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Smart energy metering and distribution systems: A review

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ABSTRACT
Nowadays numerous means for data transfer are used, however, the electric power distribution concessionaires still use employees for the procedure of reading their energy consumption meters. One solution, the target of research, for this issue is the so-called Smart Grid. This concept aims to create a new infrastructure for the distribution of electricity, enabling the development, integration and application of communication, computer and electronic technologies in the so-called macrogrids and microgrids, to optimize the control and operation of power grids through the use of real-time controls and information. This work aims to contribute significantly to the reader's understanding of the concept of SmartGrids, as well as the application of this concept can contribute to a better management of the reading of the consumption of the concessionaires through remote and automated reading.

Keywords: Smart Grid, Smart meter, Smart grids, Remote energy metering, Automation in energy metering.

INTRODUCTION

In most countries, the electrical power system is operated by a large number of independent companies, but which cooperate with each other through interconnections that allow the exchange of energy and technical-economic synergies. These characteristics, in addition to their vast geographical extension and high levels of reliability in general, make power grids unique systems, whose benefits for modern life are widely recognized, to the point of being considered as one of the great engineering achievements of the last hundred years [1].

The processes of energy generation, transmission and metering have long undergone little change since they were conceived until a few years ago. As a consequence, even today, it is possible to highlight outdated characteristics in relation to: power quality, consumption accuracy, fault tolerance, among other topics [2].

The total losses in the national electricity system reach 17.5%, of which 4.2% are located in the power transmission sector and 13.3% in the distribution area [3]. According to Eletrobrás (2001), the rate of losses in Brazil can be considered high when compared to international standards of developed

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countries, such as Finland, Germany, Japan, Belgium, Holland, Switzerland, France and Korea, where total losses are at levels below 6 (six) percent. The rate of technical losses can be justified by the characteristics of the national electrical systems, in particular the predominance of hydroelectric power, which result in long transmission systems and high energy flows between regions [4].

The outdated and inefficient infrastructure of the current Brazilian electricity supply prevents utilities from facing the challenges and keeping up with the evolution of modernity. This issue has been a major concern. The concept of Smart Grid arises from the fact that the way of measuring and supplying energy has become archaic. Several countries have been adopting this new concept of power grid in order to optimize it. One of the characteristics of the Smart Grid is the term "empowerment", which means giving power to the user. Specifically in telemetry, this power is directly related to the management, decision-making, and control of your energy consumption. In the country, only corporate clients, or large institutions, enjoy these benefits [5].

It is in this context that the present work presents a proposed project to apply the characteristics of "empowerment" to energy metering in order to benefit energy consuming customers [5]. Facilitating a greater flow of information that allows both customers and utilities to make smarter decisions regarding energy consumption and production.

MATERIALS AND METHODS

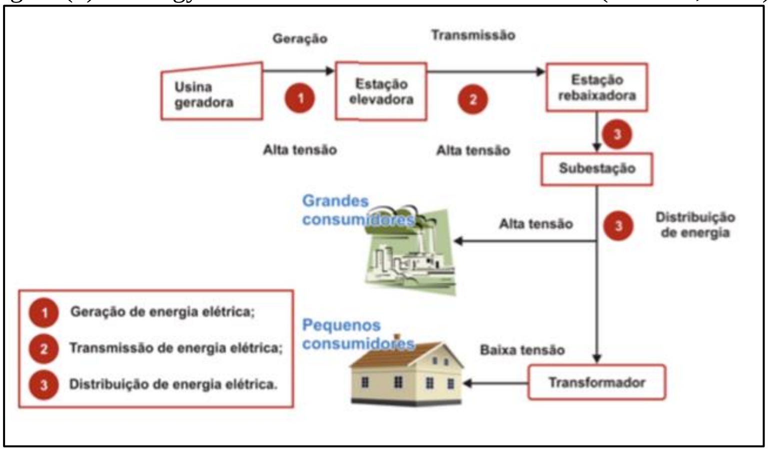
Brazil has one of the largest energy potentials in the world – given its hydro potential, solar radiation, biomass and wind power – with about 90% of the energy generated coming from hydroelectric plants, due to characteristics such as the availability of resources, ease of use and, mainly, its renewable nature [11].

In this context, the Brazilian hydroelectric system has a central system and several isolated systems, each of which consists of power plants, transmission lines and distribution assets. The central system, called the National Interconnected System (SIN), covers most of the Brazilian territory; On the other hand, the smaller systems, called Isolated Systems, extend mainly in the Amazon region, due to the geographical characteristics of the region, which make it difficult to build large transmission lines that can be connected to the SIN.

