State of Art and Comprehensive Study on Smart Meter Networking

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Abstract The considerable increment in power consumption and the quick enhancement of renewables such as wind power and solar power have presented enormous challenges in terms of energy security and the ecosystem, which in the meantime are encouraging the advancement of energy networks in a smarter direction. An advanced grid integrated with two-way power flow ability, inter-device communication, cybersecurity, physical safety, autonomous fault detection, self-healing, and incorporation of renewable energy resources to improve energy efficiency, reliability, quality, and network security can be a potential solution for smarter direction and such type of system is regarded as smart grid (SG). Smart meter is among the key instruments used in the intelligent network. The smart meter is an integrated energy meter that collects data from the load devices of end users and monitors customer energy usage and provides information to the utility provider and/or system controller. A variety of sensors and controls are used in a smart meter, assisted by a specific communication infrastructure. In this context, this paper describes in detail the architecture of the smart meter network, smart meter evolution, various functionalities, and its associated benefits. In addition, it also discusses some security problems and its solution with smart meters.

Keywords Advanced metering infrastructure · Meter data management system · Smart grid · Smart meter · Security issues

1 Introduction

Electricity is prominent in modern world, since it enables daily appliances like computers, televisions, telephones commercial buildings, industrial plants, the Internet, etc. The demand for electricity is growing rapidly, especially the demand for electricity in India will reach the value about 373.43 GW as of January, 31, 2021 [1].

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Modern society depends heavily on electricity. Electricity disturbances and failures get a significant adverse effect on life quality. The power supply must therefore be regulated efficiently to provide the customers with high quality and reliability [2]. Smart grid adoption might be a potential way of meeting the rising demand for electricity and the increased usage of intelligent meters. Introducing intelligent metering and algorithms also has the ability to rapidly detect, isolate, and restore power systems at a higher level of precision [3]. Many power measuring equipment and approaches are capable of solving problems related to electricity utilization and control. Currently, the capabilities and configurations of smart meters are extensive to different utilities [4–7]. One of the purposes of this article is to define and review the features and functions of smart meters used commercially.

In India, energy meters are mainly electromechanical but are increasingly being substituted by sophisticated and more reliable digital electronic meters. A significant proportion of energy revenues are lost from electricity theft, inaccurate reading and billing meters, and customers' inability to pay electric payments on time. The use of prepaid energy meters will minimize significant revenue losses.

The market for smart meters has seen the total number of smart meters shipped worldwide for 2019 at around 131.23 million units and is estimated to reach 188.12 million by 2025, with a compound annual growth rate (CAGR) of 6.6% for the forecast period as illustrated in Fig. 1 [8]. The overwhelming acceptance of intelligent meters makes it possible to collect a large amount of fine-grained electricity usage data. Billing is not the only smart meter feature anymore. High-resolution data from smart meters offers a wealth of knowledge on consumer trends of energy use and lifestyles. In the meantime, the de-regulation of the energy industry in several countries around the world, especially on the consumer side, is continuously moving forward. These countries now make little attempt to reform the electricity retail market. Progressively more participants, including suppliers, customers, aggregators, contribute to a more stable, active, and competitive retail sector. How enormous smart meter statistics can be used to encourage and improve the efficiency and stability of the demand side has now become an interesting issue globally.

In several electrical systems worldwide, smart meters will be implemented to provide customer real-time energy consumption and cost statistics. Intelligent meters are electronic measuring mechanisms used by distributors to convey information

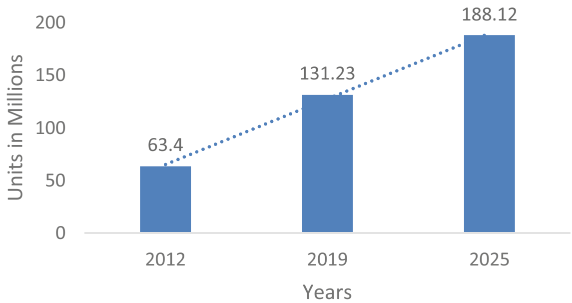

Fig. 1 Smart meter global market size

to billing consumers and to manage their electrical systems. A hybrid electronic measurement system with two-way communication technology is commonly known as advanced metering infrastructure (AMI) for information, monitoring, and control. Prior networks, which used one-way interactions to obtain data from meter, were known as automated meter reading (AMR) mechanism. Over time, AMI has grown from its origins as an AMR to the present two-way interaction and data system [5].

