POWER HARDWARE-IN-THE-LOOP INTERFACING OF GRID-FORMING INVERTER FOR MICROGRID ISLANDING STUDIES

ALEJANDRO AVENDAÑO CECEÑA

PACIFIC GAS AND ELECTRIC COMPANY

2023 NORTH AMERICAN RTDS APPLICATIONS & TECHNOLOGY CONFERENCE

ABOUT APPLIED TECHNOLOGY SERVICES (ATS)

Located at PG&E’s San Ramon Technology Center

9

Primary Technical Disciplines

~120

Engineers, Scientists, and Technicians

40+ Years Serving PG&E

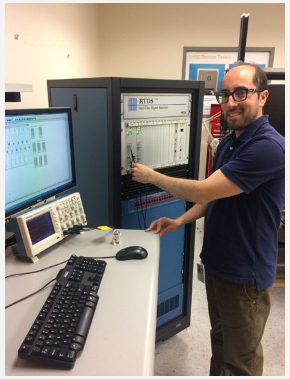
ATS ELECTRIC TESTING LABS

High Voltage Dome
T&D equipment testing up to 720 kV

High Current Yard (HCY)
T&D equipment testing up to 90,000 A
(9,000A at distribution voltage)

Distributed Gen. Test Yard (DGTY)
DER testing up to 2500 kVA

Power System Control
Hardware Test Lab
Communication and
controller testing

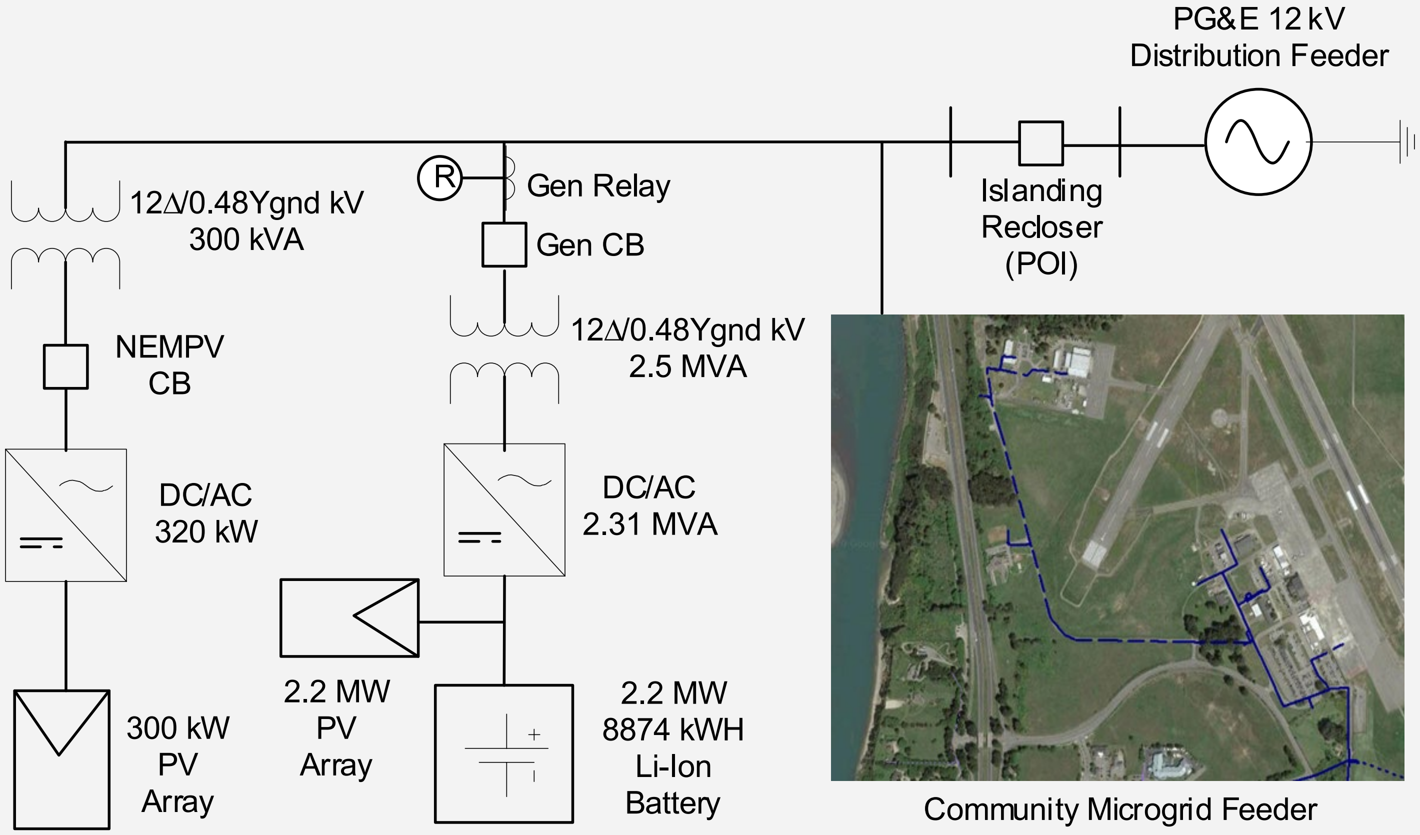


Modular Generation Test Facility (MGTF)
DER testing up to 500 kVA

Distribution Test Yard (DTY)
Distribution hardware and
automation testing

FIRST MULTI-CUSTOMER MICROGRID FOR ENHANCED RELIABILITY & RESILIENCE: ARCATA-EUREKA AIRPORT

