Harnessing Smart Power Electronics to Increase Renewable Energy Penetration in Tomorrow's Utility Grid

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Session 5: What role does power electronics play in making the grid smarter?

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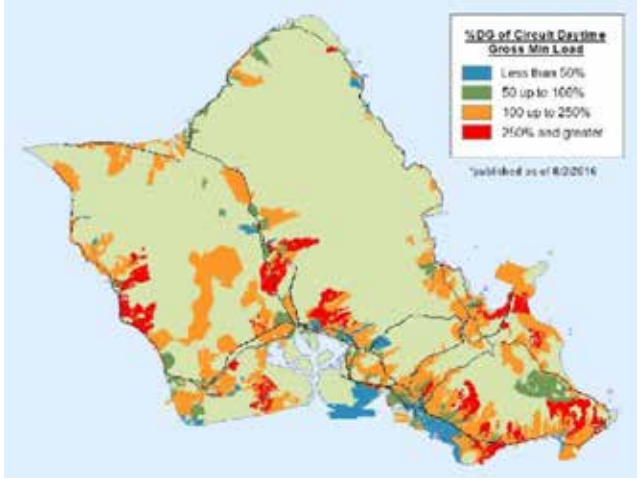
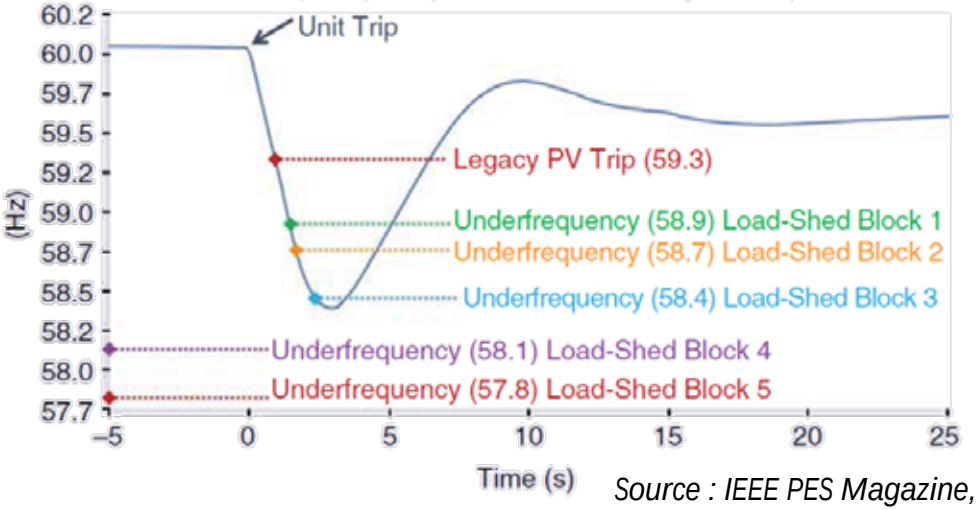
What's the Problem?

- Standard distributed PV sources behave as unsophisticated slaved current sources
- As penetration of distributed PV increases, grid stability suffers
- Exhibit #1: Oahu – Hawaiian Electric Co. (HECO)
  - Penetration of Distributed PV is growing rapidly: >35% today, 70% by 2019?
  - System stability is maintained by shrinking number of synchr. generators
  - Stability concerns have required temporary halts to distrib. PV installation



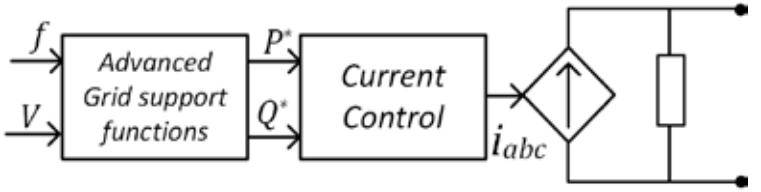
Measured Frequency Response to a Generating Unit Trip on Oahu