2 The Smart Grid and Smart Metering Concept

The concept 'smart grid' is commonly employed to describe the integration of all supply, grid, and application components linked to a digital power grid upgrade with a reliable, efficient, stable, and manageable open information infrastructure based on standards that could allow two-way communications to provide various advantages for both customers and power suppliers [6].

The smart grid employs smart devices and upgraded power infrastructure for digital communication to increase transmission and distribution grid efficiency. Using this digital technology, smart systems can analyze their health in real-time, adapt them to new environments, monitor distributed resource integrations, and manage end-user smart appliances. Performance and efficiency can be enhanced, and end users can use active positions in the smart grid to save customers' money [6, 7]. Since many years earlier, the installation of automated meter reading (AMR) infrastructure has been setup. Wireless systems or telephone lines were used to transmit data during those years. This device was designed to collect data employing a radio connection mounted in a vehicle passing by the meter, or by telephone lines or wireless networks collecting data from meters.

Intelligent meters must be able to measure simple along with other valuable quantities. Such meters must have a proper communication ports in order to address requests to collect the required information, to turn on or off commands provided by a central access server, and to record incidents and defects in a scenario of any tampering. This meter must have an interface for consumer knowledge to attach an in-home monitor (IHD). A smart meter should be able to illustrate the overall price value of the energy consumed. It should also be able to record customer data every hour, so that subscribers can control their usage.

3 Smart Grid Component

Smart grid's main components are known as follows

- Smart Infrastructure
- Smart Communication
- Smart Management
- Smart Protection Systems.

Meanwhile the smart infrastructure architecture is categorized into two sections.

(1) Smart energy system—The smart energy network is of power generation type, transmission type, and distribution type
(2) Smart information systems—Smart information system will have smart metering, sensors, phasor measurement units, as well as information management.

The first component of the smart energy system is the generation of electricity. Electricity is most commonly generated by power plants that involve the use of flowing water or heat engines powered by chemical combustion or nuclear power. Now, let us see how the generation of power will be improved or how it will take new forms. The form of smart power generation is now offering two-way flow of both data and electricity. Distributed power generation, for example, is a critical component of intelligent grid generation that can certainly play a key and significant role in our intelligent grid. The improvement of the existing transmission system by installing or building intelligent control centers, intelligent power transmission networks, and intelligent substations will also make our transmission system fairly smart. Now, distributed generation facilitates the creation of a new grid model called a microgrid, one of the corner stones of the future intelligent grid distribution. Now, a smarter distribution system would have to be built at different voltage levels so-called smart grid, which will be considered the main corner stone of the future grid.

Another part of smart infrastructure is smart information. Now what's smart information? the smart grid growth is driven by advanced power station technology as well as enhanced computer tracking, analysis, optimization, and control from solely central utilities to the distribution and transmission grid. One important concern is that a distributed system can become smarter only when the data is made available at different nodes at distance through a wireless Internet and for that it needs to have smart meters in place. The smart meter is typically an electrical meter itself which records consumption by an hour or less even at an interval of 5 min, 15 min interval, and half an hour's interval, as per the requirement.

Smart meters are efficient instruments that radically change the function of electricity grids. In contrast to conventional meter features, smart meters could be used as sensors in the whole distribution network [9]. Smart meters can calculate and record the actual electricity usage for a day at a given interval if an advanced metering infrastructure (AMI) is in place [10]. This collected data is transmitted through wireless communication from a secure network to a central data management system. In addition, service providers may use these sensors to detect failures and send alerts of failure or recovery. Using this detail, utilities may provide increasingly reliable electricity. It also allows better strategy, better execution and a more rapid network failure reaction.

