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Key performance indicators: A useful tool to assess Smart Grid goals

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ABSTRACT

In the last few years, the Smart Grid concept has gained ground in the power utility scope. However, due to its multidisciplinary character (involving a stack of technologies) it is very difficult to assess the overall project success. Due to this a metric is required. In this paper, the authors review the existing metrics and (based on their experience within the Smart Grid demonstration project "*Smartcity Malaga*"), propose a new approach of business intelligence to bring about a new metric or set of key performance indicators for its rating. An advantage of this metric is its capacity to assist in this task. Its usefulness is also complemented with a planning tool that enables us to assess the effects of each technology under potential scenarios. This information is useful for planning projects, allowing us to make the most appropriate decisions each moment. Ultimately, this usefulness is clearly demonstrated through two case studies.

1. Introduction

Nowadays, it is increasingly common to find the *Smart Grid* concept within the electricity sector lexicon [1–4]. In the last few decades, a huge transition from traditional to new Smart Grid networks has been observed [5]. This fact are translated into an evolution from a traditional radial energy flow to new more complex topologies, but with better characteristics (a greater presence of distributed generation, greater efficiency, greater respect for the environment, and better reliability). To achieve these improvements, this new paradigm of Smart Grid is defining strategies to address energy and social needs of the 21st century and beyond [6,7].

A Smart Grid always seeks to improve the current power delivery system, increasing the interaction between different stakeholders and providing an easy connection to their elements. It is always seeking "*The Energy Internet*" concept [8]. However, the main characteristic of a Smart Grid is its multidisciplinary character [9,10]. It combines technologies such as DG (Distributed Generation) [11], energy storage [12], DSM (Demand-Side Management) [13], SCADA (Advanced Supervisory Control and Data Acquisition) systems [14] and EV (Electric Vehicle) [15,16]. However, all of these systems do not work individually. They require an advanced communications system that provides interoperability amongst them [17–19].

As evidence of the Smart Grid progress, several demonstration projects or initiatives have been developed in the last years by various agencies. On the one hand, in North America, it is essential to mention the initiatives proposed by the U.S. DOE (Department of Energy), among which stand out its RDSI (Renewable and Distributed Systems Integration) projects [20]. These projects involve different Smart Grid technologies, devices and systems, seeking to reduce peak demand. More examples are the Smart Grid demonstration projects by the EPRI (Electric Power Research Institute) [21]. They are focused on the integration of different technologies to form a VPP (Virtual Power Plant) [22,23], employing integrated control of DG, storage, and demand response technology. Another EPRI initiative is the IntelliGrid program [24] which is focused on the development of new ICT (Information and Communication Technologies) for Smart Grids. Other North American initiatives are also noted because of their intense activities, such as the Edison Electric Institute, the GridWise Alliance, and the Galvin Electricity Initiative.

On the other hand, in Europe, it is normal to find a lot of projects mainly oriented towards environmental protection [25]. These projects are typically funded by the FP7 (7th Framework Programme) and their initiatives pursue the goals known as 20–20–20 targets [26]. Thus, these initiatives also have continuity within the next European Framework Programme for Research and

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Innovation (Horizon 2020) [27]. Information and reports about these initiatives are accessible through the CORDIS (Community Research and Development Information Service) [28]. Finally, it is also important to highlight several projects in Brazil [29], Oman [30] and Southeast Asia, where initiatives such as NEDO (New Energy and Industrial Technology Development Organization) Alliance [31] (in Japan) and SGCC (State Grid Corporation of China) [32,33] (in China) are very dynamic in the last few years.

As previously mentioned, a Smart Grid project involves a lot of technologies, each being a complex research area in and of itself. However, the progress so far has been conducted individually, without analyzing the interaction amongst them. Due to this, some authors conclude that the next step in Smart Grid networks is to develop projects which integrate and analyze the systems as a whole [34]. However, this poses several problems. Because of its multidisciplinary nature, it is very difficult to assess the overall success.

In order to provide a general multidisciplinary view, a hierarchical metric or a set of KPIs (Key Performance Indicators) which allow the users to assess the degree of goal achievement is presented. In addition, a big advantage over other previously proposed metrics is shown. These KPIs do not only assess the fulfillment of the project goals at realistic conditions, these KPIs extrapolate and forecast the impact caused by a hypothetical increase in the presence of different technologies.

This paper is divided as follows; Section 2, an overview of the current metrics used in Smart Grids. Section 3 briefly describes the Smart Grid demonstration project "*Smartcity Malaga*". The KPIs' hierarchy, their elements, and their models are described in Sections 4–6 respectively. Section 7 presents its planning tools. Section 8 describes a real case study. Finally, conclusions are shown in Section 9.

