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A Framework to Support Smart Grid Solutions with Ubiquitous, Autonomic and Real-Time Features Targeting the Sustainable Use of Renewable Power

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***Abstract*—Smart grid is a network infrastructure and telecommunications with a set of applications and technical features such as interoperability with legacy systems, two-way communication, ability to recover from failures, among others. This architecture is highly based telecommunications networks with inherent advantages, such as greater efficiency and reliability to the system, allowing communication between intelligent devices in the network. Among the challenges for the development of new generation network to the grid smarts, use renewable resources, security, monitoring, management, control, quality of service and technology updates. The main goal of this paper 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.**

***Index Terms*— Smart Grid, Ubiquity, Real-Time, Autonomic Systems, Monitoring Systems, Renewable Energy, Sustainability.**

I. Introduction

OVER the past decades, there has not been substantial evolution in electrical power grid structure in most countries [1]. In general, traditional approach for dealing with electrical energy consists of five phases, shown in Figure 1: 1) Generation; 2) Transmission; 3) Distribution; 4) Commercial Clients and 5) Final Users. In order to deal with the technological obsolescence, new demands and modernization of existing electricity grid, a new concept of next generation electric power system has been proposed: the Smart Grid [2].

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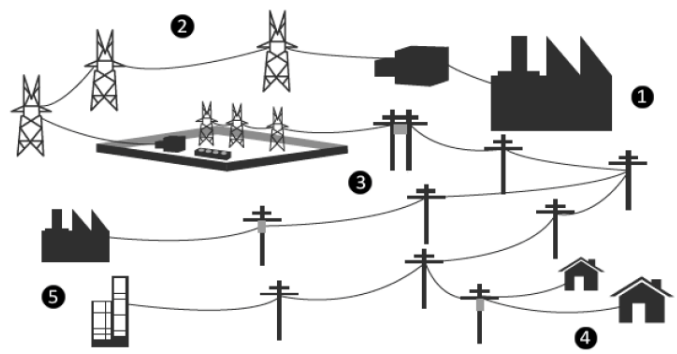


Fig. 1. Electrical Power Grid Traditional Approach

Smart Grids allow greater efficiency, reliability and integration of power grid. Efficiency implies enabling a reduction in power consumption and, at the same time, providing an equal to or higher power supply quality than the current one. This reduces costs and the environmental impact of power generation. Reliability factor leads to more resilient system operation allowing the identification of problems, such as failures in network assets, enabling management to take appropriate actions before the problem occurs or a wider area is affected. Integration, in brief, means that the power grid components will be able to better communicate, resulting in an improved overall operation. Figure 2 presents a general scheme involving different clients and applications that can be supplied by smart grids.

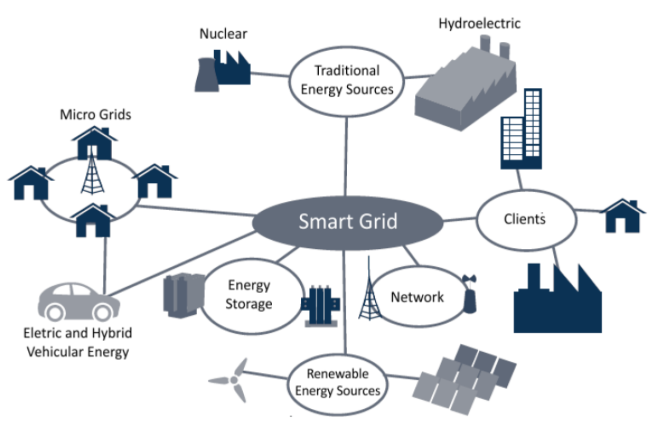


Fig. 2. Smart Grid Concept and Components

This paper presents a framework for management of renewable energy sources and vehicular (electric and hybrid cars) in micro grids (see Figure 2).

II. Actual Problems

Monitoring and supervision of electrical systems is an important and old challenge, which is, typically, deployed nowadays using centralized solutions with the use of links, mostly dedicated. Modernization of electric system automation is inevitable, making it essential to deploy a monitoring and intelligent communication system with control centers and supervision of 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. Nowadays, power grid systems have several problems such as:

1) Manual consumption control;
2) Low level of automation to control network devices;
3) Low energy quality delivered to consumers due to faults in transmission and distribution systems;
4) Generation is too far from major consumption centers;
5) Little knowledge and control on energy consumption;
6) Difficulty in integrating new power generating systems (e.g. solar power, wind power, electric vehicles);

In this paper, we work with the items 5 and 6.

