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IoT-based Energy Monitoring Flexible Solutions:

A New Smart Energy Meter

Danielly Bravin Avancini

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Dissertação apresentada ao Instituto
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“When wireless is perfectly applied the whole earth will be converted into a huge brain, which in fact it is, all things being particles of a real and rhythmic whole.”

Nikola Tesla *(1926)*

Dedication

To my mother who always showed me the path of righteousness. To my mentors, who have guided and strengthened me through this journey.

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Abstract

The significant increase in energy consumption, by the growth of the population or by the use of new equipment in daily life of industrial development, has brought great challenges for energy security and environment, which stimulate the use of energy resources for a more conscious behavior. There is a need that consumers track daily use and understand consumption standards to better organize themselves in order to obtain greater economy of resources. With the improvement of smart networks technology for better energy supply, a smart meter is not just a simple measurement gadget anymore, but it has additional functions, such as smart equipment control, bidirectional communication, which allows the integration among user and network, and other functionalities. Smart meters are the most fundamental components in smart power grids. Besides, the meters used with a management system can be used for monitoring and control home appliances and other gadgets, according to the users' need. A solution of an integrated and single system is efficient and more economical. Smart environments are becoming a key piece in the future green and sustainable energy grid due to power source integration and demand control capabilities. Advanced measurement systems make themselves necessary to the future smart grids operation. Smart measurement systems allows energy consumption monitoring of the end consumers, while provides useful information about the quality of energy. The information provided by this system are used by the system operator to enhance the energy supply, and different techniques - such as charge scheduling, management from the demand side and non-intrusive load monitoring - can be applied for this end. The Internet of Things (IoT) is becoming a great ally in the management of smart distribution and energy consumption in smart systems scenarios. This work aims to present and validate the development of an intelligent energy meter, following an IoT approach, and associated challenges and benefits. Given the IoT requirements, this dissertation explores a review analysis of the key features that smart energy meters should provide, along with the analysis of existing solutions that use smart energy meters for smart grids. A low-cost, multi-protocol, modular IoT-enabled smart energy meter design capable of collecting, processing and transmitting various electricity-related information, focusing mainly on the consumer side, is proposed, presented and validated. Finally, the integration of the solution with the middleware developed by IoT Research Group - Inatel, capable of receiving data collected by the smart energy meter, performing the necessary treatments and storing this data so that the application can, is presented via the Internet, access middleware data and make information available to users. The solution is evaluated, demonstrated, validated, and it is ready for use.

Keywords

Energy Efficiency; Energy Management System; Smart Places; Intelligent Energy Networks; Internet of Energy; Internet of Things (IoT); Smart Energy; Smart Meter.

Resumo

O aumento significativo no consumo de energia, seja pelo crescimento da população ou pelo uso de novos equipamentos no dia-a-dia ou com o desenvolvimento industrial, trouxe grandes desafios para a segurança energética e para o meio ambiente, que estimulam o uso dos recursos energéticos numa direção mais consciente. Há uma necessidade de que os consumidores acompanhem o uso diário e entendam os padrões de consumo para se organizarem melhor, a fim de obter uma maior economia de recursos. Com o aprimoramento da tecnologia de redes inteligentes para melhor suprimento de energia, um medidor inteligente de energia não é mais um simples dispositivo de medição. Esse dispositivo possui funções adicionais, como controle inteligente de equipamentos, comunicação bidirecional, permitindo integração do usuário à rede, entre outras funcionalidades. Os medidores inteligentes de energia são os componentes mais fundamentais em redes elétricas inteligentes. Além disso, os medidores de energia inteligentes utilizados junto à um sistema de gerenciamento, podem ser usados para monitorar e controlar eletrodomésticos e outros dispositivos, de acordo com a necessidade dos usuários. Uma solução de um sistema integrado e único é uma abordagem eficiente e mais econômica. Ambientes inteligentes estão se tornando uma peça-chave na futura rede de energia verde e sustentável, devido à integração de fontes de energia e às capacidades de controle por parte da demanda. Sistemas avançados de medição tornam-se necessários para o futuro funcionamento da rede inteligente. Os sistemas inteligentes de medição permitem o monitoramento do consumo de energia dos consumidores finais, enquanto fornecem informações úteis sobre a qualidade da energia. As informações fornecidas por esses sistemas são usadas pelo operador do sistema para melhorar o fornecimento de energia e diferentes técnicas - como programação de custos, gerenciamento do lado da demanda - pode ser aplicado para esta finalidade. A Internet das Coisas está se tornando uma grande aliada no gerenciamento e consumo de energia em cenários de sistemas inteligentes. Este trabalho tem como objetivo apresentar e validar o desenvolvimento de um medidor de energia inteligente, seguindo uma abordagem orientada a IoT, com os desafios e benefícios associados. Considerando os requisitos de IoT, esta dissertação explora uma análise de revisão das principais funcionalidades que os contadores de energia inteligentes devem fornecer, juntamente com a análise das soluções existentes que utilizam contadores de energia inteligentes para redes inteligentes. É proposto, apresentado e validado um projeto de medidor inteligente de energia, de baixo custo e habilitado para IoT, multiprotocolo e modular, capaz de coletar, processar e transmitir várias informações relacionadas à energia elétrica, focadas principalmente no lado do consumidor. E, por fim, é apresentado a integração da solução com o *middleware*, desenvolvido pelo IoT Research Group – Inatel, capaz de receber os dados coletados pelo smart energy meter, executar os tratamentos necessários e fazer o armazenamento desses dados para que a aplicação possa, via *Internet*, acessar os dados presentes no *middleware* e disponibilizar informação aos usuários. A solução é demonstrada, validada e está pronta para uso.

Palavras chave

Eficiência energética; Energia Inteligente; Internet das Coisas (IoT); Internet de Energia; Ambientes Inteligentes; Medidor Inteligente de Energia; Redes Inteligentes de Energia; Sistema de Gerenciamento de Energia.

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List of Abbreviations and Acronyms

AMI – Advanced Metering Infrastructure

AMM – Automatic Meter Management

AMR – Automated Meter Reading

CBR – Circuit Breaker Recorders

CPP – Critical Peak Pricing

CPR – Critical Peak Rebate

DER – Distributed Energy Resources

DFR – Digital Fault Recorders

DG – Distributed Generation

DMT – Digital Micro Technology

DNAS – Distribution Network Automation System

DPR – Digital Protective Relays

DSL – Digital Subscriber Line

DSM – Demand Side Management

EMS – Energy Management System

GIS – Geographic Information System

HAN – Home Area Network

IC – Integration Circuit

IED – Intelligent Electronic Device

IEEE – Institute of Electrical and Electronic Engineers

IEN – Intelligent Energy Network

IoE – Internet of Energy

IoT – Internet of Things

MDMS – Meter Data Management System

NAN – Neighborhood Area Network

PEV – Pluggable Electrical Vehicle

PLC – Power Line Communication
QoS – Quality of Service
RMR – Remote Meter Reading
ROI – Return on Investment
RTP – Real Time Pricing
SAR – Successive-approximation-register
SCC – Smart Control Center
SEP – Smart Energy Profile
SG – Smart Grid
SMS – Short Message Service
SSP – Secure Signal Processing
TOU – Time on Investment
TVS – Transient-voltage-suppression
WAN – Wide Area Network

1 Introduction

1.1 Motivation

In an environment where more and more people are dependent on the good functioning of machines, the idea that failures can and should be avoided highlight the need for continuous monitoring. In addition, a remote operating diagnostics system allows the user to check the status of the equipment or an environment of interest, and can be accessed at any time or anywhere in the world and reduce waste.

Variable monitoring provides sufficient data to perform trend analysis, diagnostic and decision making, indicating the actual operating conditions of the monitored services to detect any change in the state of the data. However, the measurements and records of the variables are useless if they are not analyzed and interpreted, since it is the weighted evaluation of these values that allows a diagnosis and, consequently, the making of a plan of action.

For the smart power system to work, demand-side power consumption information must be correct and reliable, and can even provide balanced management of power-to-power consumption. Power meters are a very important part of the smart grid and they make great allies as they help integrate consumers into the grid, bringing consumer automation through two-way communication [1] [2] [3]. This implementation brings a more efficient system to the end user.

When people have more knowledge about the use of electricity, it is possible to make consumption more responsible, making it more efficient, by inserting new technologies into the power grid. For this, the use of the smart energy meter is essential [2] [4] [5]. But for this balance between supply and demand to occur, information must occur in real time.

The intelligent energy meter system is an integral part of data collection and communication infrastructure throughout the Smart Grid (SG). These meters shall be capable of providing communication, interaction, data reception and, where necessary, command actuation, power consumption and/or generation, using an appropriate language format, and being able to communicate with other smart devices [6] [7] [8].

This new concept not only gives suppliers access to accurate billing data, but also provides a way to collect information from end users and establish two-way communication. Smart energy meter not only works as a sensor capable of measuring energy consumption, but also provides energy resource management in a given environment [8] [9]. In addition, by analyzing the load's time data, it would be possible to predict future demand, according to consumer behavior, and could improve the forecast of energy supply delivery [10]. Therefore, smart energy meters can be considered as a way to obtain detailed consumption profiles that can be used in high level applications [11] [12].

The Internet of Things (IoT) becomes a great ally, providing the integration and management of equipment responsible for sensing, connecting and responding information [1] [13] [14] [15]. IoT offers many sophisticated and ubiquitous applications for intelligent environments, such as the ability of devices, networks, and sensors to communicate with each other, with or without human intervention [13] [16]. It is an essential tool for smart environments to be able to use energy efficiently and address the associated challenges [16] [17].

1.2 Problem Definition

The significant increase of global energy consumption brings new challenges to energy networks [18]. It is estimated that residential and commercial buildings represent approximately half of the total world energy consumption. Smart sensors communications are critical due the fact that sensors collect and transmit very important real-time monitoring data, such as temperature, occupancy behavior, outdoor environment, humidity, light intensity, electricity quality and consumption, etc. These sensor networks placed in different buildings and environments can be abstracted and integrated into the same virtual network, which provides the benefit of allowing multiple smart environments to be remotely managed by a centralized controller [19].

This modern concept involves new challenges for energy network researchers. Several defiance and issues must be faced, such as the development of new efficient and smart sensing systems, capable for attending this dynamic scenario of energy networks [20]. Chasing a better energy quality and efficiency has been considered essential to stimulate the development of Intelligent Energy Networks (IENs) all over the world [18] [21].

Smart energy meters plays most important rule in IENs, monitoring energy consumption or energy generation and even controlling appliances. These smart devices can exchange energy consumption information between companies and consumers. Two-way communication is a key feature that distinguish smart devices from non-smart ones [22]. These equipment record electricity consumption or generation information in small time intervals, using voltage and current sensors, and send this information to a central system for monitoring and other purposes [19]. Smart energy meters are not widely studied on research publications, unlike smart grids and IENs. Technologies about smart metering are advancing substantially. However, there are important issues to address in order to promote this development, like inter-operation standards for equipment [3] [21] [23] [24].

It is necessary to develop a smart energy meter that incorporates several communication interfaces, wired and wireless, to provide two-way information flow. The developed equipment should support several communication protocols for easy integration with any remote monitoring software solution. Therefore, IoT can provide new alternatives to smart sensors networks, including the smart energy meters.

IoT can provide new criteria for sharing data and information among smart sensors. In this context, IoT can allow these sensors to share information by using wireless communication improving the network management. In addition, smart sensors must cooperate and satisfy several features, such as being dynamically adaptable to scenarios and changing conditions as well as being able to monitoring and predict electrical energy consumption, for example [20]. Through IoT, the entire power grid chain, both generation and consumption, will become intelligent. Two-way communication provided by IoT networks enables capabilities for power grid monitoring and control anywhere and anytime [25].

1.3 Research objectives

The main objective of this dissertation is to present an efficient design and implementation of a smart power meter integrated to a middleware. The design provides an intelligent low power metering system. The proposed design is implemented at the consumer end for IoT operation and is capable of sending commands and monitoring the quality of the power supply provided by the local utility, and it is possible to receive instant updates of any monitored variable failure. Data monitoring and management is performed through an implemented website, the In.IoT, developed by IoT Lab Inatel.

Based on studies of others smart energy meters models, it was designed, and implemented a cost effective three phase smart energy meter, IoT enabled, multi-protocol and modular, capable to collect, process, and transmit several electric energy related information, mainly focused on consumer-side, to any smart energy control system. The proposed platform is client-server based, expandable, and future-proof, allowing further integration.

This work presents a prototype developed to address the problems identified in the research, which is ready for use. In addition, the study will also serve as a guideline for future energy management research using Internet-based solutions (like IoT). To achieve this main objective, the following partial objectives were defined:

- State of the art review related to the concept of Smart Grids (SG) and its major applications;
- Identification of the most important parameters in the environment where smart energy meters must be applied;
- Proposal to solve the problem of the lack of energy consumption information by the user;
- Building and integrating smart binary prototypes with an IoT middleware platform;
- Performance evaluation, demonstration and validation of the complete solution.

1.4 Main contributions

The first contribution is focused on the proposal the development of an IoT based smart energy sensor. A device capable of monitoring in real-time energy quality and consumption, and flexible for being integrated to any existing wired or wireless network communication. This contribution is described in Chapter 3 and was presented at the 3rd International Conference on Smart and Sustainable Technologies (SpliTech 2018), Split, Croatia, June 26-29, 2018 [26].

The second contribution of this dissertation is a deep state of the art review on the evolution of energy meters in smart grids. This review analyzed, in detail, the models presented in the literature, evaluating their individual characteristics, architectures, protocols, and used platforms, as well as the challenges and associated problems. This study is presented in Chapter 2. This review was published in the Journal of Cleaner Production, eISSN: 0959-6526, Vol. 217, 20 April 2019, Pages 702-715 [27].

Finally, the third contribution of this dissertation exhibits the validation and performance assessment of the solution is presented as a final contribution and, together the integration of the smart energy meter a middleware platform that besides being responsible for receiving, processing and storing information related to smart compartments can also be used as an interface to present the information. This all information is detailed in Chapter 4.

1.5 Publications

During this research, two scientific papers have been published and a third has been submitted for publication.

Publication in an International Journal:

1. D**anielly B. Avancini**, Joel J. P. C. Rodrigues, Simion G. B. Martins, Ricardo A. L. Rabêlo, Jalal Al-Muhtadi, Petar Solic, “Energy Meters Evolution in Smart Grids: A Review”, *Journal of Cleaner Production*, Elsevier, ISSN: 0959-6526, Vol. 217, April 2019, pp. 702-715, DOI: 10.1016/j.jclepro.2019.01.229.

Publication in an International Conference:

2. **Danielly B. Avancini**, Simion G. B. Martins, Ricardo A. L. Rabelo, Petar Solic, Joel J. P. C. Rodrigues, “A Flexible IoT Energy Monitoring Meter”, *3rd International on Smart and Sustainable Technologies* (SpliTech 2018), Split, Croatia, June 26-29, 2018, IEEE.

Paper Submitted to an International Journal:

3. D**anielly B. Avancini**, Joel J. P. C. Rodrigues, Ricardo A. L. Rabêlo, Ashok K. Das, Sergey Kozloz, Petar Solic, "A New IoT-based Smart Energy Meter for Smart Grid", (submitted to an international journal).

1.6 Thesis statement

IoT-based energy resource management is a matter of the utmost importance, especially when considering the use of natural energy resources. Research shows that power utilities have only a forecast of demand consumption and any atypical variation can compromise energy supply. Currently, end consumers, especially low and medium power consumers, do not have an affordable solution to monitor their consumption and the quality of energy supplied by the utility in real time, and are often surprised by the lack of supply of energy resources. An essential tool to promote this management feature is the smart power meter.

