



GFM Specification and Testing

ESIG Spring Technical Workshop

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Tucson, Arizona

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ELECTRANIX

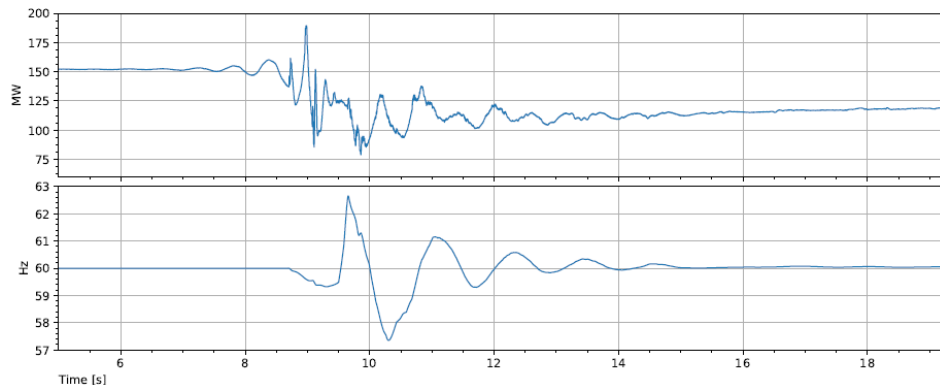
SPECIALISTS IN POWER SYSTEM STUDIES

Acknowledgements and Disclaimer

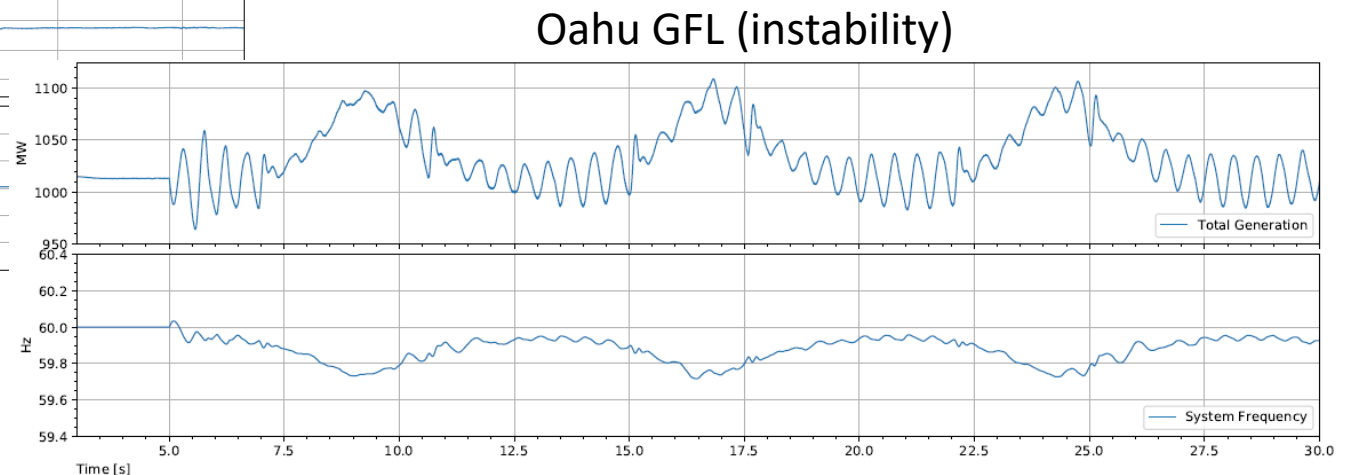
- Electranix has acquired significant GFM experience through:
 - extensive work in HECO/HELCO/MECO systems, with critical support from Interconnection Services, Transmission Planning, and System Operations
 - involvement in NERC IRPS groups
 - A range of other recent GFM projects in the US and Australia
- The views and opinions expressed here are those of Electranix

Introduction

- Instantaneous inverter-based generation pushing above 75% in several small and medium sized grids
- The trend to penetration levels near 100% is driving need for GFM
- Hawaii near-term planning cases show system instability without GFM



Maui GFL (instability followed by UFLS)



Oahu GFL (instability)

Introduction

- GFM requirements, *at a minimum*, seek to confirm:
 - Near-constant internal voltage phasor in the sub-transient to transient time frame
 - Synchronism with other devices
 - Regulate active and reactive power appropriately to support the grid
- Many other requirements / capabilities have been proposed by UNIFI, GB, HECO
- Lots of guidance on GFM specification exists, very little on how to test GFM specifications



