Intelligent Energy Metering in the Smart Grid: A Review

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Abstract: -The implementation of smart metering infrastructure may be a possible solution to reduce electricity demand, manage electricity supply efficiently. This article reviews the ways in which smart metering infrastructure can overcome the various problems of the smart grid. It provides a better understanding of the technical challenges, economic opportunities and environmental implications associated with smart grids. As such, it helps to identify gaps in current research and areas requiring future investigation, thus helping to steer research and development efforts towards more efficient and innovative solutions. It highlights the latest advances and emerging trends, while providing an overview of current technologies and methods such as smart meters, data concentrators, the data management system and the communication system. We also examine standards for smart metering, substation automation, demand response, distributed resources, and large-scale control and monitoring, to ensure interoperability, security and reliability of energy management systems.

Key-words: Smart metering infrastructure, smart grid, smart meter, concentrators, standards, interoperability, security.

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1 Introduction

Rising consumption and fluctuating trends in demand and supply are problems currently facing the energy sector worldwide. The demand for electricity is increasing day by day due to population growth and industrial development [1]. According to a 2019 United Nations report, the world's population rose from around 2.53 billion in 1950 to over 7.79 billion in 2020, equivalent to an increase of around 207.9%. According to another complementary report, the world's populationgrew by around 55% between 2018 and 2020 [2]. This demographic growth is set to continue, with a projection of over 10.9 billion by 2100, an increase of 40% [3]. Given this increase, current primary energy resources are expected to run out within 133 years [3]. Thus, the increased daily use of electrical appliances and the integration of new crypto-currency charges by consumers is a growing concern in the energy sector, creating an imbalance in the relationship between supply and demand. In addition, there are many unauthorized "grid connections", which means that a significant amount of energy is not metered or paid for [4]. Producing more electricity would improve the situation, but would not be a complete solution. There are opportunities to reduce the gap between supply and demand through better use of electricity. The advent of smart meters and advanced metering systems has solved many of these problems. The European Parliament in the Directive of 2012/27/EU, defines smart meters or smart metering systems as "an electronic system capable of measuring energy consumption, providing more information than a conventional meter, and transmitting and receiving information using a form of electronic communication" [5].

These are powerful metering devices with digital displays, the ability to record the amount of energy consumed, its date of consumption, automatic transmission of information and a Meter Data Management System (MDMS) for processing and storage [6] [7]. With interoperability between smart meters and SGDC systems in mind, standards for data collection and storage must be respected. In this article we discuss smart meters, the Advanced Metering Infrastructure (AMI) and the data flow of smart meters currently deployed worldwide in smart grids in compliance with standards. Many scientific studies have been carried out in this field by various researchers. In [8], CRAEMER and all present an overview of smart grid architecture and an analysis of existing smart grid-related ICT standards. They emphasize the need for interoperable, future-proof solutions, particularly in the context of the imminent deployment of smart meters in European countries. The article focuses on communication standards such as DLMS/COSEM and their applications in smart meter data exchange. In [9], Ansari gives a comprehensive overview of smart meter networking, including the key elements and technologies involved. He emphasizes the importance of transforming the power grid into a smart grid and modernizing it with advanced metering infrastructure to meet today's energy challenges. [10] examines an overview of the key elements of a smart metering system, including architecture, trends and applications. It highlights the importance of two-way communication, advanced tariff systems and remote control of the energy supply. The author also discusses the various technologies and standards used in smart metering systems, such as wireless networks and data collection devices. This review article will highlight the latest advances and emerging trends, while providing an overview of current smart energy metering technologies and methods. By synthesizing a wide range of recent work and developments, this review provides a better understanding of the technical challenges, economic opportunities and environmental implications associated with smart grids. In addition, it helps to identify gaps in current research and areas requiring future investigation, thus helping to direct research and development efforts towards more effective and innovative solutions.

