Design of Resilient Electric Distribution Systems for Remote Communities: Surgical Load Management using Smart Meters

Preprint

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Design of Resilient Electric Distribution Systems for Remote Communities: Surgical Load Management using Smart Meters

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***Abstract*—This paper describes a systematic process of designing resilient electric distribution systems and microgrids using smart meters for surgical load management (SLM) as part of Advanced Metering Infrastructure (AMI). The work focuses on selection approach, integration, and interoperability aspects for AMI in microgrids. SLM is proposed as a granular control methodology for serving selective critical loads across different distribution feeders in the system during extreme events. The surgical load shedding as well as load pick-up provides a robust approach for maximizing critical load served in a resource-constrained electric distribution system or a microgrid. We present the case of a 20 MW islanded microgrid in Cordova, AK, USA, which is the demonstration site for field validation of resilience enhancement technologies for the DOE-funded Grid Modernization project RADIANCE. Cordova microgrid is an islanded distribution grid that provides an environment to prove the approach, and the techniques may also be applicable to other regional distribution systems.**

***Index Terms*—microgrids, resilience, smart meters**

I. INTRODUCTION

Power generation and distribution infrastructure are typical candidates for enhancing resilience in distribution grids against extreme events [1], [2]. While these are essential for energy production and delivery, the flexibility in load management through direct load control provides a synergistic opportunity that can be enabled through Advanced Metering Infrastructure (AMI) [3], [4]. AMI data and controls have been utilized for variety of applications in distribution systems and microgrids such as identifications and modeling [5], anomaly detection [6], energy management in microgrids [7], and load management during emergencies [8]. This paper presents an approach to design AMI-based Surgical Load Management (SLM) during extreme event scenarios. The design steps are:

1) identifying feeder-level and customer-level seasonal criticality of loads assigned by the utility or operator
2) grid sensing and data sources in the distribution grid
3) extreme event contingencies: *black-sky* scenarios
4) smart meter capabilities and communication network
5) integration and interoperability with SCADA, microgrid controls, and automation
6) designing data-driven AMI-based SLM algorithms

II. GRID MODERNIZATION RADIANCE PROJECT

Resilient Alaskan Distribution system Improvements using Automation, Network analysis, Control, and Energy storage (RADIANCE) project (2017-ongoing) is funded through DOE's Grid Modernization Initiative with focus on resilient distribution systems [1]. The project aims to demonstrate resilience enhancement methods in Cordova Electric Cooperative (CEC) microgrid by field validation. The project uses distributed energy resources (DERs), advanced sensing, fast cyber-secure controls, AMI, energy storage, zonal configuration approach for electric and communication networks, and multi-dimensional resilience framework. Some details of the CEC microgrid are shown in Fig. 1.

CEC's distribution microgrid system is not connected to the AK interconnection and operates as a microgrid with about 20 MW generation including 7.8 MW hydro, 10.8 MW diesel, 1 MW–1 MWh Li-ion battery energy storage, has seasonal hydro, seasonal dynamic fishing loads, and exposed to physical threats such as avalanches, tsunami, earthquake, volcanoes, and cyber threats. Therefore, the main objective of resilience metrics is to provide a basis for decision-making in a multi-hazard environment.

A. Resilience Attributes

Multi-dimensional framework for cyber-physical resilience evaluation and decision-making at multiple timescales is developed to provide operation and planning support for various

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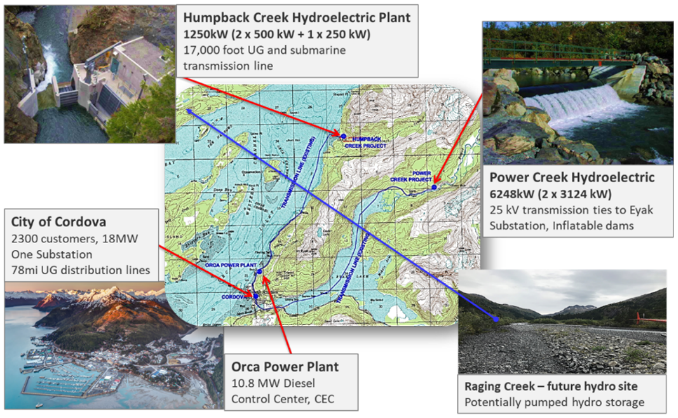

Fig. 1. Hydro-diesel-battery hybrid isolated microgrid in Cordova, AK, USA

threats in three stages: *anticipate–withstand–recover*, based on real-time microgrid state, resources, threat impact, and critical loads to be served over a finite horizon.

