A Smart and Flexible Microgrid with a Low-cost Scalable Open-source Controller

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Network Optimized Distributed Energy Systems (NODES) Annual Review Meeting

Feb. 12, 2019
Team Members and Roles

• MG design: siting and sizing strategy
• System data collection and analysis
• MG scalability
• MG controller integration to SCADA/DMS test

• MG controller commercialization
• Support on controller design & testing
• Provide NI equipment and platform training
• NI controller interface to SCADA

• Overall lead and project management
• MG controller design and testing
• Test plan development
• Help on MG design
• Help on technology transfer

• Develop commercialization plan
• Market analysis
• MG controller software packaging and distribution

• Use cases and requirements in both grid-tied and islanded modes
• System level safety and protection
• Assist with test plan & path to market

• Provide knowledge to MG siting & sizing
• Provide input to data collection & analysis
• Provide advice on testing

• EPRI
• TIVC
• National Instruments
• The University of Tennessee, Knoxville
Project Summary

Sources:
Project Objectives & Performance Targets

Enable easy MG adoption and low cost implementation

Open source, general-purpose controller

Scalability

Facilitate expansion and duplication of MGs to other communities

Further enhance the grid reliability and resiliency, while reducing the controller and MG implementation cost

20% emission reduction over the baseline case

Smart and flexible MG

Proposed Microgrid & Controller

Generic design guideline

Promote MG proliferation

20% emission reduction over the baseline case

Reduce CO₂ emission

Increase energy use efficiency

Improve reliability & resiliency

Reduce SAIDI by 98% from 50 min to 1 min

Reduce the critical customer interruption times due to extreme weather from 346.8 min to 15 min.
Uniqueness

- Flexible interfaces for better asset use, reliability, and economics
- Utilize existing smart grid capability (intelligent switches and high speed fiber optical links) for enhanced performance and reduced cost
- Open source, scalable controller based on general-purpose hardware
- Multi-platform developing and testing environment
Barriers and Challenges

‣ Lack of knowledge and design for community-based MGs and controllers incorporating grid conditions with intelligent switches and fast communication in a smart distribution grid

‣ Lack of a cost-effective MG controller that is not site-dependent, not limited by proprietary software and special hardware, and does not require additional sensors and switches

‣ Lack of effective testing platform and methodology for MGs and controllers

‣ Difficulty in further reliability improvements beyond smart distribution grid
Key Deliverables and Desirable Outcomes

**Deliverables**
- MG design achieves the performance targets
- MG controller design achieves the defined functionality and performance targets
- MG and its controller tested in OPAL-RT HIL platform, UTK’s hardware test-bed, and actual EPB electric grid
- Commercialization strategy planned and executed

**Outcomes**
- A MG design guideline considering the overall resiliency, economic and environmental benefits, as well as considering the smart grid features and the impact of the surrounding grid
- An open source MG controller ready for commercialization
Technical Approach

MG Design - Based on EPB Smart Communities

- SCADA System
- PV
- Smart Switches
- Fiber Link

MG Controller Integrated with the Existing SCADA

MG Controller Development – Open Source NI Controllers

Higher Efficiency
Lower Emission
Higher Reliability & Resilience
MG & Low Cost Controller

Accurate Real-Time MG Modeling for Different Scenarios

MG & Controller Testing

Interactive Controller R&D & MG Testing

EPB Field Test
UTK Grid Emulator
NI RT HIL Test
# Project Progress

**Feb. 2019**

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Project Progress

**Design**
- MG designed, MG performance evaluated and energy storage installed
- MG design guideline developed

**Development**
- MG controller developed and implemented
- Tested in MATLAB/Simulink

**Test**
- Tested in OPAL-RT Hardware-in-the-loop platform
- Testing in UTK’s Hardware Testbed and at EPB on site

**T2M**
- Drafted marketing plan, test license issued to EPB
- Working on demonstrations to engage commercial partners
Chattanooga Airport (PV owner) has provided the space for energy storage device within the new solar PV installation area.

