An Inclusion of Electric Grid Reliability Research Through the Enhanced Energy Informatics Research Framework

Work-In-Progress Paper

Vivian Sultan
Center of Information Systems and Technology
Claremont Graduate University
Claremont, CA
email: vivian.sultan@cgu.edu

Au Vo
Department of Information Systems
San Francisco State University
San Francisco, CA
email: auvo@sfsu.edu

Brian Hilton
Center of Information Systems and Technology
Claremont Graduate University
Claremont, CA
email: brian.hilton@cgu.edu

***Abstract*— Energy Informatics (EI) is the area of research that addresses the application of technology to resolve complex problems within the energy domain. Goebel et al. have provided an EI research framework that attempts to encompass all aspects of EI research. Due to the rapid improvements in EI, there are uncharted research areas that were not incorporated into the framework. Specifically, we posit that grid reliability is an underrepresented research area and should be incorporated into the framework. The goal of this research in progress is to bring forth grid reliability research and present to the community as a viable, important, and bountiful research domain. In this work-in-progress, we raise the need for grid reliability research, define grid reliability, and provide the Enhanced EI Research Framework.**

Keywords-Energy Informatics; Grid Reliability; EI Research Framework.

I. INTRODUCTION

The Energy informatics (EI) research covers the use of information and communication technology to address energy challenges [1]. It is the area of research that addresses the application of technology to resolve complex problems in the energy domain. The Department of Energy's Office of Energy Efficiency & Renewable Energy [2] classified challenges within the energy domain into two types: (1) the Transmission System challenges and (2) the Distribution Systems challenges. Transmission Systems challenges include issues in Grid Operations and Grid Stability while Distribution Systems challenges refer to Power Quality and Protection Coordination issues.

Goebel et al. [3] stated that energy efficiency and the renewable energy supply are the two principal types of research movements currently within the energy domain. Energy efficiency research involves studying individual incentives and behavioral dynamics to influence electricity consumers' usage behavior. This first type drives the evolution of smart energy saving systems. The second type of research, renewable energy supply, seeks to resolve challenges that arise with the integration of renewable sources of energy, such as wind and solar power generation into the electric grid. This in turn drives the advancement of smart grids.

In this work-in-progress research paper, we attempt to define grid reliability and present our initial findings of a revised EI framework. These steps are the preludes for our upcoming publication in regards to elucidate an understudied research area within the EI research area: the grid reliability research.

Due to the rapidly changing nature of energy generation, new developments of the electric power network, the incorporation of distributed energy resources into the grid, circuits and equipment overloads, grid reliability research has been underwhelming. In Goebel et al. [3] EI research framework, grid reliability research was considered an inferior topic. Specifically, he considered reliability as one of the segments under the renewable energy supply research movement. However, due to the shift in challenges within the electric utility industry, we argue that grid reliability research should be classified as a separate new type of research.

The rest of the paper is organized as follows. Section II, we raise awareness of grid reliability by putting forth the research need. In Section III, we attempt to define grid reliability. In Section IV, we describe our systematic literature review method. In Section V, we present the results of the review are described, a new enhanced EI framework is proposed, and finally, Section VI contains the conclusions of the paper.

II. RESEARCH NEED

Since EI is a relatively young field, there are scattered research that handle different aspects of EI, ranging from efficiency, storage, to societal impact of renewable energy. Two seminal work by Watson et al. [4] and Watson and Brodeau [1], and later built upon by Goebel et al [3] are the most early work that attempted to provide a comprehensive EI framework. Other related works focusing on Green Technology [5][6] are included in the framework, but it seems like a subset of reliability has been omitted.

The lack of grid reliability in the current research frameworks set forth a need analysis of grid reliability as a necessary topic in EI. An omission of grid reliability is not only detrimental to the understanding of the electric grid overall but also an impediment for creating a reliable and sustainable energy storage and consumption system. In

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addition, the research attempts to provide additional research tools that are otherwise overlooked by previous framework. Such inclusion from the domain and the tool perspectives will help facilitate a more complete research agenda with regards to EI research.