- 100% renewable energy
- 2.2 MW PV
- 2.2 MW BESS
- 300 kW NEM PV
- 340 kW load (Airport, U.S. Coast Guard, animal shelter)
- PG&E owned 12-kV, 3-wire ungrounded feeder



Community Microgrid Feeder

PG&E'S APPLIED TECHNOLOGY SERVICES (ATS) ROLE

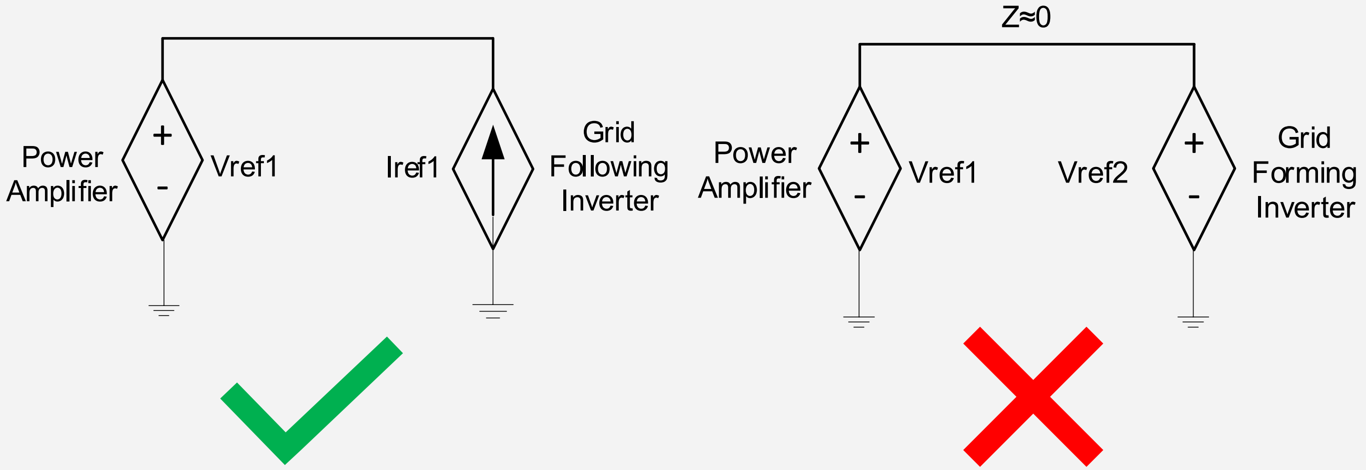
A. **Confirm the correct execution of microgrid control sequences**
    - Microgrid dispatches and PG&E constraint limits
    - Automatic and manual transitions between grid-connected and islanded states
    - BESS State of charge related functions
B. **Evaluate the stability of the microgrid for various modes of operation**
    - Microgrid voltage and frequency regulation
    - Seamless and break-before-make transitions
C. **Validate relay protection settings**
    - Grid voltage and frequency fluctuations
    - Line-to-ground (LG), three-phase (3P), line-to-line (LL), and line-to-line-to-ground (LLG)
        - Faults internal and external to the microgrid
        - Customer generation zone Faults

