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AN AUTONOMIC AND UBIQUITOUS FRAMEWORK FOR SMART GRID MANAGEMENT

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Abstract. *Smart grid is a network and telecommunications infrastructure with a set of applications and technical features such as interoperability with legacy systems, two-way communication, and ability to recover from failures, among others. Smart grid architecture is highly based on communications networks with new required and inherent advantages, such as greater efficiency and reliability to the system, allowing communication between intelligent devices in network. Among the challenges for the development of new generation network for smart grids, it is possible to highlight security, monitoring, management, control, quality of service and new technology updates. This paper focuses on investigating mechanisms for management and monitoring with ubiquitous and autonomic features aimed to better support smart grid solutions.*

Keywords: Smart grid, Ubiquitous computing, Autonomic computing, Monitoring

1. Introduction.

Over the past 100 years, no revolutionary changes have happened in the structure of power grid [1]. The current power system is a set of power plants, substations, transmission lines and other equipment which allows the generation, transmission and distribution of electricity in a specific area, whose primary purpose is to provide energy to end consumers. This supply is triggered and composed primarily by five phases, illustrated in Figure 1 which includes:

1) Generation processes – Electricity generation is the process which transforms other energy source (gas, coal, solar, wind) into electrical energy through power plants whose classification is based on used energy resources (hydro, thermal, wind, nuclear, among others). For example, for hydroelectric systems, power generation involves (a) the storage of a fluid typically water from rivers; (b) converting hydraulic energy into mechanical energy of the fluid in a hydraulic turbine and (c) converting mechanical energy into electrical energy by an electric generator. The level of tension in the generation of electricity is established between 12kV - 24kV.
2) Transmission of electricity – It features as a primary goal the transport of electricity at high voltages. The transmission network connects generation plants to areas of high

consumption whose predominant structure is airline. The voltage level is usually set between 138kV - 765kV.
3) Distribution of electricity – Conduction of electricity from power plants to consumers. The voltage level is usually set between 4.16kV - 34.5kV.
4) Trade customers – Small industries and malls that connect to the power system and receive electricity at voltage of 4.16kV - 34.5kV.
5) End customers – Residential customers who connect to the power system and receive the product and electric service at a voltage of no greater than 1kV.

Experiences have shown that twentieth century systems network obsolescence no longer fits the needs of the twenty-first century, which include not only an increase in demand for resources, but also an increase in quality and varieties of services provided.

To deal with technological obsolescence, new demands and modernization of existing power grid, also called smart grids have been proposed [2], which allow greater efficiency, reliability and integration into power grid. Figure 2 shows a general scheme involving different customers and applications that can be provided by smart grids.

Efficiency implies a lower power consumption and power supply of equal or superior quality to the current one, reducing costs and environmental impact of power generation.

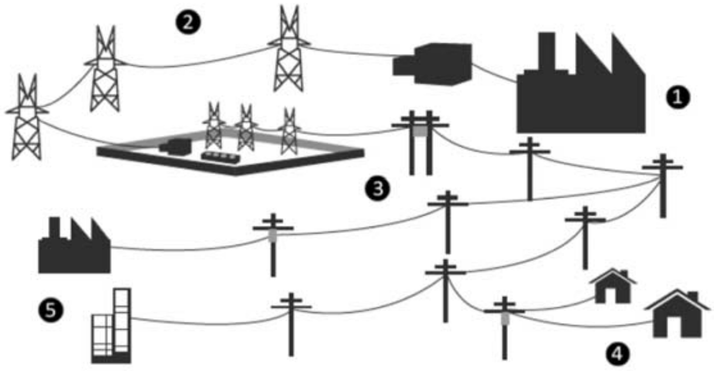


Figure 1. Approach for providing a traditional power grid

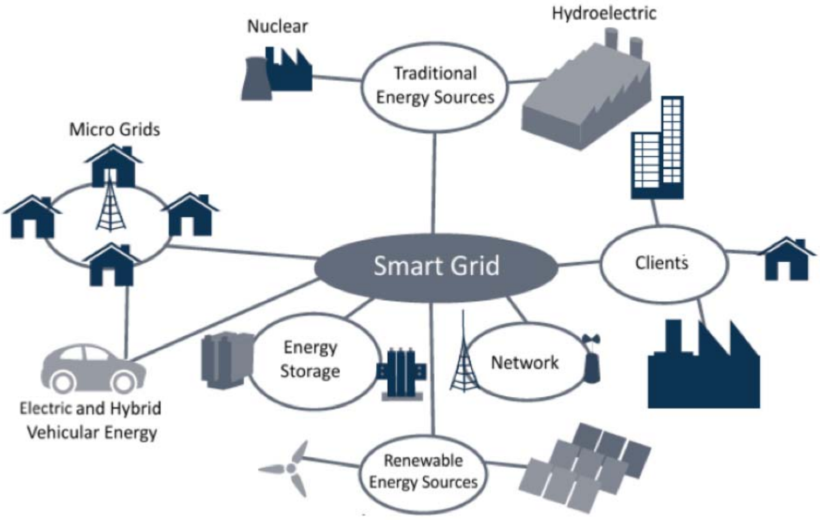


Figure 2. Conceptual model and components of a smart grid

Reliability allows problems identification, such as active faults in network, allowing dealership to take appropriate actions before the problem has occurred or that a wider area has been affected.

In this context the main contributions of this paper are (i) investigating mechanisms for monitoring and supervision with ubiquitous and autonomic features aimed to supporting smart grid solutions; (ii) identifying and proposing a flexible modeling mechanism of the problem in the Smart grid context and, (iii) proposing a framework that allows an learning with autonomy and scalability for smart grid solutions in relation to the method of choosing the most appropriate solution to the problem.

This paper is organized as follows. Section 1 presents a brief background of power system and some challenges for smart grid. In Section 2, a brief description of microgrids is done, defining the microgrid concept as basic part of the smart grid. Section 3 introduces requirements of communication system and communication technologies for the development of smart grid. Section 4 provides an overview of the IEC 61850 standard and its data model. Section 5 presents the proposed framework in terms of its functions and characteristics. Sections 6 and 7 introduces the two case study of microgrid management. Finally, Section 8 presents our conclusions and gives a glimpse of some future work.

1.1. Current problems of power system.

Monitoring and supervisioning power systems is an important and former challenge, deployed as centralized solutions with the use of links, mostly dedicated.

The modernization of the electric system automation is unavoidable, making it essential to implement a system for monitoring and intelligent communication with the centers of control and supervision of the power grid, considering that, if they are controlled by humans, they tend to have operational failures due to the large volume of information to be manipulated.

Currently the power grid has several problems such as:

1) Control of consumption is still manual;
2) Low level of automation in network devices control;
3) Generation is far away from large consumer centers;
4) Few detailed data on energy consumption;
5) Difficulty in integrating new demands (such as electric vehicles);
6) Low quality in energy delivered to end consumer due to faults in transmission and distribution systems.

Due to recent developments in advanced monitoring, information and communication technologies applied to the smart grid, new energy distribution networks will be able to respond more effectively about the desired needs.

1.2. Challenges.

The solutions in the context of smart grid to electric system, as a whole, imply in a set of technical challenges in areas such as communication (telecommunications and networking), security, automation, management and integration of components, among others. In general, it is also expected that smart grid solution will be a sustainable solution that allows, among other features, the diverse and distributed generation and advanced distribution automation. For this purpose, smart grids require appropriate and specific solutions for its communication system.

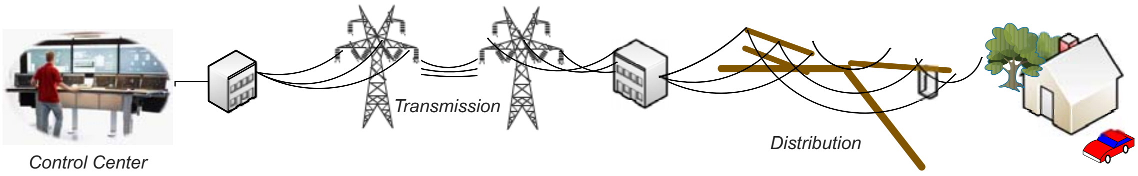
An important challenge in the development of smart grids is the creation of a telecommunications infrastructure that enables the integration of several network users. This infrastructure must provide secure communication and different requirements for quality of service [2]. Nevertheless, designing a structured network protection, supervision and monitoring that supports control and efficient management of network resources is one of the biggest challenges today [3]. Among the major challenges for the deployment of the transmission and distribution of energy in smart grids, it is possible to highlight the interoperability in communication between intelligent devices in the network. This is a key issue factor in smart grids decisions.

Several organizations in developing national and international standards have made efforts to arrive at a set of technologies, standards and rules that define the behavior of smart grids. In this scenario, the main contribution proposes the adoption of IEC 61850 [4]. This is an international standard developed by the Technical Committee TC57 of the IEC (International Electrotechnical Commission) that support automated communication and paves the way for smart grid to make integrations between systems, such as monitoring, protection, measurement and control mostly in substations [5]. Another important challenge is to provide interoperability in communication between intelligent devices in the network, so that freedom of innovation and competitiveness between companies that provide automation equipment is not put at risk [6].