Smart meters currently available on the market do not provide all the features required to create an advanced electrical management system as mentioned. To achieve these features with existing solutions, it is necessary to use different sets of equipment with complementary functions, which ultimately makes the final solution unfeasible. For example, in addition to the conventional smart energy meter for energy monitoring, if the end user needs to control their installed load (lighting and air conditioning systems, for example), it will be necessary to use equipment that has these power interfaces read and write (I/Os). Likewise, it is necessary to record this information and make it available to a centralized management system, compatible with different protocols and media. By creating a system combining these different modules, in addition to the complexity of configuring them correctly, the total price of the solution becomes too high, making commercial use of the solution unfeasible.

Creating a prototype that provides a viable solution for managing energy resources and assessing their performance in a real situation can contribute substantially to selecting the best path and achieving the goal of the scenario under study. The study aims to present the development of a complete system of management and monitoring of energy resources by the user, composed of hardware capable of monitoring and analyzing in real time the quality parameters of the network (voltages, currents, consumption, among others). Remote charge control, such as lighting and air conditioning systems, is also possible. In addition, through the interface like middleware, the solution is able to monitor a network of installed equipment, generating management reports of all monitored parameters and reporting remote alarm conditions.

The hardware to be used to meet this proposal is a smart meter - IoT-based Smart Electricity Meter, specifically designed to meet the technical characteristics required to implement such a system. An inexpensive platform for three-phase network monitoring, specifically focused on customer power monitoring, with adequate connectivity to power different management platforms (support for multiple open protocols and different media, including wireless networks).

1.7 Document organization

The remainder of this dissertation is organized as follows. Chapter 2 elaborates on a detailed description of the main functionalities that smart energy meters must provide, along with the analysis of existing solutions that make use of smart energy 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.

In Chapter 3, the author proposes a cost effective three phase smart energy meter, IoT enabled, multi-protocol and modular, capable for collecting, processing, and transmitting several electric energy related information, mainly focused on consumer-side, to any smart energy control system.

Chapter 4 presents the design and construction of a smart power meter integrated to a middleware, as well as the results of the performance evaluation of the proposed system through real experience. The design provides an intelligent low power metering system. The proposed design is implemented at the end consumer for IoT operation and it is capable for sending commands and monitoring the quality of the power supply provided by the local utility, and it is possible to receive instant updates of any monitored variable failure. Data monitoring and management is performed through a Web-based middleware for IoT, called *In.IoT* (https://www.inatel.br/in-iot/), developed by the IoT Research Group - Inatel.

Finally, Chapter 5 concludes the dissertation, showing lessons learned along the study, key conclusions, and suggestions for further works.

2 Related work

Modern network applications started leaning towards energy efficiency as more battery-powered equipment join networks. Therefore, the concept of IENs has been coined to group research efforts aimed an efficient use of networked devices energy. Along with IENs come Smart Grids, 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 [23] [28].

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 [29]. 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 [18] [30].

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 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 [18].

Elaborating on the key benefits provided by smart meters, three main improvements are expected [31] [32]: *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 [33] [34]. 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 [28] [31].

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 [23] [35] [36].

Figure 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 [37] [38].

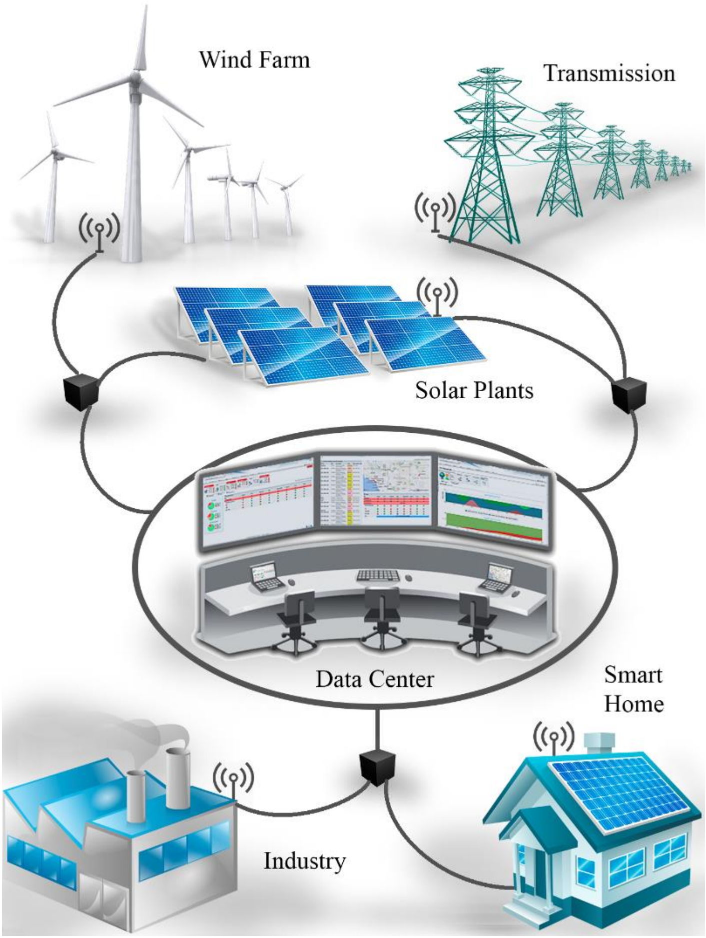


Figure 1 - A smart grid perspective with all its main components.

2.1 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 [31] [34].

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 [39] [40].

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 micro grids. Through the use of devices capable of monitoring energy, consumption-control sensors, such as lighting sensors, and remotely-controlled smart energy meters, 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 [21] [41].

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 [42] [43].

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 [44] [45] [42], 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 [1] [3] [46] [47].

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 [48] [49] [50]. 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 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 energy meters and other SG components [51] [52].

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 [51] [53].

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 [51] [52].

Cellular networks can also provide large coverage with considerable data rates. This technology could be used for connecting smart energy 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 [31] [51].

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 [31].

Finally, Digital Subscriber Line (DSL)/Optical Fiber are wired technologies that feature high-speed data transmission over the voice telephony network. 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 (SCC) [51]. In summary, these are the most promising available technologies for these networks.

2.2 Main Types of Smart Energy 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 [18] [54].

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 [18] [54]. Also, remote control of the meters allowed providers to deploy Real Time Pricing (RTP) and load leveling, making the power delivery process more efficient [18] [42]. Even further, the evolution of meters granted them modularity, which means that functionalities can be added to electronic meters by plugging in additional modules [55]. The Figure 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 [31] [36].

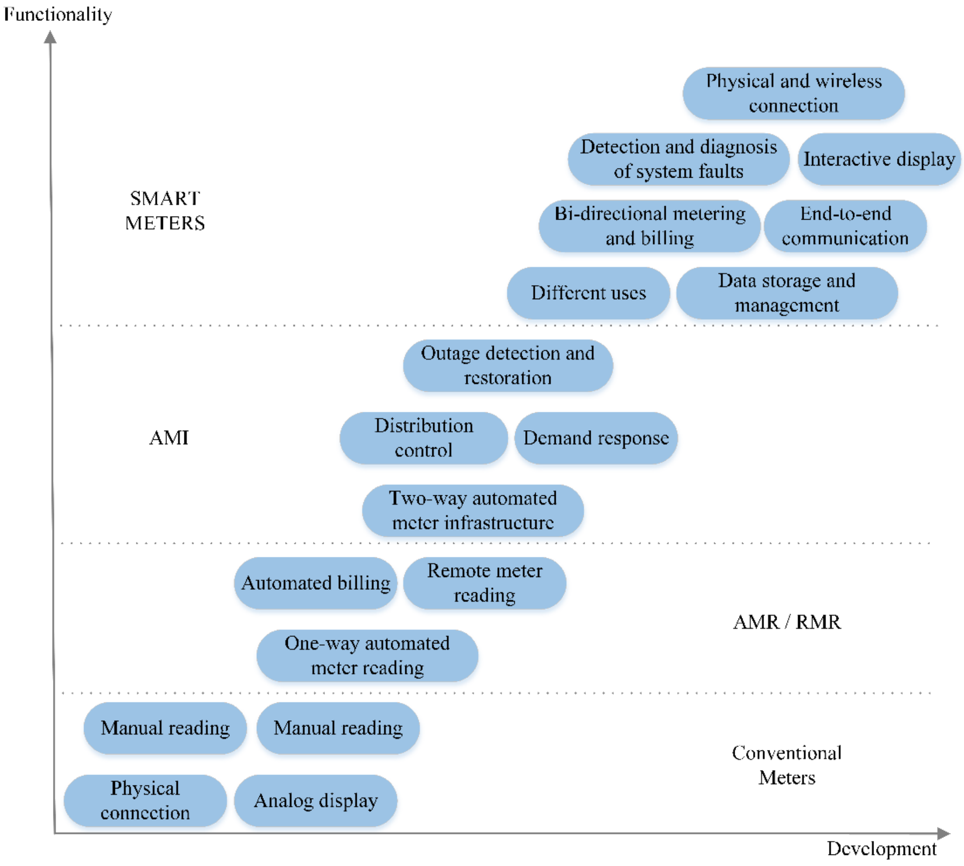


Figure 2 - Evolution of the development versus the functionalities of energy meters.

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 [18] [56] [57]. Then, it provides invested in AMI in order to manage demand, laying the basis for IENs [58].

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 [58] [59]: 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 [57] [60].

Albeit conventional meters could only measure and display total consumption, smart meters allow remote measurement in shorter intervals, *e.g.*, 15 minutes, 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 [61] [62].

It has been shown in the literature that households' behavior can be easily estimated, without aid of refined tools or algorithms. Murrill *et al.* [63] have shown from as little data as can be gathered in 15 minutes, major appliances use can be determined. Also, Molina-Markham *et al.* [10] 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.

2.2.1 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 much reduced scale [64].

Non-linear loads joining the grid, legislation, and reliability call 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 [65].

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 overvoltage that occurs 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 [65].

Smart measurement in SGs is performed by the smart meters 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 Figure 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 [3] [33]. 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, smart energy meters comprise a power supply, a control, an indicator, an encoding, and a timing module [66].

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 [67], 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 [68] 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 [69], 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.

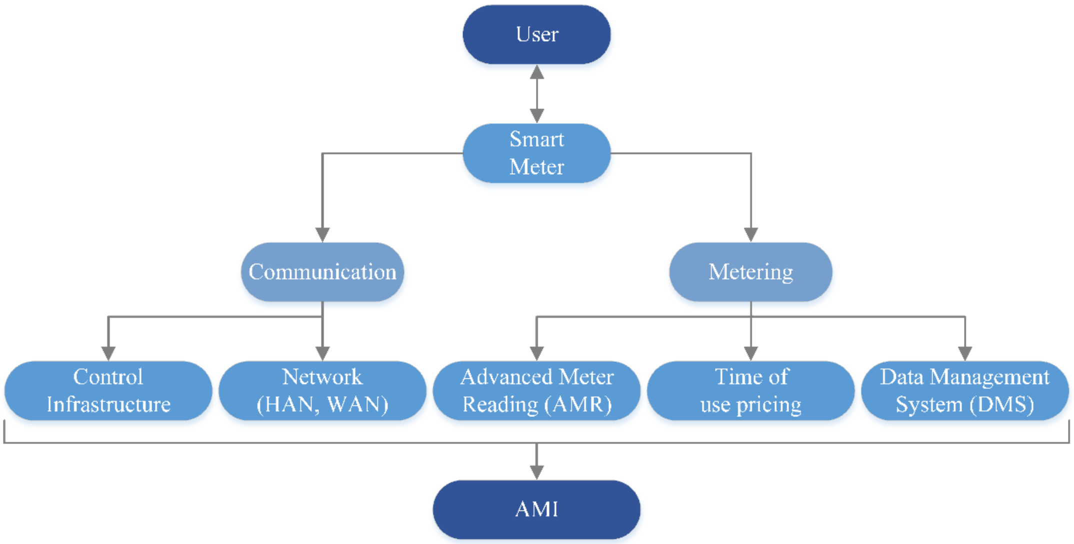


Figure 3 - Illustration of typical smart meter systems.

Along with the grid monitoring, interest also increased on the monitoring of the smart meters themselves in order to provide better management and security to the system. Data gathered from smart meters 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 smart meters, 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 smart meters 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 [70] [71] [72] [73] [74].

2.2.2 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 [75].

As a first attempt to extract data, solutions have proposed data correlation analysis and data fusion [76] [77] [78] [79]. 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 [75], would result in higher computing efficiency.

Related to periodic and precise metering, data storage and alarming is another desired function for smart energy meters. 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 [64] [80].

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 smart meter cost [81]. 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 [80].

2.2.3 Communication Interfaces

In order to be categorized as a smart meter, 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 [82].

As previously stated, two-way communication is the main improvement of smart meters 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 smart meters, transmitting and receiving data, but also capable of receiving instructions for specific actions [31]. However, the communication functionality should not prevent other smart energy meter modules from operating correctly in any case. Therefore, the communication module is independent, allowing the smart meter 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 [37].

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 (IoE), which refers to energy networks that are able to communicate through the Internet [37]. 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 smart meters. 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 [37] [83].

Roughly, SGs can be classified in three tiers: HANs, NANs and WANs, as depicted in Figure 4 and described as follows:

- HAN: Connects devices inside homes, which can be electric vehicles, smart meters, appliances, etc. From these devices, the 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 [37].
- NAN: Integrates data from several households and outdoors smart meters in a small area using data collectors. Short-range communication technologies are suitable for this scenario, such as Wi-Fi and Mesh RF [37].
- 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 [37] [84] [85] [86] [87].

2.2.4 Home Devices Control

Bidirectional communication allows smart energy meters 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 [59]. 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 [88].

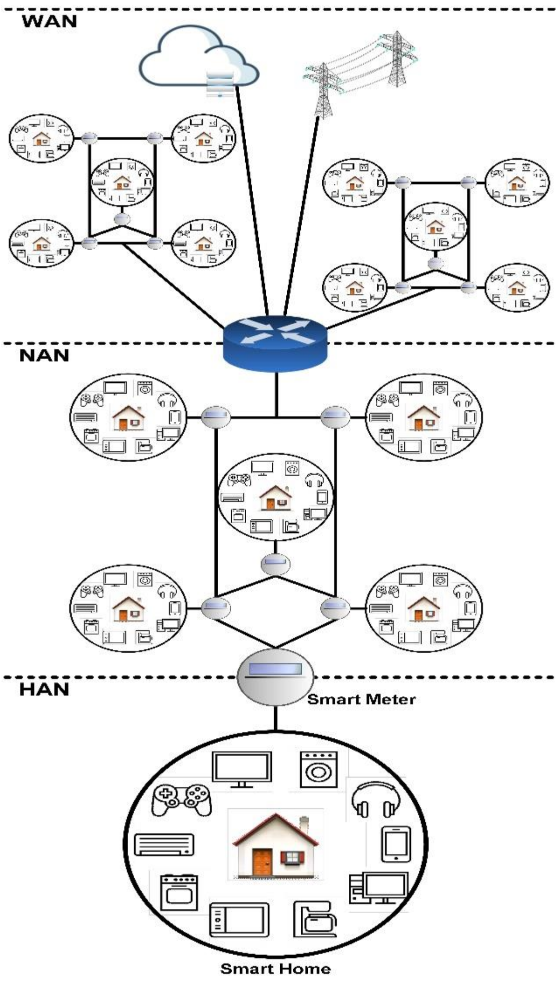


Figure 4 - Illustration of a basic Smart Grid network structure.

Smart energy meters can be associated to several applications [89]. 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 [90]. 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 smart meter 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 [83].

2.2.5 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 [91].

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 smart meters 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 [92] [93].

The 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 minutes, 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 (DNAS), 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 [94] [95] [96].

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 [94] [95]:

- **Data centers infrastructure:** physical holdings for the analysis and auxiliary systems, such as backup power, air conditioning, etc.
- **Servers:** current machines for data processing and analysis.
- **Storage:** hardware for saving collected data and connections with source and sink systems.
- **Database system:** software for organizing data and for providing easy access to it.
- **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 [94] [95] [96].