4 Smart Metering Evolution

Table 1 illustrates the evolution of electromechanical meters to AMI meters. In the subsection, detailed evolution of smart meter is discussed.

4.1 *Manual Meter Reading (MMR)*

Meter reading has historically often been performed manually. The meter had to be monitored physically to track the meter readings, normally monthly. This included inspection of remote locations or residences. Sometimes, it is also not possible to track every meter physically or manually. The same was valid not only for the reading of meters but also for the maintenance of meters.

Table 1 Evolution of smart meter technological advances

Meter system	Functionalities/capability/feature
Electromechanical meter	• Electromechanical meter operation is quite simple • As the number of rotations increases, the reading also increases • Environmental factors affect the accuracy of an electromechanical meter
Electronic meter	• Wide range of measurement of electrical parameters • Compared to electromechanical meters, these meters have a high degree of accuracy • Design flexibility • Capacity update
Automated meter reading (AMR)	• Remote meter reading • Detection of a power outage at the meter • Detection of tampering • Profiling of load
AMR plus	• Reading in real time or near real time • Notification of consumer can be read by another commodity
Advanced metering infrastructure (AMI)	• Multiple tariff framework • Remotely programmable • Home area network (HAN) or Local area network (LAN) interface • Remote connection/disconnection of the supply

4.2 Electronic Meter Reading (EMR)

The concept of an electronic meter reading was introduced as a remedy to the issue of being able to recognize or read energy usage more efficiently, and the main step in that direction was an electronic meter reading technology (EMR), adapted and still in use, especially for industrial users. With EMR, meter inspectors do not need to reach consumer premises to receive their monthly usage any more. The majority of EMR technology is a walk-by or a drive-by wherever the meter has it contain a radio frequency transmitter (RF) which helps you by transmitting the receiver reading. The receiver is a portable unit that is mounted in an automobile or employs a radio tower network to capture and transmit the data to the organization and the user. The communications are made through a wireless communication link, for example, by means of ZigBee [11].

4.3 Automated Meter Reading (AMR)

The meter reading techniques with the invention of the automatic meter reading (AMR) was further improved. Automatic meter readings (AMR) are the technology for the automatic processing of data from energy measurement instruments for the automatic acquisition, diagnostics, and status, and pass this information to a centralized billing, troubleshooting, and analytical database system [11]. Over all, this system saves the costs of daily visits to any physical place for meters scanning. Another benefit is that the billing become almost realistic. This timely analysis information helps both customers and suppliers to control better the use and manufacture of electrical energy. AMR systems usually involve handheld mobile and network technologies focused on wired and wireless telephony, radio frequency (RF), or power line transmission platforms.

4.4 Advanced Metering Infrastructure (AMI)

An experience of the advantages of two-way communication among system components such as customers, operators, and resources has resulted in the development of AMR into AMI. It would be no mistake to call AMI rather than AMR an evolutionary move. AMI is an infrastructure of next level that includes smart metering, home area networks, communication networks between utilities and metering, housing management systems, and meter data management systems, etc. Advanced metering infrastructure (AMI) is an integrated smart metering system that facilitates two-way interactions between customers and utilities. The device offers a range of significant features which had not been or should have been carried out manually before, such as the ability to control electricity usage automatically and remotely, to connect and disconnect service, to detect manipulation, to recognize and isolate faults, and to monitor voltage. Alongside customer innovations such as in-home displays and programmable thermostats, AMI also helps utilities to implement new time-based rate schemes and rewards that enable consumers to cut demand and manage energy use and costs. AMI is a designed network that incorporates a variety of technologies in order to gain its objectives. The network consists of smart meters at the user end, communications systems at various levels of the infrastructure hierarchy to join two ends, Meter Data Management Systems (MDMS), and means for connecting the collected data to software applications and interfaces at the service or head end [12].