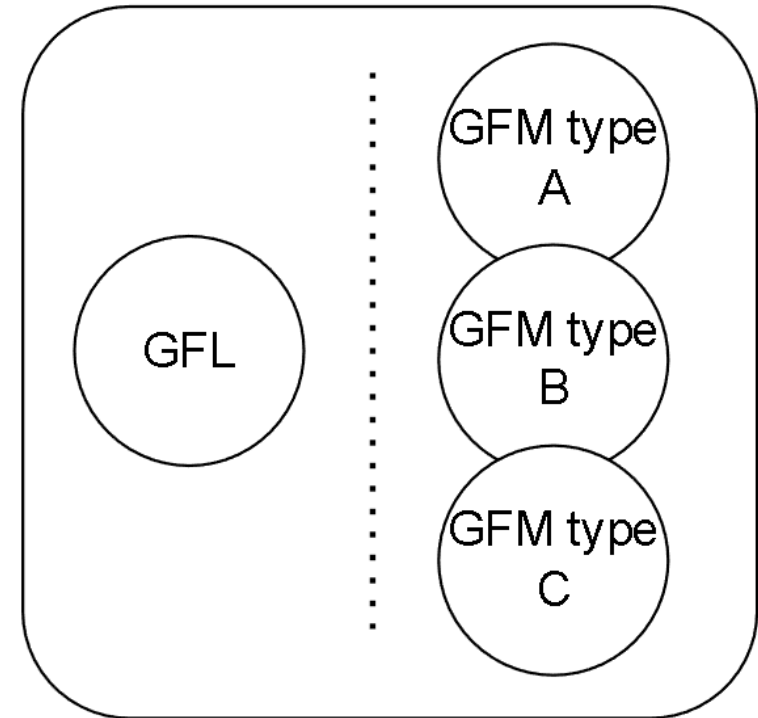
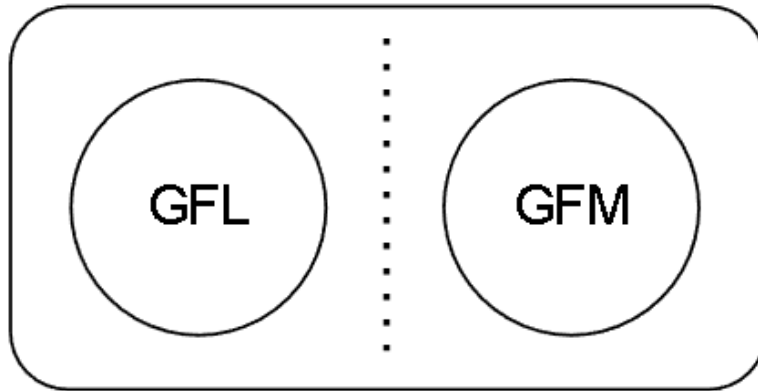
[1] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_Grid_Forming_Technology.pdf

How is GFM functionally defined?

- Method 1: Specify theoretical behavior of device only by reference to known control topologies (“Virtual Synchronous Machine”, “Droop-Based”) **Not recommended**
- Method 2: Define GFM by expected dynamic P, Q response (rise time, magnitude, etc.) resulting from changes in grid voltage magnitude, frequency, phase angle, and test accordingly
- Method 3: GFM controls have signature responses to perturbations at various frequencies. This could be leveraged to determine GFM functionality (research ongoing)
- Method 4: Observe performance of device in response to certain well-defined tests which only GFM inverters can pass, such as continuation of stable operation when last synchronous machine is lost

How is GFM functionally defined?

- Method of definition may depend on how many categories of GFM are assumed



HECO Approach

- All new BESS plants required to be GFM
- Non-BESS IBR plants not prohibited from being GFM

