GRID MODERNIZATION INITIATIVE
Program Update

GMLC 1.5.03 Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB

KEVIN SCHNEIDER (PNNL)
JOSH HAMBRICK +1 (ORNL)
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DOE Forrestal – Washington, DC

Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB (High-Level Project Summary)

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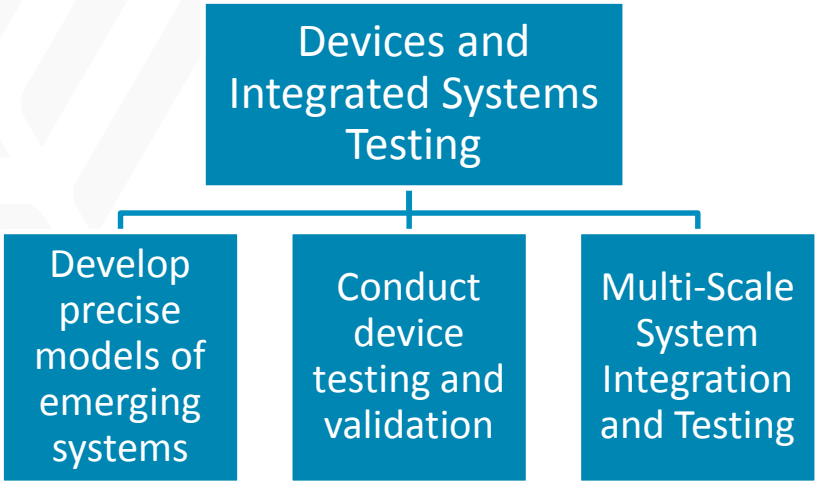
The primary goal of this project is to increase distribution resiliency through flexible operating strategies. This will be accomplished by actively engaging utility and non-utility assets as flexible resources.

Value Proposition

- DER deployments at moderate to high penetration levels prevent a "business as usual" approach
- Duke Energy has halted some self-healing systems deployments due to moderate/high penetration PV concerns
- What is needed is a way to coordinate the operation of distributed PV, to make it a resource, and not an obstacle
- This is extensible to other centralized and decentralized system combinations

Project Objectives

- Develop flexible operating strategies that integrate centralized and decentralized control systems (e.g., self-healing/PV)
- Engage utility and non-utility assets to increase the resiliency of critical end-use loads to all hazards events
- Develop, and deploy, a layered control architecture using commercial-off-the-shelf (COTS) equipment and open source code



Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB (Project Team)

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- **PNNL – Kevin Schneider and Wei Du**
  - Development of architecture, controls, and operations
  - Co-Simulation of distribution and communications
- **ORNL – Josh Hambrick and Mark Buckner**
  - Implementation of the OpenFMB Harness
  - Application of OpenFMB cybersecurity framework and microgrids protection
- **NREL – Kumaraguru Prabakar**
  - Sub-system testing of centralized controls, e.g., GE DMS
  - Cost/Benefit Analysis and technical performance analysis
- **Duke Energy – Stuart Laval and Phil Shaw**
  - Host utility which owns and operates all utility assets
  - Execute final field evaluation and cyber red team activities
- **GE Grid Solutions – Avnaesh Jayantilal**
  - Technical support for production DMS and FLISR
- **UNC-Charlotte – Madhav Manjrekar and Somasundaram Essakiappan**
  - Primary HIL performers, using Typhoon, support of controls validation
- **University of Tennessee – Leon Tolbert and Yilu Liu**
  - Integrate VOLTTRON nodes into OpenFMB Harness
- **Smart Electric Power Alliance (SEPA) – Robert Tucker**
  - Outreach agency to ensure that lessons learned are transferred
- **Project Industry Advisory Board (IAB) Members**
  - Entergy – Cat Wong
  - Avista – Curt Kirkeby
  - APS – Jason Delany
  - North America Energy Standards Board (NAESB) – Jonathan Booe & Elizabeth Mallet

PROJECT FUNDING			
Team Member	Year 1 $	Year 2 $	Year 3 $
PNNL	600,000	600,000	600,000
ORNL	483,333	483,333	483,333
NREL	300,000	300,000	300,000
Duke Energy	250,000	250,000	250,000
UNC	183,333	183,333	183,333
UTK	150,000	150,000	150,000
SEPA	30,000	30,000	40,000

Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB (Approach)

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- **Approach**:
  - R&D: foundational research in architecture, controls, simulation & emulation, and multi-scale testing
  - Market Stimulation: active Industry Advisory Board (IAB), including material developed and distributed by SEPA
  - Standards: using OpenFMB, and an open-source standards-based approach

- **Key Issues**:
  - Increasing flexibility as a resiliency resource, to address uncertainty in planning and operations
  - Coordinating centralized and decentralized systems, utility and non-utility owned/operated
  - Transforming the perspective of DER from being an obstacle to being a resource

