NEEFP) to promote efficient use of energy by increasing the use of energy efficient fans at residential level.

The cooling needs of most of the households in India are met by fans, as the use of ACs in households is still less than 10%. Considering the fact that about 30 million fans are sold every year, the potential to reduce electricity demand is quite high.

Replacement of Regular Ceiling Fans with BEE 5 Star rated ceiling fans has the potential to save 47 Billion Units of energy annually. There are 35 crore inefficient fans in India, if all of these are replaced with BEE 5 star rated energy efficient fans, India will have annual energy savings of about 47 billion KWh, with corresponding reduction of over 12,250 MW of electricity demand.

2. Specifics of EESL Scheme:

Under National Energy Efficient Fan Programme, EESL provides BEE 5 Star rated ceiling fans which are 30% more energy efficient as compared to conventional fans. The energy efficient fans will be available to the consumers on an upfront payment of Rs. 1,150/-per fan.

EESL has distributed over 5 lakh energy efficient fans under this scheme which is expected to result in an energy savings of over 1.6 lakh kWh per day and a monetary savings of Rs. 9.75 lakh per day to the consumers.

However, the higher price of the energy efficient 5 star rated fans is the primary reason for its low penetration along with the lack of awareness.

Payback period: With the usage of these energy efficient fans it is estimated that consumer's electricity bills will reduce by about Rs. 700–730 per year thus making the cost recovery in less than 2 years.

2.1 EESL Scheme in Delhi (BRPL DISCOM):

This scheme offers BEE 5 star rated Energy Efficient Fans, 50 W to consumers of BRPL at discounted price the fan will have a replacement warranty of two years for any defect.

The price of Fan is fixed at Rs. 1110/-per Fan. The saving expected per Fan is 25 W per hour.

2.2 EESL Scheme in Andhra Pradesh:

Distribution of Energy-Efficient, 50 W and 5-Star Rated Ceiling Fans.

These fans are 30% more energy efficient as compared to conventional fans, which range from 75–80 W.

At present, two energy efficient fans will be provided to each consumer at Rs. 60 a month per fan on EMI basis. The EMI amount is added to the consumers' electricity bills for two years.

> This scheme will be available to the consumer on providing a copy of latest electricity bill along with a copy of residence proof at the designated distribution centre. The consumer can also purchase the fan by paying Rs. 1250/- upfront.
>
> Consumer's electricity bill will reduce by about Rs 700–730 per year-which means that the cost of this fan can be recovered in less than 2 years.

3 PMBLDCM Motor Based Ceiling Fan

The PMBLDCM has been used in numerous kinds of industrial applications like transportation, robotics, automobiles and household. The PMBLDCM has changed the sector of appliances due to advantages of low maintenance cost, high efficiency, low electromagnetic interference, high flux density per unit volume, low noise, and availability of ranges for low to medium power rating motors with various applications drives [4, 5]. The PMBLDCM has no brushes, so electronic commutation is implemented through driving algorithm and explained in this paper.

The PMBLDCM has been designed with moderate rated voltage three phase windings wound on the stator, which are excited by a voltage source inverter (VSI) and permanent magnets on the rotor inner surface to reduce losses in the motor and it enhances the power quality with a buck-boost power factor correction (PFC) converter to reduce energy consumption.

A buck-boost converter is utilized as a front-end converter to vary the DC link voltage for its speed control and converter has a smaller number of passive components and less losses. The switching pulses for the switch of front-end converter are designed in such a way, so as to ensure improvement in the power supply quality. Hence, the switching frequency of the switch should be as high as possible. In a PFC converter, a MOSFET is used as a switch with operating frequency of 25 kHz. The variation of speed of the motor, is controlled with change of DC link voltage and to feed the VSI for electronics commutation of the PMBLDCM.

4 Parameters of Converter and Drive

The parameters of converter feeding PMBLDCM based ceiling fan, are given here, which includes the calculation of components of the proposed converter.

The proposed buck-boost converter for ceiling fan motor drive, functions on the discontinuous current mode (DCM) as shown in Fig. 2. In DCM of operation of buck boost converter, the current through input side inductor of the converter, becomes discontinuous in the switching period.

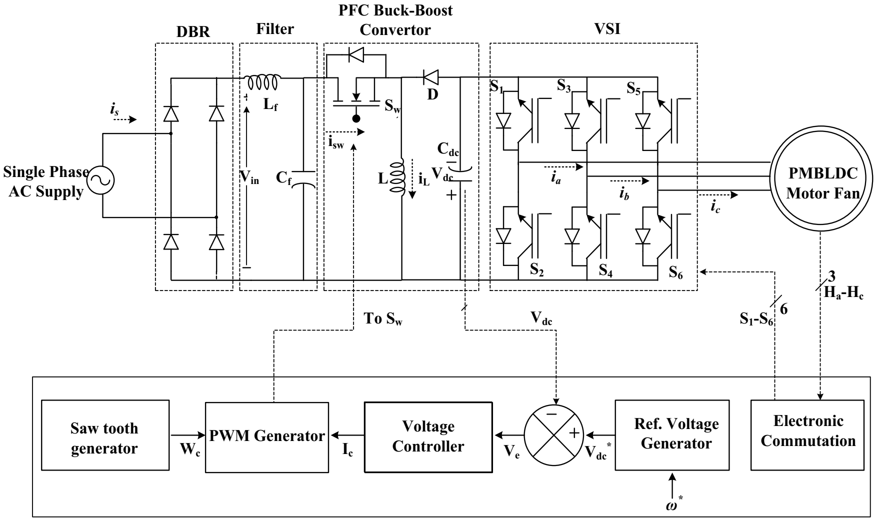


Fig. 2 Circuit diagram of proposed drive of the BLDC motor

Table 1 Component of proposed converter

Component	Rating
Inductor Lic	8.3 μH
Capacitor Cdc	600 μF
Input filter capacitance Cf max	50 nF
Input filter inductance Lf	3.3 mH

The designed power rating of PMBLDCM for a ceiling fan application is 35 W. It's designed maximum power output of the converter with safety factor of 25%, is a power of 43.75 W.

Therefore, based on the design calculation, following components are given in Table 1 for the proposed converter.

5 Control of Proposed System

The control of proposed PFC drive through a proportional integral speed controller and a pulse width modulation controller, to feed ceiling fan. There are mainly two techniques for PFC converter, current follower and voltage follower techniques.

Former one requires one current sensor and two voltage sensors. In this technique, rectifier output voltage is sensed and input inductor current is forced to follow the voltage waveform. The output voltage of this converter is regulated by PI controller.

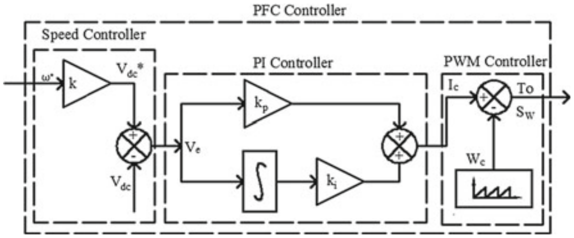


Fig. 3 Control philosophy of drive segregated as speed controller, PI controller and PWM controller to fed PMBLDCM based Ceiling fan applications

Therefore, this technique requires sensing of rectifier output voltage, voltage of DC link, and current of inductor.

In later technique, only one sensor is used and the converter is operated in DCM mode. Hence, stress is slightly high across the switch. The DCM mode has advantage of less sensors, which requires only DC link voltage sensor. The error signal is generated with a comparison of sensed voltage of DC link and voltage reference, which is fed to PI controller. The pulse width modulation of the electronic switch of proposed converter is realized through a comparison of output of PI controller and high frequency carrier wave. For the speed control of PMBLDCM, the reference speed is converted in terms of reference voltage. In steady state, neglecting small drop across motor winding resistance, back emf of the motor is equal to the terminal voltage, and back emf is function of speed. Therefore, it is expressed as,

$$V_{ref} = k\omega_{ref} \tag{1}$$

Speed Controller

If ω_{ref} be reference speed at *kth* instant, then back emf is as,

$$E_b(k) = K\varphi\omega_{ref}(k) \tag{2}$$

and the terminal voltage is as,

$$V_t = 2\left(I_a R_a + E_b + L\frac{di}{dt}\right) \tag{3}$$

Neglecting small voltage drop across the inductor and resistor, terminal voltage (V_t) is equal to twice of back emf (E_b) of PMBLDCM is as,

$$V_{ref}(k) = 2E_b(k) = 2K\varphi\omega_{ref}(k) \tag{4}$$

Proportional Integral Controller

The voltage reference, V_{dc}^* is compared to sensed voltage of DC link V_{dc} and the error signal, so generated, is fed to a proportional integral controller. If $V_{dc}^*(k)$ be the reference voltage, and $V_{dc}(k)$ be the voltage of DC link at kth instant then, the error signal is as,

$$V_e(k) = V_{dc}^*(k) - V_{dc}(k) \tag{5}$$

The output of PI controller is a control signal (I_c) as,

$$I_c(k) = I_c(k-1) + K_p(V_e(k) - V_e(k-1)) + K_i V_e(k) \tag{6}$$

where, K_p and K_i are proportional and integral constants of proportional integral controller.

PWM Controller

This control signal is relatively checked with fixed frequency carrier signal (W_c). A 25 kHz is chosen as carrier signal frequency. If $W_c(k)$ be the carrier signal at k^{th} instant then,

$$\text{If } \; I_c(k) > W_c(t) \; \text{ then } \; \mathrm{S} = 1 \tag{7}$$

$$\text{If } \; I_c(k) <= W_c(t) \; \text{ then } \; \mathrm{S} = 0 \tag{8}$$

where, S represents ON or OFF position of switch. If S = 1, then switch is ON and if S = 0, the switch is considered OFF.

6 Electronic Commutation of VSI

The PMBLDCM based ceiling fan fed by a voltage source inverter is derived through an electronic commutation.

Various combinations of Hall-Effect signals, generate switching pulses for operation of switches of VSI with the rotor position as given in Table 2. The rotor position is used to generate three Hall-Effect signals. Each particular rotor position with an interval of 60° is produced a combination of Hall-Effect signals [6]. It states that change of switches conduction with change of rotor position and only two switches conduct at particular instant of time, representing that reduced conduction losses with 120° conduction mode of operation of an inverter.

Table 2 Six switching pulses of VSI reference to rotor position

Rotor position	Hall sensor			Switching pulses					
	H 1	H2	H3	S1	S2	S3	S4	S5	S6
0–60	1	0	1	1	0	0	1	0	0
60–120	0	0	1	1	0	0	0	0	1
120–180	0	1	1	0	0	1	0	0	1
180–240	0	1	0	0	1	1	0	0	0
240–300	1	1	0	0	1	0	0	1	0
300–360	1	0	0	0	0	0	1	1	0

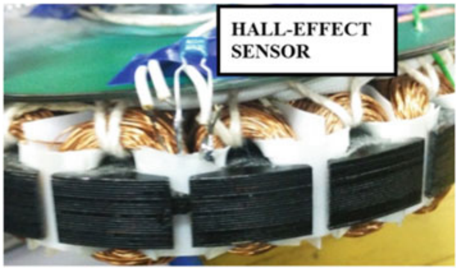


Fig. 4 PMBLDCM through Allegro Microsystem make three Hall Effect position sensors

7 Hardware Implementation of BLDC Ceiling Fan

The performance of PMBLDCM based ceiling fan fed from a non-isolated buck boost converter, is validated on a developed prototype with DSP (Digital Signal Processor) of TI (Texas Instrument) to drive PMBLDCM through Allegro Microsystem make three Hall Effect position sensors as shown in Fig. 4. The windings of the motor, are wound to increase the DC link voltage rating of the motor. Figure 5 shows the stator windings of market available PMBLDCM based ceiling fan and windings of the proposed drive of the ceiling fan to operate at higher DC link voltage.

The MOSFET based PFC converter is gated through a gate drive IC IR2110. An isolation of DSP and gate driver of VSI and converter, is realized through an opto-coupler with IC 6N136. The performance of proposed drive is analyzed and compared with available fan in the market at various speeds of ceiling fan. The hardware of this system, is implemented by using Texas Instrument DSP.

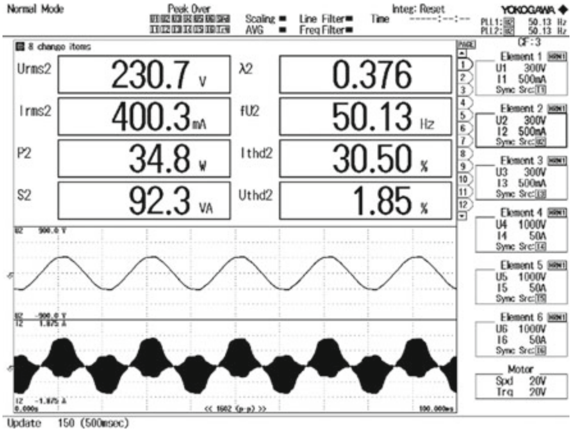
8 Performance of Existing Fan

The performance of PMBLDCM fan available in the market i.e. supply voltage and current at variable speeds of fan, are captured through power analyzer as shown in

Fig. 5 PMBLDCM based fan winding structures of **a** available ceiling fan, and **b** proposed drive

Fig. 6. The speed of the PMBLDCM based ceiling fan varies from 123 to 332 rpm and power quality performance varies with the speed, which are tabulated in Table 3. An input voltage of ceiling fan standard single supply voltage, is 220–240 V 50 Hz and DC Link voltage rating of this fan is 24 V. The least power consumption of fan at minimum speed is 4.44 W and maximum power consumption at highest speed is 34.8 W whereas power factor changes from lower speed to higher speed from 0.8 to 0.376, which is major disadvantage of it, which attributes to electrical loading of winding increases to 400.3 mA.

The THD of AC mains current of this fan, also increases up to 30.5% at rated (330 rpm) speed. The efficiency of the motor is evaluated approximately 69% where it is concluded that major losses its self in motor and converter of market product.



Urms2 230.7 V
Irms2 400.3 mA
P2 34.8 W
S2 92.3 VA
λ2 0.376
fU2 50.13 Hz
Ithd2 30.50 %
Uthd2 1.85 %

Fig. 6 Performance of company manufacture PMBLDC Motor based Ceiling Fan at various speed 5

Table 3 Power quality performance of PMBLDC based ceiling fan available in market

Speed	Speed (rpm)	Voltage (V)	Current (mA)	Power (W)	THD (%)	Power factor	DC link (V)
1	142	220.1	61.8	9.92	15.73	0.729	50.4
2	188	220.7	83.3	16.36	19.83	0.890	60
3	254	220.6	97.5	20.27	21.09	0.942	94
4	299	220.5	124.8	26.20	20.50	0.952	107.7
5	330	220.5	148.5	31.07	22.35	0.949	120

9 Performance of Proposed Drive Fan

The performance of proposed drive and modified stator based PMBLDCM ceiling fan i.e. supply voltage and current, are shown in Fig. 7. The proposed PMBLDCM based ceiling fan fed with single phase AC supply of 220–240 V, 50 Hz and maxmium DC link voltgae upto 120 V. The speed of proposed PMBLDCM based ceiling fan varies from 142 to 330 rpm and the power quality performance with variable speed, are tabulated in Table 4. The least power consumption of fan at minimum speed is

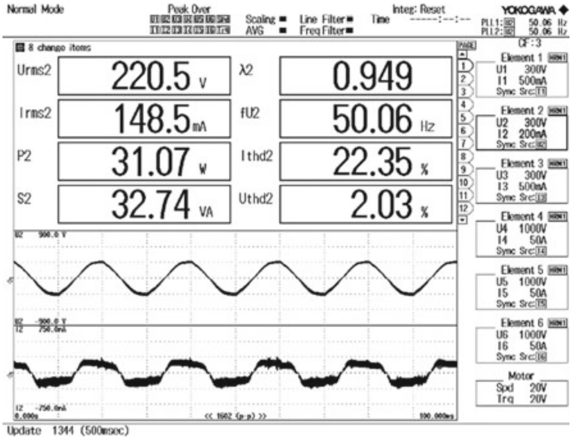

Urms2 220.5 V
Irms2 148.5 mA
P2 31.07 W
S2 32.74 VA
λ2 0.949
fU2 50.06 Hz
Ithd2 22.35 %
Uthd2 2.03 %
Update 1344 (500msec)

Fig. 7 Performance of proposed drive modified PMBLDC Motor based ceiling fan at speed 5

Table 4 Power quality performance of proposed drive fed to PMBLDC motor based ceiling fan

Speed	Speed (rpm)	Voltage (V)	Current (mA)	Power (W)	THD (%)	Power factor
1	123	230.8	24.08	4.444	15.36	0.800
2	184	230.8	35.14	7.50	10.52	0.924
3	255	230.7	102.6	15.44	29.53	0.652
4	299	230.8	171.8	23.16	16.69	0.584
5	332	230.7	400.3	34.8	30.50	0.376

9.92 W and maximum power consumption at highest speed is 31.07 W, whereas power factor changes from lower speed to higher speed from 0.729 to 0.949, which is major improvement in this case. The electrical loading of winding is reduced to 148.5 mA. The THD of AC mains current of this fan, is also improved up to 22.35% at rated (332 rpm) speed.

Hence, it is studied that the losses of the motor, are reduced with an increase of DC link voltage of the ceiling fan. The power consumption of the proposed PMBLDCM based ceiling fan, is 31 W, whereas at lower speed input power and THD of PMBLDCM of existing ceiling fan lower power consumption, but non-isolated PFC converter with modified stator winding of PMBLDCM ceiling fan power factor, is improved and power consumption at higher speed is reduced. The efficiency of motor is improved to 78% and losses are reduced with reduction of copper losses and converter losses with an increase in the DC link voltage and reduction current.