2 Evolution of the Smart Metering System

The first attempts to automate energy metering date back to the early ^{20th} century. Prior to this period, metering was mainly manual, with technicians taking regular readings from conventional electricity meters. However, with the advancement of technology and the growing need for efficient management of power grids, initiatives to automate energy metering have been developed. Milestones in the history of energy metering automation, or automated meter reading (AMR), have enabled utilities to remotely read consumption records [11]. AMR is often limited to a one-way function, where data is transmitted from the meter to a central point for billing. Over time, AMR evolves and integrates additional functionalities, hence ARM Plus. Unlike AMR Plus [12], the latter can take on bidirectional communications; i.e. in addition to collecting data, it can receive instructions from the central point or updates. It also enables more dynamic interaction between the meter and the management system [13-14]. As for the

Advanced Metering Infrastructure (AMI) [15], it presents a more advanced and comprehensive approach to meter management. This is an advanced metering infrastructure integrating smart meters with two-way communications systems, network management functions and advanced network applications [16]. Load profiling, prepayment, remote disconnection and reconnection, notification of power cuts, tamper detection and multiple pricing are also possible with smart meters. These used in an AMI system offer real-time data collection, bi-directional communications capabilities, advanced network management functions and further integration into the smart grid [17].

Table 1, Requirements for the design of an advanced metering system.

ASPECTS	EXPRESSIONS OF NEED
Technologies	Choosing the right technology Software robustness
Physic	Resilience Robustness
Communication	Wired, Wireless or Hybrid Two-way Range Bandwidth Signal quality Data security and privacy
Cost	Cost of components cost of communication infrastructure After-sales service (SAV)
Consumers	Access to personal data Power management
Vendors	Data access Control and monitoring Predicting energy demand

2.1 Smart Meter

The evolution of energy meters has gone through several phases over time, from traditional mechanical meters to more advanced electronic meters, to smart meters integrating communications and data management technologies [18]. Smart meters are powerful tools that fundamentally change the way the electricity grid operates. In addition to the functions of conventional meters, smart meters can be seen as sensors throughout the power grid [19]. It measures energy consumption in detail and possibly in real time [20]. The introduction of smart meters has been encouraged as part of initiatives to modernize electricity grids and promote more sustainable, efficient energy use. These meters can be used as advanced sensors to collect and transmit data in real time, helping to optimize power grid management. In fact, meters have two functions: measurement and communication; consequently, every meter contains two subsystems: metrology and communication [21]. There are essential functionalities that meters should have, regardless of the type or quantity of their measurement, including:

- Measurement: The meter must be able to accurately measure the amount of energy based on various physical characteristics. Power management: The smart meter enables modern energy management by allowing efficient real-time monitoring.
- Calibration: Although it varies according to type, the meter must have the ability to compensate for system variations. It is important to follow the procedures recommended by the meter manufacturer and to comply with local and national regulations on energy meter calibration.
- Display: The customer should have detailed information on the meter display. This display is needed to show energy consumption (in kWh) in real time, the current cost of energy consumed based on the current electricity tariff, consumption history (e.g. for the previous day or week), alerts and notifications, power quality information such as voltage, frequency, current to inform the user about the stability of the electricity network.
- Synchronization: Synchronization of a smart meter refers to the coordination of the meter's internal clock with an accurate time source, such as a time server, to ensure the accuracy of the timestamps of the data recorded by the meter. This enables utility providers and power system operators to make informed decisions based on temporally accurate and reliable data.
- Two-way communication: Smart meters are generally equipped with two-way communication capabilities. This means they can not only send data to electricity suppliers, but also receive instructions or updates from the network, facilitating dynamic network management [22-23].
- Fault detection and resolution: smart meters can detect network anomalies such as power outages or equipment failures. This information can be rapidly transmitted to network operators, enabling faster response and more effective resolution [24-25].
- Integration of renewable energies (RE): introducing RE into the smart grid is crucial; smart meters can help monitor and manage energy production from RE sources such as solar and wind power [26]. In short, the smart meter plays a crucial role in the smart grid infrastructure, communicating with a central point called the data concentrator.