2.2.6 Demand-side Management

Despite all functionalities provided by smart energy meters 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 smart meters, allows controlling power usage through the management of users' acts [59].

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 [29] [97].

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 smart meters 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 [64] [97]. For that matter, the methods presented below are commonly used [81] [97]: 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.

2.2.6.1 Energy Theft Prevention and System Security

With the steep increase on the number of smart energy meters 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 smart meter 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 [42] [98].

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 [84]. On a world scale, theft is not a rare problem, and providers use SMs and other methods in IENs to prevent it. Features of smart meters, 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 [85].

Even though technology may be blamed for vulnerabilities, it is also responsible for the security measures that could prevent issues [59]. Recent advances brought new

Intelligent Electronic Devices (IEDs) to IENs, which could also be integrated into smart meters, such as Digital Fault Recorders (DFRs), Digital Protective Relays (DPRs), and Circuit Breaker recorders (CBRs) [99]. In order to monitor the status of the grid, IEDs can save and dispatch information using timestamps, allowing smart meters 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 [37] [59]. 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 smart meters or IENs, neither there are standards for solution vendors, ending up in different products relaying different data formats to different kind of computing methods [37].

Besides physical security, smart meters can improve energy networks overall security in many other ways. Since the number of smart meter is ever increasing, and, with it, the number of interconnections, the risks of data hacking, malware infection, and cyberattacks increase as well [84]. 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 [37] [84].

Attacks to SMs can lead to the loss or tampering of billing data, which directly incurs in economic 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 smart energy meter. 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 [73]. 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 [100]. 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 [58] [80] [85] [101] [102] [103].

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 [61] [66] [101] [102] [104].

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 [105] 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 [75] is an example of items data fusion where the created datasets are accessible to multiple tasks.

In summary, security constraints include smart energy meter certification, physical security, frequency of emission and size of certificates, use of public networks, and security coordination among vendors [5] [61] [62] [63] [101] [106]. 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 smart meters 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.

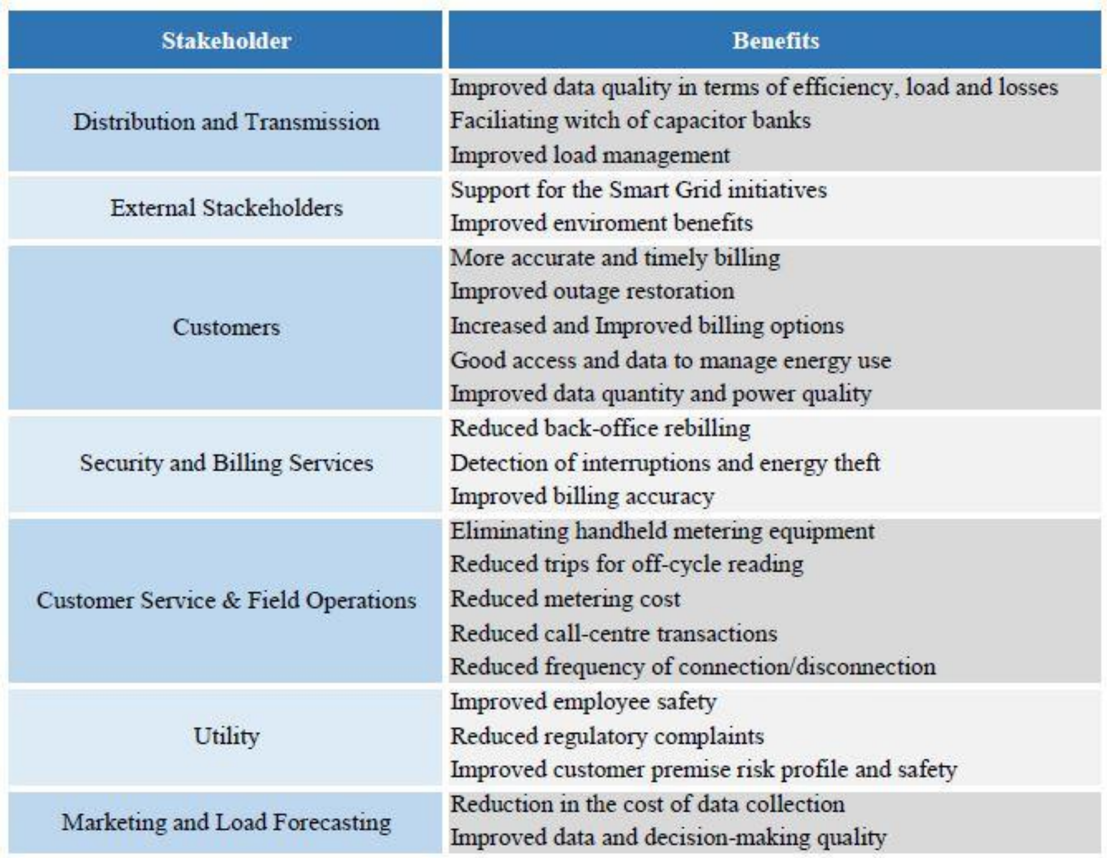
2.3 Discussion of the Available Solutions

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 I.

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, 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.

Table I - Stakeholders versus Benefits for using of smart energy meters.



Stakeholder	Benefits
Distribution and Transmission	Improved data quality in terms of efficiency, load and losses Faciliating witch of capacitor banks Improved load management
External Stackeholders	Support for the Smart Grid initiatives Improved enviroment benefits
Customers	More accurate and timely billing Improved outage restoration Increased and Improved billing options 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 & Field Operations	Eliminating handheld metering equipment Reduced trips for off-cycle reading Reduced metering cost Reduced call-centre transactions Reduced frequency of connection/disconnection
Utility	Improved employee safety Reduced regulatory complaints Improved customer premise risk profile and safety
Marketing and Load Forecasting	Reduction in the cost of data collection Improved data and decision-making quality

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. In addition the goal of smart meters development is not mainly only 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 study in this dissertation 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.

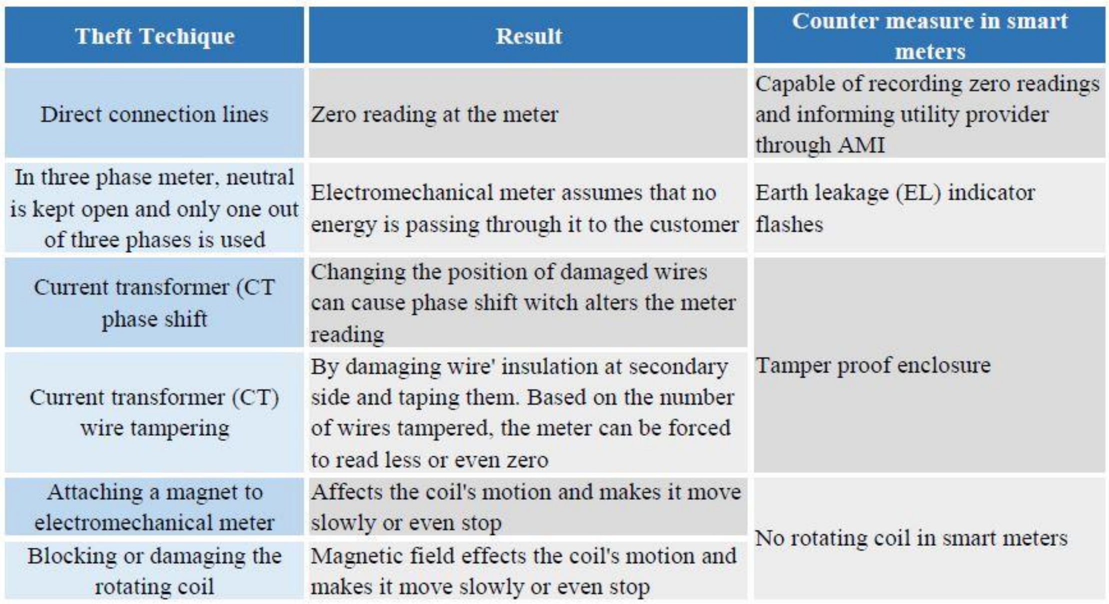
Traditionally, electromechanical meters provided no security at all. Theft in these devices can be done by connecting to the distribution wires, placing a magnet at the meter, grounding the neutral wire, blocking or damaging the spinning coil, and inverting output and input. Smart devices can be used 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 II 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 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.

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



Theft Techique	Result	Counter measure in smart meters
Direct connection lines	Zero reading at the meter	Capable of recording zero readings and informing utility provider through AMI
In three phase meter, neutral is kept open and only one out of three phases is used	Electromechanical meter assumes that no energy is passing through it to the customer	Earth leakage (EL) indicator flashes
Current transformer (CT phase shift	Changing the position of damaged wires can cause phase shift witch alters the meter reading	Tamper proof enclosure
Current transformer (CT) wire tampering	By damaging wire' insulation at secondary side and taping them. Based on the number of wires tampered, the meter can be forced to read less or even zero	
Attaching a magnet to electromechanical meter	Affects the coil's motion and makes it move slowly or even stop	No rotating coil in smart meters
Blocking or damaging the rotating coil	Magnetic field effects the coil's motion and makes it move slowly or even stop	

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 takes 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 back casting 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.

3 Proposal of a New IoT- Based Smart Energy Meter

The Smart Grid is not just a smart meter group added to the power generation. For the whole set to work, there are a number of technologies that allow integrating, interacting and controlling all elements of the grid, from generation to delivery. The Smart Grid will provide real-time information and almost instant supply and demand balancing, as well as enable two-way electricity flow and information that are capable of monitoring the entire network [13] [85] [107].

When we talk about Smart Grid, we can refer to a network that can monitor, control and protect energy generation, transmission and distribution systems in an economical way to manage dynamically changing electricity demand with acceptable quality. However, power generation capacity often does not match the need for demand, and in most cases this is because system users use the feature without concern for power availability [2] [7] [85]. In addition, other factors of serious impact are power theft and unorganized management of consumer data, which can lead to major losses for utility companies and consequently high energy bills for end users [13] [108].

IoT's built-in technology enables the interaction of internal equipment with the external environment, which in turn can affect action taken [109]. The IoT-based smart energy meter system can improve the performance and efficiency of the smart grid primarily by increasing its reliability. It also collects and analyzes data to manage active devices on the smart grid. Control can be done by analyzing the result obtained, helping the user to improve the use of the energy resource [12] [17].

3.1 Energy Meter Applications

Electromechanical meters are the most common type of electricity meter. They measure electricity flows by counting the revolutions of a metal disc, which rotates at a proportional speed to the energy metered. These equipment do not aggregate intelligence to energy monitoring systems [54].

In other hand, electronic meters are integrated with many advanced features, based on Digital Micro Technology and do not depend on mechanical moving parts. Electronic meters are becoming "smarter" as technology advances, providing real-time consumption information and other parameters to customers and suppliers, using two-way communication. Bidirectional communication distinguishes smart meters from regular meters [110].

Smart energy meters measure the amount of electrical energy consumed or generated by the consumer in kilowatt hour (kWh) unit. Other parameters commonly measured are real power, reactive power, apparent power, voltage, current, and frequency. To calculate electrical energy consumption it is necessary to have three parameters: voltage, current, and power factor. These parameters are measured by the voltage sensor, current sensor, and zero crossing detector [111].

Many comprehensive functions have been developed and added into smart energy meters based on two-way communication. These technical and logical improvements extend the applicability of smart energy meters, facilitating technological upgrade from conventional meters to smart energy meters [55]. Another important aspect regarding smart energy meters is modularization: basic meters with an open structure can receive new modules with new functionalities as needed, allowing its usage for more than just electric energy meter purposes [110].

Every energy meter must perform a regular and precise metering of energy consumption. One of IENs purposes is to reduce energy consumption and improve energy network quality, adjusting supplied and demanded energy. To perform such tasks, smart energy meters are required to operate metering hourly or more frequently intervals [112]. Another common functionality directly related to regular and precise metering is to record the registered data and send alarms notifications according to preset definitions. Besides real-time information, smart energy meters can also record historical and cumulative data over a certain period, such as energy consumption. Data recording and alarm sending are important to perform energy network status monitoring and useful for consumers to know the details about their energy usage [18].

Two-way communication enables smart energy meters to transmit not only measured data, but also specific commands and instructions for remote appliances control. With these feature consumers can remotely manage their appliances, turning them on/off as needed. Also, suppliers can perform network changes or even remotely disconnect consumers’ energy [18]. Smart energy meters should contain a communication module, which is responsible for transmitting measured data and receiving instructions to perform specific actions. In order to improve smart energy meters reliability, the communication module usually operates independently of other smart meter functions, such as metering, data recording, and alarm sending. In this way, losing connection to the network will not affect other meter's functions and communication may continue after the equipment gets re-connected [31] [113]. Two-way communication functionality for smart energy meters can be performed via wired or wireless communications. Wired connections usually provide a larger transmission capacity, while maintaining both reliability and security. However, wired networks usually require larger infrastructure investments when compared to wireless technologies. Fiber options and PLC are the most common wired technologies used on IENs [114]. For wireless communication, different technologies are available for smart meters, each one with specific characteristics regarding bandwidth, transmission distance, stability, and cost. Most common wireless technologies used to create IENs are ZigBee, Bluetooth Low Energy, Wi-Fi, and Wireless M-bus [31] [111].

Heterogeneous networks are frequently proposed when creating IENs communication networks. Wired communication can be used to connect backbones where information of many smart sensors is transmitted, due to its larger transmission capacity. In turn, wireless communication is more efficient and cheaper when connecting smart sensors in smaller areas, providing flexible and bi-directional communication [114].

In addition, a new concept has recently gained much popularity, the Internet of Energy, referring to the specific type of IENs where the Internet is used as a communication tool. Internet continuous development will enable future IENs with greater communication capacity, which invites for more advanced features and applications for smart energy meters. Given the strengths and weaknesses of every technology, it is important to combine different communication technologies in order to meet technical requirements and also maintain investment cost, system reliability, and system security at optimal levels [31]. An appropriate IoT-based networking model can be designed and implemented with such combinations, improving IENs efficiency to reach better results both for consumers and suppliers [115].

The arrival of smart devices has promoted the concept of connecting everyday objects via data networks. The extreme increase of connected devices has outreached the conventional network elements capacity, resulting in a new network architecture creation, based on IoT concept. IoT networks can manage heterogeneous devices and objects, each one uniquely addressable and capable of identifying and sharing information, with or without human interaction. IoT network concept is matured and receives extensive attention, leading towards the innovation of novel applications, i.e. smart building, smart home, smart transportation, smart healthcare, smart industry, etc. Therefore, making IoT as a standard for connecting smart sensors, it can help the creation of a universal communication platform for smart environments [116].

3.2 Project Proposal

The project presented is a complete management and monitoring system of electricity and aggregate devices and loads, consisting of a hardware capable of real-time monitoring and analysis of grid quality parameters (voltages, currents, consumption, among others). Remote load control (lighting and air conditioning systems, for example) is also possible, added to a management platform capable of monitoring a network of installed equipment, generating management reports of all monitored parameters and reporting remotely alarm conditions.

The hardware to be used to meet this proposal is a smart meter - Intelligent Electric Energy Meter, specifically developed to meet the technical characteristics required to implement a system like this. An inexpensive platform for three-phase network monitoring, specifically focused on sectored energy monitoring, with connectivity suitable for powering different management platforms (support for multiple open protocols and different media, including wireless networks).