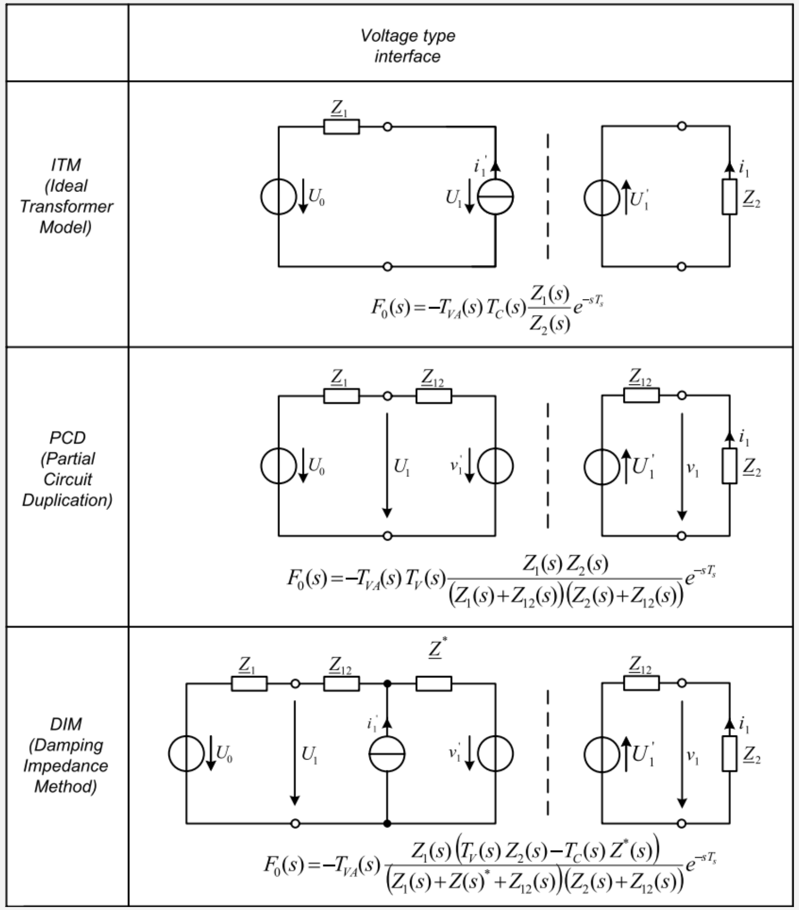
POWER HARDWARE-IN-THE-LOOP TESTBED

- Designed to support evaluation of control and power hardware to be deployed as part of the Redwood Coast Airport Microgrid (RCAM)
- Enables real-time simulation of RCAM and PG&E distribution feeder under different operating scenarios
- Incorporates Power Hardware-in-the-Loop (PHIL) interface of 57-kW Tesla BESS and 60-kW CPS solar inverter
- Incorporates Controller Hardware-in-the-Loop (CHIL) interface of protective relays and microgrid controllers

CHALLENGES INTERFACING A GRID-FORMING BESS

- Lack of literature on this topic
- Interface algorithm must allow seamless transitions between microgrid operating modes
- Power amplifier only allowed voltage-control mode
- BESS inverter output impedance was unknown
- How to scale the device under test?