10 Future Road Map to Assist Government Policies

Government is encouraging the use of energy efficient appliances, which in-turn leads to use of more and more power electronics converters and inverters. Such topologies interfere with the power quality of the electric power supply and tends to lower the power factor & increase the total harmonics distortions. Consequently large number of substations have to be installed with power factor improvement devices (primarily switchable or fixed capacitor banks) resulting in high cost implication.

Therefore, we suggest implementing the power quality standard codes & practice for the low rating appliances in India.

Even otherwise, in many states of India, State Governments are providing subsidy on the electricity bills resulting in burden on the budget of the respective State. If Government looks into the prospects of encouraging the use of energy efficient appliances, this will reduce the burden of the monthly electricity bill on the consumer and also provide relief to the overburdened distribution network of the incumbent utility.

11 Techno Economical Aspects

Based on the analysis of the market improved design induction motor based most efficient 5 star rated fan in the markets are available with power consumption of 45–50 W, whereas BLDC based most efficient 5 star rated fan in the markets are available with power consumption of 30–35 W. In respect of incremental cost of efficiency improvement is 700–1000 INR, which is equivalent to the saving cost of electricity bill of the two-years with assumption of 10 h/per day within eight months of year running of the ceiling fan.

The proposed PMBLDC based ceiling fan costing will be similar in price range of the market available fan but proposed designed ceiling fan will be more efficient for long run time and low-speed performance. Detailed analysis of the each component of the ceiling fan is itself as a separate subject in itself.

12 Latest Govt. Initiatives

GOI Initiatives: The Government of India, and the World Bank signed a $220 million Loan Agreement and a $80 million Guarantee Agreement for the India Energy Efficiency Scale-Up Program. The Program is to be run through Energy Efficiency Services Limited (EESL), to help scale up the deployment of energy saving measures in the country.

The investments under the Program are expected to avoid total greenhouse gas emissions of 170 million tons of CO2. It will also contribute to avoiding an estimated 10 GW of additional generation capacity. This would be more than 50% of the National Mission for Enhanced Energy Efficiency target of 19.6 GW committed in India's Nationally Determined Contributions under the COP21 Paris Agreement.

13 Conclusion

The proposed PMBLDCM based ceiling fan has been fed through PFC converter i.e. non-isolated buck boost converter operated in DCM mode. It is analysed that with an increase of DC link voltage, the performance of the PMBLDCM based ceiling fan has improved. The power consumption at rated speed, is reduced by 12% with an increase of the DC link voltage of DC–DC converter in DCM mode. The speed of the ceiling fan is controlled through variation of DC link voltage of VSI. The efficiency of proposed drive PMBLDCM is improved 9%. However, the modification of stator windings of PMBLDCM and change in converter system, have provided various scope of improvement of PMBLDCM based appliances as new technology in lower power consumption appliance. Such resolution may also apply to other appliances of the household to improve the power demand of residential sector.

New government policies encourage the manufacture and consumers design and innovate the new topologies of power electronics system to improve efficiency and power quality.

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Smart Meter Data Enabled Transition to Energy Efficient Cooling

Shalu Agrawal, Nipun Batra, Karthik Ganesan, Kavita Vaishanaw, and Sunil Mani

Abstract In India, residential power consumption accounts for a quarter of the country's total consumption. With increasing disposable income and living standards and indeed warming conditions, demand for cooling through the use of air conditioners, is expected to rise and with it the peak demand. There is a new opportunity to manage the growth of this demand by first identifying the contribution of various end-uses to peak demand and supporting uptake of energy efficient equipment and influencing behavior concerning the use of cooling equipment. The information that is currently available from conventional meters and the frequency of collection is not sufficient to enable such analyses. With the help of high-frequency data from smart meters, electricity utilities can identify customers driving the peak demand and respond suitably. We demonstrate this with the help of data from 93 smart meters deployed in a sample of urban households across two towns in Uttar Pradesh. We use k-means clustering to identify the customer segments driving peak demand; these are primarily AC users. We also demonstrate a simple technique to identify AC using households with demand data at 15-min interval. Thereafter, we demonstrate the use of the current signature, to estimate the hours of AC use, compressor activity rate and overall power consumption. We then estimate the potential annual energy and cost savings that could accrue by switching to a reference efficient appliance offering a similar service level. The analysis, when viewed in aggregate could inform the utility

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of the need for overall capacity augmentation, the room for peak shifting, in addition to a peak shaving with more efficient appliances.

Keywords Smart meter · Energy-efficiency · Peak demand · Demand management

1 Introduction

In India, residential electricity consumption accounts for a quarter of the country's total electricity demand [1]. Residential electricity demand is set to increase over the next decade with increasing incomes. As Indian households increasingly buy more appliances and consume more electricity, it is important to understand the changing consumption patterns, drivers of peak demand and find ways to manage this rising demand. Until recently, this was difficult with the monthly consumption data obtained from conventional meters. With the advent of smart meter technology, high-frequency data can be used to incentivise consumers to make optimal decision concerning electricity use and appliance purchase.

2 Method and Data

We deployed 93 single-phase smart meters in urban households of Mathura and Bareilly districts in Uttar Pradesh, India. The meters, installed at the mains supply, capture consumption and supply parameters at a 3-min interval, and transmit the data over the cellular network. We also conducted a baseline survey with all the household participants to capture details about appliance inventory and perceived usage of various appliances. We use these datasets to investigate electricity and appliance use in households. Our main focus is on air-conditioners (ACs), typically the highest power consuming appliance in households. ACs have a distinctive energy signature that is easy to identify, making it possible to extract their usage from the aggregate energy signature [2].

3 Findings

A. Households driving the peak demand

Between May–October, sampled households consumed 280 units of electricity per month, on average. However, the consumption varies significantly across households. With aggregate consumption levels, utilities can classify households as low–high consumers, but these do not necessarily reflect their contribution to peak load.

We employ k-means clustering and segment households into four clusters on the basis of their load profile. As shown in Fig. 1, the high and very-high demand clusters

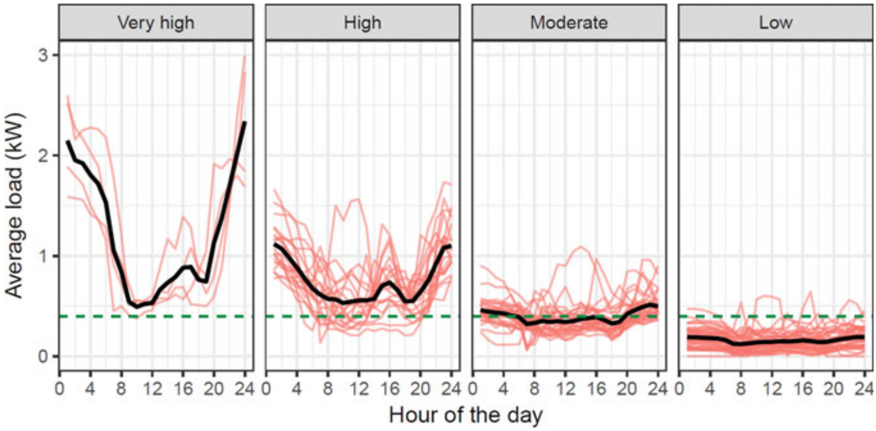


Fig. 1 Household demand clusters based on k-means clustering. *Note Orange line: average load profile of individual households. Black line: average load profile of all households; Green line: Time-indifferent average load of all households*

comprise households driving the night peak, which is also the true daily peak for the majority of the households. Data from the survey reveals that AC ownership is the key differentiating factor; 87% of the high and very-high consumers use AC, while the remaining have large coolers.

B. Identifying households with ACs

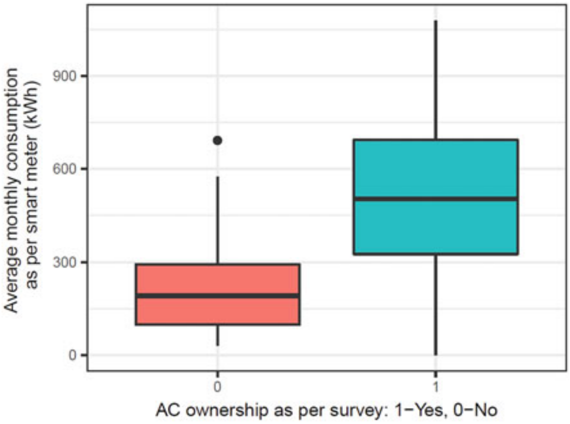
Here, we demonstrate a simple technique to identify households using ACs. We use the consumption data (kW) for the month of August, down-sampled to 15-min level, to identify the peak demand level, which sustains for at least 2 h within a day.

With our approach, we could identify 80% (27/34) of total AC users from our sample. Of five cases, which we couldn't identify, two have ACs with inverter technology, while others appear to be using ACs sparingly. We also over-identified three households having large coolers as potential AC users. One could argue that homes with and without ACs can be distinguished simply by monthly consumption data. However, there can be homes without AC having higher or similar consumption as households with AC, depending on efficiency of other appliances, number and hours of use (Fig. 2).

C. AC usage pattern and consumption

Besides identifying AC users, smart meter data can be used to understand how and when households use AC. We analyse the current signature of households correctly identified as AC users, with the help of 3-min interval data for the month of August. We identify compressor ON and compressor OFF events, by identifying events in current time series of nearly equal magnitude and opposite sign. Figure 3 shows that we are able to identify compressor ON/OFF cycles with reasonable accuracy.

Fig. 2 Boxplot of monthly electricity consumption of households with and without ACs, during August



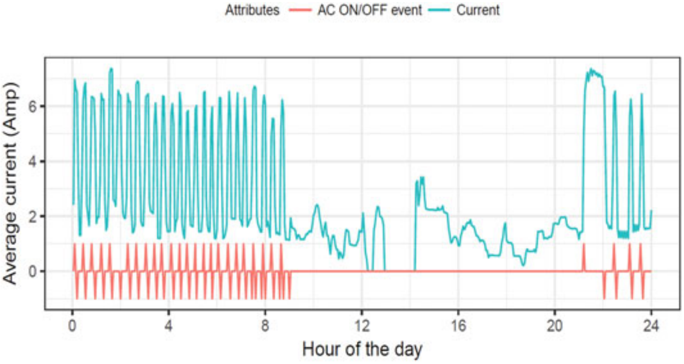


Fig. 3 Current plot and compressor ON/OFF event for MH24

Thereafter, we estimate average daily hours of AC use during the month of August. We find that households use AC for an average of 7 h a day and 200 h in the whole month. However, the usage varies widely across households (Fig. 4). This highlights the need for a tailored approach to attracting consumer buy-in for demand response measures, as expected benefits would vary with the usage behaviour.

We also observe that there is a significant difference in the appliance usage perceived by the households and the actual observed usage from the smart meter data (Fig. 5). Most households (60%) underestimate their AC use, on average by 4 h, while the rest over-estimate usage typically by 2.5 h. This clearly shows how people tend to wrongly estimate their energy consumption, and hence have poor data to optimise their usage. A feedback on their usage pattern will help them keep a better check and enhance consumers' trust in their electricity bills.

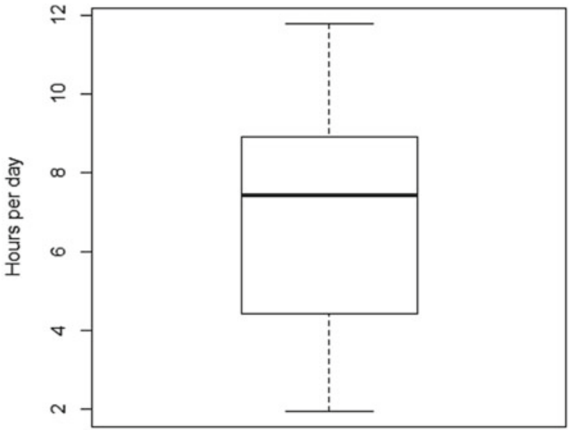


Fig. 4 Median daily hours of AC use during August

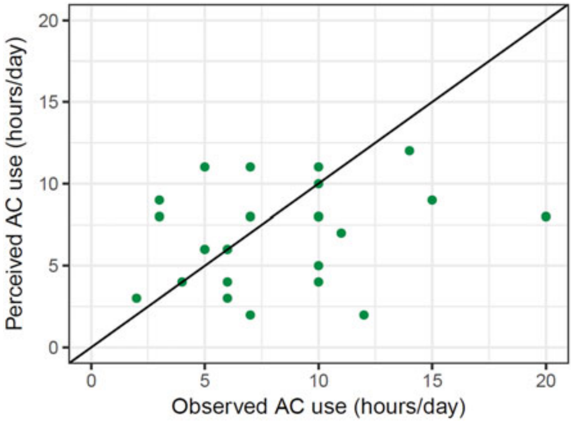


Fig. 5 Perceived versus actual hours of AC use

D. Customised energy feedback

Smart meter data can be used to help customers make informed decisions regarding appliance use and purchase. We can take the example of two households (here, MH24 and MH07). Both households have a 1 ton, non-inverter window AC, but with different BEE star ratings. We find that MH24 (with a 5 star rated AC bought a year ago) draws an average current of 5.3 Amperes when the AC compressor is ON (Fig. 3), while MH07 (with a 3 star rated AC bought 4 years ago) draws 6.5 Amperes (Fig. 6). We further estimated the average energy consumed by the AC by calculating the average power consumed, the daily usage (in hours) and the percentage of time for which the compressor remains ON. There is a difference of 0.373 kWh in the power consumption of the two ACs. Since MH07 uses the AC for 6 h/day and five months/year, a 5 star AC will save INR 1,888 per year, at the power tariff of INR 6/kWh. Thus, the higher price of a 5 star AC (of INR 10,000) could be recovered in a five year period at this use rate.

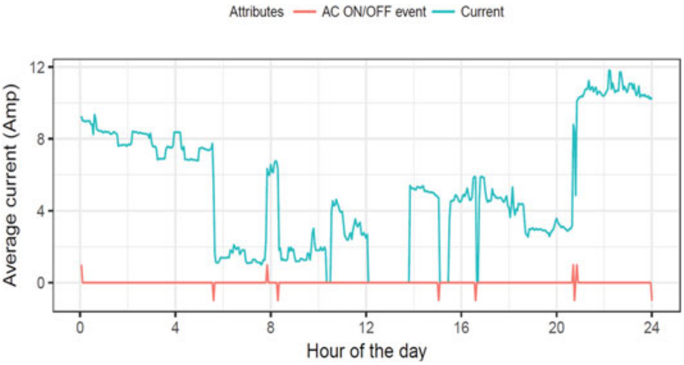


Fig. 6 Current plot and compressor ON/OFF event for MH07

We also observe that for 50% of the AC users, the compressor remained ON for more than 85% duration when the AC was switched on. This implies that either the AC used by these households is under-sized, the set-point is too low or there might be certain problem with the sensors. By sending out such advisories to customers, utilities can help consumers bring down their energy bills and improve performance.

4 Conclusion

In this paper, we demonstrate how the high-frequency data from smart meters can be used to identify households having ACs and offer advisories to consumers to help them make optimal decisions regarding appliance use and purchase. Until recently, the proposals for energy efficiency solutions have been based on an inadequate understanding of the appliance usage patterns, which often limits their attractiveness for the consumers. Often consumers underestimate their appliance usage. Advisories and real-time feedback would help utilities make targeted efforts to attract customers where most savings could be made.

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Innovation Through Topmost Disruptive Trends in Smart Grid Industry and Indian Power Sector's Stance on These Trends

Shweta Agarwal

Abstract With rapidly emerging trends in technology, the power sector is already experiencing the shift and growth at every level—from upstream generation to beyond the meter grid, network operations. Recent technology vogues like big data analytics, machine learning, artificial intelligence, blockchain combined with advancements in communication infrastructure like 5G have enabled transformative changes in numerous industries with smart grid being one of them. The sector has already been witnessing a major shift from scale-driven, centralized and standardized model, to a digital, distributed and personalized one. It becomes imperative to embrace innovation at all levels of the grid. This paper discusses the three topmost disruptive trends in power sector that could have a widespread impact on traditional elements of power infrastructure viz. DERs (Distributed Energy Resources), IoT (Internet of Things) and Analytics. It analyzes the current stance of Indian smart grid sector on each of these trends, market positions, challenges and open issues. The paper then also discusses roadmap for the utilities companies and partners to sustain growth among these disruptive trends by focusing on customer engagements, reducing administrative costs by moving towards managed services, improving product quality and more.

Keywords Component · Formatting · Style · Styling · Insert (key words)

1 Introduction

A disruptive innovation is an innovation that creates a new market and value network and eventually disrupts an existing market and value network, displacing established market-leading firms, products, and alliances [1].

Smart grid systems has itself been one of the disruptive and emerging technologies that affects the entire electricity system. With rapidly emerging trends in technology, the power sector is already experiencing the shift and growth at every level—from

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upstream generation to beyond the meter grid, network operations. From a scale-driven, centralized and standardized model, the sector is set to evolve to one that is digital, distributed and personalized. Technology economics will drive part of this shift and be complemented by changes in customer behaviors that reshape the provider–consumer relationship. Those companies that recognize and embrace this shift will find success as a valued, innovative solutions provider to their customers and partners.