2.2 Data concentrator

A data concentrator in the smart grid is an essential element of the grid management and control infrastructure. It is a central point where data from meters and distribution sensors is collected, aggregated and analyzed [27]. It provides a centralized platform for:

- Data collection: The data concentrator gathers all the data from the smart grid's various equipment and devices.
- Data aggregation: once collected, data is aggregated to provide a complete overview of the network, giving operators a global view of the situation.
- Data analysis: Aggregated data is analyzed to detect anomalies, trends and patterns, facilitating decision-making to optimize network performance, improve energy efficiency and anticipate potential problems.
- Communication: The data concentrator facilitates two-way communication between the various network elements, enabling efficient coordination and control of network transactions [28].

2.3 Data management system This system is a software platform designed to process, store and analyze data from concentrators or smart meters, as well as end-user application databases. These systems are essential for utilities and energy suppliers to manage power grids efficiently and provide customers with optimized services. In such a system, data must be stored securely and scalably [29]. This task requires robust, scalable databases with high availability mechanisms and data integrity. Given the sensitivity of data, such as customer consumption data, security is paramount. Systems must implement mechanisms to protect data against unauthorized access, tampering and leakage. This data is used in other systems, such as billing systems and demand management systems [30].

2.4 Communication system

Standard two-way communication is an essential element of the Advanced Metering Infrastructure (AMI). Given the large number of meters installed, the communication network must enable various network elements to communicate with each other to collect data, monitor and control equipment, and respond to energy demand management in an efficient manner [31]. There are several communication topologies for smart grids. The most widespread architecture is that which collects data from groups of meters and transmits them to concentrators. This communication architecture involves smart meters measuring energy consumption and transmitting this data to concentrators via local networks. The concentrators aggregate and pre-process this data before sending it to the centralized control center via medium- or long-range networks. The centralized control center analyzes the data received to optimize management of the energy network and send commands to concentrators and meters where necessary.

These concentrators act as local collection points, aggregating data from meters located in the same geographical area. The data aggregated at concentrator level will be transmitted to the central server via a large-scale communications network. In fact, there are several communication media or technologies available for implementing this system: power line communication (PLC), broadband over power lines (BPL), Lora, WiMax, cellular networks such as 4G LTE, GSM/GPRS, Bluetooth,
Zigbee, Peer to Peer (P2P) and others [32]. By combining these technologies, smart networks can benefit from diversified solutions that meet different needs in terms of coverage, bandwidth, energy consumption, cost, etc.

2.4.1 Power Line Communication Using power lines, PLC enables communication between electrical network equipment such as meters, control devices and sensors to transmit data to the AMI. Communications take place between devices such as home electronics, meters, hubs and the central server. This technology is advantageous because it uses the infrastructure [33]. Although PLC communication offers several advantages in Smart Grids, it also has certain limitations, such as sensitivity to electromagnetic interfaces, signal attenuation, data loss and limited bandwidth [34]. These challenges are related to household appliances, the poor quality of certain cables and external sources.

- (2G/3G/4G/5G): provide wireless connectivity for remote devices. It offers extensive coverage and sufficient bandwidth for high-speed applications. It also enables the transmission of safety-critical data such as emergency alerts, fault notifications and extreme metrological information [35]. Newer cellular networks, notably 4G and 5G, offer shorter latency times, which is crucial for Smart Grid applications requiring rapid response, such as real-time network monitoring [36]. Although 4G and 5G networks offer higher data rates than their predecessors, they can still encounter bandwidth limitations when supporting large numbers of devices and data in Smart Grid networks [37].

- GSM (Global system for mobile): The use of GSM provides a wireless communication method for data transmission between meters and the control centers of service providers [38]. Smart meters equipped with GSM modules can transmit electricity consumption readings to utility providers at regular intervals [39]. They can also receive remote control commands via sms or voice calls. However, GSM generally has lower data rates than GPRS (General Packet Radio Service), which may limit its ability to transmit large volume of data or support advanced applications [40].
- GPRS (General Packet Radio Service): GPRS is a wireless technology that extends the functionality of GSM, enabling packet data transfer and providing Internet connectivity for mobile devices and remote equipment [41]. In the context of smart grids, GPRS is often used to establish two-way communication between meters and energy management systems [42]. Meters equipped with a GPRS module can regularly transmit energy consumption readings to utility providers, enabling efficient management of electricity demand [43]. This module enables utilities to receive real-time data on the status of the power network, facilitating fault detection, load management and network optimization [44-45].

