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INSIGHTS FOR SMART GRID DEPLOYMENT IN THE INDUSTRIAL SECTOR

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Abstract. *Many authors believe that the potential of Smart Grids for the industrial sector is not fully appreciated, especially in light of recent and emerging technologies. Therefore in this paper the importance of the advent of SGs for the power sector is surveyed, exploring its technical characteristics, its structure and its features. The review clearly shows that the implementation of SGs in the industrial sector still requires some planning. It is necessary to identify which energy resources are available, and collect data from supply and demand to identify the characteristics and interests of those involved and interested by doing a complete cost analysis. They have to consider cost including those related to the environment, economic and social impacts. Possible strategies for managing the demand for better use of energy mixes are necessary. Finally, we hope this paper raises awareness about the need for the implementation of SGs in the industrial sector, with regard to the benefits that can be achieved with today's solutions, as well as research opportunities to make further improvements in the capability and ease of application of smart grid technologies.*

Keywords: *Smart power grids (SGs), Demand side management, Distributed generation, Smart meters, Energy mix.*

1. INTRODUCTION

In the current economic setting, energy efficiency, reliability and the integration of renewable energy resources are important themes studied with the goal of increasing the stability of electric energy systems (Mahmood *et* al., 2014).

As a consequence of the technological evolution that has taken place in the last couple of decades, the Energy Intensity for the industrial sector, expressed in terms of the energy total consumed per economic product unit, has been diminishing gradually. Still, according to Mahmood *et* al. (2014), with the increase of global population and energy demand, there is an overload of the currently installed distribution grid, since this grid has been serving humanity for decades. In this scenario, major attention should be given to the industrial sector, since its demand represented 40.70% of the energy consumption for the year 2013, as seen in Figure 1.

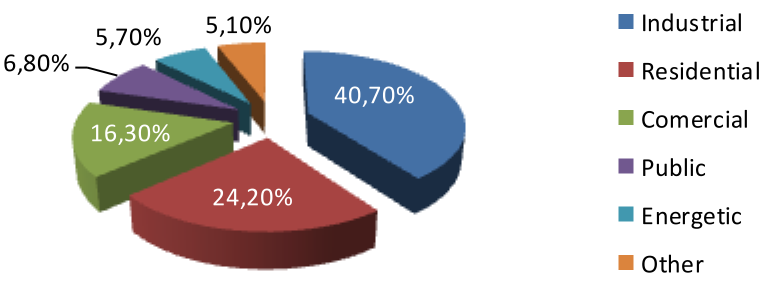

Figure 1. Electrical Consumption per Composition Sector in Brazil (BEN, 2013).

However, Brazil never had an electrical efficiency policy aimed at the industrial sector (Eletrobrás, 2009). Regardless of an energy crisis that took place in 2001 and 2002, the government stuck to releasing energy consumption reduction measure "packages" and, after this period passed and the return of normal offerings, the measures lost their importance, which was a grave mistake, for an Energy Efficiency program must be given continuous activity, identical to a quality program (Santucci, 2011).

Currently, with the growing competitiveness of the industrial market, a concern rises in regards to the increased expenses that have resulted from production costs. One of the factors that mostly contribute to these expenses is the electric energy consumption that, according to Freitas (2011), in Brazil, energy cost is one of the highest in the world. One of the causes for the high electrical energy rate is the monopoly of the system's carrier companies, called leaderships, which mostly act on all the parts of the process, from its generation, through transmission and distribution, until it reaches its final consumers (Soares, 2011). For Santucci (2011), this leads the industrial sector to increasingly search for alternative methods of electrical energy generation. Methods that are cheaper and more efficient, which avoid transferring costs to the consumer, characterize an industry attempt to break free of its dependence on the electrical carrier companies.

Tied to the attempt to minimize financial energy costs, there is the environmental branch of this search for more efficient methods of energy generation. The implementation of hydroelectric power plants, which are the country's main generation source, with 70.60% of the electrical energy produced (See Figure 2), causes environmental impacts to hydrology, climate, flora, fauna, and consequently, alters the landscape.