Smart meters currently available in the market do not provide, in a single equipment, all the features necessary to create an advanced electrical management system. To achieve these functionalities with existing solutions, it is necessary to use together different equipment with complementary functions, which ends up making the final solution unfeasible financially. For example, in addition to the conventional smart energy meter for power monitoring, load control (lighting and air conditioning systems, for example) requires the use of equipment that has these read and write interfaces (I/Os). Similarly, it is necessary to use a concentrator system to locally record this information and make it available to a centralized management system, compatible with different protocols and media. When creating a system combining these different modules, in addition to the complexity of configuring them correctly, the total price of the solution becomes too high, making the commercial use of the solution unfeasible.

3.3 Proposal of an IoT-Enabled Smart Energy Meter

The choice to develop a new Smart Meter for the proposed project was based on the possibility of incorporating all these previously mentioned features into a single solution, making the final cost of the solution accessible, its configuration easier and its implementation made possible on scale. The developed equipment consists of three distinct blocks: energy analysis block, main processing, input/output (I/O) block, communication and and IoT connection block. Figure 5 illustrates this architecture and the Figure 6 shows the hardware:

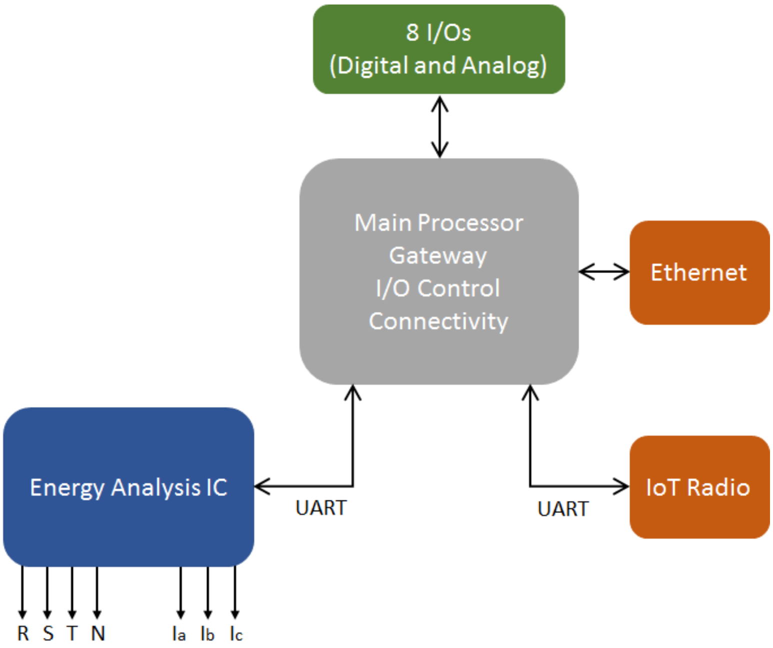


Figure 5 - Smart Energy Meter Block Diagram.

Figure 6 - Smart Energy Meter Hardware.

A Texas Instruments® SoC (System-Chip) was created specifically for the full monitoring of the power grid: MSP430F67641®. This 16-bit processor is designed exclusively for three-phase power network monitoring, featuring 24-bit Delta-Sigma analog/digital (A/D) converters for monitoring current signals and 10-bit SAR A/D converters for monitoring signs of tension. With a powerful 25MHz CPU and 32-bit hardware multipliers, this platform quickly and accurately delivers phase and voltage RMS values, active, reactive and apparent power, power factor and frequency per phase.

The circuit designed for collecting phase voltage information allows a maximum voltage reading between 260 V phase and neutral, with surge protection provided by varistors and TVS diodes. The voltage of each phase is reduced to appropriate levels (VRef) through an attenuation chain and shifted so that it can be correctly measured by the integrated circuit 10-bit SAR A/D converters. Figure 7 presents the input circuit for voltage monitoring.

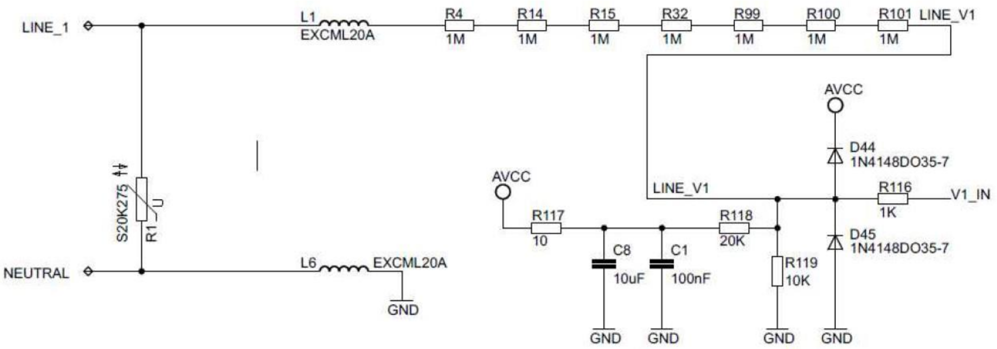


Figure 7 - Input circuit for monitoring each voltage phase.

The circuit designed to collect phase current information, measured through current transformers (TCs), measures a differential voltage across a 12,4O Ω resistor burden and allows internal currents up to 50mA. The reference voltage generated by the circuit is measured by high-speed 24-bit Delta-Sigma A/D converters and used for power factor and power factor calculations. The TC should be chosen according to the maximum rated current per phase, and the current in its secondary should not exceed 50mA. Current input circuits are also protected with TVS diodes. Figure 8 shows the current input circuit.

To create the equipment access interface, manage its connectivity and store the collected data in non-volatile memory, a Tiva C family Texas Instruments® microcontroller was chosen. Its diagram is presented in Figure 9. This platform was chosen because of its simplified support for an integrated Ethernet physical layer (Ethernet) connection and a suitable processing capacity for the proposed system. With an ARM-Cortex-M® architecture and 120MHz CPU throughput, all monitored main parameters are available on the machine's own webpage, and are available for remote reading via MODBUS protocols, Remote Terminal Unit (RTU), Simple Network Management Protocol (SNMP), Message Queuing Telemetry Transport (MQTT), Constrained Application Protocol (CoAP), and RESTful API.

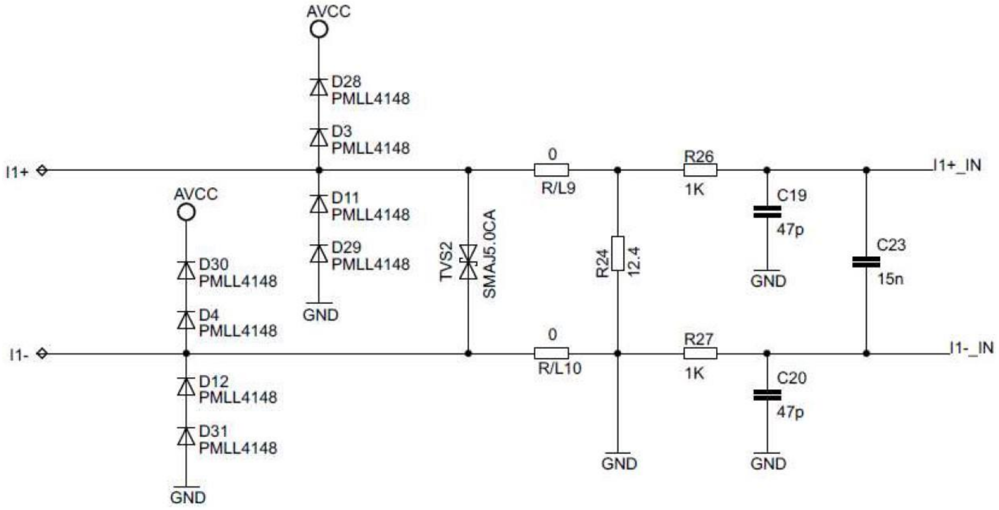


Figure 8 - Input circuit for TC current monitoring.

The micro controller mentioned above is also responsible for managing the equipment I/O's, capable of remote control of loads (such as lighting/cooling circuits on/off) and additional monitoring of the mains parameters (temperature and humidity, photovoltaic sensors, among others). Eight I/O ports were available in the developed equipment, which can be individually configured as digital output, digital input or analog input, with internal 12-bit A/D converters. All ports work in the 3.3Vdc voltage range and are protected with TVS diodes. These I/O's are accessible through the machine's web page and the protocols supported by it.

Among the protocols and form of access supported by the developed equipment, we highlight the Ethernet connectivity, through which, through its web page, there is real time monitoring of all electrical parameters and I/O's, as well as access up to 60 days historical data recorded in non-volatile internal memory of the equipment.

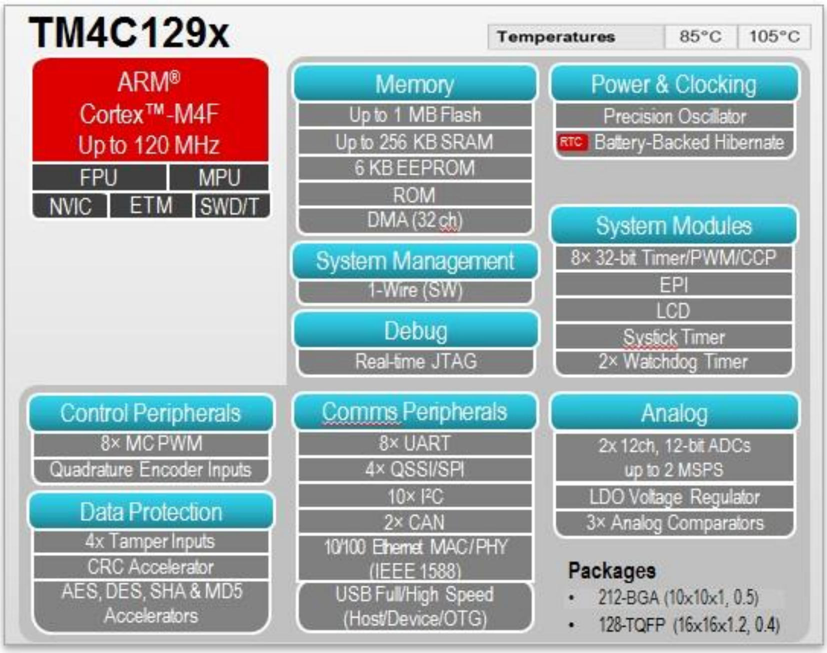
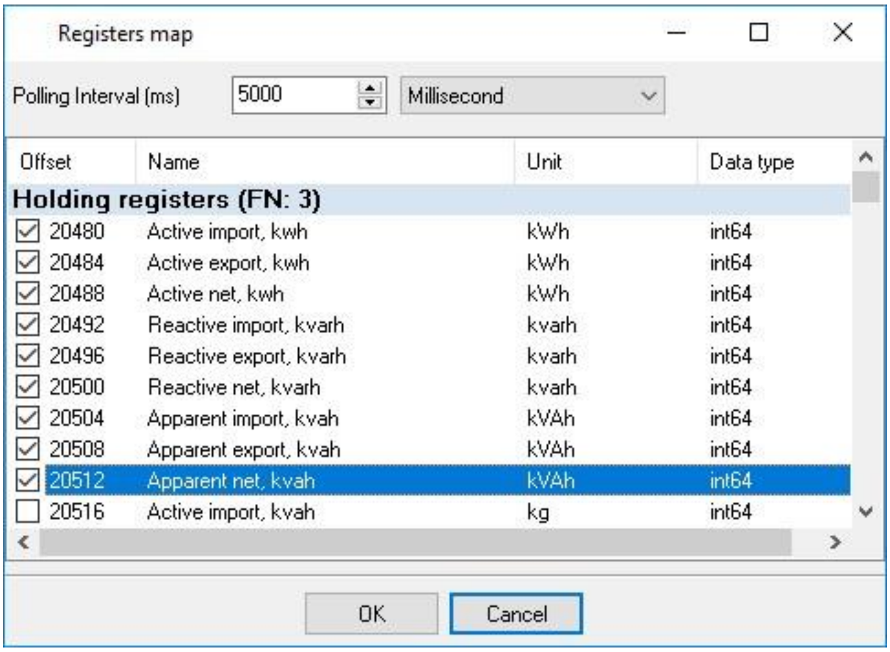


Figure 9 - Processor block diagram used in the project.

Support for the MODBUS RTU protocol, via an RS-485 serial port, was made to make the developed equipment compatible with older systems (Legacy Support). All measurements and I/O's can be accessed through an address table created for the equipment, with information updated at 1 second intervals. Below, in Figure 10 is the project's MODBUS record map.

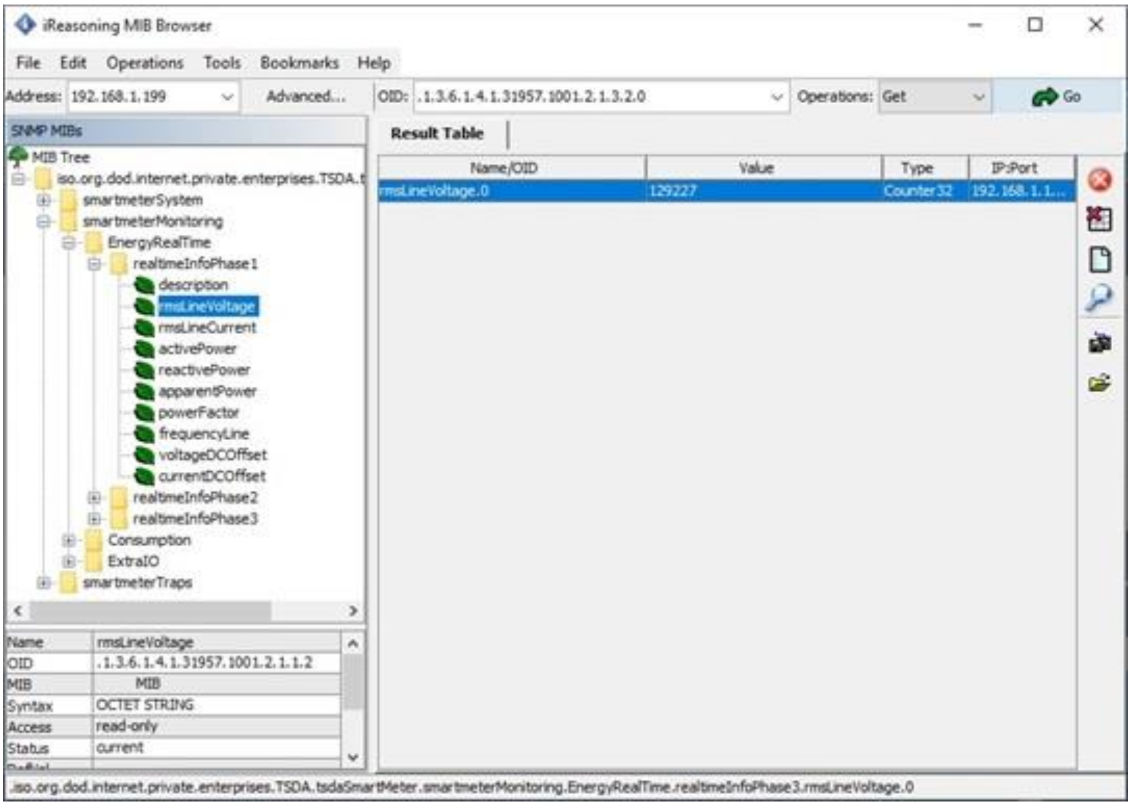
SNMP protocol support allows equipment to be monitored by any management system (NMS) compatible with this protocol, such as NAGIOS®, ZABBIX®, DATAMINER®, SPECTRUM® and many other commercially available software. The MIB table of the equipment, shown in Figure 11, with the mapping of all information reported by it through SNMP protocol, is available for download on its web page, to facilitate its integration. The equipment can also report configured alarm conditions by sending TRAPs to predefined IP addresses. This way, constant monitoring of the monitored values is not necessary to detect anomalies in the power grid.