Due to a rise in electricity usage via new technologies, such as electric vehicles, circuits and equipment overloads, a significant number of publications from research organizations, governmental bodies, and utility companies have focused on understanding grid reliability, causes of faults, and analyses of power outages events. The National Academies of Sciences [7] has recently published “Enhancing the Resilience of the Nation’s Electricity System” in response to the US Congress’s call for an independent assessment to “conduct a national-level comprehensive study on the future resilience and reliability of the nation’s electric power transmission and distribution system.” In addition, the National Academies of Sciences established a committee to conduct the relevant research. Throughout this report, the committee highlighted all elements of grid reliability and resilience, the risks of the system wide failure that will grow as the structure of the power industry becomes more atomized and complex, and laid out a wide range of actions to improve the resilience of the US power system. Analytics (including machine learning, data mining, and other artificial intelligence-based techniques) will play a very important role in response to the diagnosed attacks on the electric grid, failures, or other impairments due to their capability of generating real-time recommendations [7].

In another exemplar research, Adderly examined Department of Energy’s (DOE’s) power outage data from 2002-2013 and investigated reliability trends [8]. The research objective was to assess the correlation between utilities’ reliability and grid investment projects such as the deployment of smart grid assets. Using the deployment of smart meters as a proxy for grid investments, Adderly concluded that the increase of smart meters correlated strongly with the decrease of the frequency of outages [8]. The author acknowledged that due to the presence of confounding variables, the reduction in power outage couldn’t be attributed to any specific smart grid investment project.

There are several studies that attempt to understand grid reliability. Mitnick’s report prepared for the Electric Markets Research Foundation is another important resource that explains the reasons for concerns about grid reliability [9]. The author suggests that the incorporation of the distributed energy resources into the grid should be carefully managed to minimize the grid reliability risk. Another relevant study conducted by the Lawrence Berkeley National Lab brought the attention to the fact that reliability data trends might not improve due to the addition of smart grid technology, such as automated outage management systems is reporting service interruptions more accurately [10]. Since the study was based on a sample of reliability data from several utilities, the authors did not attempt to make claims about overall power reliability in the US.

With respect to the power outage causes study domain, the majority of the outages in the US are the result of events that occur at the distribution side of the grid. Infrequent outages are caused by the external factors. There are three main causes for the electrical outages: (1) Hardware and technical failure, (2) environment-related, and (3) human errors. In hardware and technical failure, outages are experienced due to equipment overload, short circuits, brownouts, and blackouts, to name a few [11]–[13]. These failures are often attributed to unmet peak usages, outdated equipment, and malfunction of backup power systems [14].

Interrupted power supply is not deemed as a mere inconvenience any longer. As the duration and spatial extent of electricity system outage increase, costs and inconvenience grow. Critical social services, such as medical care, police and other emergency services, and communications systems are relied upon electricity to function at the minimum. Such failure can bring catastrophic outcome; lives can be lost. Grid Reliability is slated to be a preventative research, and the more we understand the causes, the ready we are to implement redundancy and resilience into the electric grid.

To heed this call, we peruse the literature regarding grid reliability to bring forth the knowledge base of the topic. There are two approaches in reviewing the literature, either through a traditional literature review or through a systematic literature review [16]. A systematic literature review is a particularly influential tool in the hands of researchers, since it allows a scholar to gather and recap all the information about research in a specific field [15]. A systematic literature review has the following advantages over a traditional one. First, systematic literature review contains both breadth and focus in the search. Second, the review is rooted in empirical knowledge and evidence rather than preconceived notion. Third, a systematic literature review is replicable [16].

As a first systematic literature review in grid reliability research, this systematic literature review will focus on the different grid reliability topics and their specific characteristic. We intend to use this article to enrich the existing literature reviews and integrate the most recent articles into the body of knowledge.

III. GRID RELIABILITY DEFINITION

The grid reliability topic area aims to address challenges and remove barriers to integrating high penetrations of distributed energy generation at the transmission and distribution levels [2].The subject includes many unaddressed questions such as what makes the grid reliable? Why might reliability degrade? How do the changes in use of the grid that are underway impose such a risk? What can we do to improve the grid reliability? The DOE has recently released its electric grid reliability study, recommending the research prioritization on the development for grid resiliency, and reliability [17]. Additionally, in the same month, the DOE’s Office of Electricity Delivery and Energy Reliability announced an initial investment of nearly $900,000 to address the risk and uncertainty of power systems, enabling academic research in the US [18].

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There are several definitions with respect to the reliability of the grid. The North American Electric Reliability Council defined reliability as “the degree to which the performances of the elements of the electric system result in power being delivered to consumers within accepted standards and in the amount desired" [19]. Osborne & Cornelia viewed reliability as “the ability of the power system components to deliver electricity to all points of consumption, in the quantity and with the quality demanded by the customer” [10]. Reliability is measured by outage indices as illustrated by the Institute of Electrical and Electronics Engineers (IEEE) Standard 1366. To facilitate a unified view of grid reliability, we define grid reliability as the ability of the electric grid to deliver electricity to customers without degradation or failure. The argument is that today’s power systems cannot accommodate significant variable distributed energy generation, for instance, without failure [20].

