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Energy meters evolution in smart grids: A review

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ABSTRACT

Intelligent Energy Networks are comprised of devices capable of fulfilling their functions in an energy-efficient fashion and with communication and remote control capabilities. Therefore, some of these devices, such as smart energy meters, become attractive for use in the power generation and distribution industry, achieving the vision of Smart Grids. However, many are the challenges that need to be overcome in order to reach a fully-functional and security-aware smart grid. Providing measurement, control, communication, power, display, and synchronization capabilities shall be no easy task for smart meters. In this context, this paper elaborates on a detailed description of the main functionalities that smart meters must provide, along with the analysis of existing solutions that make use of smart meters for smart grids. Moreover, open challenges in the topic are identified and discussed. By the end of this research piece, the reader should be able to have a detailed view of the capabilities already offered by smart meters and the ones they will have available in order to tackle the challenges smart grids present.

1. Introduction

Modern network applications started leaning towards energy efficiency as more battery-powered equipment join networks. Therefore, the concept of Intelligent Energy Networks (IENs) has been coined to group research efforts aimed an efficient use of networked devices energy. Along with IENs come Smart Grids (SGs), which propose to handle power supply and usage or consumption more efficiently by integrating communication and control capabilities to a system previously meant to only generate and distribute power. This means adding intelligence to the power generation and distribution system, *i.e.*, making the power grid an IEN. Even though several similar terms are found in the literature, such as inter-grid or intelli-grid, the SG denomination has gained more popularity and is most widely accepted. Since energy demand is also ever-increasing, IENs have been forced to evolve quickly in order to fulfill strict requirements in a robust, flexible, environmental-friendly, and cost-effective manner (Li et al., Zhu; Fang et al., 2012).

New challenges appear on power management and demand control as energy requirements are on the rise. Hence, SG develops side by side with power electronics, sensing, and measurement technologies, enabling the grid to embody more intelligence through communication management and smart control (Li et al., 2010). Such capabilities are possible when the aforementioned technologies are combined into smart energy meters, the building blocks of IENs. By monitoring and controlling appliances, smart meters cooperate via intercommunication and sharing information among service providers and consumers. Thus, it is possible to meet users expectations with reduced costs for costs — clearly a win-win scenario (Sun et al., 2016; Benzi et al., 2011).

The simplistic nature of the conventional grid — unidirectional communication, from meters to companies, and energy flow, from generators to consumers — renders the system limited. Lacking flexibility prevents the grid from reacting to intermittent failures

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and from making the most out of opportunities, such as redirecting a surplus of power in a sector of the system to a place in need. Therefore, it is inferable that the availability of smart meters can provide benefits to the whole smart grid both by handling failures and by making good use of favorable circumstances. In summary, the ability of exchanging information, *i.e.*, bidirectional communication is clearly the main feature that smart meters bring into IENs (Sun et al., 2016; Lo and Ansari, 2012).

Elaborating on the key benefits provided by smart meters, three main improvements are expected (Gungor et al., 2011, 2012): *i*)the availability of consumption information to users enables them to adapt their power consumption (electricity consumption pattern) in order to achieve financial incentives or improve the sustainability and energy saving; *ii*) the ability to assess and control meters remotely allows service providers to reduce operational costs and human error from the process, also increasing the system security; and *iii*) the system reduces waste of energy since it can be automated to react to power shortages, failures, and excesses, redirecting energy to where it is needed the most. Furthermore, smart meters enable homes to become smart environments (Kabalci, 2016; Siano, 2014). It is not only possible monitoring power consumption from mobile devices on the spot, but also a management system can access data to perform consumption optimization. An advanced metering infrastructure (AMI) takes place by combining smart meters to home area networks (HANs), wide area networks (WANs), and neighborhood area networks (NANs), providing several improvements over the previous automated meter reading (AMR) and automatic meter management (AMM) technologies (Li et al., Zhu; Gungor et al., 2011).

Reaction to network faults is also a new ability granted to SGs by smart sensors. This capability enables smart protection, which in turn improves the network overall reliability, makes faults predictions possible, allows the isolation of unrecoverable faults, and provides enhanced security to the network. However, in order to achieve such benefits, measurement and monitoring systems as well as the communication between them become crucial. Information about all network aspects needs to be readily available for effective prevention and recovery. Some examples of important measurements are the amplitudes of voltages and currents across the grid, thermal variations, and also transient and steady state parameters. Such knowledge can be provided by phasor measurement units, smart meters, and other sensor networks, all working together to prevent faults when possible or to allow timely reaction if needed (Fang et al., 2012; Gungor et al., 2013; Gao et al., 2012).

Fig. 1 shows a thorough smart grid architecture. It is comprised by distributed generation (DG) sources — solar power, fossil fuel, wind, and other renewable energy resources; loads, such as electric vehicles, smart homes, intelligent buildings, among others; and a data center, which is responsible for managing the whole infrastructure. Such architecture should fulfill system requirements of privacy and security, reliability, sustainability, Quality of Service (QoS), and coverage. Those needs are interrelated as all of them contribute to transmitting data securely (Fadel et al., 2015). In order to shed light on the upcoming features and possible issues of smart meters in SGs, this work proposes a detailed review and evolution of smart energy meters and the main contributions are the following:

- Reviews the current developments and deployments of smart energy meters;
- Analyzes the main capabilities and applications of smart energy meters;
- Discusses the prospects and requirements for interoperation of various energy networks and identify open issues for further research in the topic.

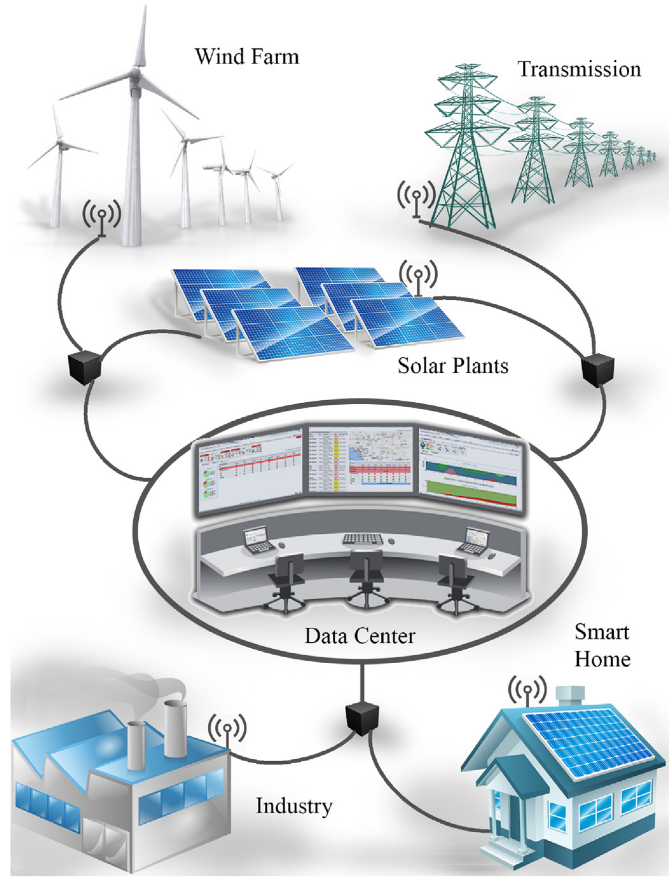

Fig. 1. A smart grid perspective with all its main components.

The remainder of the work is organized as follows. Section II brings the background concepts along with the related work. In Section III, the main types of smart meters and their capabilities are extensively analyzed. Current solutions that make use of smart meters are presented in Section IV. Section V discusses open challenges regarding the use of smart meters in smart grids and Section VI presents the main conclusions of this survey.