The customer is installed with a sophisticated, time-based electronic meter. These meters can transfer the information gathered through generally accessible established networks. The recorded data is received by the host system AMI. They are then forwarded to an MDMS that handles, analyses, and supplies the data to the service provider in a useful format [13, 14]. AMI allows bidirectional communication; thus, it is also possible to communicate or question command or price signals from the service provider to meters or to load controllers.

Coming to this basic block diagram of the AMI as shown in Fig. 2. It consists of three components. The first is the MDMS. This MDMS stands for the meter data management system, and the second is the smart meter, which is essentially located on the consumer's periphery or premises, and this MDMS is essentially present within the data and control center (DCC) utility. And these data control centers are basically located on the periphery or on the premises of the utility. And these two components, MDMS and smart meters, are connected to each other or communicate with each other through a communication infrastructure. So, this is how this very simple block diagram works with regard to the advanced metering infrastructure of the smart grid system.

Data concentrator—The data concentrator is a significant node in the AMI, linked to several smart meters and central servers. It allows data to be shared between MDMS and smart meters and it safely aggregate data.

Meter data management system (MDMS)—MDMS is an AMI heart. This method includes the data collection from concentrators entering the operating center, then proper processing and storage. As a result, the same data form is located at the same address and the data retrieval becomes easier. MDMS provides analytical tools to communicate with the various operating and management systems and collect the appropriate data.

The measurements that are essentially taken from the smart meter are shown in Fig. 3. The first is the RMS voltage, the second is the RMS current, and the third is the calculation of the phase angle. People mainly talk about the angle between the

Fig. 2 Block diagram of AMI

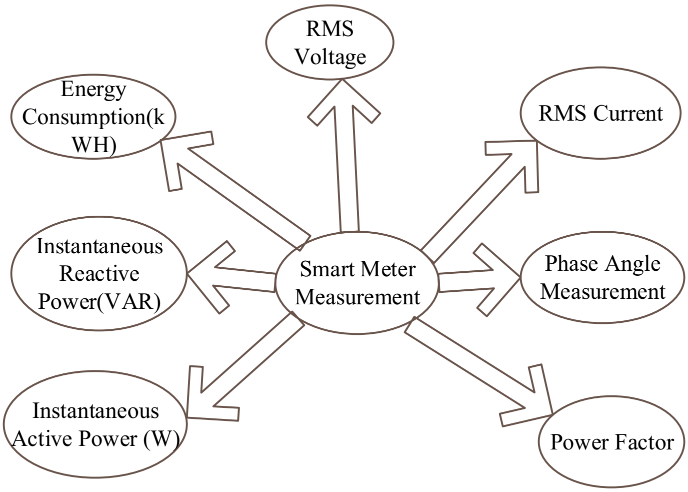

Fig. 3 Measurement from smart meter

voltage and the current of a particular network or customer network through which the load is connected. Even using this smart meter, this phase angle is calculated, and the fourth is a critical power factor for us. The power factor is of great significance to customers. This power factor can also be calculated using the smart meter, and the fifth is instantaneous active power how much power the consumer consumes and can be calculated using this smart meter infrastructure or smart meter unit. And the sixth one is instantaneous power. Power is of two types: one is instantaneous active power, and the other is instantaneous reactive power. These power calculations can be carried out by every individual using smart meter technology, and the last is energy consumption.

5 Smart Meter Network Design

Smart metering, if we see the particular evolution of the electrical metering graph shown in Fig. 4 here before the 1970s, this smart metering idea was zero, with no communication at all until almost 1995. So, basically, this is the time when users started using smart metering technology.

So, after 2000, the smart metering concept was increased and also this smart grid idea is not new which had its existence since last two decades. The 2025 target for smart metering can be achieved through an advanced smart metering facility in the smart grid environment as per above particular graph.