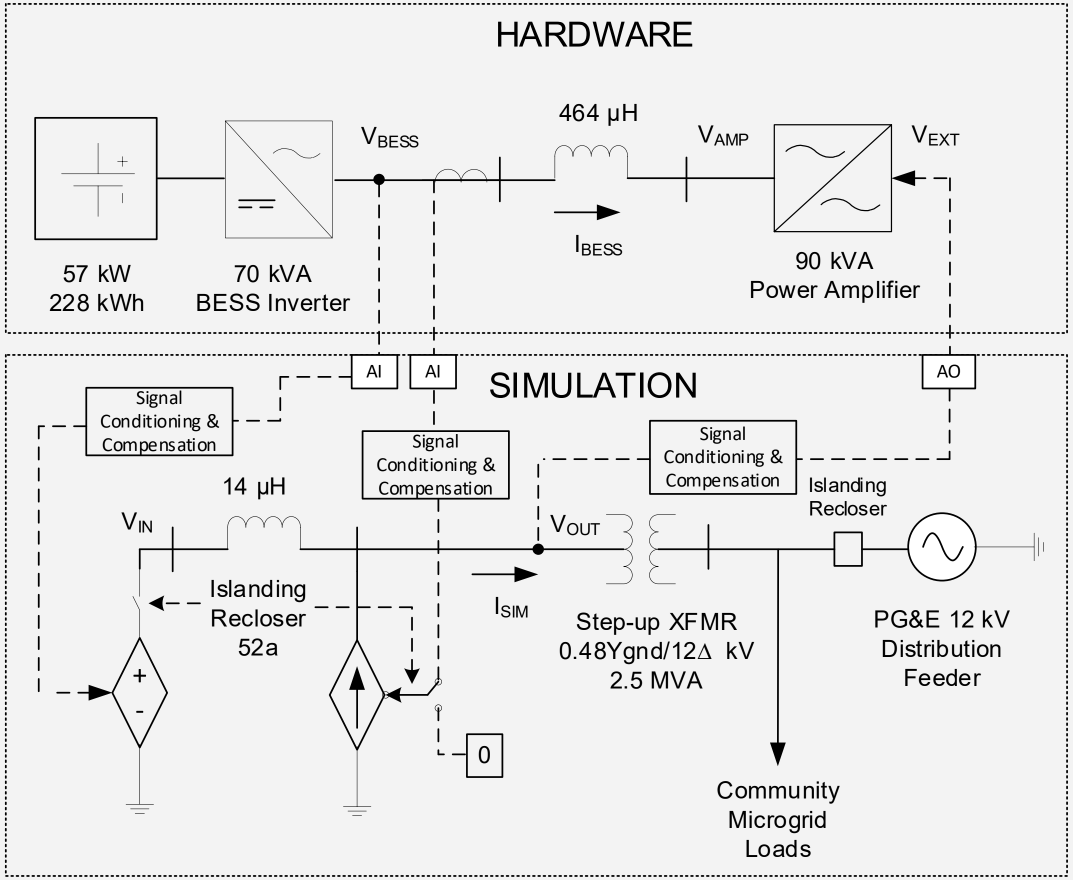




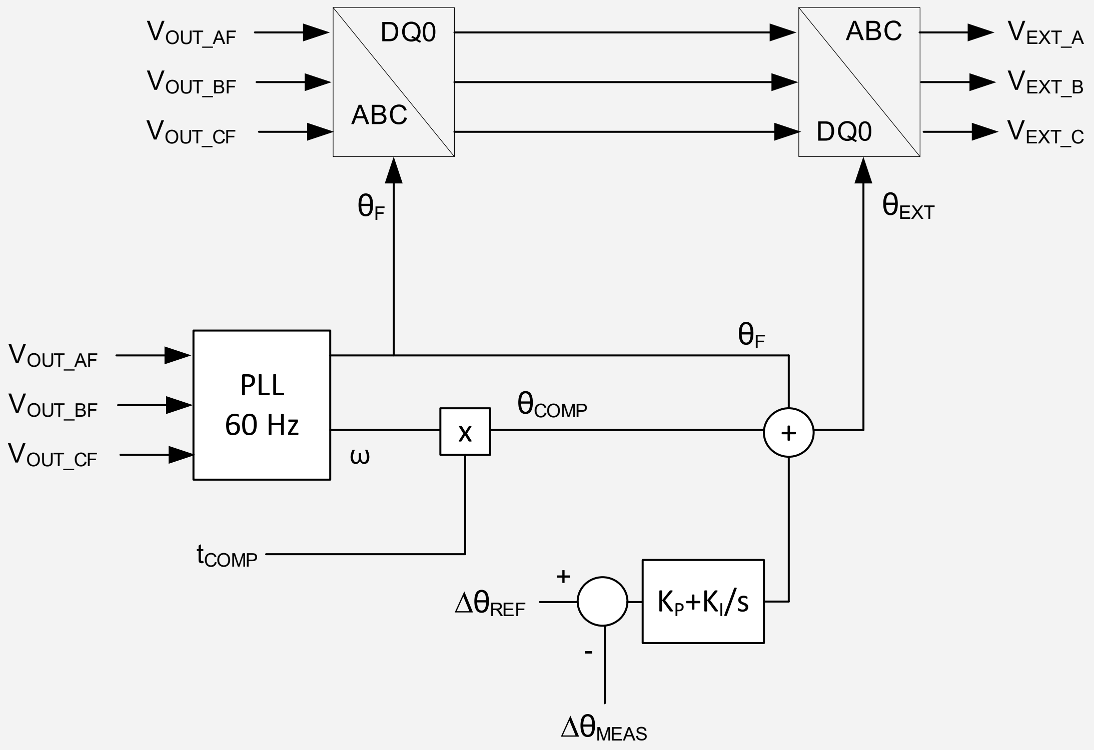
Ref: Interface Topologies for PHIL Simulation [1].