2. Background

Electrical grids were first introduced in the 1800s, but their wide adoption in developed countries only came around the 1960s. By that time, power grids reached considerable penetration and capacities, and enough quality and reliability. Power was mainly generated by fossil fuel, hydroelectric, and nuclear plants, all of which achieved great technical and economical standards for the time. Power consumption increased with time, especially in the last decades of the 20th century, when the entertainment industry also grew considerably, and when heat and ventilation switched to electrical power supplies. The high rise on consumption also brought high utilization variability. More power plants were required to handle energy supply around peak hours in order to prevent voltage oscillations and low quality of energy supply, whereas power plants became idle away from the peak periods. Therefore, electricity providers implemented Demand Side Management (DSM) in order to improve the energy system at the side of consumption through policies that alter the use and variety of modes of energy consumption, such as load shifting, peak clipping, valley filling and so forth (Siano, 2014; Gungor et al., 2011).

The power industry experimented high technological advances on the 21st century. Information and communication technologies, and, eventually, smart sensors, were integrated into the power grid. Hence, the Smart Grid vision became reality. New features eliminated the need for precise consumption measurement, enabling adaptive billing mechanisms to be deployed. Furthermore, advances reached the power generation side — wind, solar, tidal, and geothermal power added energy to the system, avoiding environmental harm in contrast with previous forms of energy generation. The availability of different kinds of power decentralized generation, which also contributed to the supply of power and reduction of power distribution costs. Finally, new technologies, especially communication, made information on production and consumption available, ending up in efficiency and reliability gains (Momoh, 2009; Wang et al., 2018).

The evolution of the power grid impacted several fields positively. On the infrastructure side, the use of smart meters and the integration of communication networks into all infrastructure levels allowed the creation of Meter Data Management Systems (MDMS), which move and store data for software application platforms and interfaces. On the user side, smart homes became integrated to microgrids. Through the use of devices capable of monitoring energy, consumption-control sensors, such as lighting sensors, and remotely-controlled SMs, energy efficiency can be added to an extra comfort provided by such homes. Even in those cases, security and reliability are not left aside since wired and wireless communication with a master controller provide such capabilities (Farhangi).

Inside homes, several measurement devices monitor energy consumption. They communicate with a data center, which can make information available for both consumers and providers. Therefore, users can monitor their consumption and configure their appliances in order to keep consumption under control, while providers can manage the systems resources to balance the load on the grid, rerouting power to places that need, especially where Distributed Energy Resources (DER) are available (Zhang et al., 2010; Borazjani et al., 2014).

Regarding smart homes, a user can deploy more meters as requirements change for monitoring the premises. New appliances, rooms, or any kind of renovation may change the house layout, so, in order to maintain home automation, sensors need to be redeployed. In any case, sensors need to present a minimal set of both metrology and communication capabilities (Taneja et al., 2010; Planas et al., 2013; Zhang et al., 2010), as discussed below. At least, meters should be able to accurately measure some monitored quantity, *i.e.*, meters must be capable for performing quantitative measurements. Also, in order to compensate for system variations, control and calibration features need to be present. Regarding communications, the least expected of a smart meter is the capability for transmitting data and receiving commands and firmware upgrades. On the power management side, metering devices should be operational even in the event of power shortages. Moreover, it is expected that meters would be able to inform users about the quantities measured in order to allow them to take action and adjust operation and, for that, some display could be used. Finally, synchronization is expected from the meters in order to communicate reliably with central nodes.

Based on the above-mentioned functionalities, it can be seen that the following features are paramount for the efficient implementation of smart grids: time-based pricing; availability of consumption data for consumers and providers; failure and outage notification; remote commands capability; load limiting for demand response; power quality monitoring; energy theft detection; cooperation with other intelligent devices; and reduced hazardous emissions through efficient power consumption. Now, focusing only on the communication requirements for devices, meters are required to send data and receive commands. Therefore, in order to allow the system to work correctly in AMI, a communication network needs to be in place. The large amount of users and meters give rise to the need of a reliable communication system, capable of moving substantial volumes of data. Consequently, diligent planning of the aspects enumerated next are required when designing such network: high capacity; data protection, authenticity, and confidentiality; consumption data availability; providing the operational status of the grid; cost-effectiveness; modernity to provide features beyond AMI requirements; and expansion capability (Depuru et al., 2011; Galli et al., 2010, 2011).

Even though, theoretically, any known topology could be applied to SGs, the most common is the two-tiered star — groups of meters send data to a local concentrator which forwards them to servers via backhaul for storage and processing, as well as for billing purposes. Hence, once more the importance of the grid communication capabilities is highlighted. The large amounts of data through backhaul links are due to the integration of technology and applications that can be used for analysis, control, and real-time actions such as dynamic pricing. Therefore, a study of available communication technologies is called for in order to determine the most suitable one for SG scenarios (Gungor et al., 2010; Roche et al., 2010; Laverty et al., 2010). Both wired and wireless technologies could be used. On one hand, the former provides higher transmission capacity and reaches longer distances. On the other, the latter may be cheaper, depending on the case, and can reach difficult areas. Therefore, several wired and wireless technologies are described below in order to attempt to reach a conclusion on the best technology available for SGs.

One of the candidates is Bluetooth. It is a low-cost, low-consumption, short-range (10 m) wireless communication technology generally used on Home Area Networks (HANs). It uses the 2.45 GHz frequency range and provides a bandwidth of up to 3 Mbps. This technology is present on most smartphones and could be used for wireless local access for Smart Meters and other SG components (Cecilia and Sudarsanan, 2016).

Another low-cost, low-consumption wireless technology, but ranging about 100 m, is ZigBee. It is already used by home-appliances communication and smart lighting, also suitable for smart meter communication. It can operate on the 868 MHz, 915 MHz, or 2.4 GHz ranges, with data rates ranging from 20 to 250 kbps. There are some variations of ZigBee, such as ZigBee Smart Energy Profile (SEP), Z-Wave, among others. In some of them, wireless mesh networks can be created by turning each network node into a wireless router. Therefore, more nodes in the network can provide extended ranges (Cecilia and Sudarsanan, 2016; Yi et al., 2011).

Wi-Fi is also for short-range communication, up to 250 m, but it does not comply with low-energy consumption. This technology can operate on the 2.4 or 5 GHz frequency bands, featuring data rates of up to 600 Mbps. In general, Wi-Fi is used for Internet access distribution (Cecilia and Sudarsanan, 2016).

Cellular networks can also provide large coverage with considerable data rates. This technology could be used for connecting Smart Meters, far nodes, and other Smart Elements. Existing LTE networks provide up to 100 Mbps downlink connections for entire urban areas. It could be used to create WANs for Smart Grids (Gungor et al., 2011; Cecilia and Sudarsanan, 2016).

One logical technology for power grids would be Powerline Communication (PLC). This is a wired technology that makes use of existing power lines for transmission at up to 3 Mbps. Even though power lines are noisy, which imposes challenges for implementation of communication over them, they are widespread, which reduces installation costs. PLCs are already used on SGs to create HANs with data rates of 20 kbps (Gungor et al., 2011).

Finally, Digital Subscriber Line (DSL)/Optical Fiber are wired technologies that feature high-speed data transmission over the voice telephony network or optical fibers. They can be used to connect SG elements in HANs and WANs, offering advantages for power providers due to its relatively low cost and its high bandwidth. Furthermore, these technologies could be used to interconnect Smart Control Centers (Cecilia and Sudarsanan, 2016). In summary, these are the most promising available technologies for these networks.

3. Main types of smart meters

The electromechanical watt-hour meter is the most common type of electrical meter. The power passing through the meter feeds two induction coils, which produce a magnetic flux on a conductive metal disc. In turn, the disc rotates at a speed proportional to the power flux, and the disc revolutions are counted in order to allow billing for the consumed power. The reliability of such measurement devices granted them widespread use, even though they provide no additional features. However, new requirements for monitoring and controlling the power grid created the need for improved meters. Therefore, electronic meters offering advanced functions started to replace electromechanical ones (Sun et al., 2016; Hambley, 2011).