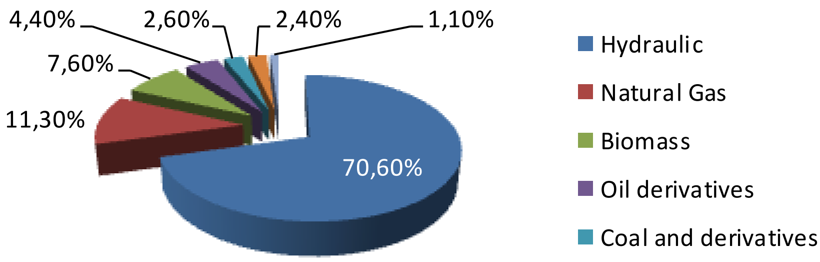

Figura 2. Domestic Supply of Electricity Source in Brazil (BEN, 2013).

In one of his papers Leite, (2005) states that thermal plants are the second most used energy generation source used in Brazil, with 28.3% of applications, that help the energy generation, further accentuating the environmental impact, as they are ravenous consumers of biomass, gas, petroleum and mineral coal. The thermoelectric plants powered by natural gas are significant carbon monoxide, nitrogen oxide, and carbon dioxide emitters, while the ones that use diesel motors emit carbon monoxide and sulfur, pollutants that accentuate the greenhouse effect and result in acid rain (de Castro Villela and Silveira, 2007). Therefore, the efficient use of electric energy results in not only expense reductions, but also in an environmental impact.

Beyond the environmental impact, another aspect of special relevance refers to the shortage of energy resources. The hydroelectric plants are hostages to climatic changes resulting from global warming. In this case, important changes in atmospheric precipitations in a global scale are in progress, causing a direct impact to the available hydrous resources (Stedman, 2009). Similarly, thermal plants function based in nonrenewable resources, which are exponentially consumed in developing countries (Miller and Spoolman, 2011). If this continues, those countries will have increasingly scarce reserves. Consequently, a paradigm shift is necessary in regards to the global energy model (Americano da Costa and Santos, 2015). In other words, it is very likely that the investment in alternative energy sources will increase, with a focus in systematic energy efficiency, once we already have new monitoring and control tools needed to increase system flexibility and maintain the balance and stability level of the distribution grid (Moura *et* al., 2013).

Given all the mentioned factors, nowadays, an increasing number of factories have searched in various ways for the efficient use of electric energy, aggregating various forms of generation. However, it is common for the industrial sector to encounter some barriers in this tireless search. Investment and rentability, information, transaction costs, lack of specialized personnel and occasional slow capital circulation restrictions in particular can be mentioned.

Current energy systems are undergoing significant changes. Many countries have specific ambitions of increasing their renewable energy quotas in their energy matrix. According to Muench *et* al. (2013), this development implies a challenge of incorporating an increasing supply of volatile energy and an increased number of energy providers at a distribution level. Smart Grid could be a solution to that challenge.

Several authors (Miller, 2009; Abe *et* al., 2011; Sheble, 2008) have stated that Smart Grid will facilitate the operation and integration of renewable energy sources to the industrial sector, as well as the storage of the generated electrical energy. In a future with low carbon, a way to balance offer and demand, without resorting to coal and gas to feed the generators, will be needed. The term "Smart Grid" refers to a system that allows for the integration of several renewable energy sources and the change from a dependency on combustive fuels, while maintaining a balance between offer and demand (Crossley and Beviz, 2010). Therefore, smart grids were created in search of an increase of control, flexibility and efficiency in production systems of energy production and distribution (Farhangi, 2010).

Samad and Kiliccote (2012) are emphatic that the public focus on Smart Grids has been mainly focused on the residential sector, but commercial and industrial installations have a bigger prospect in regards to peak load consumption and contribution. However, its implementation has been fragmented and of limited reach. The industry is a heavy user of the electric energy generated by individual plants and aggregate factories represent large loads. Paradoxically, the industrial community is not as involved in the smart grid development as the residential and commercial consumer providers. It is believed that the smart grid potential for the industrial sector is not fully appreciated, especially taking into account emerging and recent technologies.

This article is part of a research project aimed at supporting the industrial sector as a conceptual model for the application of Smart Grids (SGs), in an environment of mixed energy sources, bringing mobility to electrical energy generation, in an attempt to improve the system performance, searching for alternatives that generate qualitative and quantitative advantages to the industrial sector.

From a scientific point of view, this paper represents a literature review about SGs to allow for a mapping of its infrastructure and the identification of important compounding elements, besides some of its applications. Therefore, the theoretical foundations will guide the research, compiling important information for the development of the conceptual model of the creation and implementation of SGs in the industrial sector. The article will be organized in the following manner: section 2 identifies some elements that make up the Smart Grid infrastructure and its functions; section 3 presents possible applications of its elements in the industrial sector and its benefits; section 4 concludes the study by showing future perspectives and the directionality of the study on SGs.

