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A literature survey on Smart Grid distribution: an analytical approach

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ABSTRACT

Many different technologies have been growing under the umbrella of Smart Grids, which can be split into three major blocks: generation, transmission, and distribution. Generation and transmission have been evolving and improving as they have been under the control of utility companies, but distribution has been lagging behind on some of these improvements, due to the number of stakeholders involved in the process. With the integration of information and communication technology into the electricity distribution, there has been a spike in research and other studies to prepare for the future. In this paper, we analyzed all papers related to the topics of Smart Grids and Distribution. Because of the novelty of the concept, the results validate the expectation of an empirical approach in papers using case studies to simulate or conduct pilot runs of the technologies before their massive implementations. Strategies are mostly driven by the USA, while other countries are focusing on quality improvements of the already strategized initiatives with an efficiency-related goal in mind. Consumer participation is going to play a key role in the near future as it requires developing a new business model with the inclusion of self-generation and selling-back of excess capacity to the utility company.

1. Introduction

For many years, nations around the world have been building huge infrastructures and generation plants to ensure provision of electricity. Unfortunately, they have been facing an expected loss of energy due to transmission and distribution interconnection ranging from 10 to 52%, depending on the advancement of technology and controls to prevent theft (Najjar et al., 2012).

Looking now to the questions of environmental impact, human activities are the top contributors of the primary gases emissions with 20% of the CO_2 coming from transportation and 40% from power generation (Lo and Ansari, 2012). These activities depend mostly on fuels or coal that when burned, emit gases swelling the greenhouse gas emissions and rising global temperature. As consumers are getting more devices for the modern world needs, these gadgets require additional electricity, so more energy is being required. It is expected that by the year 2030, consumption of electricity throughout the world will increase 76% of the current consumption (Ramchurn et al., 2012). To generate this electricity, more primary gases will also be emitted along with it. Therefore, European countries are writing directives and goals to reduce these emissions in the short term to comply to the G8 leaders' agreement adopted in Heiligendamm to reduce more than 50% of the emissions by the year 2050 (Battaglini et al., 2009).

We see the integration and growth of new sources of cleaner energy like wind, photovoltaic, natural gas, nuclear, and others. New renewable resources have been growing up to 3% while nuclear generation has reached 6% of the total produced world's energy. But, after the incident provoked by the tsunami in the Fukushima nuclear plant in Japan on March 11, 2011, the reaction of the Federal Republic of Germany was to immediately close eight nuclear sites and schedule the closure of the nine remaining plants in 10 years (Römer et al., 2012). The rest of the world is also taking precautions to reduce or even eliminate nuclear energy generation.

As scientists and engineers are facing the challenge of reducing contamination and losses inherent to the distribution and transmission processes of the traditional grid, the solution seems to be the concept of Smart Grid which is based on recent technologies: Efficient distribution of energy with the inclusion of state of the art solid state electronics; use of renewable resources to generate electricity; participation of the consumers in the process by generating and/or conserving energy; feedback to consumers and utility companies about real-time consumption via smart meters; the use of electric vehicles' batteries to store and distribute energy at homes, and distributed energy resources, among others.

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Table 1
General classification of SGD research papers.

Classification	Components of the classification
Research category	Empirical Research, Modeling & Analytical Methodologies, Conceptual and General, Survey and Review, and SG Education
Research focus	Theory building, theory testing, and applications
Data collection	Case study, field research, laboratory research, archival research, and surveys
Data analysis	Descriptive statistics, neural networks, mathematical modeling, regression, Crombach's alpha, game theory, DEA, time series, simulation, non-linear and linear programming, or non-data analysis
Disciplines	Physical (P), Regulatory (R), Environmental (E), Social (S), Economic (F), Information and Communication technology ICT (I)
Taxonomy of paper's purpose	Strategy, Quality Management, Supply Chain Management, Environmental Issues, Service Design, Process Design, Scheduling, Planning, and Blackout
Smart Grid Categories	Demand Response, Automated Meter Reading, Distribution Automation, Distributed Generation, Electric Vehicles, Energy storage, Cybersecurity, Vol/VAR Analysis, User friendly enhancem ents, Efficiency, and Self-healing
Originating Countries	United States, China, Canada, Germany, Italy, United Kingdom, Japan and others

All these technologies are being developed and even implemented in some countries, while others are waiting to know the results before taking solid steps toward their implementation. The United States seems to be the leader in this effort with the support of the Electric Power Research Institute (EPRI), National Institute of Standards and Technology (NIST) Department of Energy (DoE), National Rural Electric Cooperative Association (NRECA), Edison Electric Institute (EEI), and the American Public Power Association (APPA) (Lo and Ansari, 2012).

