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Resilient Microgrids: Developing Community-scale Microgrids with High Solar Generation

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SUMMARY

Today's utilities lack a generic and cost-effective approach to plan and operate resilient community microgrids. During extreme events, both accurate network model information and the availability of communication are typically rather constrained, which directly degrade the effectiveness of service restoration. Resilient communities should be able to seamlessly change their operations from grid-connected to islanded modes, and vice versa. Especially under various scenarios such as weather, that impact utilities regularly and continue to be a challenge.

A set of interconnected PVs, energy storages, and buildings is termed as a "CELL", implying the smallest subset of the grid which can operate independently using its own resources. Using self-organizing map-based resilience quantification, Lyapunov-based stability analysis, and multiagent deep reinforcement learning enhanced DER optimization, REORG aims to transform traditionally centralized grid operations into time-varying cellular operations that can optimally partition a large group of interconnected DERs under control into multiple "loosely coupled" subnetworks, which can operate independently even when physically connected, and transform a complex centralized optimization problem into distributed and coordinated ones which demonstrate better control scalability. This project also identifies cells that inherently have energy resources to black start and can provide a certain level of backup power for their loads under the loss of utility power supply and/or external communication. Most importantly, the chosen configuration can adapt to time-varying weather conditions, propagation of faults, and communication damages, to achieve fast and robust bottom-up service restoration by clustering cells.

KEYWORDS

Microgrid, Reconfigurable Microgrid, Time Varying Microgrid, Eliminating Outages in Critically Impacted Weather Scenarios, DER Integration, Resilient Microgrid, Solar Power

1. INTRODUCTION

The project aims to develop and validate a resilience- and stability-oriented cellular grid formation and optimization approach, termed as REORG, to achieve scalable and reconfigurable microgrid operations for the distribution feeders with PVs and mobile energy storages (i.e., electric buses).

In this paper, we discuss the project in depth with the goal to allow for decisions to be made autonomously by the system, in a distributed approach at the grid edge, as opposed to manned centralized switching plans.

2. PROJECT CONTRIBUTORS

The project was created by the following organization in joint partnership. Below are the details of each party involved.

NREL: National Renewable Energy Laboratory located in Golden, Colorado, USA. Part of the DOE and will be the primary recipient of the funding and will distribute among other partners as agreed by the team. NREL will coordinate and run the project including all the lab testing which is phase 1 or the effort.

NRECA: Represents more than 900 electric cooperatives, public power districts, and public utility districts.

Minsait ACS: the technology provider of the IoT platform (iSPEED) that the whole system will be focused around. Edge Software components and IoT gateways located at each DER interconnect, account for changing topology of the system and allow for autonomous operation of DER on the system when parts of the network are out.

Mississippi State University: Develop algorithms for power system resilience using machine learning.

Holy Cross Energy: Electric Cooperative utility located in Aspen, Colorado, very progressive especially in integrating community solar into their system at a much larger rate than other cooperatives.

3. TECHNICAL APPROACH

Resilience- and stability-oriented cellular grid formation and optimization approach, termed as REORG, to achieve scalable and reconfigurable microgrid operations for the distribution feeders with PVs and mobile energy storages (i.e. electric buses). A set of interconnected PVs, energy storages, and buildings is termed as a cell, implying the smallest subset of the grid which can operate independently using its own resources.

Using self-organizing map-based resilience quantification, Lyapunov-based stability analysis, and multiagent deep reinforcement learning enhanced DER optimization, REORG will transform traditionally centralized grid operations into time-varying cellular operations that can:

- Optimally partition a large group of interconnected DERs under control into multiple subnetworks, which can operate independently even when physically connected, and transform a complex centralized optimization problem into distributed and coordinated ones which demonstrate better control scalability.