III. Proposal

A new architecture for Smart Grids must deal with these requirements, besides giving support to grid and underlying network evolution according to new demands, leaving behind the conventional model based on the requirements of a century ago. An investigation of supervision and monitoring mechanisms with ubiquitous and autonomic features aimed at supporting solutions in Smart Grid style will be held.

The basic research scenario considered are electrical systems which aims at enabling optimized solutions for smart cities and management and monitoring systems for the power grid itself. The solution approach to be pursued includes new monitoring technologies based on wireless sensor and actuator networks (WSANs) [3]. The smart grid will be able to deliver more energy to society, 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 [4].

A smart electrical system switches all power supply through network distribution, managing energy demand through a communication system [5]. Hence, network intelligence lies in the ability of devices to communicate and exchange information building, as such, a safer and efficient network.

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 to propose a framework for monitoring and supervision an electrical system, focusing on supporting Smart Grid solutions, with ubiquitous and autonomic features in order to improve and assist decision-making. Specific objectives can be highlighted:

1) Investigate, monitor and supervision systems, in order to minimize problems and improve system management of power grid. The protective measures are geared towards the faults prevention/resolution, thus, avoiding collapses;
2) Improve operational reliability in terms of resilience and ability to recover from failures;
3) Improve autonomy level of monitoring protocol which will be used and whose validation will be held through sensors and actuators components;
4) Improve integration and energy efficiency management of renewable sources and vehicles.

To achieve this goal, real-time remote power grid information will be collected, aiming at diagnosis and reliable decision-making.

IV. Framework

A. *Ubicomp Issues*

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).

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

1) 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 with extensive support of network infrastructures (wired/wireless) and device data abstraction models deployed;
2) Invisibility – Adds multi-agent system concepts to the Smart Grid scenario [6] 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 [7] and communication skills;
3) Context-Aware – The sensors will collect data about the operation and performance (voltage, current) on the environment 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;
4) Location-Based – An autonomic sequential record real-time mechanism will identify locations and operational status of various components and assets.

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 phase association 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 (smart space).

In order to safeguard the proposed objectives will be developed, firstly, a functional prototype of the framework for monitoring and supervising focused on technological experimentation with intention to consolidate the proposal framework.

The prototype will support environment simulation, testing and validation of the hypotheses of the autonomic monitoring systems.

B. Autonomic Characteristics

Autonomic computing (Autonomic Computing) is an inevitable evolution of information technology infrastructure management of [14]. 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 work of administrators more costly. Complexity is presented as the most important challenge to be addressed by such systems [10].

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 [13]. 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 [11]. 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 [10]. Indeed, it is important to mention that autonomic computing does not focus on eliminating human intervention [12].

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 [13].

In fact, the essence of autonomic systems is self-management [13], 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, in this paper looks forward to reaching framework solutions based on administrators operational definitions.

C. 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, and sometimes microseconds. Conversely, a system without real-time requirements, cannot guarantee a response within any deadline (regardless of actual or expected response times) [26].

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 in relation to these systems.

D. Proposed Framework

In order to keep proposed objectives, we first modeled a functional framework prototype for monitoring and supervision, which focus 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, as shown in Figure 3.

This infrastructure must provide secure communication and quality of service [2]. However, designing a structured network protection, supervision and monitoring that supports control and efficient management of network resources is one of the biggest challenges today [8].

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 (MC). System Monitoring and Performance integrates messages from MCs and converts them to a common format (XML) to be treated by Knowledge Plan (see Figure 3). This, in turn, is responsible for analyzing the information from System and Performance Monitoring and also offering an answer according to specified rues 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), charging between microgrids, among other aspects.