Other national governments are promoting efforts for the implementation of Smart Grids in the near future. For instance, Korea launched the K-grid project in 2002 (Son and Chung, 2009), India created the Indian Smart Grid Task Force (Mukhopadhyay et al., 2012), and China formed the Strong and Smart Grid (Uslar et al., 2012).

There are also some important efforts in promoting Smart Grids in Europe where major efforts and monies have been invested on implementing advanced meters and "green" cleaner energy. The focus in the USA, however, is targeting strategies on automation and use of solid state electronics, along with information and communication technologies (ICT) to enhance the traditional grid and shift into a new and more efficient Smart Grid.

The overwhelmingly amount of Smart Grid research investment funding comes from the United States, with 31% as reported by Bloomberg New Energy Finance. Although the USA is still the leader, analysts are predicting that China will overtake this leadership position as the Smart Grid program launched by the Obama administration comes to an end in 2015. At the same time, China is continuously growing with an investment of $3.2 billion compared to the USA that spent $4.3 billion in 2012.

The Smart Grid will result in a two-way communication and flow of energy, instead of the traditional one-way flow from traditional electricity (Ramchurn et al., 2012) and information (Fadlullah et al., 2012) systems. The U.S. government has made an important start up contribution with these investments, having released $3.4 billion in grants for the investigation of Smart Grids (Güngör et al., 2011).

As communications technology has been evolving from the typical wireline to wireless media, there are important proposals about the concept of "ZigBee smart energy" with wireless communications to remotely controlled devices. The utility company or the consumer will be able remotely to turn appliances or other devices on or off depending on their need based on the cost of energy or present environmental conditions.

With all these technologies under the umbrella of Smart Grids, we chose to focus only on energy distribution for this literature survey. Distribution is a current fast-growing area and very visible to consumers, utility companies, and governments who are trying to involve the general public in this discussion. If distribution is enhanced, the expected result is energy conservation to avoid unnecessary investments in new large generating plants by reducing energy consumption.

2. Research methodology

For this literature survey, we query ISI Web of Science using "Smart Grid" and "Distribution" as selected topics with no restrictions other than requiring the papers to be peer-reviewed. After reading the papers, each one will be classified in the 8 categories shown in Table 1, which shows the sequence and sections of the methodology for the analysis of the selected and available literature.

Once the classification process is completed, we will chart trends, distributions, and cross-matrix tables to compare percentages using the total sum of the rows and the columns. The objective of this analysis is to identify important information about the areas where the majority of efforts are being channeled, increasing this area of knowledge.

2.1. Research category

This survey classifies the articles as empirical research if they contain any real data. Papers outside this category were classified as "modeling and analytical methodologies" based on mathematical functions and/or simulated datasets, "conceptual and general category" (including papers without any data and based on comments about the topic), and the final category is called "survey and review" which consists of papers reviewing the existing literature.

2.2. Research focus

We classify the selected published papers on distribution into three main categories based on the purpose behind the research: theory building, theory verifying, and theory application (Gupta et al., 2006).

2.3. Data collection

All papers are classified by the data-collection method used. In this paper we classify the data-collection approaches for empirical research in Smart Grid's Distribution into these categories: case study, field research, laboratory research, archival research, and surveys (Gupta et al., 2006)

2.4. Data analysis

Papers are then classified based on the numerical analysis techniques used; there is a category for the papers that had no data analyzed.

2.5. Disciplines

We separate the papers by categories using the six layers presented by Giannfranco Chicco (2010) in which he identifies them on the basis of interaction between elements in the Smart Grid papers. It is important to emphasize that there are going to be overlaps as two or more layers can be addressed in a single paper. The categories are shown in Table 2.