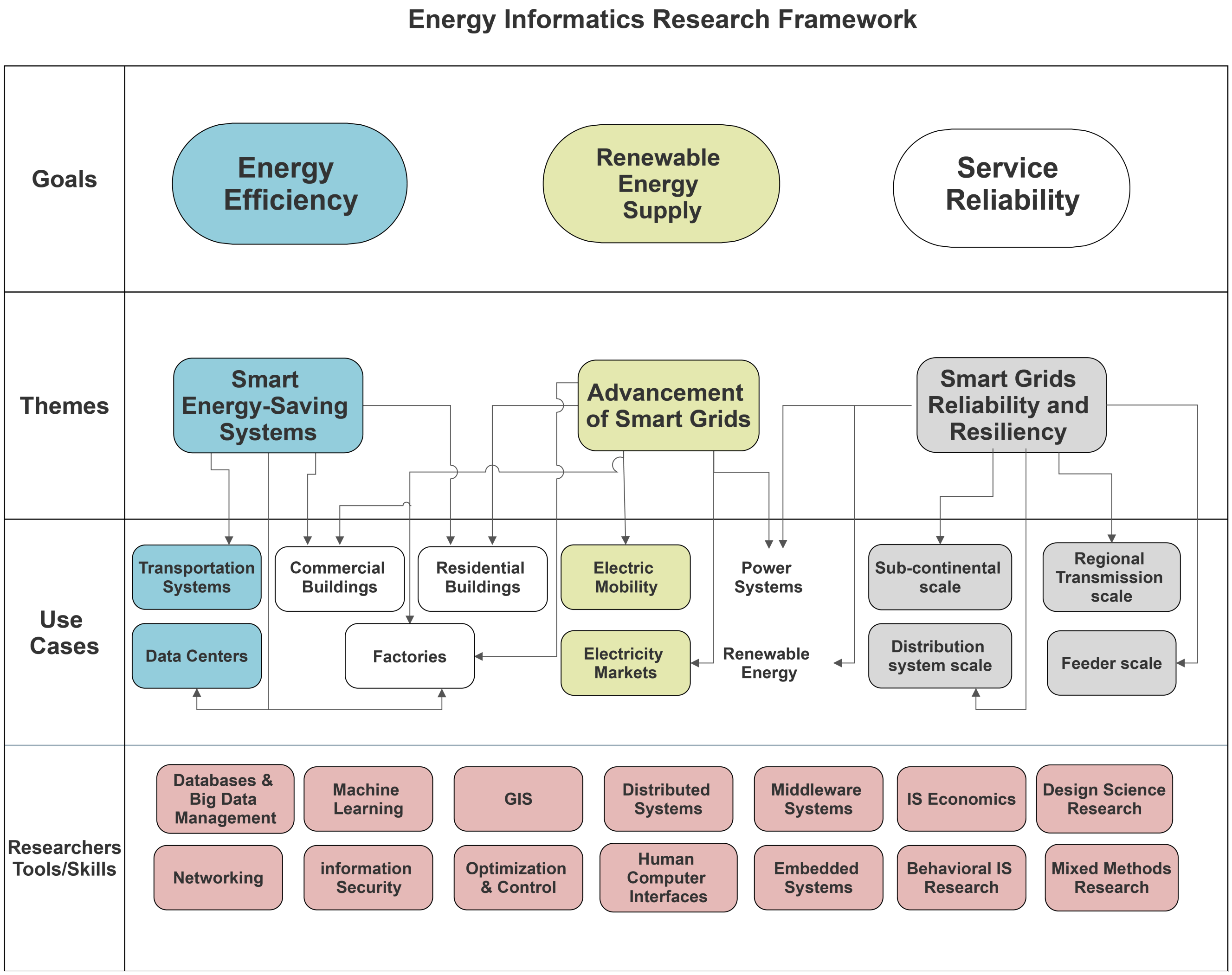

Figure 1. Energy Informatics Enhanced Research Framework - Enriched with Service Reliability Research

IV. SYSTEMATIC REVIEW METHODOLOGY

To facilitate an understanding of current grid reliability research, we conduct a systematic review under the framework offered by Kitchenham et al. [21]. There are three stages in a systematic review: the Planning Stage, the Conducting Stage, and the Reporting Stage.