2 Topmost Disruptive Trends in Energy/Smart Grid Industry

A. DER (Distributed Energy resources)

One of the most significant trend in the power grid sector has been a shift towards decentralized, community-generated energy. With increasing electricity prices and demand for reliable service owing to incidents of electricity shortages, power quality problems, rolling blackouts, many utility customers are seek alternative sources of high-quality, reliable electricity. DERs can include behind-the-meter renewable and non-renewable generation, energy storage, inverters (electronic devices that change DC, or direct current, to AC, or alternating current), electric vehicles and other controlled loads (separately metered appliances like hot water systems). DER also comprises new technology like smart meters and data services.

Common examples of DERs include rooftop solar PV units, natural gas turbines, microturbines, wind turbines, biomass generators, fuel cells, tri-generation units, battery storage, electric vehicles (EV) and EV chargers, and demand response applications. These separate elements work together to form distributed generation.

Distributed generation refers to a variety of technologies that generate electricity (in the range of 5–30 kW) at or near where it will be used, such as solar panels and combined heat and power. They may serve a single structure, such as a home or business, or it may be part of a microgrid (a smaller grid that is also tied into the larger electricity delivery system), such as at a major industrial facility, a military base, or a large college campus. When connected to the electric utility's lower voltage distribution lines, distributed generation can help support delivery of clean, reliable power to additional customers and reduce electricity losses along transmission and distribution lines.

Over time, there is more interest towards the renewable sources of energy, due to the Indian power grid sector's need to meet the ever rising demand Fig. 1.

(1) Status of Renewable Energy Industry in India

Over the years, renewable energy sector has emerged as a significant player in India especially affecting the power generation capacity. This supports the government's agenda of sustainable development while becoming an integral part in meeting the nation's energy needs. Power generation from renewable energy sources (excluding

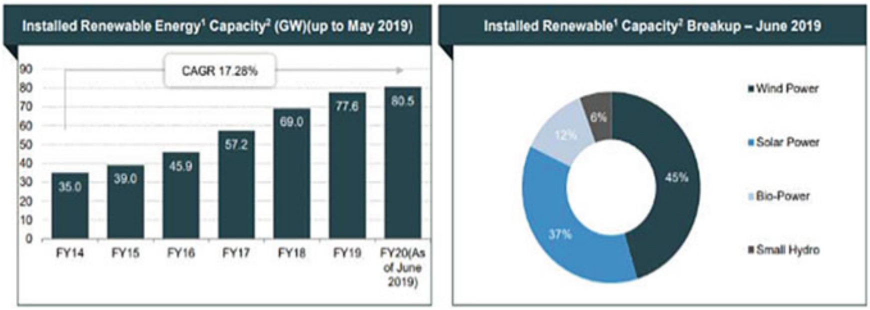
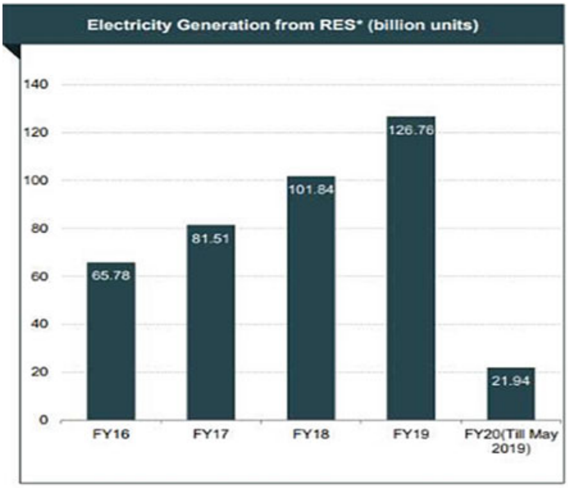


Fig. 1 Installed renewable energy capacity, installed renewable capacity breakup, *Source* CEA

large hydro) in India reached record 101.84 billion units in FY18 and has reached 126.76 billion units in FY19 Fig. 2.

1. The country ranks fourth in the world in terms of total installed wind power capacity. In 2018 (up to September), India added the second highest solar capacity in the world, after China.
2. Government of India is aiming to achieve 225 GW of renewable energy capacity by 2022, much ahead of its target of 175 GW as per the Paris Agreement.
3. Government plans to establish renewable energy capacity of 500 GW by 2030—Solar installation in India is expected to increase 360% by 2020.
4. Off-grid renewable power capacity has also increased. As of October 2018, generation capacities for Waste to Energy, Biomass Gasifiers, SPV systems stood at 175.28 MWeq, 163.37 MWeq and 767.51MWeq, respectively.

Fig. 2 Electricity Generation from RES*. Note: RES—Renewable Energy Source, *Large Hydro power projects not included, SPV—Solar Photovoltaic System, MWeq - Megawatt Equivalent. *Source* CEA, Make in India, MNRE, Mercom India, India Economic Survey 2017–18



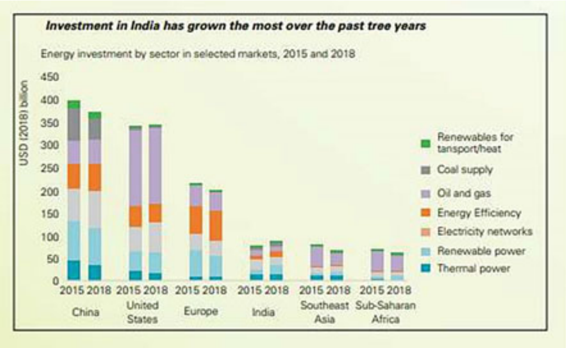


Fig. 3 Energy investments by sector in selected markets, *Source* International Energy Agency (IEA)

5. The total solar installations at the end of June 2019 reached 31.5 GW. - As in June quarter, capacity of the Indian renewable sector cross 80GW.

(2) Global view on renewable resources investments

"Among major areas, energy investment has risen most rapidly in India the past three years, up 12%," The IEA said in its latest World Energy Investment (WEI) 2019 report. "In 2018, renewable spending continued to exceed that for fossil fuel-based power, supported by tendering for solar PV, and from 2017 wind, amid uncertain financial attractiveness of new coal power, though spending in coal supply rose somewhat. While transmission spending is expanding, investment in distribution has not grown." (Fig. 3).

(3) Challenges/Storage and Deployment Issues for Distributed Energy Resource

1. Policy, regulatory and market design issues
2. Demand side management with optimization and forecasting techniques for storage and renewable energy source
3. Inertial issues of renewable energy resources with stochastic behavior
4. Optimal mix, siting and sizing of energy storages at various levels of network

B. IoT Internet of Things (IoT)

IoT is a recent new concept, on which Internet evolves from connecting machines and peoples towards connecting (smart) objects/things. Thus, we can say that IoT communications is the evolution of M2M communications. It is the extension of Internet connectivity into physical devices and everyday objects. Embedded with electronics, Internet connectivity, and other forms of hardware (such as sensors), these devices can communicate and interact with others over the Internet, and they can be remotely monitored and controlled".

(1) Smart Grid & IoT.

Briefly describing IoT allows to make smart grid smarter, extending the concept of smart from tradition AMI to virtually everywhere in the grid. With the help of

IPv6 protocol, billions of devices/objects can be connected, monitored and controlled utilizing multiple communication protocols agnostically like PLC, ZigBee, Wi-Fi, WiMAX, 3G/GSM, LET.

1. Customer engagement—With digitization driving the changing business models so that the end user has more and more control over almost everything via wearable devices, smart appliances and so on, it is also paving way for the utilities to provide the end consumer real time monitoring and control over his energy consumption.
2. Making smart meters smarter—With this newly offered connectivity routes, smart meters can now communicate with a range of other objects and applications within the network
3. Smart cities—Utilities can now remotely monitor and manage everything from lighting, traffic signs, traffic congestion, parking spaces, road warnings, and early detection of things like power influxes as the result of earthquakes and extreme weather. By installing sensors and using web applications, citizens can find free available parking slots across the city. Also, the sensors can detect meter tampering issues, general malfunctions and any installation issues in the electricity system.
4. Implementing demand response—using sensors at the devices, load curtailment or clipping events could be given over a Wi-Fi network.
5. Renewable energy resources– Each renewable energy resource like solar, wind, hydro can be assigned a unique IP address and can be controlled over the existing communication networks of the grid and with the bidirectional communication can be controlled and monitored at convenience. The consumers can be residential, industrial or commercial. Thus, with IIOT (Industrial IOT) and IOT becomes a significant enabler for distributed generation or microgrids at either home, substation, industry levels.
6. Promote energy storage—since there is a better visibility and control of usage, surplus energy can be stored.
7. Electric Vehicles—Electric cars with sensors connected through IoT can ensure smooth traffic management, regulated power supply, smart parking assistance, vehicle control, safety and road assistance.
8. Fault detection via current and voltage sensors at transmission layer.

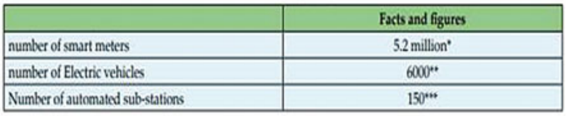
(2) Current stance of Indian Smart Grid sector on IoT

(a) Smart meters deployment

The country has deployed 200,000 smart meters in 11 cities and it is expected another 15 lakh will be deployed by end-2019 Fig. 4.

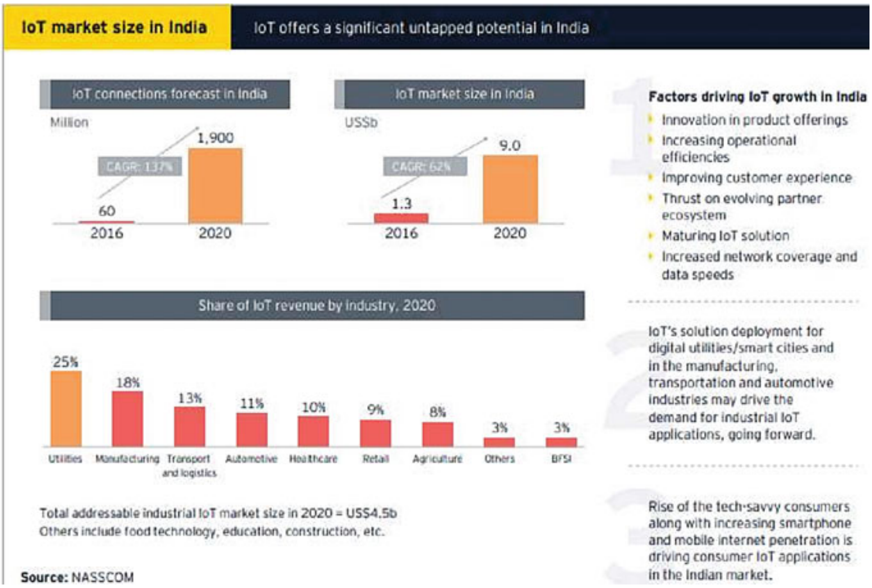
(b) IoT market size in India

According to Cisco, by 2020 there will be over 50 billion connected objects against a population of 7 billion Fig. 5.



	Facts and figures
number of smart meters	5.2 million*
number of Electric vehicles	6000**
Number of automated sub-stations	150***

Fig. 4 Smart Meters, electric Vehicles and Substations (2016) *Source* http://www.powertoday.in/News/Mission-Metering/83656



IoT market size in India

IoT offers a significant untapped potential in India

Total addressable industrial IoT market size in 2020 = US$4.5b

Others include food technology, education, construction, etc.

Source: NASSCOM

Factors driving IoT growth in India

- Innovation in product offerings
- Increasing operational efficiencies
- Improving customer experience
- Thrust on evolving partner ecosystem
- Maturing IoT solution
- Increased network coverage and data speeds

IoT's solution deployment for digital utilities/smart cities and in the manufacturing, transportation and automotive industries may drive the demand for industrial IoT applications, going forward.

Rise of the tech-savvy consumers along with increasing smartphone and mobile internet penetration is driving consumer IoT applications in the Indian market.

Fig. 5 IoT market size in India

(c) Smart cities and Internet of things

On 25 June 2015. Government of India launched the Smart City Mission, an urban renewal and retrofitting program with the mission to develop 100 smart cities across the country making them citizen friendly and sustainable. There are 4 main objectives covered under the draft policy:

1. To create an Internet of Things industry worth USD15 billion by 20,202
2. Skill development and capacity building c. Research and Development.
3. Development of Internet of Things products specific to Indians' needs.
4. network standards and domain-specific standards, to support the Smart Nation initiative and private-sector deployment of the technology.

With Internet of Things as the backbone, a smart city is able to comprehensively utilize information resources through a high degree of interoperable integration providing the essential elements of urban development.

(3) Applications of IoT in Smart cities

With the help of real time data using sensors, several applications can be listed as follows:

1. Intelligent traffic management
2. Smart Health
3. Smart environment monitoring
4. Smart meters
5. Smart water supply
6. Smart parking
7. Smart waste management
8. Smart street lighting

(4) Open Challenges and future directions for a scalable and robust IoT implementation

1. Environmental factors—Adverse environment factors most impact the communication methodology. Thus, it is important to consider hybrid alternatives which are also adaptive in nature. One of a very good examples is Open Way Riva a multi-application network, developed by Itron as adaptive communications technology. A self-healing and self-organization solution should be the vision.
2. Heterogeneous communication networks: There could be large number of power generating sources, energy distribution networks and energy consumers, each of them using a communication medium independent of the physical medium, as well as manufacturers and the type of devices. The communication architecture of IoT-aided SG systems should have coexistence of multiple communication technologies and standards.
3. Too much data: The integration of IoT technology with SG comes with the cost of more frequent processing and storing the huge volume of data which would impose a higher load on the IoT communication networks. Such data includes energy consumption, consumers load demand, advanced metering records, power lines faults etc. Using high bandwidth and data rates, such as the ones offered by LTE, increases the ability to transport such data but creates bottleneck elsewhere. Consequently, the utility companies should need to design systems with enhanced capabilities to store, manage and process the collected data efficiently and effectively.
4. Need of Standardization: Standardization is important for interoperability, compatibility, reliability and security.
5. Security issues: Since the monitoring and controlling in IoT-aided SG systems is performed over the open Internet it could lead to various security vulnerabilities like privacy, trust, authentication and authorization, data integrity, cyber-attacks.

C. Analytics

With industrial internet of things making every otherwise dumb object into an intelligent entity sending data, applications of sensors, wireless transmission, network communication, and cloud computing technologies, the amount of data being collected on both the supply and demand side has been quite staggering. Used throughout the whole process of power generation, transmission, distribution and substations, the volumes of data collected will only increase exponentially. Once this data is analyzed over the long term, very powerful results can be achieved. This leads us into next topmost disruptive trend making waves in the smart grid industry. Smart grid analytics enable utilities to more rapidly and effectively address issues regarding improved grid operations, customer engagement, and financial management Fig. 6.

One million smart meters installed in a utility results is nearly 3 TB of new energy consumption data every year.

(1) Application of Big Data/Data Analytics in Smart Grids

Valuable data obtained from multiple sources can be made useful for all the stakeholders in smart grid viz. electric utilities, end users, grid operators, etc. Primary use cases can be summarized as below:

1. Optimized demand response: Demand response is one of the drivers of big data analytics in smart grid. With Improved forecasting tools for energy resources and loads, weather conditions, human behavior, DR can be further optimized to suit the needs of utility as well as consumer. Application of advanced machine learning algorithms like K-means and ANNs to extract meaningful load patterns from large data sets, deep learning algorithms like time base Markov Model and clustering techniques, end user consumption behavior modeling can be done to lead to improved and optimized demand response methods.
2. Improved decision making for fault prevention and detection: Distribution automation (DA) is a concept of smart grid which focuses on the operation and system reliability at the distribution level. A successful DA has the capability to localize and isolate the faults in distribution system with a reduced restoration time and improved customer satisfaction. Under the concept of DA, increasing volume of operational data have been collected from supervisory control and data acquisition (SCADA) or advanced metering infrastructure (AMI) for state monitoring and fault diagnosis.
3. Visualization: Data analytics offers improved visualization at the grid layer using near real-time metering and grid sensor data can improve the overall assessment of smart grids. For example, the trend in Volt/VAr regulation can be used to utilize a large mix of voltage regulation resources (e.g. smart inverters,

Fig. 6 Pattern of Big data volume in electric utilities

solid state transformers, on-load tap changers, voltage regulators, STATCOMs) on the feeder.

4. Load disaggregation—also called non-intrusive load monitoring (NILM), aiming to segregate the overall load profiles at household level into the energy consumption of individual appliances. Unlike direct appliance monitoring framework, the NILM aims extracting data from only one smart meter installed in the house. Since different types of the household electric appliances have different potential to be involved in the DR program, the appliance-level load profiles allow the utilities to understand the customers' behavior better and helps to develop a more energy efficient strategy. Several machine learning and deep learning algorithms can help to cluster and disaggregate the household power profile.

(2)Data analysis techniques

The most important stage of the big data processing system is data analysis, which is the basis for discovering valuable information and supporting the decision-making. Several techniques are today possible because of the technology advancements available today, as listed below-

1. Statistics -The study of data collection, analysis and interpretation with mathematics methods which may discover potential relations based on some hypothesis Machine learning—A kind of technique for understanding the law in the data as well as extracting useful information with the help of computers automatically instead of humanity
2. Data mining—Computing data for discovering valuable information in large data sets with knowledge of statistics, machine learning and database system.
3. Pattern recognition—A branch of machine learning that focuses on the regularities in data.
4. Deep learning—A branch of machine learning based on complex structure of neural networks.
5. Artificial intelligence—The study of intelligent systems and agents with the ability of learning from circumstances and solving problems

(3) Regional Overview of data analytics market

The smart grid data analytics market is expected to grow at a CAGR of 25%, during the forecast period 2019–2024.