Electronic meters have been developed based on Digital Micro Technology (DMT), sparing meters from the previously bulky moving parts. As they evolved, more functionalities have been added making them "smarter", which provided benefits for both consumers and providers — it was now automatically possible for the user to know about its consumption and for the provider to control production, *i.e.*, no human energy readers were necessary in the process (Sun et al., 2016; Hambley, 2011). Also, remote control of the meters allowed providers to deploy real-time pricing (RTP) and load leveling, making the power delivery process more efficient (Sun et al., 2016; Zhang et al., 2013). Even further, the evolution of meters granted them modulation, which means that functionalities can be added to electronic meters by plugging in additional modules (Müller et al., 2012). The Fig. 2 shows the evolution of the development versus the functionalities of the energy meter.

From a basic meter module, smart meters can be enhanced by other modules. Allowing other modules to be added to an open structure can improve innovation, through an unlimited number of modules combination, and also make deployment and interoperation easier. Different meters could be based on different power flow meters, but using the same communication, storage, and processing modules. Even though plenty flexibility is added to smart meters by the use of modules, common add-ons are added for extra storage, alarms, and additional communication interfaces (Gungor et al., 2011; Gao et al., 2012).

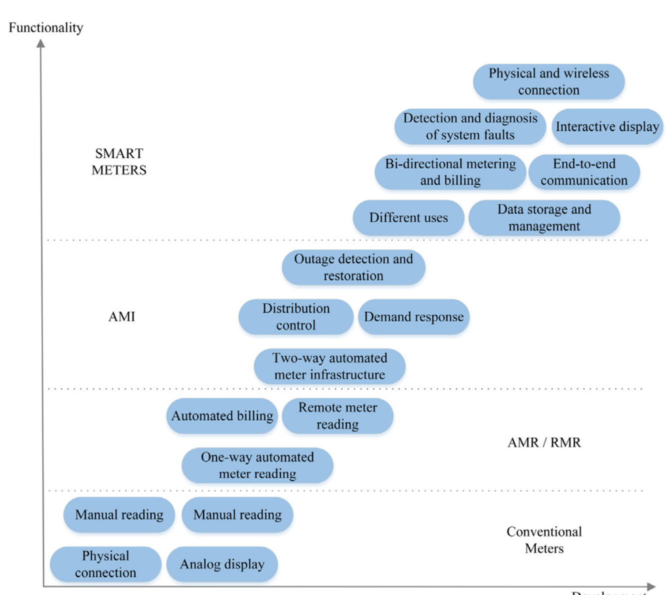

Fig. 2. Evolution of the development *versus* the functionalities of energy meters.

From modularization, electronic meters could start integrating intelligence to the system. The first generation of smart meters could report consumption back to the power provider, achieving AMR and remote meter reading (RMR). Therefore, providers could read data from long distances without human interaction (Sun et al., 2016; Bidram and Davoudi, 2012; Bhaskara and Chowdhury, 2012). Then, it provides invested in AMI in order to manage demand, laying the basis for IENs (Palensky and Dietrich, 2011).

Activity involving monitoring, overall data on the network, and monitoring result in a far-reaching part of the information exchange structure. SGs came to operation allying those substructures with the communication infrastructure and the advances of electronic parts for handling power control. Moreover, such advances granted SGs additional functions (Palensky and Dietrich, 2011; Bharothu et al., 2014): home devices control and monitoring; bidirectional communication; management of demand and load; two-way metering and billing; discovery of system defects; data storage and management; power extortion detection; smart cities evolution; security improvement; and emission control (Bhaskara and Chowdhury, 2012; Kilbourne and Bender, 2010).

Albeit conventional meters could only measure and display total consumption, smart meters allow remote measurement in shorter intervals, *e.g.*, 15 min, with more advanced ones capable of providing measurements even every minute. Therefore, energy providers can save money by moving the operator who makes measurements to other functions. Moreover, it became possible to profile users from the available data. It is feasible to estimate with high accuracy how many occupants a household shelters, how long each occupant stays home, what kind of appliances are there, the presence of security and alarm systems, and even special conditions like medical emergencies and the arrival of a newborn (Liu et al., 2012; Khurana et al., Frincke).

It has been shown in the literature that households behaviors can be easily estimated, without aid of refined tools or algorithms. Murrill et al. (2012) have shown from as little data as can be gathered in 15 min, major appliances use can be determined. Also, Molina-Markham et al. (2010) prove that current statistical methods are enough to identify usage from AMI data without need of appliances signatures or previous training. Both from the new meters functions and from the availability of data provided by their two-way communication, smart electricity meters can take the provision of electricity to the next level. Such improvements granted many new uses for smart meters, such as the ones discussed in the next subsections.

3.1. Periodic and precise metering

The basic function of meters is performing regular and precise measurement of a power flow. It is the very functionality that enables IENs to reduce energy consumption by gathering information on the energy supply and demand. However, previous daily measurements are not enough. Data collection is required more frequently but this does not pose a challenge for smart meters. Moreover, several flows can be measured simultaneously, which makes possible the use of different power sources, such as wind turbines and solar cells in very reduced scale (Joshi and PANDYA, 2013).

Non-linear loads joining the grid, legislation, and reliability calls for pervasive monitoring of the system. Monitoring loads throughout the whole infrastructure grants providers the ability to detect consumption fluctuations and their effects on the overall energy quality. Thus, it is possible to charge faulty customers for their misuse of the power grid. This is easily possible with a widespread measurement infrastructure — it becomes possible to detect the position of faults, allowing a central to issue commands to meters for taking an action. Moreover, quickly finding faults over the long distance transmission lines can both reduce outage times and economical losses for providers (Muscas et al., 2015).

SGs operation depend on the energy management system (EMS), along with its subsystems for monitoring. The EMS can be centralized — dependent on algorithms and software — or decentralized — comprised of logical applications cooperating throughout the system. Some responsibilities of EMSs are measuring and estimating active and reactive power, load demands, overloads, losses, voltage drops, and overvoltages that occur on the system. However, the plethora of available information can generate measurement ambiguities, which affects the accuracy and reliability of EMSs during measurement cycles. Therefore, intelligence is needed on the system not only on the measurement side, but also at the information processing side (Muscas et al., 2015; Moreno-Munoz et al., 2013).

Smart measurement in SGs is performed by the smart meters (SMs) and, in order to provide real-time energy consumption rates to users and providers, these devices must gather data on the instantaneous voltage, phase, and frequency for each customer's installations. Typical smart systems, such as the one depicted in Fig. 3, consist of information exchange and measurement infrastructures. The former enables bidirectional data flow providing data on customers and providers for each end of the system, while the latter is comprised of an AMR framework, a pricing control mechanism, and an infrastructure for managing data (Kabalci, 2016; Depuru et al., 2011). Moreover, the communication infrastructure is comprised by a network connection and control infrastructure, which allows meters to receive commands and reach control centers. In addition to these two parts, SMs comprise a power supply, a control, an indicator, an encoding, and a timing module (Yang et al., 2014).

The advantages of big data can be leveraged into smart grids in order to match energy consumption and generation. A cloud-based framework for big data computing fit for smart grids is proposed in (Mayilvaganan and Sabitha, 2013), where the balance between power supply and customer demand is achieved through the analysis of historic weather data and customer consumption behavior. From the gathered data, it is possible to predict supply and demand, allowing suppliers to plan generation and billing accordingly. The work in (Ye et al., 2015) explores a similar idea, focusing on the billing part and informing users beforehand in order to influence their consumption behavior to match the predicted power generation capability of the system. And, in (Deng et al., 2015), authors extend the concept with a multiseller/multibuyer environment, indicating to users which utility company to buy energy from and how much to buy from each in order to balance demand and supply.

Along with the grid monitoring, interest also increased on the monitoring of the SMs themselves in order to provide better management and security to the system. Data gathered from SMs about their own operation can be used to prevent illegal use of the grid and the meters. Since bidirectional communication must be included to send commands to SMs, concerns about security and privacy rises. Malicious access is a possibility, therefore simulated scenarios, research, and cyber warfare practices are part of the effort to make SGs safer. Unauthorized access to SMs might lead to billing manipulation and other losses for providers, thus trusted software needs to be both inside the meters and on the access side in order to prevent it. The coined concept to encompass these security requirements is secure signal processing (SSP), which defines encryption strategies and security issues handling. In recent literature, propositions of privacy-preserving billing and secure that acquisition can be found to address some of the aforementioned issues (Erkin et al., 2013; Tan et al., 2013; Wigan, 2014; Kalogridis et al., 2014; Lagendijk et al., 2013).