B. *Expected Outcomes*

The expected outcomes from the project include field validation and demonstration of resilience enhancement methods with actual deployment of real-time automation and energy storage optimization controller, micro-PMUs, AMI, secure zonal communication network, zonal load-shedding, and multi-timescale decision-support for operational control under cyber-physical events. Field implementation is guided by development, prototyping, and laboratory testing. Actual field tests are planned to validate the proposed control and resilient operation by partial system outages anticipated under avalanche, tsunami, earthquake, volcanoes, with focus on AMI-based load shedding of non-critical loads to maximize service to critical loads.

III. AMI SELECTION PROCESS

A set of choice-selection metrics were established in close coordination with CEC, NRECA and RADIANCE team. Initially, six AMI vendors were identified based on discussion with CEC, NRECA, RADIANCE, and criteria were based on unique factors for a cooperative (consumer owned) utility as shown in Table I.

After reviewing selection criteria with vendors, NRECA and some other regional cooperatives, the top-3 vendors identified for deep-dive. In the top-3 vendors, it was found that all top-3 vendors products had similar technical capabilities. Thereafter, the focus was on differentiating capabilities for the selection of the vendor such as:

- Prior deployment experience and support in Alaskan cooperatives
- Multi-vendor product support and interoperability
- Regional climatic conditions (Boreal/coastal rainforest)
- Ability to support operation via cloud-based systems (in-line with CEC's vision of lean operational staffing).

TABLE I
LIST OF IDENTIFIED CRITERIA FOR AMI CHOICE-SELECTION

Criteria	**Description**
Operational	Metering: kW, kWh, kVAr, voltage, current Polyphase and single-phase Other: power quality, time-of-use, net-metering Remote: modulation, programmable, disconnect Outage notification, restoration support Customer categorization, criticality Tamper proof, theft detection
Communication	Protocols Media: fiber optic cable, power line carrier, DSL Media: wireless RF–mesh, point to multipoint, cellular Cybersecurity Reporting rate (15minute)
Interoperability	Meter data management system, billing Cloud hosting capability Integration with SCADA, outage management system MultiSpeak compliance, version 3.0, 4.1, 5.0 GIS support Legacy and multi-vendor product support Firmware upgrade mechanism remotely
Cost	Cost per meter, license/maintenance cost Installation and operational cost Cost of communication infrastructure
Experience	Previous experience in AK/harsh environment Modular deployment approach for future expansion

A. *Interoperability*

As more utility companies install AMI systems, the potential for data overload is a common concern. A single meter publishing reads at a 15-minute frequency can produce upward of 35,000 records per year. Add blink counts and voltage information and the possibility for data overload grows. One of the cures for data overload is to share data across software platforms, thereby reducing the amount of duplicate data points created by the individual systems. One option can be to share voltage and outage information between SCADA and GIS systems. Another common approach is to share energy usage data with Outage Management and Billing systems. There are several ways to use the information generated by the AMI system. However, sharing that information between systems can be difficult, as many, if not most, utility software systems were not designed with this capability in mind. Historically, this problem was solved with expensive custom integration. This leaves utilities subject to the level of knowledge and expertise of the vendors providing the custom integration services. Some integrations are done well, while others are not. Fortunately, successfully sharing data between systems no longer needs to be difficult. Interoperability standards, such as the MultiSpeak® standard, have been developed to address this specific challenge [9]. The MultiSpeak® standard is currently in use in daily operations of more than 800 electric cooperatives, investor-owned utilities, municipals, and public power districts in at least 21 different countries worldwide. It enables both software vendors and utility users to move data around different software applications more easily. Note that the MultiSpeak standard helps create interoperable interfaces between different "head end" systems. MultiSpeak was not designed to be a field level protocol, such as IEC 61850 or

DNP 3.0. As part of the system integration process, specifying interoperability used to be a daunting task. However, as part of the MultiSpeak® standard, guide specifications are now available that support most typical use cases. Using guide specifications makes specifying the needed interoperability of a utility's given systems straightforward and pre-defined. Simply choose the use case that fits your need, download the guide specification, and include the information with your purchasing documentation. The use of guide specifications gives both parties a well-defined set of expectations, and as such, are appreciated by end users and vendors alike. In short, end users are clear about what is needed, and vendors have clarity of the user's needs.