In the distribution phase, the energy, which has already been treated in the substations and had its voltage level lowered and quality controlled, is then transmitted through overhead or underground electrical networks. These networks consist of poles, towers, underground ducts, electrical cables, and transformers for new drawdowns. Through this transmission, energy is delivered to industrial, commercial, service and residential customers. [12]

Fig. (1) illustrates the phases of the process, starting from the farrier mill to the customers.

Figure (1) – Energy Generation and Distribution Process (ANEEL, 2002).



As you can see, power generation is completely centralized, and communication is done in a unidirectional way, from the power source to the end customer [12].

ENERGY METERING

An electric energy meter is an electromechanical and/or electronic device or equipment capable of measuring the consumption of electrical energy. The most commonly used unit is kWh. It is present in most homes and dwellings in the modern world. It can be connected directly between the mains and the load (home) or through voltage and/or current coupling transformers. This type of connection is commonly used in industries and consumers of medium (13.8 kV to 34.5 kV) and high voltage (69 kV to 230 kV) [13].

These meters have a maximum error of ±2% of the value indicated for their nominal operating range, within the expected lifetime of their operation. This is a relatively high amount, considering the losses that can burden both the supplier and the consumer of energy [12].

To obtain the reading, a contracted or outsourced employee of an electric utility company makes a monthly visit to customers to obtain the consumption value displayed by the meter, Fig. (2). After this, the energy bill is printed and sent to your home [5].

Figure (2) – Electromechanical Meter [14]

There is a strong trend towards the replacement of electromechanical meters by digital meters aiming, in addition to greater measurement accuracy, at the possibility of reading energy consumption or applying a differentiated tariff controlled by the time slot or the distribution center [12].

SMART GRIDS

Smart grid, in general terms, is the application of information technology to the electric power system (SEP), integrated with communication systems and automated grid infrastructure. Specifically, it involves the installation of sensors in the lines of the electric power grid, the establishment of a reliable two-way communication system with wide coverage with the various devices, and automation of the assets. These sensors are embedded with chips that detect information about the operation and performance of the network – parameters such as voltage and current. The sensors then analyze this information to determine what is significant – for example, it is too high or too low voltage [10].

A definition of the concept set out in [7] is:

> "The term Smart Grid can be understood as the superimposition of unified communication and control systems on the existing electrical power infrastructure to provide the right information to the right entity (end-use equipment, L&D control systems, consumers, etc.) at the right time to make the right decision. It is a system that optimizes the energy supply, minimizing losses of various natures, is self-healing, and enables the emergence of a new generation of energy-efficient applications."

According to a quote in the work of the U.S. Electricity Advisory Committee [9]

> "The Smart Grid uses digital technology to improve the efficiency of the electricity system, from large-scale generation to the electricity delivery system to consumers and a growing number of distributed generation and storage resources."

Smart Grid, or a possible translation for the term "smart grids", should be understood more as a concept than a specific technology or equipment. It carries the idea of the intensive use of information and communication technology in the power grid, through the possibility of communicating the status of the various components of the grid, which will allow the implementation of strategies for controlling and optimizing the grid in a much more efficient way than those currently in use [2].

According to [6], in order to achieve the characteristics attributed to the Smart Grid, the following areas of technological innovation need to be introduced:

- Automation and digital control of the power grid, using intelligent electronic controls, capable of anticipating disturbances and correcting them before they occur;
- Introduction of smart metering with the ability to act as a smart consumer portal that will enable the provision of price signals and other information;

- Integration of a large number of small and medium-capacity power generation and storage sources, intermittent or continuous, allowing the consumer to buy and sell energy from the grid.

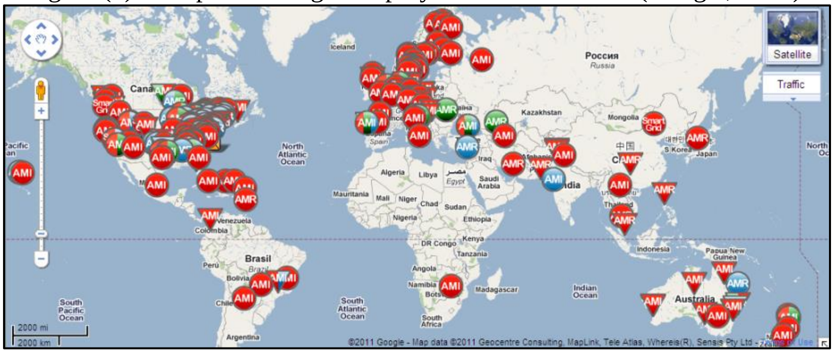
As discussed above, the empowerment of the consumer will be possible, making the consumer an active agent in the energy metering process, since he will have tools at his disposal a complete range of solutions, with a high level of reliability, for the measurement of data such as electricity consumption, tariff, consumption history, information on peak hours, among other relevant information.