The Asia–Pacific region is being dominated by two highly populated country i.e. India and China Fig. 7. The rising population in countries like China, Japan, and India has stimulated the demand for residential infrastructure and electricity consumption, therefore accelerating the demand for electricity in the nations mentioned above is the crucial attribute backing the demand of smart grids which in return will create a market for smart grid data analytics as well because of the benefits associated with it.

Moreover, according to NITI Aayog, India is home to 18% of the world's population but uses only 6% of the world's primary energy. India's energy consumption

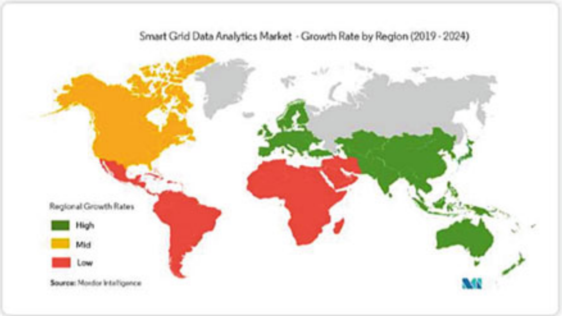


Fig. 7 Smart Grid Analytics Market—Growth Rate by Region (2019–2024)

has almost doubled since 2000 and the potential for further rapid growth is enormous. Urbanization coupled with smart city initiatives will be a key diver of this trend which as a result will create a positive outlook for the smart grid data analytics market whose main aim is to optimize their efficiency and minimize losses occurring in electricity generation and distribution of power supply.

Therefore, all the above factors combined will fuel the smart grid market which in return will boost the smart grid data analytics market in the Asia–Pacific region during the forecasted period.

(4) Open issues and challenges

1. Lack of standards: Currently, there are no established standards and regulatory frameworks for sharing data among utilities, weather corporation, and other energy systems (e.g., transportation, oil, gas sectors). Regulatory compliance as a whole may need an extensive overhaul to accommodate the impact of big data applications and also the cybersecurity aspects of such applications. Interoperability: Even though there are a few standard information models for smart grid
2. Interoperability (e.g., IEC 61,850, IEC 61,850–90-7, IEC 61,970/61968, IEEE 1815, IEEE 2030.5), there is no standard information models to describe interoperability among various big data analytics platforms, architecture, and their operational integrations with utility decision frameworks. Furthermore, storage, usage, dissemination, and sharing of data with utility operational frameworks are not unified. Interoperability between various cloud computing service vendors is necessary
3. Heterogeneous Data Existing big data applications in smart grids are based on single data type, primarily smart meter or PMU data. However, future applications shall utilize multiple sources of big data (such as data weather, traffic, oil and gas industry, social media, etc.), which can help in assessing the dependence of critical infrastructure on power grids. Therefore, data hubs should be created and be readily accessible to advance resiliency of critical infrastructures. Future grid applications shall utilize these heterogeneous big data set, which could uncover crucial hidden information otherwise not possible from electrical measurements only

3 Need for Innovation

Innovation underpins disruption, and disruption provides opportunities for growth.

Indian electricity sector has witnessed tremendous growth in its energy demand, generation capacity, transmission and distribution networks. Keeping pace with the recent technological advancements is the need of the hour. The Vision of India on Smart Grids is to "Transform the Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem that provides reliable and quality energy for all with active participation of stakeholders". This vision can be translated into following goals:

1. Zero carbon footprint
2. Increased efficiency—zero outages, sufficient supply, improved power quality, low costs.
3. A modern grid with more and more storage options and,
4. A customer centric environment.
5. The above goals must drive the path towards incremental innovation for the utilities.

4 Sustaining Growth

Historically any disruptions often warrant an immediate need for innovations for the incumbent leaders in the industry to survive and tackle competition with new entrants. However, given the infrastructure limitations, not every disruption can be addressed in a breakthrough manner. It is advised that innovation must be addressed incrementally and by utilizing the core assets of the organization. The primary focus must always be to improve the existing product quality for the mainstream customers and then target the new markets that are generated by the new entrants. Innovation targets must be broadened at every level with an aim to provide improved customer focus, energy efficiency, reduction of administrative costs via digitization of many services.

5 Conclusion

The disruptive effects of the most efficient of these innovative business models should ultimately deliver better value sustainable energy to consumers. This creates an opportunity for countries to negotiate their way through the energy transition in the smoothest possible fashion.

Some of the Indian governments key projects like 100 Smart Cities, 175 GW of renewable energy by 2022, 40% Renewable energy by 2030, electric vehicles (to combat air pollution) and 24*7 power supplies can be achieved with utilities adopting these innovative trends thus providing smart solutions to resolve Indias energy woes, and address troublesome issues such as massive transmission and distribution losses and power thefts.

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Cyber Physical Security for Last Mile in Smart Grid

Sonali Srivastava and Piyush Gupta

Abstract The last mile in smart grid comprise of gateways and electricity meters. These further can be connected to households (Residential), industrial and commercial Units or grid itself. Utility through network management systems provides controls operation of these edge devices. The smart edge devices further with the available processing power have potential to offer edge computing and control of smart devices and sensors connected to them. The distributed computing paradigm introduces a shift in security schemes. These edge devices are resource constrained devices limiting the choice in terms of security methods and requires decentralized trust model. This paper elaborates the threats and advantages of smart end points and edge computing and control. This also highlights how with inclusion of security at application layer helps bridge the gap of traditional enterprise security which focuses only on layer 3 and 4 for network security. Further the paper will take a closer look at various threats and how industrial protocol extends the traditional cyber security to include domain know how and business logics to provide better security against such threats. We conclude with how to future proof these solutions from future attacks and how securing last mile results in a secure smart grid.

Keywords Community devices · Edge devices · Meter · Gateways · Security · Edge computing · Decentralized trust model

1 Introduction

Internet of things has created vast opportunities of possible interconnections in addition to leveraging it for optimizing and improving the existing systems. Smart grid system is no exception to this. This paper focuses on distribution arm of smart grid. The distribution network consists of various components like Head

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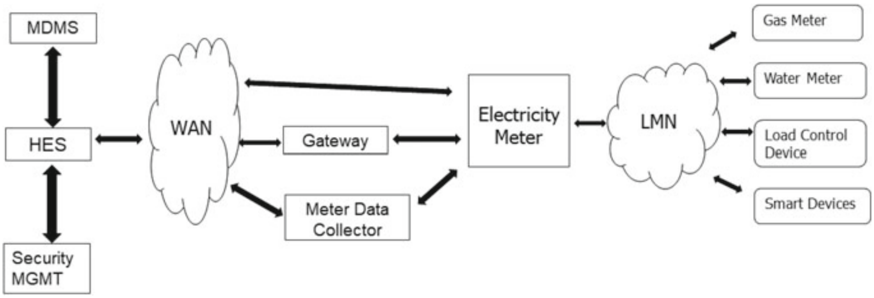


Fig. 1 Distribution network

End System (HES), Meter Data Management System (MDMS), Data Aggregators, routers, gateways, Meters, Meter connected devices (Fig. 1).

Today most of these distribution networks implement centralized control limited to network management entities like head end systems. The explosion in number of devices in network with Internet of thing coming in picture may force utilities to come up with smarter way of operation through distributed control [4].

2 Layered Intelegence in Last Mile Devices

Today the community devices and small edge devices like meter offer increased computing power and data storage capability. This enables utility managers to define their capabilities and roles in grid operation and implement applications to optimize the operation of each device as well as the entire system [4]. With this layered intelligence the decision making can be made hierarchical where the utilities can hand off some decision making to these layers.

A. Smart community devices

The data aggregators, gateway and routers are referred here as last mile community devices. As these devices interact with grid edge devices, other community devices and behind-the-meter devices, in hierarchical decision making they can be utilized for running specialized applications like outage management or smart city applications [4].

B. Smart edge devices

The meters, sensors etc. are referred as last mile smart edge devices. As these devices interact with behind the meter devices, in hierarchical decision making they can be utilized for self-directed automations and controls [4].

C. Hierarchical decision making

The hierarchical decision-making increases the venerability of system multifold. The risk with one centralized control [6].

Risk = Likelihood of Attack × Possible Actions × Consequent Outcomes.

In distributed control system, where N aggregators are collecting data and applying outage management, the risk will be N times as oppose to a centralized control. Hence it is important to shield the devices from physical and architectural security threats along with cyber-attacks.

3 Security in Last Mile Devices

The security consciousness for any system should start early even prior to development of devices. Characteristics of cyber physical systems like real time performance requirement, feedback from physical systems, geographical distribution of components which introduces vulnerability of physical security etc. adds to security concerns beyond cyber security [7].

A. Process integrity

A system is as secure as its weakest link. In order to shield device from security attacks all the processes in device life cycle including but not limited to design, development, verification, manufacturing and deployment should be reviewed and defined to rebuff security attacks (Fig. 2).

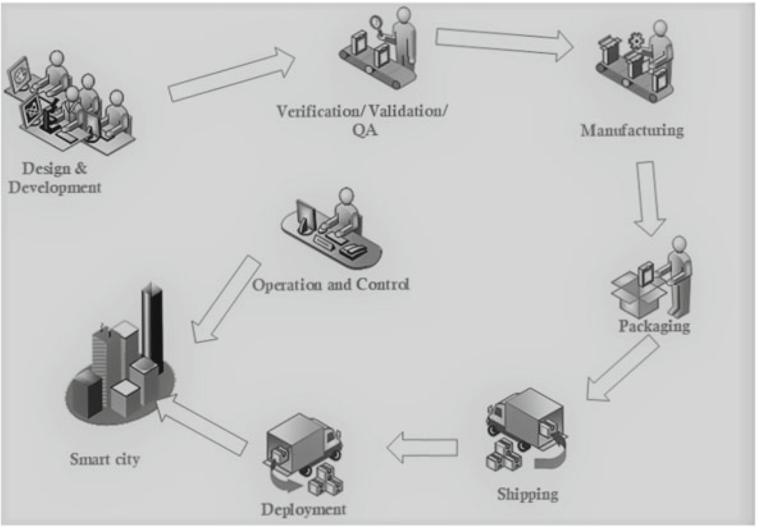


Fig. 2 Device life cycle

Common criteria (CC) an international standard (ISO/IEC 15,408) for computer security certification, elaborates these requirements and provide guidance on how to meet them.

B. Security in design

While designing last mile devices with layered intelligence and hierarchical decision making, the applications architecture should ensure that security concerns related to access of such applications is addressed. The concern could be about access of such applications (Access security as discussed in [1, 2]) or modification of such applications (Field upgrades [2, 3]).

Another area of concern would be how to protect data stored into devices in case physical security of device is compromised. As with other cyber devices like mobile phone these smart grid last mile devices should also think along the lines of encrypting the data before storing it on device. Sensitive data related to billing and user information can further be secured by putting in measures for integrity checks [3]. As community device can use data collected from meters for command and control of meter park operation, having nonrepudiation protection built in data can ensure data used in decision making can be trusted.

In all the above examples the basic data security objectives and requirement listed in [6, 9] remains same. Key difference here is the application and data are present on device itself and should be protected through architecture, design and application infrastructure.

C. Cyber Security

Cyber security focusses on protection of data, it can broadly be categorized in two parts.

- Access security: deals with protection of data against unauthorized access (Fig. 3).
- Transport security: deals with protection of data while its transported from one network node to another (Fig. 4).

Both Access and transport security mechanisms are applied in a system to achieve below security objectives [9] (Fig. 5).

These objectives can be achieved using one or multiple communication layers [5–10]. Given the scale of distributed control, PKI with distributed trust model serves as solution which can be extended easily.

In a network with layered intelligence, if we apply access security controls at application layer the security critical applications can be better protected [10]. References [1, 2] elaborate how to apply cyber physical security at application layer.

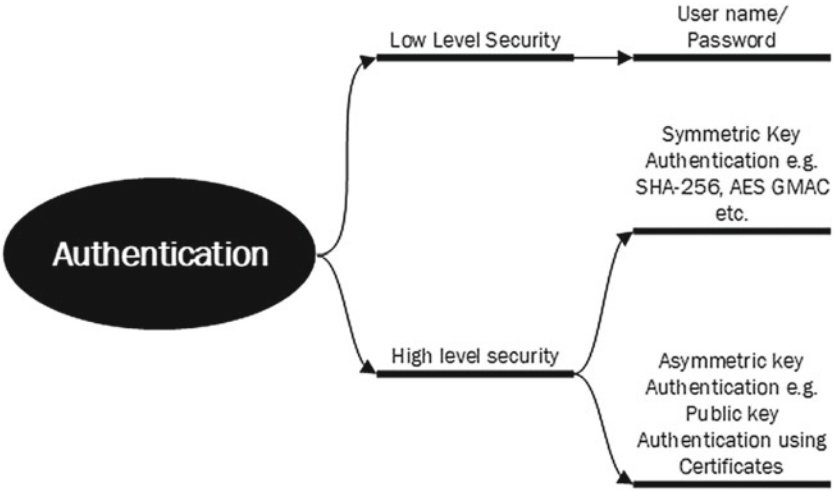
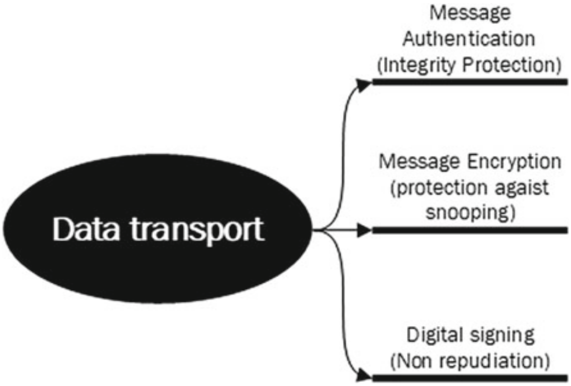


Fig. 3 Peer authentication mechenisms

Fig. 4 Data transport security



4 Conclusion

The conclusion of this paper is that security can never be viewed as an isolated piece. An overarching approach towards cyber physical security is required to secure last mile devices in smart grid. Security controls should be closer to the layer where the intelligence resides so for last mile devices application level security is a better solution.

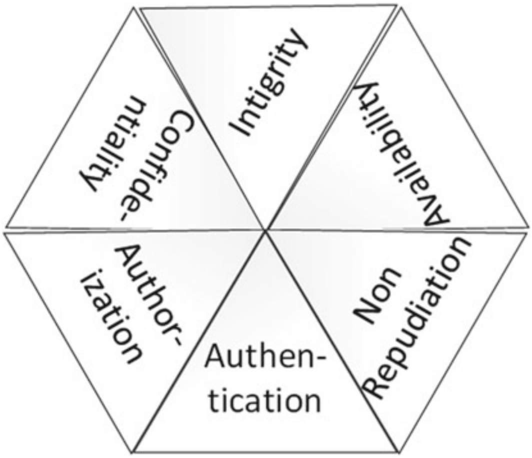


Fig. 5 Cyber security objectives

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Exploring Alternative Energy Sources to Supplement and Cover the Downtime of Wind and Solar to Improve the Resilience of Smart Grids

Srinivasa Murthy Lolla, Harish Pulluri, Bharadwaj Nidamarti, and Raghava Srinivasa Nallanthighal

Abstract This technical paper, based on engineering application aiming to promote secure and cost effective energy solution to all whoever connected to Smart Grid in general and in particular to those who are in solar or wind powered communities. At present, the solar technology has some issues at implementation level. In order to gain more popularity and to increase the customer confidence, the main key points need to be addressed and fixed. Some of the key points that are degrading the performance are like (1) The inability of solar panel to deliver consistently at varying higher temperatures, (2) Accumulation of dust specifically in places like Rajastan (India) where it demands frequent cleaning, (3) Hard water issues for cleaning purpose and difficulties in maintaining soft water plants at solar powered communities, (4) Frequent clouds and rains. To overcome these lapses and compensate, at BEES we are exploring the possibilities to utilize other renewable sources. For instance, how the threats like rains / stored water will be put to use and convert to our advantage and compensate the solar losses and other lapses. As per the initial investigation into this, we understand that our integrated system can comfortably achieve 4 h lead in 8 h span of expected solar power having capacity of 5 KW. In this paper we are describing few methods to show how one can generate extra power which can either extend the number of energy available hours or compensate the circumstantial losses in Smart Grid because of environmental conditions.

Keywords LPGS · Smart grid · Renewable energy (RE) · Permanent magnets · Pico hydro · Stored water · System design

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1 Introduction

This Local Power Generation System (LPGS) basically comprises a Guided Turbine, Torque Motor, PMG, Control System, Power Storage and Power Management Unit. This LPGS utilizes existing local infrastructure for energy recovery [1]. This system design can generate a maximum electrical output of up to five kilowatts (5 kW). LPGS of this size can get better benefit in terms of cost and simplicity from different methods in the design, planning and installation than those which are applied in larger traditional power systems. Latest developments in power generation technology have made it possible a cost effective source of power which can be implemented even in some of the world's most remote / unreachable places and is also emerging as a modular, scalable and adaptable power source. The system design is in adherence to all standards and it ensures compatibility of all electrical appliances to be used. Some of the examples of devices which can be powered by LPGS are light bulbs, fans, heaters, TV and AC etc. Usually, Pico-hydro power systems are found in suburbs or where abundant water resources like canals are available. Figure 1 shows a block diagram of conventional system with associated hydro, mechanical and electrical power losses, whereas Fig. 2 shows a system overview diagram of proposed LPGS system in town area. This system operates utilizing stored water from an overhead tank placed a few meters high from ground, typically 64 feet high. From this overhead tank, water flows down through the piping system. This down path distance is called " net Head" and it allows the water jet force to accelerate for prime moving system. And thus, the turbine will rotate the shaft of generator to produce electricity. In this application research, an effort is made to show the potential of stored water along with using a torque controlling motor as an alternative renewable energy source.

