Grid Code Enablement and C-HIL Validation of Distributed Energy Resources with OpenFMB

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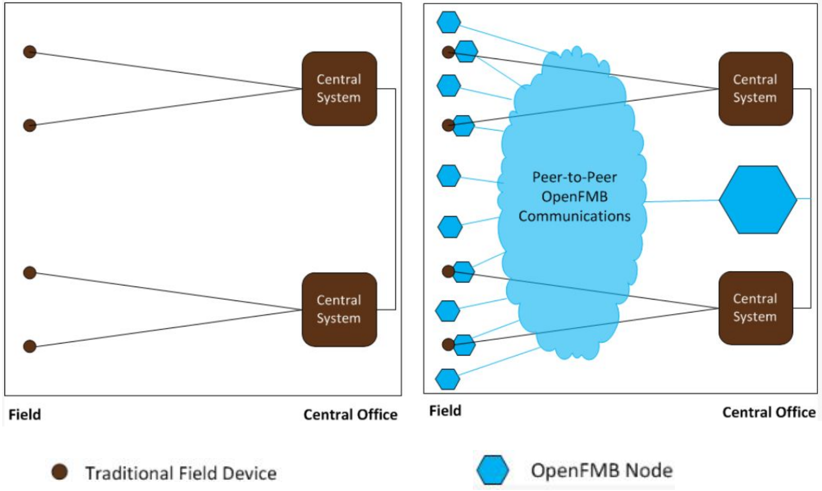
Background

- A major challenge in the DERs integration from an information technology standpoint is the **interoperability**
- Distributed intelligence (DI) allows for effective integration and operation of heterogeneous ecosystem
- To enable DI, a “grid edge integration standard” is implemented in the grid code controller
    - Grid codes data structures for energy storage systems and solar inverters leveraged to showcase interoperability and distributed intelligence
- Leveraging new and existing equipment for a safe and resilient operation of the grid

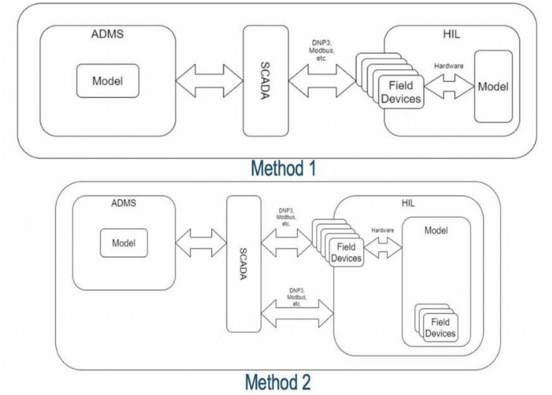


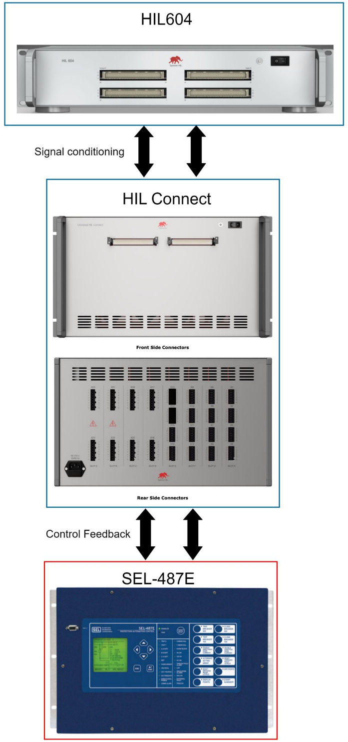
(https://openfmb.ucaiug.org/Pages/Overview.aspx)

Grid Codes: Collection of DER Capabilities and requirements, intended to support the safe and reliable operation of the grid

Duke Emerging Technology Office's Digital Twin Lab

- Leveraging C-HIL to evaluate DERs conforming to the latest IEEE 1547 interconnection requirements
- Simulator: Typhoon HIL 604
- Amplifier: Interfaced with simulator so Current/Voltage/optical I/O interfaces behave as the real power stage signals
- Relays, Voltage Regulators, Inverter Controllers