Polling Interval (ms) 5000 Millisecond

	Offset	Name	Unit	Data type
Holding registers (FN: 3)				
☑	20480	Active import, kwh	kWh	int64
☑	20484	Active export, kwh	kWh	int64
☑	20488	Active net, kwh	kWh	int64
☑	20492	Reactive import, kvarh	kvarh	int64
☑	20496	Reactive export, kvarh	kvarh	int64
☑	20500	Reactive net, kvarh	kvarh	int64
☑	20504	Apparent import, kvah	kVAh	int64
☑	20508	Apparent export, kvah	kVAh	int64
☑	20512	Apparent net, kvah	kVAh	int64
☐	20516	Active import, kvah	kg	int64

Figure 10 - Smart Meter MODBUS Records Map.



Address: 192.168.1.199

OID: .1.3.6.1.4.1.31957.1001.2.1.3.2.0

Operations: Get

Name/OID	Value	Type	IP:Port
rmsLineVoltage.0	129227	Counter32	192.168.1.1...

Name	rmsLineVoltage
OID	.1.3.6.1.4.1.31957.1001.2.1.1.2
MIB	MIB
Syntax	OCTET STRING
Access	read-only
Status	current

.iso.org.dod.internet.private.enterprises.TSDA.tsdaSmartMeter.smartmeterMonitoring.EnergyRealTime.realtimeInfoPhase3.rmsLineVoltage.0

Figure 11 - Smart energy meter MIB table.

In addition to the RS-485 and Ethernet TCP / IP protocols, the Texas Instruments MCU® CC2650 was used to connect the equipment to wireless IoT networks. This microcontroller supports the Bluetooth®, ZigBee® and 6LoWPAN® or ZigBee RF4CE® protocols, making Smart Meter compatible with most IoT networks today deployment, such as Inatel's Smart Campus. The CC26xx family of controllers has excellent value for money, low power consumption and works in the 2.4GHz frequency range. This device has a 32-bit ARM Cortex-M3 CPU capable of implementing protocols such as MQTT and CoAP, widely used in the IoT universe, as well as an ARM Cortex-M0 secondary processor, used to implement the physical layer of the Bluetooth controller® Low Energy (BLE) and IEEE 802.15.4.

4 Performance Evaluation, Demonstration, and Solution Validation

To analyze and validate the smart meter and the proposed energy monitoring system, the tests were performed in the Smart Campus environment of the INATEL (Instituto Nacional de Telecomunicações) in the IoT Research Group laboratory. The smart meter was installed in a power distribution board as shown in Figure 12. To perform the tests, the smart meter received three voltage samples, one neutral sample and three current samples, each sample corresponds to one phase of the low voltage network.

Figure 12 - Power distribution board where smart energy meter is installed - IoT Research Group Lab (Inatel).

In order to collect data from the smart energy meter it was necessary to establish a UART connection between the smart meter and the chosen radio, as already shown in Figure 5. In this case, the radio chosen was nodeMCU, a Wi-Fi radio focused on IoT application development. The choice of Wi-Fi protocol as connectivity over IEEE802.15.4, Bluetooth®, ZigBee® or 6LoWPAN based protocols is due to the environment in which this radio is inserted. The use of protocols based on IEEE802.15.4

is made when the device does not have high energy availability, *i.e.*, when the device needs to operate on batteries, unlike the scenario presented, as the smart meter receives power directly from a low distribution board, not presenting any problem with the power in this scenario.

The process of reading smart meter data can be divided into steps, which are listed below:

- The MSP430 processor® reads the grid parameters, collecting data such as voltage and current, and sends this data to TM4C®, the other processor, via UART;
- TM4C® receives this data and updates the values received in EEPROM memory through an interrupt. This process occurs approximately every 2 seconds;
- While the aforementioned processes happen, a function in TM4C® prepares a string with all parameter variables received from MSP430 to JSON format, this allows sending this data to nodeMCU, also via UART, so make it possible to make a valid MQTT publication for In.IoT. This process is also performed every 5 seconds approximately.

4.1 Prototype Demonstration and Validation at the IoT Research Group Laboratory

The data collected by the smart energy meter was sent to In.IoT, an IoT Middleware solution developed by IoT Research Group, as shown in Figure 13. An IoT Middleware is computer programmer that connects basic systems such as IoT devices to each other and to third party applications [117] [118]. It acts as a translation layer, enabling communication and data management for distributed applications. Within the power management system, middleware plays an essential role as it receives all data sent by the smart energy meter and stores it for specific queries to be quickly and consistently accessible to the user. In.IoT [https://inatel.br/in-iot/] [119] [118] [119] also allows users to view the status of the various variables measured by the smart energy meter in real-time via Web, as shown from Figure 14 to Figure 17. In.IoT currently supports the most popular application-layer IoT protocols, namely: HTTP, MQTT, and

CoAP. For this first iteration of the smart energy meter, the MQTT protocol was chosen because it can allow the solution to communicate with other devices. To connect to In.IoT using nodeMCU, an API called PubSubClient available at https://github.com/knolleary/pubsubclient was used. PubSubClient is an MQTT client for the Arduino® development environment.

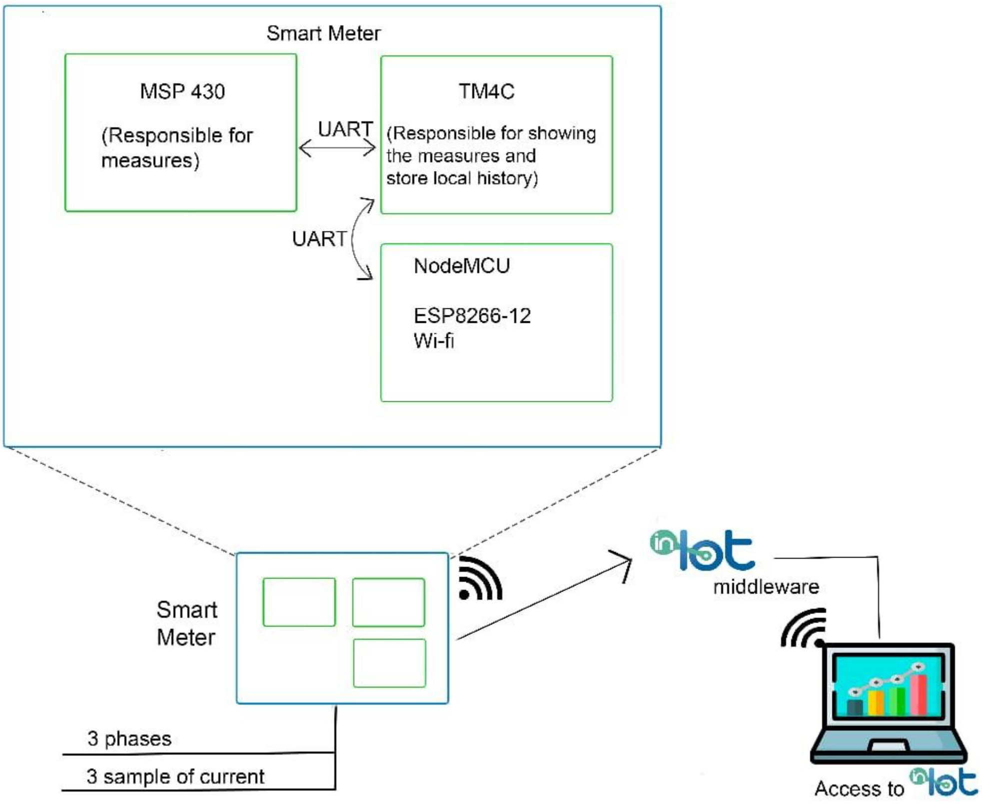


Figure 13 – Block diagram of smart energy meter connection in In.IoT middleware.

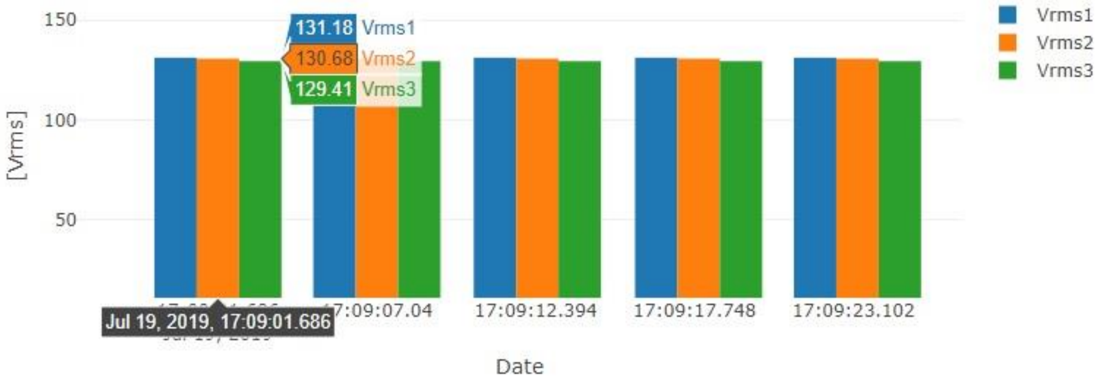


Figure 14 - Status of voltage variable measured by the smart energy meter in real time via Web – In.IoT.

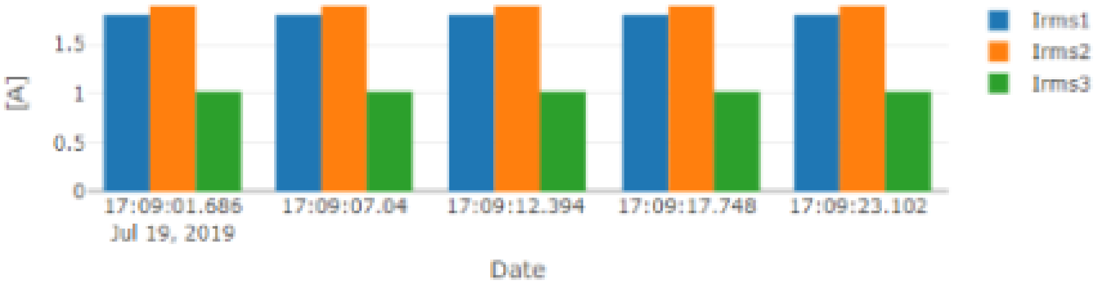


Figure 16 - Status of current variable measured by the smart energy meter in real time via Web - In.IoT

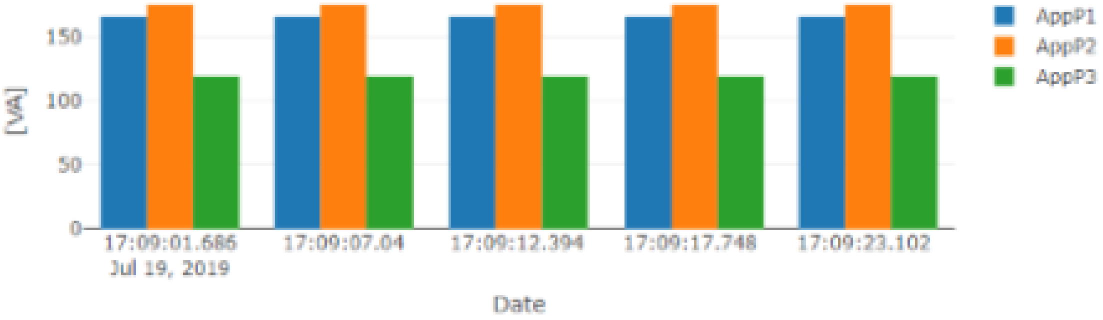


Figure 15 - Status of Apparent Power variable measured by the smart energy meter in real time via Web - In.IoT

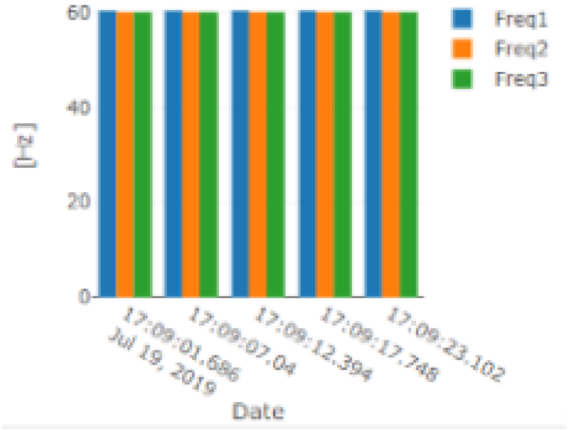


Figure 17 - Status of frequency variable measured by smart energy meter via Web - In.IoT

4.2 Solution Validation

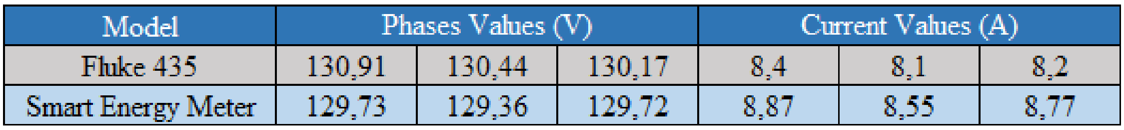
In order to validate the performance of the proposed smart energy meter, a comparison was made with a commercial metric, the Fluke 435 Series II Power and Energy Analyzer model, as shown in Figure 18. Smart energy meter readings and measurements showed great compatibility when compared to the market device. The smart energy meter has a calibration menu that makes it possible to adjust voltage and current values. This fine adjustment was performed during the tests, further approximating the measurements of voltage and current variables. Table III presents the readings taken by the proposed smart energy meter and the commercial meter.

In addition, the equipment was installed at the entrance panel of the company TSDA, as shown in Figure 19, in the city of Santa Rita do Sapucaí - MG, monitoring the three-phase network of CEMIG (Energy Company of Minas Gerais) and the consumption of the entire company. A 100A current transformers (CTs) were used for each phase, enough for the company's consumption class.

Figure 18 - Comparison of measurements between the smart energy meter and a commercial meter.

By directly accessing the smart energy meter Web interface, it was possible to have real time monitoring and data collection, as well as access to basic consumption reports, as shown in Figure 20 and Figure 21.

Table III - Voltage and Current Values Comparison Table - smart energy meter versus commercial meter.



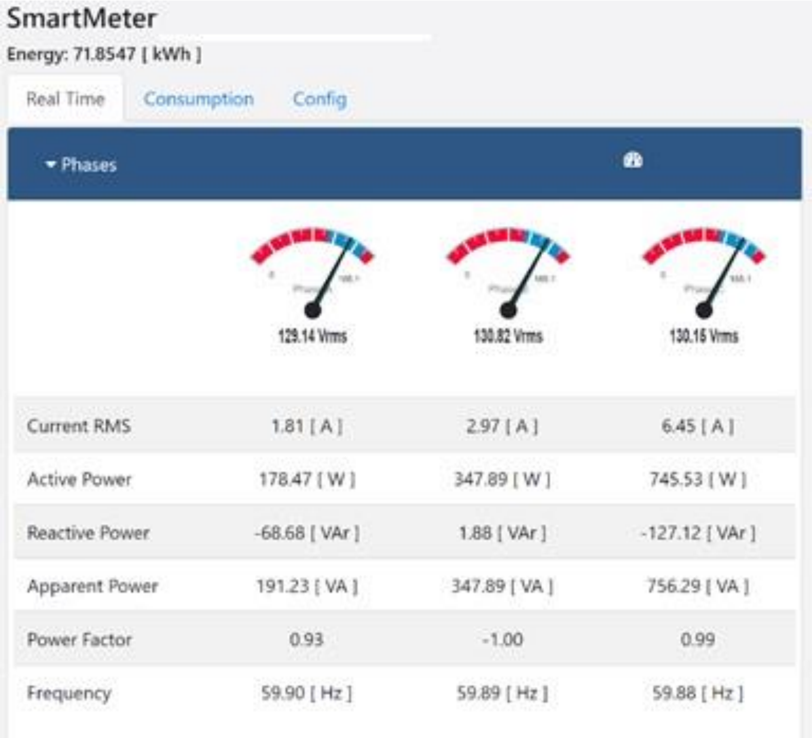
Model	Phases Values (V)			Current Values (A)		
Fluke 435	130,91	130,44	130,17	8,4	8,1	8,2
Smart Energy Meter	129,73	129,36	129,72	8,87	8,55	8,77

The equipment has internal memory capable of storing consumption data for the last 60 days of operation, totaling the consumption of the three phases and distinguishing active and apparent power, as well as daily accumulation. Figure 22 shows a historical consumption of 30 days a day. Figure 23 shows the 60-day consumption history, showing consumption per week.