The flow of water inside the PVC pipelines has potential of kinetic energy to rotate small scale turbine which in turn drives the generator shaft for electrical power generation.

After generating the required power, this water can be redistributed to houses either for household routine activities or for power generation again. That means the

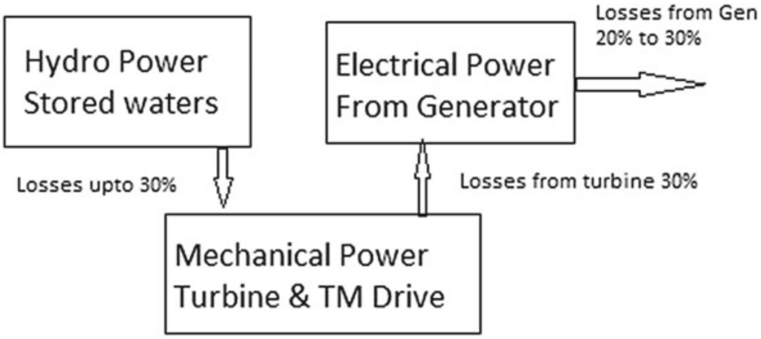


Fig. 1 Conventional system with associated losses

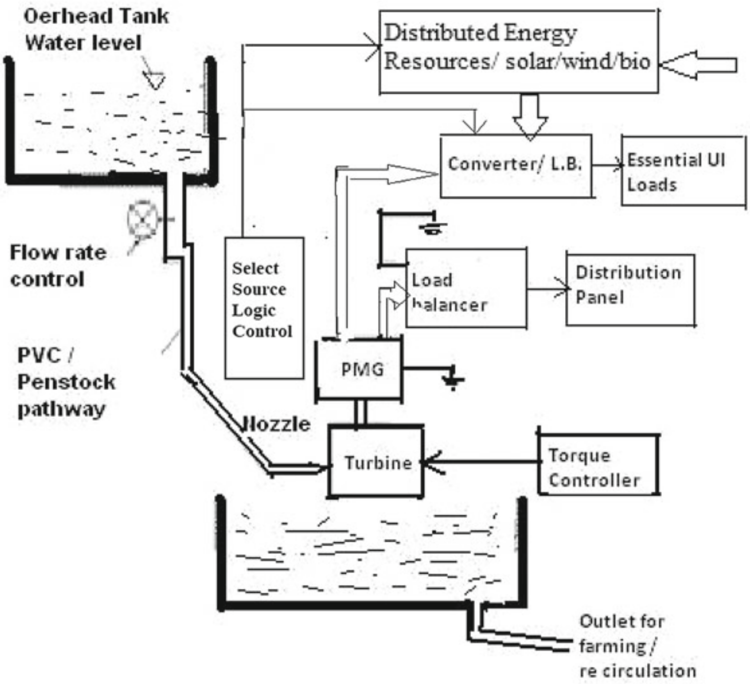


Fig. 2 LPGS system overview diagram

power can be generated using stored waters and at the same time those household activities are done without extra price on the water bill consumption.

This system can store the generated power by means of battery charging for future use especially in power blackout periods. The system proposed here is having approximate power capacity of 5 KW.

2 System Design Planning

Planning is the most critical stage in this applied research project as it determines the feasibility and practicality of the proposed LPGS system. Some factors enlisted here which determine the feasibility of the system:

i. The amount of Potential Energy and Kinetic Energy available from the water resource infrastructure and from the flow inside the pipelines. It is based on the pressure, quantity of water at disposal and the frictional losses in the pipeline structure and material.
ii. Torque controller design and functionality (torque controller block diagram as shown in Fig. 3)

iii. The generator design model and type
iv. The guided turbine design model and the type (a typical pelton wheel is shown in Fig. 4)
v. Storage and power management unit
vi. Type of complex loads

A. Theoretical Power Estimation from basic formulae

In general, the feasibility and practicality of the proposed LPGS system is based on the following potential input and output power equation:

Power (in) $= H \times Q \times g$ - - - - (1)
Power (out) $= H \times Q \times g \times \eta$ - - - - (2)
Whereas, Power (in) = Input power (Hydro power)
P(out) = Output power (Generator output)
H = Head (meter)
Q = Water flow rate (liter/second)
g = gravity (9.81m/s^2)
η = efficiency

From the above equations (1) and (2), both H and Q are very significant parameters in local power generation system. Head is a gauge of falling water on turbine, which is basically downward distance from the top of the penstock to the guided turbine at the bottom. On the other hand, Q is the amount of water flows within one second. Usually, the water flow obtainable is more than required as the flow needed for LPGS are small. Therefore, it is essential to gauge the H carefully, because the greater the H, the greater the Power (in) and thus results in higher RPM of the turbine rotation. For the proposed system, the biggest loss usually occurs when the power in the water pipeline is converted into rotating, mechanical power by hitting the turbine blades, i.e. 30% of the total hydro power going out from the nozzle. A further 20% to 30% will be lost in the generator when the mechanical power is converted to electricity. Thus, the rule of thumb for efficiency to estimate the potential output power is normally 50%.

B. Head Gauge in practicality: While determining the H (water downfall), the Static Head and the Dynamic Head are carefully considered. The Static Head is the downward distance between the top of the PVC pipe and the point where the water is hitting the turbine. The Dynamic Head is Static Head minus the pressure or head losses due to friction and turbulence in the PVC pipes, elbow bends etc.. These head losses are the function of parameters like category type, diameter, distance of the piping, and the number of bends or elbows. Static Head can be used to estimate power availability and determine general feasibility and practicability, but Dynamic Head is used to measure the real power obtainable. There are various methods of head measurement. However, as the proposed LPGS system uses stored water which is further distributed for household purposes, the easiest and most practical method for determining Head is to use water-filled tube and calibrated pressure gauge. In this procedure, the pressure gauge reading is in PSI and can be converted to Head in meters using the following equation of pressure to head conversion: Head = 0.704 × Pressure Eq. (3) Where, H = Head (meter) P = Pressure (psi). Equation (3) shows that the water pressure at customers / patrons' end is a very important parameter to be determined in the design and development of the proposed LPGS system. The water pressure represents the Dynamic Head of the system which is useful to determine the real power obtainable [2].

C. Q (Water flow rate) Measurement: The most widely used method of flow measurement for small streams is the bucket method. Throughout in this process, the flow rate of the channelized water is diverted into a container or barrel and the time duration it takes for the container to fill is noted. As the volume of the container is already known, the flow rate can be easily obtained by dividing this volume by the time it is taking to fill up the container. For instance, in our application, the flow rate of water that filled 100 L container in three minute, that is 33.33 L per minute.

D. PVC pipe System and Frictional Loss: PVC piping is used to carry water to guided turbine. This is usually known as penstock which comprises pipe from the overhead tank to the turbine with a valve or gate that controls the rate of water flow. Pressure meter also used near the turbine to note pressure readings. The planned LPGS system will have the water source which is meant for day to day household usage. Therefore, the system must be developed with capacity to produce high water pressure to rotate the guided turbine at reasonably higher speed and at the same time the water can be recycled such that it can used to other household activities. In order to do so, a torque controlling motor is also incorporated to compensate dynamic losses if any during the run time. Figure 5 illustrates the LPGS functional block diagram. The design is done by properly selecting the diameters, elbows, fittings and valve and every effort is put to minimize the use of these accessories to reduce frictional losses. Obviously, it is essential to minimize the piping system length between the water source and the turbine. But for practical limitations we could not leverage the best out of it onsite for this LPGS, however, to achieve the rated power output we used little higher capacity motors and generators to cope up with the circumstantial losses. By considering all these matters, the proposed LPGS piping scheme is assumed to have minor friction losses which can be neglected. This means the Dynamic or net hydro power at the users' end is more or less similar to hydro power to the turbine. The following are the list of accessories that are used in the system to carry the water from source to turbine with recirculation feature.

E. Valve—ball valve ½" (inlet valve)
F. Valve—ball valve 1" (outlet valve)
G. Recirculation Motor 70 W
H. Impeller pump ½ HP
I. 100 L Syntex tanks for recirculation
J. Nozzle—variable
K. Elbow—90°
L. Tee—flanged

M. Straight connector

N. Pressure Gauge—0 to 10 bar

O. Main pipe—diameter ½"

P. Design and development of suitable generator type: Power Generating system for LPGS is selected based on the following concerns: (A). The total expected power of the system. (B). Category of supply system and electrical loads to be connected: Alternating Current or Direct Current (C). Accessible generating capacity in the marketplace (D). Generator with compact size and affordable price. LPGS uses PMG AC generator of synchronous type machine. This is because the system is expected to support AC electrical appliances where as a DC generator with size above 5 kW is said expensive and has brush gear that requires appreciable maintenance. And also, the components like switches for higher DC currents are expected to be more expensive compare to their AC equivalent components. However, in LPGS, DC power is generated after rectification to store the energy (battery charging) so as to reduce the wear and tear on PMG AC Generator. Permanent magnets are made up of rare earth magnets and used on rotor. Rare earth magnets have higher flux density and therefore it reduces the weight of the machine when compare to the wire wound coils. And also, as the magnets are placed on the rotor, it is possible to achieve higher speed than the speed obtained if coils are placed on the rotor. Here the axial Flux machine topology is used, because it offers higher performance in less complicated structure [3]. Its functionality is same as radial flux generators but its rotor arrangement is in axial direction. Comparing to the Axial type, in Radial type machines the adjustment of the air gap cannot be done easily and chances of producing vibrations and noises are high. It gives better mass to torque ratio but on negative side it has a larger length, therefore the place required to install the radial flux type is bit larger [4].

Q. Turbine Type Selection and design calculations: The turbine type and the power plant calculations are very important in the design and development of LPGS which is basically an extended version of pico hydro power system. The most commonly available models are of impulse and reaction type turbines. The reaction type turbine is usually immersed deep in water and is inside a pressure casing. While designing some extra effort need to be put such that the clearance between the rotating element and casing are minimized. Whereas, the impulse turbine can work in open and operate with higher water jet force. And also, the impulse turbines are less expensive than reaction turbines as there is no need for specialized pressure casing and no extra effort needed to maintain the clearance. Based on the these considerations, the impulse turbine is better fit with the proposed LPGS as the hydro power is in the water jet force. Pelton wheel shown in Fig. 4 is the most common and well known type of impulse turbine. The turbine size and other design parameters are based on the speed range and power capacity of alternator to be used. Pelton wheel turbine is very versatile in a way that it is does not always limited to high Head. Particularly in LPGS, it is expected, yet times a lower water pressure conditions, therefore, along with the water jet force, a torque motor controller as shown in Fig. 3 is also used to give additional mechanical power.

Some of the important parameters and design calculations:

(1). Calculation of water flow rate:

The water flow rate can be calculated by the measuring the river or stream flow velocity and its cross sectional area, then

$Q = A \times V$

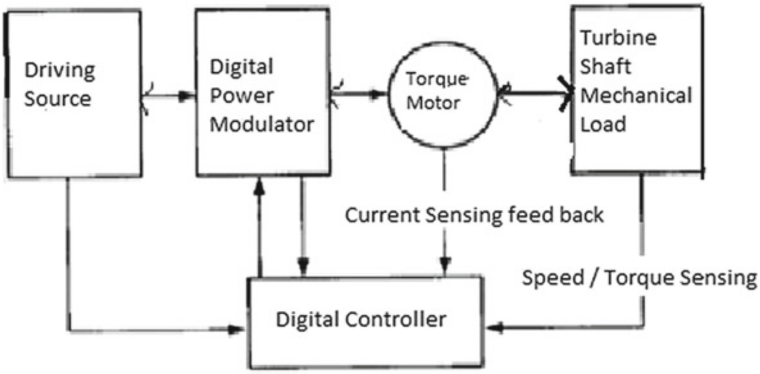
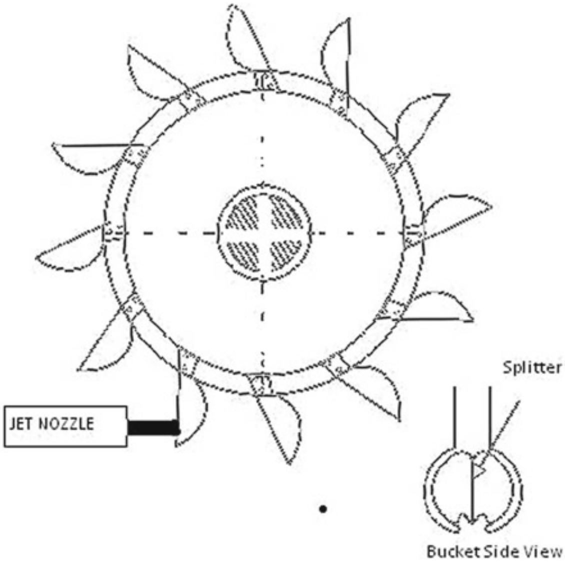


Fig. 3 Functional block of torque drive module

Fig. 4 Typical petrol wheel



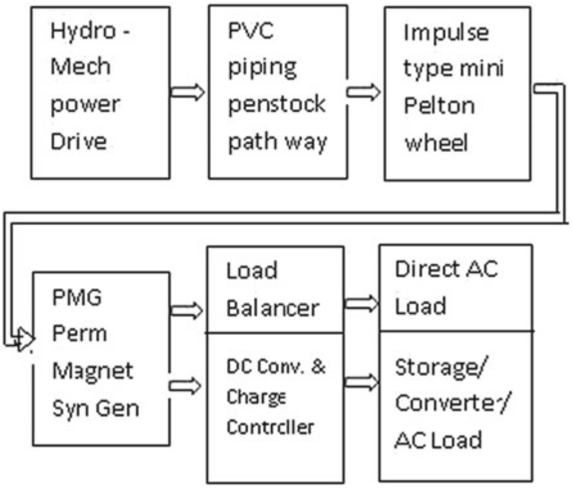


Fig. 5 LPGS functional block diagram

A = Area of channel,

V = Velocity of stream

(2) Calculation of Power:

P= ρ* g* Q* Hj 'ρ' is the density of fluid and g is the gravity.

d. Calculation of the Turbine Speed (N)

The relation between the specific speed (Ns) and the Net Head is given as

Ns= 85.49×$\sqrt{}$Nj/Hn.243, Where Nj =No. of jets and N= Ns*Hn5/4/$\sqrt{}$P

(3). Runner Design:

The mean velocity of the free jet emerging from the nozzle of the turbine is determined from the net head, by the equation

Vj = Cv$\sqrt{}$2gHn

At the best efficiency point the circumferential speed of the runner is connected with the jet velocity via the relation.

U = (0.46-0.47)*Vj, therefore the Diameter of runner 'D' = 60*U/πN

Where N is the speed of runner in rpm.

(4). Nozzle Dia or Jet 'd' = $\sqrt{}$4Q/πVj.

(5). No. of Buckets 'Z' = 15 + D/2d

(6). Efficiency of turbine

Torque T= Q*D*(Vj – U), Power transferred by shaft 'Ps' = 2π NT/60

Efficiency $\eta t = Ps/Pj$

R. Types of Electrical Loads: Electrical loads that are normally connected to LPGS system are LED or regular light bulbs, Charge Controllers, TV, exhaust or indoor fans, refrigerators and AC etc. For economical models for communities which supported by Govt. or other agencies the proposed LPGS system can be designed for generating capacities much lower for lesser price compared to the existing systems. Therefore, the system, if required, can be used for charging and store the power. The storage module allows future use of electrical loads especially during the power blackouts and can assure secured energy for emergency devices like Medical gadgets, LED lighting, mobile phone battery charging etc. particularly during the prolonged stormy days when solar energy cannot come at the rescue. Though there are many options available for storage technology [5], here for this LPGS project, keeping the low cost and affordability in mind mainly two types of rechargeable batteries are considered for providing power to small loads which are Lead-Acid and Nickel–Cadmium (Ni-Cad). Based on the power generating capacity, the size of the storage is decided Ni-Cad is preferred for Medical gadgets and mobile applications as it is easier to handle and reliable. Lead-Acid suits for regular domestic loads like LED Bulbs, TV, Fan etc. Contrary to Lead-Acid, Ni-Cad works better and gives prolonged life if it is fully discharged before re-charging. Whereas, the Lead-Acid batteries should never be fully discharged to protect them from permanent damage.

3 Major Issues in the Development of LPGS Power System

There are few concerns in the development of the proposed LPGS system. One is related to civil works, choosing appropriate location, building its own shed for small scale PVC piping system or penstock from the overhead water tank to the turbine, and the second is to deal with specially made guided turbine and clubbing with torque motor along with torque drive controller and the third is Integrating the system modules for better performance as the turbine, TM and PMG all parts determine the functionality and performance of the proposed system.

Design criteria for torque motor module.

The selection of torque motor drive depends on various factors such as:

(1) Steady state governing variables such as speed of the motor verses torque characteristics, speed regulation and control, speed range, efficiency, duty cycle, speed variations, rating etc.)
(2) Operational requirement values like acceleration, deceleration, starting, braking, and speed
(3) reversal etc.
(4) Energy sources requirements: like source types, their capacity, voltage and current magnitude, power factor, harmonics etc.
(5) Capital cost and running cost, maintenance requirements like MTBF etc.