B. Recommendation and Approval Process

After evaluating the choice-selection metrics, one of the vendors was recommended by RADIANCE team to CEC. CEC presented the process and chosen vendor's capabilities to the City of Cordova – Board of Directors in FY20Q1. The project was approved, and the decision was communicated to RADIANCE team by CEC for moving forward with procurement and integration design of AMI for CEC microgrid. A flowchart for the process is shown in Fig. 2

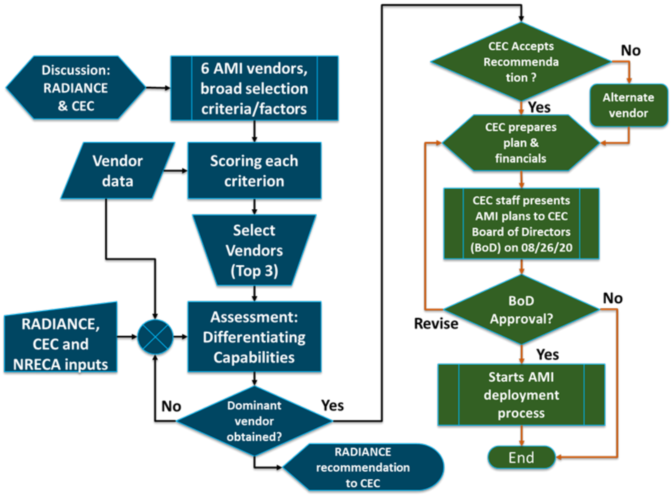

Fig. 2. Flowchart for AMI recommendation and approval from utility

IV. AMI SYSTEM INTEGRATION DESIGN

Spatial information for metering locations and pole locations for mounting communication gateways is used. Customer meter locations for about 1900 customers is shown in Fig. 3.

It may be noted that the coastal geographical terrain provides unique challenges with elevation varying drastically within a few square miles of the city where majority of load points are located. Some selective loads are located far from city center, e.g. airport is 13 miles away but provides a line-of-sight view for wireless communication. However, there may be challenges during weather events impacting communications. A propagation study is planned to better inform the placement of communication gateways, and radios for better coverage and robust design.

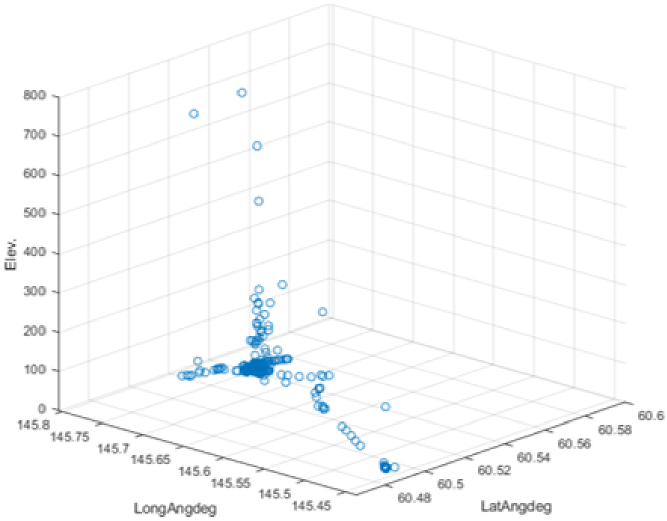

Fig. 3. Customer metering locations in main town Cordova, AK

A. AMI Communication Network Design

The communication network design is critical for SLM implementation [3], [10], and communication to end-point devices is non-trivial due to unique geography of Cordova. Mesh RF will be used for communicating with smart meters as end-points and data will be collected and relayed back through a gateway to AMI meter data management system (MDMS). The network gateways will utilize the optical fiber for reliable and resilient data transfer to/from MDMS.

B. AMI Integration with Microgrid Controller

The overall system integration architecture for RADIANCE consists microgrid controller, energy storage optimization toolbox (ESOT), high-resolution data from micro-PMUs, historical SCADA data, operational logic, and resilience metrics integration. These subsystems are interfaced using TCP-based protocols including MODBUS and DNP3.0 as shown in Fig. 4. AMI MDMS server will be interfaced to microgrid controller using DNP3.0 protocol. This interface will be used to report field measurements, MDMS analytics, and SLM control decisions relayed from microgrid controller to MDMS for end-point smart meter devices based on mesh RF (900 MHz) network.

V. SURGICAL LOAD MANAGEMENT FOR RESILIENCE

The grouping of AMI at different loads across feeders is performed based on load criticality defined by CEC. The load at different oil switches on each primary feeder with respective priorities (1:*most critical* to 3:*non-critical*) is shown in Fig. 5.

