Overview of Next Generation Smart Grids

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Abstract Due to the integration of renewable energy resources (RERs), the electric power system is undergoing a significant change in operation, maintenance, and planning. The advancement into a smart grid (SG) using advanced automation and control approaches produces new challenges and opportunities. In this work, an overview of next generation smart grids has been presented by highlighting the latest and recent innovations in the SG fields. Advantages, barriers, and opportunities of smart grids are provided in this work. Challenges of integrating the RERs into the grid and various energy storage technologies are reviewed. The output of RERs is affected by the uncertain nature of resources. The energy storage system plays a vital role to handle this uncertain nature of RERs and provides a smooth and reliable supply to the load demand. Smart energy systems present various challenges and opportunities in designing, integrating, and implementing electrical grids with network and communication technologies and essential privacy and security issues of various components within the electrical grid. Therefore, this work presents the concepts of cyber-enabled intelligence network communication, big data, machine learning, and blockchain technology in smart grids (SGs). This work also demonstrates the impact of SGs in distributed energy generation and the comparative study on electric vehicles (EVs) along with the classification, i.e., battery, hybrid electric, and plug-in electric vehicles, current issues and challenges on the EV technology. Further, a discussion is also provided on SG protection issues and their remedy.

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Nomenclature

BEV	Battery electric vehicle
CHP	Combined heat and power
DG	Distributed generation
DR	Demand response
DER	Distributed energy resources
DMS	Distribution management system
PV	Photovoltaic
VVO	Voltage/VAR optimization
AMI	Advanced metering infrastructure
GIS	Geographic information system
OMS	Outage management system
WAMS	Wide area measurement system
ML	Machine learning
PMU	Phasor measurement unit
EMS	Energy management system
IED	Intelligent electronic device
SG	Smart grid
RERs	Renewable energy resources
WT	Wind turbine
ICE	Internal combustion engine
PHEV	Plug-in hybrid electric vehicle
IoE	Internet of energy
IED	Integrated electronic device

1 Introduction

A smart grid (SG) is an advanced distribution and transmission grid that uses information, control, and communication technologies to enhance the electrical grid's security, efficiency, economy, and reliability. The conventional grid can be changed into the SG by smart metering, advanced network operation and control, faster fault identification, and self-healing capabilities using grid automation. SG can be defined as an interconnected system of information, communication technologies, and control systems used to interact with automation and business processes across the entire power sector, encompassing electricity generation, transmission, distribution, and consumers [1]. Smart renewable energy control centres which can forecast and monitor renewable energy availability and potentially use energy storage to manage the dispatch of power to match grid conditions or manage demand through demand response (DR) programs to match capacity availability are expected to become critical to the future integration of renewable energy.

In recent days, the power generation from renewable energy resources (RERs) is increasing significantly, and the power generated from renewable energy will play a significant role soon. To enhance the integration of renewable power in the conventional power network, it has to deliver the liabilities acted to the network due to the irregular nature of these resources. Because of their effect on system adjusting, reserves procurement, scheduling and commitment of generating units, changeability, and ramp or slope events in power output are the fundamental difficulties to the system administrators [2]. With the integration of RERs such as solar PV and wind, significant uncertainty into the power system is developed. It is a tremendous challenge for system operators to maintain reliable operation and efficient electricity markets with simultaneous maximum utilization of renewable energy. As the electric market structures change to improve the management of renewable sources, advances in the design and pricing aspects of energy and ancillary services markets are needed [3].

Distributed generation (DG) is from many small energy sources connected directly on the customer side of the meter or to the distribution network. DGs are also termed as embedded generation or dispersed generation or decentralized generation, or on-site generation. Optimal size and location of DGs can reduce the power losses in the system, improve system voltage, maximise DG capacity, enhance system reliability, and minimise investment. Power companies generally generate electricity with a relatively fixed amount of energy over short periods, regardless of the daily fluctuation of the energy demand. The energy demand fluctuation leads to energy storage techniques to supply enough electricity to consumers during peak demand. Electricity storage techniques allow power companies to provide electricity when needed [4]. The electricity is first generated and then stored in storage devices to be used during the peak load.

Oil, natural gas, uranium are all power sources that the world has been using for a long time and they all have the potential to run out at any time. RERs are the sources that can last longer than the human race. Most renewable energies are environmentally friendly, fight against global warming by reducing carbon emission. Renewable energies are sustainable, reliable, and cost less compared to fossil fuels and other nonrenewable energies. Solar energy initial installation remains expensive, but it is increasingly being used around the globe, especially in the rural world where people don't have access to electricity or simply can't afford to pay for their monthly electric bills. Biomass is one of the most renewable energies used today due to its advantages [5]. In addition to the fact that biomass energy does not pollute the air allows countries to protect their environments by burning the wastes. Renewable energy is a resource used all over the world. Renewable energy produces from natural resources such as wind, solar photovoltaic (PV), biomass, geothermal, etc., and is known to be beneficial to the earth. Table 1 presents the various characteristics of the traditional power grid and the SG [6].

Table 1 Characteristics of the traditional power grid and smart grid

Characteristics	Traditional power grid	Smart grid (SG)
Technological aspect	The traditional power grid is electromechanical. As a result, it has no means of communication and there is minimal internal regulation	SG uses advanced digital technology. It allows for communication between devices and promotes self-regulation
Distribution system	It involves the one-way distribution of power. Power is only distributed from the main power plant with the help of traditional infrastructure	It allows for the two-way distribution of power, i.e., power can also go back to the distribution lines from a secondary power provider
Generation	The generation infrastructure is highly centralized. All the power is generated from a central system that minimises incorporating alternative energy sources into the grid	The generation infrastructure is scattered and distributed. It allows the power to be distributed from multiple power sources, which help in balancing the load and limit power outages
Incorporation of sensors	It involves limited sensors as the infrastructure is unable to handle sensors making detection of problems difficult	SG infrastructure system allows multiple sensors throughout the line, which helps to pinpoint problems
Monitoring of power plants	Traditional infrastructure is minimal. As a result, energy distribution has to be manually monitored	The SG involves advanced technology and can monitor itself, which prevents troubleshoot outages
Restoration and repairing	For restoration purposes, technicians must physically go to the failure location and make corresponding repairs to prevent excessive power outages	In the case of SG technology, the sensors can detect, analyze and rectify the required problems without the need for physical intervention
Equipment	Due to the ageing and limited capacity of the traditional power grid, it is prone to failures and blackouts	In the case of an SG system, alternative energy sources limit the area that is impacted by the power outage
Control of energy	In the case of traditional power infrastructure, energy companies have no control over the distribution of energy	With the availability of sensors and innovative infrastructure, energy providers have pervasive control over the power distribution
Choices of consumers	The traditional power grid system does not provide consumers with any flexibility in receiving their electricity	SG allows consumers to have more choices in the way they receive energy

