State-of-the-Art Impacts of Smart Grid in the Power Systems Operation and Expansion Planning

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ABSTRACT

In this article, a state-of-the-art review on the impacts of Smart Grid in the operation and planning of the expansion of the Electric Power System is presented. The concept of Smart Grid is increasingly integrated in conventional networks, and the impact that this new technology generates on operation and planning must be investigated. Thus, in this article a survey of the main scientific publications was made with the purpose of determining the impacts and methodologies most used in this analysis. Efforts to analyze impacts are large because of the high degree of uncertainty of this new technology added to the problem. After the bibliographic survey, it was concluded that Robust Optimization and Genetic Algorithms are methodologies that are effective in problems of this nature and are the most adopted methods.

Key words: State-of-the-art; methodology; smart grid; impact; power systems expansion planning; power systems operation planning.

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INTRODUCTION

There is a growing trend to modernize the conventional Power Electrical System (PES) by implementing the concept of Smart Grids.

Smart grids are the distribution and transmission systems that use the Information Technology (IT), telecommunication and high-level automation resources to significantly increase energy quality and operational efficiency. Due to the high level of aggregate technology, Smart Grids are able to respond to various demands of modern society, both in terms of energy needs and sustainable development ¹.

The Smart Grids represent for many the revolution of the electric sector and, consequently, the revolution of the world economy. The rationale for this is that the great economic transformations of history occurred when a new communication technology converges with new energy systems. Communication infrastructure eliminates time and reduces distance, connecting people and markets, facilitating new economic relationships.

The concept of smart grid is increasingly close to consumers. The innumerable advantages that these intelligent systems can provide for the electrical system, the technological advancement of the equipment and the constant growth of the demand for electric power, drive research on the subject. Smart Grid enables real-time metering and bidirectional communication, ensuring greater user participation in the power grid. Home appliances built into smart grids make it possible to determine the power consumption characteristic, allowing the user to control their consumption and reduce their energy tariff costs.

To put the smart grid into practice, it is necessary to consider the modernization of infrastructure, installation of digital layers, with high-capacity data processing software, which is the essence of smart grid.

Despite the mentioned benefits, it is necessary to develop new tools to assist in analyzing the impacts of adding the Smart Grid to the PES. Above all, to analyze the direct impacts on the planning of the operation and the expansion. Smart Grid technologies mainly involve a reduction in peak load demand, reduced operating costs, improved efficiency, and address environmental issues ². The contribution of these tools would facilitate the advances in the implementation of smart grids.

It is very important to take into account the state-of-the-art regarding the impact of these new elements in planning the operation and expansion of the electrical system. Therefore, this article presents a review of the literature on the impact of smart grid concept on the operation and expansion planning of electric power systems.

The objective of this article is to perform a comparative analysis between the recurrent computational methodologies in the studies of the impacts of the Smart Grid in the operation and expansion planning of the PES.

For this purpose, it is necessary to develop a state-of-the-art study regarding the impacts of the Smart Grid in PES, considering the most relevant research. This preliminary study is necessary in order to determine which lines of research are more developed and present better results.

METHODOLOGY

The methodology adopted is, initially, to carry out the selection of the most relevant publications. The selection of publications is made considering the number of citations that the publication has generated and its impact factor.

After the selection, it is necessary to analyze the main challenges faced during the development of the studies, in order to detect the most critical points. Through this, it is

possible to determine which impacts are the most recurrent in the electrical system and the computational methodology adopted for analysis.

Soon after, classifying selected publications considering the number of citations and the computational methodology is carried out. Thus, it is possible to compare which methods presented greater relevance to the state-of-the-art of the impacts of smart grids.

RESULTS

Studies related to Smart Grid can be classified into three categories: I - Stability, modeling and control; II - Security and protection; III – Operation and expansion planning. In Group III, most studies focus on the Energy Management and Planning of Smart Grids. Energy Management is a restricted optimization problem whose objective is to optimize the equipment used, which renewable energy resources will be exploited, distributed energy storage systems, distributed generation (DG), electric vehicles connected in the network, cogeneration of generating units among other variables ³.

The difficulty in managing the energy of Smart Grids is associated with the uncertainties of the renewable energy resources and the variation of the load. These uncertainties can be predicted and included in the optimization problem. However, the predictions are not accurate, so several methods are proposed to approximate these predictions of accuracy, such as the Stochastic Programming Method, Predictive Control Model and Robust Optimization ³.