2. TECHNICAL CARACTERISTCS AND STRUCTURE OF THE SMART GRID

Nowadays, factories have become "smarter" when they explore the available data and technical analysis, in order to increase the electrical efficacy and efficiency through the integration of physical infrastructures and available digital technologies (Gann *et* al., 2011). For a successful propagation of smart factories, the interoperability between sensors and smart devices must be achieved and security and privacy must be guaranteed. Consequently, the implementation of a new system, like SGs, can contribute to diminished energy consumption in the industrial sector (Naphade *et* al., 2011).

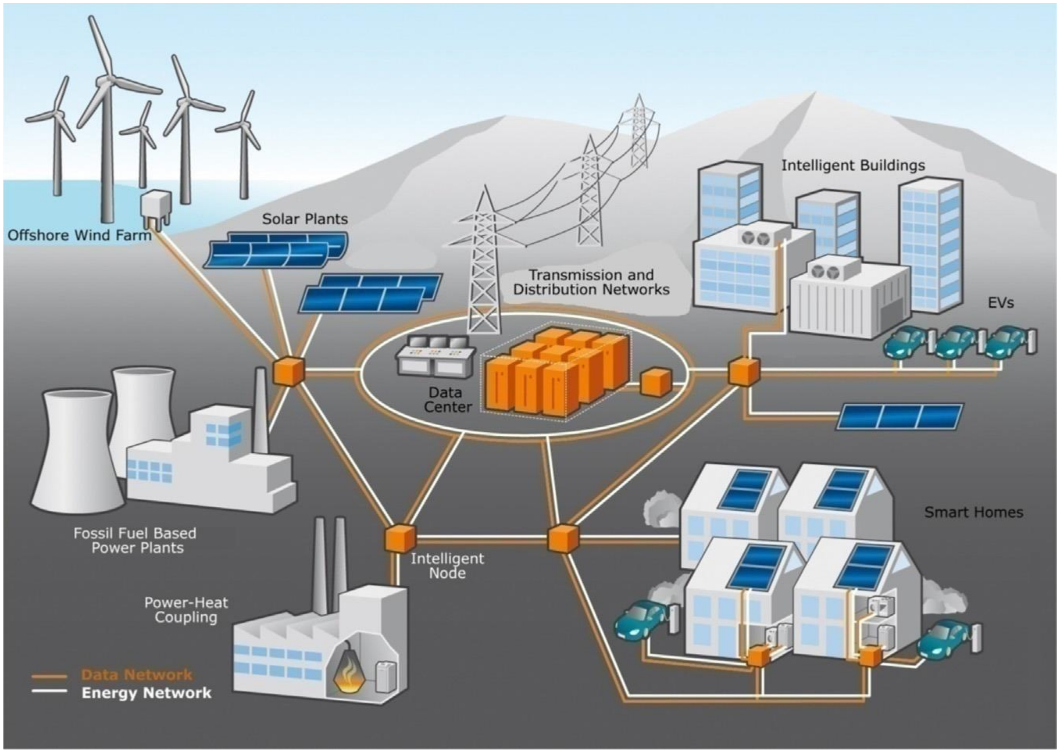

Figure 3. Conceptual and structural Smart Grid design (Paudyal et al., 2011)

In the figure 3, we see that smart grids represent a recent tendency to integrate energy systems in diverse applications. The power is generate by several energy sources, as wind, solar or fossil fuel plants. They represent an evolution for the most well-conditioned and sustainable energy system that utilizes an integration of information and communication technology (Potter *et* al., 2009; Gungor *et* al., 2011; Hashmi *et* al., 2011) to improve its security, trustworthiness, efficiency and sustainability in electricity production and distribution (Amin, 2005; McDaniel and McLaughlin, 2009; Kundur *et* al., 2010; Kezunovic, 2011).

A smart grid is an electricity grid with elevated information and telecommunication technology integration and high level of measurement and automation (Falcão, 2009). This combination considerably increases its capacity to attend to scenarios such as: intermittent and distributed energy sources like solar and wind power plants, high reliability requirements, and low environmental impact and adequacy to new energy markets. In other words, the grid would utilize the information to improve its operational decisions (Potter *et* al., 2009).

Operational decisions are made in a Data Center, like in figure 3, created to operate and monitor the transmission and distribution networks. The monitoring is done in specific points of the grid known as Intelligent Node. In these nodes, data is collected from generating sources through the distribution and transmission networks, and the involved consumer data from intelligent buildings and smart homes. Therefore, the grid becomes a more efficient form of control, managing demand through the information given by the measured values.