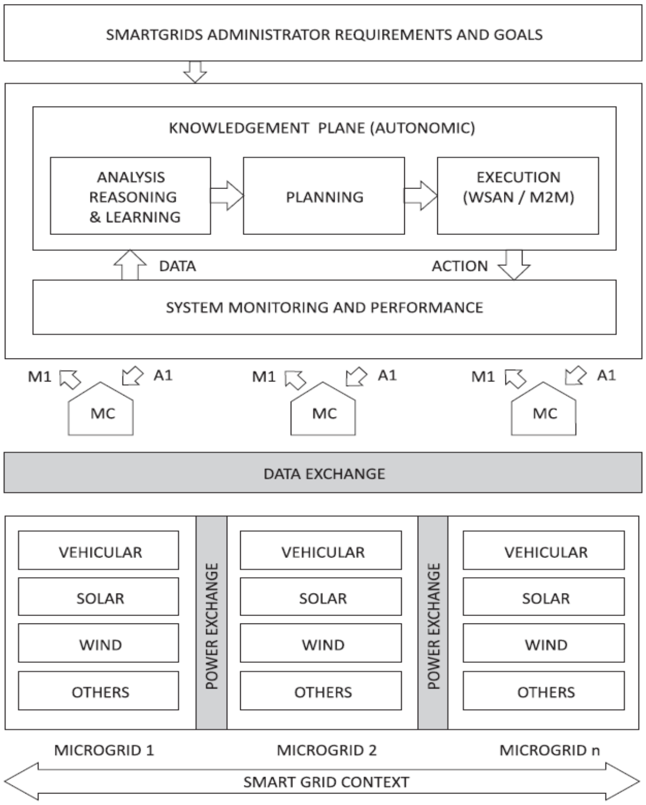


Fig. 3. Proposed Framework

E. *Microgrids – Distributed Energy Generation*

Microgrid is a new paradigm developed by inclusion of distributed generation of Smart Grids. These enable an efficient way to connect power sources of different types and capacities [19] and the creation of localized and small power systems consisting of generation, storage and energy loads.

The new system of distributed energy generation, the microgrids, lists various impacts on system operation, especially in regard to network control and protection equipment. The situation increases the criticality when microgrids have the resources to generate intermittent energy (ie, wind generation, solar generation, among others) [20]. The intermittent generation does not guarantee the continuous supply of energy and ensures that even the largest consumer of energy in the microgrid happen at the same time generating maximum intermittent source [21].

In [23] a model is presented to evaluate reliability of microgrid with distributed generation trusted in renewable energy resources. Stochastic models are proposed to represent the energy storage and the availability of power generation from intermittent sources in order to reduce the intermittency of supply from these sources. Thus, microgrids collaborate to guarantee the reliability of the grid, as they are likely to be self-sufficient in the question of the generation and consumption of energy, minimizing network overhead electric. Reliability models based on renewable energy sources for electrical distribution networks can be found in [22].

Lasseter et al. show that the use of microgrids distribution systems may simplify the implementation of various functions of new electrical systems [24]. Authors describe the isolation of small generations and loads can provide greater system reliability by full capacity for rapid reaction to a fault.

You also need to ensure flexibility in the management of renewable energy sources to enable the maximization of its use, minimizing waste. In this context, we consider six important points in microgrids management, as shown in Figure 4:

1) Efficient use of renewable energy sources;
2) Autonomic Management to guarantee temporal requirements to better quality of service offered;
3) Provision of services and detailed information to the final consumer;
4) Use energy-conscious vehicle;
5) Provide integration and interoperability between microgrids and also with the distributor;
6) Communication between microgrids order to meet the above requirements.

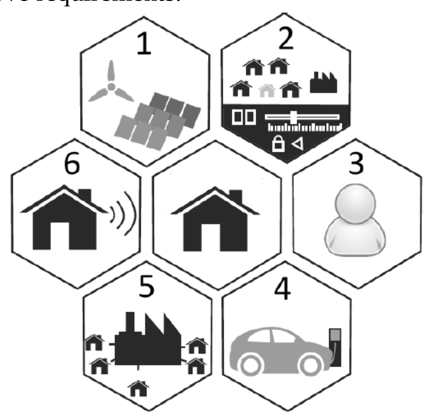


Fig. 4. Aspects of micrigrids management

This work focus on the four first items described above.

F. *Real Scenario and modeling for microgrid management*

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. The test scenario corresponds to a condominium residence with the following structure:

1) 100 homes divided into ten streets, where every street is mapped as a microgrid. The condo also is seen as a microgrid.
2) The condominium residence has a wind power turbine that is capable of generating between 2.3 MWh and 3.6 MWh [25].
3) The solar panels installed in homes can generate between 100Wh to 300Wh.
4) 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 because of taxes, high cost of manufacturing and the lack of a well defined policy. [25] Thus only one residence will be mapped with this vehicle.

