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# A Systematic Literature Review of Electricity Distribution in Smart Grid Scenarios

F. D. Ribeiro[1], A. G. Pinho[2,3], R. A. Gomes[1,2], and E. G. Domingues[1,2]

Master's Program in Technology Sustainable Process[1]
NExT - Nucleus of Experimental and Technological Studies[2]
Electrical Engineering/Control and Automation Engineering Program[3]
Federal Institute of Education, Science and Technology of Goiás, Goiânia, Brazil
Câmpus Goiânia - Rua 75, nº 46 - Centro, Goiânia - GO, 74055-110, Phone number:+55 62 3227-2811,
e-mail: fred727@gmail.com, andre_g_p_@hotmail.com, raphael.gomes@ifg.edu.br, elder.domingues@ifg.edu.br

**Abstract.** With the massive increase in electricity consumption, technologies that help the production and distribution of this resource became indispensable. In particular, distribution becomes a major challenge when taking into account alternative sources through Distributed Generation. In this view, this paper aims to survey the main contributions related to the application of intelligent solutions in the process of electricity distribution. Through a systematic literature review, a comparative analysis of the most relevant work on the target topic is performed considering the application of Smart Grid principles. The methodology adopted in the literature review and the main results are presented by means of a six group categorization, namely: communication in electrical structures, computational modeling, load control, microgrids, energy storage, and economic viability.

**Key words.** Smart Grid, Distributed Generation, electricity distribution.

## 1. Introduction

The expansion of electricity generation carried out by the inclusion of sustainable sources (photovoltaic, wind, biogas, geothermal, among others), through Distributed Generation (DG), has the advantage of generating positive impacts on the environment with the reduction of greenhouse gas emissions [1]. However, this new model turns the complexity of distribution, hitherto caused by factors such as variable demand and the need for loss reduction, even more challenging [2]. As an alternative to dealing with this challenge, it is increasingly noticeable the inclusion of innovative communication and information technology solutions generating what is known as the Smart Grid (SG). SG should be interpreted as a concept and not a specific technology. It can be defined as an electrical network that uses information technology, sensing and automation in order to supply electricity efficiently, reliably and safely [3][4]. Several solutions in this direction are being proposed. As an example, for the Brazilian electric system, there is development planning aiming to implement a national intelligent electricity grid whose goal is to optimize generation and distribution [5].

One of the main goals in SG is to converge technologies for the control and balancing of grids with DG [6]. As a result, optimizing the distribution and use of smart grids will increase the efficiency of electrical systems, as well as reduce the caused impacts and losses in the production and distribution of electricity in conventional models. Moreover, more efficient distribution of electricity will no longer require excessive use of resources, optimizing those already employed [2].

Given the relevance of the presented theme, a systematic literature review is carried out with the goals: i) raising the main proposals for intelligent electricity distribution when considering DG with alternative sources of energy generation; ii) highlight the main techniques, strategies, and solutions on the topic, disregarding studies that deal merely with the physical infrastructure used; iii) obtain the necessary basis for proposing a solution taking into consideration the Brazilian scenario, due to its peculiar characteristics such as increasing use of generation using biomass [7]. The methodology used in the systematic review is presented, and a comparative analysis of the main selected works is performed.

The remaining of the paper is organized as follows: Section 2 presents the methodology used, describing the sources used and the criteria for inclusion and exclusion of work; Section 3 discusses the main results through a separation according to the main theme identified; Section 4 presents a critical analysis of the research opportunities resulting from identified limitations and gaps; Section 5 discusses related work, and final remarks are presented in Section 6.

## 2. Review Methodology

The systematic literature review is a research method to aggregate and evaluate the available evidence on a specific topic [8]. This technique has as feature the adoption of a precise and rigorous sequence of methodological steps, based on a well-defined protocol that can be reproduced later. The review protocol in this paper was developed and executed according to the guidelines provided by Kitchenham and Charters [8]. Four steps were established: (a) formulation of the question/problematization, (b) location and selection of studies, (c) data collection, and (d) analysis of results. The following describes each one in detail.