3.2. Data storage and alarming

In the smart grid, wireless sensors, energy distribution equipment, and communication devices serving as interface with consumers will greatly increase the amount of generated data in the grid. In this data-driven scenario to come, it is required that the huge amount of data be processed and only meaningful content extracted in a timely manner in order to provide a useful decision-making process. Usually, computing capacity throughout the grid is not evenly distributed, which causes bottlenecks to appear when redirecting data. Therefore, since current technologies are not enough to process the anticipated plethora of generated data, it is expected that energy networks be able to extract features from the data efficiently (Hou et al.).

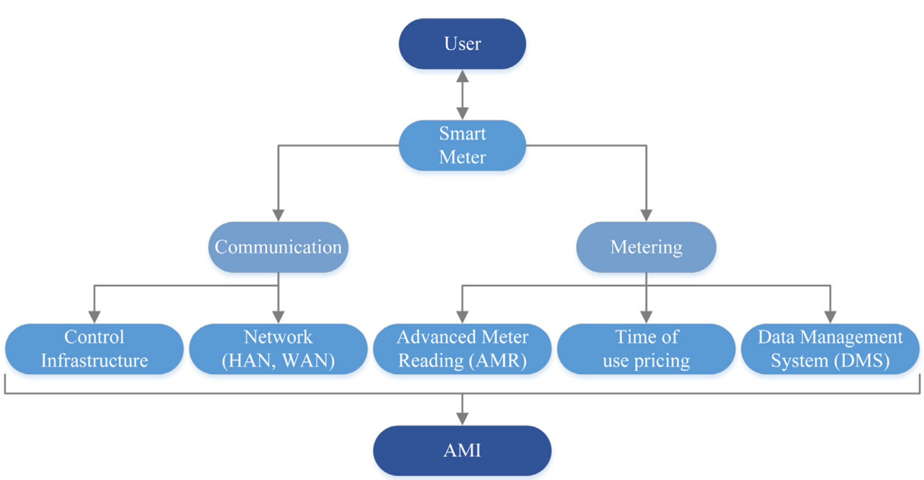

Fig. 3. Illustration of typical smart meter systems.

As a first attempt to extract data, solutions have proposed data correlation analysis and data fusion (Wang et al., 2014; Lu and Wen, 2014; He et al., 2017; Xu et al., 2017). However, most proposals assume the immediate use of extracted data in a single task. For instance, consider two separate tasks, such as electrical load prediction and voltage stability analysis, depend on a single dataset of meteorological data. Right now, this scenario is neglected, requiring extraction of the same meteorological data twice — once for each task. Clearly, the process is inefficient. Therefore, planning data extraction for multiple tasks, usually considered separately, such as fault/attack detection, demand response and power management (Hou et al.), would result in higher computing efficiency.

Related to periodic and precise metering, data storage and alarming is another desired function for SMs. Despite real-time information, stored data is also useful for energy providers and users to check the history of energy consumption. Along with consumption, billing and cost data can also be stored for further reference. Moreover, the ability to send alarms given programmed conditions is also useful for users, which can, for instance, take action to reduce consumption once a determined threshold is reached (Joshi and PANDYA, 2013; Choi et al., 2011).

Smart devices inside a household usually have displays that shows recorded data, alarming information, and other data. When connected to input devices, displays may also act as control centers, receiving commands from the user and acting upon them. However, displays are expensive and account for a great percentage of a SM cost (Gellings, 1022). Because of that, new ways of showing data to users are developed with the objective of cost reducing. For instance, some solutions use Web portals in order to convey consumption information to users. Since input devices are already present on computers and smartphones that access these Web portals, it is easy to implement alarming configurations, enabling users to have greater control over their own consumption. Even further, such alarms can fire e-mails, SMSs, or phone calls to reach users even when it is not connected through the Web (Choi et al., 2011).

3.3. Communication interfaces

In order to be categorized as an SM, a meter needs, at the least, metering and communication capabilities. This is why the main accomplishment of SGs is the use of AMI to measure, communicate, and analyze users consumption data. Bidirectional communication between meters and users, and meters and energy providers allows the latter to deliver better maintenance, to manage demand, and to plan expansion more efficiently while keeping users informed on their own consumption habits. Therefore, it is clear that with such data traffic, data management is crucial for generating reliable billing data (Zhou et al., 2012).

As previously stated, two-way communication is the main improvement of SMs over regular meters, making SGs possible. This functionality not only allows communication between the meters and users or providers, but also between users and providers, and even between users. Moreover, as also commented previously, the communication module is the key for SMs, transmitting and receiving data, but also capable of receiving instructions for specific actions (Gungor et al., 2011). However, the communication functionality should not prevent other SM modules from operating correctly in any case. Therefore, the communication module is independent, allowing the SM to perform measurements, generate alarms, and store data even when connection is loss. Of course, sharing data can be resumed when the connection is reestablished (Fadel et al., 2015).

Communication capabilities can be performed using wired and/or wireless connections. The advantages of wired over wireless ones are higher communication capacity, reliability, and security, which comes at the cost of higher infrastructure costs. A new concept that has been receiving attention lately is the Internet of Energy, which refers to energy networks that are able to communicate through the Internet (Fadel et al., 2015). Therefore, the advances of the Internet itself will benefit IENs, providing more communication capacity, which will lead to more advance functions and wider adoption of SMs. Furthermore, meters could present more than one communication interface, which directly affects their communication reliability. The advantages of several different technologies can be combined in order to meet communication requirements, keep infrastructure costs low, and achieve optimal levels of reliability and security (Fadel et al., 2015; Salvadori et al., 2013).

Roughly, SGs can be classified in three tiers: Home Area Networks (HANs), Neighborhood Area Networks (NANs), and Wide Area Networks (WANs), as depicted in Fig. 4 and described as follows:

(i) HAN: Connects devices inside homes, which can be electric vehicles, SMs, appliances, etc. From these devices, the

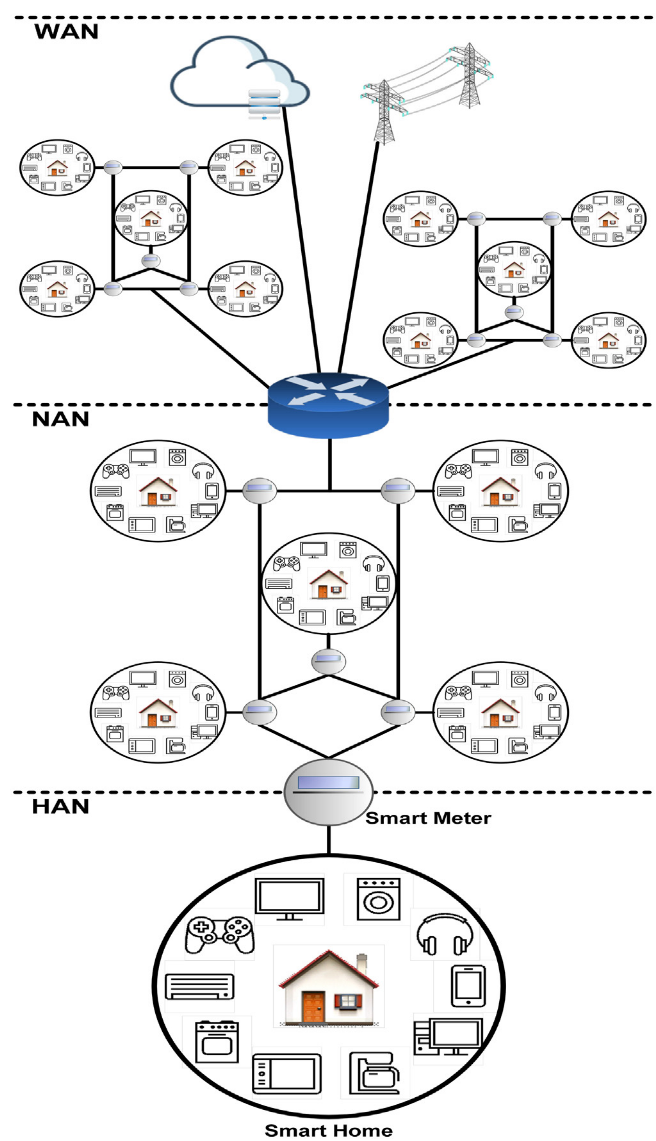

Fig. 4. Illustration of a basic smart grid network structure.

network needs data on consumption behavior and energy usage. In order to provide it without a great increase of consumption, low-energy communication technologies are needed. Examples include ZigBee, Bluetooth (low-energy), and Wi-Fi (Fadel et al., 2015).