2. Smart Grid metrics: an overview

The complexity of the technologies involved in a Smart Grid makes an analysis tool essential for its evaluation. Thus, there are many authors who apply metrics for evaluating specific areas within a Smart Grid (e.g. residential EE (Energy Efficiency) [35], home communications [36], EVs deployment [37], network robustness [38], etc.). However, from an overall standpoint, agencies, such as EPRI [39], propose a standardized approach to estimate the benefits and cost of a Smart Grid. Specifically, EPRI's study concentrates on aspects such as efficiency, environment, reliability, PQ (Power Quality), safety, security, and cost reduction.

Additionally, it is important to highlight the U.S. DOE's efforts in this direction. It has identified and mapped down key Smart Grid "Assets" to thirteen "Functions" that may be enabled by this type of network [40]. Thus, the U.S. DOE defines a metric for Smart Grid in its reports [41] and it is extensively detailed in its appendix A [42]. A Proof of the DOE's engagement was the organization (in association with the Office of Electricity Delivery and Energy Reliability) of a workshop to promote the development of a Smart Grid metric [43]. In this forum, more than 140 experts worked to identify the metrics for seven major Smart Grid characteristics. Additionally, the GridWise Alliance has developed together with DNV KEMA corporate that provides a legislative background, citations, and lays out metrics that could be considered when developing or assessing a Smart Grid project [44].

Some authors have also proposed an interesting alternative metric [45]. They have defined six steps to approach a Smart Grid evaluation. They have also defined a hierarchical metric, in which each element is classified into five aspects, such as economic performance, technical performance, customer quality, environmental friendliness, and safety. However, this metric has only been tested on an artificial sample, using simulated information from a hypothetical model, and not using real data. Additionally, in the last years new metrics with interesting validation methods have been proposed by some authors [29]. However they continue focusing their work on a metric which evaluates many aspects independently.

Based on the information above, currently it is possible to argue that (although more and more efforts to unify and to standardize a metric) the diversity of scopes that encompasses a Smart Grid network makes it very difficult to assess it as a whole.

3. Smartcity Malaga project: a brief description

An example of a Smart Grid demonstration project is "*SMCT (Smartcity Malaga)*" [46], (see Fig. 1). This initiative is located in the south of Spain, in Andalusia. Specifically, it is on a seaside area of Malaga city (managing around a 70 GWh per year and more than 12,000 customers).

SMCT has been developed by 11 leading companies (led by Endesa) and supported by research centers. It is valued at €31M, and its main goal is to reveal the advantages of the new Smart Grid networks. It seeks the aforementioned 20–20–20 targets:

- 20% increase in energy savings.
- 20% increase in renewable energy use.
- 20% reduction in CO_2 emission below 1990 levels.

To accomplish these three goals, the SMCT project aims to get optimal integration of renewable energy in the grid, bringing energy generation points to end-user consumption points using new electricity management models. SMCT poses the use of higher efficiency systems which can reduce consumption in three areas; street lighting, domestic customers, and high power customers (e.g. city hall, hotels, hospitals, etc.). Thus, this project seeks to involve the customers through their active participation. For this purpose, it is equipped with new generation smart meters within the framework of remote management to enable more sustainable electricity consumption.

Additionally, EMSs (Energy Management Systems) are another important part of the SMCT project. These systems manage multiple renewable generation points and storage systems. They reduce transport losses and the dependency on fossil fuels. Moreover, SMCT has a management infrastructure of EV fleets to assess its impact at different levels.

Finally, to support all these systems, the SMCT project has an advanced telecommunication and remote control system. This infrastructure combines real-time management with automatic control algorithms. It enables a better management of the distribution network to enhance the quality of service.

Obviously, to perform all of these actions it is necessary to have a DAS (Data Acquisition System). It was developed as a data collector of the different sensors and subsystems which make up the SMCT. The DAS architecture is shown in Fig. 2. The DAS should be able to gather all this real-time information (typically huge in Smart Grid projects [47]) and store it in a database. This database is shaped using the CIM (Common Information Model). The CIM provides a common definition of management information for systems, networks, applications and services, and allows vendor extension. This is a standard that has been used on several projects and is very important in power distribution. There is even a specific model for electricity distribution [48], including: a methodological approach to use CIM in projects [49], CIM as the standard to bring IEC 61850 and Smart Grid together [50], and a CIM extension of the microgrid Energy Management System [51].

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