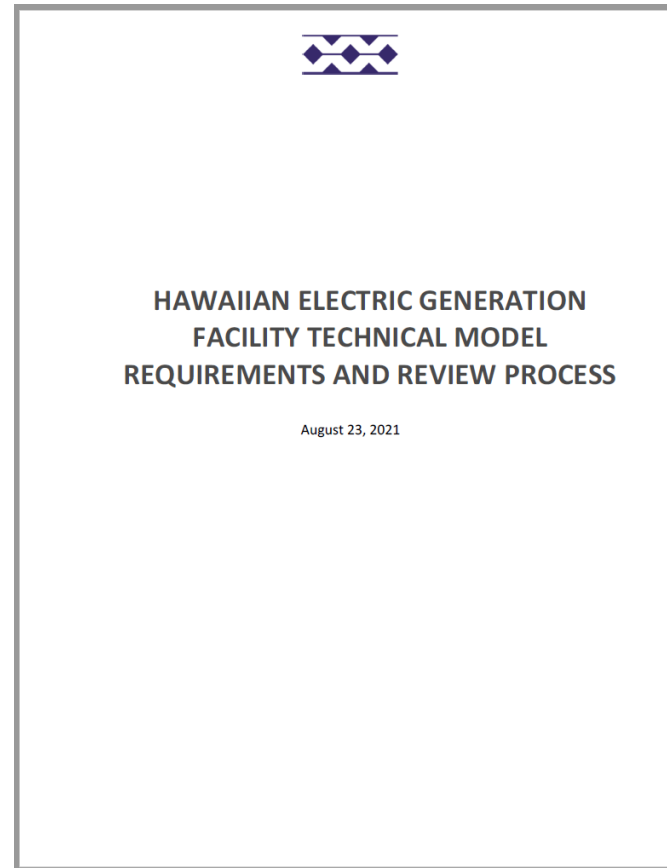


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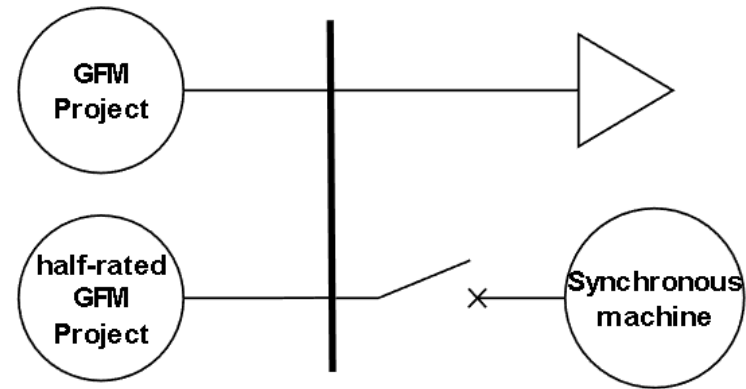
HECO Approach

- GFL and GFM plants tested for initialization, voltage / frequency / fault ride-through
- Extra GFM-only pass/fail tests to confirm GFM capability:

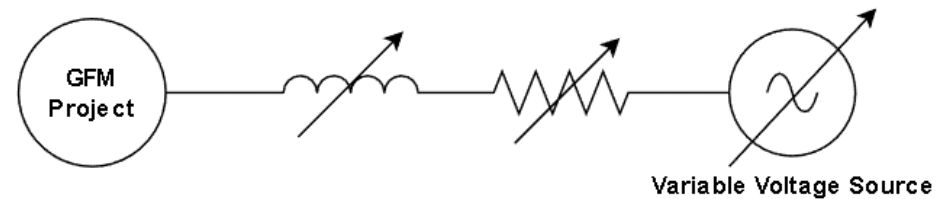
Test	Description	Success Criteria
1: Loss of Last Synchronous Machine (LLSM)	Start with project, project duplicate, load, and synchronous machine. Trip machine	Voltage and frequency remain stable throughout, settling according to droop curves
2: Weak Grid operation	Start with project and variable-strength system equivalent. Reduce system strength until project is unstable	
3: Ability to operate in harmony with other IBRs and machines	Start with same setup as (1). Test load step changes, fault ride-through	
4: Ability to black start (only if applicable for the project)	Energize plant from project side. Connect to load. Connect to grid.	

HECO Approach

- Test system for 1 & 3:

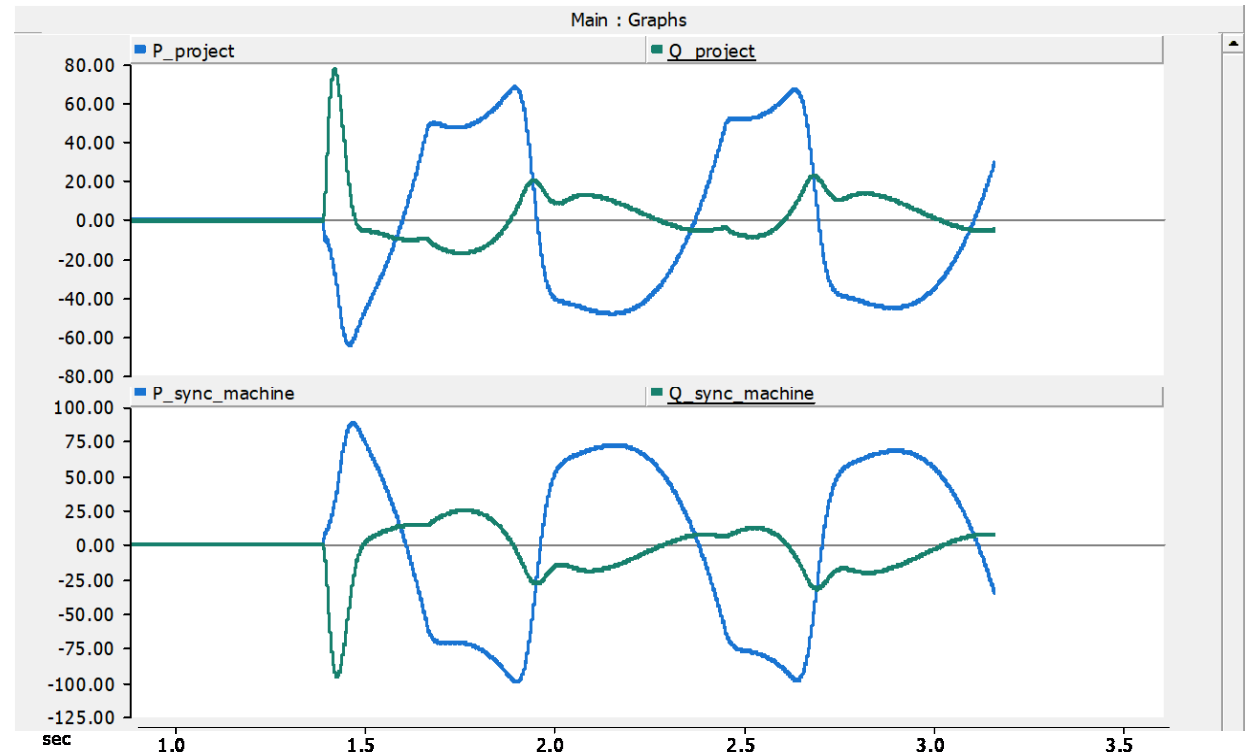


- Test system for 2 & 4:



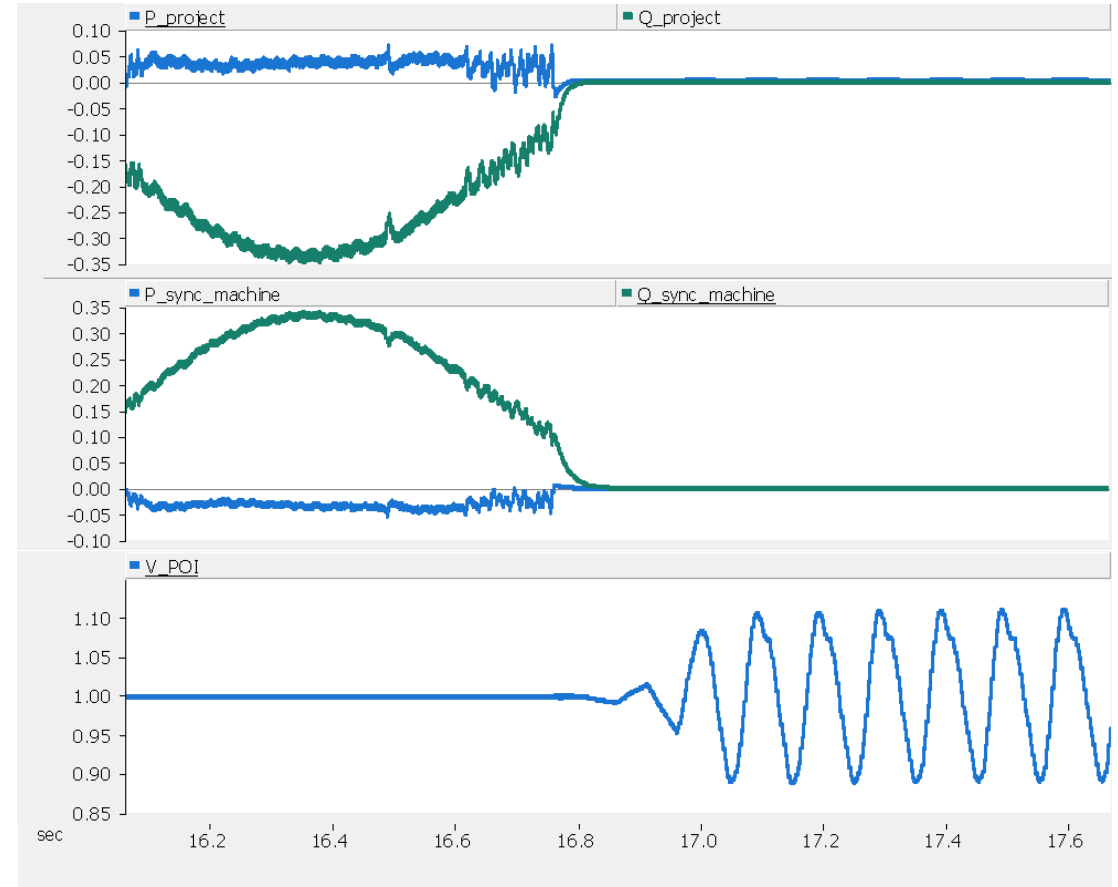
HECO Testing Examples: no P-F droop

- GFM model unable to operate in parallel with synchronous machine
- This inverter did not have frequency-droop capability
- Unclear understanding of GFM expectations



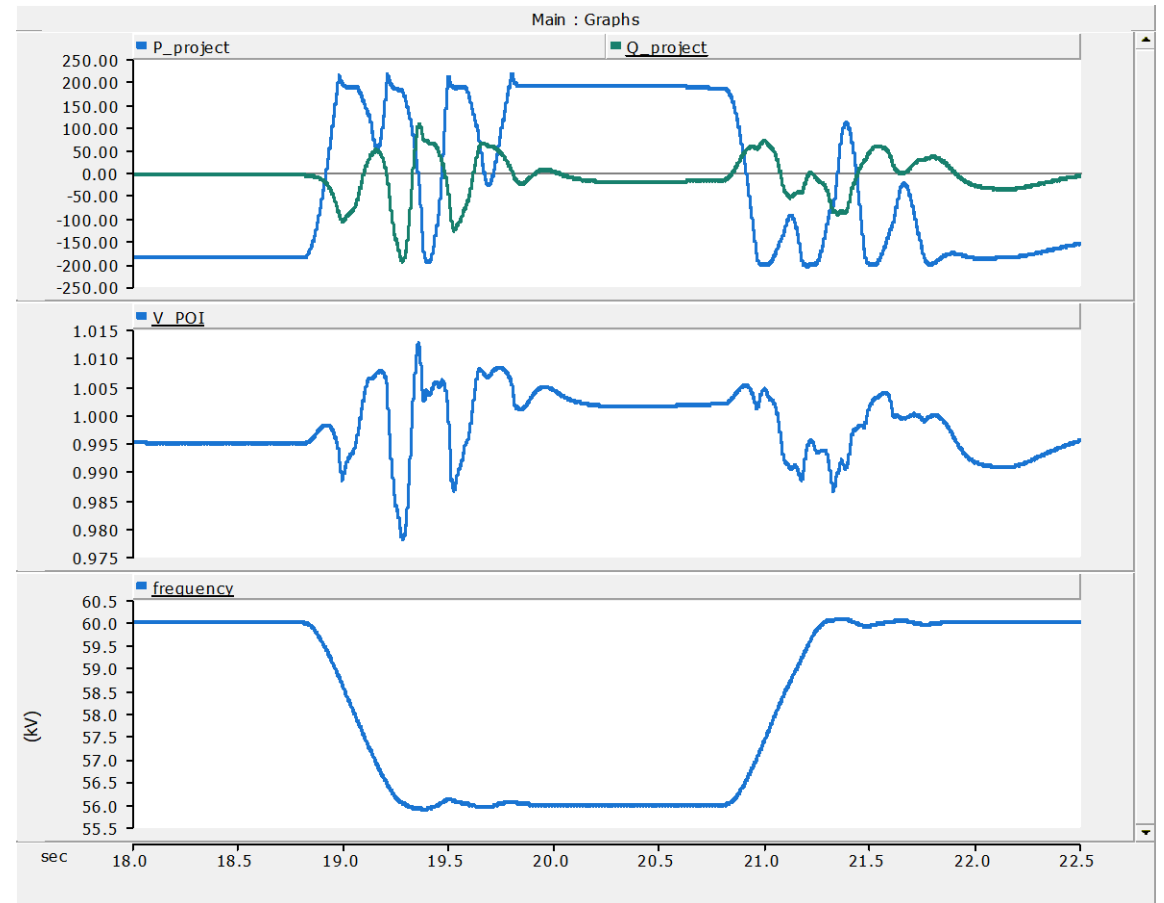
HECO Testing Examples: no-load oscillations

- Oscillations when plant operates in isolation with no load, or when operating in very low SCR
- Mitigated by reducing voltage control gain



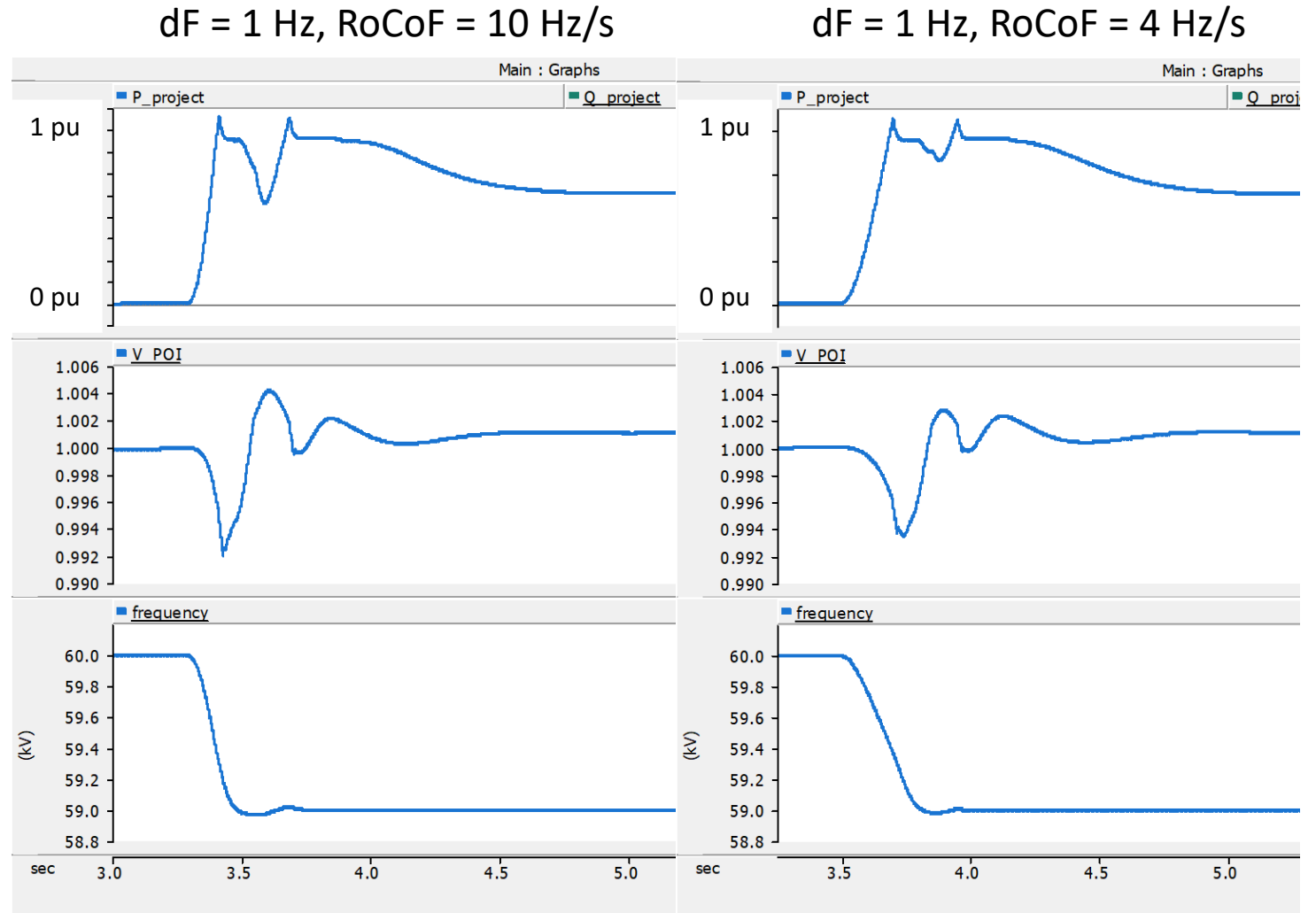
HECO Testing Examples: high RoCoF instability

- RoCoF checked incidentally during frequency ride-through test
- GFMs have sensitivity to RoCoF. High RoCoF with large ΔF can be unstable



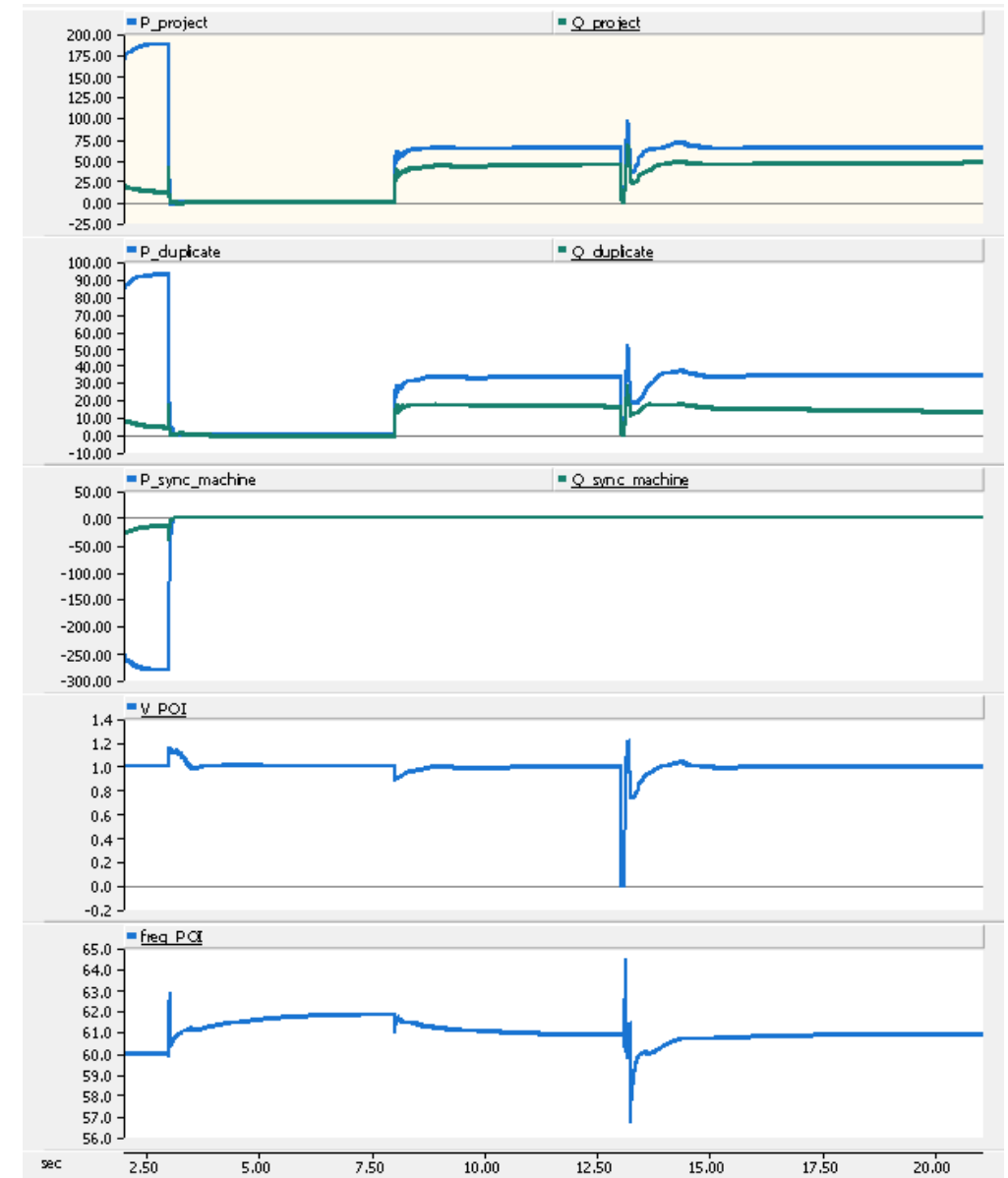
HECO Testing Examples: high RoCoF instability