2.4.3 LoRa (Long Range)

This technology uses long-range radio frequencies to cover vast areas with little infrastructure. With low-energy technology, it is used to connect IoT devices at low data rates, even in rural or remote areas. Enabling reliable connectivity even in rural or remote areas [46]. This enables Smart Grid devices, such as smart meters and network sensors, to stay connected even over long distances [47]. LoRa technology is economical to deploy and operate, making it an attractive option for largescale Smart Grid deployments [48]. Hardware and infrastructure costs are generally lower than other wireless communication technologies. LoRa is able to penetrate physical obstacles such as buildings, walls and natural barriers, improving communication reliability in complex environments [49]. Nevertheless, while this technology offers many advantages for Smart Grid applications, it has some potential limitations in terms of limited data throughput, latency, radio interference, capacity limitations, the need for dedicated infrastructure, network management complexity and technological evolution [50].

2.4.4 The IEEE.16 Group

The IEEE.16 group, commonly known as WiMax, is a wireless technology for metropolitan area networks that was initially presented as an alternative to other communication technologies such as WiFi and 4G [51]. In particular, IEEE.16g aims to provide specific requirements for wireless communication systems for smart grids. It covers aspects such as quality of service (QoS), security, spectrum management and support for remote control applications in the energy domain [52]. IEEE.16s can also be used in the context of smart grids to provide high-speed connectivity to fixed devices such as smart meters and power grid monitoring devices [53]. These standards thus facilitate applications such as smart meter remote reading, real-time power grid monitoring, load management, renewable energy coordination and other functions critical to power grid modernization. However, this standard has certain limitations that may diminish its effectiveness in the specific context of the smart grid [54]. For example, the deployment of a WiMax network may require significant investment in infrastructure, including the installation of transmission antennas and base stations [55].

2.5 Standards and Protocols

Several standards are used in smart grid design to guarantee the interoperability, safety and reliability of energy management systems [56]. The majority of previous articles focus on the crucial standards and protocols of a specific domain [57]. On the other hand, there are a limited number of publications providing a comprehensive study encompassing all aspects of the smart grid, e.g. smart metering, substation automation, demand response, cybersecurity, electric vehicles, distributed resources, wide-area control and monitoring.