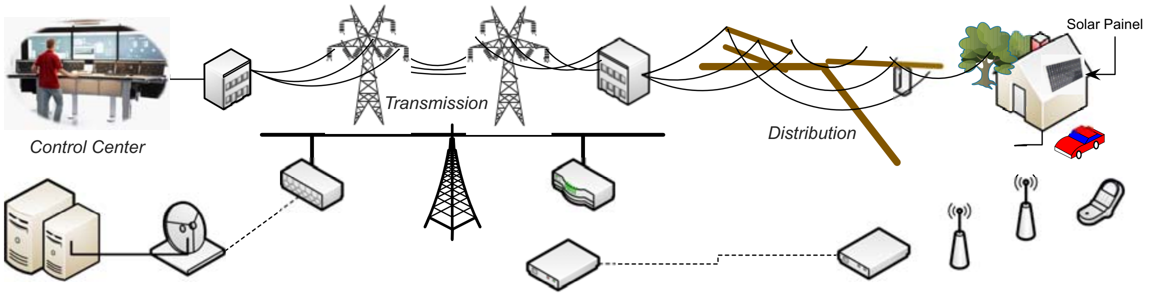
1.3. **Smart grid – An innovative solution.** Smart grid is the term generally used to describe the elements integration of the grid with information infrastructure, offering numerous benefits to both generators and distributors and consumers of electricity.

An intelligent system switches all electric energy supply through the distribution network, managing energy demand through a communication system. Therefore, network intelligence is the ability of devices to communicate by exchanging information that allows one to build a safer and more efficient network, as shown in Figure 3. Thus, smart grids can provide and control various sources of energy, allowing users to choose which sources to use and at what times, aiming at reducing costs and decreasing the risk of overloading the network.

For electric energy distributor it is crucial to have or create a network that gives full connectivity among all its network elements, data sources, and equipment. Thus, decision making is made more precise parameters, which is critical to efficiently manage the smart grid [7].



(a) Current power grid



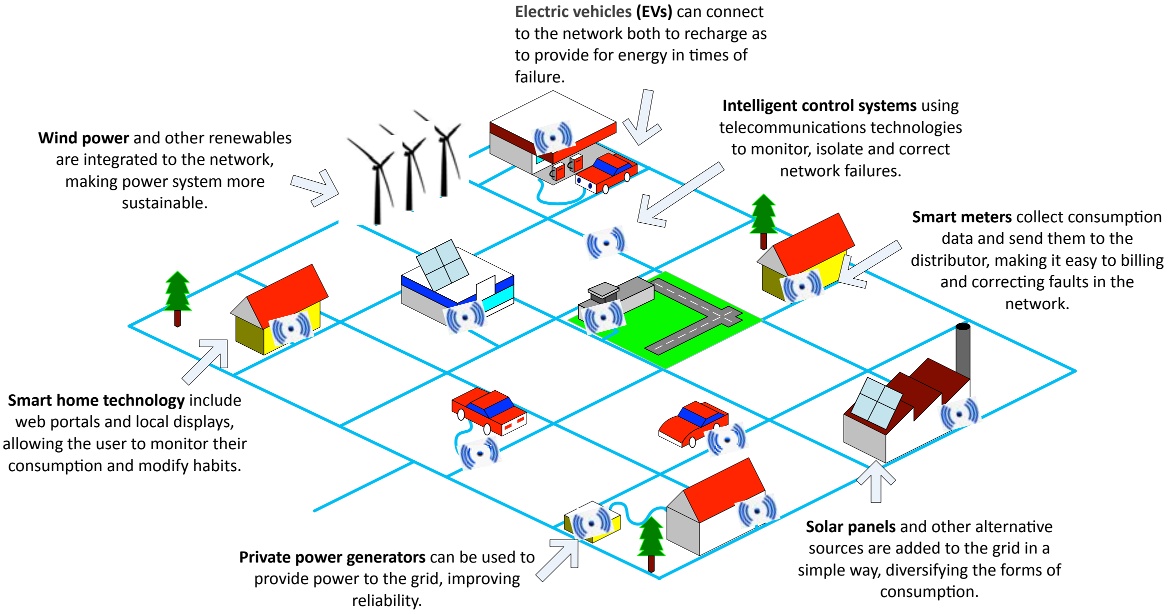
(b) Smart grid, widely supported by telecommunications

Figure 3. Comparison between a standard power grid and a smart grid

The common idea in smart grid is the integration of energy infrastructure in communication and information technologies to build a smart electricity infrastructure providing continuous development of applications to benefit end user.

Current electrical grid is outdated; it does not have a suitable management system and control of its equipment. Today, telecommunications and information systems allow the creation of a management system, a more efficient and intelligent control and service delivery. With the deployment of a fully automated and smart grid, utilities and distributors may provide more reliable, efficient and safe services [8].

Within the context of smart grids, there arise some new technologies that end up becoming remarkable features of the network, as shown in Figure 4.



Electric vehicles (EVs) can connect to the network both to recharge as to provide for energy in times of failure.

Wind power and other renewables are integrated to the network, making power system more sustainable.

Intelligent control systems using telecommunications technologies to monitor, isolate and correct network failures.

Smart meters collect consumption data and send them to the distributor, making it easy to billing and correcting faults in the network.

Smart home technology include web portals and local displays, allowing the user to monitor their consumption and modify habits.

Solar panels and other alternative sources are added to the grid in a simple way, diversifying the forms of consumption.

Private power generators can be used to provide power to the grid, improving reliability.

FIGURE 4. Overview of smart grid elements [3]

One of the contributions of smart grids is to allow different energy sources to be available to customers, ensuring a larger use of clean energy.

Another major innovation is that, in the smart grid, customers also can become energy suppliers, with the energy it stored or produced during the day, using, for example, solar panels.

With this, the energy flow becomes bidirectional and clients less dependent on the main power distributor. Besides the economy, this innovation also allows a greater robustness to prevent failures because if there are problems with the main distribution system, it may be cut off and replaced temporarily by alternative sources. Table 1 summarizes current power grid and compares with the smart grid.

1.4. **Perspective for implementation of smart grids around the world.** Different initiatives, projects and demonstrations have been implemented in different countries with public, private and mixed alliances. To study the evolution of traditional electricity system, encourage different research and study new concepts. This subsection seeks to clarify some of these projects and their major contributions in smart grids.

Table 1. Comparison of current power grid characteristics with smart grids [9]

Current power grid	**Smart grids**
Consumers are uninformed and do not participate in the system.	Price information is available, so the customer has the choice of many plans, prices and buying and selling options.
Dominated by central generation, very limited in the generation and storage.	Plug and play energy resources to complement centralized production.
Limited and not integrated market.	Market enabling innovation and integrated.
Focus on failures rather than the quality of energy.	Quality is a priority, with a variety of pricing options according to customer needs.
Limited intelligence network.	Intelligent integration of the network with the management.
Focus on protection after the failure.	Avoid interruptions, reduce the impact and recover rapidly from failures.
Vulnerable to vandals and natural disasters.	Detect, mitigate and restore quickly and efficiently after a disaster.

1.4.1. *Europe.*

- PowerMatching City: It is a project led by DNV KEMA Energy and Sustainability involving 25 homes in the district of Hoogkerk in the Netherlands that are interconnected and equipped with micro heat and power systems, hybrid heat pumps, photovoltaic panels for smart meters, vehicle recharging stations electrical and smart home applications [10].
- GRID4EU: It is a project led by a group of operators of distribution systems of six countries which aims to test in scale real concepts and new technologies to reduce the technical, economic, social, environmental and regulatory barriers in the distribution system [5].
- EU-DEEP: It is a project implemented between 2004 and 2009, integrated eight energy companies in the distribution system of various countries of Europe, seeking to remove most of the technical barriers that prevented management of distributed energy sources [5].
- Fenix: From 2005 and 2009, Iberdrola Distribuction organization developed with eight countries, an integrated system involving distributed sources of energy, decentralized management and virtual power plants [5].

1.4.2. *United States.*

- EPRI IntelliGrid: The main focus of this program established in 2001 by the Electric Power Research Institute is to create a new infrastructure of the electric system that integrates advances in communications, computer, and electronic systems to improve reliability, capacity and customer service. This program provides methodologies, tools and recommendations for standards and technologies by implementing advanced measurements, distributed automation, demand response, and measurement over wide areas [11]. The IntelliGrid is composed mainly of five projects: Architecture of IntelliGrid; Simulation e fast modeling; Communications for distributed energy sources; Customer Portal; and Advanced system monitoring.
- PNW-SGDP: The Pacific Northwest Smart grid Demonstration Project is a project with the participation of the Bonneville Power Administration, supported by the U.S. Department of Energy under development in the states of Oregon, Idaho, Montana, Washington and Wyoming. The project is considered one of the greatest in smart grid projects, involving 11 companies in the electricity market, three universities and

five technology partners and aims to deploy 60,000 consumers with smart metering, provide two-way communication, distributed generation with renewable integration, storage energy, demand response, smart applications, fault recovery and integrate electric vehicles [12].