Figure 19 - Smart energy meter installed on TSDA Company three phase frame.

To demonstrate the operation of the smart energy meter in a more commercial management system, it was also monitored using SNMP management software, developed by TSDA itself, called Horus NMS®. This software is capable of managing any equipment that supports the SNMP, simply by pre-registering the parameters provided by the equipment through this Management Information Block (MIB) protocol, as shown earlier in Figure 10. The developed equipment has full support for this protocol, including alarm sending (TRAPs) in case of alarms.

Using the Horus NMS® tool, a graphical interface was created for real-time information visualization using appropriate dials and pointers for this function. For each input phase the following parameters were monitored: RMS voltage, RMS current, frequency, power factor, active and apparent power. Examples of the presentation of measurements cited in the software can be seen in Figure 24 and Figure 25.



SmartMeter

Energy: 71.8547 [kWh]

	129.14 Vrms	130.82 Vrms	130.15 Vrms
Current RMS	1.81 [A]	2.97 [A]	6.45 [A]
Active Power	178.47 [W]	347.89 [W]	745.53 [W]
Reactive Power	-68.68 [VAr]	1.88 [VAr]	-127.12 [VAr]
Apparent Power	191.23 [VA]	347.89 [VA]	756.29 [VA]
Power Factor	0.93	-1.00	0.99
Frequency	59.90 [Hz]	59.89 [Hz]	59.88 [Hz]

Figure 20 – Real-time analysis electrical parameters.

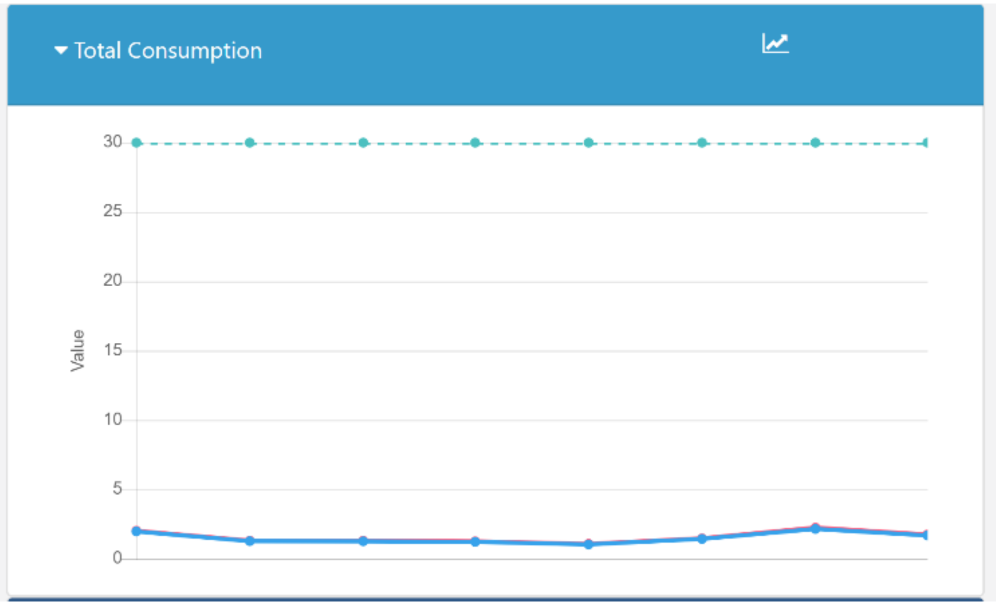


Figure 21 – Real-time analysis consumption.

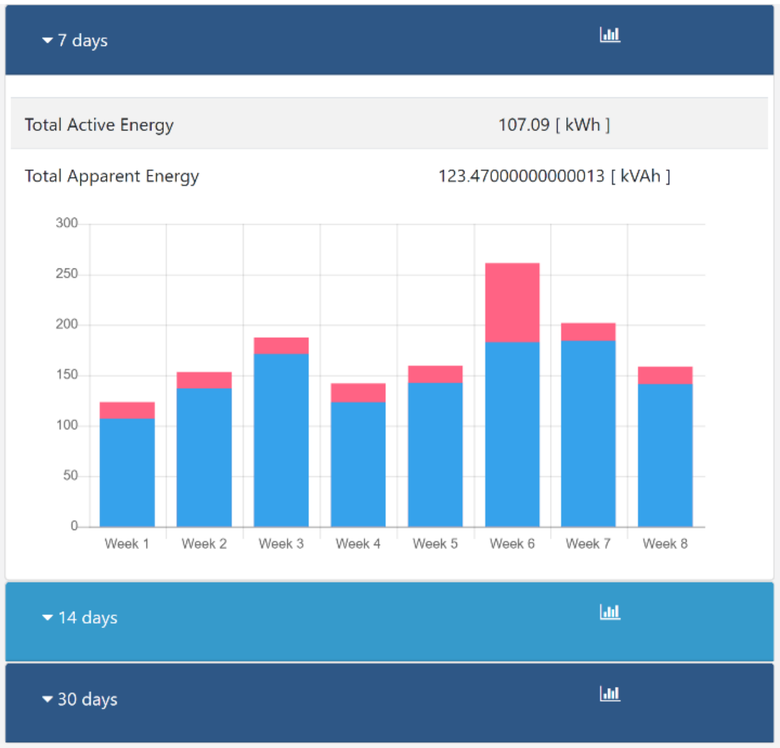

SmartMeter

Energy: 71.9683 [kWh]

Total Active Energy 17.79 [kWh]

Total Apparent Energy 20.14000000000001 [kVAh]

Figure 22 – History of 30 days of consumption, with daily accumulation.



Total Active Energy 107.09 [kWh]

Total Apparent Energy 123.47000000000013 [kVAh]

Figure 23 – History of 60 days of consumption, with weekly accumulation.

In addition to the real-time monitoring of the company's electrical parameters, the Horus NMS® tool was responsible for generating several reports, through which it is possible to analyze the quality of energy supplied by the utility to the company, as well as consumption characteristics, analyzing periods and different times. Figures 26 and 27 present a utility voltage report where an interrupt record has been verified.

Figure 24 – Three-phase monitoring interface created in Horus NMS®.

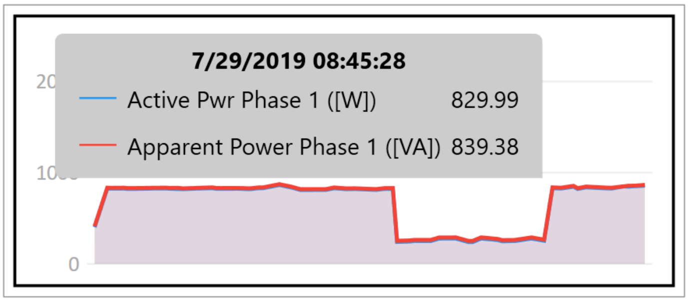
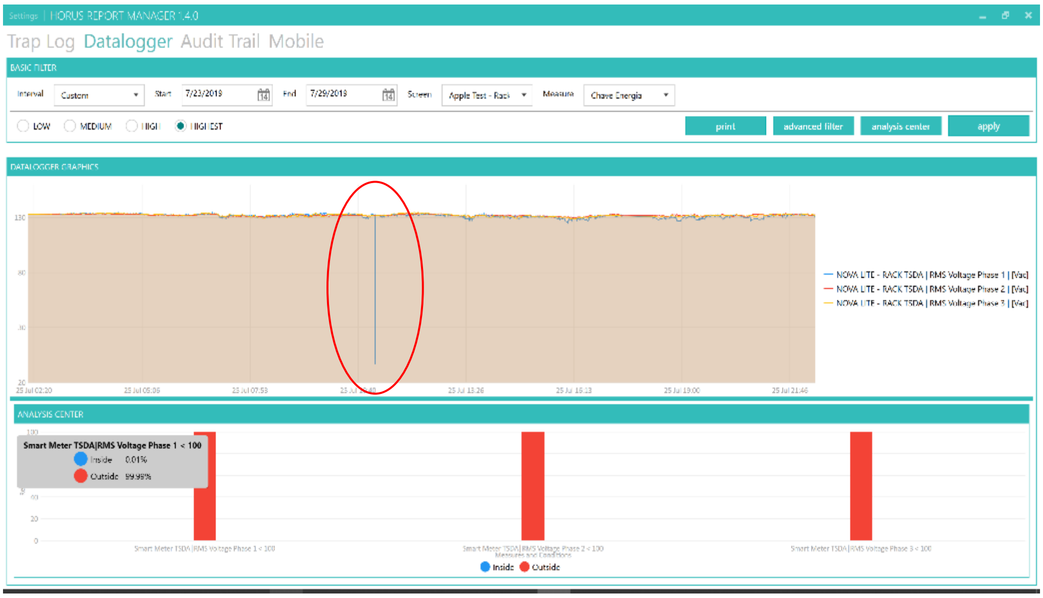


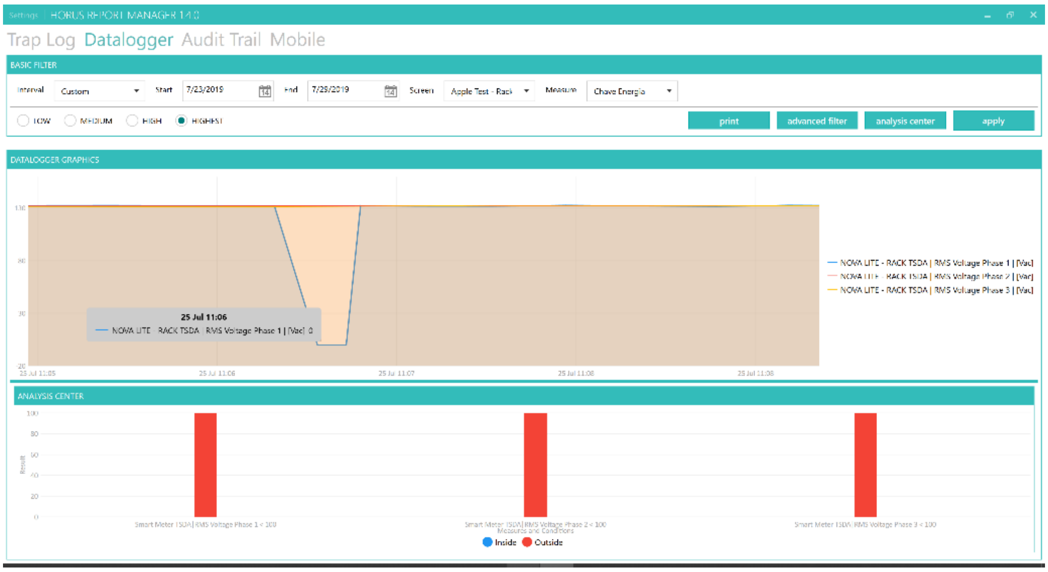
Figure 25 – Consumption by phase: active and apparent power.



Interval: Custom
Start: 7/23/2019
End: 7/29/2019
Screen: Apple Test - Rack
Measure: Chave Energia
○ LOW ○ MEDIUM ○ HIGH ● HIGHEST

Smart Meter TSDA|RMS Voltage Phase 1 < 100
Inside 0.01%
Outside 99.99%

Figure 26 – Management report of mains input voltage, with interruption record.



Interval: Custom
Start: 7/23/2019
End: 7/29/2019
Screen: Apple Test - Rack
Measure: Chave Energia
○ LOW ○ MEDIUM ○ HIGH ● HIGHEST

25 Jul 11:06
NOVA LITE - RACK TSDA - RMS Voltage Phase 1 | [Vac]: 0

Figure 27 – Breakdown of the registered mains failure.

In addition to the equipment installed at TSDA, a smart energy meter was also installed in the city of Joinville - Santa Catarina, in one of the company's customers. In all cases observed, the information and reports generated by the equipment were extremely reliable and the equipment met all desired specifications. In Figure 28 you can see the installation of the CTs in the local power distribution board (left of the image) and the installation of the smart energy meter (the right image).

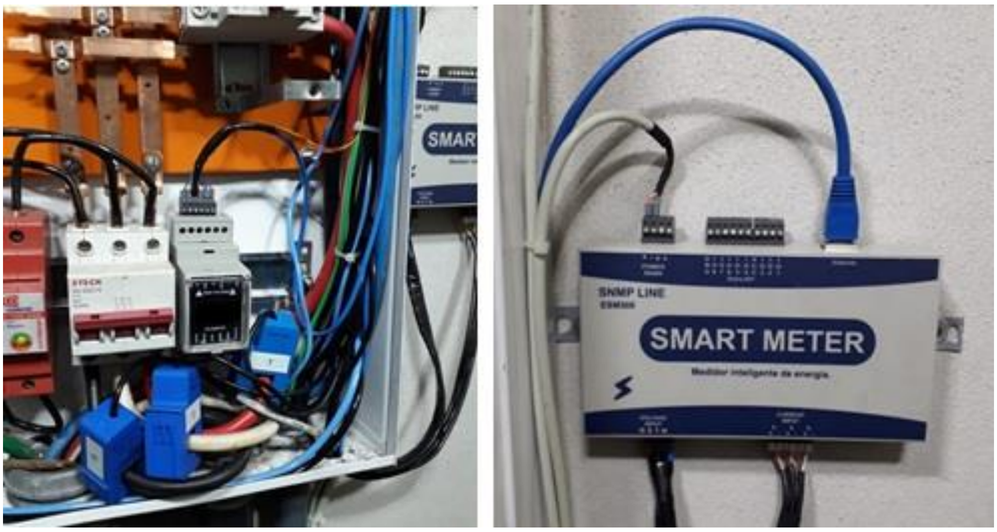


Figure 28 – Field installed experiment equipment.

5 Conclusion and future works

5.1 Learned lesons

Through this research study, valuable lessons have been learned that can help future researchers interested in IoT-based energy resource management solutions, such as developers trying to create/improve solutions, or users who want to evaluate solutions.

Using an energy resource management system by itself does not solve the problem of using these resources unconsciously. Users need to be aware of and exercise their humanity and care for the environment, avoiding misuse and waste of energy resources. It is also critical that utilities responsible for energy supply provide quality and efficient delivery of this resource that is, ensuring that the end user has guarantees about the origin, continuity of service and honesty regarding the measurement of the charge.

Another point noted is the complexity of promoting an integrated solution for the management of energy resources and the performance of installed loads. For the user to be able to obtain a service where it is possible to receive energy consumption data in real time and to be able to interact with the loads installed in their home (such as lighting circuits and other devices), it is necessary to use more than one device. The more equipment we have installed on the same system, the greater the chances that the solution will malfunction. In addition, the more equipment, the more likely the cost of the solution will be.

5.2 Final remarks

Throughout this dissertation, an up-to-date study on energy management for the end-consumer side was presented, as well as the development of a low-cost multiprotocol IoT-based intelligent multi-protocol power trigger.

The dissertation first introduced the motivation and delimited the research theme, describing the objectives and exposing their main contributions. In Chapter 2, a detailed description of the key features that smart energy meters should provide is provided. This chapter provides an overview of existing solutions and smart grid energy meters, giving the reader a detailed look at the capabilities already offered by smart meters and what they will have available to meet the challenges that smart grids present.

Chapter 3 presented a low-cost, multi-protocol, modular IoT enabled, three-phase intelligent power proposal capable of collecting, processing, and transmitting a variety of electricity-related information, focused primarily on the consumer side. This chapter outlined the end-user needs and benefits that the proposed device could offer. It then presented the desired technical details and prototype construction requirements.