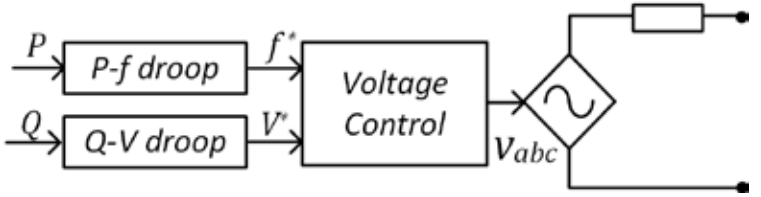
Source : IEEE PES Magazine, Nov. 2017

Grid-Following & Grid-Forming Control

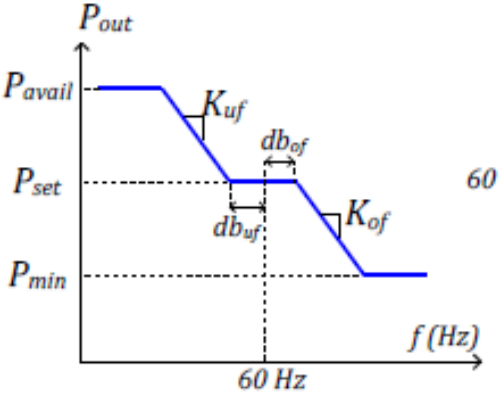
Grid Following Control (GFL)



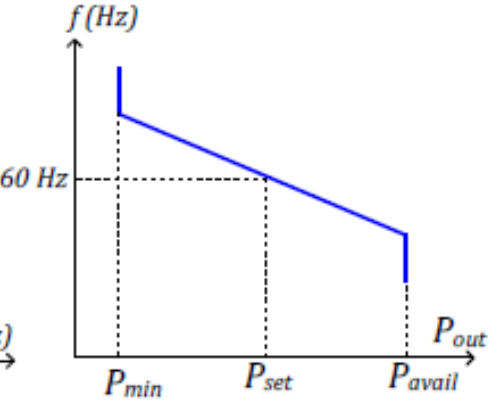
Grid Forming Control (GFM)



Frequency-Watt (GFL)



P - f Droop (GFM)



Grid Following Control (GFL)	Grid Forming Control (GFM)
Controls Current and Phase angle	Controls Voltage and Frequency
Controls Real & Reactive power as well Fault Currents	Instantaneously Balances Loads without Coordination Controls
Cannot operate standalone	*Can* operate standalone
Cannot achieve 100% penetration	*Can* achieve 100% penetration

Grid-forming control can naturally provide frequency support by taking advantage of the fast inverter response!

Oahu Power Grid Simulation Results

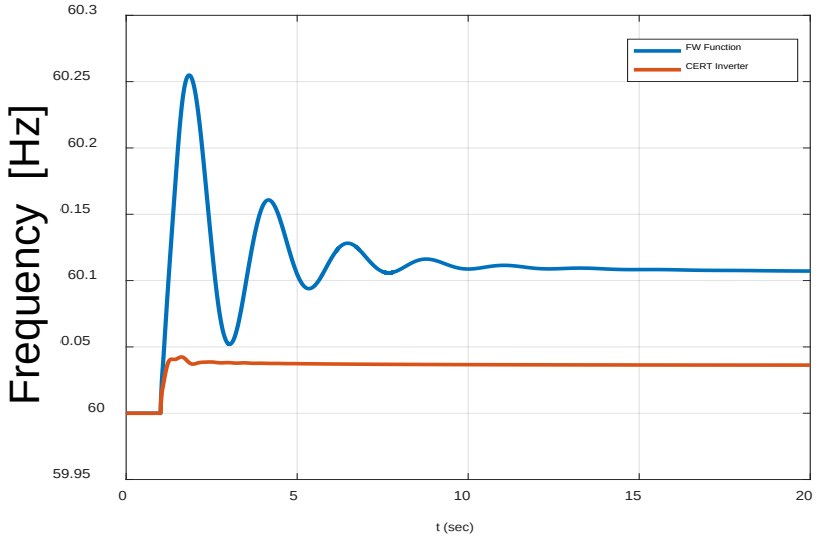
(Sandia NL – UW-Madison)