- **Distinctive Characteristics**:
  - Industry driven: the project is motivated by utility needs, and supported by IAB members with similar classes of operational challenges
  - Standards based: all work is being conducted with open platforms to facilitate broad adoption
  - Deployable: the final field validation will use COTS equipment running containerized open-source software, further facilitating broad adoption

Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB (Architecture and Controls)

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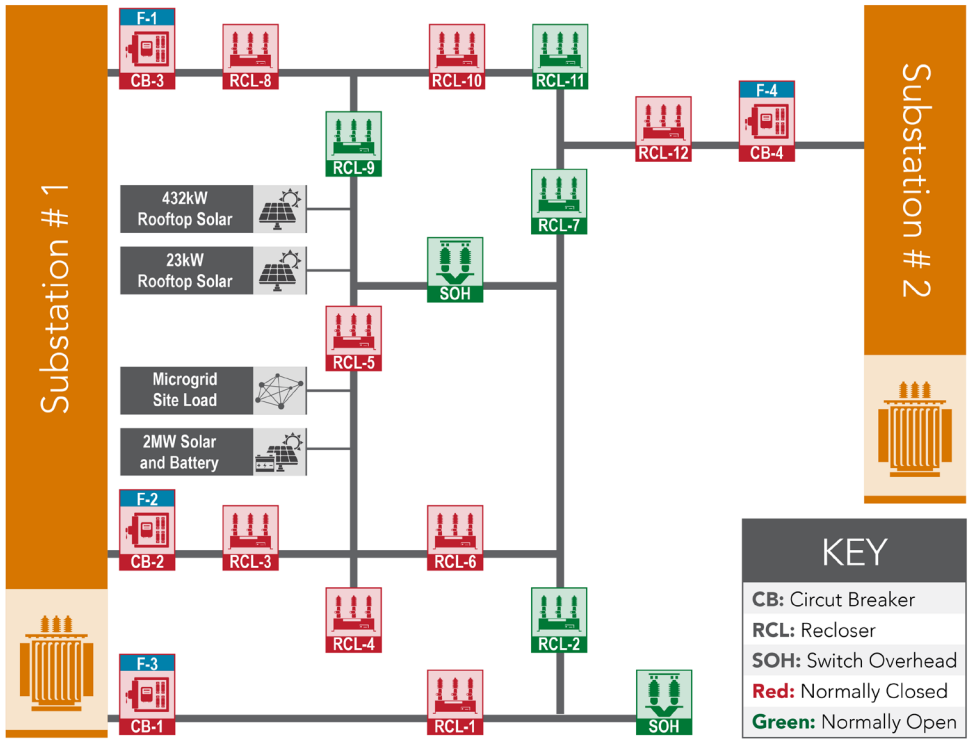
A layered control structure with elements of a laminar control architecture developed to coordinate self-healing, microgrids, and DERs.

Concept of Operations (CONOPS) has been completed, including 12 use-cases

- Protection operates autonomously at the device level, using local set point groups
- OpenFMB maintains protection coordination after system changes (publish & subscribe)
- The central DMS determines “optimal” topology post event, issues commands
- The DMS can engage transactive to incentivize non-utility assets to generate additional switching options
- Operations across layers are coordinated, enabling effective centralized and distributed system operations



Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB (Simulation/HIL/Emulation)

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Before equipment can be operationally deployed, the architecture, controls, and set points must be developed, simulated, and validated. A multi-stage validation approach has been taken.

- Co-Simulation: HELICS, GridLAB-D, and NS-3
  - Initial electric and communications models complete
  - Results supporting HIL simulations
- HIL Simulation: Typhoon HIL & ADMS Testbed
  - Typhoon running at UNCC and Duke Energy
  - NREL is working on setting up GE DMS
- Emulation: ORNL SI-Grid
  - ORNL and UTK are working with Duke RTUs
  - SI-Grid connected to NREL, working on UNCC
- Field Deployment: Anderson, SC
  - Schedule has been pushed back due to siting issues
    - Equipment selection Q1 CY20
    - Field validation Q2 CY21
- All software and HIL models have been coordinated, so team members are using consistent information.