- Perfect Power System for Mesa del Sol: It is a project in the United States, led by Galvin Electricity Initiative, which has different initiatives. One of them is to create microgrids, which were recently installed and have energy storage, generation with solar panels, fuel cells, natural gas. Microgrids are integrated into an automated management system that regulates the supply and distribution of energy [13].
- EPRI Advanced Distribution Automation (ADA): The main objective of this program is to create the future distribution. Their resources are targeted on strategic issues such as improving the reliability and power quality, reducing operating costs, improving restore time, increasing the service consumer, integrate distributed generation and energy storage systems and integrating consumer [14].
- GridWise: The GridWise program, founded in 2003, represents the view that the Department of Energy of the United States (DOE) has of the power system. The mission of the Integration of Distribution DOE program is to modernize the infrastructure and operation of the distribution network from distribution substations (69kV and below) to consumers, with a bidirectional flow of energy and information [14, 15].
- GridWorks: A program of the agency Electricity Delivery and Energy Reliability of Department of Energy (DOS) that aims to improve the reliability of electric system through modernization of key network components: cables and conductors, substations and protection systems and electronic devices. The plan includes long-term activities to develop new technologies, tools and technical support [14].
- GridApps: The Advanced Grid Applications Consortium (GridApps), which was formed in 2005 by DOE and Technologies Corporation, applying technologies and practices to modernize transmission operation and distribution systems. Such a consortium works on applications that are not yet implemented, classified into three domains: (1) monitoring technologies and management of T&D, (2) new devices, and (3) engineering applied in systems integration to optimize network performance [14].

1.4.3. *China.* Since 2004, electricity consumption in China has increased mainly due to the increase of industrial sector. According to the survey of Hashmi et al. [15], this country has focused on expanding capacity in transmission and distribution and reduce line losses. The major challenge is related to long distances to transport energy from generation to consumption. This is due to the fact that major hydroelectric plants are located in west, the coal in northwest, and higher consumption is concentrated in east and south. According to State Grid Corporation of China, the implementation plan for smart grid can be divided into three stages: Planning and Testing (2009-10), construction and development (2010-15) and update (2016-20) [16, 17].

1.4.4. *Brazil.* The evolution of traditional electricity system to smart grid has been designed to cross an early stage of implementation in smart metering, followed by a stage of developing more efficient energy storage and distributed generation systems. Also, it considered a long-term implementation phase focusing on electric vehicle.

There are several development projects with private and public partnerships, most of them focused on the implementation of smart metering systems and service to consumers. The AES Electropaulo and Silver Spring Networks are deploying a platform of smart metering in thousand homes in Sao Paulo. The platform uses wireless technology for measuring, monitoring and remote commands to reduce operating costs, and allows customers to monitor their energy consumption. Currently, the project is collecting the first measurements, since the meters were installed in initial stage [18].

The Light SA company proposed Smart grid Light Program, which is a pilot project that covers thousand customers. Actually, clients use smart meters and plugs that allow them to meet their consumption in real-time. Also, such a solution detect points of waste, times instants in which consumption has increased, reduces possibles points, allowing that effective action can be taken aiming at conscious use of energy [19].

Since 2010, Cemig is running the Cities of the Future project, analyzing the benefits and capabilities of the architecture for smart grid implementation in the city of Sete Lagoas (MG). The distribution company intends to apply trends in the value chain of smart energy networks in their electrical systems, telecommunications, computer systems and interface with consumers and distributed generators [20]. The Brazilian System of Advanced MultiMetering (Sibmah), is a system developed by the Center for Advanced Studies and Systems of Recife (CESAR) that aims to automate the measurement of electrical energy at a distance from the utility to the consumer [21].

2. Microgrids – Distributed Energy Generation.

Microgrid is a new paradigm developed by inclusion of distributed generation of smart grids. Microgrid provide an efficient way to connect power sources of different types and capacities [22] and creates small localized electrical systems and components for generation, storage and loads. Thus several interconnected microgrids, according to plug and play concept can create a smart grid, in which the information transmission follows a different flow of energy flow, as shown in Figure 5.

The microgrid structure, Figure 6, consists of several types of Distributed Energy Resources (DER) such as wind turbines, photovoltaics, microturbine, fuel cell, thermal power plant each in the form of distributed generation (DG), including energy reserves from battery (Distributed Storage – DS).

Implementation of microgrid systems provide many advantages from both user and electric utility provider point of view. Microgrid user's application is connected to the

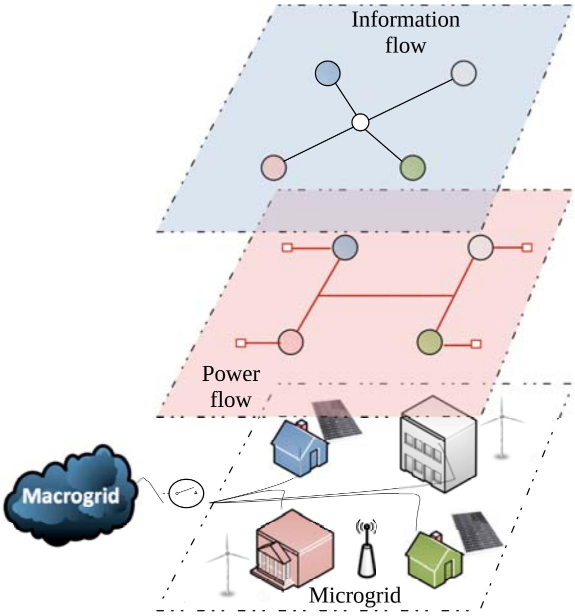


Figure 5. Example of microgrid [5]

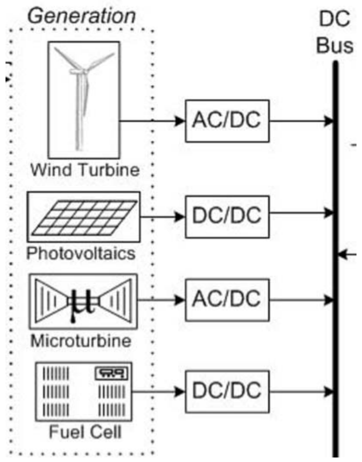


FIGURE 6. DER microgrid example

grid, it can improve network quality, reduce emissions and reduce the cost to be incurred by users. Considering electric utility provider the implementation of distributed generation systems with the ability microgrid can reduce the power flow on transmission and distribution lines, while it reduces losses and reduce costs for additional power [23].

As a new system for distribution energy generation, the microgrids, lists various impacts on system operation, especially in regard to network control and protection equipment. The situation critically increases when microgrids deal with intermittent energy generation resources, as for example, wind, solar, among others [24]. Intermittent generation does not guarantee continuous energy supply and does not guarantee that the largest energy consumption in the microgrid happen at the same time as the maximum of intermittent generation source [25]. In [26] it is presented a model for reliability evaluation of microgrid with distributed generation backed by renewable energy resources.

Stochastic models are proposed to represent the energy storage and generation availability from intermittent energy sources in order to reduce the intermittency of supply from these sources. In this way, microgrids collaborate to guarantee the reliability of the electric grid, as they are likely to be self-sufficient in power generation and consumption by minimizing the overhead mains. Reliability models based on renewable energy sources for power distribution networks can be found in [27].

Lasseter showed that the use of microgrids in distribution systems can simplify the implementation of various functions of new electrical systems [28]. Authors describe isolation of young generations and shows that loads can provide greater reliability in the whole system capacity for fast reaction to faults. Microgrid system operate at a low voltage distribution, and has several distributed energy resources. Also it has the ability to operate connected (on grid) or disconnected (off grid/islanded) to the grid [29]. It is also necessary to ensure flexibility in renewable energy sources management to enable the maximization of its use, minimizing waste. In this context, we consider six important points in microgrids management, as shown in Figure 7:

1) Efficient use of renewable energy sources;
2) Autonomic management to guarantee temporal requirements to better quality of offered service;
3) Provision of services and detailed information to final consumer;
4) Use energy-conscious vehicles;
5) Provision of integration and interoperability between microgrids and also with the distributor;

Figure 7. Aspects of micrigrids management

6) Provision of communication between microgrids order to meet the above requirements.

This work focuses on the four first items described above.

3. Information and Communication Technologies in the Context of Smart Grids.

This section presents a summary of key challenges involved in designing a communication system for smart grid. Then, the main requirements involved and the key technologies for communication that can potentially be used in smart grid solution as a whole are shown and discussed.

Smart grid, from communications viewpoint, will be supported by a heterogeneous set of network technologies, possibly in different domains, in that no technological solution fully match the requirements of smart grid. Thus, it is observed that telecommunications and networks in the context of smart grid necessarily adopt several wired and/or wireless technologies.

Taking into account this scenario, there are many proposals for standards and communication protocols, such as, for example, IEC 61850. As an example of the need for standardization in the area, one of the main barriers to the deployment of measurement applications strategy (AMI – Advanced Metering Infrastructure) is the existence of distinct patterns of communication [2], namely, different semantics data for information exchange between system entities, since it is necessary to consider, among other things, the convergence of several applications.

The adoption of interoperability standards is an indispensable prerequisite to make the smart grid a reality.

There are several lines working towards the standardization of communication for smart grids focused, mainly, smart metering features and interfaces of communication for electricity sector [2]. Table 2 shows an overview of some of the major standards developed or developing for smart grid with a brief summary of its objective.

An important element of control grids is SCADA system (Supervisory Control and Data Acquisition). The SCADA is used to monitor, control, optimize and manage the systems for generation and transmission of electricity. Among the benefits brought by SCADA systems, they include the analysis of consumption and demand, analysis of consumer load, fault verification, the redesign of topology, analysis of load on transformers, smart metering, among others.