APPROACH: HYBRID INTERFACE ALGORITHM

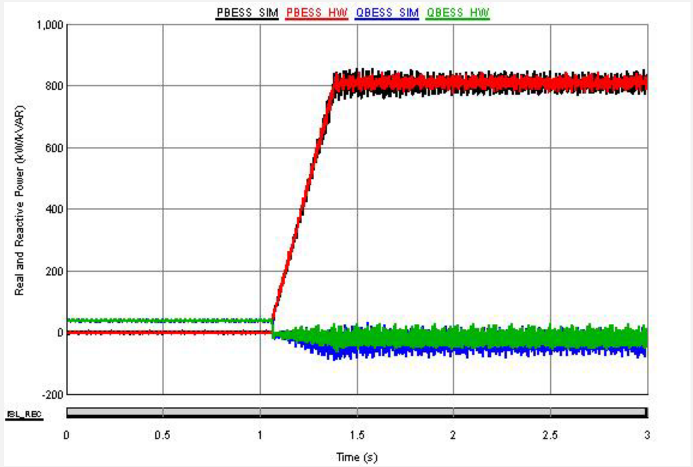
- Use Partial Circuit Duplication (PCD) during grid-forming operation
- Use Ideal Transformer Model (ITM) for grid-connected cases
- Switching of IA based on Islanding Recloser status
- Maximized accuracy while connected to the stiff power grid
- Maximized stability during islanding
- Allowed reproducing the correct behavior of the BESS as either a current source or a voltage source



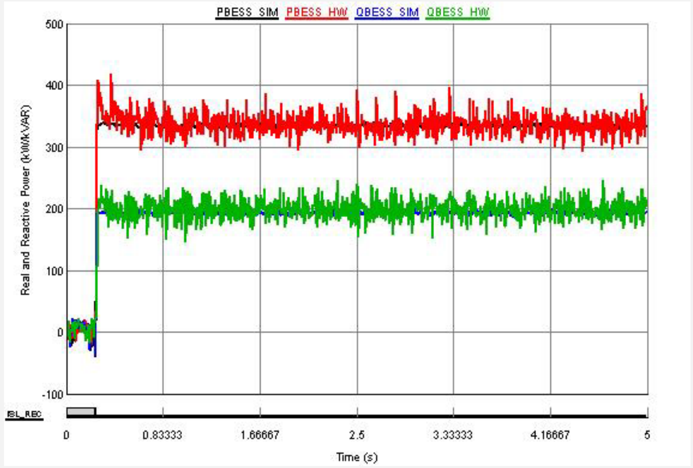
ACCURACY AND COMPENSATED RESPONSE



800 kW Dispatch (Grid-Connected)