(6) Space limitations and weight constraints.
(7) Neighborhood, environment and location.
(8) Quality, standards, Reliability

4 Conclusion

There are three important things which assure LPGS System to function better as an alternative energy system for electrical power generation intending mainly for small scale utility needs that include domestic usage. These are (1) the pressure of water which is supplied thru the PVC pipe representing the Head (downstream water), (2) the flow rate of water and (3) the torque required to overcome the inertia. This is achieved through a torque motor. This torque motor also ensures consistent required RPM. The first two are often prone to circumstantial change and therefore, it is better to determine both the parameters prior to erection and installation for probable output power estimation. As the friction loss depends on the PVC pipe fitting and other infrastructure, the use of flexible or adjustable nozzle is another solution. Pressure can be varied accordingly to compensate the pressure loss by achieving optimum pressure value. This can be made possible by using an impeller in conjunction with torque motor. And also, the design of guided turbine and the selection of generator in terms of their type, size and capacity are equally important in developing the proposed LPGS System. In the forthcoming paper there will be more details on methods and testing to evaluate the proposed LPGS system performance.

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Energy Storage System—Applications and Case Study

Swajjal Rastogi

Abstract This paper presents the application and business case study of Compressed air energy storage (CAES) system. To achieve low carbon emission, India is moving towards renewable energy sources and constantly reducing the carbon footprints. Transport ministry is also intending for India to move towards 100% electric cars by 2030. As per energy generation report, in year 2009–10 the power generation of India was short by 10% of the required power and by year 2018–19, this figure has dropped to 0.6%. India is targeting for installation of 175GW of Solar, wind and hybrid power plants by year 2022. It's expected that in the coming years, India will be generating surplus power. In such scenario, a technology to store the energy can play a major role for Indian grid. Energy storage system can provide flexibility needed to better integrate the unreliable power generated by various energy sources and meet the flexible power demand. Technology in storage system is continuously upgrading and various modes of energy storage systems have developed in the recent time. Many pilot energy storage projects are successfully executed in the world. Asia is being considered as the hub for investment in energy storage market. In this paper, application, case studies and environmental impacts of CAES technologies shall be covered.

Keywords Energy storage system · Compressed air energy storage · Micro grid · Renewable energy

1 Introduction

Reduction in the usage of fossil fuels is a global challenge. Wind, solar and other renewable energy sources are being explored and developed worldwide. Technology in the storage system is continuously upgrading and various modes of energy storage systems have developed in the recent time. The various types of storage technologies are shown in Fig. 1.

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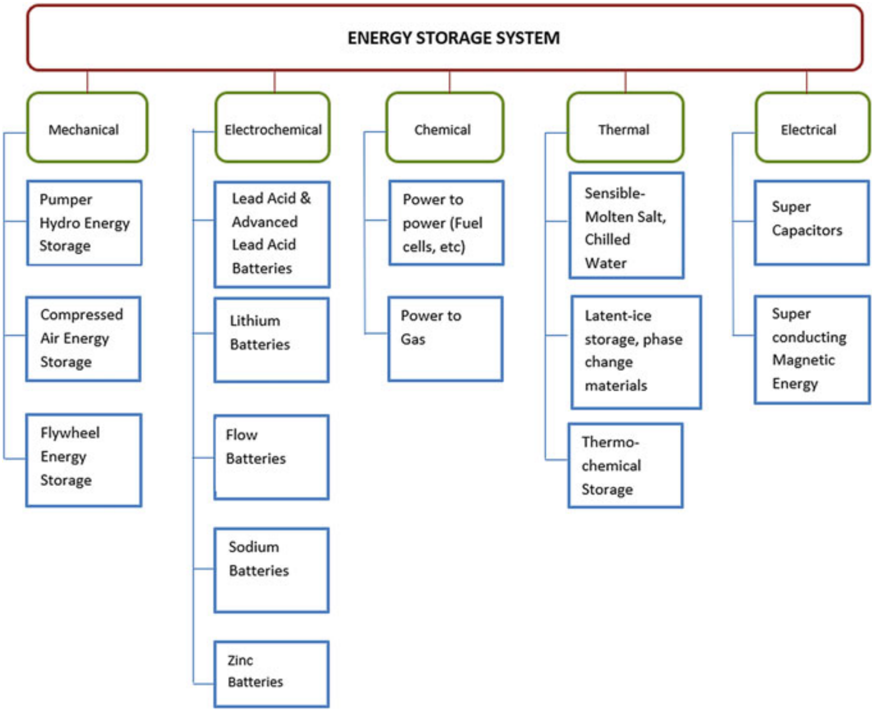


Fig. 1 Energy storage system technologies

In this paper, application and cost estimates of compressed air energy storage system. CAES is ideal for utility from 10 to 100 MW. It requires underground storage in natural or man-made caverns, and can work for storing wind or solar energy outputs. CAES uses tanks and compressors that are capable of 30 years or more of continuous use (over 10,000 cycles) with complete discharge capability (compared with 70% discharge for in Li-ion). Further, CAES can be used to store energy from a few weeks to years. Refer Table 1 for key attributes of CAES system:

2 CAES Working

CAES is a technology known and used since the nineteenth century for different industrial applications including mobile ones. Air is used as storage medium due to its availability. Refer Fig. 2 for working principle of CAES.

Electricity from grid or renewable sources is used to compress air and store it in either an underground structure or an above-ground system of vessels or pipes. When needed the compressed air is mixed with natural gas or store heat, burned and expanded in a modified gas turbine. Typical underground storage options are caverns,

Table 1 CAES system details

Power range	In range of 100 MWs
Energy range	100 MWh–10 GWh
Life duration	>30 years
Reaction time	3–10 min
Efficiency	50–65%
Discharge duration	4–10 h
Construction period	5–9 years
Operating cost	High
Energy to power ratio	16
Cycles at 70% depth of discharge	10,000

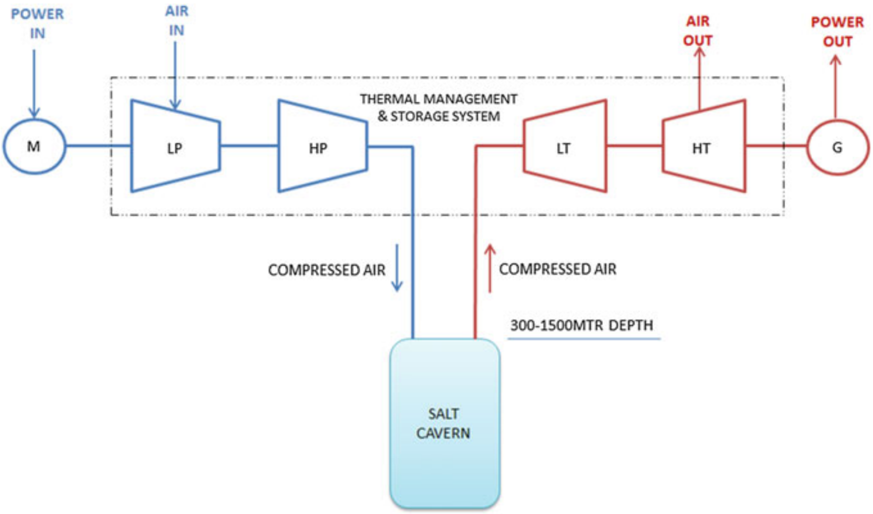


Fig. 2 CAES working principle

aquifers or abandoned mines. If the heat released during compression is dissipated by cooling and not stored, the air must be reheated prior to expansion in the turbine. To control the air pressure in salt cavern, air pressure controllers may also be used.

A. *Diabatic Compressed air energy storage (D-CAES)*

These plants operate without heat storage and therefore use natural gas as a heat source for the discharging process. Refer Fig. 3 for working principle of D-CAES system and Table 2 for project details (Fig. 4).

B. *Adiabatic Compressed air energy storage (A-CAES)*

A form of CAES that does not require the use of natural gas to reheat the air during generation is currently in the research and development phase. This technology is

Fig. 3 D-CAES working principle

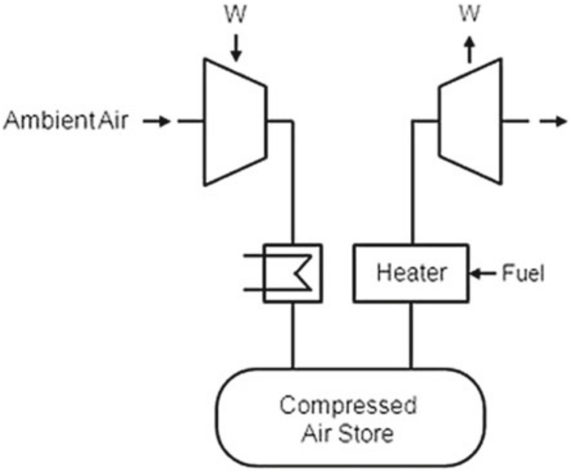
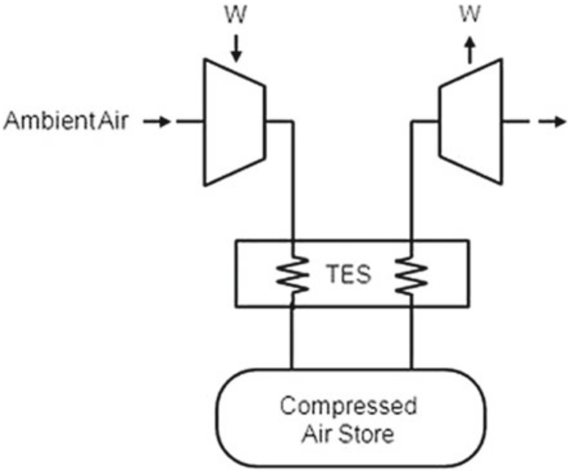


Table 2 D-CAES running projects

Project	Huntorf, Germany	McIntosh, USA
Capacity	321 MW	110 MW
Commissioning Year	1978	1991
Purpose	Commercial	Commercial
Efficiency	41%	54%
System type	Diabatic	Diabatic

Fig. 4 A-CAES working principle



called ‘Adiabatic CAES’ and it will store the excess heat created during compression above ground. Then it will be reused to heat the air upon expansion.

3 Application of CAES

A. The government is planning to implement of micro grids in rural areas. Micros CAES projects may be installed with the micro-grid to provide better flexibility.
B. Renewable energy plants provide flexible power which may lead to unbalancing grid. CAES may provide flexibility in power demand if integrated with renewable energy sources.
C. Micro-CAES projects at hospitals, commercial complexes, malls etc. may be installed to provide backup to the emergency loads.
D. It can play essential role in the future of smart grid
E. Loads of domestic consumers always keep fluctuating. Stored energy may be play vital role in time shifting/cost savings of consumer loads.

4 Economic Analysis

The cost of storage technologies is changing with the continuous development of technology and the trend shows that the cost is normally getting cheaper with technology advancement (Tables 3 and 4).

The initial cost includes the spending on design, specification, civil works, and installation. Specifically, to CAES, the reported data related to the power capital cost are: 1700–2050 \$/kW (small-scale CAES), 1000–1600 \$/kW (large-scale CAES); the reported data related to the energy capital cost have: 150–200 \$/kWh (small-scale CAES), up to 105 \$/kWh (large-scale CAES). From the data, it can be seen that the cost relies on the scale. Among the mature and developed EES techniques, CAES have quite low energy capital costs compared to other technologies. Also it is worth mentioning that, to the underground large-scale CAES, normally 50–60% and even more of the capital cost will be spent on the construction of storage reservoirs. From the above description of geological study, it can be seen that, to different geological formations, the cost can be quite different. In addition, the capital cost to

Table 3 A-CAES running projects

Project	Toronto, Canada
Capacity	660 kW
Commissioning year	2015
Purpose	R&D
Efficiency	65%
System type	Adiabatic

Table 4 CAES cost estimate

Cost estimate of CAES–210 MW plant	
Item description	Cost (In $)
Procurement packages (Turbines, generators, compressors)	160,630,735
Cavern development	122,956,933
Erection, testing and commissioning (including civil works)	49,078,498
Total cost	**$ 332,666,166**
Per kW cost (Annum)	**$ 1584.12**
O&M Cost (per kW-year)	**$ 17**

a specific CAES system can be various from the data in cited references here due to, for example, the time of construction, the location of the plant/facility, and the size of the system.

The initial cost of CAES system is high as it involves construction of salt caverns 300–1500mtr below earth. This cost will be reduced if natural caves or existing salt caverns may be explored. The running cost of CAES is high as natural gas is required for heating up the compressed air. Using alternate sources for this purpose will reduce the running cost.

5 Conclusion

The paper explained the overall working of different types of CAES, cost estimate and applications of CAES plant. It is found that cost and performance largely depend on the scales; in general, with the same types of components in a CAES system, large scale results in more efficient performance and lower cost. CAES systems offer a combination of good performance, long lifetime, low net environmental impact and reasonable cost compared to rechargeable batteries. There are huge application potentials for CAES in strengthening various aspects of electric power system reliable operations, however, the enormous challenges and barriers are present for further deployment. Funding support and joint effort from academic and industrial sectors are required to speed up the technology innovation and breakthrough to realize the great potential of CAES and demonstrate its role in supporting power system operation. Replacing natural gas with renewable energy for heating of air may reduce the running cost of CAES plants by a huge margin. On a $/kWh basis, CAES & PSH are the most cost-effective systems. CAES faces environmental restrictions when constructing the caverns that will store the compressed air. With advancement and development in the equipment technologies, effective turnaround efficiencies of 70–80% may also be achieved in the future in the applications as stated.

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Forecasting of Power Demand for Distribution Utilities Using Machine Learning Models

Tanmoy Mitra and Abhijit Das

Abstract In order to provide 24 × 7 affordable and quality power to its customers, it is essential for the power utilities to take the correct decisions while doing power purchase. Traditionally, utilities in India have been using variables such as calendar data (Season, hour, holidays, etc.), weather forecast data (temperature, humidity, rainfall, etc.) and demand data (historical consumption of electricity i.e. monthly data available through consumer meters and feeder meters) for predicting future demand towards deciding the quantum of power to be purchased. But, due to growing use of distributed generation techniques such as roof-top solar, wind, biomass etc., the power demand scenario for the distribution utilities are changing. Also, basing daily demand predictions on monthly consumption data may result in incorrect estimations in power demands. Under these circumstances, traditional demand forecasting methods may prove to be inadequate for the utilities trying to provide uninterrupted as well as affordable power. The objective of this paper is to propose robust machine learning models by using huge volume of consumption data, made available to the utilities after implementation of smart metering with AMI, along with historical weather information and calendar data to accurately predict power demand thereby helping the utilities to take scientifically accurate power purchase decisions.

Keywords Demand forecasting · Decision tree regression · Machine learning models · Scatter plots · Correlation

1 Introduction

In order to build power demand forecasting models, necessary data has to be accumulated from available sources.

Implementation of Smart Metering with AMI has facilitated collection of the following data in one hour intervals for all consumers under a feeder-

- Instantaneous Load in kW
- Timestamp.

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Historical weather data as well as weather forecast data can be collected from sources like www.openweather.com by calling specific APIs provided by them. In the present context, the following hourly attributes are relevant-

- Temperature in Celsius
- Relative Humidity in %
- Timestamp.

From calendar data, the following attributes are relevant in the present context-

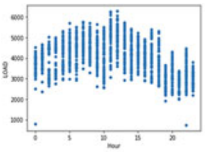
- Type of day (Holiday/Working day)
- If holiday, weather it is a festival day
- If festival day, the name of the festival
- Timestamp.

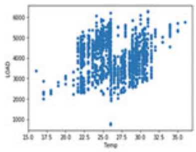
With the help of data wrangling methods, the above data can be converted to a single data source with the following hourly attributes/features for a complete feeder-

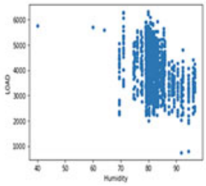
- Hour of the day
- Instantaneous load in kW
- Temperature in Celsius
- Relative Humidity in %
- Type of day (Holiday/Working Day)
- Festival day
- Name of festival.

2 Examining Correlation

The single data source, obtained as described under section I, is examined for correlation between the feature 'Instantaneous load in kW' with the other features. It was detected that a correlation exists between the feature 'Power allotted in MW' and Hour of the day, Temperature and Humidity as shown in the following scatter plots.







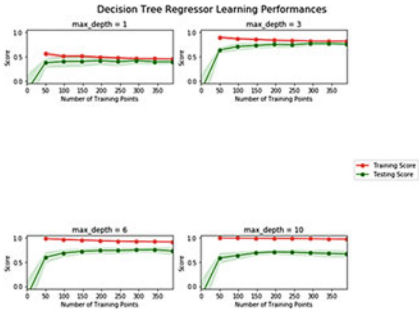
3 Creating and Fitting the Model

Using train_test_split module of sklearn cross_validation library of Python [1], the given data set was split into training and testing sets. Load in kW was then chosen as the target label and decision tree regressor was used. The findings are given below.

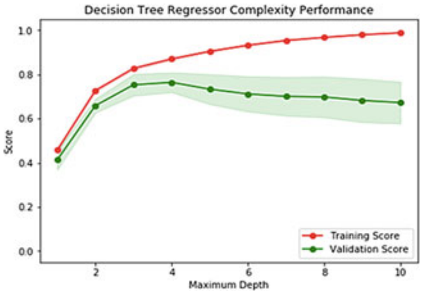
Accuracy score when test size is 20%: **0.76803 i.e. 77%**

Accuracy score when test size is 25%: **0.79005 i.e. 79%**

Then four graphs were generated, showing the learning curves of the decision tree models with different maximum depths for both training and testing as the size of the training set is increased.



Then complexity curves were generated for the decision tree models that has been trained and validated on the training data using different maximum depths. The graph produces two complexity curves—one for training and one for validation. The shaded regions of both the complexity curves denote the uncertainty in those curves, and the model is scored on both the training and validation sets using the performance_metric function.



4 Evaluating the Model

We have used Grid search technique to find the best of a class of models which were built using different parameters. Grid search technique is a process in which we have a list of models with different parameters. The parameters are called hyper-parameters. The grid is defined along the parameters. The models with the corresponding combination of parameters are placed in the grid.

Cross-validation is applied on the models in the grid and the model with the best score is chosen. From the grid we can know the values of the hyper parameters which gives us the best model.

From our evaluation, it was deduced that parameter ‘max_depth’ is 10 for the optimal model.

Once the model was trained, we have used the model to make predictions on new sets of input data. The model learnt what was the best questions to ask about the input data and could respond with a prediction for the target variable.

Reference

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Electric Vehicle Infrastructure Planning for Indian Distribution Sector

Tripta Thakur and Tushar Kumar

Abstract Massive target for adoption of Electric vehicle (EV) in India aims to save an estimated $60 billion in energy bills by 2030 and is way forward not only for meeting decrease carbon emissions by 37%, but also having immense health benefits for the public. Preparedness of robust electric vehicle charging infrastructure and power sector is necessary to facilitate electric mobility for India. This paper looks at India's ambitious policy plans and prospects for EVs and its likely implications for India's distribution sector. Issues in the deployment of charging infrastructure and possible solutions for existing challenges are proposed.

Keywords Electric vehicles · Fast charging · Charging infrastructure

1 Introduction

Right to a clean environment is becoming a distant dream as air pollution levels are becoming severe day by day. Transition to Electric vehicles (EVs) can reduce and shift the emissions from residential areas. A paradigm shift will take place in the planning of distribution infrastructure as EV penetration in the market increases. For electricity markets Electric vehicles can serve as a distributed plug in facility of energy storage at low cost requiring minimal capital investment from grid utilities.

However widespread Electric vehicle (EV) adoption faces a number of hurdles [1], such as limited range in comparison to IC engines but from the grid perspective it faces following issues:

- Charging time for Electric vehicles is much longer currently as compared to refueling fuel driven vehicles.
- Limitations of available charging infrastructure to charge large number of Electric vehicles.

The International Energy Agency estimates that the sales of passenger light-duty EVs/plug-in hybrid EVs (PHEVs) will increase significantly from 2020 onwards and

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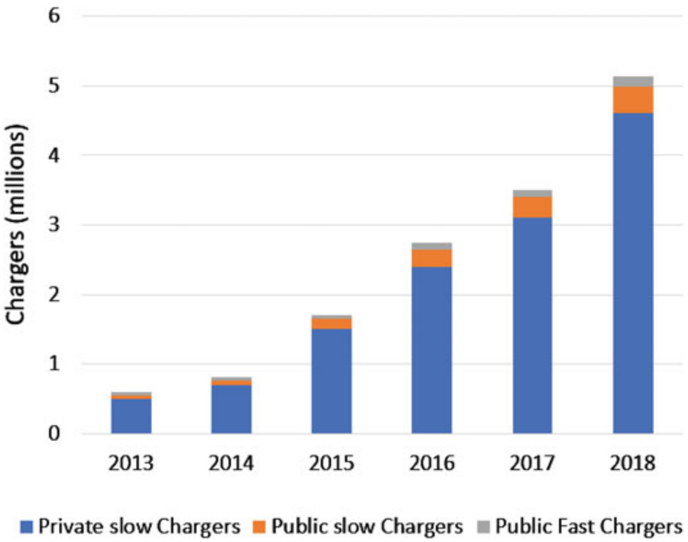

Fig. 1 Installation of Elecrtric Chargers globally 2013–18 [3]

might reach more than 100 million EVs/PHEVs sold per year worldwide by 2050 [2]. However 5.2 million charging points were available at the start of 2019, which shows a 44% increase from 2017 [3] (Fig. 1). More than 90% of the 1.6 million installations were accounted for by private charging points. Around 3,95,000 slow chargers and 1,44,000 public fast chargers were installed by the end of 2018.

2 Classification of EV Charging

Based on type of connection, charging strategies and accessibility, charging infrastructure can be further classified.

A. *Based on Accessibility*

The Charging infrastructure based on accessibility is classified as private, semi-public and public. Charging ports installed at homes privately would mostly be available to the residents only. Semi-public charging facilities would be available to a limited group such as company employees, club members etc. in their premises. Public charging facilities on the other hand are available for the general public commercially. Currently most EV owners around the world charge at private charging facilities but studies done by Kihm et al. [4] and Sierzchula et al. [5] show that the penetration of EVs is well predicted by availability of public charging infrastructure.

B. *Based on Charging Power*

The Based on charging power four levels are currently described in literature [6]: level 1 (slow charging), level 2 (slow/semi-fast charging), level 3 (semi-fast/fast charging) and level 4 (fast charging). level 1 charging has a typical power level of 2.3 kW and hence domestic cables and sockets are sufficient. level 2 charging would require safety protocols such as thermal limits, overcurrent protection, grounding detection along with a special charging cable. For level 3 safety protocols are same as that of level 2 but for a power level of 20 kW customized circuit with a special plug socket is needed. Power level higher than 50 kW from mode 4 is based on DCs fast charging which need advanced safety and communications protocols.

C. *Based on Charging Strategies*

Improper management of charging loads can negatively impact grid operations and reliability, increase emissions and electricity prices [7, 8]. Uncontrolled charging refers to charging when little or no information is available regarding electricity prices and the time for plug in is decided by the owner. Till the battery is charged fully, the charger draws maximum power from point of plug-in. Controlled charging involves directing EV charging behavior by providing price signals or other incentives to the consumer, in order to limit negative grid impacts [9]. With controlled charging, EVs can levelize the overall load, make better use of base load generating units, and require no extra installed capacity.

3 Technical Standards in India

The duration for EV charging depends on the charging characteristics as well as the battery storage capacity. Currently there is no single charging standard that is unanimously accepted throughout the world but various systems emerged for higher-current charging connectors with the standardization in IEC 62,196 and IEC 61,851 for electric vehicle conductive charging systems, parts of which are currently still under development. SAE combo standard developed by Society of Automotive engineers (SAE) consists of a combination of fast DC charging and AC charging points in the same connector [10]. Apart from this CHAdeMO, a fast charging standard developed by TEPCO (Tokyo Power Electric Company) was revised to CHAdeMO 2.0 which would allow up to 400 kW charging [11]. On the other hand tesla has its own standard tesla supercharger that can currently supply 120 kW for each car.

Since a suitable framework was required to support creation of EV infrastructure therefore Ministry of Power (GoI) released guidelines and standards for charging infrastructure in 2018 [12]. Combined charging system (CCS) and CHAdeMO standards were accepted for fast charging in the range of 50 kW or above whereas for slow/moderate charging in the range of 15 kW Bharat DC and AC specifications formulated in "Standardization of Protocol for EV Charging Infrastructure—2017" is adopted [13]. Revised Minimum requirements for charger models in public charging

Table 1 Minimum requirements for charger models in India (public charging stations) [14]

Charger type	Charging connectors	Rated voltage (volts)	No. of connector guns	Vehicle type
Fast	Combined Charging System (CCS) (min 50 kW)	200–750 or higher	1 CG	4-wheeler
	CHAdeMO (min 50 kW)	200–500 or more	1 CG	4-wheeler
	Type-2 AC (min 22 kW)	380–415	1 CG	4-wheeler, 3-wheeler, 2-wheeler
Slow/moderate	Bharat DC-001 (15 kW)	48	1 CG	4-wheeler, 3-wheeler, 2-wheeler
	Bharat DC-001 (15 kW)	72 or higher	1 CG	4-wheeler
	Bharat AC-001 (15 kW)	230	3 CG of 3.3 Kw each	4-wheeler, 3-wheeler, 2-wheeler

stations are as shown in Table 1. These guidelines are for two, three and four-wheeler vehicles. For long range or heavy duty EVs atleast two chargers of minimum 100 kW and appropriate cooling facilities for cables is mandated.

4 Policy Initiatives

Government of India approved the national mission on electric mobility in 2011 and thereafter national electric mobility mission 2020 was formulated with a target of deploying 5 to 7 million electric vehicles in the country by 2020. With the provision of distribution of fund amongst the 4 focus areas i.e. Technology Development, Demand Creation, Pilot Projects and Charging Infrastructure, demand incentives were also considered for buyers (end users/consumers) in the form of an upfront reduced purchase price. While the phase-I of FAME India—“Faster Adoption and Manufacturing of (Hybrid & Electric) Vehicles” in India was launched in 2015, the shorter duration of the plan (for a year) made carmakers unsure about its longevity. With Fame II scheme a Rs 10,000-crore, three-year plan was laid out to incentivize vehicle owners and battery makers, with Rs 8,596 crore as subsidies to owners, up from the Rs 795 crore allocated in 2015 under Fame I scheme. FAME India Scheme Phase II launched in April 2019 has three broad verticals namely demand incentives, charging infrastructure along with information and communication. The fund allocation for these verticals is shown in Table 2.

Table 2 Fund allocation for in fame-II [15]

Component	2019–20	2020–21	2021–22	Total fund requirement (in crores)
Demand incentives	822	4587	3187	8596
Charging infrastructure	300	400	300	1000
Administrative expenditure (including information and communication)	12	13	13	38
Total for fame-II	1134	5000	3500	9634

As the country is at an early stage of EV deployment, public charging infrastructure is still limited. In this regard, the Ministry of Power has already identified 9 major cities and 11 intercity routes as pilots to enable EV charging infrastructure.

However, as the Table 2 shows the policy initiatives are currently heavily tilted towards battery subsidies while charging stations that are available are few and hence the range anxiety persists. monetary incentives alone cannot drive EV penetration. In US for example West Virginia offers more monetary incentives for EVs, but EV adoption has been low there. On the other hand, fewer monetary incentives are offered in California, but the government's investment in providing better EV infrastructure and promoting workplace charging facilities with parking benefits has led to the highest EV penetration [16].

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5 Effects on the Distribution Sector

While policy initiatives have been made regarding battery technologies and charging infrastructure it is equally important to focus on the effects on the distribution sector.

A. *Additional load on the Grid*

Although studies [16] estimate that a 30% EV penetration throughout the country might increase the load on the grid by 3–4%, local effects on the grid needs to be studied. It is possible that the time for peak load of charging may coincide with other loads resulting in voltage limit violations that may damage or reduce the lifetime of equipment. Usage of controlled charging could minimize such problems but such schemes require additional data handling and communications to manage multiple vehicles. Sending adequate price signals to customers would incentivize the shifting of charging from peak to off peak hours, thus reducing contribution to the peak demand by EVs. Programs that engage various stakeholders by utilizing smart charging schemes, integrating EV owner's feedback on charger deployment and devising partnerships between public and private utilities are more likely to be effective [17]. Operating costs for electric vehicles could vary a lot depending on the charging location and the policies that are in effect there. For example, with a tiered electricity rate scheme it is quite possible that if users charge electric vehicles at home then their electricity consumption may cross over into a higher priced tier. Compared to fossil fuel driven vehicles, pure electric vehicles would be more expensive to drive in such a case as shown by Huang et al. [17].

B. *Managing Grid Congestion*

Apart from sending price signals DISCOMs could use congestion pricing for day ahead electricity markets taking into consideration the grid constraints [18]. Although this is used in transmission level but has not been tried at distribution level. Another alternative could be the use of variable capacity contracts that allow DISCOMs to keep the connection within limits of mutually agreed variable capacity. This would involve treating charging stations as controllable loads and hence can be interrupted. This method has been used in UK to handle the impact of intermittent distributed generators. Since it affects the availability of charging whenever the users need it, therefore it is not a long-term solution. However, it can be used in the meanwhile as structural reinforcements take place.

A market place for flexibility services could be developed where EV owners directly or through the aggregators could offer their services for reducing congestion. They could either increase or decrease their charging rate and even provide additional power through vehicle-to-grid (V2G) scheme.

6 Conclusion

In spite of the potential of EVs to reduce emissions and improve mobility, EV adoption has been slow. They are expensive for common users and the availability of models for different market segments such as taxis which can run very long distances in a single day is limited. Such intensive pattern of usage reduces lifetime of battery which leads to increased costs for operators. Reduction in battery prices and research on the storage devices could increase their lifetime. However policy measures and business models adopted would influence faster adoption as seen in case of California.

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Adoption and Assessment of Machine Learning Algorithms in Security Operations Centre for Critical Infrastructure

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Abstract Perception of establishing a Security Operations Centre (SOC) depends on the criticality of information assurance and security operations in response to the ever-changing security threat landscape and adoption of formal security standards. From a security perspective, both IT and OT systems are vulnerable to similar threats—botnets, script kiddies, viruses and other malware. The key difference between the two environments, however, has to do with human safety. Typically critical infrastructures are provided with security measures like firewall, demilitarized zones, Intrusion prevention systems (IPS), Intrusion detection systems (IDS), anti virus etc. However, with new threats always around the corner, it's important to have a dedicated infrastructure to deal with these problems, like the SOC. SOC is a centralized unit that deals with security issues on an organizational and technical level. It can be used by utilities which form a part of critical infrastructure like power systems for any threat detection and taking timely action. Typically, SOC is divided into four layers i.e. data collection source, data processing, technologies and display platform. This paper gives an in depth review and comparison of the machine learning models that can be used by the SOC at different layers. Different machine learning models are to be applied at different layers, so its required to evaluate which models give better accuracy in detecting threats. For evaluation of ML algorithms cases covered in this paper are event correlation, breach detection, rule based processing and anomaly detection.

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1 Introduction

The security defenses deployed by organizations yield large volumes of security logs which record attack-related activities but Advanced Persistent Threat (APT) campaigns often remain undetected for long periods of time [1]. In order to detect these malicious activities, the SIEM (Security Information and Event Management) system along with a Security Operations Center (SOC) is established by organizations. Analysts in the security operations center (SOC) investigate the alerts by manually unveiling advanced attacks through log data analysis and decide if it is truly malicious or not [2]. SOC analysts team typically employs rule based correlation with one or more indicators from different logs. If any predefined use case is triggered, SIEM system will generate an alert in real time [3]. SOC analysts will then investigate the alerts to decide whether the user related to the alert is risky or not. If they find the alerts to be suspicious from the analysis, SOC analysts will create OTRS (Open Source Ticket Request System) tickets. After initial investigation, certain OTRS tickets will be escalated to tier 2 investigation system as severe security incidents for further investigation and remediation by Incident Response Team [4].

Generally, the number of alerts is overwhelming with the majority of them being unnecessary events and exceeding the SOC's capacity to handle all alerts. In this situation, extracting intelligence from security logs or events in an automated manner seems to be a promising direction for preventing organizational breaches, but nevertheless it is a daunting task and introduces unforeseen challenges. In addition to the large amount of data that needs to be processed and analyzed, logs come from multiple vendors, are sometimes inconsistent in their format, and there is usually a high semantic gap between the information recorded in the logs and what is required to detect a breach [5]. Machine learning, in this case, is a viable approach to reduce unnecessary events and improve the productivity of SOC analysts [6].

Most organizations have inadequate security monitoring tools and miss security incident management process. Also, the implemented security tools are not acquired based on a well-articulated security strategy. In this paper, we present a planned and automated security strategy for critical infrastructure protection through systematic implementation of SOC, which assesses how to leverage various machine learning algorithms to detect security breaches, security event correlation and anomaly detection in SOC for CI. For this, in the second section, we first illustrate the need of SOC in protecting CI then present the Operational technology(OT) specific security behaviour and finally compare in-house vs service based model for SOC implementation. In the third section, we model a machine learning based analytics framework that divides the security threat discovery and detection process into four layers namely automatic data collection from various sources, data processing, threat intelligence and security information management. This section identifies the three significant threat detection cases namely security breaches, security event correlation and anomaly detection in SOC for CI. In the fourth section, we discuss the case studies for adoption of appropriate machine learning algorithms for automated security threat identification and proactive protection of SOC [7]. This section explains the threat detection case specific ML algorithms. The next section concludes with substantiating improvements in the discovery of threats by the adoption of appropriate ML algorithms for cases discussed in the paper.

2 The Case of Critical Infrastructure(CI)

The attack landscape faced by critical industrial networks today is continuously evolving, Industrial Control systems traditionally achieved security by using proprietary protocols to communicate in an isolated environment from the outside. This paradigm is changed with the advent of the Industrial Internet of Things that foresees flexible and interconnected systems. Also CI networks are vulnerable even today due to lack of many built-in controls which we now take for granted in IT networks, such as automated updates and strong authentication. A variety of security defenses (firewalls, intrusion-detection systems, anti-virus software, etc.) are used to protect their perimeter against breaches. Nevertheless, well-funded attackers develop custom tools that attempt to evade the security protections in place. This has resulted in an astonishing number of successful breaches highly publicized by the media [27–29].