*A. Formulation of Research Questions*

The research questions used to guide the review were formulated to characterize how SG solutions are adopted in the electricity distribution process when considering DG. On doing so, two questions were established:

**RQ1:** What SG-based methods/tools/techniques are used to improve electricity distribution?

**RQ2:** What is the scope of each selected study in relation to:

*i)* Distributed generation;
*ii)* Scalability of the solution;
*iii)* Self-healing mechanisms; and
*iv)* Solution validation.

*B. Search of Studies*

Automated searches were performed in the following scientific bases: CAPES CAFe[1], Google Scholar[2], IEEE Xplore[3] e SciELO[4], which are common sources used for systematic reviews in engineering areas and offer reasonable confidence to cover relevant publications. The searches were performed using the following search string considering the papers' titles and abstracts (* stands for the wild card):

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("electrical energy" OR "power grid*")
AND "distribution" AND "smart grid*"
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In addition, searching was performed again using the equivalent expression in Portuguese language aiming to select work that was published in Brazil and thus more likely focused on the national scene. Both expressions had to be customized according to the syntax used by each source.

*C. Inclusion and Exclusion Criteria*

By applying the search string on each data source, the resulting studies were ordered using relevance criteria (evaluated by each search engine). To be included, the paper should propose or discuss a solution for electricity distribution considering the improvement of this process. When the search returned different studies by the same authors, it was checked if they were on different topics. Otherwise, the most complete paper was chosen. In addition, to be included, the files should be available for download. It was excluded from results all publications that:

- simply represent a literature review, that is, which do not propose a novel contribution;
- deal with regulatory acts related to electricity distribution;
- constitute invited editorial or merely express an opinion; and
- present case studies that are not applicable to the Brazilian scenario.

The paper selection process followed the steps described in Table I.

Table I. - Paper Selection Stages.

| | |
|---|---|
| Stage 1 | Apply the query to all sources and get the results |
| Stage 2 | Remove duplicates and invalid results |
| Stage 3 | Apply inclusion/exclusion criteria to papers titles |
| Stage 4 | Apply inclusion/exclusion criteria to abstracts and conclusions |
| Stage 5 | When necessary, apply inclusion/exclusion criteria to the whole text |

The initially proposed methodology aimed to apply the search string to the entire text of the articles. However, for most of the taken sources were gettered more than 20K studies. Because of this, the initial methodology was changed so that the search was performed considering only the papers titles. Even with this refinement, the data set obtained was still extensive, with an average of 375 works. Therefore, as a way of making the analysis feasible, it was established that the 30 most relevant work of each base would be analyzed. In the case of redundancy of papers among the sources, the redundant results would be discarded. This ensures that exactly 30 different papers from each base would be analyzed.

The main attributes of each selected paper (title, author, vehicle and year of publication, etc.) were stored in a spreadsheet to facilitate analysis.

*D. Protocol Evaluation*

Before performing the systematic review, the protocol was evaluated by asking an expert in scientific methodology to review it. All observations made by the expert were taken into consideration. In addition, we conducted a pilot study on a single basis, refining the inclusion/exclusion criteria.

## 3. Review Results

This section presents the analysis of the filtered studies according to the proposed methodology. By applying the inclusion/exclusion criteria to the 30 papers selected from each source in March 2019 was obtained a total of 18 papers. Table II presents the number of papers returned in

1 Available in http://www.periodicos.capes.gov.br. The Federated Academic Community (CAFe) is a service provided by Coordination for the Improvement of Higher Education Personnel (CAPES), a Brazilian federal government agency responsible for quality assurance in undergraduate and postgraduate institutions in Brazil. This service has a goal to provide access to academic journals and other research publications.
2 Available in https://scholar.google.com.
3 Available in https://ieeexplore.ieee.org.
4 Available in https://www.scielo.org.

each data source, as well as the number of selected papers. It can be seen that by applying the proposed methodology the CAPES CAFe base offers a higher level of accuracy of results.