Chapter 4 presents the performance evaluation, demonstration, and validation of the proposed solution through actual experiments. The design provides an intelligent low power metering system. The proposed project is implemented at the end consumer and is capable of sending commands and monitoring the quality of the power supply provided by the local utility, and receiving instant updates of any monitored variable faults. Tools for the management of energy resources were presented, where the consumer is able to consult in real time the variables measured through the proposed smart energy meter. The focus on the monitoring and data management solution is achieved through Web-based IoT middleware developed by IoT Research Group – Inatel, the In.IoT Middleware.

Through the IoT point of view, smart energy meters will use the Internet to improve the efficiency and resources of the power grid. 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.

In addition to all the benefits that a smart energy meter can provide, as mentioned in this work, one of the main benefits of this previously mentioned protocol diversity equipment is its possible integration into existing or new systems without the need to use a proprietary solution provided by a single manufacturer. Thus, the smart energy meter developed, supported by IoT technology, can be applied in the most different scenarios, where quality monitoring and power consumption are required.

Several other applications can be inserted into the proposed smart energy meter. In addition to the real time reading of the quality and consumption of electricity delivered by the utility, it is possible to trigger other devices, due to the I/Os present in the equipment. With middleware integration and web access, you can, for example, remotely turn on/off air conditioners or even lighting circuits. Such a resource can avoid wasting energy resources.

Another advantage of smart energy meter is its development value. According to the company TSDA, which provided hardware prototyping, the value of the inputs, considering the current transformers (TCs), was a total of R$ 512.59. This value is much lower compared to other smart meters in the market and with capacities, inferior techniques.

The objective of this work was to design, develop and validate a low cost system that monitors the energy consumed and then sends the data through a wireless transmission system through a smart meter using the IoT protocols. The data is collected by a Middleware capable of managing and providing the user with energy usage information over the Internet. The smart meter works online where all data is received in real time. Bluetooth®, ZigBee® and 6LoWPAN® or ZigBee RF4CE® protocols are enabled and for testing Wi-Fi was used for testing and validate the smart meter's ability to communicate with Middleware. Other resources may be explored in future work. Also, as future work, the system may be installed in a smart environment, such as installation in a smart home.

Nowadays people check their energy use manually and depend on the reading done on the meters installed by the utility representatives, being a system with little information and often inefficient. There is a growing concern about the amount of energy consumed and the awareness of consumers' use of energy resources. By making use of smart meters, consumers will be able to use the Internet or the smartphone app to monitor and save their energy consumption. With more information on energy consumption, people will be able to reduce their energy consumption and thus save energy and money.

Advancement in technology has been a great ally for the spread of information to all and, increasingly, we are hostage to energetic resources, making electricity an irreplaceable protection. In this scenario, IoT is an indispensable tool, providing developments of various shapes and types. Consequently, we can apply it perfectly to the study scenario, providing a low cost, intelligent solution of great importance for the best use of energy power. And from the tests we can conclude that the smart meter developed allows consumers to easily, accurately, efficiently and reliably monitor their energy usage and can meet the growing information needs.

5.3 Future Works

Usage of Internet could contribute to smart power grid configuration and control in real-time. Next, the concept of the Internet of Things 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 micro grid. 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 micro grids 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 a 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.

References

[1] S. Galli, A. Scaglione and Z. Wang, "For the Grid and Through the Grid: The Role of Power Line Communications in the Smart Grid," *Proceeding of the IEEE,* vol. 99, pp. 998-1027, 2011.

[2] A. Jadhav and N. R. Patne, "Priority-Based Energy Scheduling in a Smart Distributed Network With Multiple Microgrids," *IEEE Transactions on Industrial Informatics,* vol. 14, pp. 3134-3143, 2017.

[3] S. S. Depuru, L. Wang, V. Devabhktuni and N. Gudi, "Smart Meters for Power Grid - Challenges, Issues, Advantages and Status," in *2011 IEEE/PES Power Systems Conference and Exposition*, Phoenix, AZ, USA, 2011.

[4] M. Popa, "Data Collecting from Smart Meters in an Advanced Metering Infrastructure," in *2011 5th IEEE International Conference on Intelligent Engineering Systems*, Poprad, Slovakia, 2011.

[5] J. Momoh, Smart Grid: Fundamentals of Design and Analysis, IEEE Press Series on Engineering, 2012.

[6] J. Gao, Y. Xiao, J. Liu, W. Liang and C. L. P. Chen, "A Survey of Communication/Networking in Smart Grids," *Future Generation Computer Systemns,* vol. 28, pp. 391-404, 2012.

[7] V. C. Gungor, D. Sahin, T. Kocak, S. Ergut, C. Buccella, C. Cecati and G. P. Hancke, "A Survey on Smart Grid Potential Applications and Communication Requirements," *IEEE Transactions on Industrial Informatics,* vol. 9, pp. 28-42, 2012.

[8] H. Das and L. C. Saikia, "GSM Enabled Smart Energy Meter and Automation of Home Appliances," in *2015 International Conference on Energy, Power and Environment: Towards Sustainable Growth (ICEPE)*, Shilong, India, 2015.

[9] S. Haben, C. Singleton and P. Grindrod, "Analysis and Cluestering of Residential Customers Energy Behavioral Demand Using Smart Meter Data," *IEEE Transactions on Smart Grid,* vol. 7, pp. 136-144, 2016.

[10] A. Molina-Markham, P. Shenoy, K. Fu, E. Cecchet and D. Irwin, "Private Memoirs of Smart Meter," in *BuildSys 2010*, Zurich, Switzerland, 2010.

[11] J. Zheng, D. Wenzhong and L. Lin, "Smart Meters in Smart Grid: An Overview," in *2013 IEEE Green Technologies Conference (GreenTech)*, Denver, CO, USA, 2013.

[12] T. Tony, P. Sivraj and K. K. Sasi, "Net Energy Meter With Appliance Control and Bi-Directional Communication Capability," in *2016 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, Jaipur, India, 2016.

[13] M. Saleh, A. Althaibani, Y. Esa, Y. Mhandi and A. Mohamed, "Impact of Clustering Microgrids on Their Stability and Resilience During Blackouts," in *2015 International Conference on Smart Grid and Clean Energy Technologies (ICSGCE)*, Offenburg, Germany, 2015.

[14] N. Ruiz, I. Cobelo and J. Oyarzabal, "A Direct Load Control Model for Virtual Power Plant Management," *IEEE Transactions on Power Systems,* vol. 24, pp. 959-966, 2009.

[15] A. Arif, M. Al-Hussain, N. Al-Mutairi, E. L-Ammar, Y. Khan and N. Malil, "Experimental Study and Design of Smart Energy Meter for the Smart Grid," in *2013 International Renewable and Sustainable Energy Conference*, Ouarzazate, Morocco, 2013.

[16] S. Rani, R. Talwar, J. Malhotra, S. H. Ahmed, M. Sarkar and H. Song, "A Novel Scheme for an Energy Efficient Internet of Things Based on Wireless Sensor Network," *Multidisciplinary Digital Piblishing Institute,* 2015.

[17] Benoit, J.; Cooper, E.;, "The Internet of Things and the Energy Sector: Myth or Opportunity," in *Power and Energy Automation Conference*, Spokane, WA, EUA, 2016.

[18] Q. Sun, Z. Ma, C. Wang, J. Campillo, H. Li, Q. Zhang, F. Wallin and J. Guo, "A Comprehensive Review of Smart Energy Meters in Intelligent Energy Networks," *IEEE Internet of Things Journal ,* pp. 464-479, 24 December 2015.

[19] Z. Zhou, J. Gong, Y. He and Y. Zhang, "Software Defined Machine-to-Machine Communication for Smart Energy Management," *IEEE Communications Magazine,* vol. 55, pp. 52-60, 2017.

[20] R. Morello, C. d. Capua, G. Fulco and S. C. Mukhopadhyay, "A Smart Power Meter to Monitor Energy flow in Smart Grids: The Role of Advanced Sensing an IoT in the Electric Grid of the Future," *IEEE Sensors Journal,* vol. 17, pp. 7828-7837, 2017.

[21] H. Farhangi, "The Path of the Smart Grid," *IEEE Power and Energy Magazine,* vol. 8, pp. 18-28, 2010.

[22] Faruqui, A.; Mitarotonda, D.;, "The Costs and Benefitis os Smart Meters for Residential Customers," *IEE Whitepaper,* 2011.

[23] X. Fang, S. Misra, G. Xue and D. Yang, "Smart Grid - The New Improved Power Grid: A Survey," *IEEE Communications Surveys & Tutorials,* vol. 14, pp. 944-980, 2012.

[24] Z. M. Fadlullah, M. M. Fouda, N. Kato, A. Takeuchi, N. Iwasaki and Y. Nozaki, "Toward Intelligent Machine-to-Machine COmmunications in Smart Grid," *IEEE Communications Magazine,* vol. 49, pp. 60-65, 2011.

[25] W. Chin, W. Li and H. Chen, "Energy Big Data Security Threats in IoT-Based Smart Grid Communications," *IEEE Communications Magazine,* vol. 55, pp. 70-75, 2017.

[26] D. B. Avancini, S. G. B. Martins, R. A. L. Rabêlo, P. Solic and J. J. P. C. Rodrigues, "A Flexible IoT Energy Monitoring Solution," in *2018 3rd International Conference on Smart and Sustainable Technologies (SpliTech)*, Split, Croatia, 2018.

[27] D. B. Avancini, J. J. P. C. Rodrigues, S. G. B. Martins, R. A. L. Rabêlo, J. Al-Muhtadi and P. Solic, "Energy Meters Evolution in Smart Grids: A Review," *Journal of Cleaner Production,* vol. 217, pp. 702-715, 2019.

[28] X. Li, R. Lu, X. Shen, X. Lin and H. Zhu, "Securing Smart Grid: Cyber Attacks, Countermeasures, and Challenges," *IEEE Communications Magazine,* pp. 38-45, 03 August 2012.

[29] F. Li, W. Qiao, H. Sun, H. Wan, J. Wang, Y. Xia, Z. Xu and P. Zhang, "Smart Transmission Grid: Vision and Framework," *IEEE Transactions on Smart Grid,* vol. 1, pp. 168-177, 2010.

[30] F. Benzi, N. Anglani, E. Bassi and L. Frosini, "Electricity Smart Meters Interfacing the Households," *IEEE Transactions on Industrial Electronics,* vol. 58, pp. 4487-4494, 2011.

[31] V. C. Gungor, D. Sahin, T. Kocak, S. Ergut, C. Bucella, C. Cecati and G. Hancke, "Smart Grid Technologies: Communication Technologies and Standards," *IEEE Transactions on Industrial Informatics,* vol. 7, no. 4, pp. 529-539, 06 September 2011.

[32] V. C. Gungor, D. Sahin, T. Kocak, S. Ergut, C. Cuccella, C. Cecati and G. P. Hancke, "Smart Grid and Smart Homes: Key Players and Pilot Projects," *IEEE Industrial Electronics Magazine,* vol. 6, pp. 18-43, 2012.

[33] Y. Kabalci, "A Survey on Smart Metering and Smart Grid Communication," *Renewable and Sustainable Energy Reviews,* vol. 57, pp. 302-318, 2016.

[34] P. Siano, "Demand Response and Smart Grids - A Survey," *Renewable and Sustainable Energy Reviews,* vol. 30, pp. 461-478, 2014.

[35] V. C. Gungor, D. Sahin, T. Kocak, S. Ergut, C. Buccella, C. Cecati and G. P. Hancke, "A Survey on Smart Grid Potential Applications and Communication Requirements," *IEEE Transactions on Industrial Informatics,* vol. 9, pp. 28-42, 2013.

[36] J. Gao, Y. Xiao, J. Liu, W. Liang and C. L. P. Chen, "A Survey of Communication/Networking in Smart Grids," *Future Generation Computer Systems,* vol. 28, pp. 391-404, 2012.

[37] E. Fadel, V. C. Gungor, L. Nassef, N. Akkari, M. G. A. Malik, S. Almasri and I. Akyildiz, "A Survey o Wireless Sensor Network for Smart Grid," *Computer Communications,* vol. 71, pp. 22-23, 2015.

[38] C.-H. Lo and N. Ansari, "The Progressive Smart Grid System from Both Power and Communications Aspects," *IEEE Communications Surveys & Tutorials,* vol. 14, pp. 799-821, 2012.

[39] J. A. Momoh, "Smart Grid Design for Efficient and Flexible Power Networks Operation and Control," in *2009 IEEE/PES Power Systems Conference and Exposition*, Seatle, WA, USA, 2009.

[40] Y. Wang, Y. Huang, Y. Wang, M. Zeng, F. Li, Y. Wang and Y. Zhang, "Energy Management of Smart Micro-Grid With Response Loads and Distributed Generation Considering Demand Response," *Journal of Cleaner Production,* vol. 197, pp. 1069-1083, 2018.

[41] A. Moreno-Munoz, V. Pallares-Lopez, J. J. de la Rosa, R. Real-Calvo, M. Gonzalez-Redondo and I. M. Moreno-Garcia, "Embedding Synchronized Measurement Technology for Smart Grid Development," *IEEE Transactions on Industrial Informatics,* vol. 9, pp. 52-61, 2013.

[42] P. Zhang, F. Li and N. Bhatt, "Next-Generation Monitoring, Analysis, and Control for the Future Smart Control Center," *IEEE Transactions on Smart Grid,* vol. 1, pp. 186-192, 2010.

[43] P. Borazjani, N. I. A. Wahab, H. B. Hizam and A. B. Che Soh, "A Review on Microgrid Control Techniques," in *2014 IEEE Innovative Smart Grid Technologies - Asia (ISGT ASIA)*, Kuala Lumpur, Malaysia, 2014.

[44] J. Taneja, D. Culler and P. Dutta, "Towards Cooperative Grids: Sensor/Actuator Networks for Renewables Integration," in *2010 First IEEE International Conference on Smart Grid Communications*, Gaithersburg, MD, USA, 2010.

[45] E. Planas, A. Gil-de-Muro, J. Andreu, I. Kortabarria and I. M. d. Alegría, "General Aspects, Hierarchical Controls and Droop Methods in Microgrids: A Review," *Renewable and Sustainable Energy Reviews,* vol. 17, pp. 147-159, 2013.

[46] S. Galli, A. Scaglione and Z. Wang, "Power Line Communications and the Smart Grid," in *2010 First IEEE International Conference on Smart Grid Communications*, Gaithersburg, MD, USA, 2010.

[47] G. kalogridis, M. Sooriyabandara, Z. Fan and M. A. Mustafa, "Toward Inified Security and Privacy Protection for Smart Meter Networks," *IEEE Systems Journal,* vol. 8, pp. 641-654, 2014.

[48] V. C. Gungor, B. Lu and G. P. Hancke, "Opportunities and Challenges of Wireless Sensor Networks in Smart Grid," *IEEE Transactions on Industrial Electronics,* vol. 57, pp. 3557-3564, 2010.

[49] R. Roche, B. Blunier, A. Miraoui, V. Hilaire and A. Koukam, "Multi-agent Systems for Grid Energy Management: A short Review," in *IECON 2010 - 36th Annual Conference on IEEE Industrial Elelctronics Society*, Glendale, AZ, USA, 2010.

[50] D. M. Laverty, D. J. Morrow, R. Best and P. A. Crossley, "Telecommunications fo Smart Grid: Backhaul Solutions for the Distribution Network," in *IEEE PES General Meeting*, Providence, RI, USA, 2010.

[51] A. A. Cecília and K. Sudarsanan, "A Survey on Smart Grid," in *2016 International Conference on Emerging Trends in Engineering, Technology and Science (ICETETS)*, Pudukkottai, India, 2016.