(ii) NAN: Integrates data from several households and outdoors SMs in a small area using data collectors. Short-range communication technologies are suitable for this scenario, such as Wi-Fi and Mesh RF (Fadel et al., 2015).

(iii) WAN: Communicates with NANs and other devices in larger areas. It is able to harvest data from devices and data collectors, forwarding it to data centers. In order to cover such area, cellular networks (LTE/2G-3G systems), optical fiber and power line communication are cost-effective solutions (Fadel et al., 2015; Yigit et al., 2014; Sauter and Lobashov, 2011; Goldfisher and Tanabe, 1901; Yang et al., 2011).

3.4. Home devices control

Bidirectional communication allows SMs not only to send data measurements, but also receive remote control instructions. This capability allows users and providers to control consumption, yielding more effective use of the power system. As an example, end-users can disable home appliances such as air conditioning systems, drying machines, and heaters, at peak demand times, when billing is highest, turning them on again outside of those periods. Therefore, the providers goal of reducing system usage during peak periods will be closer than it would if only manual control of the appliances by the user were possible (Bharothu et al., 2014). These concepts are grouped under the denomination demand-side management. Reducing energy consumption during peak periods is also known as peak clipping, while increasing consumption on valley periods is called valley filling (Strbac, 2008).

Smart energy meters can be associated to several applications (Murray et al., 2018). An important one is detecting how elderly people use their home appliances and other devices in order to determine health variations before they become critical (Patrono et al., 2018). Smart meters have integrated so many new functions that these advances rendered them very different from their conventional predecessors. Moreover, other existing devices, such as home appliances have absorbed smart metering capabilities, which completely change the way meters are produced and deployed. Companies that produce meters do not seem interested on producing such complicated SM devices, mainly due to two issues — concerns about higher costs given new meters functions and keeping meters easy to use, which might become very complicated due to the plethora of available functions combinations. Eventually, IENs development might be steered by consumer's choices, not by industry (Salvadori et al., 2013; An).

3.5. Data management systems

The continuous high demand for power supply pushes governments and energy companies to keep the research effort on energy management efficiency. IoT can be an important tool for the management and control of devices connected to the energy grid, which is seen on pluggable electrical vehicles (PEV) stations for charging the user's credit card autonomously (Fachechi et al., 2015).

Conventional management systems use computer-based tools and procedures to identify, diagnose, and locate faults, provide feedback to customers, restore supply by dispatching repair teams, keep historical records of outages, calculate statistics on outages, etc. Given such set of capabilities in order to avoid and recover from failures, it is clear that outage management is decisive for the operation of a distributed network like power grids. Smart metering has become a trend in the utility industry due to the new data SMs can provide to management systems. For instance, meters can send last gasp messages, which are sent when devices lose their power supply and are about to shut down. Using these messages, fault diagnosis and location algorithms become more effective (Olivares et al., 2014; Wang et al., 2011).

The Meter Data Management System (MDMS) is the central module for management, which features analytical tools for processing data from other interconnected modules. The MDMS is responsible for validating, editing, and providing estimations based on AMI data, allowing for accuracy and to complete information from the customer to the management system. In current AMIs, measurement periods are about 15 min, which, on top of the large number of meters, adds up to the generation of huge amounts of data, in the order of terabytes. Such quantity of information is referred to as “Big Data”, requiring special tools for analysis and processing. Sources of data on SGs include AMI, where smart meters collect data on consumers' consumption; the Distribution Network Automation System, which gathers data to allow concurrent control of the whole network; minor proprietary systems connected to the power grid comprising storage units, scattered energy surpluses, and electric appliances; and Asset Management, that provides data exchange between the remote center and other components connected to the system (Zhou et al., 2016; Diamantoulakis et al., 2015; Hernández et al., 2013).

Vendors have their own views about MDMS and, therefore, they sell solutions based on their own concepts. Thus, the number of meters additional features changes from vendor to vendor. Some MDMSs only provide data that require external applications for accessing and processing it while others include a full application suite. Nonetheless, all solutions for MDMSs should fulfill three demands: *i*) improving and optimizing utility grids operation, *ii*) improving and optimizing utility management, and *iii*) enabling customer engagement. On top of that, since data analytics has become quite an important research topic on the smart grids field, MDMSs features should be able to benefit from all the information incoming from the power system, to interconnect data sources with mining and analysis centers, and to obtain useful data for management and control of the grid. With those capabilities in mind, the following components become necessary to the system from the infrastructure and hardware sides (Zhou et al., 2016; Diamantoulakis et al., 2015):

(i) Data centers infrastructure: physical holdings for the analysis and auxiliary systems, such as backup power, air conditioning, etc.
(ii) Servers: current machines for data processing and analysis.
(iii) Storage: hardware for saving collected data and connections with source and sink systems.
(iv) Database system: software for organizing data and for providing easy access to it.
(v) Virtualization systems: software for providing more productive application of available assets.

Given the importance of personal and business data collected by energy providers, their repository resources need to be protected against catastrophes, offer very good security, and have well-designed backup and contingency plans considering even uncommon scenarios. Nonetheless, costs for these solutions are gargantuan. Virtualization and cloud computing have emerged as possible solutions for these cases. The former allows the aggregation of available resources in order to improve their efficiency and return on investment (ROI), however, additions to infrastructure are needed, also increasing the complexity of the overall system. The latter provides access to resources from different locations, uniting them to look like a single resource to the user. Nonetheless, the use of cloud computing brings concerns about security and is complicated considering laws and regulations from different places where cloud servers might be located. Notwithstanding, any user of cloud services would not need to invest on their own data centers since available capacity from different centers can be redirected to users, making its use very efficient and keeping idle capacity at minimal levels (Hernández et al., 2013; Zhou et al., 2016; Diamantoulakis et al., 2015).

3.6. Demand-side management

Despite all functionalities provided by SMs discussed in the previous subsections, there is still room for applications. Demand-side management is yet another application with growing popularity. This kind of management is opposite to the conventional power generation principle, which means that utilities should provide enough capabilities to achieve users' requirements, also known as management of the supply-side. In industry, there is a prevalence of supply-side management since the beginning of power generation and distribution, but demand-side management, enabled by the use of SMs, allows controlling power usage through the management of users' acts (Bharothu et al., 2014).

The fundamental role of demand-side management is to redistribute consumption. Consumers are motivated to reduce use of the power grid during peak periods, deferring their energy needs for valley periods. The former, reduction, also known as peak clipping, aims at reducing the utilities need to activate high-cost facilities, which are used only to provide extra capacity needed on peak periods. The latter increase, also called valley filling, it takes advantage of the energy surplus during valley periods, which use the base infrastructure only. Hence, the blend of valley filling and peak clipping allow providers to decrease the activity of costly facilities while still fulfilling consumers' demand, simply by managing usage behaviors (Hoosain and Paul; Li et al., 2010).