In the past, SCADA systems were supported by mainframes and closed systems providers. Currently, it makes use of open platforms with connectivity to corporate networks and the Internet. The energy operators in Brazil use SCADA to perform measurements such as: phasor diagram of voltages and currents, decrease in consumption, decrease energy demand, load curves profiles of active and reactive power, sensor door opening of

TABLE 2. Main standards for smart grid

Standard	Details	Application
IEC 61968 and IEC61970	Provide a Common Information Model (CIM) related to the exchange of information between control centers. The first is related to transmission and second is related to distribution.	EMS (Energy Management Systems)
IEC 61850	Flexible, future proof, open standard, communication between transmission, distribution and substation automation systems devices.	SAS (Substation Automation Systems)
IEC60870-6/ TASE2	Data exchange between the control center utility and the regional control center.	Communication Center Intercontrol
IEC 62351	Definition of security for communication protocols.	Security Systems Information
IEEE P2030	Interoperability guidelines, terminology, characteristics, functional criteria, and performance evaluation.	Applications on 'client side'
IEEE P1901	High-speed communications in power lines.	Smart grid and residential applications.
ITU-T G.9955 and G.9956	Physical layer and link layer Especifications, respectively.	Distribution Automation, AMI
ANSI C12.22	Describe the communication of C12.19 tables on any networks.	AMI
ANSI C12.18	Data structure for two-way communications with the meter.	AMI
ANSI C12.19	Set data structures tables to be transferred from the meter to the communication module.	AMI

the meter box, date and time inconsistency of meters, alarms, reversing the current loop and voltage and suspected measurement under supervision. These data are analyzed by experts that trigger corrective measures, contingency and even network planning.

A great part of this analysis is automated based on historical data, the network topology and human experiences [30]. On the evolution of smart grids, SCADA incorporates new intelligent elements, such as phasor measurement units, smart relays, new technologies using renewable sources, energy storage in electric vehicles (EV) [31].

The network support for traditional model and centralized SCADA grids commonly used a combination of technologies to communicate as follows:

- Wireless links;
- Permanent lines of communication and/or dialed (dial-up leased lines);
- Ethernet and IP technologies over SONET/SDH[1] with dedicated optical fiber mesh.

The transmission component of smart grid (HV Grid – High Voltage smart grid) must undergo major changes it compared to current solution which, in turn, makes intensive use of optical fiber links and wireless radio.

The communication network supporting transmission component should be trustworthy and, the communication network supporting transmission component should be trustworthy and also must pass to make use of switched strongly based on IP technologies (IP/MPLS – Multiprotocol Label Switching, IP over WDM – Wavelength Division Multiplexing, among others) and more native grid technological solutions such as PLC – Power Line Communications. Typical applications of this component include protective relays, remote SCADA systems, remote monitoring and estimation of grid status (PMU – Phasor Measurement Unit over WAMS – Wide Area Measurement Systems), among others.

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[1] Synchronous optical networking and Synchronous Digital Hierarchy

The medium voltage smart grid component (MV Grid) must have the ability to transmit status data of MV grid with information about equipment status, fault detection (especially with systems that are already quite old), monitoring, measurement power quality. Furthermore, power flow conditions must be transferred between substations of grid.

Traditionally, MV substation level is not equipped with telecommunications capacity and, in this context, smart grid solution based on optical fiber technology, optical switching, PLC, Ethernet (several options: E-Carrier, EPON – Passive Optical Network, Gigabit, other), dynamic circuit networks, wireless sensor networks, mesh networks and switched networks will constitute a new set of available communication links.

The low voltage smart grid component (LV grid) mainly includes monitoring applications (AMR – Automatic Meter Reading, AMI – Advanced Metering Infrastructure, communication vehicles to network and management of energy consumption in residential environment (HEM – Home Energy Management). The essence of the LV approach on smart grid is to allow users a greater control and notion of their demand and energy consumption.

In smart home scenario, different technologies are feasible (PLC, ZigBee, Bluetooth, WiFi, Ethernet) and as illustration, we mention some technologies such as PON access networks and technology solutions based on mobile telephony (GSM, GPRS, 3G and 4G) among others. Thus, from data communication networks point of view, smart grid solutions can make potential use of a extensive network technologies set such as: PLC (Power Line Communications) – versions broadband and narrowband; Ethernet (E-Carrier, Gigabit, EPON and others); IP/MPLS and IP/GMPLS – Generalized MPLS (IP-switched circuit and efficient restoration); IP/WDM (IP optical networks with high performance); DCN (Dynamic Circuit Network); WSN (Wireless Sensor Networks); Wireless Mesh; WiFi – IEEE 802.11; WiMax; Technological solutions based on mobile (GSM, GPRS, 3G, 4G); ZigBee; Bluetooth.

Besides, it is possible to add up all traditional technological solutions that in certain contexts, may be well reapplied in smart grid solution.

4. **IEC 61850 and Smart Grid.**

The electric power industry is going through a period of great change with the use of advanced technologies, an effort to develop a smarter network that can successfully meet today and future challenges [34], the smart grid.

One of the major challenges faced by substation engineers is to justify investments in automation. The positive impact that automation has on operating costs, increasing power quality and reducing interruptions are well known. However, less importance is given to how the use of a standard communication impacts the cost to build and operate substations [32]. The existence of an excessive number of protocols in different areas and with different purposes brings incompatibility problems in communication between equipment from different manufacturers.

In current substation automation systems, each manufacturer has its own communication protocol, increasing the amount of protocols on the market. In this scenario, the use of protocol converters – to interconnect which are devices from different manufacturers – is usually complicated. Some of them are the DNP[2], PROFIBUS, Fieldbus, Modbus and LON [33]. When dealing with different protocols, it is also necessary to use an interface for connecting equipment and do the conversion protocols. Thus, communication becomes a limiting factor for substations evolution. This architecture offers no requirements as interoperability, configuration flexibility and long-term stability.

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[2] Distributed Network Protocol

Based on that, it came to light the incentive to build a single standard that specifies parameters and how the IEDs[3] must communicate. As a result, the IEC 61850 standard was created, which is identified as one of the bases for smart grid development [34]. Due to its characteristics, the IEC 61850 standard has been adopted as one of the standards for smart grids, as a solution for communication in electrical substations automation.

IEC 61850 standardizes all communication, gateways are no longer necessary, and the interconnection can be made by an Ethernet network. New efforts are being developed to use standard proposed model also outside the substation, in order to ensure interoperability and simplify new solutions development.

The standard proposes a unified communication solution and applications to ensure interoperability between different manufacturers that allow, among other features, monitoring and real-time control of system distribution.

4.1. **Structure of the standard.** IEC 61850 is divided into parts. Figure 8 shows the component parts, highlighting the assumed standard basic parts.

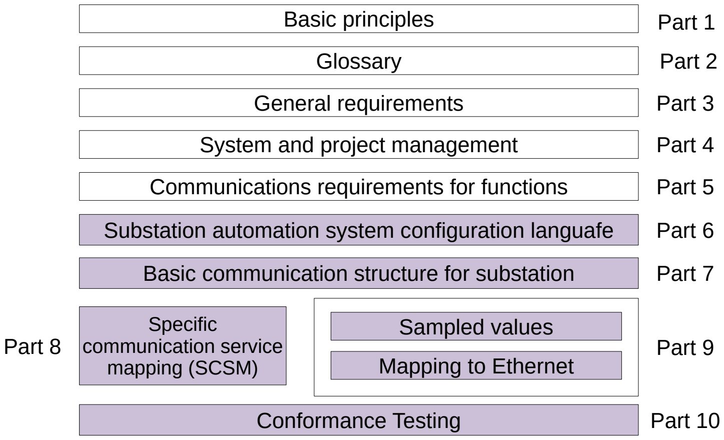

FIGURE 8. Composition of IEC 61850 standard [35]

Observe in Figure 8 that IEC 61850 is structured in 10 parts: general requirements, communications requirements, configuration language, communication model, among others. Each part acts as an assembly manual and defines characteristics implementation of all standards and protocols necessary for the proper functioning of IEC 61850.

4.2. **Data model.** The data model specified by IEC 61850 defines the attributes and functions of physical devices of an electrical substation. The data model is based on object-oriented data structure [36], using for such all relevant concepts of this programming data, for example:

- Class – representing a objects set with similar characteristics. The behavior of objects is realized through its methods;
- Object/Instance of a Class – it is used to store states through their attributes and interact with other objects through messages;
- Attribute – it is the characteristics of an object;
- Methods – the functions are implemented in objects, such as the ability to send and receive messages;
- Inheritance – a feature of a class extends another class, inheriting its methods and attributes.

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[3] Intelligent Electronic Device

A physical device is defined as a device that connects to the network. Within each physical device, there may be one or more logical devices. The Server instance, which is a physical device, is the highest component in the hierarchy defined by IEC 61850 [37], being constituted by a hardware and a classes set that characterizes its behavior.

In a structured way an IED can have one or more instances of Server. Each Server can aggregate one or more logical devices [37]. In turn, each logical device is composed of a set of logical nodes (LN), which by definition are the smallest part of a function that is capable of communicating.

Each logical node contains one or more Data Objects, composed of Data Attributes. The object of a logical node represents a data function of automation and control. For example, an object's position would be a disconnector or circuit breaker. The attribute is the value of an object, such as the open or closed state of the circuit breaker position. Hence, the standard provides a hierarchical view to classify the duties performed by each IED.

According to object-oriented model, data is represented by maintaining a hierarchy, which is initiated by the physical device at a higher level until reaching the lower level of the data attributes. Figure 9 provides an example of object names to identify an instance of a class in a hierarchy.