A smart grid (SG) network should posses

- **Better communication**: This deals with interaction with the network and within the network itself. An illustration of this will be the automatic shutting off of power supplied to the home when people living in a house. In light of that, it is easy to see that a lot of work goes into sensing and feedback circuitry built into the grid as it receives information about the power grid itself.
- **Self-healing capability**: SG employs technologies that assist in self-healing in response to natural faults or breakdown without human intervention.
- **Adaptiveness and flexibility**: SG should be able to adapt to variations in conditions within the grid, especially regarding ever-changing load and the direction of flow of power.
- **Resilience**: This refers to the ability of the SG to withstand attack, i.e., both human and natural.
- **Real-time measurements and control**: In monitoring the central generation, distribution generation, and other plants in the system, the grid must be capable of making real-time measurements and controlling the grid due to the sensitivity of generated power even within just microseconds.
- **Reliable technology**: SG uses state estimation technologies, which improves fault detection and allows self-healing of the corresponding system without the need of the technicians to intervene [7]. This ensures a proper reliable supply of electricity and reduces related vulnerabilities.
- **Flexibility in networking**: SG technology enables better handling of the bidirectional flow of energy, allowing for distributed generation. This includes solar panels, fuel cells, electric batteries, wind turbines, and other such sources.
- **Increased efficiency**: SG technology has resulted in numerous contributions towards the overall improvement in the efficiency of the power grid system and energy infrastructure. The demand-side management has highly benefitted from the smart infrastructure. This includes the voltage/VAR optimization (VVO) technique which reduces the power usage through the distribution lines during idle time and advanced metering infrastructure (AMI) systems which improve the outage management of usage data [8]. All these have resulted in better efficiency and greater utilization of energy resources.
- **Peak curtailment-usage and pricing**: Communication systems and metering technologies have reduced demand during high cost and peak usage hours. Smart devices allow users to track the energy demand and usage of electricity. Moreover, it also allows utility companies to reduce consumptions and avoid system overloads. This is done by increasing the electricity cost during peak hours which is termed peak curtailment.
- **Sustainability**: The SG system is supposed to be highly flexible as it allows the correlation of various RERs such as solar and wind energy without any additional storage.
- **Demand response**: Demand response allows loads and generators to interact amongst themselves in an automated real-time manner [9]. This, in turn, eliminates

the additional costs of reserve generators and increases the life expectancy of power systems [10].

- **Advanced services in the near future**: The use of robust two-way communications combined with technologically advanced sensors and distributed technology will drastically improve the efficiency, productivity, reliability, and safety of power generation, transmission, and distribution.

SG combines various technologies and applications to provide efficient, clean, reliable, easily accessible, and low-cost energy. The need of the hour is to perform complex testing and improve applied techniques and improve threshold and optimized operation of the SG, keeping in mind the sustainable development of the environment [11]. Various applications of SGs include:

- Improve response and adaptivity of transmission and distribution systems.
- Enables quicker detection and recovery from faults, disturbances, and outages in the distribution lines and feeders.
- Reduces the cost and peak demand for energy.
- Allows for integration and scalability of various alternative sources of energy such as wind and solar power.
- Utilizes sharing of load, which in turn reduces the load on a large scale.
- Many other technologies have also helped to optimize the SG on a large scale, such as advanced metering infrastructure (AMI), distribution management system (DMS), geographic information system (GIS), outage management system (OMS), wide area measurement system (WAMS), phasor measurement unit (PMU) and energy management systems (EMS).

The international energy roadmap study ranks windmills, biomass, solar PV, and tidal power as future renewable power sources to sustain the world's economy. Progress in the field of sustainable energy scenario over the previous period has been exceptional. The two primary sustainable energy resources are the sun and the wind. The growth in electricity generation from renewables was substantially increased [12, 13]. The IEA ventures by 2050, around (15–18)% of worldwide power will be created from the wind, with sun-powered PV contributing as high as 16% [14, 15] regardless of its different favourable circumstances.

2 Smart Grids: Advantages, Barriers, and Opportunities

A smart grid (SG) is a system that utilizes digital processing and communications technology to manage resources connected to a power grid. The heavy dependence on technology and hence power supply that aid the operation of these technologies across all facets of life from the auto industry to medical equipment, households, and so on has increased the need for efficient management of the assets to maximize productivity [16]. The ageing power grid, workforce also compound this, and infrastructure within the US SG will help ensure better communication between human beings and the power grid.

2.1 Advantages and Barriers of Smart Grids

Advantages of SG include:

- **Growth of economic sector**: The manufacture, installation, maintenance, and corresponding operation of the SG and its respective components will create opportunities for skilled and unskilled job sectors [17]. Moreover, it will help in growth in business along with providing advanced technological solutions.
- **Cost efficiency**: SG technologies tend to be cheaper than traditional energy sources. Moreover, with advancements in technologies, energy expenses reduce over time.
- **Greater customer satisfaction**: The improved reliability and lower costs have resulted in greater customer satisfaction [18]. Additionally, SG provides better customer control over energy distribution and usage.
- **Better reliability**: SG reduces power outages and, at the same time, improves power efficiency.
- **Environment**: SG results in a positive impact on the environment as it helps reduce greenhouse gas emissions by enabling alternate RERs and electric vehicles (EVs) [19]. Moreover, it also reduces oil consumption because of efficient power generation.
- **Intelligence**: SGs enhance the capacity and capability of the existing power grid. Also, they have predictive maintenance and self-healing capabilities.