The block diagram shown in Fig. 5 illustrates working of smart meter. The smart meter must first recognize that the signal is either a voltage signal or a current signal, and then move to the next stage known as signal conditioning. It is important to

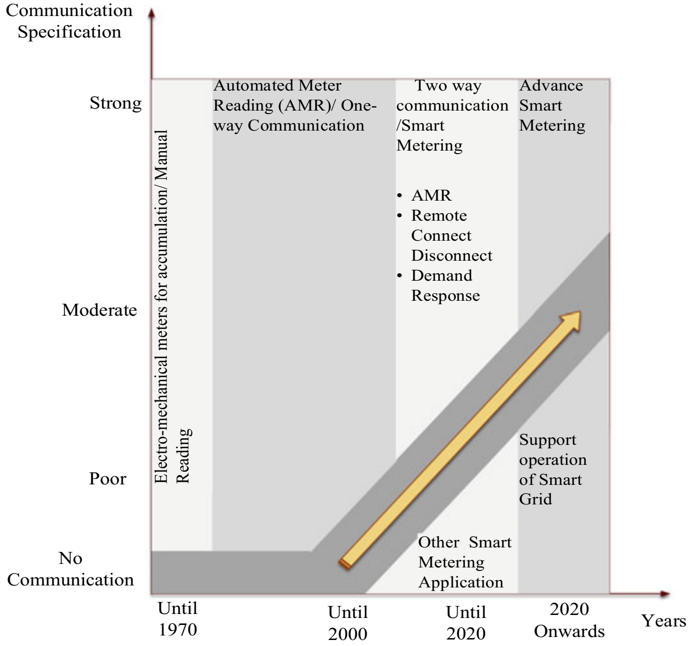

Fig. 4 Evolution of smart metering

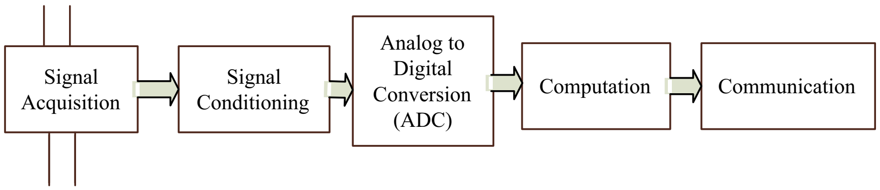

Fig. 5 Smart meter block diagram

control the signal because we must have to stabilize it. Since the signals in the power grid are not strictly sinusoidal, the fundamental frequency part of 50 Hz is not the only one. In this context, high-frequency components and harmonics must ultimately be eliminated. And we also often get aliases within the signal, because the aliasing effect often means that very high-frequency signal components will behave as a fundamental signal component. Consequently, those difficulties which are essentially present on the desired signals which are present within the basic frequency component of the voltage current should be eliminated. Only a simple 50 Hz voltage and a current signal should be allowed for the next block; this is the signal conditioning. An ADC may provide an independent measurement, e.g. an electronic device converting an analog voltage or current to a digital number equal to the voltage or current magnitude. And then it proceeds to the computing block

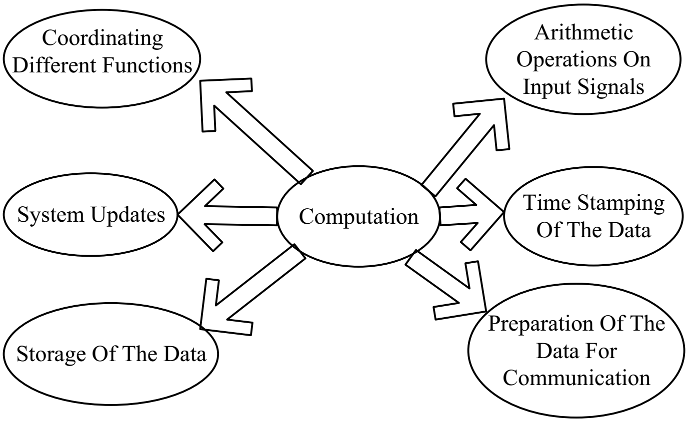

Fig. 6 Measurement using smart meter

where the calculation is done, and this is done essentially by the processor. And the processor helps to calculate whatever components or sub-components it needs from the signal voltage. It will then coordinate for further action.