Being demand-side management a wide service, many basic functions are required for its implementation: periodic and precise metering are needed to access updated consumption data; operation limits for alarming and data storage; bidirectional information exchange is needed to send instructions to SMs and to receive metering data; and home devices control is a requirement to allow the implementation of actions needed to change consumption. However, not only IENs are needed, but also regulations and instruments must be created to trust consumers and change their consumption behaviors at the demand side. Among these, dynamic pricing mechanisms are the most effective on affecting consumption habits (Joshi and PANDYA, 2013; Hoosain and Paul). For that matter, the methods presented below are commonly used (Gellings, 1022; An; Hoosain and Paul): two or more charge rates can be applied at peak and valley periods, which is known as the Time-of-Use (TOU) method; in Incremental Pricing, as consumption grows, charges increase; very high prices can be applied when critical operations take place, characterizing Critical Peak Pricing (CPP); in Critical Peak Rebate (CPR), consumers receive money back when they avoid using energy on peak periods; and prices can be adjusted in real-time, according to the energy supply and demand, which is the Real-Time Pricing (RTP) method.

3.7. Energy theft prevention and system security

With the steep increase on the number of SMs also come security issues both from external attacks and exploits and from the inside. The successful implementation of AMIs depend on the gathering, processing, and analysis of detailed consumers' data, which could reveal the users' lifestyle. Therefore, merely the traffic of this kind of data and its storage create serious vulnerabilities, which could lead to extortion of user information. The reception of prices and instructions at the user end are prone to physical and cyber attacks that could target data or power theft, or damaging the infrastructure. Hence, since the consumer's trust is critical for SMs and AMI expansion, if they suspect their data might be vulnerable, AMI may face problems on its adoption. Potential physical and economical threats will undermine consumers' decision, which will be slanted towards not adopting a new technology. In order to better analyze these issues, the following three aspects are considered: maintaining users' privacy, system robustness against attacks, and power theft (Zhang et al., 2010; Yazdanian and Mehrizi-Sani, 2014).

Ever since technological advance made the transmission of power possible through wide areas and even different time-zones, power theft is an issue utilities need to deal with (Yigit et al., 2014). On a world scale, theft is not a rare problem, and providers use SMs and other methods in IENs to prevent it. Features of SMs, such as sensors and processors, enable utilities to pinpoint unauthorized consumption and losses while allowing consumers themselves to monitoring abnormalities and even theft with high accuracy (Sauter and Lobashov, 2011).

Even though technology may be blamed for vulnerabilities, it is also responsible for the security measures that could prevent issues (Bharothu et al., 2014). Recent advances brought new intelligent electronic devices (IEDs) to IENs, which could also be integrated into SMs, such as digital fault recorders (DFRs), digital protective relays (DPRs), and circuit breaker recorders (CBRs) (Yang et al., 2011). In order to monitor the status of the grid, IEDs can save and dispatch information using timestamps, allowing SMs to monitor the operation status of the grid at any time. Therefore, whenever a fault happens, utilities are able to identify and isolate it to avoid compromising the whole system (Fadel et al., 2015; Bharothu et al., 2014). Additional components that could be part of the fault detection system include power quality monitors, microprocessor relays, database applications, up-to-date distribution circuit models, and geographic information system (GIS) databases. Nevertheless, there is no common sense or standard for SMs or IENs, neither there are standards for solution vendors, ending up in different products relaying different data formats to different kind of computing methods (Fadel et al., 2015).

Besides physical security, SMs can improve energy networks overall security in many other ways. Since the number of SMs is ever increasing, and, with it, the number of interconnections, the risks of data hacking, malware infection, and cyberattacks increase as well (Yigit et al., 2014). However, any such tampering attempt should be detected and remedied instantaneously to prevent damage. Moreover, in order to find detailed information about such attempts, warning signals should be sent and all data available should be recorded. Therefore, the analysis of the additional data could help preventing future breach attempts. Furthermore, since hackers are continuously improving their attack techniques and tools, so should the energy providers improve their defensive capabilities to level the battlefield (Fadel et al., 2015; Yigit et al., 2014).

Attacks to SMs can lead to the loss or tampering of billing data, which directly incurs in economical harm for providers. Moreover, since consumers' data include private information, the cost of failing to provide reliable two-way communication and to keep personal data confidential may lead to even higher costs due to legal factors. Therefore, maintaining the integrity of billing data, information sent by meters, commands, and software throughout the system is highly important. One way of identifying meters normal operation is monitoring their behaviors. For instance, from the consumption side, signature values of voltage, current, and power can be verified for each SM. Thus, by making these signature values indistinguishable from regular load patterns for someone trying to breach into the system, it is possible to verify the legitimacy of a meter. For that, load signature moderation reshapes data patterns in order to make signatures undetectable among load patterns (Kalogridis et al., 2010). The technique applies three methods — hiding, smoothing, and mystifying — to consumption data combining the power from the provider and from storage/batteries as power supply, therefore changing the consumption pattern. These techniques fall under the “undetectability” label (Pfitzmann and Hansen). Hence, measurement privacy becomes crucial for devices identification and access control, preventing unauthorized accesses. Moreover, in order to contain information theft, which threatens the network resources, privacy can be guaranteed through the use of network-wide cryptography, ensuring that, even if data is stolen, it cannot be exploited (Choi et al., 2011; Palensky and Dietrich, 2011; Sauter and Lobashov, 2011; Wang and Lu, 2013; Bou-Harb et al., 2013; Mo et al., 2012).

The foreseen SG framework will need to integrate millions of devices capable of high-volume two-way communication to reach an energy management and monitoring in an interactive way. These devices will be required to manage several processes, such as demand response, AMI, and AMR. Since it will be a critical system, protection methods against threats and mitigation of vulnerabilities will be required to be in place and to be efficient. The biggest vulnerability of the SG comes exactly from its required infrastructure — millions of deployed and integrated devices. Therefore, the SG must monitoring such a huge number of meters reliably, having perfect awareness of the whole system in order to keep it secure. Many studies can be found in the literature trying to determine possible security risks. Their aim is to improve the security of the system, both logical and physical, through the use of security agents, protocols, and algorithms. Some of these studies focus on attacks at the physical layer level, which is the most visible vulnerability of SGs (Wang and Lu, 2013; Yan et al., 2012; Bou-Harb et al., 2013; Bou-Harb et al., 2013, 2013; Liu et al., 2012; Finster and Baumgart, 2014).

Detection of attacks in the grid can be carried out accurately by collecting enough samples of the provided power in the time domain. For instance, in (Meier et al., 2014) the analysis of synchrophasors — timestamped current and voltage data — is applied by using statistical correlation. Through the use of data from several measurement units, it is possible to identify deviations in the data, allowing for the detection of anomalies created by attacks. Nonetheless, all research mentioned previously focus on a single task provided to the smart grid. The work in (Hou et al.) is an example of items data fusion where the created datasets are accessible to multiple tasks.

In summary, security constraints include SM certification, physical security, frequency of emission and size of certificates, use of public networks, and security coordination among vendors (Murrill et al., 2012; Khurana et al., Frincke; Mo et al., 2012; Liu et al., 2012; Hu and Gharavi, 2014; Wang and Lu, 2013). These constraints are analyzed below. Even though revenue grade certification of SMs is not something new, meters security upgrades will change the device, which will require new certifications. Also, since SMs are generally deployed at easy-to-access locations, physical security becomes troublesome. Regarding security certificates, the use of low-bandwidth communication in some parts of the AMI (ZigBee, Wi-Fi, or PLC), sending large certificates frequently to increase security will not be possible. Moreover, AMI may also make use of public networks, such as the cellular system, therefore having its security limited, as opposed to use only a proprietary network. Finally, since different systems owned by different vendors will need to have access to the utility AMI data in order to achieve the system objective, security must be coordinated among these parties, which is a challenge itself.

4. Discussion of the available solutions

Once there is no universal standard for smart meters on IENs development and due the fact that more than one supplier provide equipment to IENs networks, different communication standards, data formats and computation methods are present and all generated information must be processed. However, the use of smart meters on IENs brings countless benefits for various concerned parties, as summarized on Table 1.

Many types of energy meters were used in energy network to meet cost limitations and technical specifications before the advent of smart meters. Since requirements on energy saving and environment protection continue grow along with new technologies for data processing and communication, the use of smart meters is expanding very fast. Modular products, allowing adjust desired features for each application, are becoming very popular among smart energy meters and also motivate network inter-operation.