Battery energy storage installation completed

2.1 MW Solar PV and 560 kW (510 kWh) BESS location
Project Progress - MG Design Guideline

- Sizing and siting PV and battery energy storage
- Developed MG design guideline for sizing and siting MG assets for use at EPB and other utilities

<table>
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<tr>
<th>Performance target</th>
<th>Energy efficiency improvement</th>
<th>Emission reduction</th>
<th>Average interruption time in extreme weather</th>
<th>Reliability (SAIDI of critical load)</th>
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<tr>
<td></td>
<td>20%</td>
<td>20%</td>
<td>15 min</td>
<td>Under 1 min. (49.34 min without MG)</td>
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<td>Performance of design</td>
<td>35.5%</td>
<td>34.0%</td>
<td>15 min</td>
<td>0.99 min. with an extra automated switch</td>
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Project Progress - MG Communication Structure

- Developed hierarchical MG control structure
- Fully utilize communication asset
- Target for commercial use

1. BESS local controller ----- BESS
2. BESS local controller ---- MGCC
3. PV ---- SCADA (Already in Place)
4. Smart switches----- SCADA (Already In Place)
5. SCADA ---- MGCC
Hardware-in-the-loop test on OPAL-RT

- Real-time Simulator: MG circuit, PV, battery, IntelliRupter
- Desktop PC: setup system model, visualization
- Communication protocol: DNP3
Closes when Angle. Diff is 0

Project Progress - MG Controller Testing on OPAL-RT HIL

A Smart and Flexible Microgrid with a Low-cost Scalable Open-source Controller

Communication
Resynchronization
Active power control
Reactive power control

Battery SOC
Battery Output

Energy Mgmt.
State Estimation
Communication
Data Logging
Black Start

Microgrid State:
Islanded

Max PV
Total Load

PV Local Controller

PV Forecast

Video
Project Progress - MG Controller Testing on UTK Hardware Testbed (HTB)

- Hardware-in-the-loop test on UTK’s HTB
  - Power electronics based hardware emulation platform with actual voltages and currents, measurement, communication and control for more realistic testing
  - MG circuit, PV, battery, and IntelliRupter emulated on HTB
Project Progress - MG Controller Testing on UTK Hardware Testbed (HTB)

Video
Project Progress - MG Controller Testing on UTK Hardware Testbed (HTB)

Grid becomes available

Grid picks up adjacent loads one-by-one

Boundary Switch Closes

Battery changes to current control

Filtered voltage across boundary switch

Battery Current

L7 Current

L8 Current

Voltage across boundary switch

Grid (G1) voltage

Battery voltage
Project Progress - MG Controller Field Testing

- MG central controller (MGCC) and local controller installed
- Preliminary integration test: SCADA can send control commands to MGCC, and poll data from MGCC
- A separate virtual RTU (vRTU) is established for the MGCC to poll data and pass control signals to the IntelliRupter
List of Achievements

- Filed patent
  - Microgrids with dynamically configurable boundaries including multiple main grid feeder coupling locations and methods of operating the same, filed on 11/09/2017
- Filed invention disclosures
  - A protection scheme for inverter-dominated microgrid with dynamic boundaries, filed on 08/22/2017
  - A scalable controller for community-based microgrid with dynamic boundary, filed on 02/21/2018
- Publications
  - Battery and Backup Generator Sizing for a Resilient Microgrid under Stochastic Extreme Events, published by *IET Generation, Transmission & Distribution*.
  - A Controller for Microgrid with Dynamic Boundary, presented at *IEEE Energy Conversion Congress & Exposition (ECCE)*, 2018
  - A Smart and Flexible Microgrid with Dynamic Boundary and Intelligent Open-Source Controller, published by EPRI as a technical whitepaper
Tech to Market Path

- **Commercial Objectives**
  - Transfer the controller technology developed to commercial partners for integration into their existing or new product offerings to simplify and boost MG deployment and hardware applications
  - Develop and distribute open-source software for core technologies common to most MGs to stimulate MG development/adoption

- **Target Market**
  - Primarily distribution utilities looking to improve resiliency and reduce emissions
  - Also large commercial or government entities that own/operate their own distribution grids
Tech to Market Path, cont’d

- **Key commercial partners, customers, advisors**
  - Team partners EPRI/NI/GEC/TVA/EPB are serving as commercial partners and advisors
  - CURENT industry members also consulted during the project. Utility members first targeted as potential customers

- **Commercial activities**
  - Mapped out novel capabilities and applications enabled by MG controller and developed commercialization plan
  - Developed commercialization strategy plan and approved by ARPA-E
  - Completed competitive analysis
  - Test license issued to EPB
  - MG design guideline and MG controller application guideline documentation developed and being revised according to new results
Future Plan

- Important upcoming activities
  - Complete testing on HTB at UTK
  - Testing at EPB on site (selected scenarios)

- Major achievements by the next annual meeting
  - Open source release of MG controller software
  - Complete field demonstration at EPB

- Important upcoming commercial activities
  - Finalize marketing plan
  - Engage discussion with potential licensees and customers
Acknowledgements

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