The measurements that are carried out by smart metres are depicted in Fig. 6. The first is one basically an arithmetic operations of input signals and may be time stamping of the data, and it contains data for communication, storage of the data, updates system, and synchronization of various different functions.

6 Smart Meter Benefits

The introduction of smart metering will have wide range of benefits for the service utility, consumer, and community itself [15–18].

6.1 Benefits for the Consumers

- Customers gain detailed knowledge about their use of electricity. This will provide both customer and company with energy productivity improvements.
- Reduced power outages.
- Improved delivery efficiency awareness and more comprehensive energy use reviews. Bills are based on actual consumption. Pricing is based on current usage.
- The need to estimate the bill is minimized.
- Consumers may change their service behaviors to lower electric bills during peak hours.
- No need to offer permission to utilities for reviewing indoor meters.

- Movement and switching are fast.

6.2 Benefits for Utility Services

- Remote control allows better billing management and other customer issues.
- Remote and automated measurement reading.
- Reduced power outages.
- Existing resource income optimization.
- Reduced operating costs.
- Dynamic pricing enabled.
- Enable more effective use of electricity resources.
- Increased low voltage network information.
- Electrical systems are controlled faster.
- Release experienced staff to serve customers in other high key sectors.

6.3 Benefits for Environmental

- Smart meters minimize greenhouse gas emissions from installed power plants indirectly.
- Smart meters avoid need for new power stations by ensuring that current power consumption is adequately distributed, thus reducing emissions.
- Smart meters interact with the service provider directly, thereby removing the need to place trucks on the lane.

7 Barriers to Smart Metering

There are a variety of challenges to smart metering [15–20].

7.1 Electric Company Challenges

- Transition from old to modern technologies.
- Management of data metering security.
- Carefully handle the consumer to consider the latest technologies and procedure.
- Handle public response with formal introduction to the new meter.
- Dynamic programs and long-term projects.
- Optimizing smart meter rollout.
- More meter and infrastructure costs.

7.2 *Challenges for Customers*

- Verification of the precision of the data obtained and analyzed by new meter.
- Protection of your confidential data's privacy.
- Additional new meter fees.

7.3 *Environmental Challenges*

- Old meter destruction.

8 Functionalities of Smart Meters and Smart Metering

The providers might also hope to ensure the highest degree of smart metering functionality and ensure that current levels of technology are used in full by the legislation so that investments are not too quickly redundant [21]. For intelligent meters, the following main functionalities can be considered

- Load data profile
- Access to data metered for consumers and approved third parties on request
- Supply consistency
- Customer price indicator
- Choice of tariffs for variable time of use
- Management of remote meters
- Identification of power outage
- Reduction of remote demand
- Identification of power consumption over particular demand
- Remote login/disconnection
- Competitive pricing and response to demand
- Detection of manipulation and stealing! and rectification.

9 Smart Metering Security Problems

Smart measurement raises a range of security issues and potential security threats [22–28]. Some of these are mentioned here.

9.1 Eavesdropping

Eavesdropping helps the offender to actively listen to information exchanged between an intelligent meter (or an intelligent measuring gateway) and the providers. This attack aims at consumer privacy and can easily be carried out on a wireless communication channel or power line. It is very difficult to detect eavesdropping as it does not interfere with communication.

9.2 Denial of Service (DoS) Attacks

DoS attacks threaten the entire intelligent metering network, the smart grid or sections of the grid. DoS attack can be carried out by an opponent by sending instructions far more than planned to the intelligent metering access points or to the other end of the utility's server. This saturates the network such that it can no longer address the valid requests. The grid or parts of the grid are mostly shut down for essential services.