In the Planning Stage, we define the research questions, select the search strategy and parameters. In the Conducting Stage, we conduct the search via two prominent research databases: IEEE Xplore and Web of Science. We have found 503 papers from 2015-2017. After quality assessment, we have perused 231 relevant papers in our systematic review. We compare the results with the search strategy and select the appropriate research to include in the in-depth analysis. Using this knowledge, we set out to finalize our research by revising the EI Framework. That is the product of the Reporting Stage.

V. A PROPOSED REVISED EI FRAMEWORK

We restructured Goebel et al. [3] framework to include service reliability as a third research movement in addition to energy efficiency and the renewable energy supply to recognize this understudied research. In our proposed the Enhanced EI Research Framework in Figure 1, energy efficiency, renewable energy supply, plus service reliability are the three types of research movements within the energy domain. The first theme, Energy Efficiency, drives the evolution of smart energy saving systems, the second theme, Renewable Energy Supply, drives the advancement of smart grids, while the third additional theme, Service Reliability, drives smart grids reliability and resiliency.

In the context of the service reliability research theme, we classify use cases (a collection of possible scenarios) into four fundamental scales: sub-continental, regional transmission, distribution system, and feeder scale. Sub-continental scale can be described as a large, relatively self-contained landmass forming a subdivision of a continent. Within this category, multiple grids, transmission, and distribution systems may exist and be interconnected. Regional transmission is the high-voltage transmission network that enables power to travel long distances from generating units to substations closer to local end-use customers where the voltage is stepped back down and sent into the distribution system for delivery to consumers.

As for the third type of use cases, the electric distribution system moves power from the energy system to the meters of electricity customers. Typically, power is delivered to distribution substations from two or more transmission lines, where it is converted to a lower voltage and sent to customers over distribution feeders. Although distribution system outages tend to be more frequent than those occurring on transmission facilities, the impacts of such outages are smaller in scale and generally easier to repair [7].

Considering the fourth fundamental category of uses cases, they fall under the feeder scale. Customers on radial systems are exposed to interruption when their feeder experiences an outage. In metropolitan areas, these feeders typically have switches that can be reconfigured to support restoration from an outage or regular maintenance. When a component fails in these systems, customers on unaffected sections of the feeder are switched manually or automatically to an adjacent, functioning circuit. However, this still exposes critical services such as hospitals or police stations to potential outages, so these facilities are often connected to a second feeder for redundancy [7].

We also enhanced the Researchers' Tools/Skills category by adding the use of tools such as those of Geographic Information Systems (GIS), Design Science Research, and Mixed Methods research. Analytics through the use of these tools would set out to transform the way we think, act, and use energy. It can help elucidate a root cause of a problem, define a solution through data, and also implement the solution with continuous monitoring and management.

VI. DISCUSSION AND CONCLUSION

In this research in progress, we proposed the Enhanced EI Research Framework to augment the original framework by Goebel et al. [3]. The Revised EI Framework brings forth two important contributions to knowledge. First, our systematic literature review provided a scientific approach and add value to the ever-expanding research in the EI domain. As the old saying goes, prevention is better than cure, we bring forth the reliability to help spark another stream of research focusing on power sustainability and reliable scaling. As renewable sources of energy start to become mainstream, the difficulty is to disperse, manage, and sustain energy storage and consumption in both local and global scale.

Second, we provided tools that were not included in the original framework. The inclusion of GIS as a research tool is imperative to research that focus on location and spatial arrangements of power stations, energy distribution grids and networks, and spatial-enabled events. In addition, with space-time analysis, GIS could assist in understanding the development of power grids through time.

Another important research tool is through the use of Design Science Research. Design Science Research is a type of Information Systems research that focuses on the science of the artifacts [22]–[25]. Researchers utilize two processes: the build and evaluation cycle of Design Science to develop algorithms, methods, and tools to solve real-world problems while relying upon research rigor [22]. Design Science strives when faces with new issues where technology can be the catalyst for change and solution for problems.

As the world has increasingly relied on energy, grid reliability is both an understudied topic and an important one. We hope that with the introduction of the grid reliability research into the Enhanced EI Research Framework, we invite more productive research conversations about this topic. In addition, new tools will help research able to answer existing questions with renewed perspectives, furthering the understanding of EI.

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