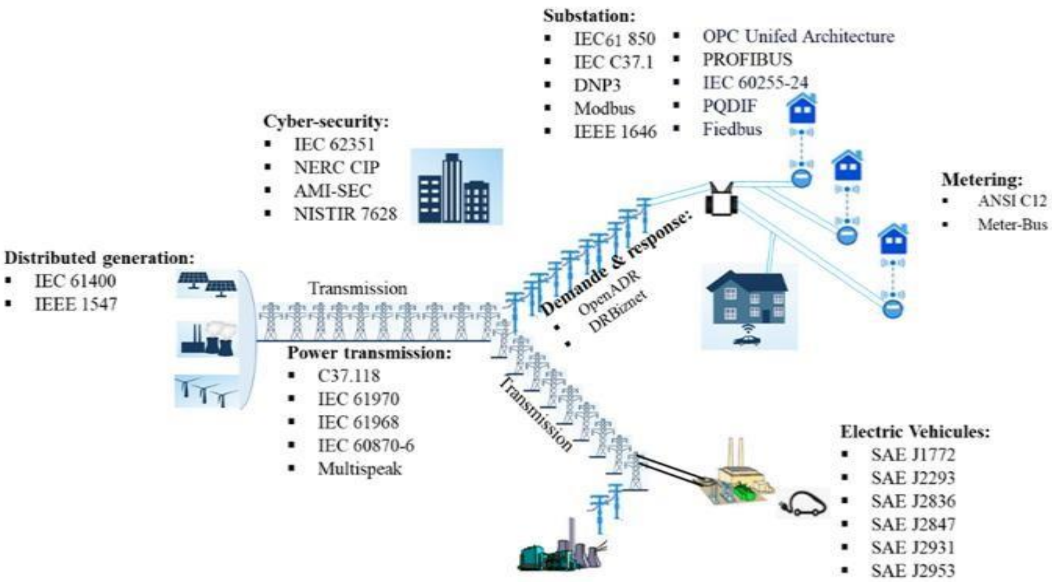

Fig.1, Smartgrid standards and protocols

2.5.1 Metering

- ANSI C12 is a series of standards developed by the American National Standard Institute (ANSI) for the measurement of electricity [58]. The ANSI C12 series: ANSI C12.18, 12.19, 12.20, 12.21, 12.22, 12.27 defines the protocol for metering applications, specifies requirements and guidelines for electricity meters and other metering devices used in the electricity network [59].
- The Meter-Bus standard: Initially developed in Germany in the 1990s [60], M-Bus is now a European standard (EN 13757) and an international standard (ISO/IEC 61107). It is widely used for remote meter reading in utilities such as electricity and gas [61]. This standard is a robust and reliable communication protocol widely used in the field of energy measurement and management, offering an efficient solution for the remote reading and control of meters and associated devices such as actuators and sensors.

2.5.2 Substations

In power grid substations, several standards and protocols are used to enable efficient and secure electricity management. As an example, here are some of the key standards and protocols at smart grid substation levels [62].

- IEC 16850: This international standard defines communication protocols for the automation of electrical substations [63]. It specifies network and system communication in substations with the aim ofproviding interoperability between intelligent electronic devices (IEDs), enabling them to perform protection, monitoring, control and automation functions in substations [64].
- DNP3 (Distributed Network Protocol): is a communication protocol widely used in substations. It enables real-time monitoring and remote control of equipment, as well as data analysis and diagnostics. As an open communication protocol, DNP3 is generally used in SCADA systems to specify communication protocols between different components, i.e. between a SCADA master station and RTUs (Remote Terminal Units) [65-66].
- C37.1: C37.1 is a standard developed by the Institute of Electrical and Electronics Engineers (IEEE) that establishes standardized definitions and terms for electrical equipment used in power systems. It also covers network performance requirements related to reliability, maintainability, availability, safety, scalability and variability [67].
- Modbus: is an open serial communication system, a protocol often used in various applications, such as industrial/building automation, energy management, substation automation, etc. The Modbus protocol plays an essential role in the implementation and operation of smart grids, enabling communication between the various network components and facilitating the monitoring,

control and optimization of the entire electrical system [68].

- IEEE 1646, entitled "IEEE Standard for switching shunt power capacitors," is a standard issued by the Institute of Electrical and Electronics Engineers (IEEE) that provides recommendations and guidelines for switching parallel (shunt) power capacitors in electrical systems. It defines communication delays as the time spent in the network between applications running on two end systems, including processing and transmission delays [69].

2.5.3 Demand responses (DR) Demand response standards and protocols are essential to ensure the efficiency, reliability and safety of the power grid.

- OpenADR (Automated Demand Response) is a communication protocol providing a standardized information model in the field of demand response. The protocol is based on Web services, Web Service Definition Language (WSDL), SOAP and XML [70].
- DRBizNet is an IT platform developed by the Ministry of Energy of the Republic of Korea to facilitate the management and implementation of demand response programs in the energy sector [71]. It is a highly flexible, reliable and scalable platform for supporting DR applications. DRBizNet has a service-oriented architecture and provides a standardized Web services interface. It enables automatic notifications to customers, aggregators and distribution/grid operators, and triggers all types of intelligent load control devices [72].