A. Approach: Grouping of Loads

The preliminary categorization for initial AMI deployment divides the loads with priorities 1, 2, and 3 into Groups A, B, and C & D, respectively, and is listed below.

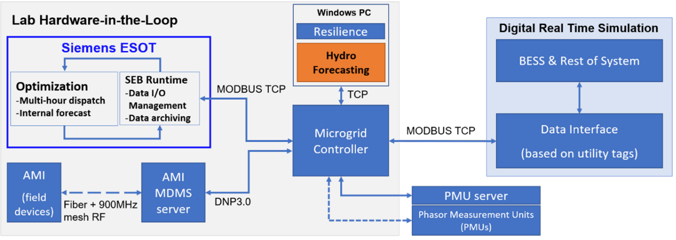

Fig. 4. System integration and hardware-in-the-loop (HIL) testing setup for RADIANCE project. The lab HIL will test actual hardware controllers for deployment in CEC microgrid.

- Group A: critical always; e.g., hospital, CEC control room, airport, fire station, U.S. Coast Guard.
- Group B: seasonal May-Sep commercial critical, Oct-Apr go to group D
- Group C: essential/firm loads, including medically sensitive residential
- Group D: flexible residential and commercial loads.

The load groups will be used to identify candidates of load-shedding under extreme event conditions. The loads can be dynamically assigned by the operator to certain groups based on event information or grid conditions. Groups can also be defined for different seasons, and for severity and impact of each extreme event. Further refinement of categorization will be established during final deployment.

B. SLM versus primary feeder shedding

SLM consists of surgical load shedding as well as load pick-up for maximizing critical load served in a resource-constrained electric distribution system or a microgrid. The SLM will allow efficient utilization and granular service of critical loads based on limited resources in the microgrid during finite time horizon of pre- and post-event operation. This will allow avoiding shedding of whole primary feeder and/or avoid serving of non-critical loads on the same feeder where critical load is connected and served during emergencies. The smart meters will allow disconnection of such non-critical load points and continue serving critical loads across the system without de-energizing one or more primary feeders with no critical loads.

VI. CONCLUSION

We presented a design and integration approach for AMI in microgrids using case example of CEC microgrid in Cordova, AK. As part of RADIANCE project, the benefits of SLM approach will be quantified using results from AMI HIL testing at NREL, and performance validation based on field data collection post-deployment. This will be reported in future work. SLM will potentially be useful in mitigating resilience challenges in other regional distribution grids and microgrids.

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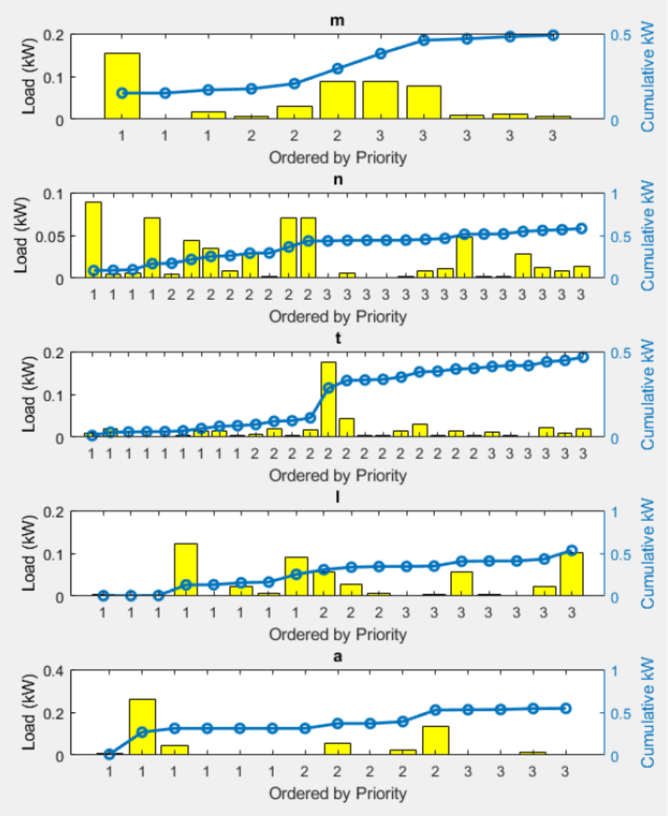

Fig. 5. Load priorities and example profiles at primary feeders in CEC microgrid