Barriers of SG include:

- **Security and privacy concerns**: As the SG is void of human interference, it is highly prone to hacking and cyber-attacks. It may lead hackers to gain access to numerous smart meters and manipulate the data [20]. Also, since the system is fully automatic, privacy concerns are raised over data collection and the use of smart meters.
- **Lack of government norms and policies**: As SG technology is still in its budding stage, there is a lack of proper stringent government policies to avoid thrift, loss, and misuse of the power system. Also, there are no standard regulations regarding the safety and threshold limitations of SG systems.
- **Higher installation costs**: The present energy infrastructure scenario is inadequate and insufficient to develop SG technologies [21]. As a result, SG systems require a higher installation cost as it involves the procurement of smart meters and various other sensors for monitoring and data distribution.
- **Congestion in network topology**: Smooth operation of a SG requires a continuous network channel. This may result in network traffic, especially during peak

hours. Moreover, there is no guaranteed service during abnormal conditions such as heavy rainfall, storm, and lightning conditions.

2.2 Challenges

There are bound to be vital challenges with the rapid growth in digital technologies and their widespread applications. These include insecurity and privacy issues along with a lack of government policies [22]. The most common challenges regarding SG include:

- **Privacy issues**: With the involvement of technology, there are bound to be privacy concerns. There is a possibility of some people hijacking the system to gain sensitive data regarding the consumers.
- **Security issues**: SG technology is prone to attack by hackers who may gain access to the power system and disrupt the underlying technology to gain an advantage by hampering the net-metering system [23].
- **Grid volatility**: SG is considered to be a volatile network, being highly intelligent at both the transmission end and distribution end but a bit vulnerable along the way due to a lack of complete network intelligence.

Various processes and systems to overcome the above challenges include:

- **Increasing the grid strength**: The power grid should have enough tensile strength to withstand the power requirement. The power grid is one of the most complex inter-connected physical systems in the world. Hence, absolute care should be taken to sustain the grid network.
- **Communication systems**: SG should be optimized to integrate all kinds of sensors and digital devices to enhance and upgrade the level and performance of the grid. Additionally, there should be proper coordination and communication among all the components to ensure reliable operation. Fiber optics has enabled faster travel of data signals, thus reducing propagation time.
- **Advanced metering infrastructure (AMI)**: It involves a net-metering system that includes a smart meter and the infrastructure to allow for two-way communication of energy. With the help of broadband and radio technology, it has become possible for grids to communicate with other grids. Moreover, it is also a viable option for energy sustenance and reduces consumer costs.
- **Economic dispatch and integration of various sources**: It involves cost optimization of electrical power analysis and minimises production and distribution costs. Also, the integration of various energy sources like solar and wind is achieved with the intermittent coordination of multiple generators.
- **Advanced power system monitoring**: Use of synchronised PWMs and SCADA has enabled better monitoring of SGs and proper control over the utility. AMI has helped real-time measurements of voltage and current phasors. GPS has allowed us to pinpoint the fault location and reduce the outage time precisely.

3 Technologies Required for the Smart Grid Development

SG has a set of diverse necessities. To accomplish all the requirements, various technologies have been enabled and utilized [24].

3.1 Sensing and Measurement Technologies

These technologies include:

- **Phasor measurement units (PMU)** and **Wide area monitoring, protection and control (WAMPAC)**: These help in maintaining the security and reliability of the power grid [1].
- **Intelligent electronic devices (IED)**: These devices are used for protection relays and determining faults. These involve integrated sensors and automated systems for rapid analysis and diagnosis and results in timely resolutions. They also function to minimize network congestion and reduce the risk of outages. As a result, these devices enhance the efficiency and operation of the resultant SG.
- **Smart appliances**: These devices form the control and communication part of the power grid system [25]. They monitor the operation of consumer appliances and try to maximize their efficiency, reliability, and safety.
- **Smart meter and its associated software**: These form the building blocks of the entire SG system. It provides better electricity control and allows consumers greater control over their electricity consumption. They also make the consumers responsible by providing real-time info and proper bills.

3.2 Communication Technologies

The various technologies include:

- **Two-way communication**: It enables a back and forth bridge to allow a two-way flow of electrical energy across various loads in a power system.
- **Advanced architecture**: It allows for technologies regarding EVs, micro-generation, and plug-play home appliances.
- **Communication technology**: Along with the corresponding software, communication technology aims to provide the energy consumers with better opportunities and more meaningful information [26].
- **Hardware and software**: These formed the building blocks of the system and were responsible for maintaining the security and reliability of the utility.

3.3 Smart Meters and Advanced Metering Infrastructure (AMI)

AMI is defined as the integration and interconnection of numerous smart meters and communication equipment that work in cohesion to enable a two-way flow of power in the power grid between utilities and consumers. It involves data management systems and advanced sensors that make the SG capable of monitoring its power requirements. Smart meters are equipped with power monitoring software technologies that enable faster detection and diagnosis of faults along with ways to resolve power problems [27]. Moreover, AMI prepares the grid with self-healing capability by monitoring power outages, enabling faster detections of faults. Various other features of AMI include:

- Power generation systems and storage components can be analyzed and controlled at the consumer level. It provides data to improve the operation and management of the utility network.
- Before AMI enables auto-detection of faults and outages, it also informs the repair crew of the location of the fault.
- An AMI system provides accurate records and notifications regarding outages and their corresponding restoration through the smart meter sensors. This helps in quicker resolution of outages and also enables faster providing of power supply.
- AMI implementation reduces the daily reading of meters as the readings are taken automatically at regular intervals [28].
- It implements built-in analysis tools and software which detect and prevent possible energy theft and tampering.
- By combining with SCADA, the AMI systems automatically generate investigation reports for field managers making their work easier.