Digital electricity meters partially enable the empowerment of the consumer, but issues such as user-friendly interface, practicality and physical disposition can be decisive factors in the consumer's role as an active agent in the electricity distribution process. [5]

On the Internet, it is possible to follow the transformation of networks around the world. Google provides a map showing the initiatives for the use of intelligence in electricity, water and gas networks.

In the figure, each red symbol indicates a deployment of smart grids in the electricity sector, while blue symbols represent initiatives in the water distribution sector and green symbols indicate gas initiatives. By clicking on the symbols on the goole page, it is possible to obtain information from metering and smart grid applications in unlikely places, such as Pakistan, Iran, Azerbajan, Syria (water), Trinidad and Tobago, Dominica and Jamaica. [15]

Figure (3) – Map of smart grid deployments in the world (Google, 2012).



RESULTS

REMOTE CONSUMPTION METERING – SMART METERS

Nowadays, in Brazil, most of the measurements of electricity consumption involve the reading of a display present in the electromechanical meters, the totalizer, requiring the displacement of employees of the concessionaire to collect this information.

This method of performing the consumption reading service involves an operational cost, with payment of employees, transportation, and work material. In addition, as all work is manual, it becomes slow, with the possibility of errors in recording information.

Within this context, remote consumption measurement, known internationally as AMR (Automatic Measurement Reading), is, without a doubt, a promising technology for electric utilities. Implementing an automatic system for reading consumption allows the knowledge of the demand curve, the precise identification of the frequency and duration of supply failures, and the remote disconnection and reconnection of delinquent customers. "Thus, the company can improve its performance and increase the final profit. [8]

An explanation of how the system works is in [10]:

> Which is usually a software system. This system will analyze the data and determine what is wrong and what should be done to improve network performance. For example, in a case where we have very high voltage, the software detects the voltage level and will instruct one of the devices already installed in the network to reduce the voltage, thus saving the energy generated and contributing to reducing carbon emissions.

"Smart Meters" are electronic meters with processing, storage and communication capabilities that go far beyond measuring consumption. They allow the exchange of information in real time and bidirectionally between the electricity company and the end user, as well as the monitoring of power quality.

Technically, this equipment has an accuracy of less than 1%, made possible mainly by the fact that there are no mechanical limitations in the elements involved in the measurement and recording process, and by the possibility of using high-precision sensors.

With these devices, the consumer has access to various information, such as electrical quantities, price of the energy supplied and how much energy has been consumed so far or is being consumed at that moment, in KWh or in financial terms. [12]

BENEFITS

According to [12], from the consumer's point of view, smart meters offer a series of benefits to the whole family, among which the following stand out:

- The possibility of predicting the value of the energy bill;
- The immediate detection of meter failures, which allows greater agility in repair and greater consumer confidence with access to detailed information;
- The fact that you have a tool that can help you better manage your energy consumption, which raises awareness of the rational use of energy. It is believed that, since the charge can be made based on the time and day, consumers tend to adjust their consumption habits in order to consume less at peak times, when energy is more expensive.

On the utility side, smart metering can revolutionize processes such as asset management, fraud detection, and fault and power outage management, promoting better quality and reliability of services. It will also allow the reduction of operational costs related to the pricing process, since it reduces the number of steps between the meter and the distribution of the bill.

The implementation of smart metering should also bring increased revenue to the concessionaires, due to the speed with which failures can be detected and corrected, the fact that it is not necessary to go to where the meter is installed to take the reading, and the possibility of remote disconnection, which makes it possible to reduce the evasion of revenues due to unpaid bills or delays in the cuts of delinquent customers. [16].