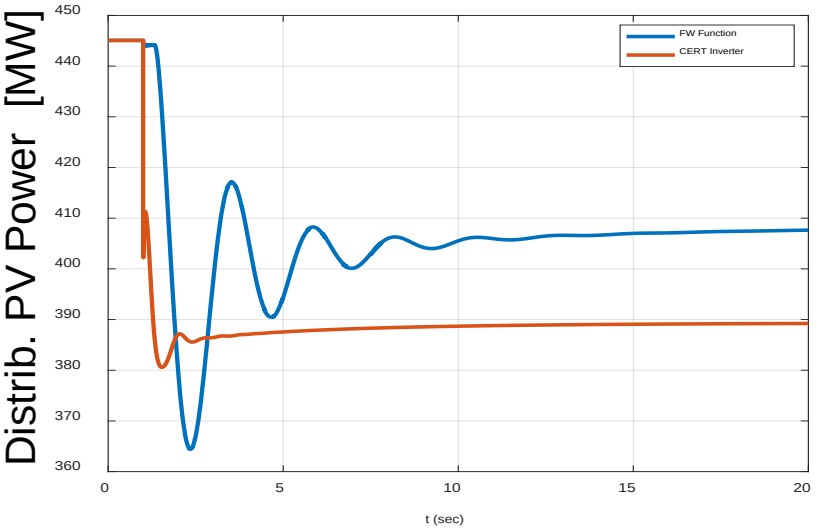
Initial Conditions: Total Load: 920 MW Distributed PV: 445 MW (48%)

Event: Loss of 62 MW load

Grid-following: Inverters with Frequency-Watt

Grid-forming: Inverters with Power-Freq. droop



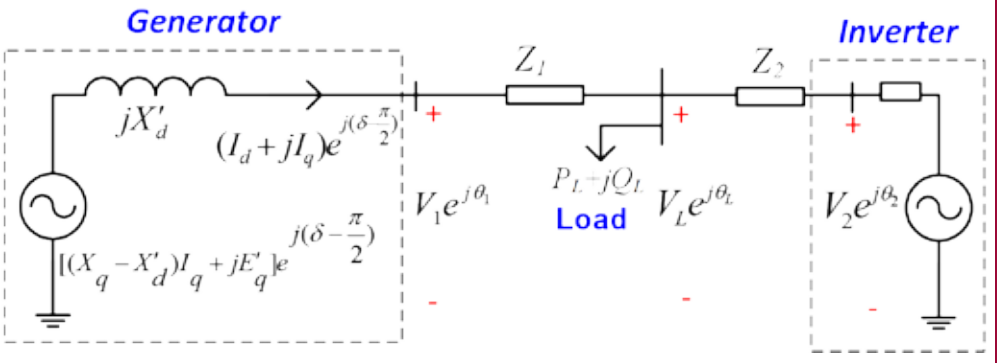


- Although Frequency-Watt function improves grid stability with GFL control, dynamic performance is mediocre, and degrades as penetration level increases
- Dynamic performance with grid-forming control is dramatically better

Source: "Evaluation of Inverter-based Grid Frequency Support using Frequency-Watt and Grid-Forming Control", by M. Elkhatib, W. Du, R. Lasseter