- Behaviour was acceptable for smaller delta-F and improves further with lower RoCoC



HECO Testing Examples: Pass

- Survives loss of last synchronous machine (3s), initially no-load
- Shares load step-up with project duplicate (8s)
- Rides-through fault (13s)
- Success!

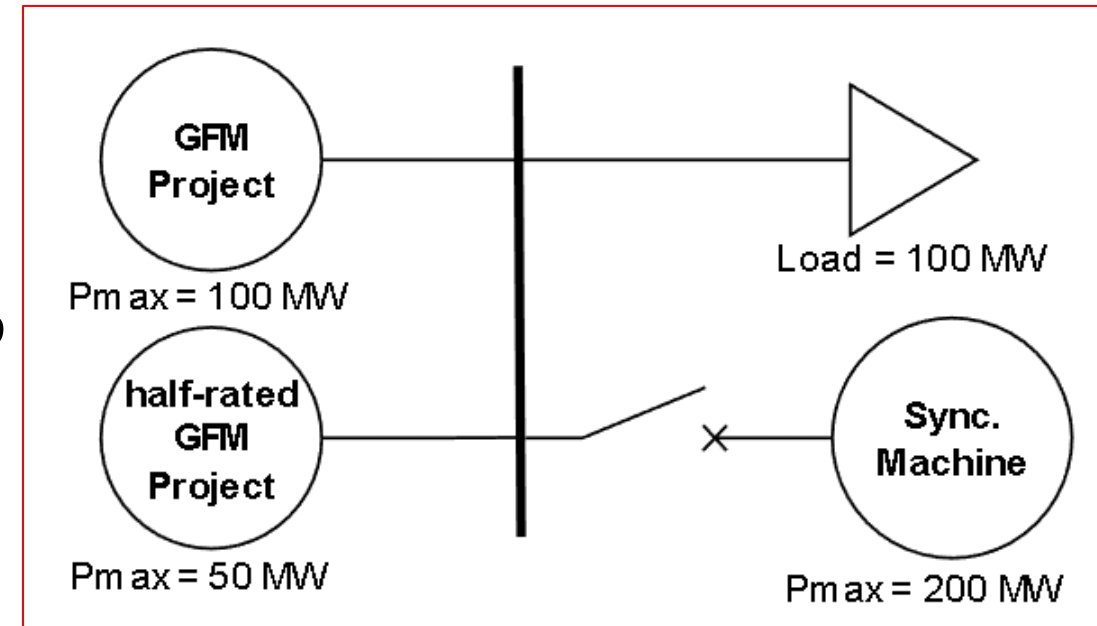


Upcoming NERC guide

- Upcoming guide to help specify GFM as part of interconnection requirements. In draft form, has not yet been publicly circulated
- Recommends Loss of Last Synchronous Machine (LLSM) to determine GFM
- Other tests left out because capabilities should be expected of new GFL devices as well. GFL is not likely to be able to pass LLSM test.
- LLSM test covers core GFM functionalities:
 - Fast Voltage & Frequency control
 - Phase jump
 - System strength
 - Seamless transition from grid-connected to islanded
 - Real/Reactive power sharing between devices
 - Evaluate Inertia?

