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Geographic Information System (GIS) Based Evaluation of a Utility Service Territory for Public Purpose Microgrid Installations

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SUMMARY

Emerging smart grid technologies, growing penetrations of grid-connected distributed energy resources, and increasing demand for reliability, resiliency, and power quality are shifting the electric utility industry from a centralized power grid to a more distributed and integrated grid. Microgrids will play a key role in this transformation. Until recently a large portion of installed microgrids have been third party installations, but utility-owned microgrids are also beginning to emerge as microgrid technologies have matured and utilities have realized their potential to address issues such as integration of intermittent renewables and increasing demands for resiliency.

This paper discusses a study we performed to address the utility service territory for potential microgrid installations with a focus on public good, and more specifically on added security and resiliency for critical infrastructure. In this study, a holistic data driven approach was applied to determine prime locations for microgrid installations within our service territory. The approach divided the service territory into nearly 13,000 geographic sections. Each section was evaluated based on its applicability for a microgrid installation in terms of existing power delivery infrastructure, critical customers and facilities within the section, and external input from various stakeholders. All of this information was utilized to form a comprehensive resiliency metric to identify areas for microgrid installations; a geographic information system was then utilized to map the section rankings and to provide a visualization of areas that would benefit the most from a potential microgrid installation.

Based on the results of this study, we selected six candidate sites for microgrid installations. These locations provide a foundation for a proposed microgrid pilot program. This pilot program was recently introduced to our state government in a proposed legislation that would allow us to invest up to $300 million to construct microgrids for the six identified sites. These locations demonstrate applications of microgrids for multiple types of critical infrastructure that are required to operate during extreme conditions. The targeted infrastructure includes water, transportation, communications, healthcare, community, and local government that are dispersed in geographically diverse locations throughout our service territory providing potential benefits to a large number of customers.

KEYWORDS

Microgrid, Distributed Energy Resources, Resiliency, Reliability, Integration of Renewables

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1. INTRODUCTION

The electric utility industry is in the midst of an unprecedented transformation from a centralized power system to a more distributed and integrated grid. Among many other factors, this transformation is enabled by emerging smart grid technologies, real-time communications and controls, increasing penetrations of grid connected Distributed Energy Resources (DERs), and increasing customer demands for higher reliability, resiliency, and power quality. As part of the transformation, utility owned microgrids have begun to emerge. As defined by the United States Department of Energy (DOE), a microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and can connect and disconnect from such grid to enable it to operate in both grid-connected and islanded modes [1]. Microgrids capable of such operations are in high demand, as the annual microgrid market forecast is expected to increase to nearly $20 billion by 2020 [2]. Although the first microgrid deployments were mostly third party, utility owned and operated microgrids are beginning to surface.

Microgrid deployment is driven by many factors, most importantly the increasing severity and frequency of extreme weather events across the US [3]. According to the recently published Quadrennial Energy Review (QER) by the DOE, the US loses between $18 and $33 billion annually due to power outages that result from weather events [4]. In addition, physical and cyber security threats to the power delivery infrastructure are rising [5]. In the generation sector, the centralized power production is being partially challenged by distributed generation (DG) near load centers causing the grid face operational challenges such as bi-directional power flows on radial distribution feeders. Data obtained from operational microgrids indicate that microgrids can provide significant increase in system up-time compared to the traditional power system. Operational microgrids have achieved up-times of 99.999% - 99.9999%, commonly referred to as “5-nines” and “6-nines”, compared to the U.S. grid at 99.9% [6]. Increased resiliency has driven many state actions to increase microgrid deployment including New Jersey Energy Resiliency Bank [7], New York Prize competition [8], and Connecticut Microgrid Program [9].While the enhanced resiliency is driving a number of microgrid deployments, improved economics of grid operations also contribute to the benefits of microgrids including reduced transmission and distribution (T&D) losses and localized economic dispatch based on local pricing. Microgrids have potential to also provide ancillary services [10]; however, typical utility deployments would not necessarily be able to capture all of these benefits under the existing regulatory frameworks. Additionally, renewable DERs within a microgrid provide environmental benefits such as reduction of CO_2 and other harmful emissions, increased sustainable generation resource, and improved system efficiency [11 - 13]. Overall, the true value of microgrids is realized through aggregated value from various value streams.