Figure 9 illustrates the hierarchical structure of the data model according to IEC 61850.

In general, each data object has a unique name. These names are determined by the standard and functionally related to the purpose of the power system.

A circuit breaker is modeled by an XCBR logical node that contains a variety of objects, including, "Pos" for indications related to the position of the equipment. The object "Pos" has, for example, "StVal" attribute, which indicates the current state of the breaker (intermediate, open, closed or failed). We can refer to objects name as follows: *Logicaldevice.LogicalNode.Object.Attributes.*

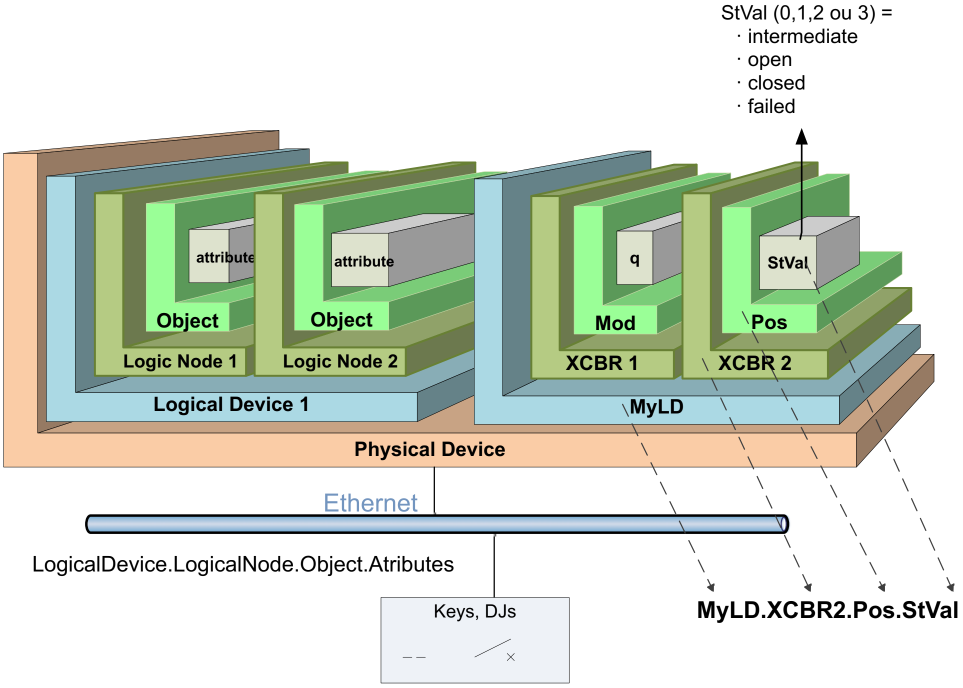

FIGURE 9. Example of a name reference object of IEC 61850 and its hierarchical structure

In Figure 9, the term "MyLD" represents the logical node. The term "XCBR2" represents the logical node, "Pos" represents the data object and finally the term "stVal" represents the attribute data.

IEC 61850 standard can create settings function based on user needs. So automation systems based on standard can be titled as the "future-proof", to be an open standard, being able to perform new functions. Therefore, no matter the progress in technologies or functionalities that equipment incorporate, these will always be able to communicate and interoperate properly with the devices currently installed, allowing safeguard investments related to suppliers.

5. **The Framework.**

A new architecture should deal with requirements (details in subsection 5.1), and support an evolution network according to new demands, leaving behind the model designed based on last century requirements.

An investigation of mechanisms for monitoring and supervisioning with ubiquitous and autonomic features aiming at supporting a style of smart grid solutions will be held. The baseline scenario of the proposed research is the electrical system aimed at enabling optimized for smart cities and power distribution systems management and monitoring.

A solution approach being stalked includes monitoring technologies and performance-based wireless networks (e.g., WSAN[4] [38], techniques of learning machine and M2M[5] [39]).

Smart grid will be able to deliver more power to society and also perfom a better management on energy generation, transmission and distribution, being invulnerable to security breaches, terrorist attacks, natural disasters and the human and mechanical fails [42].

An intelligent system switches all electric energy supply through network distribution, managing energy demand through a communication system [5]. Therefore, network intelligence lies in the ability of devices to communicate by exchanging information that allows you to build a safer and more efficient network.

The proposed framework, illustrated in Figure 10 should include characteristics of ubiquity and autonomy, according to current need systems management and energy operators supervision. Therefore, the general objective of this work is to propose a framework for monitoring and supervisioning with ubiquitous, real-time and autonomic features for electrical systems [43] aiming to support smart grid solutions in order to improve and assist decision making, through intelligent networks. Some specific objectives can be highlighted such as:

i. Investigate the monitoring and supervision systems, aiming to minimize or extinguish problems and improve the grid management system;
ii. Draw up the use of WSAN in the context of intelligent smart grid networks;
iii. Raise operational reliability in terms of resilience and ability to recover from failures;
iv. Raise autonomy level of monitoring elements (sensors) and actuators components (computing and autonomic services);

Also, it is possible to mention in detail the functions of each plan and their modules:

- **Physical Plane** – It includes the physical structure of distributed energy sources (DER) which is performed to generate electricity. These DER exchange power among themselves using powerlines and exchange information using the suitable network technology for each situation. The types of distributed energy sources can be:

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[4] Wireless Sensors and Actuators Networks
[5] Machine to Machine Communication

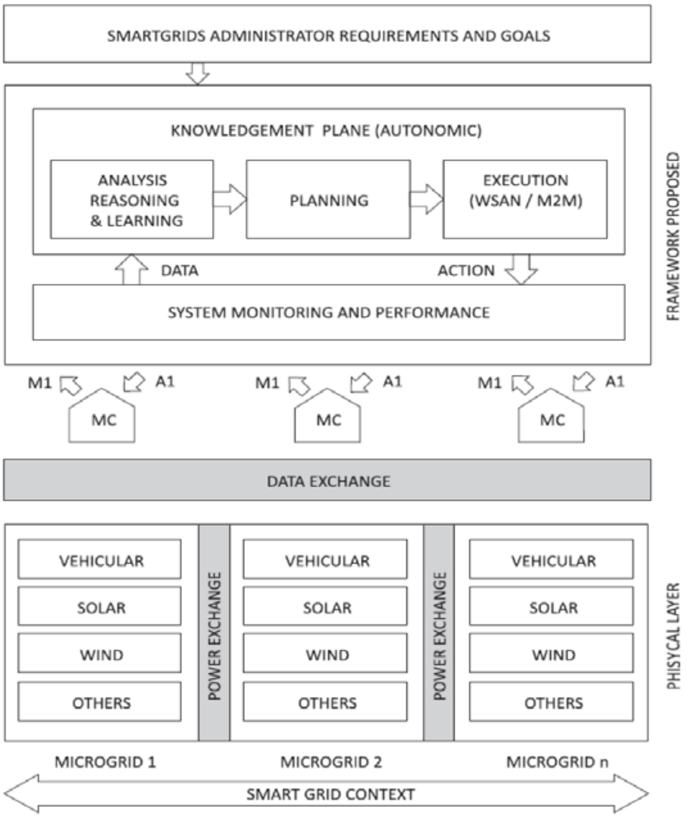

Figure 10. Proposed framework to support smart grid solutions

  - **Electric Vehicle (EV)**: These vehicles generate power from using one or more electric motors or traction motors for propulsion and serve as a distributed battery storage system to store power. A battery-powered or plug-in hybrid vehicle could use its excess rechargeable battery capacity to supply power for a utility (e.g., at peak electricity usage times or when they are parked). This concept is known as Vehicle-to-Grid (V2G).
  - **Solar Panels**: Small-scale power generators (electrical devices) that convert the energy of light directly into electricity by the photovoltaic effect.
  - **Wind Turbines**: Turbines catch winds energy with their blades to convert the kinetic energy from the wind into mechanical power. This mechanical power can be used by a generator to convert this mechanical power into electricity.
- **Microgrids Controller (MC)** – It allows the self-configuration engine to deal with dynamic system changes at the physical layer, due to DER fluctuant and intermittent nature or any kind of device faults. Also, it ensures that these changes are properly handled and keeps power supply efficiently, effectively and reliably to running systems. MC has the capability to register several alternate settings, allowing the protection device to be efficient in various conditions to avoid protection problem. Moreover, it allows power management control to deal with several generation sources and loads. Added to these features, collect data that will be filtered, aggregated and converted so they can be used in framework analysis phase, i.e., the MC receives a variety of messages from various manufacturers and converts these messages into a standard data model. This ensures interoperability between DER devices and framework. MC should also promote interoperability within management process allowing interaction between different devices regardless of manufacturer. To do so, MC will

promote the conversion of data into a standard format – as XML[6] – based on the standard IEC 61850.

- **Knowledgment Plane** – Its primary goal is to ensure stable delivery of electrical power to its local load customers, through a sequence of actions required to manage this autonomic cycle (monitoring, analysis, planning and execution), while optimizing energy production and protection problem (fault location, isolation, and service restoration) towards an assigned objective. For example, what should be done is to supply the power more efficiently, effectively and reliably to customers (e.g., find the one among DERs in an isolated microgrid) or even among microgrids, as its power supply source, in case of faults.