INFORMATION TECHNOLOGY STUDIES

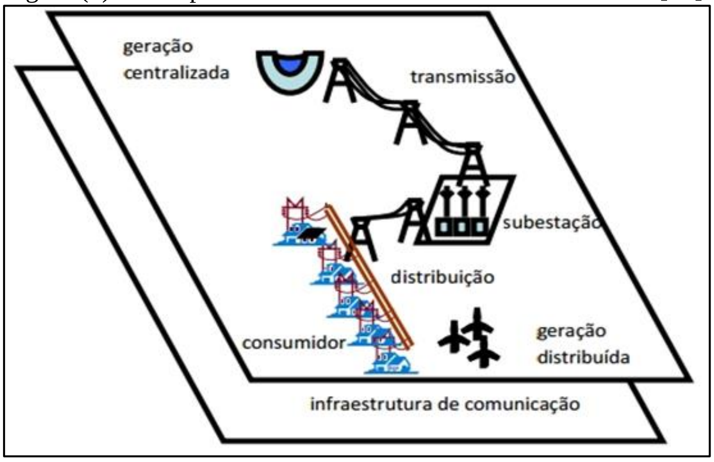
The scenario of evolution of the electricity sector, when reaching the concept of Smart Grid, brings benefits to consumers, concessionaires, other agents participating in the electric power sector and society in general, but also demands important requirements for its implementation. These requirements should be considered during the evolution of the medium to long-term scenario for the adoption of Smart Grid concepts. This scenario is composed of intelligence in transmission and control centers, intelligence in substations, intelligence in distribution and in the final consumer's facilities. In short, it involves evolution in all phases in the electricity sector. In particular, the scenarios for the deployment of Smart Grids require a large dependency between heterogeneous systems.

In terms of system architecture, the concept of Smart Grid involves multiple entities with potential data exchange that can achieve large volumes of data and different response times. Performance must be scalable to allow for new entities to come in. Thus, it is necessary to understand the requirements of communication between entities and outline how it would be possible to make the architecture scalable. [18]

SCENARIO

A complex system for energy supply involves multiple processes. In the case of Smart Grid, we are looking for elements of technology to provide intelligence in various phases of the electricity supply. Fig. (4) presents a comprehensive view of processes arranged in a physical layer, composed of phases of transmission, substation, distribution, consumer, alternative sources, etc. The physical layer is composed of the various technologies that allow intelligence in the transmission, distribution or consumption of electricity. It is composed of elements such as electronic meters, equipment for the protection and operation of transmission and distribution networks, distributed generation, synchrophasors and intelligence elements in substations such as IEDs (Intelligent Electronic Devices).

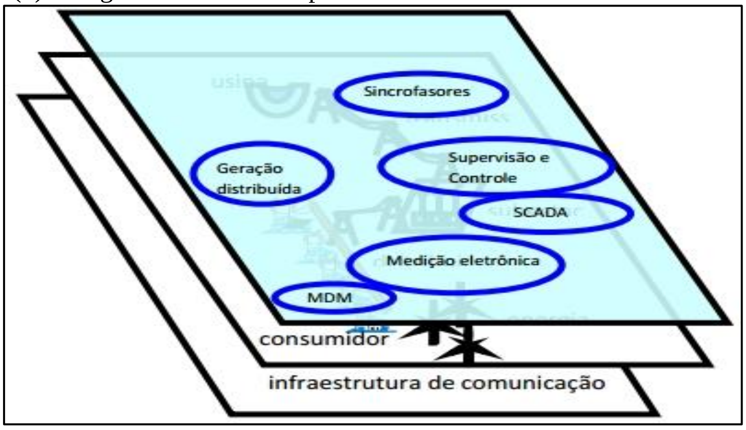
Figure (4) – Comprehensive view of the Smart Grid scenario [18].



Due to the need for monitoring in these various phases, logical layers are also identified for the Smart Grid scenario to help the processes occur. The supervisory logical layer must monitor and manage the processes that occur in the physical layer. There are numerous systems managing such processes as a SCADA system – Supervisory Control and Data Acquisition System – in an Operator responsible for multiple agents, a measurement data management system (MDM), automation and control systems in substations, automation systems in distribution networks, etc.

Fig. (5) illustrates the supervision layer with some of these elements on top of the physical layer. There is at least one additional layer to make monitoring possible in these various phases. This supervisory infrastructure relies on a communication infrastructure layer that allows for the exchange of information between various entities. In distribution, for example, data acquisition from electronic meters is required for the MDM metering system. In these systems, due to the need to cover potentially extensive geographical areas, the use of Mesh networks, which allows the data communication elements to form a mesh for centralized transmission of data, for example, can be an attractive option. In urban areas with high population density, it is also possible to use communication alternatives, such as fiber optics. Fig. (6) illustrates the communication infrastructure layer." [18]

Figure (5) – Logical view of the supervision and measurement infrastructure [18].