These days, smart energy meters have as basic functions routine and accurate measuring and bidirectional communication. More sophisticated functions can also be integrated in this equipment,

Table 1
Stakeholders x Benefits for using of smart meters.

Stakeholders	Benefits
Distribution and Transmission	- Improved data quality in terms of efficiency, load and losses - Faciliting witch of capacitor banks - Improved load management
External Stackeholders	- Support for the Smart Grid Initiatives - Improved environment benefits
Customers	- More accurate and timely billing - Good access and data to manage energy use - Improved data quantity and power quality
Security and Billing Services	- Reduced back-office rebilling - Detection of interruptions and energy theft - Improved billing accuracy
Customer Service and Field Operations	- Eliminating handheld metering equipment - Reduced metering cost - Reduced call-centre transactions
Utility	- Improved employee safety - Improved customer premise risk profile and safety
Marketing and Load Forecasting	- Reduction in the cost of data collection - Improved data and decision-making quality

such as appliance control and energy quality analysis, with alarm log and report generation. So far, smart energy meters were applied in many different ways, managing demand-side for example, as well as electricity stealing detection improving IENs security. Nonetheless, smart meter are very expensive especially for consumers. Therefore, an adequate operation point that can equally allot gains and prices among the different concerned parties is valuable for the deployment of smart meter designs.

Creating a modular smart meter with and open structure, allowing additional functionalities to be added when needed, can widely ease up the innovation and implementation of IENs. Furthermore, it is more suitable for modularized structures to reach inter-operation. Distinct devices may use separate modules to scope power and perform precise metering while communicating using compatible modules. Although the goal of smart meters development is not mainly to benefit the IENs, it offers a lot of benefits to its planning, operation, and management, which is playing an important role on the operation of the power grids and it is one of the main applications in the control center of said power grids.

The review noted that smart energy meters technologies applied to IENs brings severe gains over conventional power systems. In addition, current and future IENs' development seems to be clear. Smart energy devices will become smarter and more flexible by applying an interchangeable structure, allowing inter-operation between distinct manufactures and novel capabilities can be added via new modules to the smart device. Another choice to reduce initial investment on smart meter equipment itself is to embed the smart energy meter module in other devices to reach the smart metering function.

Bulk-metering is done by measuring the total used energy of a whole building. The net amount is split between the residents according to a factor that can be the size of the residential areas, for example. This is not a fair method of collection because someone can live in a bigger area but demand less energy and vice-versa. Nevertheless, sub-metering conveys the consumption of measurement users to individual areas in a complex. The goal is to achieve the needed consumption of utilities for accurate billing. The upside of this technique is that users only pay for the used power. Sub-metering information can also be indicator of equipment usage in relation to some given standard. In short, while smart measurement can offer larger quantities of data, sub-metering can offer data sideways, which increases the granularity of the acquired information. This suits the maintenance and operation workers and the occupants, since they are able to plan consumption needs, adjusting consumption dynamically.

Other benefits of sub-metering include support to clearly identify where performance improvements can be implemented, collecting data and information for preventive maintenance, allowing real-time monitoring and quick response to failures. They also support financial planning of equipment lifespan, motivating the facilities department to be accountable for the building operations, providing an energy consumption baseline to establish contractual terms with energy companies, allowing energy upgrades in buildings, encouraging energy efficiency measurements, fostering awareness about the effects of behaviors regarding energy consumption, and reducing demand peak costs through virtual sub-meters combination.

Traditionally, electromechanical meters provided no security at all. Theft in these devices can be done by connecting to the distribution wires, placing a magnet at the meter, grounding the neutral wire, blocking or damaging the spinning coil, and inverting output and input. Smart devices can be used to eliminate or minimize these security issues. They are capable of registering null readings and informing the energy service company through IENs. On the second stealing method cited above, smart meters consider the circuit is not closed and does not carry out the reading. The spinning coil is not present in smart meters, so the related aforementioned issues are also absent from them.

Extortion methods used on electromechanical meters work in smart meter systems as well. Tampering with information can be done in three stages: *i*) during collection of information, *ii*) when data are stored, and *iii*) as information traverses the power system. Manipulating data during the collection may be carried out using standard and smart meters. But only smart meters are prone to the other two stages. Table 2 summarizes the stealing techniques on standard meters and their possible application on smart meters.

Compared to regular systems, IENs make meddling with meters difficult due its data-logging functionality. The data logged records power failures or reversed energy flow in the meter. Intruders who aim at using disconnection or inversion methods also need to clear the logs saved in the meter. Thus, the erasure is categorized as a second type of data tampering stored in the meter. If the intruders gain access to data stored in the smart meter, they will have total and unrestricted control of the meter, data logged, and firmware. In the usual case of power extortion, the data and the firmware stored in the meter are not the valuable information for the intruders. Tampering with the total stored demand and the assessment logs is usually enough and this action requires smart meters password.

Data also can be changed as it is transmitted throughout the grid. This includes inserting fake data into the grid or hijacking transfers within the infrastructure. This kind of attack is possible on each meter of the infrastructure. If the tampering occurs at a combination point or backhaul link, data from a set of devices will be jeopardized. In order to do this, either intercept the backhaul link or the communication channel to change or inject false information between the device and the consumer. Because the management system may use encryption and authentication for

Table 2
Summary the stealing techniques on standard meters and their effect on smart meters.

Stealing Technique	Result	Proposed solution for smart meters
Direct connection lines	no reading at the meter	Recording such readings and deliver information to utility provider through AMI
In a three-phase meter, keeping open neutral and therefore using only one phase	measurements show that no energy is being delivered to the customer	Flashing Earth leakage indicator
Current transformer phase shift	Position switching of damaged wires cause phase shift which alters the metering	Tamper proof enclosure
Current transformer wire tampering	Damaging wire insulation at secondary side and tapping them. Related to the number of wires that are tampered, the meter can be forced into reading less	Tamper proof enclosure
Placing a magnet at the electromechanical device	Affects the coil motion and slows it down	No mechanical coil in smart meters
Blocking or damaging the mechanical coil	Magnetic field affects the coil motion and slows it down	No mechanical coil in smart meters

communicating, intruders have to acquire encryption keys stored in devices. If the authentication and encryption or the integrity between the meter and the utility are not properly made, intruders may forge methods to transmit their consumption values or event logs to the end user. If authentication is defective but there is encrypted communication between the device and the user, a malicious device between the meter and the utility in the backhaul will be required by the intruder to take the place of the meter for the provider, and vice-versa, during encrypted information exchange to acquire encryption keys. This type of intrusion is known as Man in the Middle.

There are many security debates related to information collection and guidelines for protecting and creating privacy in the smart meter data management system. There is no solution to address all the security requirements for these topics, and each one has its own characteristics, measurements, and considerations. However, any solution should, at least, fulfill the requirements discussed below.

A proactive approach is needed if energy meters are to anticipate and prevent privacy invasion events before they happen. Also, privacy and data protection must be implemented into the system by default — the consumer shall not be required to enable it. Privacy will be a primordial part of the network, without affecting its main functionality or fading over time. Moreover, end-to-end security needs to be in place, from the first to the last bit, ensuring that all data is kept safely and, if necessary, destroyed at the end of the process. In addition, designers and operators should meet customers needs by providing strong privacy standards, proper notifications, and an easy-to-use system interface. Finally, visibility and transparency should be provided, meaning that components and system operations will be accessible to users and providers.

Many security necessities in the management system are similar to those of typical networks. Nonetheless, there are one-of-a-kind security concerns that must be taken into account, as discussed next.

Regarding information availability, there are critical and non-critical information that can be distinguished. Large time intervals can be used to collect non-critical data and estimated values can be used instead for real-time values. However, critical information must be read more frequently (*e.g.*, every minute) and actual values are required. Data unavailability is related to two main factors: component failure — physical damage, software problems, human tampering; and communication failure — interference, cut cable, grid traffic, etc. Once information is available, a new concern appears: accountability. This is important from the economical point of view given these smart energy meters are responsible for generating all the billing information. The demand for accountability is particularly worrisome due to different components of a management system being generally manufactured by different suppliers and are owned by different customers, energy service providers, etc. The exact timestamp of information as well as the network time synchronization are also important for accountability. Audit logs are the most common way to ensure accountability. However, these audit logs are vulnerable. With smart meters, all the measured values, changes in parameters, and billing should be accounted for as they are the basis for charging users.