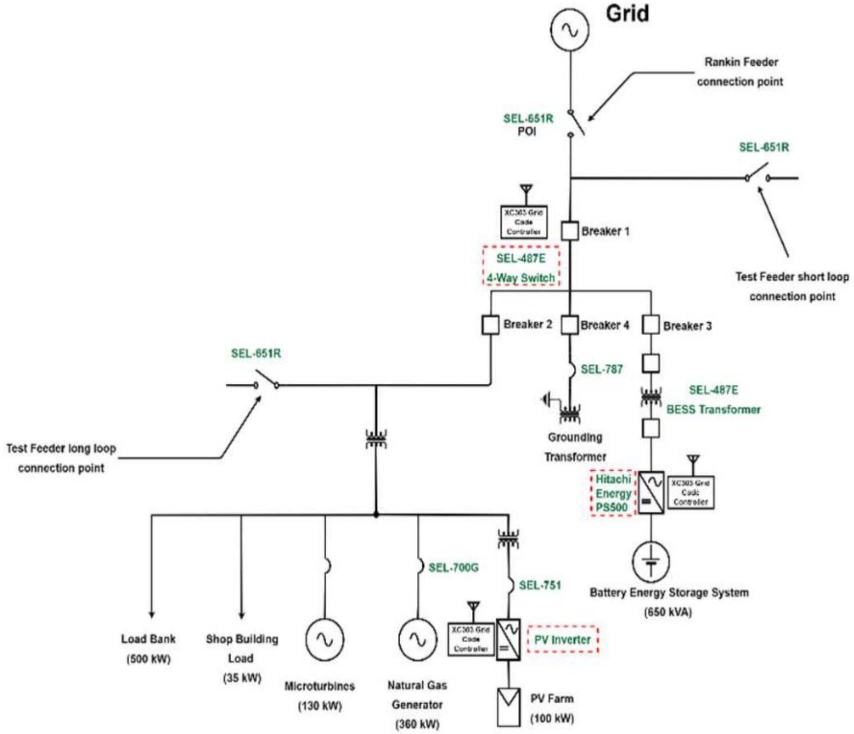
Controller-Hardware in the Loop (C-HIL): Allows the testing of Intelligent Electronic devices (IEDs) with less risk to equipment and safety

- Flexibility to utilize physical device controllers, simulated models, and digital interfacing components to perform various tests in **real time** with **high accuracy**.

IEEE 1547: Standards related to performance, operations and testing of interconnections between utility grid and DERs

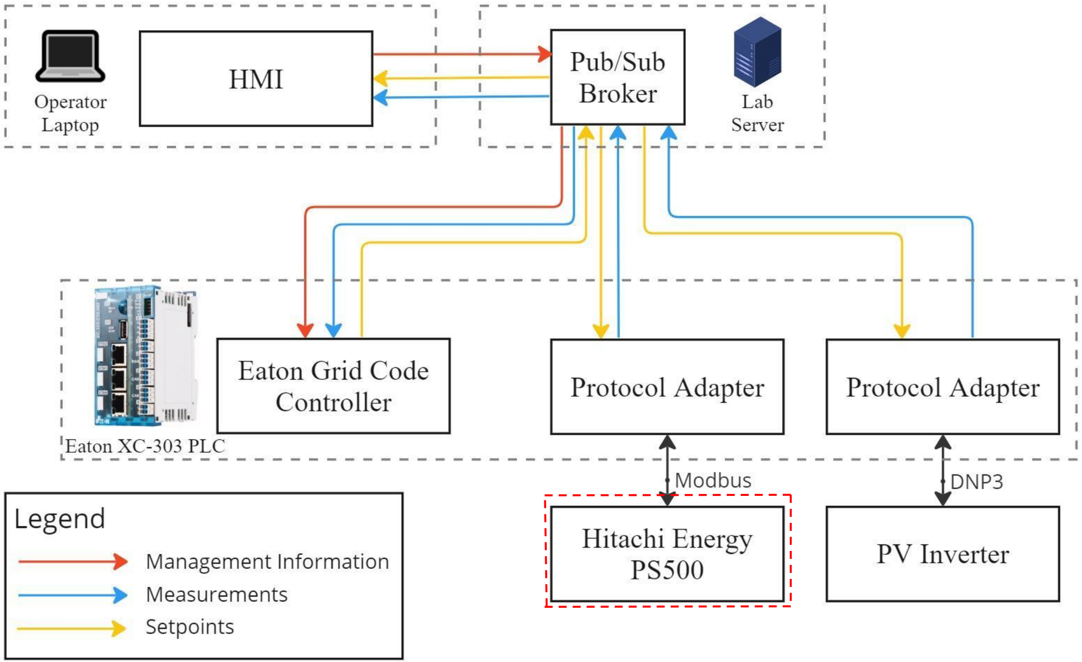
Power System Model

- 12.47 kV distribution feeders connected to the Mt. Holly Microgrid
- 4-Breaker Switchgear
  - Breaker 1: Synch Check
- DER models
  - Battery and PV inverter
- OpenFMB nodes are located at the antenna symbols (next to the red boxes)



Control Setup and Gateway

- Communication diagram showing OpenFMB messages
- OpenFMB adapter reads measurement values from the BESS (Modbus) and PV inverter (DNP3) and publishes the values as OpenFMB messages to a NATS publish-subscribe message broker
- HMI is the interface to configure different schedules and receive measurements