[52] A. E.-A.-U. W. Paper, "Smart Meters and Smart Meter Systems: A Metering Industry Perspective," *A Join Project of the EEI and AEIC Meter Committees,* March 2011.

[53] P. Yi, A. Iwayemi and C. Zhou, "Developing ZigBee Deployment Guideline Under WiFi Interference for Smart Grid Applications," *IEEE Transactions on Smart Grid,* vol. 2, pp. 110-120, 2011.

[54] A. R. Hambley, Electrical Engineering: Principles and Applications, PEARSON, 2013.

[55] C. Muller, H. Georg and C. Wietfeld, "A Modularized and Distributed Simulation Environment for Scalability Analysis if Smart Grid ICT Infrastructure," in *5th International Workshop on OMNet++*, Desenzano, Italy, 2012.

[56] A. Bidran and A. Davoudi, "Hierarchical Structure of Microgrids Control System," *IEEE Transactions on Smart Grid,* vol. 3, pp. 1963-1976, 2012.

[57] S. N. Bhaskara and B. H. Chowdhury, "Microgrids - A Review of Modeling, Control, Protection, Simulation and Future Potential," in *2012 IEEE Power and Energy Society General Meeting*, San Diego, CA, USA, 2012.

[58] P. Palensky and D. Dietrich, "Demand Side Management: Demand Responde, Intelligent Energy Systems, and Smart Loads," *IEEE Transactions on Industrial Informtics,* vol. 7, no. 3, pp. 381-388, 2011.

[59] J. N. Bharothu, M. Sridhar and R. S. Rao, "A Literature Survey Report on Smart Grid Technologies," in *2014 International Conference on Smart Electric Grid (ISEG)*, Guntur, India, 2014.

[60] B. Kilbourne and K. Bender, "Spectrum for Smart Grid: Policy Recommendations Enabling Current and Future Applications," in *2010 First IEEE International Conference on Smard Grid Communications*, Gaithersburg, MD, USA, 2010.

[61] J. Liu, Y. Xiao, S. Li and C. L. P. Chen, "Cyber Security and Privacy Issues in Smart Grids," *IEEE Communications Surveys & Tutorials,* vol. 14, pp. 981-997, 2012.

[62] H. Khurana, M. Hadley, N. Lu and D. A. Frincke, "Smart-grid Security Issues," *IEEE Security & Privacy,* vol. 8, pp. 81-85, 2010.

[63] B. J. Murrill, E. Liu and R. M. Thompson II, "Smart Meter Data: Privacy and Cybersecurity," in *Congressional Research Service*, 2012.

[64] H. Joshi and V. J. Pandya, "Real Time Pricing Based Power Scheduling for Domestic Load in Smart Grid," *International Journal od Power System Operation and Energy Management,* vol. 2, no. 2, pp. 2231-4407, 2013.

[65] C. Muscas, M. Pau, P. A. Pegoraro and S. Sulis, "Smart Electric Energy Measurements in Power Distribution Grids," *IEEE Instrumentation & Measurement Magazine,* vol. 18, pp. 17-21, 2015.

[66] Z. Yang, Y. X. Chen, Y. F. Li, E. Zio and R. Kang, "Smart Electricity Meter Reliability Prediction Based on Accelerated Degradation Testing and Modeling," *International Jounal of Electrical Power & Energy Systems,* vol. 56, pp. 209-219, 2014.

[67] M. Mayilvaganan and M. Sabitha, "A Cloud-based Architecture for Big-Data Analytics in Smart Grid: A Proposal," in *2013 IEEE International Conference on Computational Intelligence and Computing Reserarch*, Enathi, India, 2013.

[68] F. Ye, Y. Qian and R. Q. Hu, "An Indentity-Based Security Scheme for a Big Data Driven Cloud Computing Framewprk in Smart Grid," in *2015 IEEE Global Communications Conference (GLOBECOM)*, San Diego, CA, USA, 2015.

[69] R. Deng, Z. Yang, F. Hou, M. Chow and J. Chen, "Distributed Real-Time Demand Response in Multiseller-Multibuyer Smart Distribution Grid," *IEEE Transactions on Power Systems,* vol. 30, pp. 2364-2374, 2015.

[70] Z. Erkin, J. R. Troncoso-pastoriza, R. L. Lagendijk and F. Perez-Gonzalez, "Privacy-preserving Data Aggregation in Smart Metering Systems: An Overview," *IEEE Signal Processing Magazine,* vol. 30, pp. 75-86, 2013.

[71] O. Tan, D. Gunduz and H. V. Poor, "Increasing Smart Meter Privacy Through Energy Harvesting and Storage Devices," *IEEE Journal on Selected Areas in Communications,* vol. 31, pp. 1331-1341, 2013.

[72] M. Wigan, "User Issues for Smart Meter Technology," *IEEE Technology and Society Magazine,* vol. 33, pp. 49-53, 2014.

[73] G. Kalogridis, C. Efthymiou, S. Z. Denic, T. A. Lewis and R. Cepeda, "Privacy for Smart Meters: Towards Undetectable Appliance Load Signatures," in *2010 First IEEE International Conference on Smart Grid Communications*, Gaithersburg, MD, USA, 2010.

[74] R. L. Lagendijk, Z. Erkin and M. Barni, "Encrypted Signal Processing for Privacy Protection: Conveying the Utility of Homomorphic Encryption and Multiparty," *IEEE Signal Processing Magazine,* vol. 30, pp. 82-105, 2013.

[75] W. Hou, Z. Ning, L. Guo and X. Zhang, "Temporal, Functional and Spatial Big Data Computing Framework for Large-Scale Smart Grid," *IEEE Transactions on Emerging Topics in Computing,* pp. 1-1, 2017.

[76] Y. N. Wang, J. F. Ye, Q. M. Chen, H. Y. Li and X. R. Liu, "Novel Hierarchical Fault Diagnosis Approach for Smart Power Grid With Information Fusion of Multi-Data Resources Based on Fuzzy Petri Net," in *2014 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE)*, Beijing, China, 2014.

[77] Z. Lu and Y. Wen, "Distributed Algorithm for Tree-Structure Data Aggregation Service Placement in Smart Grid," *IEEE Systems Journal,* vol. 8, pp. 553-561, 2014.

[78] X. He, Q. Ai, R. C. Qiu, W. Huang, L. Piao and H. Liu, "A Big Data Architecture Design for Smart Grids Based on Random Matrix Theory," *IEEE Transactions on Smart Grid,* vol. 8, pp. 674-686, 2017.

[79] X. Xu, X. He and R. C. Qiu, "A Correlation Analysis Method for Power Systems Based on Randam Matrix Theory," *IEEE Transactions on Smart Grid,* vol. 8, pp. 1811-1820, 2017.

[80] D. E. Oh, S. H. Choi, Y. J. Kim and I. K. Yang, "Consumer Energy Information Exchange for the Smart Grid Service," in *8th International Conference on Power Electronics - ECCE Asia*, Jeju, South Korea, 2011.

[81] C. Gellings, "Estimating the Costs and Benefts of the Smart Grid," *Electric Power Research Insiture,* February 2011.

[82] J. Zhou, R. Q. Hu and Y. Qian, "Scalable Distributed Communication Architecture to Support Advanced Metering Infrastructure in Smart Grid," *IEEE Transactions on Parallel and Distributed Systems,* vol. 23, pp. 1632-1642, 2012.

[83] F. Salvadori, C. S. Gehrke, A. C. de Oliveira and P. S. Sausen, "Smart Grid Infrastructure Using a Hybrid Network Architecture," *IEEE Transactions on Smart Grid,* vol. 4, no. 3, pp. 1630-1639, 2013.

[84] M. Yigit, V. C. Gungor, G. Tuna, M. Rangoussi and E. Fadel, "Power Line Communication Technologies for Smart Grid Applications: A Reviewof Advances and Challenges," *Computer Networks,* vol. 70, pp. 366-383, 2014.

[85] T. Sauter and M. Lobashov, "End-to-End Communication Architecture for Smart Grid," *IEEE Transactions on Industrial Electronics,* vol. 58, pp. 1218-1228, 2011.

[86] S. Golsfisher and S. Tanabe, "IEEE 1901 Access System: An Overview of its Uniqueness and Motivation," *IEEE Communications Magazine,* vol. 48, pp. 150-157, 2010.

[87] Y. Yan, Y. Qian, H. Sharif and D. Tipper, "A Survey on cyber Security for Smart Grid Communications," *IEEE Communications Surveys & Tutorials,* vol. 14, pp. 998-1010, 2012.

[88] G. Strcbac, "Demand Side Management: Benefits and Challenges," *Energy Policy,* vol. 36, pp. 4419-4426, 2008.

[89] D. M. Murray, L. Stankovic, V. Sankovic and N. D. Espinoza-Orias, "Appliance Electrical Consumption Modelling at Scale Using Smart Meter Data," *Journal of Cleaner Production,* vol. 187, pp. 237-249, 2018.

[90] L. Patrono, P. Rametta and J. Meis, "Unobtrusive Detection of Home Appliance's Usage for Elderly Monitoring," in *2018 3rd International Conference on Smart and Sustainable Technologies (SpliTech)*, Split, Croatia, 2018.

[91] A. Fachechi, L. Mainetti, L. Palano, L. Patrono, M. L. Stefanizzi, R. Vergallo, P. Chu and R. Gadh, "A New Vehicle-to-Grid System for Battery Charging Exploiting IoT Protocols," in *201 IEEE International Conference on Industrial Technology (ICIT)*, Seville, Spain, 2015.

[92] D. E. Olivares, A. Mehrizi-Sani, A. H. Etemadi, C. A. Canizare and et. al, "Trends in Microgrid Control," *IEEE Transactions in Smart Grid,* vol. 5, pp. 1905-1919, 2014.

[93] W. Wang, Y. Xu and M. Khanna, "A Survey on the Communication Architectures in Smart Grid," *Computer Networks,* vol. 55, pp. 3604-3629, 2011.

[94] K. Zhou, C. Fu and S. Yang, "Big Data Driven Smart Energy Management: From Big Data to Big Insights," *Renewable and Sustainable Energy Reviews,* vol. 56, pp. 215-225, 2016.

[95] P. D. Diamantoulakis, V. M. Kapinas and G. K. Karagiannidis, "Big Data Analytics for Dynamic Energy Management in Smart Grid," *Big Data Research,* vol. 2, pp. 94-101, 2015.

[96] L. Hernandez, C. Baladron, J. M. Aguiar, B. Carro, A. Sanchez, J. Lloret and D. Chinarro, "A Multi-agent System Architecture for Smart Grid Management and Forecasting of Energy Demand in Virtual Power Plants," *IEEE Communications Magazine,* vol. 51, pp. 106-113, 2013.

[97] M. S. Hoosain and B. S. Paul, "Smart Homes: A Domestic Demand Response and Demand Side Energy Management System for Future Smart Grids," in *2017 International Conference on the Domestic Use of Energy (DUE)*, Cape Town, South Africa, 2017.

[98] M. Yaszdanian and A. Mehrizi-Sani, "Distributed Control Techniques in Microgrids," *IEEE Transactions on Smart Grid,* vol. 5, pp. 2901-2909, 2014.

[99] Q. Yang, J. A. Barria and C. A. H. Aramburo, "Communication Infrastructures to Faciliate Regional Voltage Control of Active Radial Distribution Networks," in *2009 52nd IEEE International Midwest Symposium on Circuits and Systems*, Cancus, Mexico, 2009.

[100] A. Pfitzmann and M. Hansen, "A Terminology for Talking About Privacy by Data Minimization: Anonymity, Unlinkability, Undetectability, Unobservability, Pseudonymity, and Identity Management," *Anon Terminology,* p. Version v0.32, 2009.

[101] W. Wang and Z. Lu, "Cyber Security in the Smart Grid: Survey and Challenges," *Computer Networks,* vol. 57, pp. 1344-1371, 2013.

[102] E. Bou-Harb, C. Fachkha, M. Pourzandi, M. Debbabi and C. Assi, "Communication Security for Smart Grid Distribution Networks," *IEEE Communications Magazine,* vol. 51, pp. 42-49, 2013.

[103] Y. Mo, T. H. Kim, K. Brancik, D. Dickinson, H. Lee, A. Perring and B. Sinopoli, "Cyber-Physical Security of a Smart Grid Infrastructure," *Proceedings of the IEEE,* vol. 100, pp. 195-209, 2012.

[104] S. Finster and I. Baumgart, "Privacy-Aware Smart Metering: A Survey," *IEEE Communications Surveys & Tutorials,* vol. 16, pp. 1732-1745, 2014.

[105] R. Meier, E. C. Sanchez, B. McCamish, D. Chiu, M. Histand, J. Landford and R. B. Bass, "Power System Data Management and Analysis Using Synchrophasor Data," in *2014 IEEE Conference on Technologies for Sustainability (Sus Tech)*, Portland, OR, USA, 2014.

[106] B. Hu and H. Ghavari, "Smart Grid Mesh Network Security Using Dynamic Key Distribution With Merkle Tree 4-Way Handshaking," *IEEE Transactions on Smart Grid,* vol. 5, pp. 550-558, 2014.

[107] Y. Loewenstern, L. Katzir and D. Shmilovitz, "The Effect of System Characteristics on Very-Short-Term Load Forecasting," in *2015 International School on Nonsinusoidal Currents and Compensation (ISNCC)*, Lagow, Poland, 2015.

[108] M. P. Lee, "Assessment of Demand Response and Advanced Metering," *Federal Energy Regulatory Commission,* 2013.

[109] N. Langhammer and R. Kays, "Performance Evalution of Wireless Home Automation Networks in Indoor Scenarios," *IEEE Transactions on Smart Grid,* vol. 3, pp. 2252-2261, 2012.

[110] K. Spees and L. Lester, "Impacts of Responsive Load in PJM: Load Shifting an Real Time Pricing," *The Energy Journal,* pp. 101-121, 2008.

[111] L. Labib, M. Billah, G. M. S. M. Rana, M. N. Sadat, M. G. Kibria and M. R. Islam, "Design and Implementation of Low-Cost Universal Smart Energy Meter With Demand

Side Load Management," *IET Generation, Transmission & Distribution,* vol. 11, pp. 3938-3956, 2017.

[112] S. Darby, "The Effectiveness of Feedback on Energy Consumption," *Environmental Change Insitute,* 2006.

[113] J. Liu, D. Niu and X. Song, "The Energy Supply and Demand Pattern of China: A Review of Evolution and Sustainable Development," *Renewable and Sustainable Energy Reviews,* vol. 25, pp. 220-228, 2013.

[114] F. Uddin, "Energy-Aware Optimal Data Aggregation in Smart Grid Wireless Communication Network," *IEEE Transactions on Green Communications and Networking,* vol. 1, pp. 358-371, 2017.

[115] J. Pan, R. Jain, S. Paul, S. Vu, A. Saifullah and M. Sha, "An Internet of Things Framework for Smart Energy in Buildings: Design, Prototype, and Experiments," *IEEE Internet of Things Journal,* vol. 2, pp. 527-537, 2015.

[116] M. Khan, B. N. Silva and K. Han, "Internet of Things Based Energy Aware Smart Home Control System," *IEEE Access,* vol. 4, pp. 7556-7566, 2016.

[117] M. A. A. Da Cruz, J. J. P. C. Rodrigues, J. Al-Muhtadi, V. V. Korotaev and V. H. C. de Albuquerque, "A Reference for Internet of Things Middleware," *IEEE Internet of Things,* pp. 871-883, 2018.

[118] M. A. A. Da Cruz, J. J. P. C. Rodrigues, A. K. Sangaia, J. Al-Muhtadi and V. Korotaevd, "Performance Evaluation of IoT Middleware," *Journal pf Network and Computer Applications,* vol. 109, pp. 53-65, 2018.

[119] I. Inatel. [Online]. Available: https://inatel.br/in-iot/. [Accessed 28 july 2019].