Also in Group III, the planning of Smart Grids is usually formulated as a mathematical optimization problem whose objective is to minimize the cost function operation planning and expansion taking into account emissions and system reliability. The result of the planning of Smart Grids is to determine the type of optimal distribution network (AC, DC or hybrid), type energy resources to the DG and energy storage system and distributed capacity.

In Hemmati, Saboori and Siano ³, a two-level stochastic planning tool is presented, which includes the long-term expansion plan and the short-run operation plan. The expansion plan, allows to determine the optimal size and location of the DG features, power storage systems and lines. For the operating plan the optimization result presented, which minimizes the total operational cost, shows the optimal operation for the technologies. Uncertainties are modeled through the Probability Distribution Function and Monte Carlo simulation is applied to deal with these uncertainties. Both long-term and short-term problems are mathematically formulated with mixed non-linear programming and solved through PSO co-evolutionary (CPCE) culture.

In Possemato et al. ⁴ efforts are focused on optimizing the performance of active distribution networks through a reduction of losses. The main techniques used in the literature are the correction of the Power Factor (PF) and reconfiguration of the distribution grid. The application of the first technique guarantees a reduction in the amount of reactive power present in the network, which provides a reduction in losses per Joule, increases the capacity of the network and the quality of service. The second technique is based on the possibility of switching circuit breakers present in the network, which causes the network topology to change, improving the operating conditions. The optimization problem involving changing the network topology is complex because the status of the circuit breakers are not differentiable.

To minimize power losses in smart grids in Possemato et al. ⁴, a model that considers the two techniques has been used. Therefore, the optimization problem is to find the optimum parameters and the topology best suited to the network, considering the constraints imposed on the voltage and current, as well as the topological constraints of the network. Due to the problem with derivation, the standard genetic algorithm was used, which does not require derivation in the implementation.

The approach of Weiss and Schulz ⁵ was to use genetic algorithm, which allows the choice of the time horizon of the optimization and determines which units of DG are used. It is also possible to stipulate different objectives to be achieved, such as CO₂ emission costs and emission limits. First, the mathematical approach used in the modeling of technologies, with their technical restrictions, is described. Next, the implementation of the model created in a Matlab / Simulink environment.

In Han and Yan ² Robust Optimization (RO) is used, which allows to consider the uncertainties of expected load demand and the availability of new technologies. In this way, it is possible to determine the impact of Smart Grid technologies in the scheduling of investments considering the uncertainties in their worst case. In the planning of the expansion of the generation, uncertainties can considerably affect the projects' feasibility, justifying the efforts in finding the methodology that best considers these uncertainties.

In conventional power grids, the uncertainties are related to predictions of load and price, transmission capacity, climate change, variation of operating costs, among others. In the case of Smart Grid, other uncertainties are added to the problem. For example, the intermittence of wind or photovoltaic generating units, which undergo significant interference due to climatic factors ².

There are several methods to deal with the uncertainties, the most widespread in the literature are probabilistic, possibilistic, hybrid approaches that consider probabilistic / possibilistic and RO.

The stochastic nature of uncertainties can be modeled by conventional techniques; however, there is the possibility of rare events occurring. Small disturbances can make a solution unfeasible, and a large amount of smart grid technologies have inaccurate information, making it difficult to obtain accurate data. In Han and Yan ² RO is also adopted to circumvent these obstacles, considering the Smart Grid technologies that present economic and technical feasibility in generation planning.

Therefore, the RO application is designed to model the generation expansion planning under uncertainties with incomplete information, whose objective is to determine the optimal feasible decision for any scenario that the uncertainties can create ².

According to Han et al. ⁶, the main uncertainties in the Generation Expansion Planning (GEP) are the prediction of load, price forecasting, availability of energy system components, fuel and energy prices, new generation technologies and government policy issues. Therefore, the approach used in Han et al. ⁶ is RO, which allows to deal with the uncertainties derived from the new Smart Grid technologies. The advantage of RO application compared to other stochastic optimization methods is the option of not requiring the distribution of uncertain variables, and the ideal solution may be feasible for the worst case. The problem is converted into a deterministic linear programming, and no longer a stochastic programming.