Open Field Message Bus (OpenFMB): Communication framework allowing interoperability between different vendor devices

- Ratified by the North American Energy Standards Board (NAESB) in 2016

Setup: Driving the EPC inverter

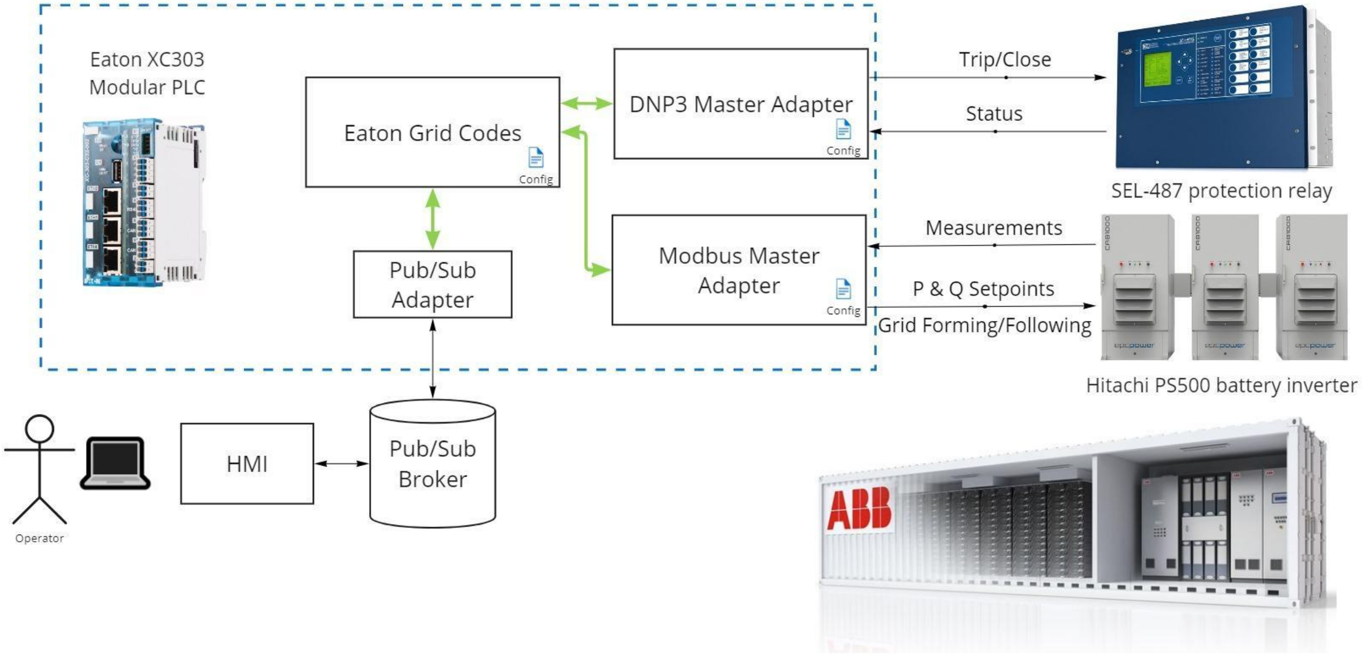


ABB PowerStore BESS

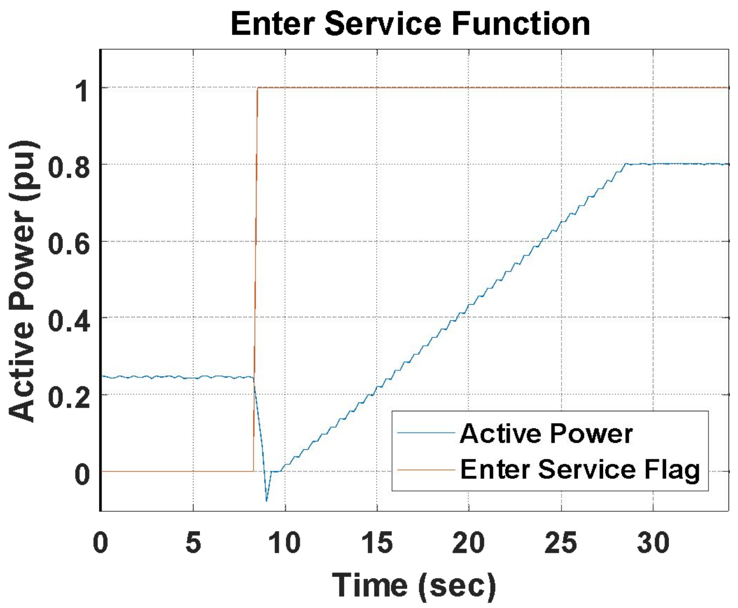
Tests Performed

- Enter Service
- Volt-Var
- Hz-Watt

Enter Service Test Results

Grid Code Controller driving DER Enter Service Function

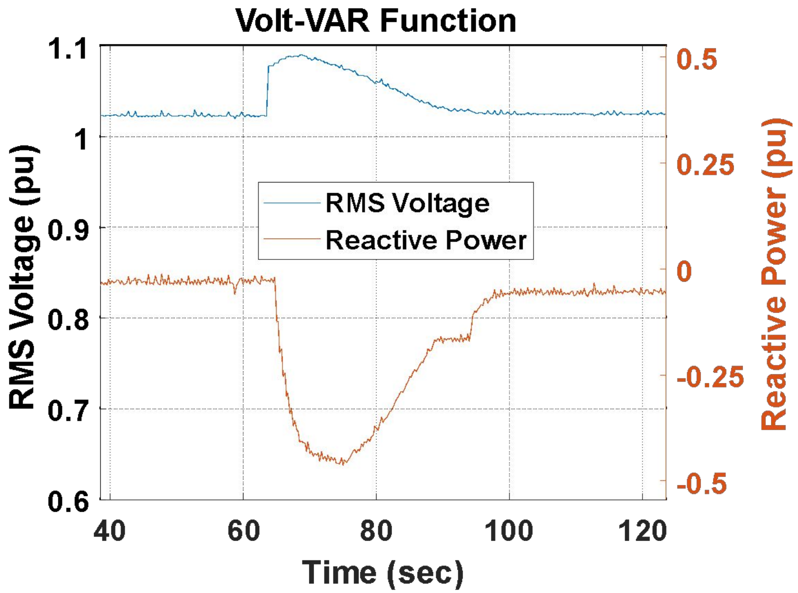
- Enter service at time = 8 seconds (red curve)
- Configured active power ramped up rate = 0.04 pu/s (blue curve)
- Configured steady value = 0.8 pu reached at time = 28 seconds
- Prior to the enter service, the unit was acting as a grid forming unit with an active power delivery of 0.22 pu



Volt-Var Test Results

Volt-Var Enabled by Grid Code Controller through OpenFMB

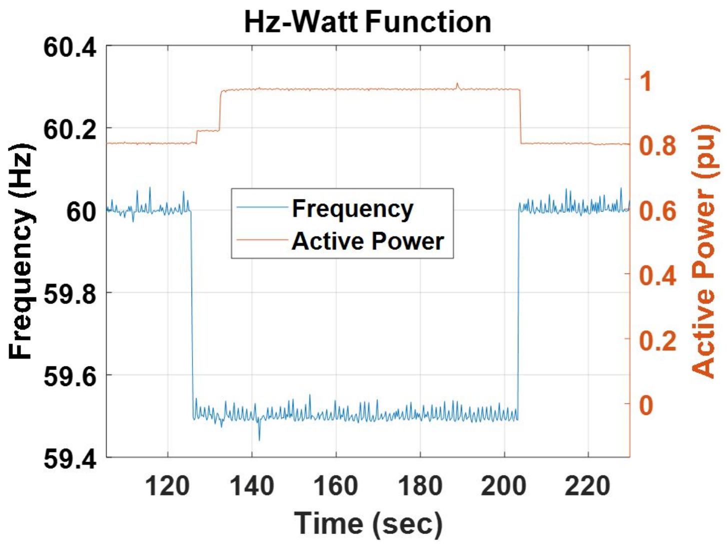
- Overvoltage of 0.1 pu occurring at time = 65 seconds (blue curve)
- The reactive power decreased from 0 pu down to nearly -0.5 pu following an open-loop response time of 5 seconds (red curve)
- Voltage regulators bring the the voltage back and hence reduce the reactive power absorption back to -0.05 pu



Hz-Watt Test Results

Hz-Watt Enabled by Grid Code Controller through OpenFMB

- Frequency dip of 0.5 Hz applied at time = 125 seconds (blue curve) resulting in an increase in active power to 0.95 pu as per the Hz-Watt characteristic with an open-loop response time of 5 seconds (red curve)
- Active power drops back to 0.8 pu after the frequency recovered at time = 203 seconds



Conclusions

- The Grid code controller was developed to satisfy IEEE 1547-2018 standards which provides “performance, operation, testing, safety considerations, and maintenance of interconnections.”
- The implementation of the OpenFMB communication framework allows devices with different protocols to communicate and make distribution level decisions.
- The architecture presented enhances legacy DERs by adding grid code functionality, adhering to IEEE 1547-2018.
- Real-time simulation enabled by the Duke ETO Digital Twin testbed allowed OES and Eaton to perform testing

Grid support functions enabled using DI providing a Path to DER integration in a resilient and reliable grid

Acknowledgements

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