ARCHITECTURE REQUIREMENTS

DATA COMINICATION

Because interfaces occur between disparate entities potentially coming from disparate vendors, data communication must follow an open standard. Many systems already use real-time communication, e.g. SCADA systems. In this case, communication necessarily occurs by communication protocol. In recent years, the trend towards the use of shared and packet-based networks has been consolidating. This trend comes from the strength of the internet's architecture, which is also based on packet networks (IP Internet Protocol networks). The trend is to use ICCP – Inter control Center Communications Protocol for communication between control centers and also as an inter-SCADA solution in the companies themselves, for example, when transmitting information in real time from regional centers to a company operation center.

In localized protection and automation systems, such as substations, the IEC 61850 standard has come to allow flexibility and design through the use of high-speed networks such as Ethernet (100 Mbit/s or 1Gbit/s). By using Ethernet networks, it becomes possible to group functions between multiple Smart Electronic Devices. This makes it possible to provide intelligence in substations to compose solutions for automatic substation restoration, load transfer between transformers, etc. [18]

DATA MODEL

Data transmitted in an interface must be presented in a data model that is understood across different entities. The current trend of formatting semantic information in XML–Extensible Markup Language–based formats should be followed.

There are several recent cases of XML-based data models:

- The IEC 61850 standard defines a model for data acquisition of smart electronic devices. The standard defines a Substation Configuration Language (SCL) that is based on XML. From this configuration, the designer can plan a scheme for the supervision, control and protection of a substation. The model is used to define IED parameters. This allows an IED manufacturer to provide the information to a data supervision system manufacturer so that it becomes simple to import the dat
- The Common Information Model (CIM) standard defines a common model for supervisory and control system data. The model can be extended and has been adopted by operators and companies in the electricity sector. Interoperability testing is currently taking place between several manufacturers
- The IEC 61968 standard defines an extension of the CIM model for power distribution system data. [18]

INFORMATION SECURITY

It is necessary to define solutions that guarantee the integrity of transmitted data in order to avoid possible fraud, or attacks on information systems, such as electronic measurement. It is also necessary to define authenticity of entities that transmit and receive data.

The area of security is recognized by NIST as an area where the state of the art still falls short of what is necessary for the security requirements in Smart Grid. There is a need for protections against information breaches in electronic meters, for example, when updating device firmware. In systemic terms, one challenge is the management of credentials as cryptographic keys for a large number of devices, perhaps on the order of tens of millions.

The requirements for safety are numerous, and the solutions are likely to comprise an additional layer to our model, in parallel to the logical layer of supervision and measurement. [18]

PROCESSING AND STORAGE CAPACITY

A large volume of data is expected to be caused by a large number of traffic sources or by high intensity data demand. In SCADA systems, there is typically a heavy flow of limited traffic sources supplying data to a concentrator unit. These traffic sources include, for example, smart electronic devices. In the case of measuring systems, there is a flow of data between a large number of traffic sources and a concentrator unit. These traffic sources include, for example, consumer electronics. The number of traffic sources is large and potentially growing, so communication must be scalable. The traffic generated from traffic sources tends to be lower than traffic from SCADA sources, but with the need for monitoring at short intervals (1 hour, 10 minutes, etc.), the individual traffic generated per source tends to grow as well. The result is a large volume of data to be stored and processed in the data concentrators.

In the past, data was essentially obtained for system operation. Today there is a demand for queries to operational data and historical data by corporate systems.

This is the case, for example, with computational tools for the study of technical and non-technical losses in measurement data. With a large volume of data stored by constant measurement readings, the processing becomes quite intensive on the part of such tools. [18]

ADVANCED METERING INFRASTRUCTURE – AMI

The Advanced Measurement Infrastructure (AMI) consists of a system composed of electric energy meters with embedded computational intelligence and provided with data communication ports and other peripherals, supported by an information technology infrastructure (telecommunication, software and hardware) that allows the acquisition of data remotely, at time intervals, as well as the sending of information and commands at a distance. Currently, it is preferable to implement AMI solutions composed of commercial products and some developments with data communication capacity and reliability and advanced measurement, and with technical characteristics appropriate to the different scenarios of distributors – whether with dispersed consumers or with high population density. In addition, it is imperative to find solutions for AMI that have an open protocol. [20]

It is recommended that any AMI solution should have the following facilities:

- Loss control;
- Interaction with the consumer;
- Telecommunications infrastructure management;
- Physical infrastructure management;
- Availability of information for distribution processes.