Table II. - Number of Retrieved Studies per Source

| Source | Total | Filtered | Selected | Precision (%) |
|---|---|---|---|---|
| CAPES CAFe | 705 | 30 | 7 | 38.9 |
| Google Scholar | 275 | 30 | 5 | 27.8 |
| IEEE Xplore | 519 | 30 | 6 | 33.3 |
| Scielo | 1 | 1 | 0 | 0 |

The year of publication of the selected papers was analyzed. The result is shown in Figure 1. As can be seen, the publications were concentrated between 2011 and 2017, with the growth of published papers from 2012 to 2014. Regarding the publication vehicle, 66.7% of the papers were published in event proceedings, and the others were published in journals.

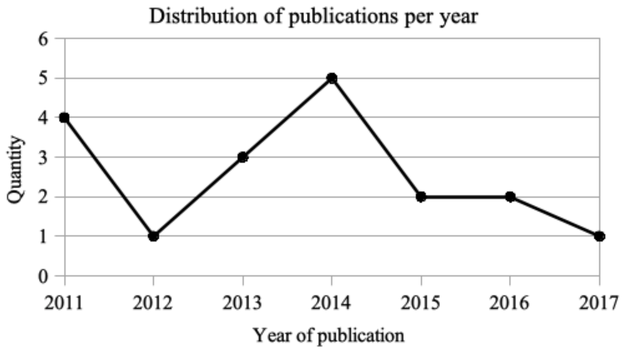


Fig. 1. Distribution of Selected Papers per Year.

As a way to answer **RQ1** and **RQ2**, the selected papers were divided into categories, taking into account their main theme. Table III presents the identified themes, as well as the distribution of the selected work. A discussion of the studies based on this classification is presented following.

Table III. - Distribution of Studies per Focus

| Category | Quantity | % |
|---|---|---|
| Communication in electrical structure | 4 | 22.22% |
| Computational modeling | 4 | 22.22% |
| Load control | 4 | 22.22% |
| Microgrid | 3 | 16.67% |
| Energy storage | 1 | 5.56% |
| Economic viability | 2 | 11.11% |
| Total | 18 | |

*A. Communication in Electrical Structures*

For reliability in the electrical system, the automation of communication between its parts is extremely necessary [9]. The ability to communicate allows precise action to perform control, monitoring, supervision, protection, better management of the system, among others. This ability allows the relevant grid distribution conditions to be increased and optimized, consequently increasing the degree of efficiency and safety [10]. Thus, among the selected work, some refer to relevant topics about data transmission within the physical structure of electric networks [9]-[12]. This technology is already consolidated and is called Power Line Communication (PLC) and can be used for information transmission by SG controller systems.

It was possible to identify a concern with the quality of communication offered. The main challenge identified was to provide satisfactory levels of latency, which is more important than bandwidth, since for many operations such as fault detection and recovery, messages are relatively small but require high transmission speeds. On this hand, including processing devices closer to endpoints is also important aiming to report only actionable information to centralized servers [13].

The identified proposals mostly contemplate resource scaling strategies targeting efficiency and economy. Using heuristic-based solutions they seek to operate the distribution system in a reliable and improved manner. Resources are then optimally controlled to meet operator needs while respecting operational constraints [12].

The solutions proposed in the studies are validated through simulation tools. However, it was possible to identify only an incipient use of co-simulation, combining both perspectives of electrical and computational environments [14]. It was also proposed adjustments and projection of new structures that could adopt PLC. In addition, some of the authors highlight the caveats that exist among the specific characteristics of electrical networks that require appropriate treatment aiming at cohesion between computational technologies and electrical particularities [14][15].

*B. Computational Modeling*

Intelligence technologies may have significant strategic value due to their inherent flexibility in dealing with different evolution paths of the electrical system [16] [17]. Thus, the use of computer systems for the simulation of physical structures is very important to study and correctly dimension an electrical structure [14] [15]. The use of modeling tools such as OpenDSS[5] e OMNet++[6] generates results that can be considered in studies such as safety conditions assessment for specific operations [18]. These simulation platforms allow developer teams to design more accurate structures and assist decision-making support in the areas of preparation, planning, formulation, and more. To raise the level of efficiency is suggested to use platforms for aggregation and data management. With this data it is then possible to simulate various distribution systems intelligently, obtaining more comprehensive assessments.