Another important aspect related to smart energy meters and intelligent networks refers to confidentiality, which can be understood as privacy of the user's consumption behavior and personal information, as previously discussed. In sum, clients' consumption data must remain confidential. This means that physical tampering of the meter to access stored data, unauthorized access to data by other automated systems connected through gateways as well as customer access to information of other customers must be avoided. Customer information will remain secret and only authorized subsystems will have access to data sets.

Finally, system integrity is of utmost importance. Although the head-end of an energy service provider premises in a physically secure system, its multiple endpoints with many other systems make it vulnerable by design. Integrity should be applicable to the data sent from the meter to the utility as well as control commands from the concessionaire to the device. Hackers aim to violate systems integrity by pretending to be authorized operators and issuing commands to perform their attacks. In comparison to electromechanical meters, smart meters must be resistant against physical and cybernetic attacks. The smart meter should also be able to spot cyber attacks and discard all commands avoid compromising system integrity.

Attacks should be studied from another point of view as well: the intruders and their motivations. The reasons can be countless such as personal or financial reasons, sabotage, terrorism, etc. This is important when designing countermeasures. It is obvious that a single solution is not enough to protect IENs.

Unavailability area identification algorithm will be developed and it should use the information from smart meters and the derived simplified grid model. The identification of the outage area can act as one of the main functions of a management system, providing possible information about the extent of the unavailability. If there are a lot of smart meters, more information will be available to make decisions easier. But since handling a large amount of "last gasp" messages with multiple communication latencies is a challenge, an efficient algorithm is necessary for the identification of fault area based on several "last gasp" messages.

Some questions need to be raised such as the following: *i*) How long would it take to develop functional smart energy meters? *ii*) What are the challenges that can affect development and how can they be solved? *iii*) It can be seen that technology will not be a problem, as long as the development is not restricted to one specific type of technology. A more important issue to influence development is the economic aspect. Therefore, it requires effective political instruments that can take advantage of the market as an important way to distribute resources, costs, and benefits. For this purpose, greatly detailed scenarios like gradual forecast mixed with backcasting can be established in order to create possible different script for the future where many important factors like costs and benefits are used as criteria to optimize every way.

5. Open issues

Usage of Internet could contribute to smart power grid configuration and control in real-time. Next, the concept of the Internet of Things (IoT) is supposed to share the data through the grid in order to improve its performances usually described with the efficiency, reliability, and safety of the electrical system. Then, these data could be further transferred to the remote location. This means that by using IoT, the energy meters can deliver data on their important measurement parameters to remote locations. Moreover, IoT allows the smart power grid to increase its resources and services. This will create, in a near future, a new way of differentiating power grid services. Also, these approaches will improve the way power grid is controlled, while providing new related opportunities. Further, based on the user needs, it will be able to establish and change energy requirements and the smart power grid will be configured to ensure the required energy quality level.

In the near future, it will be required to cope with the scalability of idea: large number of energy meters would need efficient maintenance technique. Interpretation of mutual information from multiple meters and data processing techniques is also important issue. Also, the capability of querying data from devices is relevant to the power grid of the future. Further, in future grids, nodes should be able to query data from an individual node or a group of nodes about a specific microgrid. All these issues are actually well known and evolved by the Internet itself. Thus, the needs currently requested for the grid are the one previously imposed on Internet. Therefore, through an IoT point of view, the power grid will be able to perform the following tasks: demand management, disturbance detection, power flow quantity management, specific microgrids isolation, power storage management, energy flow from any node to another one (where there is lack of energy flow, using innovative routing algorithms). In view of the future power grid, smart energy meters could solve all the current difficulties related to sensing and measure problems.

The design of smart energy meters should take advantage of the IoT concept. As a matter of fact, nowadays energy meters can share data only with the power company remote center aiming at billing the user's power consumption. With a different approach, future energy meters should share information about consumption and energy quality with the Internet to improve power grid management. Energy meters can no longer be considered an instrument simply for consumer billing. Through this IoT view, information about each device of the system is shared across the whole grid to enhance its efficiency. Measured data is used to charge for consumption but, simultaneously, to configure the power grid based on the energy usage and the energy quality requirements defined by an user. This way, the smart energy meter will implement the concept of IoT to improve the resources and services provided by future power grids. Nevertheless, several other issues remain unresolved. Other challenges include standardization of communication protocols, redesign of safety rules, harmonization of equipment standards to enable plug-and-play and interfaces, big data management inbound from several thousands of sensor systems scattered over the grid, recalculation of metrics used for charging users, and modernization of the current power grid architecture.

The main key strengths will be the following: ability to remotely control and program the smart energy meter; data will be processed in real time to support the tasks of decision making; remote control station can simultaneously manage several smart meters; integrated metrics will offer new potential criteria to efficiently manage routing and power sharing among multiple nodes, even considering energy quality features.

Smartphones will be ideal for monitoring, controlling, and managing energy control systems remotely from anywhere and anytime. After proper authentication and authorization users can modify and change their online policies regarding energy saving interacting remotely with the policy servers. This design allows dynamic changes in policies regarding energy saving and offers better flexibility to users. It can be a good add-on to the overall policy decision process based on the modeling results. This new *App* can be easily developed for smartphones. Also, another concept to be studied is how the utility company charges users and how the latter pay for the service in easier ways, for instance, by using cryptocurrencies.

6. Conclusion

Prior smart meters, conventional electromechanical meters were commonly used for electricity flows measurement. In such meters, data is displayed on an analog counter and needs to be recorded manually. Smart meters are more sophisticated, electronic devices that measure power consumption and communicate bidirectionally energy consumption, billing information, real time price, and the status of power grids. The bidirectional communication capability is the most important difference that distinguishes conventional and smart meters. Note that there is no switch point of conventional meters by smart ones, and the development of smart meters is a continuous process like other technologies.

This research is comprehensively focused on smart meters and smart management systems, considering related technologies, applications, and challenges. The real situations of each system are outlined and future research directions were introduced in several subsections along the text.

To emphasize the importance of advanced sensing system in power grids, strengths and weaknesses were analyzed, where the last should be resolved before power grids could be considered truly smart. Hereby, IoT concept gives new solution to solve these problems. Also, the current power grid should be upgraded in order to include the new requirements of current energy demand. Taking all of the weaknesses, there is still effort to be done, especially regarding the definition of the most appropriate architectural design of the power grid.

Through the IoT point of view, smart energy meters will use the Internet to improve the efficiency and resources of the power grid. This work also proposed a possible solution to the questions regarding the aspects of sensing and measuring, discussing the potential of deploying smart energy meters.

In the future power grid, smart sensors and energy meters will play an important role for energy monitoring. Smart sensing systems could enable new ways for automatic energy measurement and data processing to make real time decisions. This new scenario needs new systems that allow power grids to be truly smart, managing bidirectional energy flow and flow change. Furthermore, such systems must ensure interoperability between new and legacy equipment. Smart power grids must be able to immediately remedy a supply discontinuity. These will need new, advanced and innovative detection systems. Consequently, managing energy flow is a really complex task. Currently, these aspects do not receive enough attention in the grid. The end user sometimes needs to tolerate low quality energy. The main consequences are for home users to bear. Therefore, uninterrupted supply of high-quality and average energy are fundamental requirements that should be ensured in the transmission and distribution of electricity.

Many issues are to be deal with, involving the development of new efficient and smart detection systems. In this context, power grids need a radical renovation in order to dynamically change its configuration. In fact, the current architecture is designed to manage only the mono-directional power flow from the power plant to end users. Creating this IoT structure in smart homes or offices, not only the proportionality of multiscale energy will be enabled, but also creating a smart home space will be possible, which is an important part of the future smart world. The driver for this idea will provide not only significant economic benefits but also enormous social benefits regarding global sustainability.

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