Co-Simulation

HELICS

GridLAB-D

ns-3 NETWORK SIMULATOR

HIL Simulation & Emulation



Field Deployment

Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB (OpenFMB Harness)

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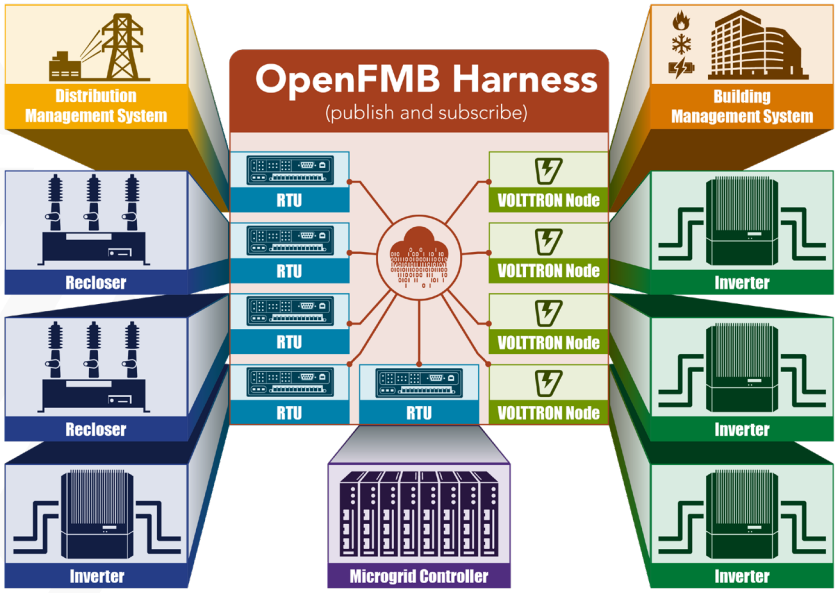
The OpenFMB "Harness" is the physical realization of the reference architecture.

- Built using the standards-based OpenFMB reference implementation: leveraging past work the data structure and models are almost defined
- The harness is scalable for large numbers of DERs, and does not use proprietary adaptors
- Utility assets connected via COTS Remote Terminal Units (RTUs) with containerized applications: RTUs are being tested with initial harness
- Non-Utility assets connections will use VOLLTTRON on commodity platforms: work is continuing on VOLTTRON integration



Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB (Hardware Transitions)

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For a resilient control system to be viable, there must be a path to deployment with COTS equipment.

- Early OpenFMB work used commodity Raspberry Pi™ prototype controllers
- The utility assets for this project will use COTS RTUs and/or 4G LTE gateways, with OpenFMB in a containerized environment
- Using open software containerized applications on COTS equipment enables hardening for industrial applications while ensuring interoperability and portability
- COTS devices integrates TPM2.0 crypto-chips and X.509 certificates with whitelisted containerized OpenFMB applications
- COTS devices are being tested on the initial harness implementation

Substation/Microgrid RTU: SEL 3555

Recloser RTU
SEL 3505

4G LTE Gateway
Sierra Wireless MP70+

Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB (Industry Advisory Board)

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This project is driven by an active IAB, providing input that impacts direction.

- IAB members reviewed proposal concept
- IAB members have provided direct feedback as the work has progressed
- Two in-person IAB meetings in 2019
- IAB feedback has been incorporated to the research direction, including the Concept of Operations (CONOPS) document
- IAB members have participated in follow-up activities, including proposals

Example IAB "needs" which have been integrated into project work plan

- "Faster, more secure, and non-proprietary plug-n-play integration of DERs/microgrids with the existing DA devices being controlled by the ADMS. "
- "A more resilient self-healing system integrated with ADMS that could reduce the duration and frequency of momentary faults and leverage DERs for back-up when a permanent fault occurs."
- "Faster and more modular development and deployment framework for grid-edge applications. ADMS or DERMS are monolithic and cannot be easily extended for new functionality without breaking it."
- "Need multiple sources of supply with diverse vendor & technology mix for best in breed solution."

Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB (Next Steps and Future Plans)

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Year two has focused on integrating software and hardware analysis, to implement physical systems

- Simulation
  - Co-simulation of the CONOPS scenarios has been conducted to evaluate impact of communications infrastructure
  - Reliability analysis has been conducted on the CONOPS scenarios
- Hardware
  - HIL work has been conducted at UNCC to validate relay level operations
  - Emulation at ORNL has implemented an OpenFMB harness for testing
  - The OpenFMB Plug Fest demonstrated that multiple vendors can implement the proposed concepts

Reliability Improvement Evaluation Using Sensor Placement Optimization Tool (SPOT)

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- **Cases:** Evaluate the reliability improvement in three scenarios:
  1) Self-healing
  2) Self-healing + microgrid
  3) Self-healing + microgrid + transactive control of reactive power

- **Progress**
  - Imported Duke system model into SPOT and validated model
  - Evaluated reliability improvement and voltage regulation for 3 scenarios
    - Integrated self-healing algorithms with power flow constraints
    - Integrated transactive control algorithm