  To provide efficient autonomic solutions, it is essential to adopt learning and reasoning techniques such as CBR (Case-Based Reasoning) [44]. In order to extract the knowledge to solve a new problem, CBR uses as its premise an adaptation of solutions used in past cases. The use of this technique is recommended for problems that are not fully understood (poor models) or in which there are many exceptions to the rules whose success factors of a solution cannot be modeled explicitly [45].
- **System Monitoring and Performance** – A permanent monitoring system to be aware of whether the system is meeting its optimization goals, gathering data to prevent and detect exceptional conditions, diagnose the underlying causes and then perform a reconfiguration plan, ordinary or emergency actions to MC for resolving the problem.
  - **Analysis Reasoning and Learning** – Focus on correlating data from the MC aiming to extract information that is used to know the environment current state, identifying their changes and predicting future situations. The learning phase is responsible for learning the relevant microgrid's statistical data and residence behavior to autonomously make optimal energy scheduling and allocation decisions (e.g., considering a residential energy pricing marketing).
  - **Planning** – Check contingency analysis and create the possible actions necessary to reach the objectives specified by an assigned objective. Such actions can affect just one or several managed elements in the system. It is important to mention the difference between planning and execution phases: The former indicates what should be done, while the second indicates how the solution will be deployed on managed devices.
  - **Execution** – Control the set of actions and strategies resulting from planning phase, aiming at correctness of elements configuration by the framework. It is essential that all tasks are executed on success or none of them in case of failure, avoiding partial results of execution ordered.

5.1. **Requirements.** The communication system of smart grid solution is, usually, a comprehensive solution from a technological standpoint. For example, the communication system for the smart grid has distinct elements which include:

- Specific local networking solutions for internal communication between the control elements in substations (IEDs, actuators, etc.);
- Communication systems supporting long-distance transmission of efficient power;
- Support monitoring and data collection of different types of sensor systems;
- At the edge of the electrical system, the integration of communication and integration of end users, distributors and homes with their management and control systems, sensors, smart devices and monitoring system of energy demand.

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[6] eXtensible Markup Language

A necessary starting point in this discussion, that can be efficient in the argumentation of the requirements and scope of the solution, consists of understanding the motivation of smart grid solutions. Indeed, the rising demand for electricity in parallel to the increasing need for monitoring and checking electrical quantities, integration equipment, new methods of supervision and protection, processing of contingencies and adaptation to the requirements of regulatory agencies has contributed to the significant growth of power systems operational complexity, making manual activity control and monitoring rather complex.

Smart grid solutions stem primarily from this need and seek an integrated solution with greater efficiency and effectiveness for control, protection, metering and monitoring. Moreover, the objective is an integrated solution which should also ensure interoperability between involved systems (both new and legacy), that additionally must adapt to the needs for regulation of many countries specific energy.

The infrastructure and telecommunications networks that must support smart grid solution follow mostly from this motivation and one of its first challenges is to identify requirements for a complex system, multifunctional and extensive integrating all elements of electric system (generation to the end consumer).

Networks and telecommunications are already used in current power systems and what is expected is a more efficient communication that explores the benefits and facilities of new network solutions (optical networks, sensor networks, broadband networking access, DCN networks, other) and integrate network components comprehensively (bidirectional flow of data and information), interoperable and secure and, therefore, allows the evolution of the power system as a whole.

There is a consensus in research and development community that most of the challenges faced are long term with an expectation that can be achieved between five and fifteen years, depending on the area or subarea of action considered.

The basic requirements of communication (telecommunications and networking) of smart grid solution are, a first moment, resulting from its structure in terms of a system that is still strongly based on Information and Communication Technologies (ICTs). Reiterating the basic view, the smart grid aims at greater efficiency, reliability and safety coupled to the integration of new renewable energy sources through automated control and using advanced telecommunication technologies [46].

Some of the features that must be supported by the communication systems of the smart grid include the automation of grid (monitoring and control), the coordination in the distribution of power generating sources (including microgrids and renewable), power control, billing, management of protection, restoration schemes of service and contingency analysis, among others.

The basic requirements of the communication network for smart grid stem from the integration and distribution of the above elements and may, at least initially, be focused on some technical key aspects such as:

- the need for bidirectional communication between the elements of the smart grid network model (distributed);
- the need to deal with various operating requirements (delay, loss, jitter, resilience, etc.) typically referred in the literature as adequate in terms of quality (QoS) and Quality of Experience (QoE);
- the need to monitor data on remote systems (wide-area monitoring);
- the need to handle a significant volume and an increasing data generated by the participants of the smart grid systems (sensors, domestic meters, elements of performance, other);

- the need for high availability and resilience to network control coupled to very strong security requirements and privacy of the data grid; and
- the need to deal with data semantically consistent and appropriate manner on the grid as a whole.

In summary, it is essential a basic set of requirements that are simultaneously focused on viability issues of control functions new distribution model, the temporal requirements (Section IV-D), the volume of information handled by the network (capacity) and the structuring of the data itself (representation, manipulation, and semantic network data). Safety aspects are an area of research and development very important to the feasibility of the solution.

5.2. **Ubiquitous computing caracteristics.** The demand for efficient supervision and monitoring in electrical system is the result of increasing complexity, which leads to a large number of variables to be monitored and controlled in a dynamic and unpredictable environment, either by the insertion and/or removal of sensors, by communication failures or by changes in the characteristics (i.e., bandwidth and latency dynamics).

This work includes some relevant features to ubiquitous computing paradigm, namely:

i. **Heterogeneity** – Smart grids are broadly based on monitoring and integration of network devices without user interfaces (sensors, actuators, among others) with different hardware and software architectures from different manufacturers. This is possible due to the extensive support of telecommunication and network infrastructures (wired or wireless) and device data abstraction models deployed;

ii. **Invisibility** – Add multi-agent system concepts to the smart grid scenario [47] bringing the possibility of no human permanent intervention in ongoing monitoring through a coordinated control system between its components. The autonomy tries to solve known issues coming from applications with a certain level of intelligence as well as the use of smart features embedded in its logical structure [48] and communication skills;

iii. **Context-Aware** – The sensors will collect data about the environment operation and performance (voltage, current) in which the application is associated in power grid. Sensors autonomically analyze data to determine what it is meaningful (i.e., high voltage) and assigns actions (sending messages) to actuator devices to report abnormality of situations (reduce the voltage). Thereby, it saves the energy generated and contributes to the environment by reducing carbon emissions;

iv. **Location-Based** – An autonomic sequential record real-time mechanism will identify locations and operational status of various components and assets, supporting, as such, the resilience of the system.

Regarding security and data privacy, verification mechanisms will be used to exchange messages (hash algorithms) aiming at detecting changes in the information exchanged between devices. Furthermore, in the association phase of sensors with the existing network, a location-based authentication protocol will be used, whose validation will be done through a restricted physically channel and with limited range of monitoring area.

In order to safeguard the proposed objectives will be developed, first we developed, a functional prototype of the framework for monitoring and supervising focused on technological experimentation with intention to consolidate initial ideas. The prototype will support environment simulation, testing and hypotheses validation of the autonomic monitoring systems. A key challenge in the development of smart grid solutions is the creation of a communications infrastructure that enables the integration of network parts and users. This infrastructure must provide secure communication and has quite different QoS requirements [2].

Nevertheless, designing a protection structured network, supervision and monitoring that supports effective and integrated management and control of the grid resources is the utmost present challenge [6]. Among main challenges related to transmission and distribution of energy deployment in smart grid, we highlight the interoperability in communication between intelligent devices in network. This is a central factor in the design of smart grid solution. Another important challenge is to provide interoperability in communication between smart devices in the network, such that freedom of innovation and competitiveness could be maintained between industrial partners that provide automation equipment [3].

5.3. **Autonomic computing caracteristics.** Autonomic computing is an inevitable evolution of information technology infrastructure management [49]. This change was necessary because the complexity of computing environments has increased, due to increasing sophistication of the services offered, the demand for quality and productivity, the growing volume of data, and the heterogeneity of devices, technologies and platforms. Such features have increased the difficulty of management infrastructure, making the administrators tasks more costly. Complexity is presented as the most important challenge to be addressed by such systems [50]. Thus, it is possible to define an autonomic computing system that has the ability to manage itself in accordance with the objectives set by the administrator [51]. Actually, the essence of autonomic systems is self-management, which aims at making managed environment able to perceive, analyze its current conditions and have the ability to reconfigure its components and devices proactively. Hence, it is apparent that autonomy can be applied to high-level management of smart grids.

In complex systems management, human intervention can be considered as a failure point [52]. According to this point of view, an autonomic system can be defined as a system in which there is no need of administrators to run administrative routines and perform operational tasks [50]. Indeed, it is important to mention that autonomic computing does not focus on eliminating human actions [53].

Instead, administrators should have a high-level participation and focus on setting goals and business rules that must be followed by such systems. Thus, it is possible to define an autonomic computing system as the one which has the ability to manage itself in accordance with the objectives set by the administrator [51]. In fact, the essence of autonomic systems is self-management [51], which aims at making the managed environment capable of perceiving and analyzing its current conditions. Also, it must have the ability to reconfigure its components and devices proactively. Thus, it is apparent that autonomy can be applied to high-level management of smart grids. In particular, this paper looks forward to reaching framework solutions based on administrators definitions.

5.4. **Real-time requirements.** Many real-time systems (RTS) must meet strict real-time performance demands and a smart grid system may be one where its application can be considered to be mission critical. Real-time responses are often required to be in the order of milliseconds or microseconds. Conversely, a system without real-time requirements, cannot guarantee a response within any deadline (regardless of actual or expected response times) [54].