4 Renewable Energy and Energy Storage

Renewable energy is a resource needed to transform the electric power system by enhancing the SG's performance, sustainability, and reliability. Distributed energy resources (DER) in a microgrid would include photovoltaic (PV), small wind turbines (WT), heat or electricity storage, combined heat and power (CHP), and controllable loads. Renewable energy sources are practically inexhaustible in that most of their energy is from nature and sources that will continue to exist like the sun. Renewable energy is an area that will continue to grow in research and development; more money has gone into the exploration of both new and existing renewable sources. Solar, the most commonly used, has improved its application in our world drastically with the advents of solar-powered cars, light, and houses [29]. More work needs to be done to eradicate non-renewable energy in our society to create a world where green power is the dominant energy source used. Finally, for renewable energy to facilitate energy shortage, extensive research on utilising the available RER to its maximum efficiency is needed. Also, areas throughout the world should implement primary RER based on their most vital natural resource. For example, areas with the strong wind will implement more hydropower, and regions with constant sunlight will use solar.

4.1 Renewable Energy

Renewable energy resources (RERs) could be harnessed from technological sources like solar, wind, biomass, biogas, geothermal, and hydroelectric. There has been an improvement in technologies and advancement in the equipment and use of renewable energy. More companies, through research and government incentives, have increased the operational experience of renewable energy technologies. The issue of renewable energy and its application presents questions on the efficiency, reliability, tracking, and accountability of these resources. However, most renewable energy technologies struggle to compete economically with conventional fuel technologies making the budget and funds for renewable energy smaller than its counterpart [30]. The regulatory commission has categorized the utility industry into three; generation companies cover utility and non-utility companies, transmission companies, and distribution companies.

The intermittent nature of wind generation makes its operation and planning a complex problem, and there is a need for the current analytical models to consider this uncertainty appropriately. Current electricity market clearing schemes cannot fully integrate the essential features of non-dispatchable generation such as wind power. This limitation is becoming an issue for grid operators as there is more and more public and political pressure to increase the penetration of renewable generation. This is due to the uncertainty associated with wind forecasts. As wind cannot be forecast to a high degree of accuracy, additional reserve capacity needs to be carried by the system in addition to the reserves already allocated to cater for unit outages and demand forecast errors. Renewable energy could be discussed regarding connectivity, sustainability, cost, environmental impact, security, etc.

- **Connectivity**: Renewable energies usually require different levels before they could be used as power for its consumers' stages from generation to transmission to distribution and the utilization levels in its connectivity. Based on a particular renewable technology, this varies [31]. Some RERs could be stand-alone, grid-connected, or hybrid, which combines both stand-alone and grid-connected. In comparison to non-renewable energies, the connectivity for renewable energy technologies is quite challenging.
- **Sustainability**: This is one of the strong positives of renewable energy. In comparison to non-renewable energies, it's readily available to be harnessed. Since most RER are gotten from nature like the wind, sun, water, it's always bound to exist, and others RER like bio-mass will exist due to human waste.
- **Cost**: The amount necessary to have RE technologies is said to cost less than the amount used in electricity production. Most massive amounts go into research on

renewable technologies and how to utilize these sources rather than how they are set up effectively.
- **Environmental impact**: Renewable energy is considered green power due to its friendliness to the environment. Most RERs have a significantly low carbon emission rate and insignificant waste. In regards to areas of scenery, wildlife, and land utilization, it has a negative impact. Most facilities/instruments for RERs are huge, land-consuming, and disquieting to the area.
- **Security and regulations**: An essential concern to RERs is how safe the facilities, devices, and instruments used in the operations are? From the production to transmission to distribution and then utilization, companies try to fight off vandalisms, wastage and enforce rigid standards on how the procedure should be.

A summary of some of the advantages of renewable energy [32] could be the following:

- The abundance of these sources used in renewable energy technologies.
- RE sources are considered environmentally friendly and green due to low carbon emissions.
- The research and development in this field provide thousands of jobs and employment opportunities to the society, thereby helping the economy of its subsequent country.
- Like in non-renewable sources where some resources are gotten from other countries and either imported or exported, all renewable sources are present everywhere in all countries as it is abundant in nature.
- Renewable sources cost less than the current price of electricity. Crude oil is projected to increase its price in the coming years.
- Various tax incentives in the form of credit deductions, tax waivers are available for businesses and individuals who use renewable resources.

4.2 Energy Storage

RERs such as solar and wind are not available throughout the year, i.e., seasonal. So, it is of utmost importance to store the maximum amount of energy possible with minimum losses. The SG requires energy storage directly or indirectly. In the present scenario, the pumped hydroelectric storage technology is considered bulk energy storage technology. Proper storage units connected with OFF-grid systems are further connected to the utility to form a hybrid system, improve robustness, and prevent intermittent outages. Older storage units include batteries, flywheels, and compressed air systems. Nowadays, a hydrogen network is connected in parallel to the grid utility as a storage unit. Storage devices, including batteries, supercapacitors, and flywheels, could be used to match generation with demand in SGs [33]. The storage systems can supply generation deficiencies, reduce load surges by providing a ride-through capability for short periods, reduce network losses, and improve the protection system by contributing to fault currents. V2G and EV mobility can reduce the SG reliance on the grid supply.

5 Big Data, Machine Learning, and Blockchain Technology in Smart Grids

5.1 Big Data

Data identification and collection, data storage and data filtering, data classification and extraction, data cleaning and data summarization, data analysis and processing, and data visualization are the various life cycle of big data analysis. Apache Spark, Apache Hadoop, Apache Storm, Apache Flink, Apache Kafka, and Apache Samza are the big data processing tools that are being developed. But the main challenge faced during the data collecting is a time delay in receiving data [34]. This problem is resolved by using 5G technologies, which can reduce the time delay problem. Big data applications in power and energy systems include transient power prediction, distribution and utility systems, SG applications, fault detection and prevention, weather data and wind speed prediction, etc. Table 2 presents the applications of big

Table 2 Applications of big data in various industries

Industries	Applications of big data
Power and energy	Distribution systems, generation systems, utility systems, SG applications
Health care and life sciences	Clinical trials data analysis, disease pattern analysis, chain management, drug discovery and development analysis, patient care quality, and program analysis
Telecommunications	Customer churn prevention, call detail record analysis, mobile user location analysis, network performance and optimization, revenue assurance, and price optimization
Web and digital media	Large scale clickstream analytics, abuse, click-fraud prevention, social graph analysis and profile segmentation, campaign management, and loyalty programs
Retail/consumers	Supply chain management and analytics, market and consumer segmentation, event and behaviour-based targeting, merchandising, and market-based analysis
Finance and fraud services	Compliance and regulatory reporting, risk analysis and management, fraud detection and security analytics, credit risk, scoring, and analysis
E-commerce and customer service	Cross-channel analytics, event analytics, right offer at the right time, next best option, or following best action

Table 3 Challenges, state of the art, current status, and recent developments in big data

Challenges	State of the art, current status, and recent developments
• Privacy • Data miming • Integration of data • Cybersecurity • Demand prediction through analytics processing in SG applications • Data quality and cost balance • Industrial fault diagnosis using big data • Quantum cryptography for data security in smart grids	• Big data technique to handle a large amount of information in a short time using meter data management • Big data requirements and enhancements throughout the entire power network dispatching and planning • Fault diagnosis on bogies of the high-speed train with big databases on deep neural networks • Schedulable capacity forecasting technique for thermostatically controlled load by big data analysis • Concept of device electrocardiogram in fault diagnosis using big data • Tensor-based big data management scheme in SG systems • The artificial neural network approach is used for efficient electricity generation forecasting

data in various industries [35, 36]. Multiple challenges, state of the art, current status, and recent developments in big data are presented in Table 3.

5.2 Machine Learning (ML)

A myth is that artificial intelligence (AI) is only one application that is robotics. Still, AI has much application such as medical sector, education sector, agriculture sector, pharmacy sector, research sector, energy sector, transport sector, etc. AI makes it possible for the machine to work as a human, learn like a human, and resemble the behaviour of humans. AI can be divided into artificial general intelligence (AGI) and artificial narrow intelligence (ANI). ANI is a type of AI in which a machine would perform only some specific task. AGI is a type of AI in which machines perform any given task that humans can perform or many more. In the future, all the sectors are upgraded with AI. Various AI applications in the SG are power load forecasting, power generation forecast of renewable energy, fault diagnosis, and protection of flexible equipment, electricity consumption behaviour, network security protection, and energy supply. Machine learning can be classified into two groups one is based on the learning model, and another one is based on learning methods. The learning model can be classified into supervised learning, unsupervised learning, and reinforcement learning [37, 38]. The learning model can be classified into Deep learning and traditional machine learning. The various application of ML is electrical power and energy, transportation, education, healthcare, financial services, and marketing and sales.

5.3 Blockchain Technology

Blockchain technology can overcome all the difficulties faced by power utility sectors, and it will effectively help in the futuristic vision of economic herald in the energy distribution sector. The distributed ledger can start experimenting on blockchain to adopt new business strategies and goals. There are many applications of blockchain. One of those is electrical energy distribution. By using blockchain, one can effectively convert electrical energy into electronic money for transaction purposes, and it can be converted to any form. Blockchain provides a crystal clear, secure, and transparent form of transaction. Some of the technical challenges for applying blockchain technology in electricity trading, checking, and certifications. It gives a comprehensive view of the implementation of smart contracts under varied blockchain technologies in power systems. At the same time, implementing this technology [39]. The most important two items that must be handled with utmost care in blockchain application are the time frame and data privacy in power systems applications.

In recent time there is a massive demand for energy, primarily electrical energy. We are surrounded by innumerous electrical equipment. So, it becomes an integral part of the generating stations to fulfil this electricity demand and supply of electricity stably. Prosumers are the producers of electricity, and consumers, on the other hand, consume electricity. With the help of SG, one can fulfil the objective of consumers and keep an eye on the transmission losses, which can be minimized to a large extent. The transaction can be done in a peer-to-peer fashion among the prosumer and the consumer. To have this type of transaction, blockchain comes into the role to initiate a centralized transaction system which would be very costly in other means [40]. By using blockchain, one can solve complex problems that may arise in a SG.

With the help of blockchain technology, the trade of electricity became easier without any intervention from a third party. A trust is created between the prosumer and consumer. It has few advantages as we have real-time market records, less transaction cost because of simple structure, more privacy within the grid. In a centralized structure of energy systems where there is a large-scale implementation of industrial and commercial loads and environmental hazards, the power generation center has been located from the load centres at a far distance. High voltage (HV) transmission with distribution is used to transfer the power generated from the source to the load centres [41]. Currently, three technological trends provide a new dimension of the transformation in energy fields:

Table 4 Advantages and disadvantages of centralized and distributed systems

System	Advantages	Disadvantages
Centralized system	This system is rapid, and it can make effective decisions. No duplicity in any transactions. This system has an efficient bureaucratic chronology	In this system, the central government controls and handles all power and authority. Applications run on a single process. The component constitutes a single failure point
Distributed system	There are multiple processes for cooperating and executing the application processes Workloads can be distributed to different machines in this system The limit to tolerate faults is relatively high All data can be shared in different networks, but all the decision-making processes will only be held at one particular node	There may be privacy issues Complexity is more with very little predictability They require a lot of effort to managing all the systems operating Synchronization problems may arise

- The energy sector is more and more interested in shifting away from the direct energy consumption of non-renewable energy sources commercially toward the integration of different sources or hybrid grids.
- The increasing use of RERs and grids facilitates the decentralization of the energy field and increases the versatility in real-time operation in the power-system applications.
- Large parts of the energy value chain are digitalized due to the increased digital elements in a grid.

Blockchain technology works on a decentralized system having a peer-to-peer network, which signifies a collective model of trust among the peers who are unknown to each other and an immutable ledger of records of transactions (distributed). Decentralization means a user-to-user basis network. A Distributed immutable ledger means data that is stored in it cannot be further modified or deleted. Transactions in blockchain are just the transfer of values in Bitcoin. UTXO, an unspent transaction output, defines input and output in the transaction of bitcoin.

Once a block is verified algorithmically, and when a data miner agrees to it, it is added to the blockchain chain. An unspent transaction output (UTXO) can be spent as a currency unit in further transactions. The main operation in a blockchain is validation and block creation of transactions with the consensus of the users participating in the transaction. There are also many underlying operations. A smart contract gives the capability for code execution in business logic on a Blockchain. Miner nodes in the network receive, verify, gather and execute the transaction. Significant innovations like smart contracts have broadened the applications of blockchain technologies. Private and permitted blockchains to allow for access to the blockchain in a controlled manner, enabling much more diverse business models. Table 4 presents the advantages and disadvantages of centralized and distributed systems.

Blockchain technology has a significant impact on utility industries. It has three levels of technologies benefitting both permissioned and private ledgers [42]. These levels are classified based on different technology attributes for the adaptability of the leading utility.

5.3.1 Level 1: Foundational Technology

Foundational technology consists of bill pay, electric vehicle charging transactions etc. It enhances the reliability and security of transactions inside the grid framework. The transaction is unified from disrupting generating stations in the energy ecosystem. Some common application include

- **Bill pays**: there are a lot of startup companies that are facilitating effective methodology for transactions. Such as prepaid energy meter, transaction through cryptocurrency, bitcoins, etc.
- **Solar renewable energy certificates**: Blockchain technology is used in trading and earning credit certificates related to renewable energy. One example is the solar coin that can be made for the generation of solar energy individually.
- **EV charging**: In the US, most people use an EV and blockchain-based transaction is there to charge EVs in certain charging stations. Some of the companies which are using blockchain are bloch charge, innogy. This technology enables the user for digital payments
- **Customer switching**: There is a UK-based company known as electron. It is a blockchain-based company. It enables the user for faster switching of suppliers.

Because of blockchain security and tracking of transactions, this application is quite fruitful without intermediaries.

5.3.2 Level 2: Medium for Sustaining Business

Utility technology should adopt blockchain as well as internal business units to sustain the investment made in technology. There should be some regulatory board to keep an eye on all the transactions [43]. Appropriate support model to ensure guard of interest of utility business. Some examples of experimental permissioned blockchain applications with relevance for the utility sector are:

- Microgrids: specific distributed energy systems such as microgrids function independently. Distributed energy systems like microgrids mainly operate independently from a centralized system due to the small size of the operation. Blockchain is much more relevant for managing all transactions.

Table 5 Current market shortcomings and the possible role for blockchain

Current market shortcoming	Possible role for blockchain
The cost of production is much more than electric markets	The combination of the Internet of things, records and information about generation time/demand, location, type of generation/demand, and other aspects of predicting the price for electric market customers
Integration renewable energy sources integration into the electric grid	Blockchain can be used for de-centralized and automatic grid management and control systems. As there are many producers and consumers in the distribution grid, blockchain technology balances the supply of electricity and demand for auto verification of grid components
Adequate power resource	Cryptocurrencies can be used as a token for creating new markets and business models. There will co-ownership for such models
Increase in coordination in-between operators of system	Blockchain can give promising results in developing an automated decentralized and completely efficient asset control and management of such assets, including a better balance between demand and supply at different networks
Integrating demand response for ancillary services	Smart contracts are designed to engage and reward willing customers for helping in DR activity for maintaining the grid more economically
Much adequate cross-border data exchange in power system	Cross-border data exchange incurs costs and data flows through multiple intermediates, which add time delays in decision making and thus a potential loss of data. Blockchains can streamline this process by removing intermediaries, removing delays, and maintaining data integrity as data is not transferred but immutably shared

- Grid settlements and wholesale market trading: independent power producers integrate a small number of people in a microgrid grid settlement, and wholesale markets involve many users within industry regulations, so blockchain does provide scalability and regulatory compliance to all those units. Table 5 presents the current market shortcomings and the possible role of blockchain.

6 Electric Vehicles (EVs)

This section focuses on EVs, which are trending in the latest era for meeting the energy needs replacing the internal combustion engine (ICE) vehicles. In recent years, EV's have much attention as compared to conventional internal combustion engine vehicles. This contemplation is due to the economic and environmental trouble concerns linked with the utilization of natural gas and petroleum fuels. These are used as fuel in ICE vehicles. More advancement and researches on vehicles like fuel cell and hybrid cars, pure battery-powered electric vehicles, etc., are pursued actively [44]. Because these vehicles are reasoned to serve as an efficient means to deal with global warming caused by the tail pipe-auto emissions. In eco vehicles, the compatibility between safety and running performance has to be ensured, especially in EVs where electric devices like batteries, converters, and inverters are part of their propulsion force-producing system. If such an electric device fails during the motion of the EV, the EVs shall fail to run safely and comfortably. This kind of failure in motion may constitute series of traffic accidents like rear-end collisions. As an advancement for developing the next generation of EVs, fail-safe functions must be interlinked within the propulsion force-generating system. The EV can persist in running safely even if malfunctions occur during EV motion. The hybrid electric vehicles (HEV), which mainly contains at a minimum of two sources of power, first one is a primary power source, and the other one is named as a secondary power source, which has the favours of both the EV and conventional ICE vehicles also could vanquish their disadvantages. Considering the HEVs and PHEVs, more electrical components are utilized in the making. Electric machines, power electronic converters, batteries, ultra-capacitors, sensors, and microcontrollers are examples of various such features. Besides these electrification components and their subsystems, the traditional internal combustion engine or other mechanical and hydraulic systems have also been present. Those difficulties generated due to the modern propulsion systems demand the advanced design of powertrain components, namely power electronic converters, energy storage, and other electric machines. This power management system includes modelling, simulation of the powertrain, hybrid control theory and optimization control of vehicle [45].

Characteristics of EVs:

- The EV's are designed to steer with high voltage electrical energy stored batteries. In this way, the exhaust emissions can be excluded, which further reduces air pollution since gasoline or other fossil fuels are not required for the propulsion.
- The engine's noises and vibrations are negligibly small during the entire driving range compared to traditional ICEs. The electric motor employed in EVs is generally higher performance motors.
- During the downhill or decelerating motion of the said vehicle, the restoring of brake energy by regeneration can be employed and stored in the high voltage batteries. Thereby the driving range from single charging will be extended and also reduce the loss during braking.
- If the battery's existing charge is not adequate to drive the vehicle, various charging methods like AC or DC charge are applicable. The trickle charge can also be applied.

6.1 Battery Electric Vehicles (BEVs)

A battery electric vehicle (BEV) runs entirely on a battery and electric drive train without an internal combustion engine. To recharge their batteries, these vehicles must be plugged into an external electricity source. A hybrid electric vehicle (HEV) with an internal combustion engine and an electric motor together with an engine or generator depends on one or more energy sources [46]. A plug-in hybrid electric vehicle (PHEV) uses rechargeable batteries or other power storage systems that can be recharged by connecting them to external electricity sources.

Instead of an ICE vehicles, EVs have an electrical motor. The electric battery vehicle uses a large traction battery pack to power the electric motor and, since it operates on electricity, it must be plugged into the charging station. The vehicle emits no exhaust from the tailpipe and does not contain the fuel components such as fuel pump, fuel line, and fuel tank. The battery pack used to store the electrical energy that drives the motor is used in the car. By plugging the vehicle into an electric power source, batteries are charged. BEVs are more costly than conventional hybrid vehicles.

The battery stores the energy necessary for the vehicle to operate. The battery supplies the motor with an electric current. And the engine, thus, drives the greater the battery size, the greater the range of the vehicle. Lithium-ion type batteries are the most widely used batteries. The higher energy density of these batteries is capable of storing more energy [47]. Using an inverter, the battery energy in the DC is converted to AC. The AC is transmitted to the induction motor from the inverter, which generates a spinning magnetic field that allows the motor to turn.

The single-speed transmission transfers power to the wheels from the induction motor. This electric motor converts electrical energy into mechanical energy that turns the wheels to move forward. The car uses more energy during the acceleration, but the energy transforms through the induction motor into electricity during the stop. This power is stored in the battery pack and can be used when more energy is required. An electric vehicle battery can be charged by plugging it into an outlet or charging station. Advantages of BEV are less air pollution, less noise pollution, higher efficiency, low fuel and operating cost, and low maintenance cost. The disadvantages of BEVs include are high prices and low range.

6.2 Hybrid Electric Vehicles (HEVs)

The phrase *hybrid vehicle* makes reference to a vehicle with the least of two power sources. Among the two sources of power for HEV, an electric motor acts as one energy source. In contrast, the other source of motive power can be extracted within several divergent technologies. But the most used secondary source of power will be an ICE destined to run either on gasoline or petroleum fuel [48]. As put forward by the technical committee of the international electrotechnical commission (electric road vehicles), an HEV is a vehicle in which propulsion energy is available from two or more types of energy sources, and at least one of them can deliver electrical energy. Predicted on the definition by the commission, various kind of energy combinations of HEVs are:

- The battery and gasoline IC engine combo
- Battery and ICE with diesel
- Fuel cell and battery combo
- Battery with ultra-capacitor
- Battery along with flywheel combo
- Hybrid battery and other batteries

Incorporating an ICE with an electric motor is the most widely used combo for the generation of propulsion force in hybrid EVs. With this integration, energy efficiency will be improved and vehicle emissions will be fall off due to the electric motor. The driving range will be extended because of the ICE in contemplation of advancements in the HEV. The stereotypical ICE vehicles bestow good performances and an extensive operating range because of the high energy density yielded by the petroleum products. But these standard ICE vehicles have the disbenefit of indigent fuel economy and more significant risks of environmental contamination [49]. By far, the reasons behind their indigent fuel economy are:

- The contrast between real operation requirements and the vehicles fuel expertise
- Operating in urban areas, the wastage of kinetic energy during braking
- Due to the stop-and-go driving pattern, the productivity of hydraulic transmission in current day automobiles.

The EVs powered by battery packs have dominance over typical ICE vehicles by high energy productivity and almost zero environmental contamination. The comparison of these vehicles based on the performance of their driving range per battery charge ICEs holds the upper hand. However, HEVs can outsmart both traditional ICEs and EVs due to the use of two power sources.

An ICE and an electric motor that utilizes energy stored in the battery are powered by HEVs. Instead of charging the batteries by regenerative braking and an ICE, a hybrid car cannot be plugged in to charge the battery. A smaller engine could theoretically allow for the extra power provided by the electric motor. When stopped, the battery can also control auxiliary loads such as sound systems and headlights and decrease engine idling. Together, these characteristics result in increased fuel economy. During coasting or braking, the regenerative braking mechanism restores energy normally lost. It uses the wheels' forward motion to spin the engine. This provides energy which makes the vehicle slow down.

6.3 Plug-In Hybrid Electric Vehicles (PHEVs)

A battery and an electric motor are available for PHEVs. They also have an ICE and a fuel tank. The PHEV works with electricity until the battery is almost empty. In the engine, the fuel is then burned to create extra electricity for the electric motor or power the wheels. With plug-in supplies and a regenerative braking system, the PHEV batteries can be recharged.

As proposed in the name itself, it's also a shade of hybrid electric vehicle (HEVs). Also named as electric vehicles with an extended running range that utilizes battery packs to deliver energy to an electric motors and an alternate source of energy like fuel or gasoline to satisfy the energy demands of ICE employed. i.e., similar to HEVs, PHEVs also make use of both the electrical and mechanical power path with the help of conventional ICE and general electric machines. The batteries could be charged alongside plugging through an electric power source or regenerative braking with the ICE. The PHEV may have larger battery packs than common HEVs [50]. The PHEVs gain almost all their power while running through urban areas with the already stored electricity in the battery packs. Before even beginning, one must ensure the battery is sufficiently charged. In case of distress or complete depletion of batteries, ICEs may power the vehicle during situations where sudden acceleration, at high speeds, or when rigorous heating or air conditioning is needed. The dissimilarities of PHEVs and HEVs depend on the capacity of the battery and their recharging techniques. PHEV's are furnished with larger capacities of batteries that can operate only with battery power within a reasonable driving range, also called an all-electric driving range.

The utilization of fuel/gasoline in PHEVs depends upon the total distance travelled within the complete discharging period. The tailpipe emissions of a PHEV are zero if it's driven only with battery power. Even if it's operating with an ICE alone, gasoline consumption will be practically lesser and produce lower emissions than similar conventional vehicles do. Comparing with the traditional ICEs that blindly rely on fossil fuels, PHEVs offer consumers to choose between alternate cheap and clean energy, thereby diminishing the dependence on a single source of energy.

Two fuel sources, an electric motor and a combustion engine, drive PHEVs. PHEVs use less fuel and emit fewer emissions than traditional ICE vehicles powered only by combustion engines. In contrast to HEVs, PHEV uses a high-capacity battery for energy storage. The greater battery capacity allows the vehicle to cover longer electric-mode driving distances than hybrid vehicles. The electric motor alone or the combustion engine powers the car, depending on the driving conditions [51]. The high voltage battery either absorbs energy or emits it. The high voltage battery releases energy while the electric motor is running, via regenerative braking, the battery is partially charged by kinetic energy while driving. You should plug the vehicle in to recharge your high-voltage battery. Charging can be done at any location with domestic electricity installed. From the public charging stations, they can also charge. The car must be parked with the ignition switched off before being charged. The charging indicator illuminates until the vehicle is fully charged when the charging cable is attached.

The vehicle functions in two modes to encapsulate it. The first mode is called the charge depleting mode, in which only the electric motor powers the vehicle before the high voltage battery reaches a low energy level [52]. When the battery level is low, the mode of the vehicle switches to the hybrid mode's charge sustaining mode. It's the second mode of driving. The vehicle uses power from the electric motor to drive in hybrid mode during mild acceleration, providing enough pickup to help increase speed. The gasoline engine and the electric motor are used to get the desired speed when the acceleration is higher or uphill motion. The machine goes to power assist mode while cruising at a relatively steady rpm, where the gasoline engine is the primary source of drive power [53]. The device captures energy through a regenerative braking system as the vehicle's speed decreases and stores it in the battery for future use. As mentioned above, external charging is often used to optimize high voltage levels. Table 6 presents different types of EVs and their characteristics.

7 Protection of Smart Grid

A grid would be more efficient when more resiliency is added into the existing electric network and made ready for diffident unavoidable tragedies and natural calamities. Therefore, if some extra powerful features are supplemented to the existing grid, it becomes a SG. The extra powerful features can be advanced protection schemes in grid operation. This will make the existing grid network more efficient, faster in power transmission and self-repair after power disturbances, inexpensive, improved security etc.

Protection in SG refers to the protection of devices connected to the SG against unintentional failures like fault, overload etc. One of the power system protection applications in the SG is quick to fault diagnosis to prevent fluctuations in voltage and power outages. When some schemes protect the physical infrastructures of SG, it is referred to as physical protection of SG. This type of protection refers to inadvertent situations because of equipment failure, errors created by human's, natural disasters etc. In this type of protection, two essential things have to be looked into. One is the reliability of the system and the other one is protection scheme failure. Reliability refers to SG's component's reliability and the way they are placed and they are achieved in four various ways:

- Reliability of distributed generation
- Reliability of measurement infrastructure
- Reliability of network before action
- Decision-making performance by sub-station

RERs are used as DG in a SG whose penetration into the system makes coordination between them with other protection devices quite challenging. As a result reliability and stability of the system becomes a concern for the protection engineer.

Table 6 Different types of electric vehicles (EVs) and their characteristics

Type of electric vehicle	Battery electric vehicle	Hybrid electric vehicle	Plug-in hybrid electric vehicle	Fuel cell hybrid electric vehicle
Propulsion	Electric motor	International combustion engine (ICE) and electric motor	International combustion engine (ICE) and electric motor	Electric motor
Energy system	Battery	ICE unit and battery	ICE unit and battery	Fuel cell along with battery and ultra-capacitor to enhance power density
Energy source	Electric grid charging	Gasoline station	Electric grid charging and gasoline station	Hydrogen, Hydrogen production, transportation, and infrastructure
Characteristics	Zero-emission, high energy efficiency, and high initial cost, readily available	Low emission, high fuel economy, long-range of driving, high cost, commercially available	Low emission, large battery capacity, long driving range in road trips, and high cost	Zero-emission or ultra-low emission, high energy efficiency, high cost, less dependent on fossil fuels
Challenges and issues	Battery management, high cost of charging facilities	Control of multiple energy sources, battery management	Control of multiple sources, maintenance cost	High fuel cell cost, fuel cell durability, and reliability, Hydrogen infrastructure

One SG operation requirement is the smart measurement infrastructure, which helps monitor network reliability, stability, and healthiness, which can be met with a phasor measurement unit (PMU). Suppose the decision making performance by sub-station can be achieved. In that case, the time span can be reduced as it does not have to wait for the control network's decision and the system achieves better stability and reliability. Failure prevention and prediction are two important aspects of SG physical protection. Prediction means identifying the failure event in the SG, and prevention means to inhibit the failure from an occurrence. Recovery is another important aspect of the SG that can be achieved by developing efficient techniques. For example, a smart meter is used to recover missing data from the system. Because of the inverter-based DGs into the SG, the operating characteristics differ from standard distribution systems, making the protection engineer challenging. Another challenge before power system engineer's is to attain reliability and efficiency in a wired and wireless communication network for control and data transfer purpose. For proper unit protection and to optimize the relay coordination in SG, internet of energy (IoE) based communication technology is recently used, which mainly exchanges information that is further collected by integrated electronic devices (IED). This type of protection scheme is called i-protection, which precisely identifies the fault with the help of IEDs and IoE through a wide-area wireless network.

8 Conclusion

Smart grid (SG) has been the most impactful technology in recent times and is still rising because of its significant benefits. But like any other more substantial change, transition to the SG system from a conventional power grid system is highly tedious and time-consuming. At the same time, it is a great decision to meet the growing electricity demand of modern civilization. The successful transition requires meticulous preparation, thorough understanding, and proper knowledge, along with their corresponding impacts on every part of the ecosystem. The distributed energy resource (DER) applications would increase the efficiency of the energy supply and reduce the electricity delivery cost and carbon footprint in the SG. The SG needs to be well-designed, robust structure to withstand the tension, efficient and reliable, sustainable with the environment, intelligent enough to discover outages and fault locations, secured and safe from cyber-attacks, able to monitor real-time data and act upon it, scalable and integrable with other sources of energy. Various features of the SG need to be implemented cost-effectively to form a symbiotic relationship and benefit grid operators, energy providers, consumers, and the environment. There are many challenging issues of protection in SGs like maintaining reliability, stability, coordination etc. All these can be solved by developing optimized algorithms, which is also ongoing research.

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