In addition, the recommended solution should cover the following applications:

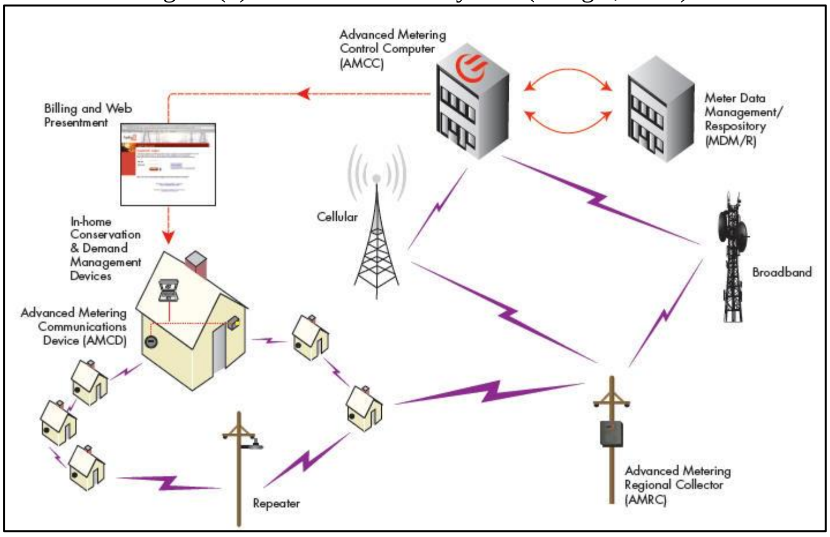
- Remote reading of energy meters in the urban region;
- Remote reading for rural consumers or those in hard-to-reach areas;
- Energy balance to combat losses;
- Remote cutting and rewiring;
- Monitoring of transformer conditions;
- Survey of the customers' consumption curve;
- User load monitoring.

The introduction of this AMI solution will allow the obtaining of accurate individual information on energy consumption that, presented in an intelligible way, will enable the customer to exercise effective control over their consumption. [20]

With the implementation of AMI, the possibility of remote communication with devices located in the consumer's home is opened up and the meter becomes an access gateway to a service provision network. Possible examples are security services and services that increase consumer comfort.

Finally, the large amount of data traveling through the AMI will require a Meter Data Management (MDM). It is a measurement platform that will allow distributors to carry out operations remote measurement (readings and commands), analysis and processing of data with exchange with other corporate systems and performing, among other functions, loss management. [20]

Figure (7) – AMR and AMI system (Google, 2014)



SMART METERS

It is one of the main components of the entire system. It is responsible for most of the tasks in a smart grid. Capable of processing data and sending commands to various other equipment, allowing the integration of the entire supply chain.

In addition to measuring consumption at scheduled intervals, the smart meter uses a combination of technologies, such as real-time sensors, outage notification, and power quality monitoring.

One of its biggest advantages is that it has two-way communication, being able to receive and send data. Various technologies can be used for this, such as ZibBee, PLC, Mesh network, GRPS, among others." [18]

In Brazil, ANEEL instituted Public Hearing No. 043/2010 to discuss the meter model to be installed in homes and commercial and industrial establishments served at low voltage. According to the draft submitted for debate at the Hearing, the quantities of measures should cover, at least, active and reactive energy and supply voltage. As functionalities, the Agency proposes that the meters can record the beginning and duration of interruptions, calculate DRP Relative Duration of Precarious Voltage Transgression and DRC Relative Duration of Critical Voltage Transgression, register up to four tariff stations, in addition to others at the discretion of each concessionaire.

This interaction of the consumer with the energy meter – which shows, through the internet, cell phone, tablet and even in a coupled interface what the consumption has been so far and how much the electricity bill will cost is capable of generating between 20% and 30% of the energy expenditure, this saving is good for the consumer and for the utilities themselves. [18]

It is cheaper for the concessionaire to invest in research and implement intelligent systems than to promote an expansion of its lines, which are congested at peak times and may, in some years, not support the demand.

The necessary change in energy networks to implement smart grids and meters should be through the replacement of energy meters or the insertion of a digital collection system in all consumer units. More appropriate meters will be installed, which provide an interface for interaction with the consumer. The burden of this change is borne by the concessionaire, not by the user. [18]

FINAL THOUGHTS

The present work made a brief analysis of the current situation of the Brazilian electricity sector, addressed in general the concepts of Smart Grid, exposing the main changes provided by the use of this system and the ways of monitoring energy consumption through Smart meters and some proposals for identifying consumption of household appliances individually.

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