A recent paper by Park *et* al. (2014) shows that numerous countries have sought to install smart meters in residential buildings, as well as commercial and industrial. This meters includes an advanced measurement infrastructure considered to be primary in a smart grid, which can communicate with the energy provider and deliver information about the consumer's energy consumption (Dütschke and Paetz, 2013; Depuru *et* al., 2011). Generally, unbalanced loads can cause fluctuations in the voltage profile in a distribution feeder located in a distant substation. Smart meters can analyze and control these voltage fluctuations in the low voltage grids.

As shown in figure 4, the system of smart metering includes meters of cables interconnected by communication devices. This allows the supplier to collect usage data for every connected device along with operational parameters like interruption, adulteration and energy quality information, allowing for faster correction of service interruptions, increasing meter reading, invoice, and client support operations efficiency. These systems also allow the supplier to share the usage information collected in real time with consumers though residential displays or the internet. When consumers are connected to their usage information, they can save energy in peak times as well as through the regular invoice period. Reductions in peak demand will allow suppliers to optimize their generation technologies in order to deliver the most cost efficient energy with the lowest possible environmental impact.

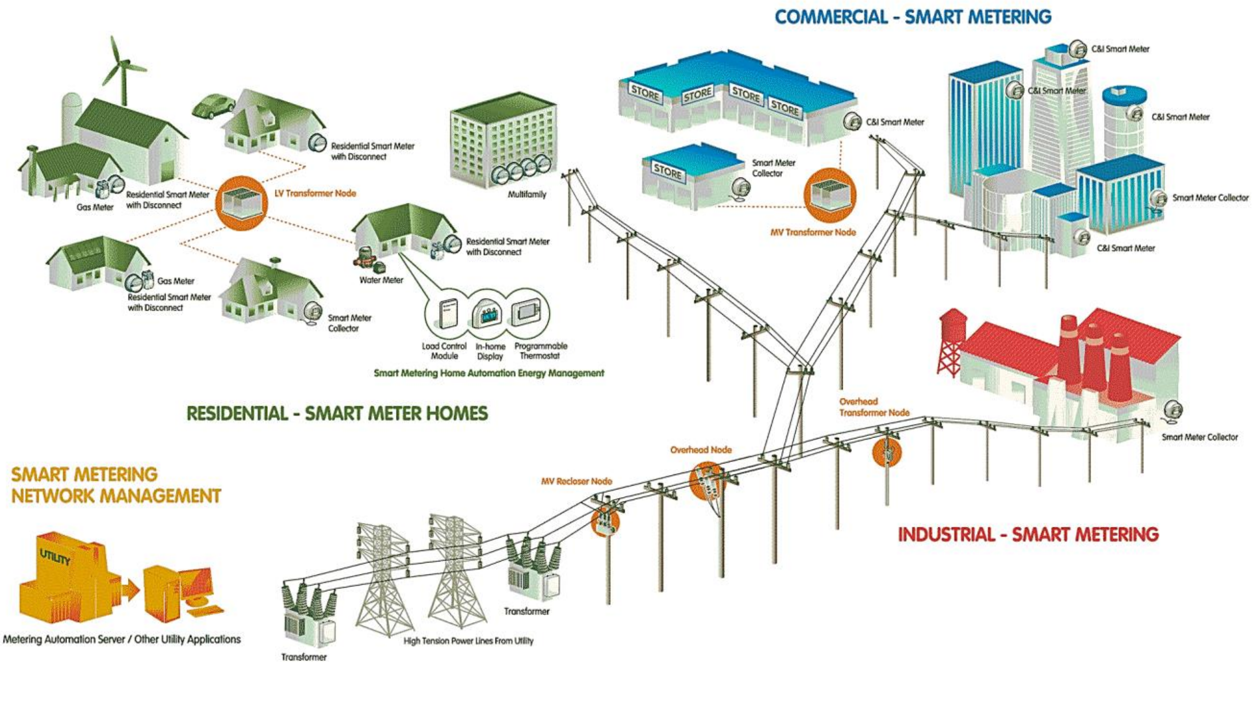

Figure 4. Smart meters and grid communication scheme (Elster, 2014)

In regards to cogeneration, generators integrated to a distribution grid must be registered so they can be accessed and controlled by the smart meter system (Boat, 2009). Standard recognition techniques can also be employed as a part of the smart meter system. Similarly, it is possible to discriminate the contributions from different energy sources in a single combined energy flux, allowing both the distribution grid and non-renewable energy sources to be measured separately from an individual measuring point.