2.5.4 Distributed generation

- IEEE 1547: This standard establishes the basic requirements for the connection and operation of distributed generation (DG) systems to the electrical grid. It covers aspects such as protection, synchronization, voltage control, etc. It addresses the physical and electrical interconnection and interoperability of distributed energy resources with electrical power systems, providing requirements for performance, operation, testing and safety [73].
- IEC 61400 is a series of international standards drawn up by the International Electrotechnical Commission (IEC), dealing with aspects of the design, manufacture, operation and maintenance of energy systems, particularly wind turbines [74].

In terms of cybersecurity for smart grids and power transmission systems, several standards and protocols such as IEC 62351, NERC CIP, NIST SP 800-82, NISTIR-7628, C37.118, IEC 61968, IEC 61970, IEC 61970-6 are relevant to ensure data protection, synchronization of measurement systems, standardization of interfaces between different information systems and infrastructures [75-76-77-78-79-80].

3 Some of the Smart Meters deployed around the world

Today, new players are emerging in the smart meter field as technology evolves and new markets develop. According to the American Smart Meter Manufacturers Association, there are several major manufacturers deploying smart meters worldwide. These manufacturers produce a range of smart meters for different applications, and operate on a global scale to meet the needs of power companies, utilities and governments. Their meters comply with ANSI and/or IEC standards [81]. A list of smart meter models from these manufacturers, currently in use by various utilities, is given in the table.

Table 2, Some of the Smart Meters deployed around the world.

Providers	TECHNOLOGIES	Models Smart Meter	User countries [89]
ECHELON [82]	PCL, GSM	EM-502XX ANSI meter IEC Single Phase Smart Meter, IEC Poly Phase Smart	▪ Italia: 30Millions by Enel ▪ Austria and Central Europe: by Kapsch Smart Energy ▪ Brazil: 3400 in collaboration with ELO Sistemas Electronicos ▪ Norway, Sweden, …
GE Energy [83]	PCL, GSM, GPRS, ZigBee	ANSI: GE kV2c, GE kV2e, GE kV2m, GE I-210 IEC : SGM3000, SGMM100.	▪ USA ▪ Canada ▪ Italia ▪ India, Brazil,
Honeywell (ex Elster) [84]	PCL, GPRS, ZigBee	Alpha A1800, A3 Alpha, AS1440, AS3000/AS3500, Rex2	▪ Netherlands ▪ United Kingdom ▪ France
Landis + Gyr [85]	PCL, GSM, GPRS, RF Technology	E130 FOCUS, E350/E650 Series, Focus AX, ZMD300, Gridstream.	▪ Netherlands ▪ Finland ▪ India ▪ Japan ▪ Spain, New Zealand
Itron [86]	GPRS, ZigBee, Wifi, Wimax, CDMA	CENTRON, OpenWay, Gallus, Sentinel, SOLID-STATE, Solar Meter.	▪ Benin, ▪ South Africa, ▪ Tunisia
SENSUS [87]	RF Mesh, ZigBee	ICON A ICON APX	▪ Saint-Martin Island
Siemens [88]	DPN3 IP, Modbus TCP	SICAM Q, Q100, Q200.	▪ France (Linky) ▪ Germany ▪ India ▪ United Arab Emirates
Schneider Electric [88]	DPN3 IP, Modbus TCP	ION6200, ION7400, PowerLogic PM8000 Series, Easergy T300.	▪ Switzerland ▪ Francophone Africa

In recent years, the growing demand for smarter, more efficient energy solutions has led to an increase in the production of smart meters by many companies around the world. These smart meters are designed to offer advanced functionalities such as accurate measurement of energy consumption, two-way communication, real-time monitoring and remote energy management. Depending on their different applications and voltage ratings, these meters are classified into two types of application: residential smart meters and industrial smart meters. Below, we describe some of the smart meters currently on the market. General Electric (GE)

GE offers a range of meters designed for residential and industrial applications, complying with both ANSI (American National Standard Institute) and IEC (International Electronic Commission) standards.