This paper provides highlights of a unique approach we have taken to evaluate our service territory for potential microgrid installations. For this evaluation, we utilized a holistic data driven approach to find prime locations to address needs of critical infrastructure and to provide value for a large number of customers. We also utilized a Geographic Information System (GIS) to map the areas of high microgrid potential to provide a comprehensive visualization of our entire service territory. Based on the study, a microgrid pilot program was formed and proposed to our state legislature. The remainder of the paper is structured as follows: Section 2 provides descriptive highlights of the service territory evaluation for microgrid deployment; Section 3 describes the results from the study and the transition from the results to a microgrid pilot program; Section 4 provides key highlights of the proposed pilot program; and Section 5 provides conclusions from the study and related pilot program.

2. HOLISTIC APPROACH TO EVALUATE UTILITY SERVICE TERRITORY FOR MICROGRID DEPLOYMENT

For the selection of microgrid locations we adopted a holistic data driven approach to evaluate the existing power delivery infrastructure along with critical infrastructure it supports for potential microgrid installations. In this approach, our service territory was divided in one-mile by one-mile sections in rural and suburban environments and in half-mile by half-mile sections in metropolitan city environment. As a result, our service territory was divided in nearly 13,000 individual sections for microgrid considerations. Among other factors, each section was evaluated in terms of critical facilities and customer information, state of the existing power delivery infrastructure, and feedback from external stakeholders. Each of the factors contributed to an overall section resiliency score that was calculated as a weighted summation of the key contributing factors. The division of the service territory to the small sections allowed for a robust GIS based visualization of candidate areas for microgrid installations.

Individual metrics that contribute to the overall resiliency metric are described in the following subsections. All of the analyzed data were compiled into a common database to allow for a robust evaluation and interfacing with the GIS based mapping software for visualizations. Throughout the following subsections a sample location from our service territory is shown for each individual metric. Due to the sensitive nature of some of the data contained in the study, a conscious decision was made not to include specific details of certain metrics in this paper. The metrics highlighted in the following subsections include critical customer metric, reliability metric, capacity metric, and substation resiliency metric. The overall resiliency metric is also showcased in this section.

2.1. Critical Infrastructure Metric

The critical infrastructure metric identifies customers and facilities most critical for continued operations of the society during an extreme event causing disturbances to the traditional power delivery infrastructure. Utilities themselves often keep a database of the customers that are of highest priority for restoration during an outage event. The critical infrastructure evaluated includes but is not limited to healthcare, transportation, communication, water delivery, community, evacuation centers, certain federal facilities, correctional facilities, and local government. During the evaluation of the critical infrastructure, we leveraged external partners to broaden the analysis. Based on the critical infrastructure contained in a specific footprint of a section, a criticality score was assigned based on the level impact to local, regional, and national levels. Each section received a representative score, with higher scores indicating higher criticality. A selected sample of critical customer information within the mapping interface is show in Figure 1.

Figure 1 depicts a sample area within our service territory, signifying critical customers are sparse. In the figure, the sections with the darkest color indicate the highest level of criticality among the sections. As the analysis was concentrated to establish locations where microgrids would support important grid infrastructure, the critical customer information received a significant weighing in the overall resiliency metric.

2.2. Reliability Metric

The second metric highlighted herein is the reliability metric. This metric was based off of the five-year System Average Interruption Duration Index (SAIDI) which is a combination of System Average Interruption Frequency Index (SAIFI) and Customer Average Interruption Duration Index (CAIDI) [14]. We have scores for individual circuit equipment which could be linked to the section by the equipment number depicting the location. SAIDI is measured in minutes and shows the total duration of interruptions for an average customer over a pre-defined time period [15]. The index provides an overall representation of the system reliability within each individual section. A selected sample of system reliability information within the mapping interface is shown in Figure 2. The SAIDI numbers are converted to numeric representations based on pre-determined thresholds, which are confidential. The higher the reliability score, the poorer is the system 5-year average SAIDI score for the particular section. Poor reliability areas represent locations where microgrids can add value to improve the system reliability.

2.3. Capacity Metric

The system configurability and future growth were considered through the multifaceted capacity metric. The capacity metric included portions relating to potential load at risk conditions. This identified load that is in danger of not being served in the case of a substation transformer failure, N-1 conditions, and load that is fed by radial transmission lines or long radial taps off of our sub-transmission system. The load at risk portion is most influential relating the power delivery system to supply resiliency and security. The other factors included in the capacity metric are feeder loading and terminal loading at the substation. Feeder loading relates to each feeder's unique capacity limits and was based on projections for average loading and overloads for three years. Similarly, terminal loading was based on the projected average and peak substation terminal loading for three years. Load at risk, terminal loading, and feeder loading all contributed to the overall capacity metric via weighted average formulation specific to us. Higher capacity score would indicate challenges in terms of load at risk, feeder loading, and/or terminal loading. A sample area of our service territory is shown with the capacity metric in Figure 3. The dark areas illustrate highest potential for microgrid deployment with respect to the defined capacity metric.

2.4. Substation Metrics

The substation metric utilized in the study provides a score for each section based on the substation infrastructure in place to support each section. The substation metric is a combination of consequence and probability associated with a bus-tie failure to operate. The consequence of failure was based on the number of customers served coupled with the deployment of distribution automation switches with the ability to restore customers from alternate feeds, and reliability information for the customers served. The probability of failure was determined based on bus ties, circuit breakers, and transformer health scores, historic bus lockouts over the last ten years, and previous performance of the substation bus-tie equipment. The substation score was a combination of consequence and probability of failure; a higher substation score would indicate that either the probability or consequence of the failure for a specific area is high. High score also relates to a higher potential for a microgrid to address some of the issues related to the consequence or probability of substation bus-tie failure to operate. A sample area of our service territory is shown with the Substation metric in Figure 4. Darker locations indicate the areas where microgrids could help to alleviate risk associated with substation bus tie operations and provide customers with added level of resiliency.

2.5. Overall Resiliency Metric

Along with a few other factors related to system performance and customer perception of our service, all of the aforementioned factors contributed to the overall resiliency metric. During the analysis each section received a score based on a weighted summation of all metrics considered, the higher the score the more the section met the requirements deemed important for microgrid locations. In terms of mathematical representation, the overall resiliency metric is described as follows:

$$R_n = \sum_{i=1}^{k} C_i * X_{i(n)} \tag{1}$$

Where R_n is an overall resiliency score for section n, C_i is the coefficient associated with the individual score i (reliability, capacity, etc.), $X_{i(n)}$ is the score associated with the individual score i for section n, and k is the total number of individual scores considered. The overall resiliency scores for each section within the sample of the service territory are shown in Figure 5. Higher scores relate to a darker color on the visualization, and potential better candidate area for a microgrid installation.

3. RESULTS OF THE STUDY

The aforementioned overall resiliency score translates to the overall results from the study, the distribution of which is shown in Figure 6. As the figure displays, most sections score low on the overall resiliency metric scale normalized to 10 points. The figure also shows that a very low number of sections score high (above 7) on the resiliency metric scale. Out of the nearly 13000 sections and quarter sections considered, only 30 or 0.23% had an overall score of seven and above. Thus, Figure 6 illustrates the ability of the methodology to isolate a small number of locations with the highest overall potential for microgrid installations. It is worth noting that these results are specific to the coefficients and individual sections' scores assigned for this particular study, but the results could be different based on the coefficients and scores assigned by another utility. Rather than providing exact factors, the study provides a frame work that could be used in other utility studies.