Regardless of the various definitions of a smart grid, the needed grid attributes are clear to multiple authors.

Amongst them are the Demand Response (DR), and the Demand Side Management (DSM), through the integration of smart meters, smart equipment, microgeneration and the storage of electrical energy (Momoh, 2012). In order to achieve such control, Giri *et* al. (2009) mentions that SG is capable of providing clients information on energy consumption and pricing, with the ability to allow for the participation of factories that use them in competitive markets, increasing their new products and services investment

DR and DSM are considered to be directly related to the ability of electrical energy consumers to respond automatically to signals emitted to alter energy demand (Park *et* al., 2012). Demand variation can occur as a function of price variation or signals that provide evidence of a specific emergency condition. This change can show the displacement of load operations to different time periods, from some load operations for others, or through altering the parameters of the load status.

The collection of energy consumption data from all sectors allows factories to manage the electricity demand more efficiently. Recently, smart grid technologies and DR programs have been proposed as a technical solution for more flexible demand and the adaptation of energy generation. Aghaei and Alizadeh (2013) have presented a revision of the challenges and opportunities for the demand response programs in electrical energy smart grids equipped with energy renewable sources.

In recent years, various journals have included a discussion of the “smart grid” concept. Many defend the need for smart grids to facilitate a better integration of fluctuating renewable energy (Orecchini and Santiangeli, 2011). When the distribution grid is integrated in wind turbines, for example, a sudden failure similar to a production unit disconnection or a large load can alter the feed frequency (Depuru *et* al., 2011). A smart system can therefore quantify and maintain those parameters within the desired band, even in strong winds.

Smart grids can also include a continuous current, direct elements and conversion inverters. In order to facilitate the integration of renewable sources, for example, the solar cells produce continuous current outputs and electronic equipment requires a continuous current to operate. Significant conversion inefficiencies can, therefore be avoided (Samad and Kiliccote, 2012).

The challenge of the large scale integration of the existing renewable energy systems is to coordinate the fluctuation and production of intermittent renewable energy with the rest of the energy system (Lund *et* al., 2012). This challenge is essential, especially in regards to electricity production as electrical energy systems depend on an exact balance between offer and demand at any given time.

3. INSIGHTS FOR THE INDUSTRIAL SECTOR

Electrical auditing is the energy efficiency evaluation process of a system that identifies ways in which the system can be improved (Cambay *et* al., 2004). Industrial electrical audits accomplish an important role in obtaining data that allow for cost reduction and goal stipulation for industry peak load reduction. These audits can become more efficient if more details about plant behavior and consumption or industrial sectors are known. Smart meters, utilized as a part of a Smart Grid infrastructure, offer different data levels that can reveal precise energy consumption tendencies which allow audits to become more efficient (Aslam *et* al., 2013).

Depending on how smart meters are configured to collect data, different types of load diagrams can be produced. Within factories, these diagrams can correspond to individual machines or whole plants and each diagram can highlight certain factor, according to the plant’s needs.

The use of smart meters in factories would demand modifications, infrastructure changes, monitoring increases and business process modifications. The implementation without the necessary studies can be extremely inefficient and costly. Consequently, it is essential to first understand different layers of the smart measurement infrastructure (applications, communications and energy) and identify the business’ financial and technical requisites for the infrastructure. Although the final use instances are of primordial importance, it is also essential to take into account the objectives of each transaction. Kazman *et* al. (2011) argues for a detailed architectural evaluation approach that is extremely relevant given the absence of a well-defined architecture for the use of smart counters inside factories.

The management programs of industrial loads in some countries are based in the judgment and experience obtained by the system operation manual. In certain countries, these cannot understand and incorporate the current energy profile that has worsened with the energy shortage. On the other hand, the load diagrams generated based on smart meter data can propose a design for demand management programs (Carrie Armel *et* al., 2013). With an increasing amount of precise information on industrial demand, the grid would be capable of developing an increased comprehension of demand patterns and precisely evaluating its effects.