According to Tekiner-Mogulkoc, Coit and Felder ¹, the main impacts and benefits that Smart Grid technologies interfere with in the power system are: change or reduction of the energy demanded during peak times, increase in the effective availability of the system components and reduced losses during transmission and distribution.

The approach adopted in Tekiner-Mogulkoc, Coit and Felder ¹ is to simultaneously minimize multiple objectives, such as costs, CO₂ emissions, taking into account long-term planning that involves large uncertainties.

In Tekiner-Mogulkoc, Coit and Felder ¹, two classes of technologies that impact planning are considered: technologies that increase the feasibility of the components of the distribution systems (breaker circuits, distribution lines, etc.) and technologies that can alternate the demands that are at peak power hours.

To represent the stochastic nature of the problem, the Monte Carlo simulations were used. The simulation has generated several scenarios representing random demand situations and different network topologies. As the horizon of planning is long, we must

consider an increase in demand every year spent in the simulation. This increase is applied by increasing demand peaks ¹.

Table 1 shows the publications that were selected along with the year of publication, number of citations, citations factor per year and the methodology adopted in solving the problem. From this table notice that RO and GA are mostly used.

Table 1- Methodology used in publications

TITLE	PUBLICATION DATE	CITED BY	CITED / YEAR	METHODOLOGY
(3)	05/2017	1	1,00	Robust Optimization and Monte Carlo
(4)	12/2015	9	4,50	Genetic Algorithms
(5)	12/2015	2	1,00	Genetic Algorithms
(2)	07/2015	3	1,50	Robust Optimization
(6)	10/2014	4	1,33	Robust Optimization
(1)	05/2012	27	5,40	Multiobjective and Monte Carlo

Source: The author, 2017.

DISCUSSION

In Hemmati, Saboori and Siano ³ they have shown a reduction of 10% compared to the methods of conventional planning (based on long-term planning). The proposed planning modeled the uncertainties of renewable energies and the load as probabilistic functions.

The results indicated that the cost of installing the stochastic planning is similar to that of the deterministic one; however, the operational cost is higher. This means that a more robust strategy for the operation of new technologies is more efficient than the installation of new technologies ³.

The results presented in the literature also indicate that the cost of planning is increased by increasing the level of uncertainty. This is due to the fact that the proposed stochastic planning uses more technologies to face these uncertainties ³.

A sensitivity analysis is also done on the planning costs and it is confirmed that the planning cost is highly sensitive to the energy price (for example, purchase and sale prices) ³.

In Possemato et al. ⁴ the results show a reduction of energy losses due to the impact of Smart Grid. The reduction may seem insignificant, but the tests performed simulated only one hour of a specific day per year. If the reduction is considered for a long period, it can be observed that the improvement is quite considerable.

In Han et al. ⁶ the objectives of the proposed model include investment, operating and maintenance cost, generation cost, cost of reliability and cost of carbon emission. In addition, grid and customer sector constraints are considered in generation planning. According to the results obtained, RO model is better than the deterministic model, which indicates that the uncertainty brings more cost to the problem. In addition, variations in the uncertainty interval influence the optimal value, making it increasingly larger as uncertainties change for each scenario ⁶.

In Tekiner-Mogulkoc, Coit and Felder ¹ the main focus was on technologies that affect network topology and demand. The results have shown that the technologies have an impact on the reduction of the operating cost, reducing the cost of unsatisfied demand

and allowing using units of smaller costs. Another impact is the reduction of the emission of gases. However, the analysis did not consider the implementation costs of these technologies.

CONCLUSION

Studies related to the impact of Smart Grid on the management and planning of the operation and expansion of power systems are growing in recent years, however, due to the current need, there are just a few of them. The importance of this article is to raise the state-of-the-art in the subject to carry out future studies.

After this review, it is possible to conclude that the research topic is of great relevance, mainly due to the improvements that the technological advance can provide in the electric sector, especially in the electricity distribution sector. Its importance is mainly justified by the increased efficiency and reliability that the implementation of the Smart Grid concept can provide for PES.

The most applied methodologies are Robust Optimization and Genetic Algorithms, and the articles analyzed prove their effectiveness. Another methodology that is widely discussed is the Monte Carlo Simulation to create the scenarios of uncertainties.

For future studies, the need for more complete analysis tools, which consider the distributed generation and the characteristics of the wind and solar plants that are being more widespread, is evident. It is also necessary to integrate distributed energy storage systems in the analysis, such as electric vehicles, among other aspects.

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