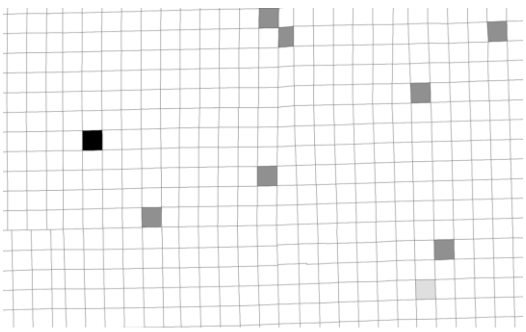

Figure 1: Critical Customer Sample Area

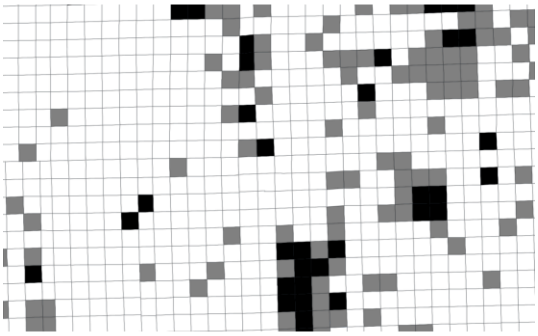

Figure 2: Reliability Metric Sample Area

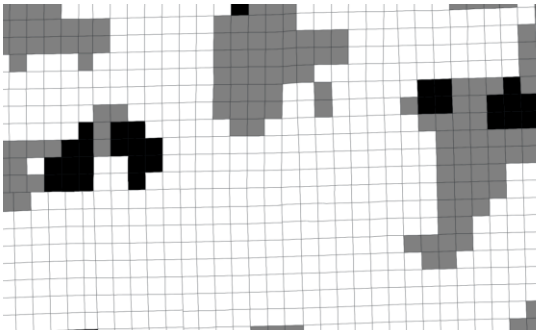

Figure 3: Capacity Metric Sample Area

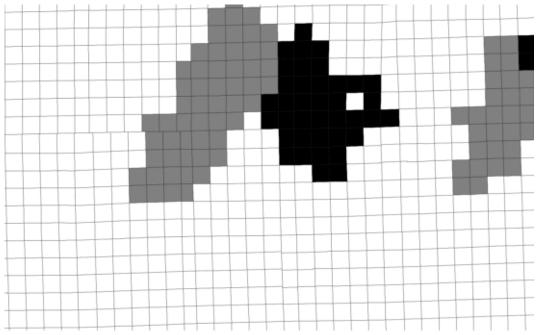

Figure 4: Substation Metric Sample Area

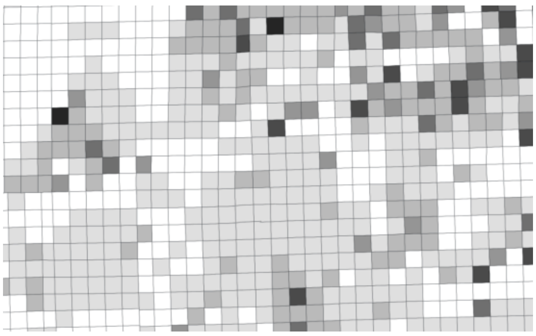

Figure 5: Resiliency Metric Sample Area

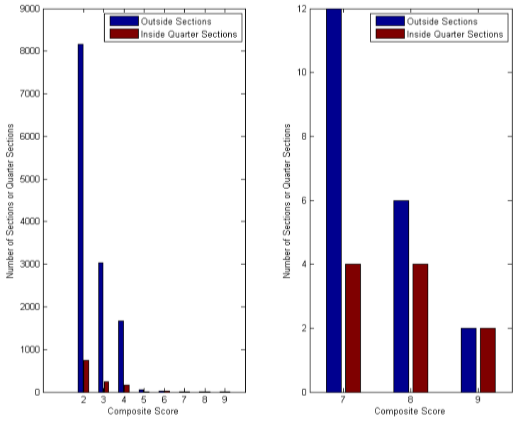

Figure 6: Distribution of Composite Scores

4. PROPOSED MICROGRID PILOT PROGRAM

The study described in the sections above was used to establish six microgrid locations for a proposed pilot program. As part of the program, we proposed pilot microgrid installations to six locations identified by the study to address resiliency and security of critical infrastructure. The pilot program was proposed as part of a recent bill introduced to our state legislature. The proposed locations were selected to demonstrate applications of microgrids for multiple types of infrastructure that are required to operate during extreme conditions with geographically diverse placements throughout our service territory. The locations include:

- A community with nearly 1,000 electric customers that included a police headquarters.
- Water pumping and water treatment infrastructure in a suburban setting serving nearly 100,000 people.
- A cluster of local government offices within a small footprint in a major county within our service territory.
- A critical communication facility for aviation with national operating impact.
- Cluster of hospitals in an urban footprint.
- Medium size airport with a regional cargo impact.

While the proposed pilot program only includes six locations, the study revealed a number of other locations that could be considered as potential future microgrid installations.

5. CONCLUSION

A utility approach to evaluate its service territory for microgrid deployments was discussed in this paper. A holistic data driven approach was utilized to determine prime locations for utility microgrid installations, considering metrics related to critical customer, capacity, reliability, and substation equipment. From the study, we established and proposed a microgrid pilot program to address security and resiliency for critical infrastructure throughout out service territory. The microgrid pilot program was recently introduced to the state legislature as part of a bill proposal, and if passed it would allow an investment up to $300 million to install microgrids in six locations identified in the study. The industry consensus is that microgrids will become an integral part of the future integrated grid. The investment for the pilot program today will result in more resilient, reliable, and efficient electric service in the future.

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