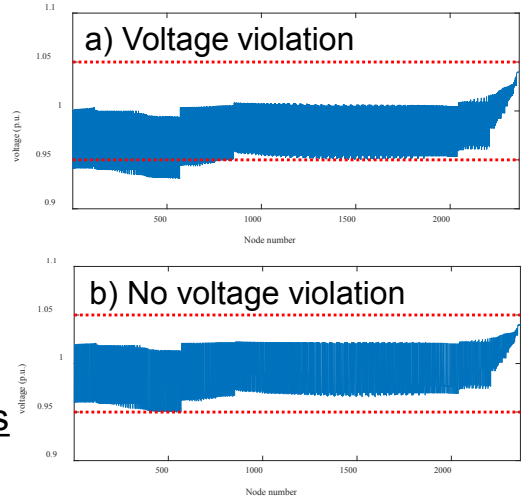

Fig. 1 Voltage profile: a) without transactive control b) with transactive control of reactive power

Table I. Reliability of the whole system

Scenario	SAIFI	SAIDI	% of SAIFI ↓	% of SAIDI ↓
Base case	14.31	59.75	--	--
1	11.46	55.28	19.92%	7.48%
2	11.44	55.18	20.06%	7.65%
3	9.38	43.53	34.45%	27.15%

Table II. Reliability of the critical load

Scenario	SAIFI	SAIDI	% of SAIFI ↓	% of SAIDI ↓
Base case	9.54	31.56	--	--
1	5.00	24.71	47.59%	21.70%
2	4.76	23.58	50.10%	25.29%
3	4.76	23.58	50.10%	25.29%

Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB (Current Hardware)

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OAK RIDGE National Laboratory

OpenFMB Harness

Connected

Pending

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

GE ADMS

UNC CHARLOTTE

Digital Real Time Simulation

Substation/Microgrid RTU: SEL 3555

Recloser RTU
SEL 3505

4G LTE Gateway
Sierra Wireless MP70+

Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB (Plug Fest)

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- Event hosted by UNC-Charlotte 9/24-9/26
  - Day 1: Plenary Session / Vendor presentations at PORTAL building
  - Day 2: Tutorials / Lab / Utility presentations at UNCC ECE building
  - Day 3 morning: OpenFMB interoperablity plugfest demos in UNCC ECE Lab
  - Day 3 afternoon: Microgrid Tour at Mount Holly
- 55 attendees from 25 different companies
- Participants: ABB, Cisco, Eaton, Itron, OES, RTI, SEL, Sierra Wireless, SGS, ORNL, EPRI, UNCC
- Distributed Intelligence Use-cases: Distribution Automation, FLISR, DER Optimization, AMI telemetry, Microgrid State Estimation, Distributed Historian, and Digital Twin.
- 4 utilities in Attendance: Duke, Avista, Entergy, ConEd

- ABB
  - REF615 protection relay (61850 GOOSE native)
  - E-mesh RTU540 / HMI (61850 GOOSE native)
- Cisco Systems
  - IC3000 compute gateway (with OpenFMB Docker container)
  - IE 4010 substation switches
  - IR1101 ruggedized router (Docker capable)
  - Cybervision and Stealthwatch network diagnostics and analytic tools
- Eaton Corporation
  - CL-7 single-phase Voltage regulator (DNP3 native)
- Electric Power Research Institute (EPRI)
  - Photovoltaic (PV) simulator (IEEE 1547 functions, DNP3 native)
- Itron
  - Single-phase Riva Meter (with OpenFMB MQTT adapter)
- Oak Ridge National Laboratory
  - OpenFMB NATS adapter for TyphoonHIL Simulator
  - Digital-twin OpenFMB protobuf profiles for Battery, PV, Switch modules
- Open Energy Solutions
  - Containerized OpenFMB adapter (DNP3/Modbus/GOOSE to NATS/MQTT/ DDS)
  - OpenFMB protobuf message viewers (subscribers on NATS and MQTT message buses)
  - Grafana visualization and displays (via OpenFMB time-series database adapter)
- Real Time Innovations (RTI)
  - DDS publish-subscribe licenses
  - Battery simulator (OpenFMB DDS native)
  - DDS Viewer and HMI
- Schweitzer Engineering Laboratories (SEL)
  - 651R recloser controller (DNP3 native)
  - 735 Revenue Grade meter (MMS native)
  - 700G generator protective relay (MMS native)
  - 3355 industrial computer (with multi-tenant container orchestration and Docker)
  - 3555 RTAC (with OpenFMB NATS adapter and FLISR demo)
- Sierra Wireless
  - MP70+ 4G LTE cellular gateway (with multi-tenant container orchestration and Docker)
- Smarter Grid Solutions
  - DERMS with HMI application (OpenFMB NATS native)
- UNC Charlotte
  - OpenFMB users group plugfest venue host
  - Typhoon HIL 604 real-time grid simulator

Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB