GFM Specification and Testing

ESIG Spring Technical Workshop

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Tucson, Arizona

Presented by Lukas Unruh

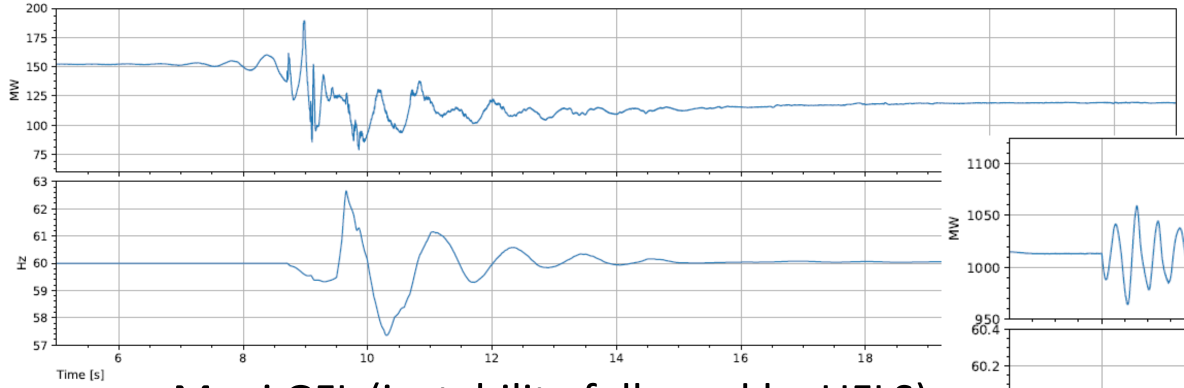
Acknowledgements and Disclaimer

- 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

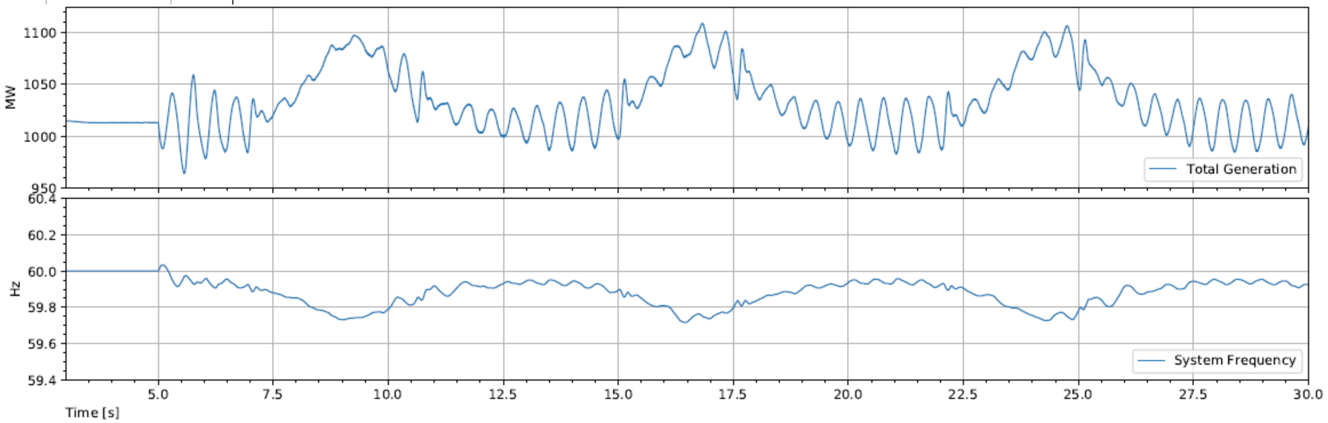
Introduction

- 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


NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Grid Forming Technology
Bulk Power System Reliability Considerations

December 2021

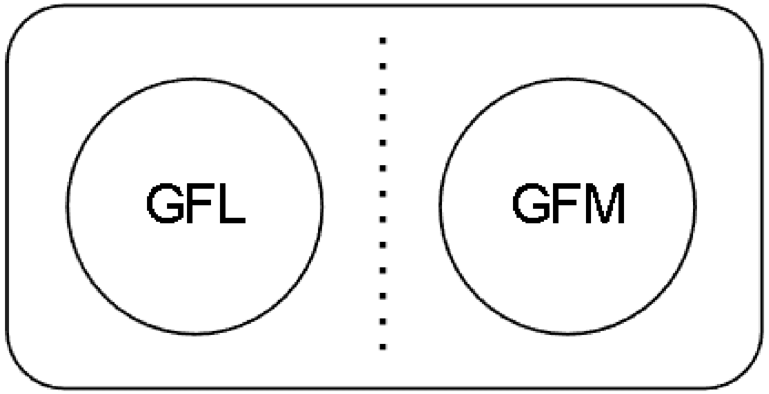
[1] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_Grid_Forming_Technology.pdf

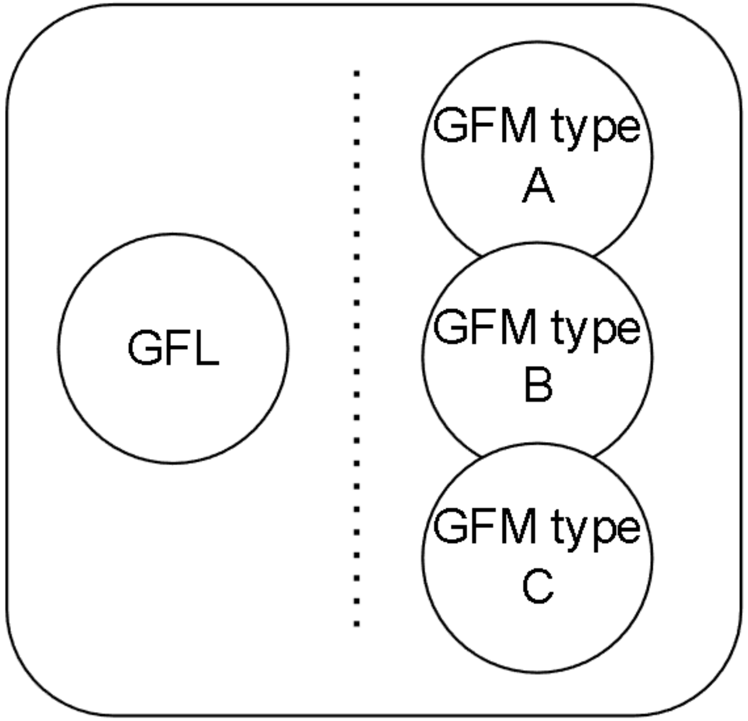
How is GFM functionally defined?

- 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

HAWAIIAN ELECTRIC GENERATION FACILITY TECHNICAL MODEL REQUIREMENTS AND REVIEW PROCESS

August 23, 2021

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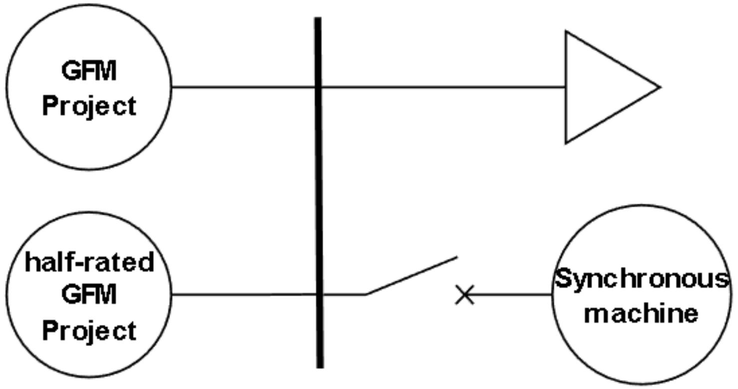
HECO Approach

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

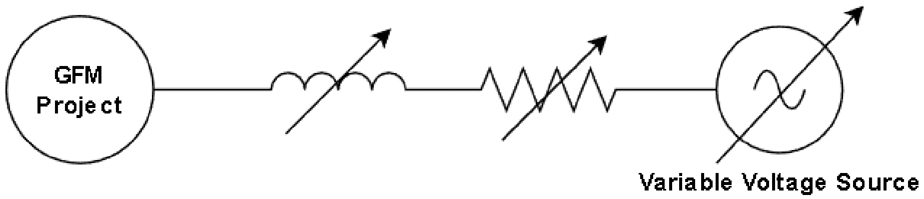
Test	Description	Success Criteria
1: Loss of Last Synchronous Machine (LLSM)	Start with project, project duplicate, load, and synchronous machine. Trip machine	Voltage and frequency remain stable throughout, settling according to droop curves
2: Weak Grid operation	Start with project and variable-strength 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:

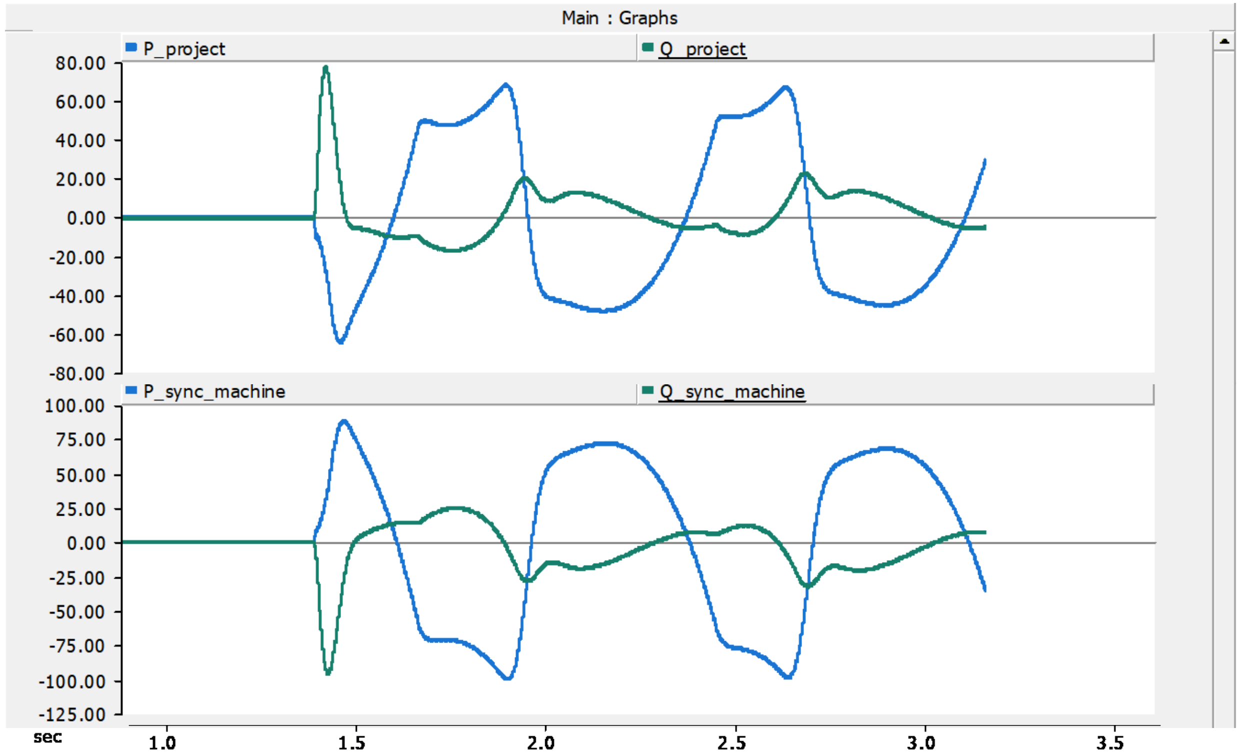


- Test system for 2 & 4:



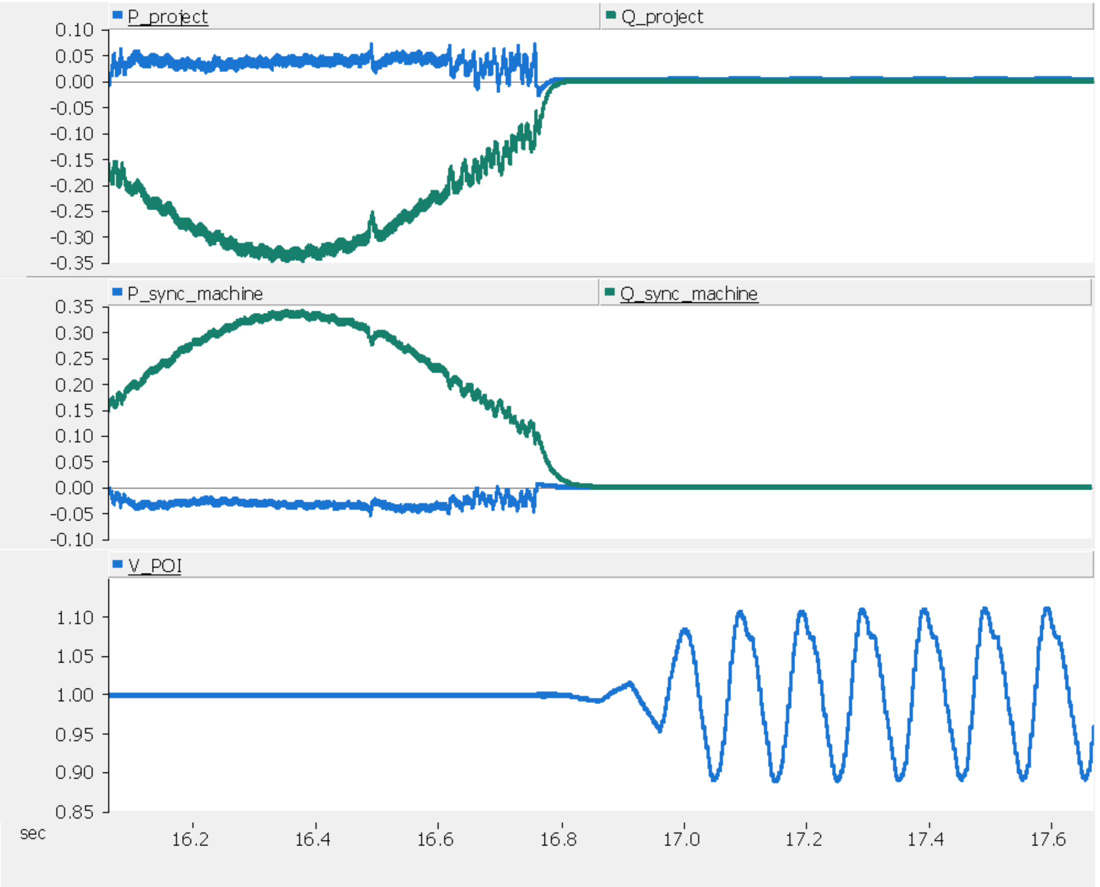
HECO Testing Examples: no P-F droop

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



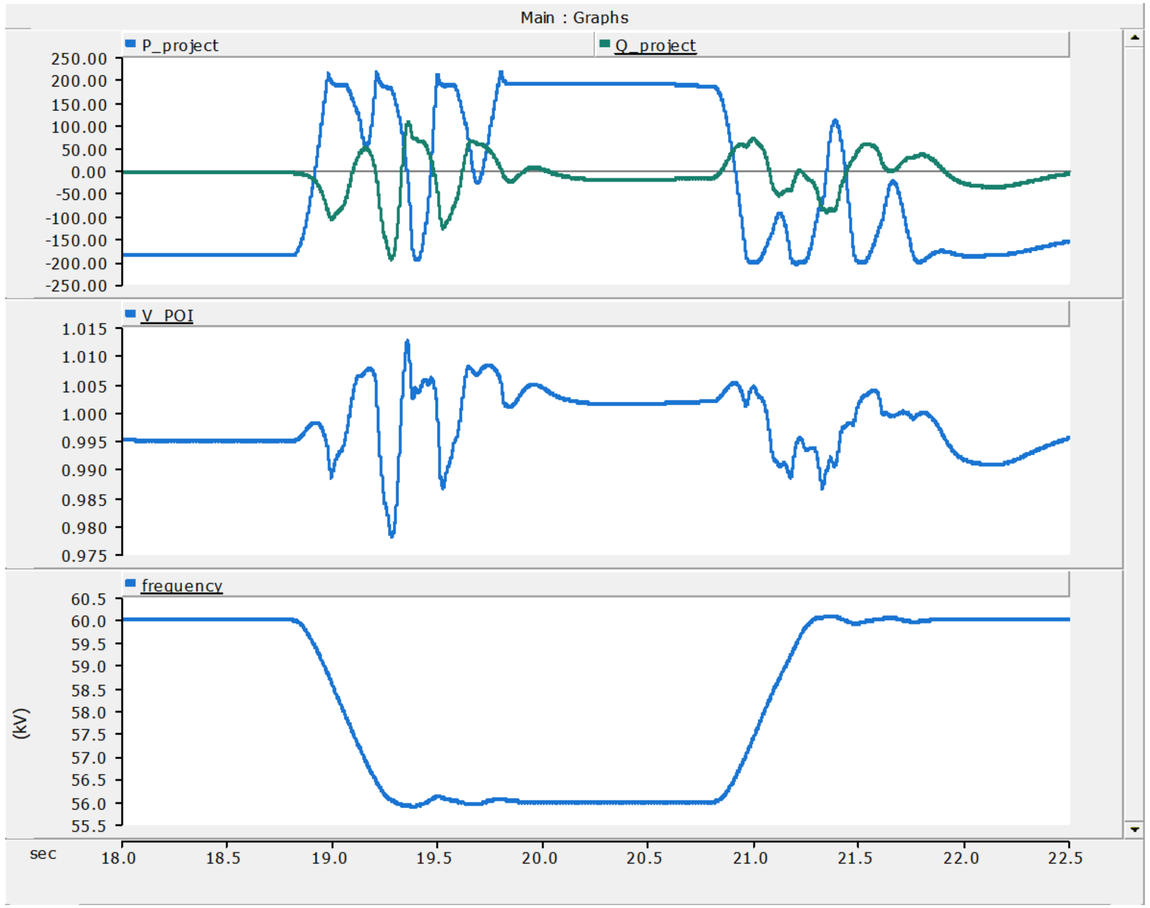
HECO Testing Examples: no-load oscillations

- 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

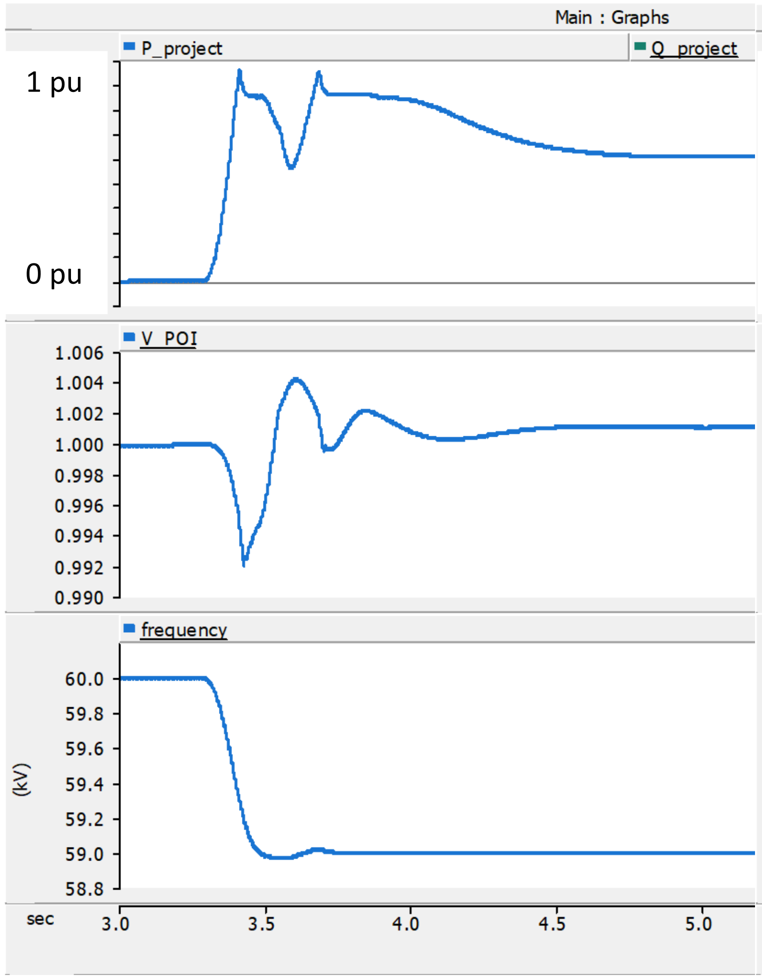
- RoCoF checked incidentally during frequency ride-through test
- GFMs have sensitivity to RoCoF. High RoCoF with large delta-F can be unstable



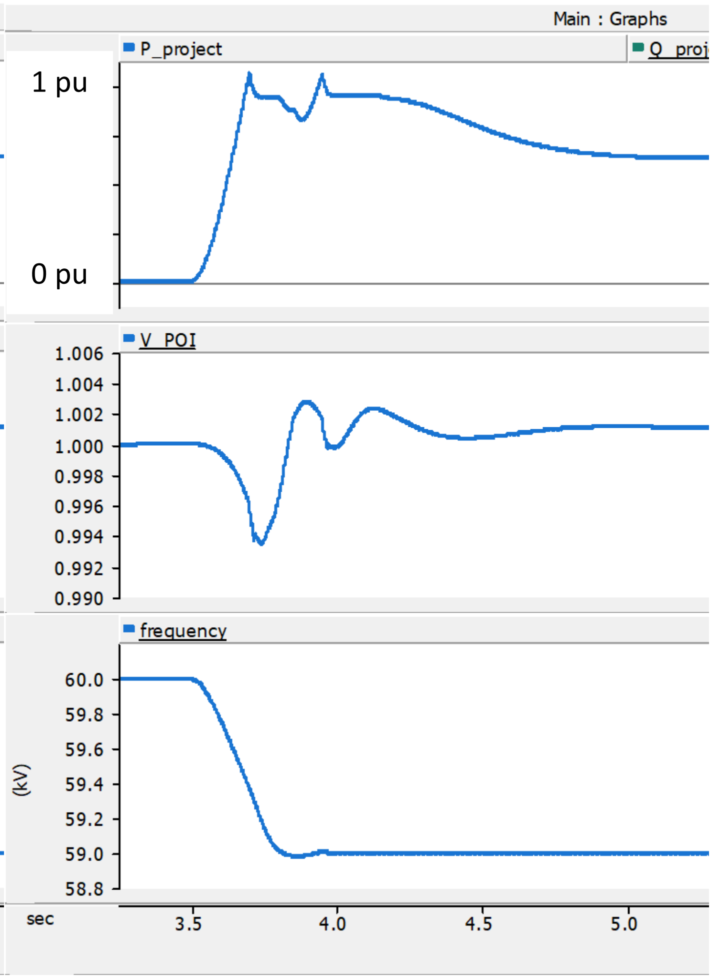
HECO Testing Examples: high RoCoF instability

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

dF = 1 Hz, RoCoF = 10 Hz/s

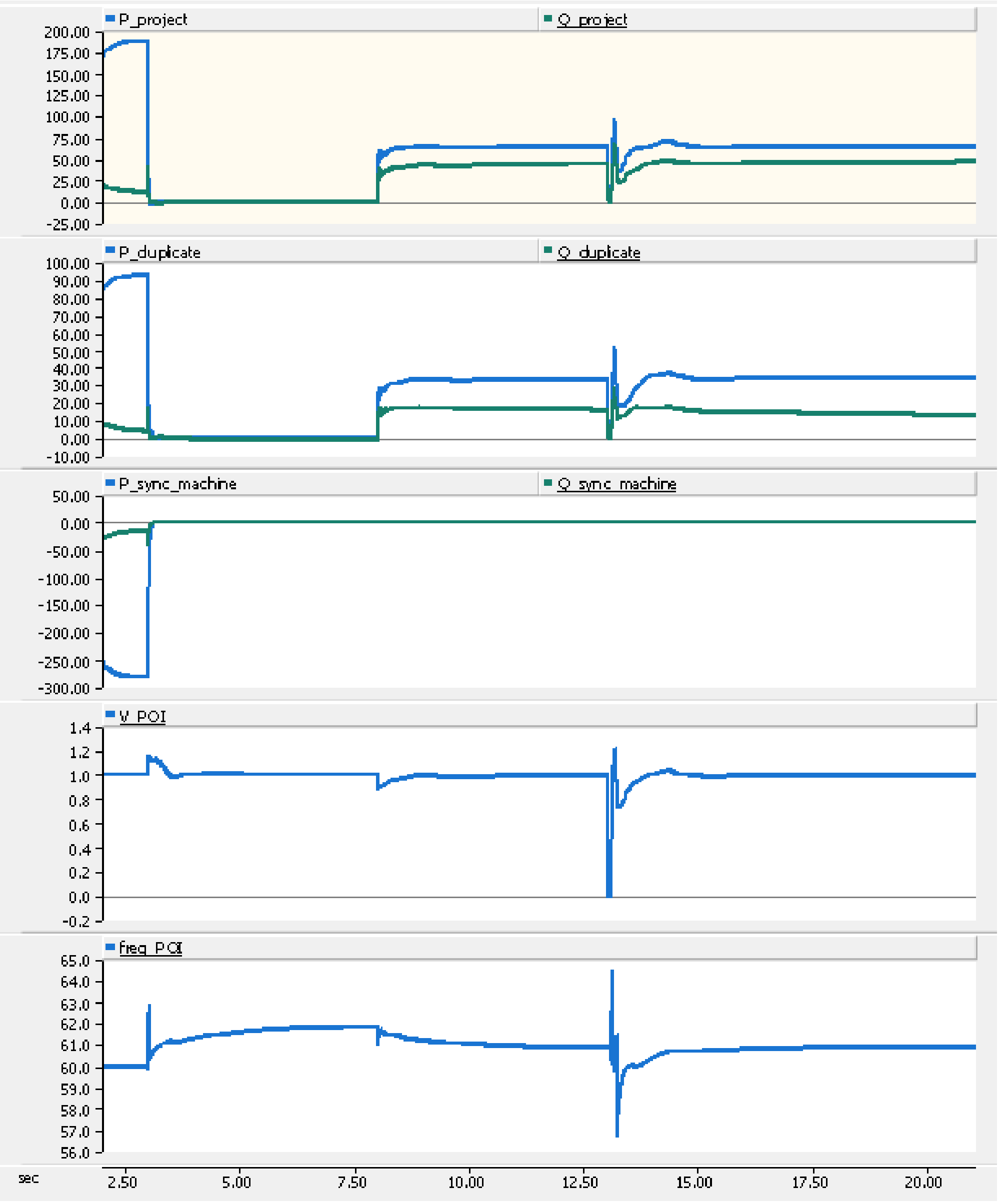


dF = 1 Hz, RoCoF = 4 Hz/s



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!

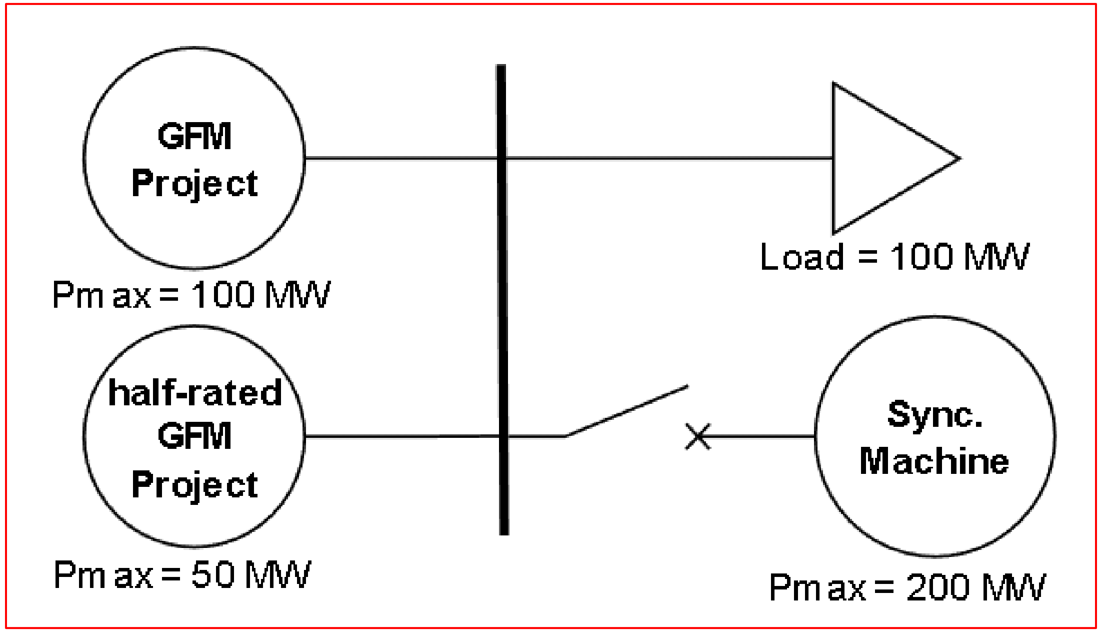


Upcoming NERC guide

- 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?

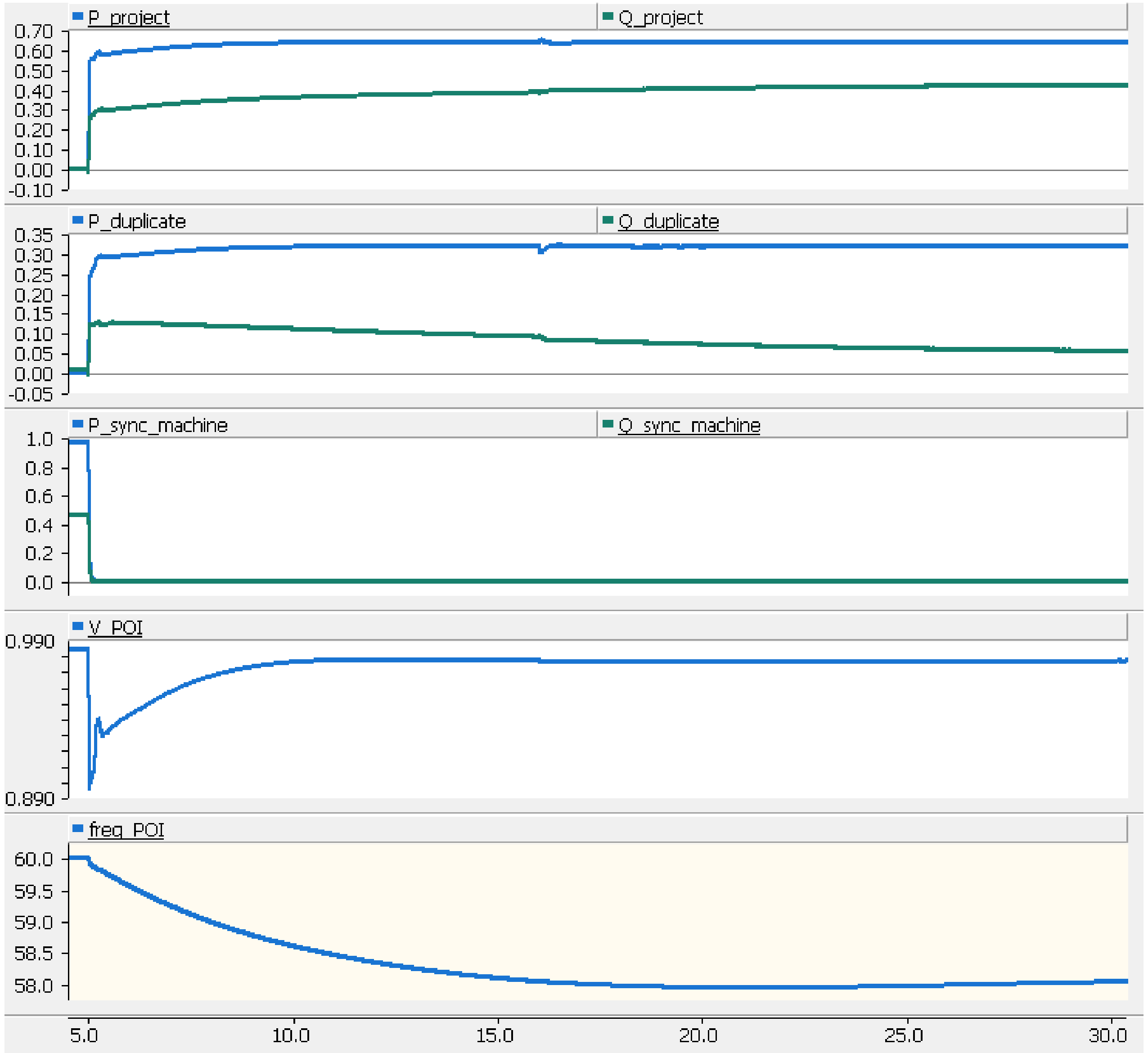
Loss of Last Synchronous Machine Testing

- 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 @ Pmax (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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