The Demand Response is widely understood as the modifications in a consumer’s energy consumption pattern, with some incentive, price effect, or utility indication in mind. The energy efficiency and the demand response have different nature and objectives as explained by Goli *et* al. (2011). The correlation between these two concepts can be seen in figure 5. While the demand response serves as an incentive for consumers to temporarily reduce energy usage, the energy efficiency programs present proposals for permanent usage reduction. That occurs through the installation of energy use efficiency technology while demand response is a series of measures that reduce electrical loads during grid failure, peak demand, or other emergencies. The marriage of the two can create synergy by applying the new revenue stream generated by the demand response in more energy efficiency projects. This allows for better financial results than with just one or the other. This is an example of why demand response programs in factories are well stablished in the United States and parts of Europe (Torriti *et* al., 2009).

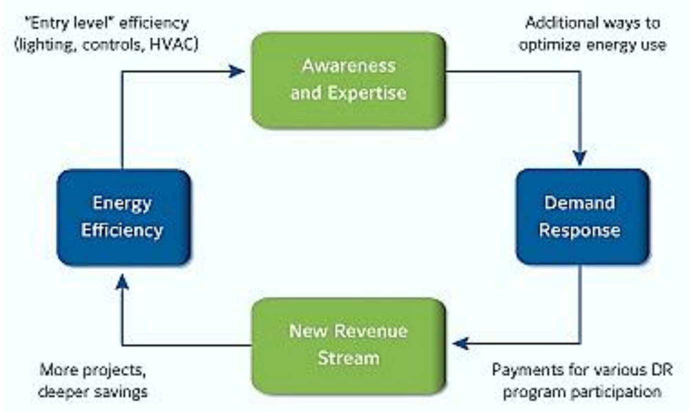

Figure 5. Relationship between energy efficiency and demand response (Smith, 2012)

In the industrial sector, the application of DSM promotes investment delay in new infrastructures that would guarantee installed output increase (electric energy production), system load balance, or peak hour's energy price reduction (Ekanayake *et* al., 2012). By avoiding the need to introduce expensive and pollutant units, the DSM allows for increased sources of alternative energy generation, which are less pollutant and have smaller dimensions, besides being operated in an easy and transparent manner, like solar and eolian energy, for example. These technologies usually reach energy generation peaks that don't coincide with consumption peaks. Besides, these sources tend to be subject to climatic questions and have a smaller size than traditional sources. Difficulties in energy storage and intermittent generation lead to an increase in system operational complexity, which would be better managed by a smart grid.

According to Phuangpornpitak and Tia (2013) recently, the use of renewable energy in smart grids has increased. There is a significant number of industrial sector implemented programs in different parts of the world, most of them developed countries and some developing countries. Some studies indicate that these technologies can provide a reliable energy source with comparatively low service and electricity cost (Consentino *et* al., 2012; Alonso *et* al., 2012; Al-Ali *et* al., 2012). To feed the industry energy consumption, renewable sources managed by smart grids serve as alternative energy source offerings. They allow for the consideration of the environmental impact as well as other social and economic factors.

Besides the numerous promised benefits, there are important concerns over this new proposal. Many unanswered questions remain in regards to the smart grids. In many places, however, a definite cost-benefit analysis aimed at the industrial sector has not been completed. It is not known with certainty which services the system will actually enable and if those services will be valued by consumers or if the consumers will respond to this information influx and change they behavior pattern (Faruqui *et* al., 2009).

4. CONCLUSIONS

Problems in the implementation politics for renewable energy have shown that the development of the smart grid is very important to improved energy applications. Policy makers advocate that the efficiency of smart grids is unquestionable against the possibilities it offers the electric sector, though there are social determinants neglected by policy makers (Wolsink, 2012). Researchers and professionals are extremely dedicated to the study of blended energy grid infrastructures due to their societal and economic impact (Lin *et* al., 2013). Moreover, due to the growing use of smart grids, new political action will be necessary. Public policy will have to adapt to the smart grids to allow for potential gains and information flux; furthermore, incentive policies will be needed to regulate the new grids (Clastres, 2011).

According to current research, it can be noted that the implementation of smart grids in the energy sector lacks planning. The study related to this article will analyze the various factors relative to smart grid implementation in the industrial sector. It will identify the available energy resources, collect offer and demand data and will attend to the concerns of those involved and those interested considering a complete cost analysis. In that context, the costs related to the environmental, economic and social impact should be considered and the best energy demand management strategies should be analyzed

Considering the advances achieved and searching the consolidation of the smart grid systems, future papers will present a conceptual base for this new energy model and point to important indicators in the different engineering departments. There is an increasing need for the application of smart grids in the industrial sector due to the benefits that can be achieved as research opportunities will facilitate the application of this emerging technology.

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