In general, the RTS requirements are dependability, scalability, determinism and reliability. Also, they are directly applicable in the context of smart grids. Dependability and reliability are intrinsic to the generation and transmission phases. Scalability is associated with the distribution, due to the large number of consumers and their peculiarities. The determinism – always return the same result any time they are called with a specific set of input values and given the same state – is a positive feature to these systems.

Temporal guarantees of communication are essential to the correct execution of the functions of the devices and the overall system performance. These temporal guarantees are established by IEC 61850 and designated as transfer time and tag time [55]. The first refers to the time requirements of the system as a whole, while the second is relevant to the devices. The IEC 61850 standard defines the temporal requirements of telecommunication according to the message type (Table 3) and their respective performance classes [55]:

- **Class P1** – Refer to distribution level or levels with a time requirement are not criticality;
- **Class P2** – Apply to the transmission level;
- **Class P3** – Assign to the transmission level with critical features of synchronization.

For example:

- Type 1A (trip) – for being considered the most important fast message substation, temporal limits are defined 3ms (Class P2/3) e 10ms (Class P1);
- Type 1B – are defined temporal limits of 20ms (Class P2/3) and 100ms (Class P1);
- Type 2 (Mean Speed Message) – a time limit of 100ms is defined;
- Type 3 (Low Speed Message) – a time limit of 500ms is defined;
- Type 4 (Raw Message) – time limits are 3ms (P2/3 Class) and 10ms (Class P1);
- Type 5 (File Transfer) – a time limit equal to or greater than 1000ms is defined;
- Type 6A (Time Synchronization Message "a") – it defines a time offset of +/– 1ms;
- Type 6B (Time Synchronization Message "b") – are defined temporal deviations between +/– 4μs e 1μs (Class P2/3) e +/– 25μs (Class P1);
- Type 7 (Control Messages) – a time limit of 500ms is defined.

Table 3. Message types by the IEC 61850 [55]

Type	Class	Example	Message
1A	Fast Message	*Trips*	GOOSE
1B	Fast Message (others)	Commands, Simple Message	GOOSE
2	Mean Speed	Values Measurements	MMS
3	Low Speed	Parameters	MMS
4	Burst of Data (Raw)	Output data of the instruments (transformers)	SV
5	File Transfer	Large Files	MMS
6A	Time Synchronization A	Time Synchronization (station bus)	TimeSync
6B	Time Synchronization B	Time Synchronization (process bus)	TimeSync
7	Message Command	Command station HMI	MMS

For example, an important requirement in the design of telecommunications network to support smart grid refers to the guarantees of delay in data communication (latencies involved). Data communication networks supporting the smart grid require latency values in the order of milliseconds between some devices end-to-end. As an example, delivery times of the order of 5ms are required for information protection in substations, and time between 8ms and 12ms for deliveries outside the substation, command transfer time in the order of 5ms are defined in IEC 61850 [4] and disaster recovery timeless than 4ms are some examples of requirements communication in the context of the smart grid.

On the other hand the functions of reading and data transmission of digital meters are less demanding on suits latency, whereas the messaging can be conducted every 15min. The key requirement in this context corresponds to the volume of data involved and the issue of monitoring and semantic structuring of measurement data.

6. Validation 01 – Real Scenario and Modeling for Microgrid Management to Maximize the Renewable Power Sources.

6.1. Objetives.

The main goal is to investigate mechanisms for monitoring and supervision with ubiquitous and autonomic features aimed to supporting smart grid solutions with a case study in efficient management of renewable energy sources for the sustainability and social importance.

6.2. Framework modeling validation.

In order to keep proposed objectives, we first modeled a functional framework prototype for monitoring and supervisioning, which focuses on technological experimentation in order to consolidate the initial ideas. With prototyping it is possible, through a simulation environment, to test and validate the hypotheses of interactive systems monitoring.

In practical terms, our proposal incorporates a management layer to the physical layer of the grid. The communication between them is accomplished by microgrids controllers. System monitoring and performance integrates messages from MCs and converts them to a common format (XML) to be treated by knowledge plan (see Figure 10). This, in turn, is responsible for analyzing the information from system and performance monitoring and also offering an answer according to specified rules by the network administrator. As an example, we can imagine the lack of energy distribution. In this context, smart and/or microgrids – if they have stored energy – should choose to share or individualize energy. This may seem simple, but the knowledge plan should check the current load, the consumption perspective (based on history), if there are critical services (such as hospitals, health centers or police stations), billing between microgrids, among other aspects.

For approval of data model proposed in this paper we detail the data model that should provide an infrastructure capable of supporting real-world situations, including clean and sustainable energy sources [56]. The test scenario corresponds to a condominium residence with the following structure:

i. 100 homes are divided into ten streets, where every street is mapped as a microgrid. The condo also is seen as a microgrid.
ii. The condominium residence has a wind power turbine that is capable of generating between 2.3MWh and 3.6MWh [57].
iii. The solar panels installed in homes can generate between 100Wh to 300Wh.
iv. Some homes have electric cars that will also be energy suppliers. The Toyota Prius as an example, contains a set of batteries which provide 400WH. The use of electric cars is still not a reality in some countries due to the high cost of these vehicles which includes taxes, high cost of manufacturing and the lack of a well defined policy [57]. Thus only one residence will be mapped with this vehicle.

6.3. Data modeling.

The mapping of the logical model is based on graph theory as follows:

i. Each microgrid is connected to the microgrid controler using bidirectional edges indicating that microgrids can provide/receive power. Each microgrid (vertex), aggregate data generation and consumption of renewable beyond the waste of energy and charging.
ii. The MC is connected to the electricity distributor also bidirectional edges. The MC will aggregate the data from all microgrids. Each microgrid representation will be used – in tables – as described in Table 4:

TABLE 4. Logical model

Table	Description	Details
MGESCA	Load of MG Energy Sources	Indicate the actual charge of renewable energy sources present in each microgrid.
MGESCC	Energy Sources Consumption of MG	Indicate the total daily consumption for energy source of each microgrid.
AL	Storage Limits	Inform the maximum stored charge for energy source.
MGESF	Function of MG Energy Sources	Store the mathematical functions applied to energy generation from renewable sources.
MGHCE	Consumed Energy	Store microgrids consumption per hour, based on consume history.
MGESD	Availability of Generated MG Energy Sources	Indicate when the energy generation is available. As example, solar energy is not available at night. There is an input TYPE, which indicates if energy generation is continuous, in case of solar, eolic or discrete energy, regarding electric vehicles, where energy is only available when the client return hoe.
MGRED	Wasted Renewable Energy Source	Store the wasted energy by energetic source. This occurs when storage limit is reached, because generation is greater than consumption.

6.4. **Simulation scenarios.** The simulation scenarios objective maximizes the energy renewables use in microgrids (detailed in Section 2). This simulation uses R Project for Statistical Computing [41] compiler and igraph package. For the simulation purposes we used three models of cooperation:

i. **Without cooperation** – Each microgrid uses renewable sources when the sum of the load of renewable each microgrid is greater than or equal to its estimated consumption;
ii. **Total Cooperation** – Cooperation exists when the sum of the renewable microgrids is greater than or equal to the estimated total load for all microgrids;
iii. **Total/Partial Cooperation** – This cooperation model extends full cooperation, since when the sum of renewable microgrids is the lowest estimated total load for all microgrids, there still exists partial cooperation of microgrids with sufficient charge.

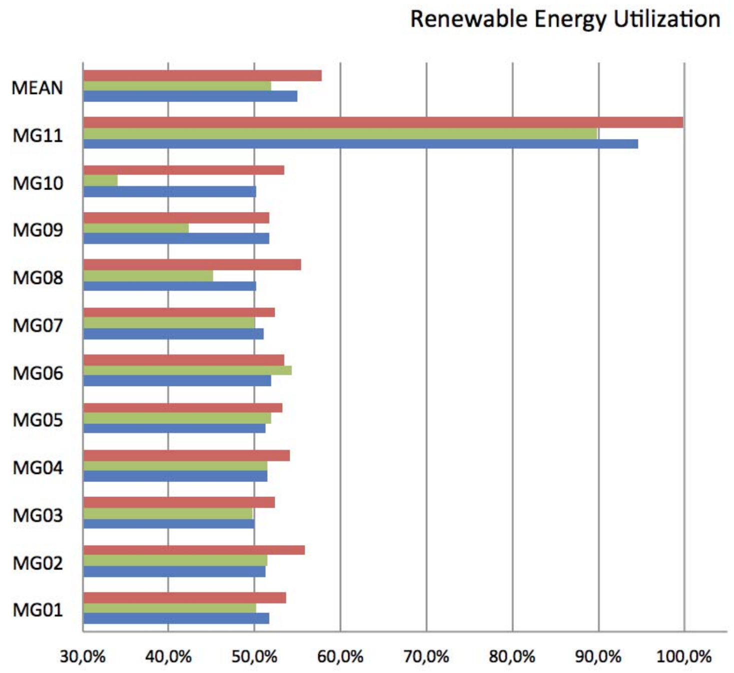
Next, we present the simulation results, which indicate the percentage of renewable energy used by microgrids (see Figure 11). It is observed that the proposed cooperation model has a higher average utilization and enables a more equitable distribution generated energy use. For this model the average energy used was 57.73% with a confidence interval (with 95% confidence) between 57.64% to 57.83%.