5 Available in https://www.epri.com/#/pages/sa/opendss.
6 Available in https://omnetpp.org.

Using computational modeling, Ayman [19] proposed an algorithm that calculates the distribution load flow for SG. The strategy considers a specific area of interest in the distribution system and is based on reducing the scale of the problem to minimize the effect of system size in solution time.

Other studies [9][18][20] aim to calculate percentages of efficiency, functionality and correct positioning of SG systems before implementation. The objective is to analyze the incorporation of controllers in an existing control system using real-time data and historical series through a forecasting model of the demanded energy. With this forecast, the integrator can apply a larger number of tools and methods for dispatch optimization and wrapping to be used in the structure [16][21].

A common concern in the selected studies refers to the challenges associated with the use of computer modeling, such as the need to develop and improve the simulation tools themselves. This need includes the integration of systems from energy production to consumption as well as the general operations of the electricity system [22].

### *C. Load Control*

Part of the selected studies [8][10][16][21] focuses on load control, proposing the use of DG from the point of view of the system owner. With the use of DG, part of the electricity is produced and consumed in the same place, reducing transmission and distribution losses. This feature optimizes consumption and reduces most of the losses that occur, especially in transmission [23]. On the other hand, the increasing penetration of DG in distribution networks can cause severe problems for electrical structures, as uncertainty about the magnitude, location, and capacity of electricity producers from DG makes planning complex. In this context, Spyros et al. [16] proposed a planning model that considers investing in various smart technologies to alleviate the violation of network constraints due to DG penetration.

Current electrical distribution systems are based on structures where meters work in unidirectional reading and measurement which significantly affects new structures that require bidirectional actuation. Moreover, DG may cause a change in the direction and magnitude of the short circuit current. Due to these conditions, systems may misinterpret measurements, causing problems with security devices. In addition, there are limits to improvements to older distribution systems that are currently being used. Conte et al. [8] argue that it will be necessary to upgrade primary feeders and considerable parts of the grid.

Another important point mentioned in the studies refers to the use of centralized data servers in SG. The goal is to store and analyze the data to establish statistics as historical average consumption, and thus create contingency plans and prepare the electrical system for the required energy injection.

### *D. Microgrid*

Current conditions in the distribution and transmission of electricity suggest the creation and use of microgrid (MG). This strategy consists of using several sources of energy production and storage that can act as network independent manageable entities [24]. Electricity generated in MG is safer and can be customized according to users' classification and demand [23]. However, a main driver for the deployment of MGs is to allow seamless integration of DG units [25].

In studies related to MG [23][24][26] a network arrangement for autonomous distribution is generally proposed that takes into account a structure that interconnects several production cells. This proposal divides the distribution network into sets of subnets. Nirwan and Chun-Hao [24] address both energy flow and energy balance issues to optimize the distribution operations of the entire structure. Zhiqiang et al. [23] present a load management model considering energy storage in scenarios where there is the isolation of MG from the main network. Selvam et al. [26] discuss issues related to the self-healing time of electrical systems, as well as the connection and disconnection conditions of conventional transmission and distribution networks. They proposed a technique to reduce the response time in the electrical system as a way to avoid losses and damage to the electrical structures involved.

### *E. Energy Storage*

Energy storage plays an important role in many SG viewpoints. Much of the effort with this focus is due to the existence of Electric Vehicles (EVs) that are now being used as an alternative source of energy. The electrical demand or charge profile for EV use is defined by the size and depletion of the battery, as well as the level and efficiency of the charger. For the use of this technology within a distribution system it is necessary to consider the use of vehicle chargers with bidirectional energy flow capability that will allow the receipt or supply of electricity [18].

Targeting to analyze the impact of EVs as a storage source in distribution systems it is very important the use of modeling tools capable of assisting in the correct sizing, adjustments, and adaptations necessary projections [15][20][27]. Despite the importance of the topic, only Roger et al. [15] focuses on energy storage. They relate traditional distribution models and analysis techniques, highlighting that new models and analyses are needed to enable distribution planning to access the possible benefits and impacts of this technology.

### *F. Economic Feasibility*

In general, in the selected work it is possible to notice a wide discussion about the economic viability conditions, more precisely about the cost and benefit issues for the implementation of the SG. The cost is also constantly discussed with respect to old electrical structures that are still in operation and that do not meet the needs of new systems that need to be implemented [19][28]. The former systems need to be restructured allowing operations related to safety, interaction, flexibility, transmission circuit optimization, among others.