G. *Data Modeling*

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

1) Each microgrid is connected to the MC 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.
2) The MC is connected to the electricity distributor also bidirectional edges. The MC will aggregate the data from all microgrids. For each microgrid representation will be used - in tables - described below:

TABLE I
LOGICAL MODEL

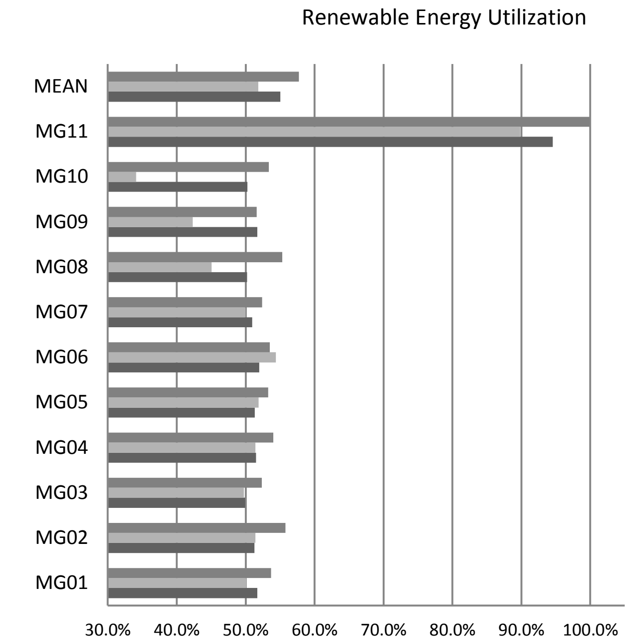
Table	Description	Details
MGESCA	Load of MG Energy Sources	Indicates the actual charge of renewable energy sources present in each microgrid
MGESCC	Energy Sources Consumption of MG	Indicates the total daily consumption for energy source of each microgrid.
AL	Storage Limits	Informs the maximum stored charge for energy source
MGESF	Function of MG Energy Sources	Stored the mathematical functions applied to energy generation from renewable sources
MGHCE	Consumed Energy	Stores microgrids consumption per hour, based on consume history.
MGESD	Availability of Generated MG Energy Sources	Indicates 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	Stores the wasted energy by energetic source. This occurs when storage limit is reached, because generation is greater than consumption.

V. SIMULATION SCENARIOS

The simulation scenarios objective maximizes the energy renewables use in microgrids (detailed in Section IV-F). This simulation uses R compiler and igraph package. For the simulation purposes we used three models of cooperation:

1) 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;
2) Total Cooperation - Cooperation exists when the sum of the renewable microgrids is greater than or equal to the estimated total load for all microgrids;
3) Total / Partial Cooperation - This model of cooperation extends full cooperation, since when the sum of renewable microgrids is the lowest estimated total load for all microgrids, still exists partial cooperation of microgrids with sufficient charge.

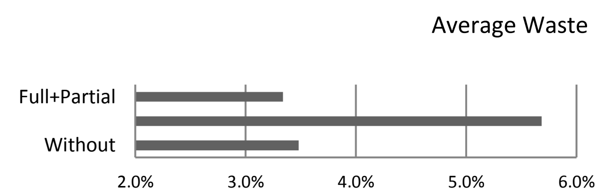
Next, we present the simulation results, which indicates the percentage of renewable energy used by microgrids (see Figure 5). It is observed that the proposed cooperation model has a higher average utilization and enables a more equitable distribution generated energy use. For this model the average energy used was 57.73% with a confidence interval (with 95% confidence) between 57.64% to 57.83%.



	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%

Fig. 5. Percentage of used energy from renewable microgrids sources

In Figure 6 we present the percentage of wasted energy – for each model, when the sum of generated energy is greater than the consumed and the storage limited is finally reached.



	Without	Full	Full+Partial
Average Waste	3.5%	5.7%	3.3%

Fig. 6. Percentage of wasted energy from renewable sources

A. *Analysis of Simulation Temporal Requirements*

In electrical systems temporal requirements of applications supervision and control must be met in order to ensure quality of service 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 defined in some countries and our framework achieved a response time of 1.03ms.

VI. CONCLUSION

This research project aims at exploring new paradigms of computing (ubiquity, autonomicity and real-time) through a framework focus on monitoring and supervision in the context of a smart grid solutions with the objective to improve and assist the decision-making process through an intelligent network with ubiquitous and autonomic characteristics. To achieve this goal, real-time remote power grid information will be collected, aiming at diagnosis and reliable decision-making. The 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 [4].

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.

The results show the effectiveness framework in the power management in micro grids, considering the first four challenges mentioned in Section IV-E. The simulation results also gave satisfactory response time, demonstrating high-level frameworks that can be used in autonomic decision-making.

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