- For ANSI residential meters, we offer the I-210 series and the GE KV2c series. The I-210 series consists of single-phase electronic meters in three models: I-210 +c; I-210+ and I-210. This series covers almost all metering needs, from the invention of energy-only electronic meters to the emergence of highly flexible smart meters. This series offers a number of advantages, such as Plugand-Play AMR/AMI functionality, and several communications technologies linked to AMI systems for real-time data transmission [82].
- For ANSI standard industrial meters, we offer the KV2c family, comprising two models, KV2c and KV2c+. This family offers key benefits such as AMR/AMI Plug-and-Play designed to adapt to RF, PLC, GSM, GPRS, Ethernet. It also features functions for recording voltage, current, energy, apparent power, reactive power, power distortion, power factor, etc.
- For IEC smart meters, the SGM3000 series is the most popular meter series with advanced features. It contains eight series meters designed for both residential and commercial demand, including single-phase and polyphase meters. The SGM3000 suite offers key benefits such as improved energy efficiency from utility to home, extended relay and multi-element configurations for application flexibility [83].
- Itron smart meters are based on industry standards and offer unprecedented interval data storage, remote upgrading and configuration changes, and a gateway to consumer smart devices. They provide the two-way communications customers need to build their advanced metering infrastructure. For example, the Itron CENTRON OpenWay smart meter offers enhanced security and a reliable approach to data collection and communications between the smart meter and the network system [84]. Usage data processing and calculation takes place at the meter level, enabling utilities to exploit time-based tariffs, demand response and other smart grid applications. This type of meter offers distinctive features such as a license-free, bidirectional RF module, ZigBee communication for interfacing with home networks, and a remote service switch relay to support certain functionalities such as prepaid metering [85][86].
- Sensus supplies the ICON series of smart meters, comprising the ICON A and ICON APX models, enabling residential and industrial consumers to deliver accurate, reliable results. In combination with the advanced FlexNet meter infrastructure, utilities can install and upgrade the ICON meter's electricity management platform for significant efficiency [87]. ICON meters offer a reliable, simple system with a number of key benefits: power quality reporting, accuracy that exceeds ANSI C12.20, inversion resistance, advanced, user-friendly configuration software [88].

4 Conclusion

In this article we have reviewed and discussed the evolution of the smart energy metering system; the meters, the data management system, the communication system, communications standards and protocols. Examination of various smart metering system solutions indicates that most solutions are versatile and have many common functionalities; however, implementation of these functionalities depends on utility requirements. Among the various functionalities, real-time two-way communication and the data management system proved to be the two key features, benefiting both consumers and utilities. Interoperability between utilities requires that meters be designed to collect data according to certain standards and protocols. We have presented a smart grid architecture by examining the standards and protocols. We have presented a smart grid architecture, examining the standards and protocols that ensure the interoperability, safety and reliability of energy management systems. Furthermore, as the CEER (Council of European Energy Regulators), ANSI and IEC point out, despite many years of standards evaluation, the world is still facing a difficult situation due to the lack of a common standard for smart meter interoperability. This situation complicates the involvement of multinationals in certain markets, due to the imposition of local manufacturing standards. Data protection and security issues also need to be addressed. Not all technologies offer the same levels of security, and this needs to be addressed. A precise framework needs to be assessed, and the protection of personal data must remain a central concern in the development of standards and protocols. What's more, most communication networks use low to medium bandwidths, so high levels of data traffic result in an inefficient system. This communications system can also be subject to interference: wireless communications are subject to interference from transmitting devices in the environment. Despite the savings resulting from smart metering systems, most utilities are becoming reluctant to invest in the new systems on the market. For example, the implementation and maintenance costs of smart metering systems are often high, which may discourage some utilities from adopting them. In addition to the high cost, smart metering systems require a good technical understanding and specific skills for their installation and (technical complexity). This can be an obstacle for companies that do not have these skills in-house.

AI tools for text enhancement

Grammarly: To improve article quality by detecting and correcting grammatical, stylistic and structural errors. Reformulate expressions to create an alternative version.

Perplexity: To explore recent trends and obtain references from recent, properly sourced and validated academic publications.

Deepl: To translate some texts in the article.

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