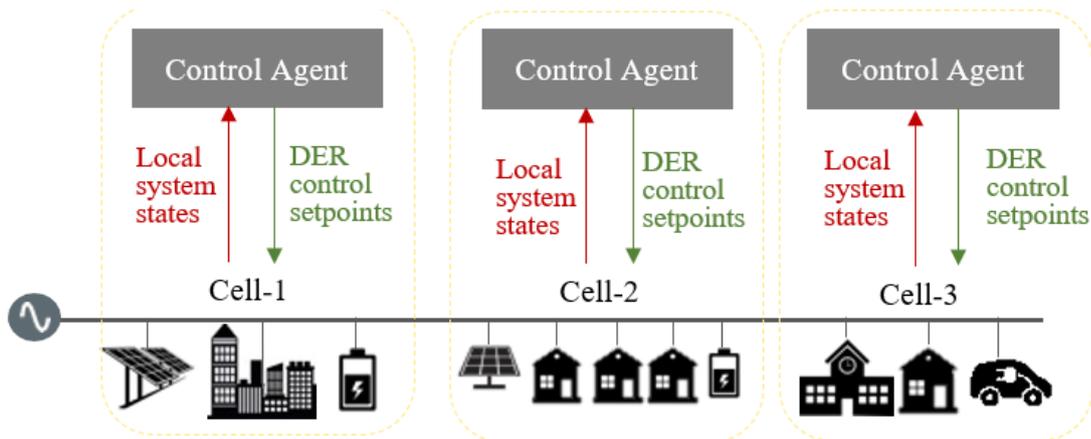
- Identify cells such that each cell inherently has energy resources to black start and can provide a level of backup power for its loads under the loss of utility power supply and/or external communication.
- Adapt to time-varying weather changes, propagation of faults, and communication damages, and achieve fast and robust bottom-up service restoration by clustering cells and routing electric buses while satisfying optimal resilience objective and stability constraint.

REORG is implemented using modern internet of things (IoT) solutions, in the Roaring Fork Valley community serviced by multiple Holy Cross Energy’s distribution feeders. It includes 5 MW PV solar installations, a community-scale battery energy storage with grid-forming capability, a business park with hundreds of rooftop PVs and building loads, a variety of critical service facilities (such as Aspen airport, a transit agency facility, a county government building, and a sanitation district facility). Some of the facilities have grid-forming backup generators, and multiple other residential and commercial loads. Additional grid-forming inverters for PVs and batteries will also be installed to support this project. Resilient communities should be able to seamlessly change their operations from grid-connected to islanded modes, and vice versa.

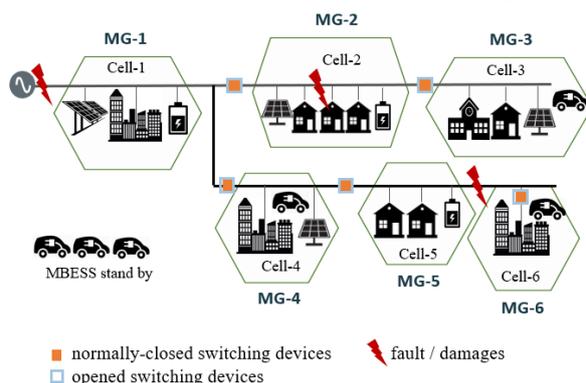
4. PROJECT ANALYSIS

How to guarantee system stability under various scenarios is another critical challenge. REORG can effectively address these challenges by:

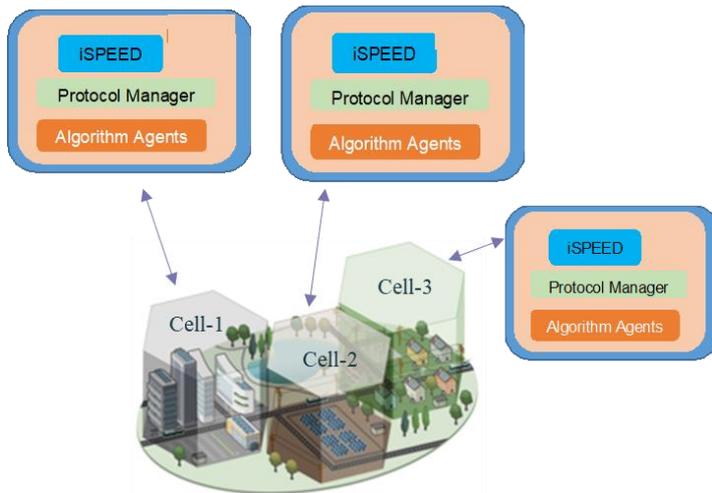
- (1) Quantifying component-level resilience and characterizing system stability. We will use self-organizing map (SOM) to integrate a selection of relevant features affecting resilience and to quantify the resilience index of each component (e.g., building, PV farm, and community energy storage) into a single value. Component-level resilience reflects the capability of a component to endure disturbances, black-start and operate independently under extreme events for a certain period. The resulting resilience quantification and stability analysis will be performed in real-time, as they are affected by weather, grid topology and communications. They will inform cell forming and clustering.
- (2) Forming cells by optimally clustering components. Resilience and stability indices will be used as inputs for the affinity propagation clustering algorithm to form cells. Cells are identified by optimally grouping interconnected components so that each group’s integrated resilience, i.e. cell resilience, meets the desired threshold, and maintains stability. Additionally, different cells are “loosely coupled”, e.g. the operation of a cell has minimum impact on others. To this end, each cell can a) operate independently even when they are physically connected during normal operations, b) receive service request signal from utility control system and provide grid services in coordination with other cells, and c) operate as islanded microgrid under disruptive events.
- (3) Developing an integrated optimization method to achieve reliable and resilient cell operations. Each cell has a DER control agent, which is developed by integrating edge flexibility-enhanced model-predictive control² and model-free real-time optimal power flow³. A variety of grid-forming and grid-following resources inside the same cell are controlled to achieve reliable normal operations and secure services to critical loads in the presence of disruptive events. Note that the use of model-free optimal power flow can overcome the uncertainties due to renewable generation and model incorrectness caused by insufficient information of network topology changes – a common problem during restoration.



(4) Clustering cells and routing electric buses to maintain optimal resilience under extreme events using reinforcement learning. Under disruptive events, cells are subject to continuous clustering in order to pick up loads and adapt to time-varying cell resilience. This will yield a fully bottom-up service restoration. A multi-agent deep reinforcement learning approach will be used to solve the optimal clustering decision for multiple cells simultaneously in a distributed manner. Under loss of communication between cells, the behaviors learned using deep reinforcement learning along with a “probe and connect” approach will help each cell autonomously synchronize and connect. The cell where the school bus should be located during cell clustering, e.g. optimal bus routing, will be considered as another decision variable in the optimization process with mobile generators leveraged if needed.



Two feeders are connected to Aspen substation, supplying power to Roaring Fork Valley, will be modeled as the test system. It will consist of >10,000 DERs and >75% of peak load PV penetration, with a variety of behind- and front-of-the-meter resources. Also, >30 hardware devices including grid-forming inverters will be integrated into the simulated model to construct power-hardware-in-the-loop experiment. Misait ACS’s flexible and secured IoT platform will be the fundamental platform to integrate and implement REORG. Wherein, its industry-leading PRISM distribution application processor is designed to enable decentralized and distributed applications, which will be used for cell operations and clustering. Interoperable and secured data communication is realized through the use of open communication standards and proprietary real-time data bus.



“Node #1”, ACS’s edge IoT platform, is integrated with DERs, to provide real-time measurements together with supply/demand and flexibility forecasting via its unique edge computing and analytics.

5. PROJECT CONCLUSION

The outcome of this project will provide a generic and cost-effective approach to plan and operate community microgrids, and enable fast and robust bottom-up service restorations. REORG will help Roaring Fork Valley, which is vulnerable to wildfire, operate reliably against contingencies and resiliently against extreme events. The objective is to provide continuous power for 100% of critical loads for at least 5 days, reducing cumulative customer-hours of outages for non-critical loads by 20%, reducing time to recovery by 50%, reducing the loss of utility revenue including recovery cost by at least 30%.

With the support of Pitkin County, Colorado the success of this project can inform a broader society and demonstrate a nationwide example. Also, the project can help the county to better understand the benefit of using PVs to enhance resilience and can further promote PV adoption with potential enactment of new policies or incentive programs in the state.