The economic feasibility analysis is very important before implementing SG technologies and energy production systems through less impactful sources [17]. It is important to evaluate the monetary implementation costs for all components of the electrical system and also to note the benefits of decreasing environmental impacts. The criteria for investment costs, operating costs, life cycle, and environmental benefits also need to be taken into account [20]. In this context, Wang et al. [28] proposed a cost-benefit analysis approach to energy storage and distribution in SG. Nasiri et al. [17] analyzed two storage methods from technical and economic viewpoints. However, it is important to highlight that, although economic viability is not the focus of the other studies, about 55.5% consider stochastic planning models that contemplate investment in conventional assets, as well as SG assets, contracted demand needs and control voltage coordinate.

## 4. Opportunities Identified from the Selected Studies

Through the analysis of the selected studies, it was possible to extract some limitations and gaps that constitute opportunities to be explored in future research. These limitations are related to meeting demand, generation from renewable sources, storage and distributed generation.

In general, the conditions of use or simulation of parallel and/or redundant networks are not fully explained in the papers, especially considering the use of alternative structures such as fiber optic and infrared. Another issue not addressed is the maintenance and continuity of operation of these smart structures in the absence of electricity in the main grid.

Regarding computational structures, the specifications of the structure required for the implementation of systems for the development, analysis, and monitoring of electrical systems are not described. Nor are technological issues addressed for data storage using cloud computing platforms.

The studies focused on load control are directly related to technologies for structure management. These point out in their methodology the use of SG to solve this problem but do not refer to the connectivity issues among the computational structures necessary to manage the functioning of operations.

With regard to energy storage, there is a high expectation with the introduction of EVs in the market. The studies that point to this solution do not present data regarding the cost/power required to meet an economically viable scenario. Another important aspect not widely discussed is the technical standards and legislation for the use of this type of technology.

Regarding the development of MG, new methodologies will be needed to model the components that need to be considered in an electrical structure, especially those related to DG that are influenced by seasonal periods. Future prospects for GD system implementation and next-generation efficiency factors need to be considered. The MG-related studies refer to the use of energy sources from photovoltaic plants, wind and diesel generators. There were no studies that allude to the use of stemmed biomass sources, a considerable source, especially when considering the Brazilian scene.

More than 65% of the selected studies use empirical research, which is not surprising since smart grid distribution efforts require a high level of analysis prior to implementation in real-world scenarios. Only two selected studies presented data and methods from structures in operation. Thus, another gap to be filled is the development of research that more accurately explore real data.

## 5. Related Work

As in this paper, there are other systematic literature reviews related to the distribution of energy in SM [29]-[32]. Notably, Robert and Roger [29] discuss relevant research in smart grid analysis for rural service companies. They focus on the tools used for decision making on this topic. Wieslaw et al. [30] present research findings that address proposed solutions in the area of improving supply reliability and reducing energy losses.

In general, related work addresses revisions with a smaller scope than proposed in this work. In this paper, the theme was discussed in a more general and comprehensive way, seeking results that include small and large electrical structures.

## 6. Final Remarks

This paper has presented the results of the application of a systematic literature review seeking to analyze the main contributions related to energy distribution using Smart Grid concepts. The methodology adopted was described and a discussion related to the selected studies was presented.

Currently, the methods used to improve the distribution of electricity are related to the application of SG in order to meet the particularities of each case. The main bottlenecks for these applications are related to the economic viability, connectivity, and suitability of existent structures.

With regard to self-healing mechanisms, technologies are already in operation. What still limits the progress of this application is the connectivity requirements of electrical systems for the performance of SG. Another important result is that we note that there are few contributions focused on the Brazilian scenario.

It is possible to observe that there is a growing trend in the number of papers published in the last five years and that because it is a still-emerging topic some significant works may have been eliminated by applying the sorting by relevance. As future work is proposed to analyze the impact on review results by applying again the proposed methodology considering the results sorting by the year of publication. Another future work is to consider a larger amount of filtered studies in each data source.

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