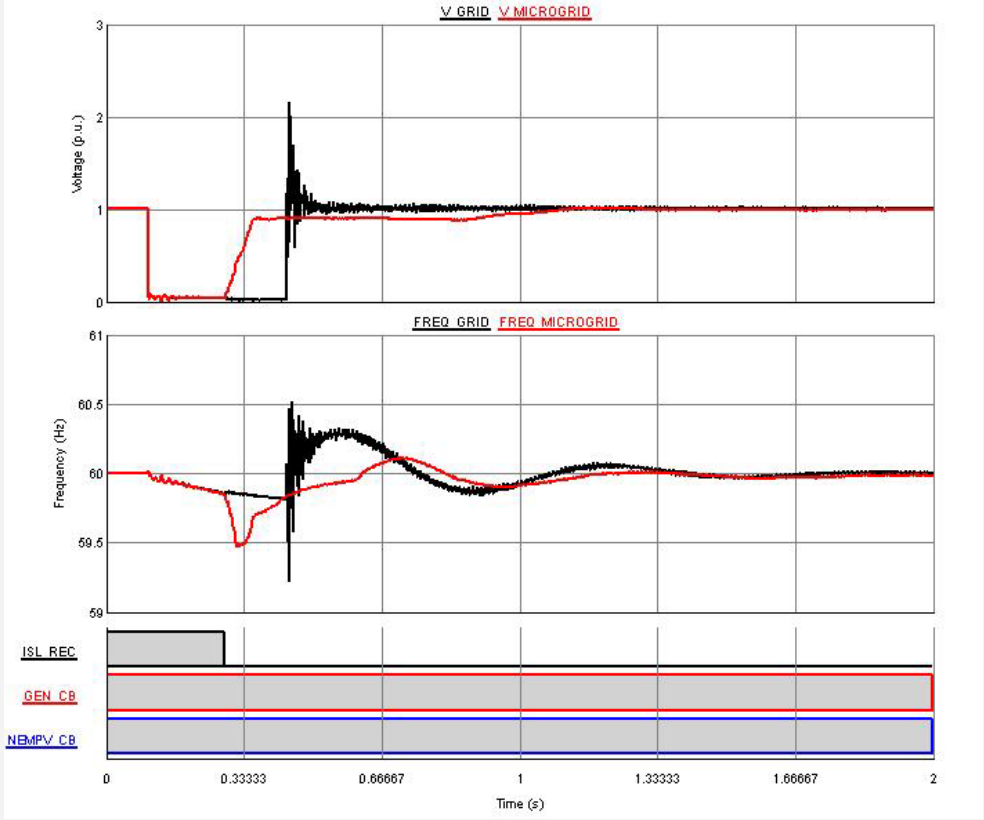


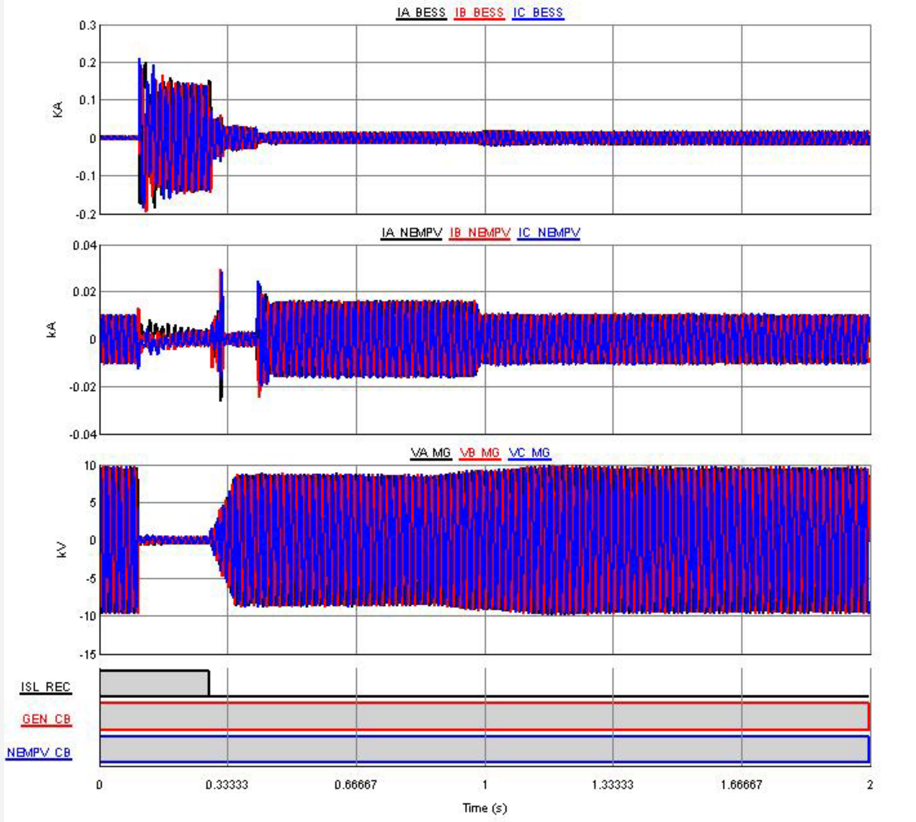
Islanding Transitio