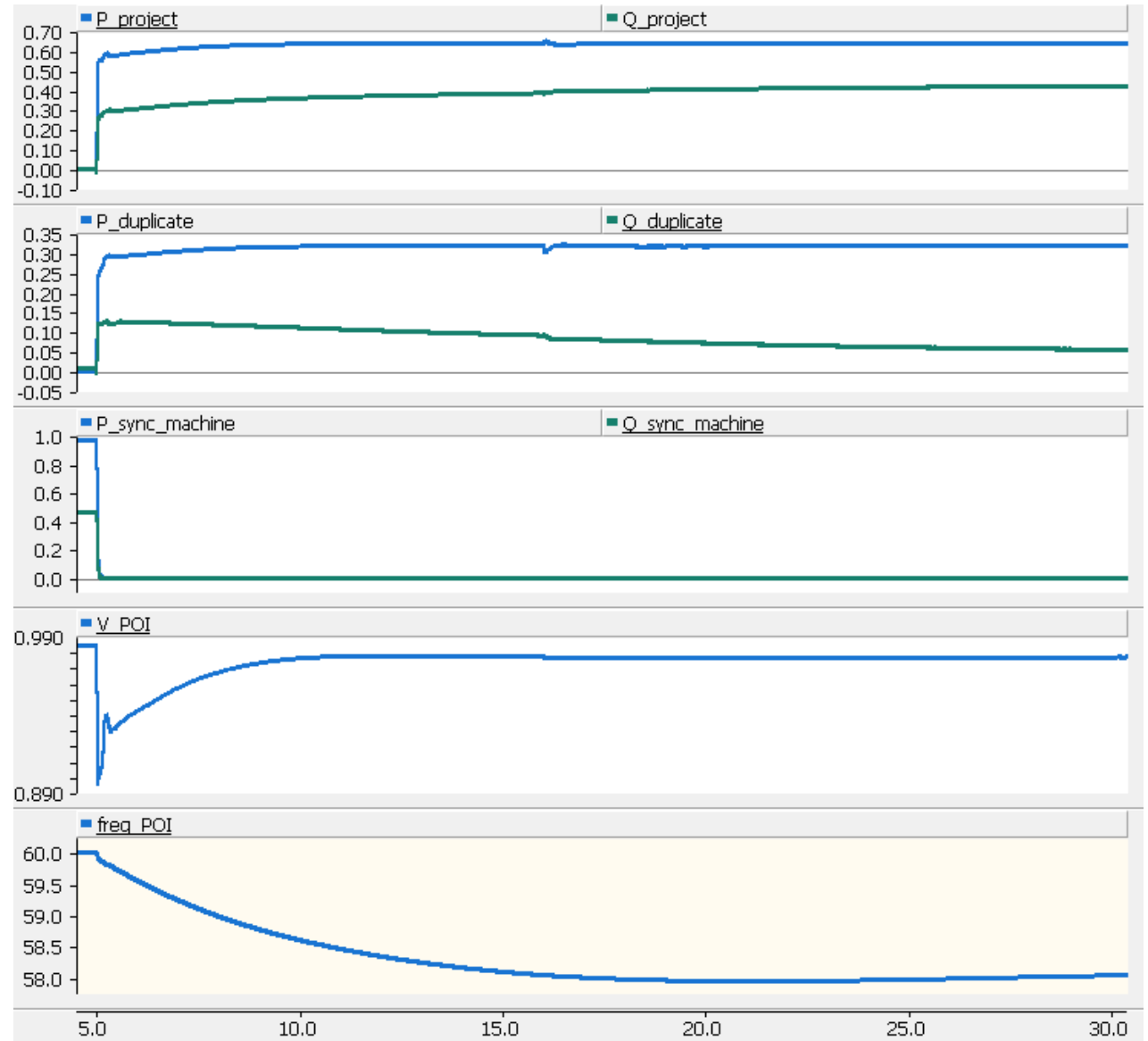
Loss of Last Synchronous Machine Testing

- Studied event is trip of Synchronous
- Three initial dispatches considered, so that GFM BESS transition from:
 - 1: Discharging -> High Discharging
 - 2: Charging -> Discharging
 - 3: Discharging -> High Discharging, one BESS initially @ P_{max} (limit test)
- Some things may need relaxing for purpose of test (voltage control gains, frequency protection settings).
- This is initial SMIB-type testing. System impact study is still needed



Example LLSM

- Phase jump power
- Strong resistance to RoCoF
- Power sharing



Key Messages

- Basic GFM controls in BESS has huge potential for grid reliability
- Specification of basic GFM can be straightforward using a test-based approach
- Can be agnostic to control topology
- Are we past chicken-and-egg?



Questions?

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