NREL
Transforming ENERGY

Testing IBRs Participation in Wide-Area Stability Services

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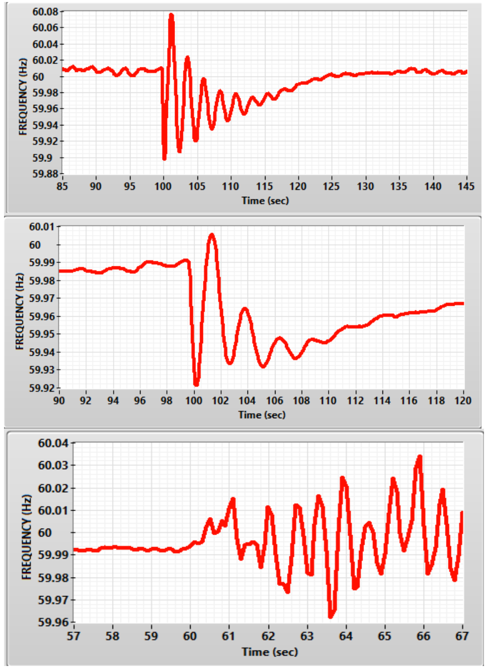
Photo by Dennis Schroeder, NREL 55200

Motivation

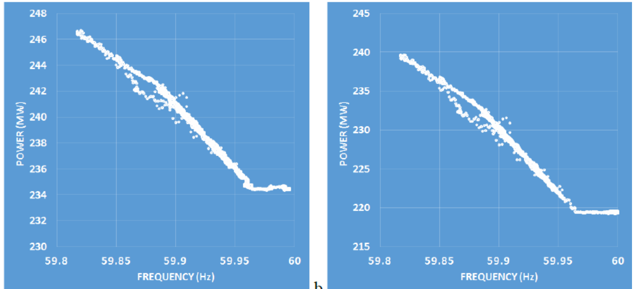
- Current stability paradigm:
  - Decentralized and uncoordinated control to responds to local measurements (mainly PSS)
- IBRs are not used for stability services:
  - They can provide reliability service (proven, but not used)
  - Can provide damping services if properly controlled (needs to be demonstrated)
- Problem exists – US, Europe interarea modes, oscillations in high-IBR systems (islands, AEMO, etc.)
- Novel IBR stability control strategies can be enabled for damping inter-area and local modes
- Improvements in WAMS and WADC systems (faster speed and better determinism)

Stability services by IBRs is part of many NREL research projects funded by DEO WETO, SETO, WPTO, OE, and many industry collaborations.

Examples of local mode oscillations measured in Colorado

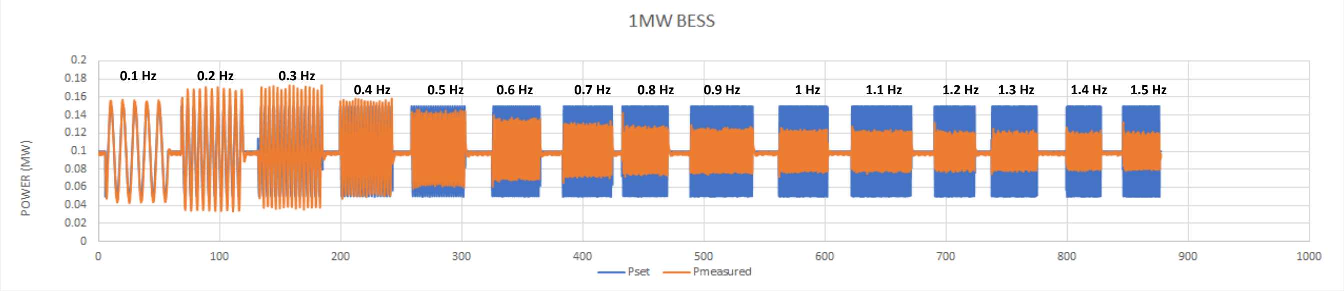


Measured frequency droop response of 300 MW PV plant

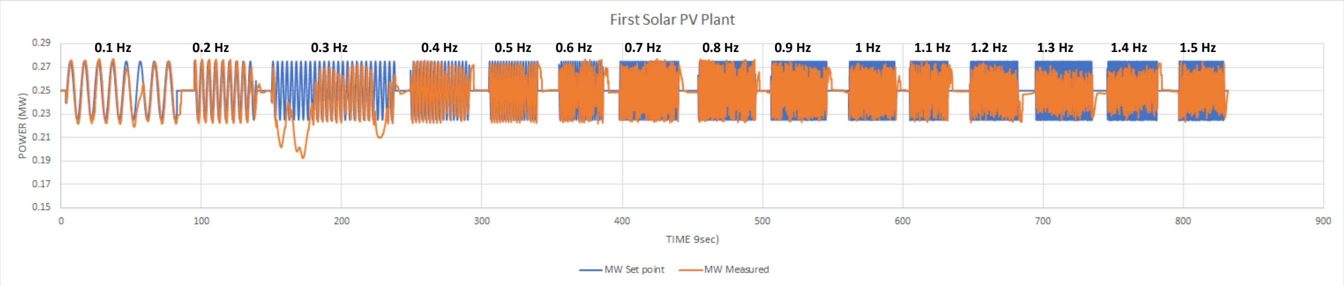


IBR Resources to provide damping: Examples of tests at NREL

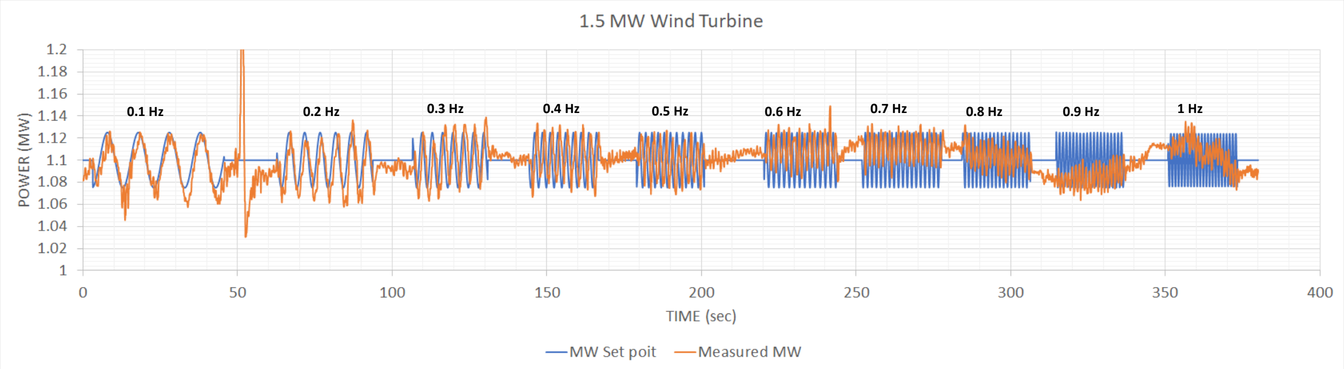
1MW BESS



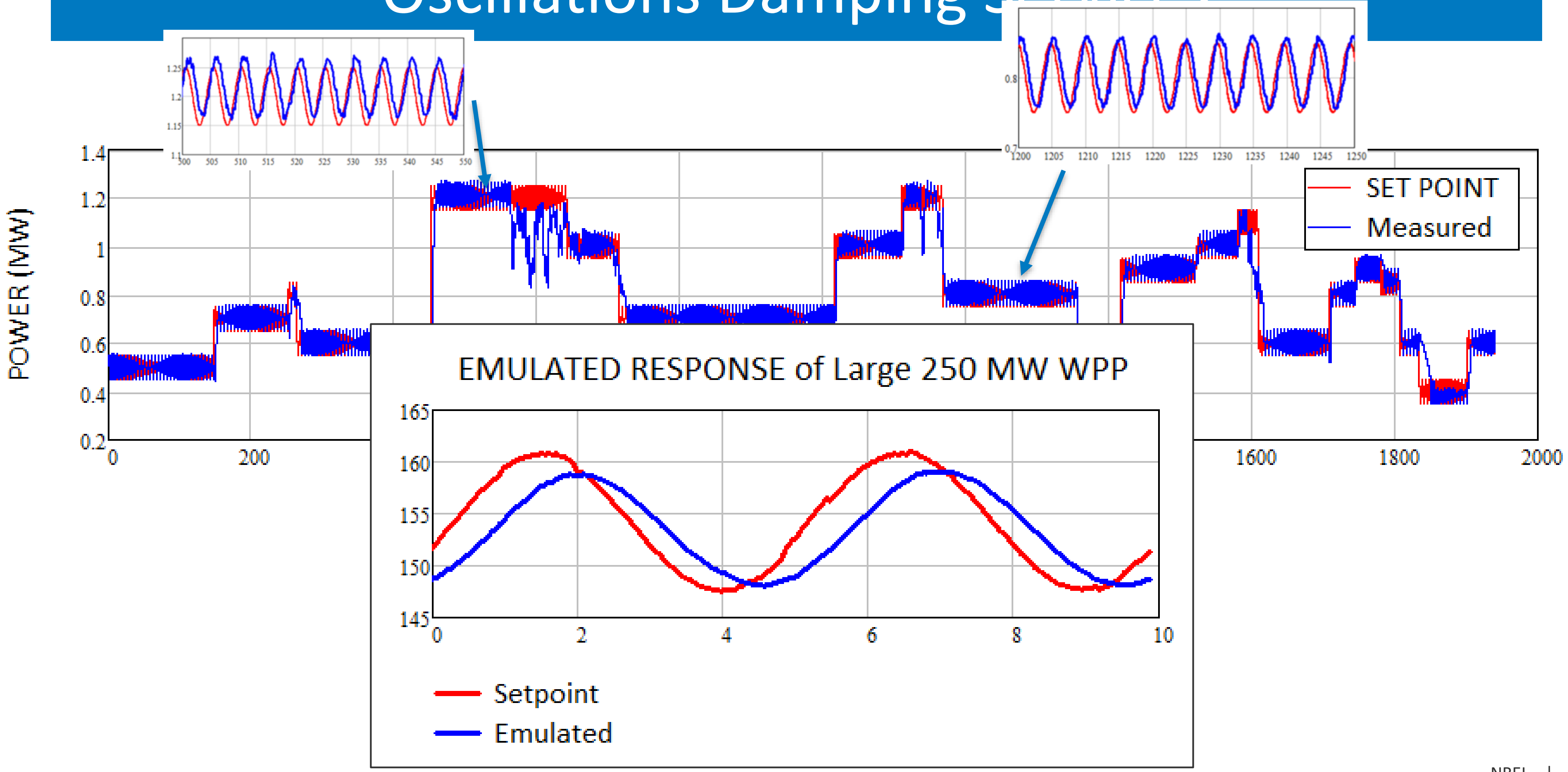
450 kW PV



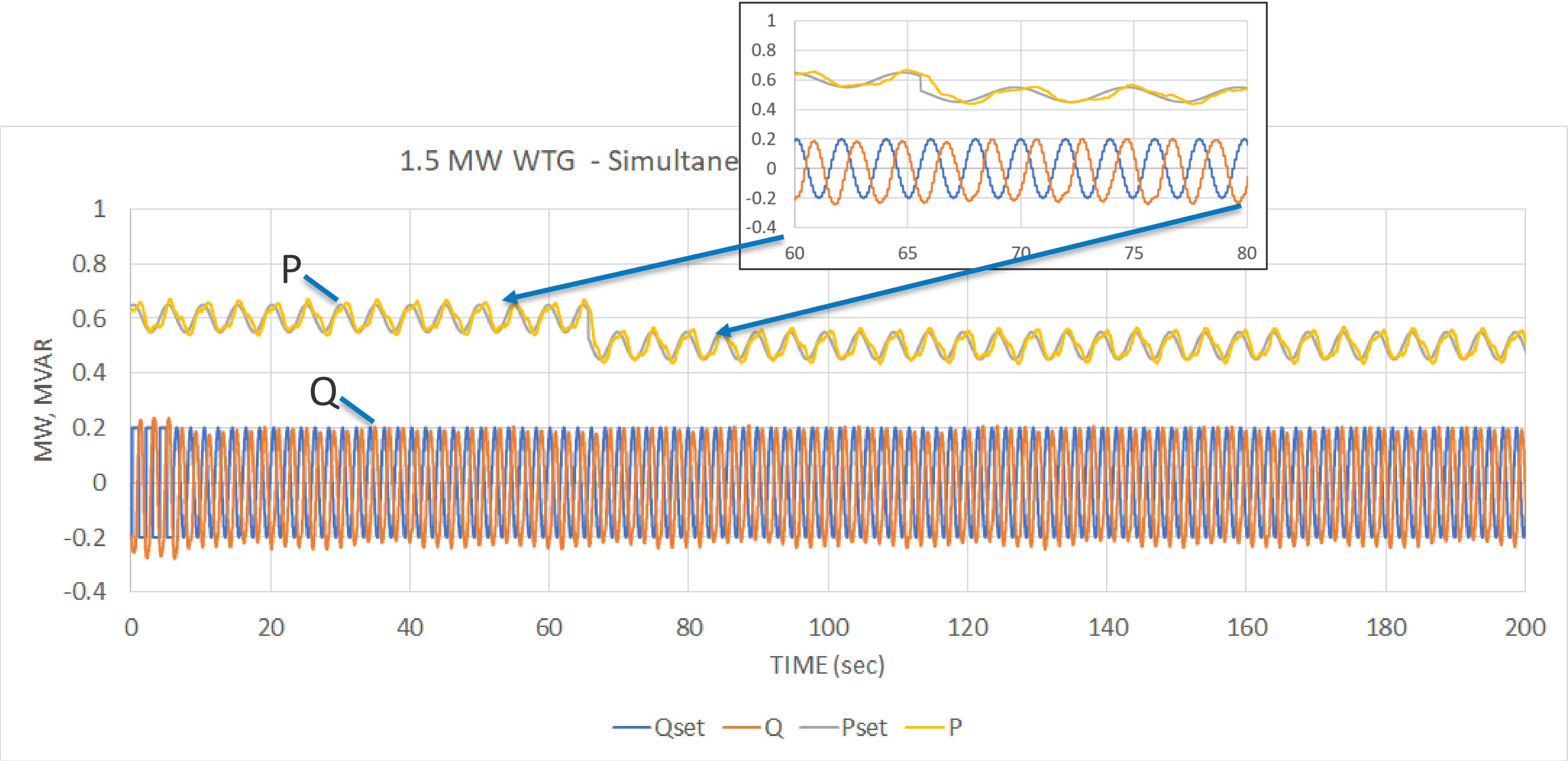
.5 MW Wind



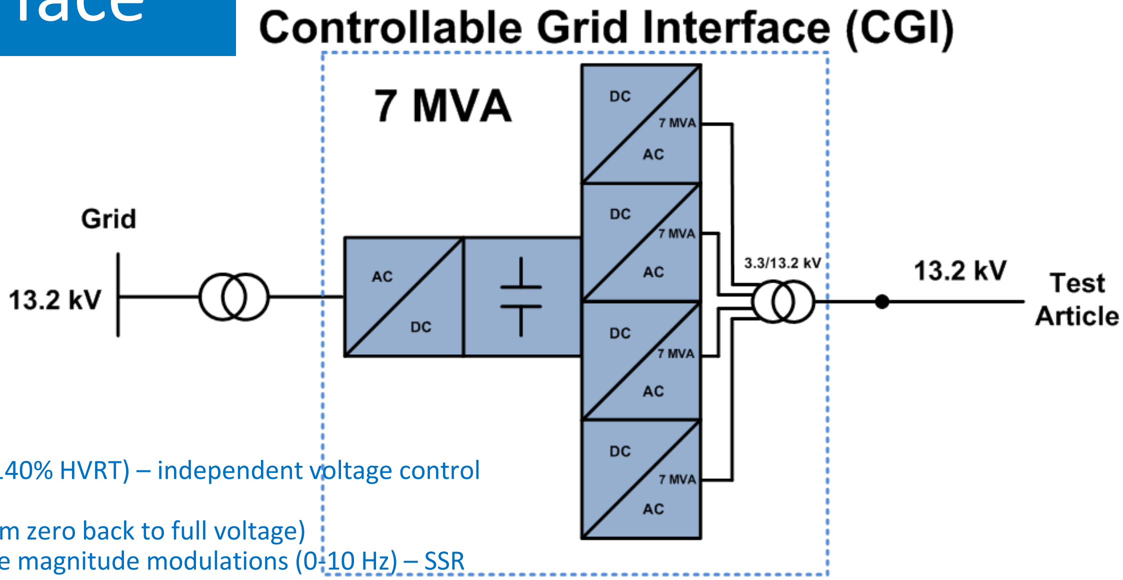
Testing of 1.5 MW Type 3 WTG for Power System Oscillations Damping Services



Ability of DFIG WTG to Provide Simultaneous Modulation of P and Q



Controllable grid Interface



Power rating

- 7 MVA continuous
- 39 MVA short circuit capacity (for 2 sec)
- 4-wire, 13.2 kV

Possible test articles

- Types 1, 2, 3 and 4 wind turbines
- PV inverters, energy storage systems
- Conventional generators
- Combinations of technologies

Voltage control (no load THD <1%)

- Balanced and un-balanced voltage fault conditions (ZVRT and 140% HVRT) – independent voltage control for each phase on 13.2 kV terminals
- Response time – 1 millisecond (from full voltage to zero, or from zero back to full voltage)
- Long-term symmetrical voltage variations (+/- 10%) and voltage magnitude modulations (0-10 Hz) – SSR conditions
- Programmable impedance (strong and weak grids)
- Programmable distortions (lower harmonics 3, 5, 7)
- Impedance characterization of inverter-coupled generation
- Full STATCOM functionality

Frequency control

- Fast output frequency control (5 Hz/sec) within 45-65 Hz range
- 50/60 Hz operation
- Can simulate frequency conditions for any type of power system
- PHIL capable (coupled with RTDS)
- Test-bed for PMU-based wide-area stability controls
- **Test article impedance scan**

Less than 1 ms response time

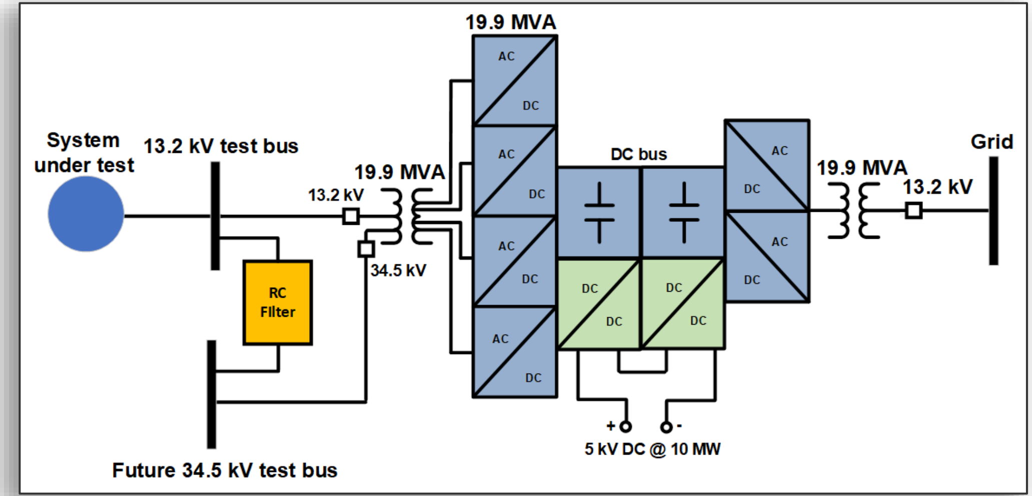
Summary of CGI#2 Specifications

Power rating
- Continuous AC rating - 19.9 MVA at 13.2kV and 34.5 KV
- Overcurrent capability (x5.7 for 3 sec, x7.3 for 0.5 sec)
- 4-wire 13.2 kV or 35.4 kV taps
- Continuous operational AC voltage range: 0 - 40 kVAC
- Continuous DC rating – 10 MW at 5 kVDC

Possible test articles
- Types 1, 2, 3 and 4 wind turbines
- PV inverters, energy storage systems
- Conventional generators
- Combinations of technologies / hybrid systems
- Responsive loads

Voltage control (no load THD <1%)
- Balanced and unbalanced voltage fault conditions (ZVRT, LVRT and 140% HVRT) – independent voltage control for each phase on 13.2 kV and 34.5 kV terminals
- Response time – less than 1 millisecond (from full voltage to zero, or from zero back to full voltage)
- Programmable injection of positive, negative and zero sequence components
- Long-term symmetrical voltage variations (+/- 10%) and voltage magnitude modulations (0-10 Hz) – SSR conditions
- Programmable impedance (strong and weak grids, wide SCR range corresponding to a POI with up to 250 MVA of short circuit apparent power)
- Injection of controlled voltage distortions
- Wide-spectrum (0-2kHz) impedance characterization of inverter-coupled generation and loads
- All-quadrant reactive power capability characterization of any system

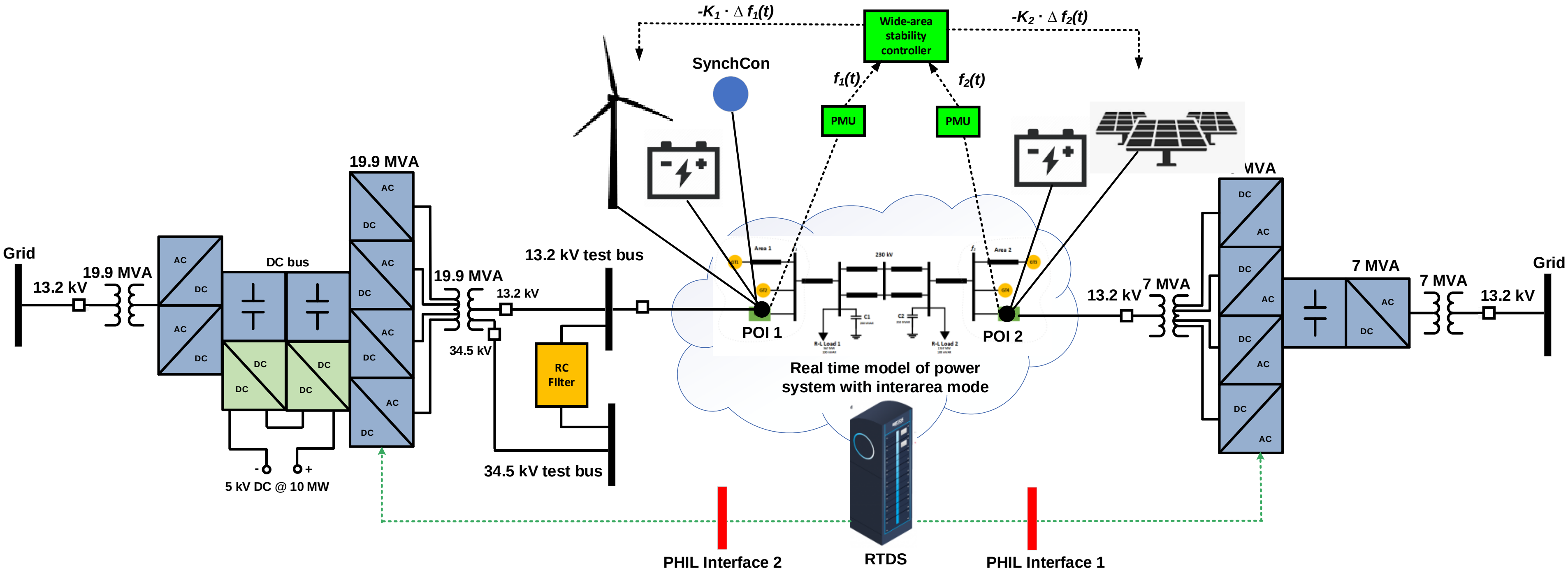
Frequency control
- Fast output frequency control (3 Hz/sec) within 45-65 Hz range
- 50/60 Hz operation
- Can simulate frequency conditions for any type of power system
- PHIL capable (can be coupled with RTDS)
- Coupled with PMU-based wide-area stability controls validation platform



100 µS response time

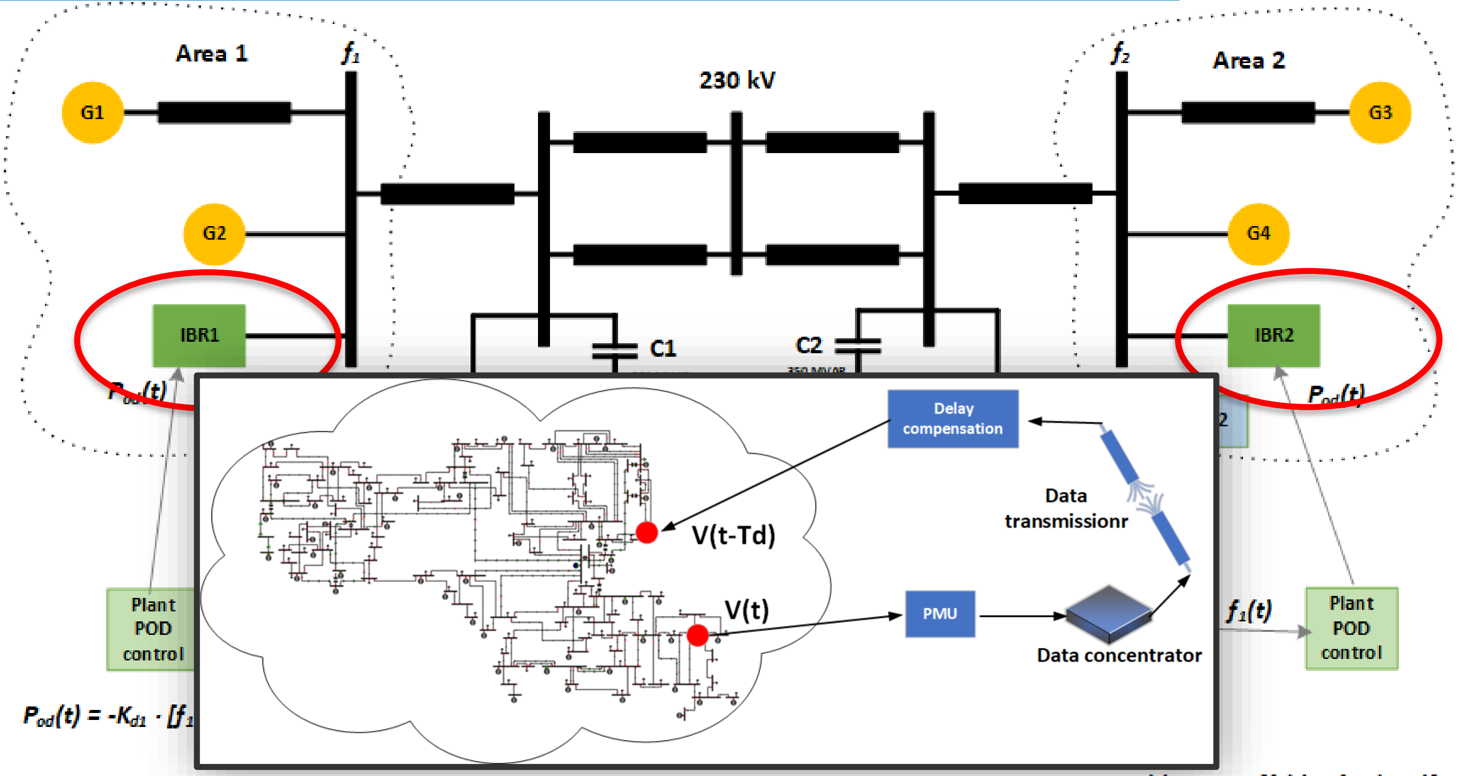
New features
- 5 kV MVDC grid simulator (PHIL capable)
- Voltage or current source operation
- Seamless transition between voltage and current source modes
- Emulation of full set of resiliency services:
  - Black start
  - Power system restoration schemes
  - Microgrids
- Flexible configurations are possible when combined with CGI#1:
  - Two independent experiments
  - Parallel operation
  - Back-to-back operation
  - Emulation of isolated, partially or fully grid-connected microgrids

Wide-Area Stability Controls Validation Platform



- Two-POI PHIL platform using real0tuime model of a power system
- Multi-MW real IBRs (wind, PV, BESS), synchronous machine and loads coupled with real controllers, measurement units and communications

POD controls



$P_{od}(t)$ = -K_{d1} · [f_1

$P_{od}(t)$ = -K_{d2} · [$f_2(t) - f_1 \cdot (t\text{-}T_d)$]

K_{d1} – damping gain (MW/mHz) for area 1

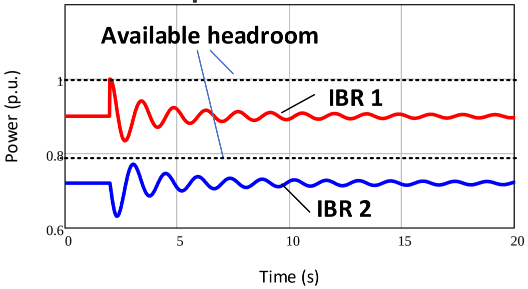
$T_d = T_{d1} + T_{d2}$ – communication delay (ms)

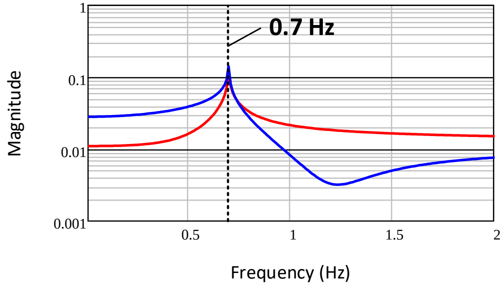
K_{d2} – damping gain (MW/mHz) for area 2

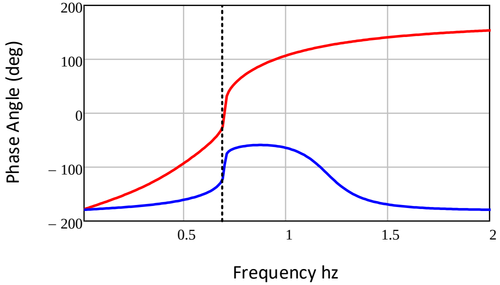
Method presented in: J. Neely, et. al. "Damping of Inter-area Oscillations using Energy Storage", IEEE PES GM, July 2013

Active Power Damping Control Strategies – 0.7 Hz inter-area mode

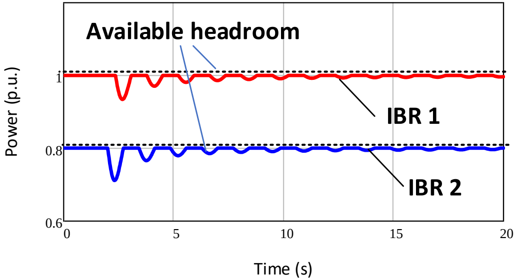
1. Curtailed operation – headroom available

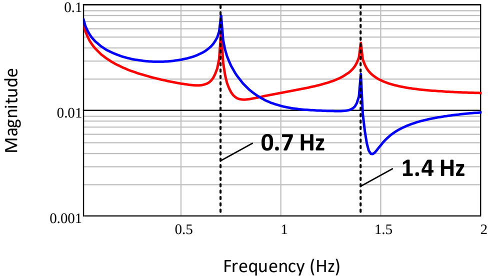


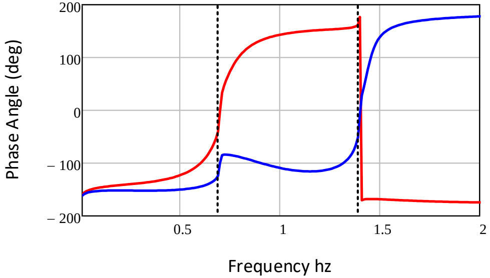




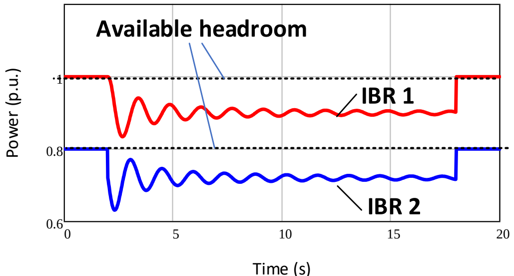
2. Max power operation – no headroom available

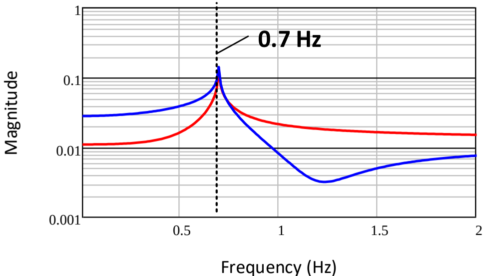


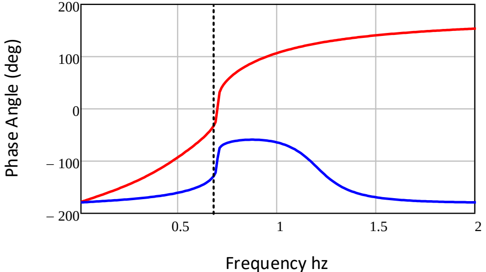




3. Temporary curtailment

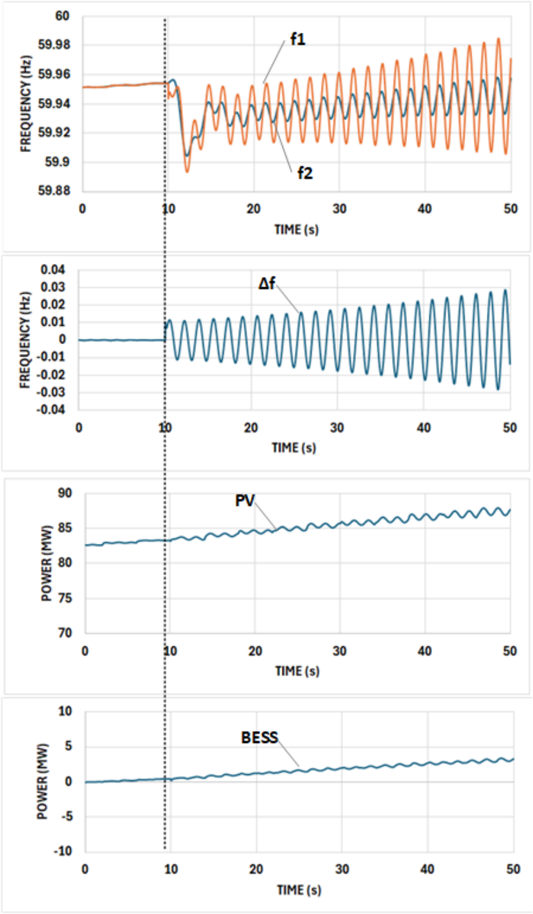




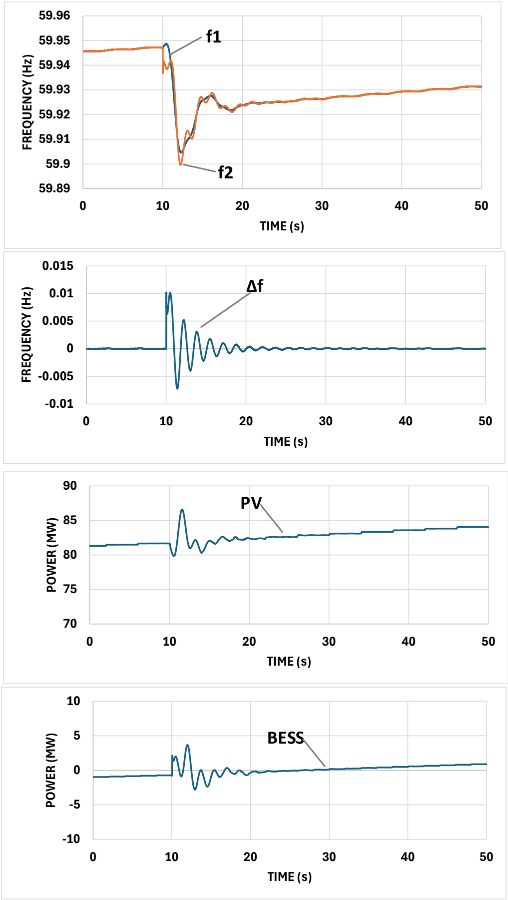


PV and BESS provide damping

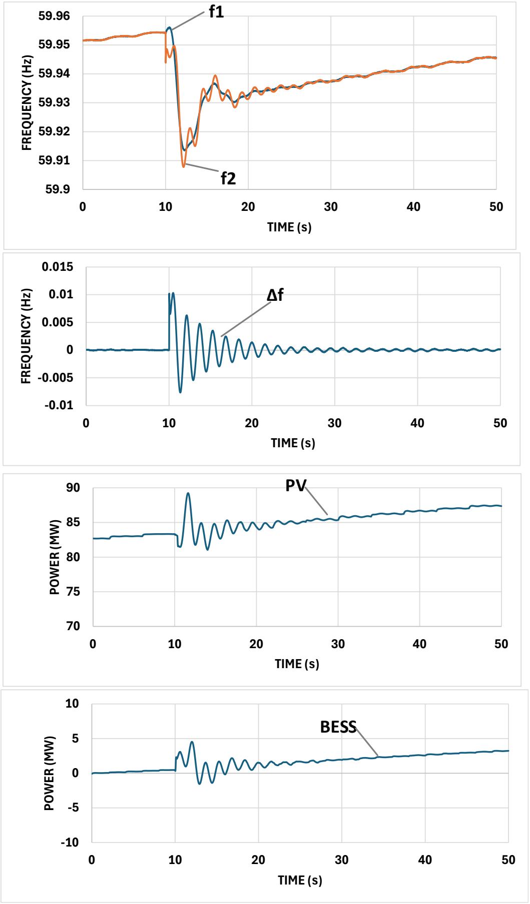
1. No damping – system unstable



2. Damping – 300 ms delay

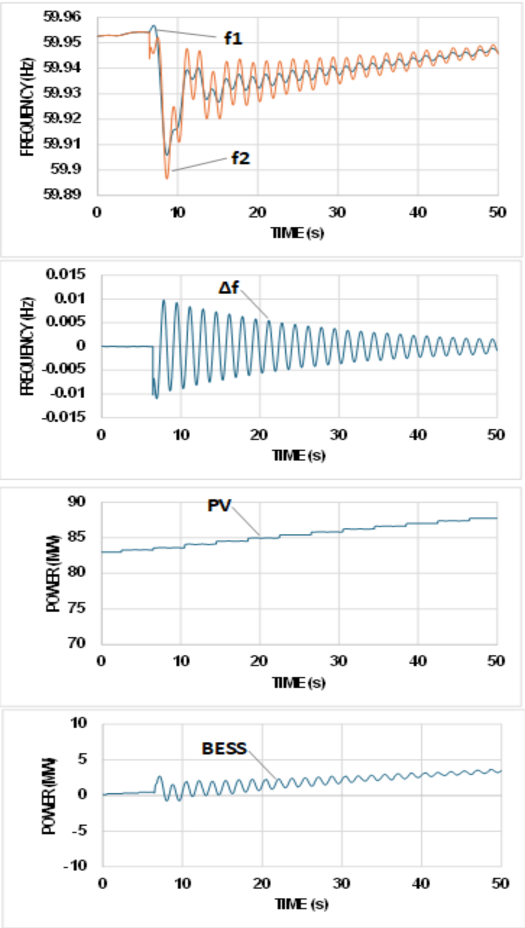


3. Damping – 900 ms delay

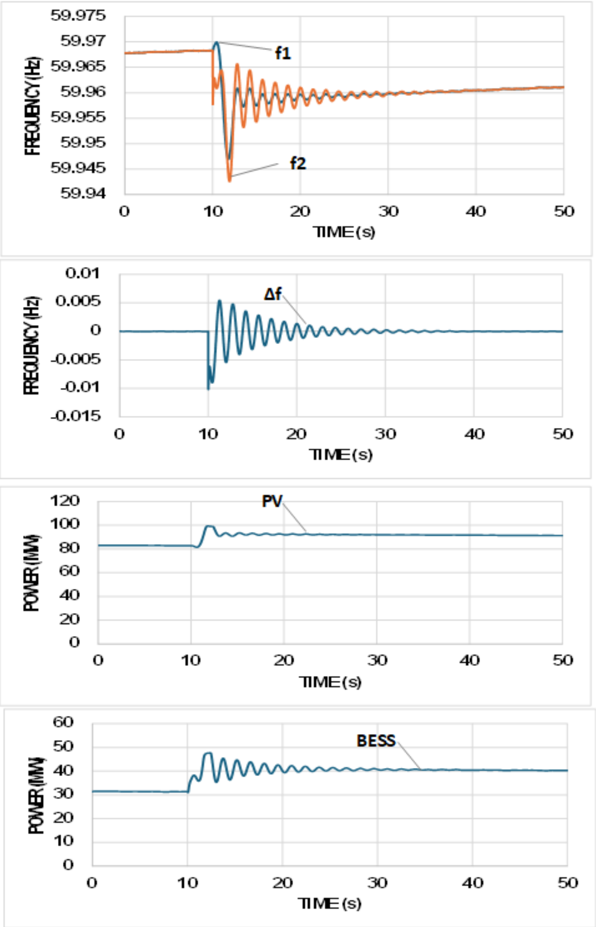


PV and BESS provide damping

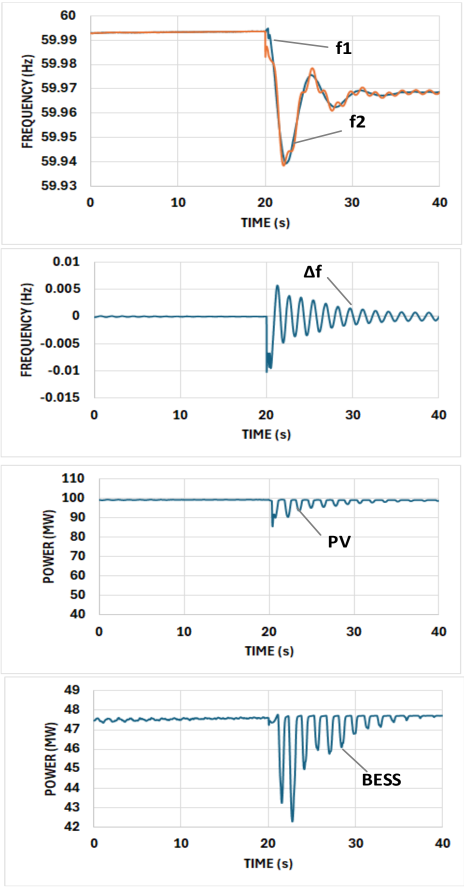
4. One-area damping



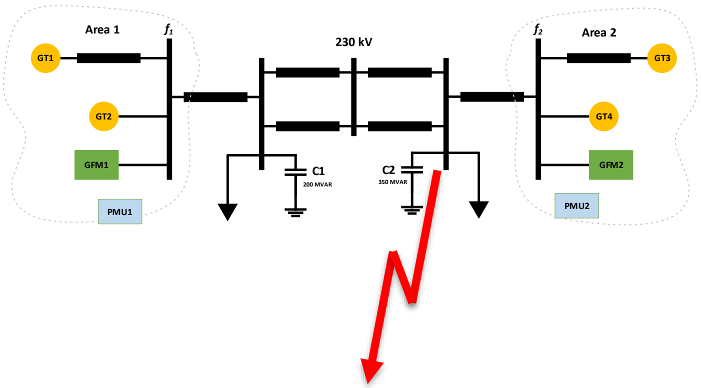
5. Local damping control



6. Damping without pre-curtailment

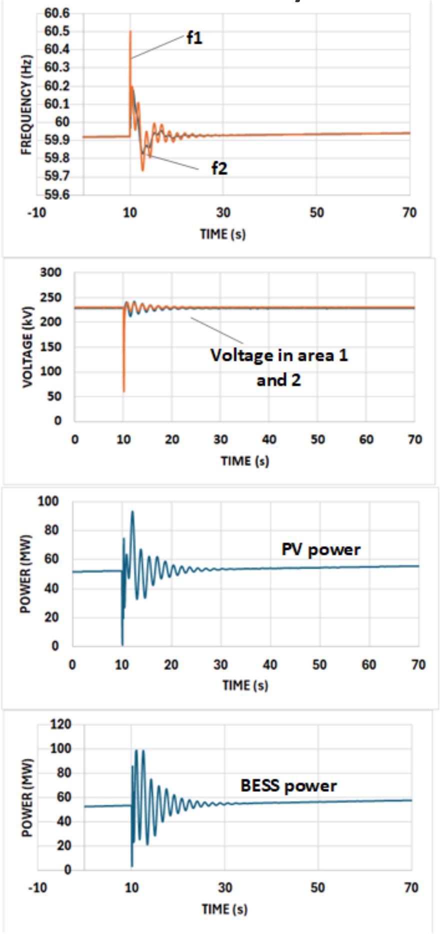


Instability triggered by voltage fault

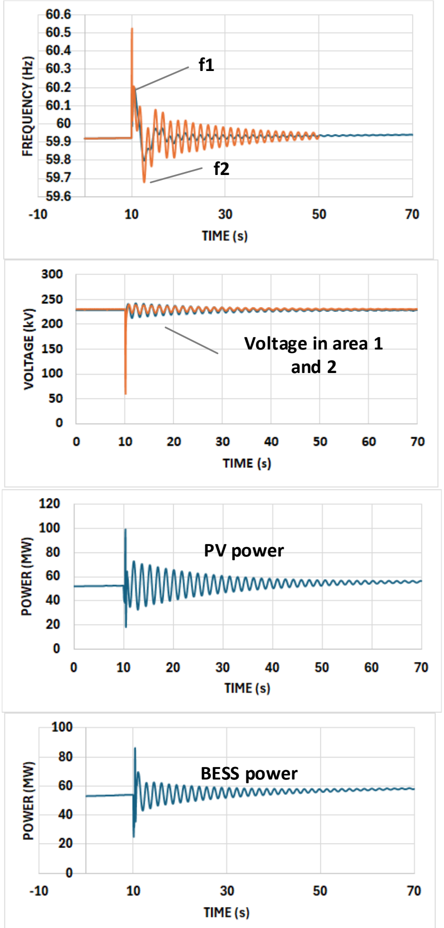


100 ms 3-phase voltage fault

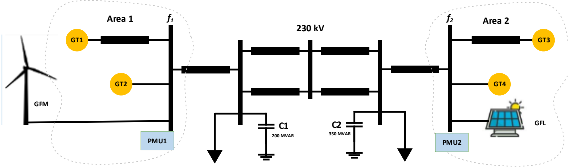
300 ms delay



900 ms delay



Damping by Wind and PV

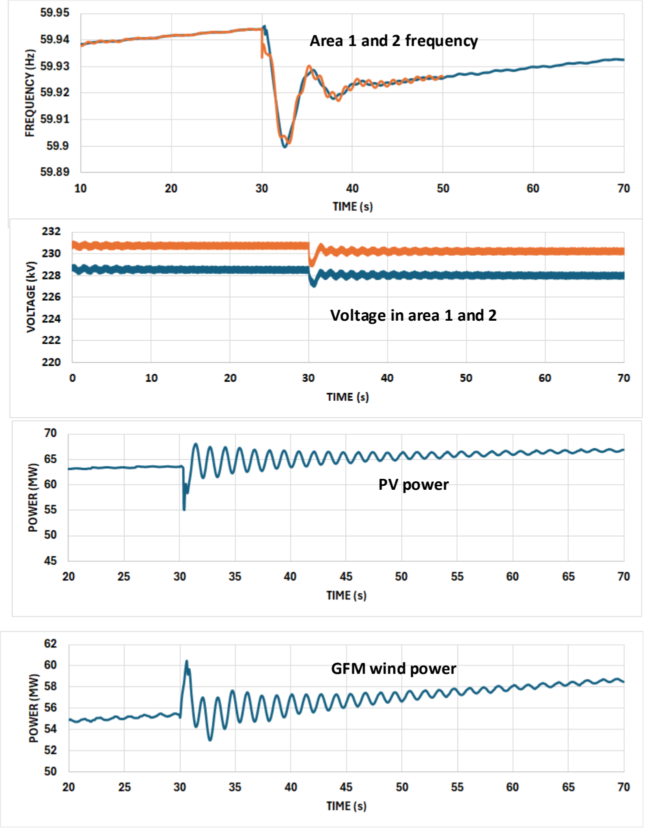


- GFM Type 3 wind turbine
- GFL PV plant

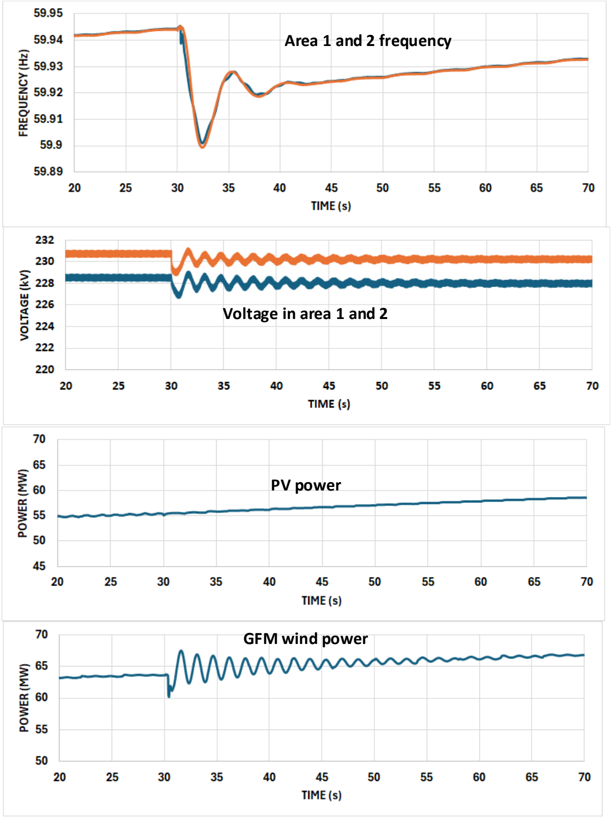
Advantages of GFM Type 3 GFM:

- High levels of SC current
- Immunity to SSR

GFM wind and PV provide damping



Only GFM provides damping



Synch Condensers to Provide POD Services

Lister Drive greener Grid park (Liverpool, UK).
ABB's synchronous condensers with flywheels.
Photo courtesy: Statkraft

- **2 x 67 MVAR**
- **2 x 465 MWs**
- **13.8 kV**

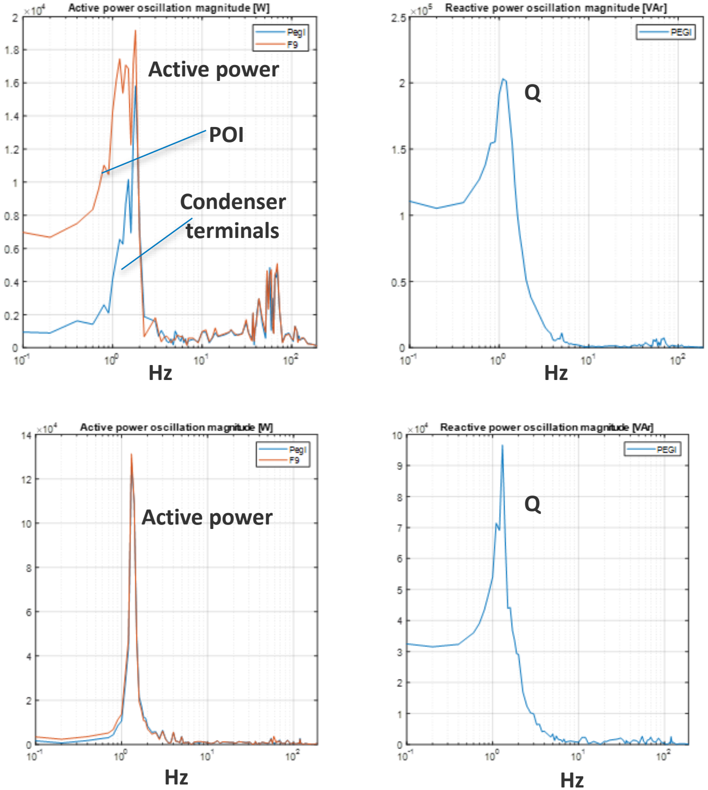
- **275 kV tie with National Grid**

- **POD function implemented in ABB's Unitrol AVR platform at this site**

- On going research using NREL's 2.5 MVA synchronous machine
- NREL SC characterization experiment
- SC P and Q response to field voltage modulations

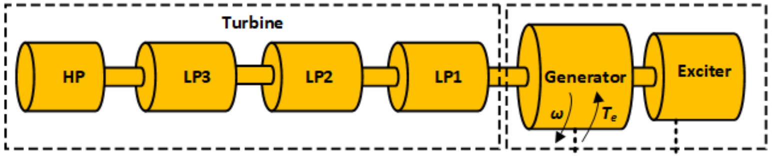
Strong grid

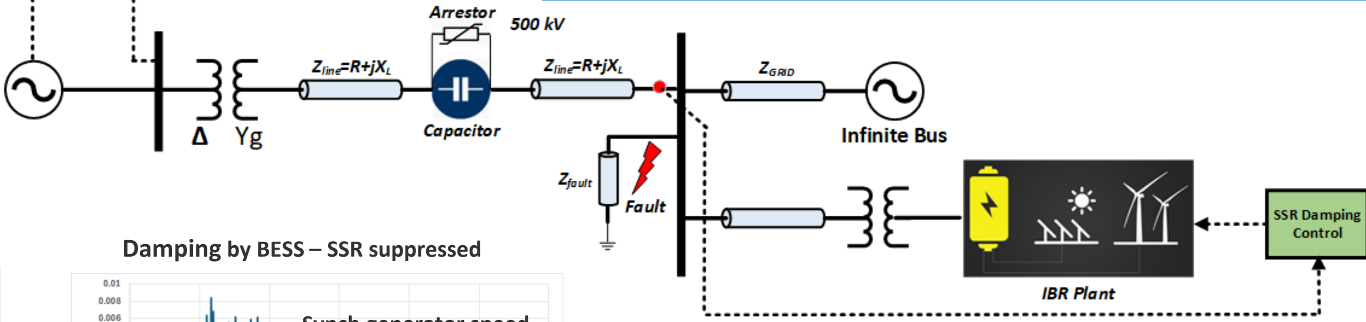
Weak grid



SSR Damping with IBRs

Spring mass model of thermal power plant

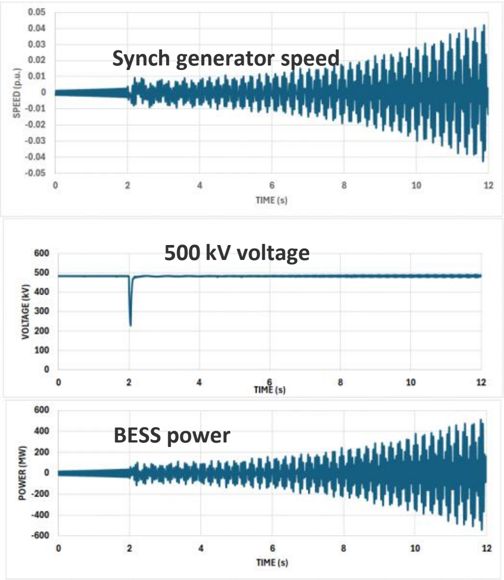




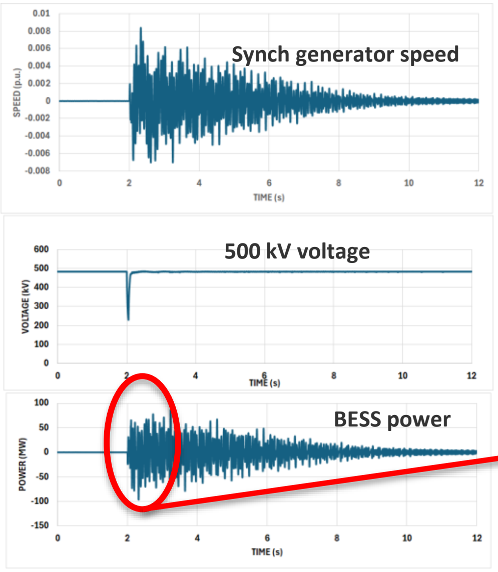
System with 17 Hz resonance

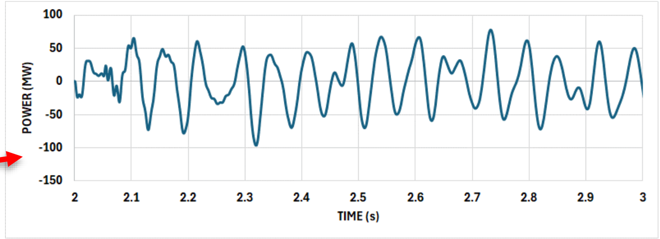
GFL BESS providing SSR damping control

No damping by BESS – SSR progressing



Damping by BESS – SSR suppressed





Summary and Next Steps

- It was demonstrated that that IBRs can provide damping services with local and centralized controls
- Delay compensation technique can be used to compensate for comm latencies
- Local vs. centralized stability controls (PSS functionality vs. wide-area damping controller):
  - Which method is better, especially for low/zero inertia and weaker grids?
- Next steps: demonstrations of stability services in low/zero inertia grids (including inter-area oscillations, SSR, voltage instabilities, etc.)
- Role of GFM resources and synch condensers in wide-area stability

Thank you

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