n



TESTING

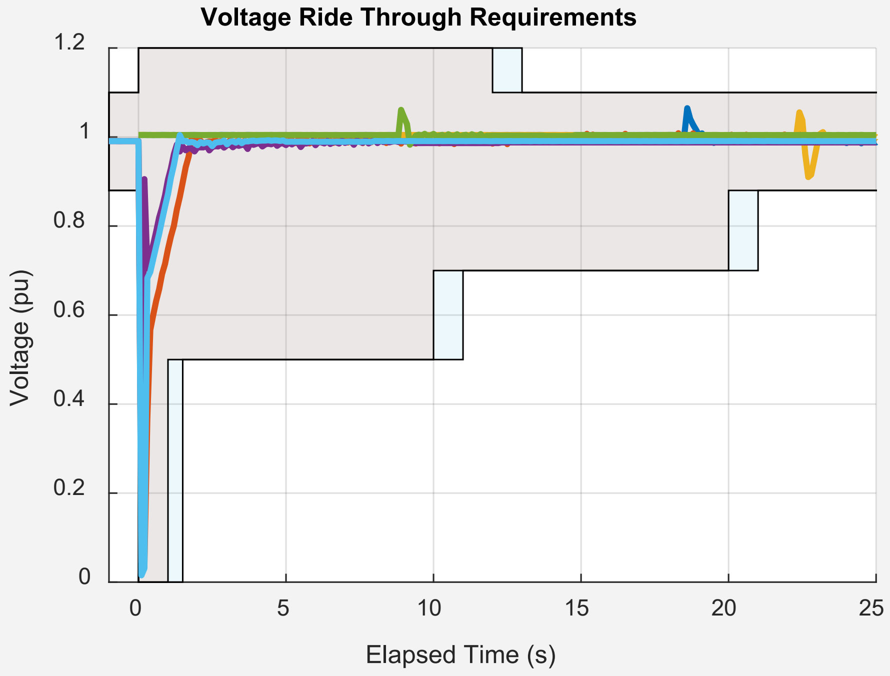
Grid-Connected Fault Detection – 3P External Fault

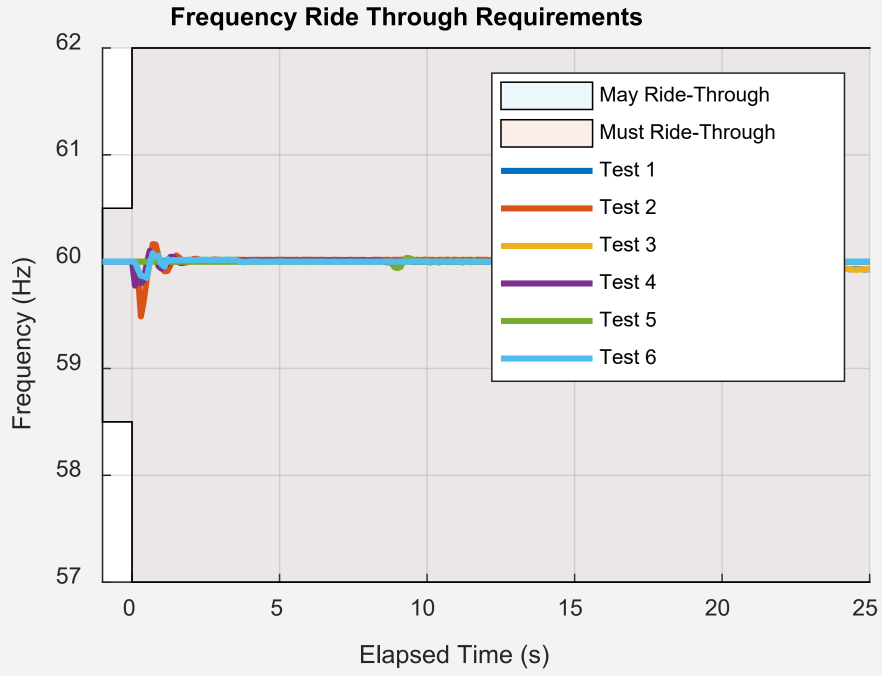




TESTING

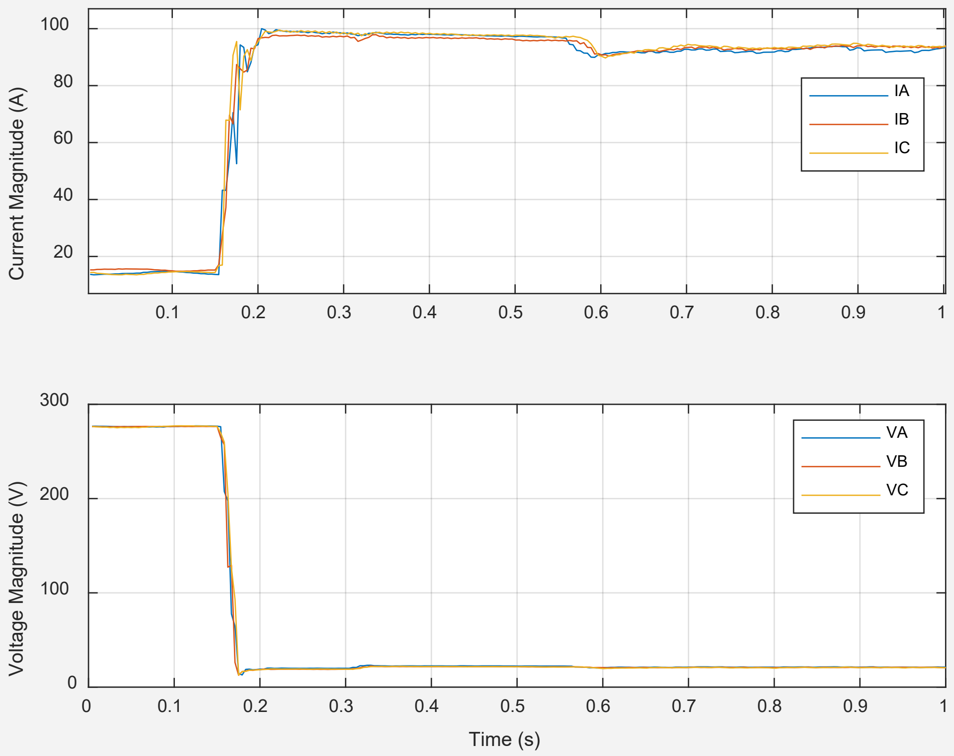
Voltage and Frequency Profiles with CA Rule 21 Grid Code





BESS FAULT CURRENT CONTRIBUTION

3-Phase Fault on Microgrid



BESS Fault Current Characterization

Test	BESS Current (p.u.)			BESS Sequence Currents (p.u.)		
	IA	IB	IC	I1	I2	I0
AG Fault	≈ 0 (ungrounded system)					
3P Fault	1.17	1.16	1.17	1.17	≈ 0	≈ 0
BC Fault	1.07	1.2	1.16	0.83	0.63	0.46
BCG Fault	1.24	1.23	1.2	0.91	0.63	0.52

REFERENCES

1. G. F. Lauss, M. O. Faruque, K. Schoder, C. Dufour, A. Viehweider, and J. Langston, "Characteristics and design of power hardware-in-the-loop simulations for electrical power systems," IEEE Trans. Industrial Electronics, vol. 63, no. 1, pp. 406-417, Jan. 2016.
2. A. Avendaño, "Power hardware-in-the-loop interfacing of grid-forming inverter for microgrid islanding studies", in *Proc. 2023 IEEE Power and Energy Society Innovative Smart Grid Technologies (ISGT) Conference*. Link: Power Hardware-in-the-Loop Interfacing of Grid-Forming Inverter for Microgrid Islanding Studies

QUESTIONS?

Alejandro Avendaño Eceña
Applied Technology Services
Pacific Gas and Electric Company
San Ramon, USA
alejandro.avendanocecena@pge.com