9.3 Packet Injection Attacks

This threat is initiated by inserting false packets into the system like false requests. The aims of these actions may be to cut the electricity of sections of the intelligent metering system by generating false bills which cause large financial problems or to compromise the billing mechanism.

9.4 Malware Injection Attacks

Malware injection into the system affects information exchange between grid devices and jeopardizes accounting and control process. The grid's demand/consumer status could be manipulated in order to destabilize the grid load.

9.5 Remote Connect/Disconnect Attacks

The smart grid remote connection/disconnection capability can be used to avoid the grid or its parts. This attempt of attack would isolate a large number of users from power, water, and gas supplies.

9.6 Firmware Manipulation Attacks

The configuration of a smart meter or measuring gateway could be manipulated to interrupt the meter's billing and payment system. This involves the management of the prepayment feature or reporting to the remote reader fake usage status. Firmware handling attacks can be rendered via physical access by modifying a smart meter or through the WAN when the gateway promotes remote firmware updates. These attacks usually impact a single person, but can also be massively launched.

9.7 Man-In-The-Middle Attacks

A man-in-the-center attack is a sort of action or attack that the attacker "inserts" himself in the center parties. An attacker connects with both parties, catches and transmits their messages to the other end, and makes everybody think they are talking to explicitly to each other else. The intruder thus has the right to passive elimination or alteration of details exchanged between the partners of communication.

10 Smart Metering Security Solutions

Various safety measures are used to counter security risks and threats on intelligent measurement devices. This involves a combination of security utilities, networks, embedded systems, operating systems, and intrusion detection and protection systems designed for general purposes [27–32].

10.1 Gateway-Based Approach

Gateway is a modern solution suggested by European nations such as Germany and the United Kingdom to smart metering. A gateway allows for secure communications between the intelligent meters and the smart grid. A gateway (or smart metering gateway) serves as a contact system between customers' metering devices and the utility. This gateway acts not just as a contact and control unit between the meters and the service provider, but also to protect the customer's privacy. One gateway is accountable for smart meters and other intelligent devices mounted in a house or building. The gateway interacts regularly with the utility servers via wide area network (WAN). The gateway also offers loading control instructions based on load in the intelligent grid. Therefore, it must be able to help various protocols and standards in communication including wireless MBUS, PLC, RS-485, MBUS, GSM, GPRS, PSTN, Zigbee, etc.

10.2 Encrypted Communication

Interaction should be encrypted between organizations in smart metering systems. Encrypted communication is typically obtained while using existing methods like Transport Layer Security (TLS). However, TLS is no longer considered safe, and therefore, other ways to maintain the security of correspondence need to be coupled with TLS. These involve encryption of the application layer in addition to TLS to boost the overall encrypted communication. An example is the BSI approach to protection profiles (PP) developed in Germany, usually recognized as the BSI PP. They suggest dual encryption and end-to-end encryption on the application layer and also on transport layer.

10.3 Systems for Intrusion Detection and Prevention

Smart metering system networks can be employed for intrusion Detection systems (IDS) and intrusion prevention systems (IPS). This helps to detect intrusions, detect rogue nodes or attacks, and remove these nodes from further network contact.

10.4 Verification of Authenticity

The authenticity of communications participants and the origin of data must be assured. Standard methods, such as digital signatures, may be employed toward this objective.

10.5 Integrity Protection

In order to assure the integrity of the communicated data, security protocols should be employed to facilitate integrity safety. This involves the use of message authentication codes (MAC) to maintain energy usage integrity.

11 Conclusion

Electricity meters in India were primarily electromechanical but are increasingly succeeded by more modern, reliable digital and electronic meters. A significant proportion of energy market share has been lost to power theft, inaccurate meter reading and billing, and customers' inability to pay electricity bills in due course.

In this paper, we analyzed and addressed the modern grid systems and smart metering features and functionalities of smart meters which are sustainably used by different utilities, the operational concepts of smart meters, advanced metering technology, and meter data management system metering. The paper also includes a list of possible security and privacy issues arising from the use of smart metering and possible protection solutions are explored.

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