In Figure 12 we present the percentage of wasted energy – for each model.

6.5. **Analysis of simulation temporal requirements.** In electrical systems temporal requirements of applications supervision and control must be met in order to ensure QoS and security of offered service. The most critical point is in the generation and distribution of energy that should provide response within 30ms. In Home Smart Grid approach no specifications are defined in some countries and our framework achieved a response time of 1.03ms.

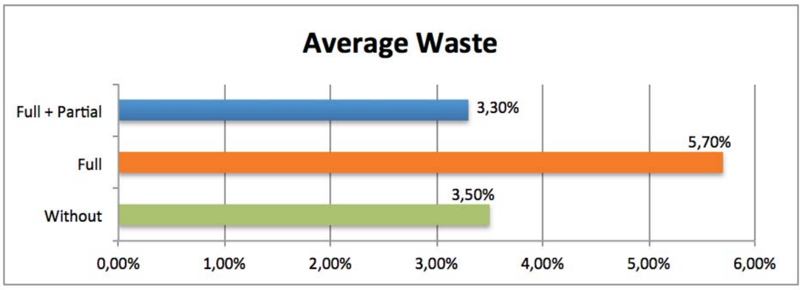
7. Validation 02 – Modeling a Reconfiguration Problem in Smart Grid Networks.

7.1. **Objetives.** Present an application of network reconfiguration focused on infrastructure analysis.



	MG01	MG02	MG03	MG04	MG05	MG06	MG07	MG08	MG09	MG10	MG11	MEAN
🟥 Full+Partial	53,7%	55,8%	52,3%	54,0%	53,3%	53,5%	52,4%	55,3%	51,6%	53,4%	99,9%	57,7%
🟩 Full	50,1%	51,4%	49,7%	51,4%	51,9%	54,4%	50,0%	45,0%	42,3%	34,1%	89,8%	51,8%
🟦 Without	51,7%	51,3%	49,9%	51,5%	51,3%	52,0%	50,9%	50,2%	51,7%	50,3%	94,6%	55,0%

Figure 11. Percentage of used energy from renewable microgrids sources



	Without	Full	Full + Partial
Average Waste	3,50%	5,70%	3,30%

Figure 12. Percentage of wasted energy from renewable sources

7.2. **Modeling validation.** In [40], a method using graph theory for determining the contribution of each generator to each load in the system has been presented. The method is mathematically performed without assistance of computational tools which may cause delays in the computation depending on the size of the environment to be analyzed.

In this paper, the validation of the flexible modeling will be presented (which uses graph theory), simple and algorithmic by mapping the results of [40], using algorithms developed in the simulation environment named "R" [41] and Igraph package.

In [40], an IEEE standard 6-bus (Figure 13) test system is used. This system has generators (A, B, C, D), buses (1, 2, 3, 4, 5, 6), transmission lines and their respective loads.

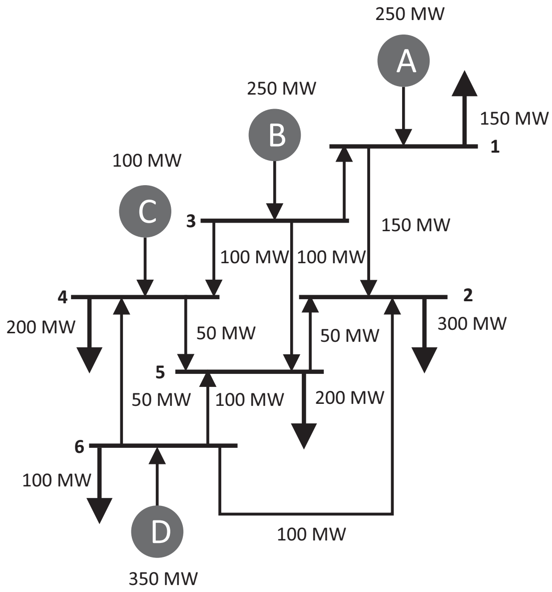


Figure 13. 6-bus test system IEEE model

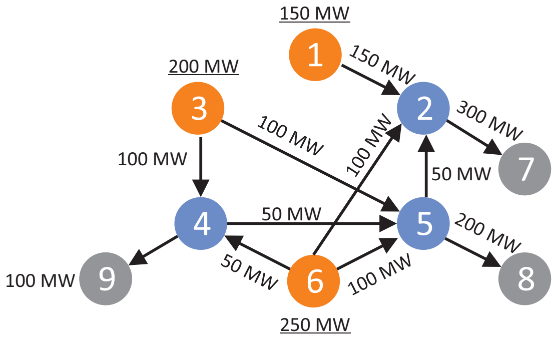


Figure 14. Oriented graph modelling an IEEE 6-bus system

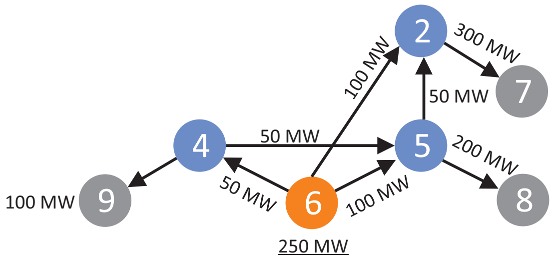


Figure 15. Root subgraph of generator C

Then the mapping of graph theory is presented. Based on the direction of the flows in all the branches of the 6-bus system, an oriented graph is constructed. Such mapping was redesigned according to new modeling seen in Figure 14 with generation buses (1, 3, 6), load buses (2, 4, 5) and load of a neighborhood, a city or even a microgrid (7, 8, 9).

A subgraph of a graph G is a graph whose vertex set is a subset of that of G, and whose adjacency relation is a subset of that of G restricted to this subset. In this mapping, subgraphs are constructed in such a way that the power can reach to all vertices in that subgraphs. Figure 15 shows a subgraph of generator C.

After the development of the algorithms according to the mathematical calculations based on article [40] using "R" approach, we obtained an equivalent result as shown in Table 5.

Table 5. Contribuition of each generator to each load in the system

	Load 2	Load 4	Load 5
Generator A	0.3333	0.0000	0.0000
Generator B	0.2500	0.7500	0.5000
Generator C	0.4167	0.2500	0.5000

Table 5 shows the individuals contributions of each generator to the loads. As we can verify, the Load 4 receives 75% power from Generator B and 25% from Generator C, but its load does not receive any contribution of generator A.

The model is flexible enough in such a way that, with this information (Table 5) it is possible to propose a network reconfiguration, for instance, to make the system optimized, thus minimizing dependence on a single transformer, thereby reducing the consequences of a possible failure. This is a kind of new feature and flexibility not yet available with conventional mathematical calculations executed, typically, by hand or pre-configured computer applications.

8. **Conclusion and Future Directions.** This work aims at exploring new paradigms of computing (ubiquity, autonomicity and real-time) through a framework focusing on monitoring and supervision in the context of smart grid solutions aiming to improve and assist the decision-making process through an intelligent network with ubiquitous and autonomic characteristics.

In order to achieve this goal, real-time remote power grid information will be collected, aiming at diagnosis and reliable decision-making. The protective measures are aimed at preventing and offsetting of faults, thus avoiding major breakdowns and problems such as large blackouts, that generate a loss in the order of millions of dollars for electric utilities.

The basic new advantages brought by using "R" and the proposed modelling method (SG features and capabilities mapping) is that, firstly, we get a more straightforward way to represent the components of a reconfiguration smart grid problem and, secondly, "R" modelling creates a new set of possibilities in terms of "handling and/or manipulating" the problem being considered. This is basically due to the inherent capabilities resulting from using graph theory to handle a multi-objective problem such as the reconfiguration or optimization ones in the smart grid context.

The "R" model proposed is adaptable to the context of network reconfiguration and can be expanded even beyond the scenario presented. For future work, it is expected to adapt the model to simulate random loads by proposing (i) an autonomic decision making to the system before a transformer fails or the insertion of distributed energy resources; (ii) propose, in real time, a network reconfiguration system aiming to balance the loads (optimization problem) and the minimization of possible occurrences of failures due to overload.

Smart grid will be able to deliver more energy to users, as a consequence of an improved management of energy generation, transmission and distribution, being less vulnerable to security breaches, attacks, natural disasters and mechanical and human errors [42].

The proposed framework should include characteristics of ubiquity and autonomy depending on the need of considered management and supervision systems and utilities. Thus, the overall goal of the present work is the proposal of a framework for monitoring and supervision with ubiquitous and autonomic features in the electrical system aimed at supporting smart grid solutions in order to improve and assist decision-making.

There are several challenges to be overcome in the context of project solutions with ubiquitous technology and features in logical terms.

The architecture and constituent technologies allow the attendance of a minimum set of fundamental requirements in the context of smart grid, among the most relevant, namely:

i. High throughput of messages;
ii. Two-way communication;
iii. High availability;
iv. Reliability;
v. Dependability;
vi. Fault Detection and Recovery.

The results show the effectiveness framework in the power management in microgrids, considering the first four challenges. The simulation results also gave satisfactory response time, demonstrating high-level frameworks that can be used in autonomic decision-making. Therefore, the ubiquitous solutions should provide, among other features, transparency and invisibility users.

Future work involves figure out characterizations of distribution network which could guarantee the efficient solvability of reconfiguration problems in smart grid. The framework should be able to autonomically adjust configuration when requirements of the system change based on the grid events, and it should implant the self-healing capability to communication network.

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