A. *Need of SOC for CI*

The evolution of Information Communication Technologies (ICT) made it feasible and convenient to control critical infrastructures (CIs) remotely using control systems. Today even the lower levels of a modern OT architecture (endpoints, field devices, instrumentation, intelligent sensors and actuators) now rely on remote connectivity for communication, control, configuration and data collection. As these boundaries become more fluid, OT and IT teams need to break down traditional communication barriers to support this new architectural norm for control systems across industries and throughout application domain. This strong correlation between OT and IT comes at the cost of increased complexity and, as a consequence, increased risks of accidental faults. The impact of an OT incident can be far greater, causing not only disruption to business operations and services but also potential damage and destruction of equipment, and injury to people. This convergence of IT and OT encourages us to build SOC which form a part of critical infrastructure for any threat detection and taking timely action.

3 SOC for CI—A Hybrid Approach

Achieving the goal of better security depends on how that budget is allocated and how the security program is managed and optimized over the long term. In this case, three options can be thought of First, your organization may have employees ready to step in to fill the role of incident responders and SOC analysts, Second, you may opt for outsourcing (via managed security service providers, or MSSPs), Third, contracting specialists to provide surge incident response (IR) support. For organizations without a formalized incident-handling capability, the building from scratch a dedicated security team that provides OT specific SOC (Security Operations Centre) functionality is an expensive and daunting proposition. So, incident response needs cannot be completely with in-house staff or completely outsourced. A hybrid or virtual SOC service with a mix of these options is suggested in this paper. A hybrid approach can be like outsourcing services for monitoring the perimeter or a remote site while using a local SOC to secure an internal network such as a control system environment used for classified communications.

Again in hybrid or virtual SOC existing IT support team is utilized to provide SOC functionality to monitor and respond to both Operations Technology (OT) and Information Technology (IT). Some of the propositions which support hybrid SOC approach are (i) most attacks on utilities started from IT, (ii) OT focussed training for IT personnel is easier than having two separate teams.

Concerns of IT and OT differ in some cases but have common functional requirements like (i) Both operation side and IT care about mean time recovery but root cause analysis for whether its a fault in line or a disruption in a process is only the major concern for operation side, (ii) OT includes cyber physical systems which require appropriate control through the network to be performed but fault monitoring in this case is required for both IT and OT, (iii) Using process modeling tools and by monitoring the process a fault could be distinguished from a cyber attack which is an additional requirement for OT [8].

4 Architectural Framework of SOC

Here we present a model for operation of a SOC using Machine learning based analytics framework where we address the various functions of SOC as a bottom up approach starting from the data collection, followed by data processing and threat detection using case specific Machine learning algorithms. Machine learning enables an automated and real time threat detection while reducing the unnecessary events, it trains the system to learn from earlier incidents and improve the detection mechanism. All security information is presented through an easy to manage security information display console. Some of the outcomes can be escalated and sent to an outsourced agency for specialized Incident Response (IR) support. This framework is divided into four layers i.e. data collection source, data processing, threat intelligence using ML technologies and security information display and management (Fig. 1).

1. Data Collection Sources

One of the most significant challenges for SOC is data collection. Gathering data after a suspected incident is also difficult in real time scenarios. The SOC captures

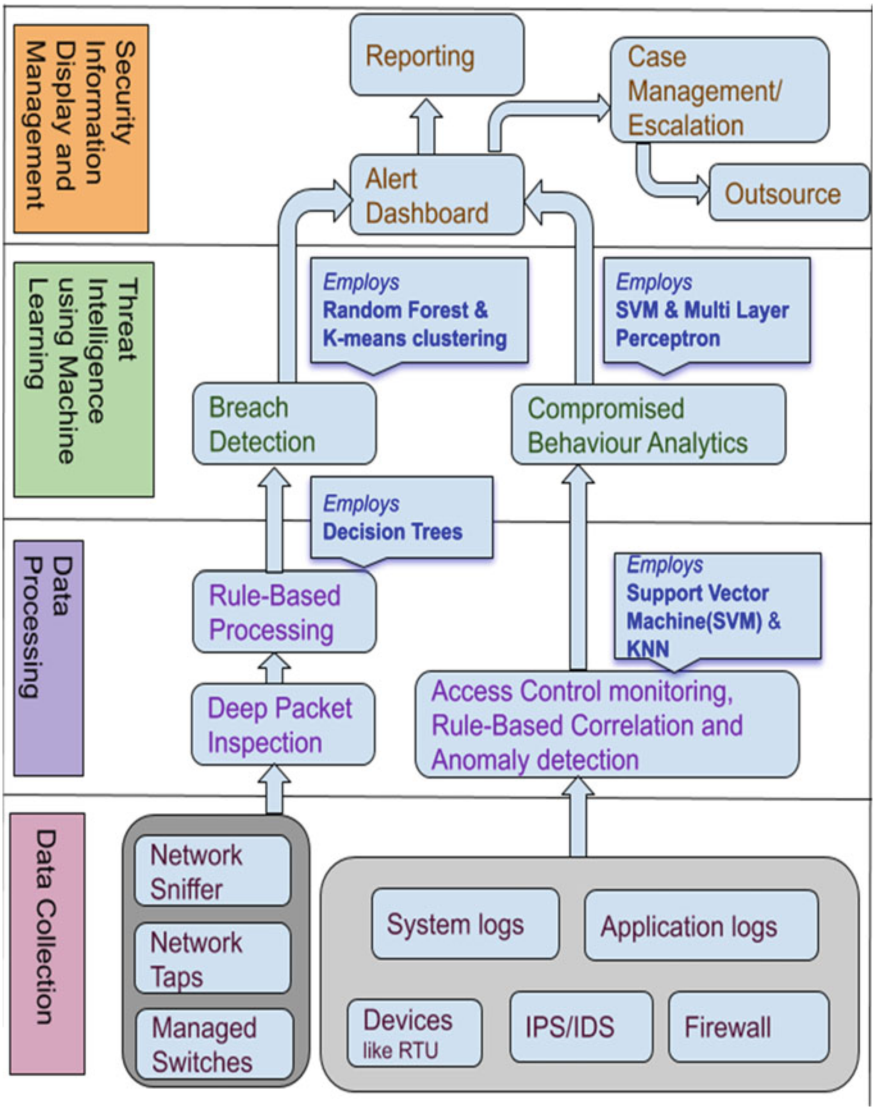

Fig. 1 Machine learning based analytics framework for Security Operations Center (SOC)

data from event logs, network packets, and network flows, static content of a web page or the hash value of a file etc. SOC collects logging messages from various forms of security, network, and application products. Typical devices for collection sources include network devices, security devices, operating systems, application logs and database logs.

2. Data Processing

This layer reviews the different protocols and mechanisms used to collect data, filters relevant useful security data, analyzes the data for any malicious activity and finally redirects for appropriate processing to a higher layer [31]. Initially, environment profiling is done which typically generates multiple baselines corresponding to network, application, device or process. Data Processing Layer mainly addresses network/device vulnerability scanning, rule based correlation for detection, correlation based anomaly detection, access control monitoring, account compromise, hijacking and sharing monitoring, VPN activity anomalous behavior, geo-location anomaly [32–34]. All these detection mechanisms in this layer detect direct violation of any pattern or normal functioning of network, application, device, process etc. The paper proposes to automate this pattern mismatch detection in this layer using a scenario-based machine learning algorithm implementation. We handle OT specific case of captured network traffic by forwarding to a deep packet inspection engine (DPI) which detects the rule violation based on the protocol and process [35].

4. Threat Intelligence Using ML Technologies

Real time security analysis is performed in this layer by researching data for the purpose of uncovering potential known and unknown threats. This layer detects the threats which were either classified in the data processing layer and escalated or new threats which can again be classified as known or unknown threats. This layer identifies threats using context based event correlation, breach detection over user/application/network activities, compromised system behaviour analytics, data exfiltration, data loss prevention and protection, insider threat detection and prevention[36–40]. Here the context based event correlation relates to identifying events related to same attack or OT control system process instead of a rule violation as in the case of rule based event correlation discussed in data processing layer. This layer focuses on detecting unknown threats through behaviour based anomaly detection and context based event correlation. This layer employs various machine learning mechanisms at every step as we expect that the complexity of the task to discover unknown threats may vary from performing basic incident mapping to advanced mathematical modeling.

4. Security Information Display and Management

This layer of SOC security information dashboard that integrates all layers over a uniform graphic display and management platform through which any security related activity can be tracked in real time as well as used for forensics. This layer provides some crucial features like (i) simple presentation and user friendly navigation (ii) auto-identification of security events at different layers (iii) separation and classification of security events based on security threat criticality score (iv) escalation of security event to the next layer based on security threat criticality score as well as operator driven (v) presenting/alerting the operator/SOC analyst to take timely action for the security event. (vi) SOC analyst can track any security events based on action taken and origination. The security threat criticality score is calculated based on at what layer the threat is detected using the ML algorithm. Detection at higher layer adds more weightage to criticality score. Any suspected threat which cannot be investigated locally can be outsourced.

5 Adoption of Ml Algorithms in SOC

In machine learning, machine learns from its experience to make predictions and perform a specific task without using explicit instructions. ML algorithms do this by building a mathematical model based on training data used to teach it to figure out the patterns. If the model is trained using data that is labeled then its called supervised learning. After that, the machine is given a new set of data to analyse. With the knowledge of the trained data, the model produces the correct outcome of given new data. If the model is trained using data that is not labeled then it is called unsupervised learning. Unsupervised learning is usually used to group unsorted information according to similarities, patterns, and differences without any prior training of data [23]. Algorithms adopted in this paper under supervised learning are random forest [10], Support Vector Machine [12, 24] and decision trees and under unsupervised learning algorithms are K-Means Clustering [13], K-nearest neighbors [14].

In this section we will investigate four important SOC cases i.e. breach detection, anomaly detection, rule based processing and event correlation. Each case discusses the importance of its implementation or existence in SOC explaining their crucial roles in aiding to defend the critical infrastructure assets. Usage and assessment of machine learning algorithms used to make the detection technologies have been discussed as well.

A. *Case 1—Breach detection*

Network breaches mean detecting unusual behavior that is not linked to an attack signature. An example would be a trusted user performing reconnaissance on the network and connecting to sensitive systems that the user has never accessed before. Most common security products, such as firewalls and intrusion prevention system (IPS) technology, would probably ignore this behaviour [9]. Looking at Random forest to address breach detection, it has the following advantages when compared to commonly known Machine-Learning methods i.e. (i) low training time complexity O(nlog (n)), (ii) fast prediction, (iii) resilience to deal with imbalanced datasets and is able to deal natively with categorical and continuous features [15, 26]. When using an unsupervised learning algorithm K-means clustering is chosen. K-means represents a type of useful clustering techniques by competitive learning, which is also proved to be promising techniques in breach detection [17].

Unsupervised machine learning algorithms can gain an understanding of a typical network and help report anomalies without using any labeled dataset. It can detect new types of threats and intrusions but it can be prone to false positive alarms. When accuracy based metrics are considered, studies demonstrate and show that ensemble learning methods obtain better results when compared to single learning methods [19]. This implies that ensemble machine learning also has the potential to address false detection issues in OT.

B. *Case 2—Anomaly detection*

Anomaly detection is to identify malicious patterns by measuring the deviation of current behavior with normal behavior as the standard. Anomaly detection plays a significant role in the defense process of critical infrastructures. Anomaly detection is better than rule based approach for critical infrastructures [18]. Typically, anomaly detection consists of 4 phases i.e. collection of data, extracting features, similarity engine, and anomaly detection. Anomaly detection approaches can be classified into three approaches [16] i.e. Knowledge based, statistics based and machine learning based. Knowledge based approach baseline the system behavior and any deviation from baseline flags the anomaly. Statistical anomaly detection method uses statistical methods to analyze the normal behavioral contours of a system and identifies anomalies based on statistical approaches. Machine learning models based on supervised or unsupervised learning methods are used to detect anomalies in the CI environment. Advantage of supervised learning algorithms is the learning/training phase. Data used for the training phase should be free from anomalies and filtering data during training is the biggest challenge.

Using a supervised learning mechanism, One class SVM has been proposed to detect anomalies in SOC. In this method, training data belongs to only one class. During classification, points are distinguished to correct class and other points are treated as negative. Advantage of selecting SVM is the flexibility in selection of parameters to detect anomalies as well as handling high dimension vectors. SVM is the most used algorithm in many papers [20].

Using unsupervised learning mechanism, combined strangeness and isolation measure KNN (CSI-KNN) has been proposed to detect anomalies in SOC [21]. CSI-KNN uses two different models to detect two kinds of behaviour of the attacks. Unknown behavior is mapped to either similar or different to normal behavior. Based on results from the behavior analysis, the correlation unit is able to aggregate and decide the anomaly. Generating training data and abnormal training data during the training and testing process is crucial for proper classification of events into normal or abnormal.

C. *Case 3—Event correlation analysis*

Event correlation is one of the critical features of SOC to classify events/ incidents minimizing the unnecessary events and improving the accuracy. Some of the challenges in correlation analysis [22] are avoiding duplicate alerts, analyzing among individual events and analyze the risk of correlation events. Some of the methods for correlation analysis is a method based on similarity, a method based on machine learning and a method based on the bayesian classifier. The correlation method based on similarity correlates security events by calculating similarity among events. Though this method is effective, the challenge is to get the causality among the security events. The Correlation method based on machine learning generates rules by training with large number of security events. This method can create new rules based on training data but need large number of data and the accuracy is based on the quality of training data. The Correlation method based on bayesian classifier is to use the nodes of the network for security events and transfer between nodes is determined by probability. This method needs the prior probability of security events and the results of correlation relies on the experts knowledge.

Talking about the accuracy, unnecessary events reduces the reliability of the system and makes it difficult to determine actual attacks. Method proposed by Stroeh [25] helps to address it. This method works by collecting the events from different sources and normalizing them so they could be processed homogeneously. The normalized events are clustered into groups, or meta-events. Meta-events present a more complete description of a possible attack scenario than single events as they constitute a more refined expression of the underlying attack when compared to isolated alerts. Grouping events into meta-events leads to better situational awareness, improving the classification between real attacks and false alarms. Meta events are classified by using SVM and bayesian classifier based on the attributes of a meta-event.

D. *Case 4: Rule based processing*

Data is the most crucial part of any machine learning algorithm. It doesn't matter how good the machine learning tools are being used, in the end, they are as good as the quality of the data. Even sophisticated algorithms will not make up for the poor data. Data preprocessing provides a significant edge for the success rate of projects. This reduces the complexity of the data under analysis. So it is important to process network data before it is being fed into and other cascading algorithms. As this filters a lot of irrelevant traffic, it would not increase processing time which is quite important for real time analysis of data. Here the network traffic is captured using deep packet inspection to give log that can be used to classify the data.

The next step would be to use a method to feed that log into a classifier. C4.5 [30] is being used here because it inherently employs Single Pass Pruning Process to mitigate overfitting. Mitigating overfitting is important since network traffic is very diverse and we don't want all the new kinds of packets to be dropped. C4.5 is trained beforehand to learn about the local network. C4.5 classifies the network data into categories based on the application and then the irrelevant network packets are dropped.

E. *Performance metrics.*

In this section, performance metrics used to validate the performances of the models mentioned in different cases. Each mathematical representation [20] involves any of True Positives(TP), True Negatives(TN), False Positives(FP) and False Negatives(FN).

1. Accuracy (Acc): Percentage of correctly classified/ predicted instances in testing dataset.

$$\text{Acc} = (TP + TN)/(TP + FP + TN + FN)$$

2. Error rate: Percentage of all predictions that were incorrectly classified.

$$\text{Error rate} = (1 - \text{Acc})$$

3. Recall or sensitivity or true positive rate (TPR): Measures the proportion of actual positives that are correctly identified.

$$\text{Recall} = (\text{TP})/(\text{TP} + \text{FN})$$

4. Precision: Precision score is to derive correct proportion of positive identifications.

$$\text{Precision} = (\text{TP})/(\text{TP} + \text{FP})$$

5. F-Score: The harmonic means of recall and precision is also known as F-Score

$$\text{F} - \text{Score} = (2 * \text{Precision} * \text{Recall})/(\text{Precision} + \text{Recall})$$

6 Conclusion

The paper addresses the threat detection mechanisms used in SOC for CI. The paper suggests the use of well articulated strategy for securing CI through the adoption of automated threat detection by leveraging Machine Learning techniques in a SOC. Here we first model the SOC operations by segregating the various functions of SOC into a layered framework. Further, we study and assess the features of different machine learning algorithms which suit the SOC operations for CI. We identify the four major SOC use cases namely breach detection, anomaly detection, rule based processing and event correlation for which we investigate the usage of appropriate ML algorithms. We substantiate the adoption of a particular ML algorithm for a SOC threat detection use case by researching and discussing the advantages of using that ML algorithm. The following paragraph summarizes why a chosen ML algorithm is suitable for threat detection use cases discussed in the paper.

Breach detection requires detection of unusual behaviour by categorizing normal and abnormal activities. In this case, Supervised ML method Random forest, which can natively deal with categorical features can suitably discard normal activities.

Likewise, unsupervised ML algorithm K-means clustering classifies breach using competitive learning where data partitioning is done through creating clusters of similar data. Anomaly detection finds deviations from normal behaviour. In this case, supervised ML algorithm SVM is proven useful by categorizing new examples through linear or nonlinear classification over high dimensional vectors. Similarly, unsupervised ML algorithm KNN classifies attacks through plurality vote for classification under known or unknown behaviour. Event correlation classifies security events by calculating similarity among events and eliminating unnecessary events. In this case, supervised ML algorithm SVM was found suitable which first finds events that are part of the same attack and classify whether it is an actual attack or false alarm. As part of data analysis and data filtering, rule based processing approach has been adopted. C4.5 decision trees has been adapted for rule based processing.

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