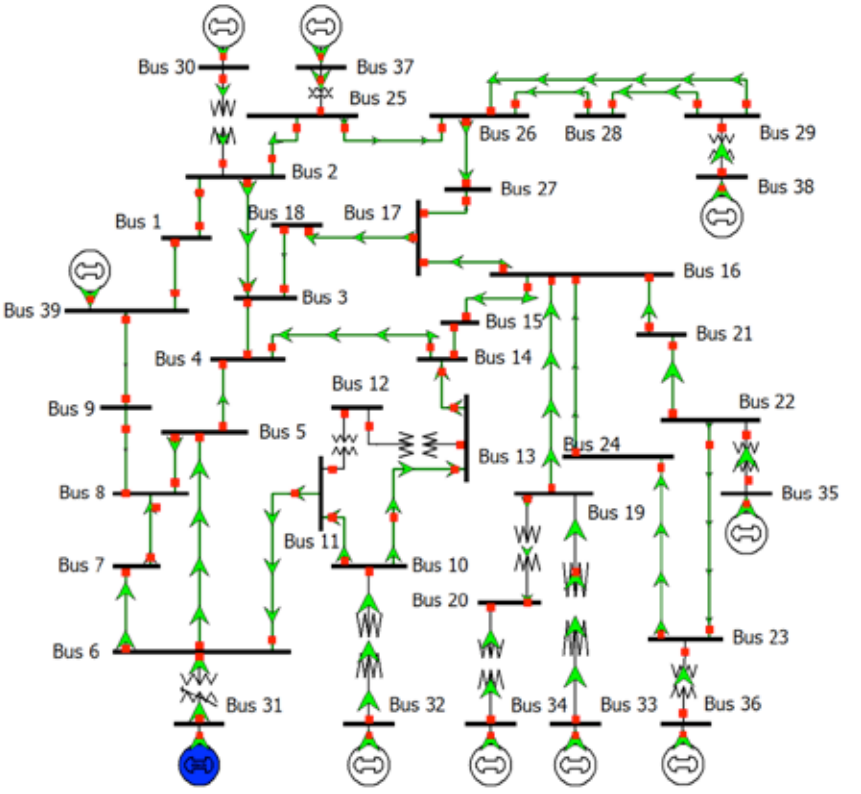
Test Cases Used for Analysis of Inverter-based Source Penetration Effects

Two-Source System



- q *Preliminary approach* to understand system behavior & small signal analysis
- q 1 synchronous machine & 1 Inverter source
- q Unity power factor control applied for grid-following (GFL) inverter-based sources
- q Power rating of one source varied relative to the other to vary penetration level

IEEE 39 Bus System



- q 39 buses, 10 generators. 6.1 GW total load
- q Replace generators with inverter-based sources of equal rating to vary penetration

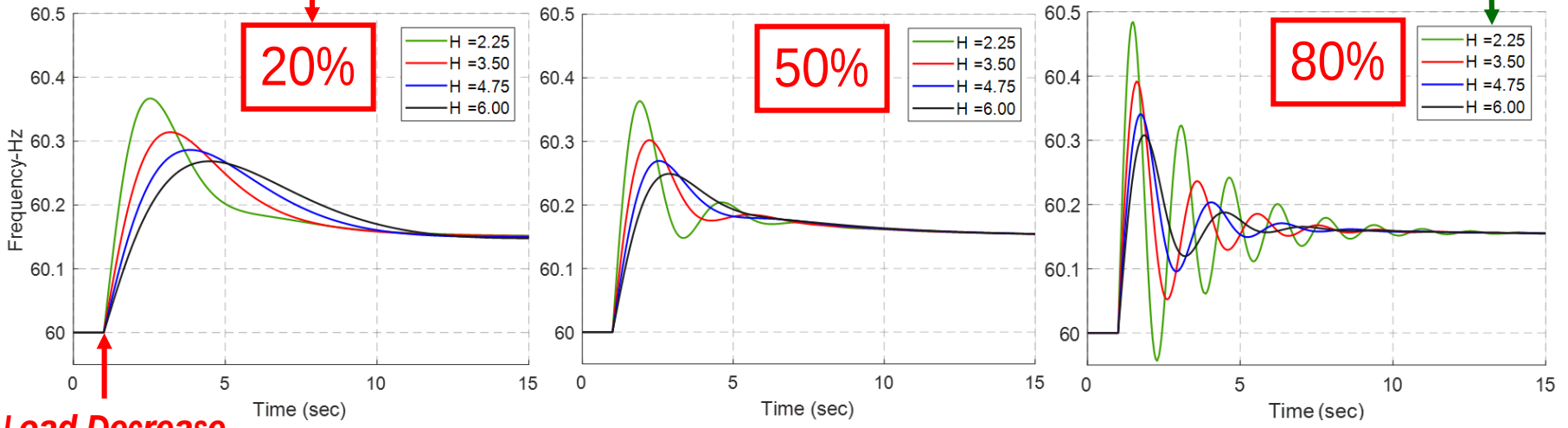
Matlab simulations used to investigate impact of inverter-based source penetration

Two-Source System Simulations

Inverter Penetration Level

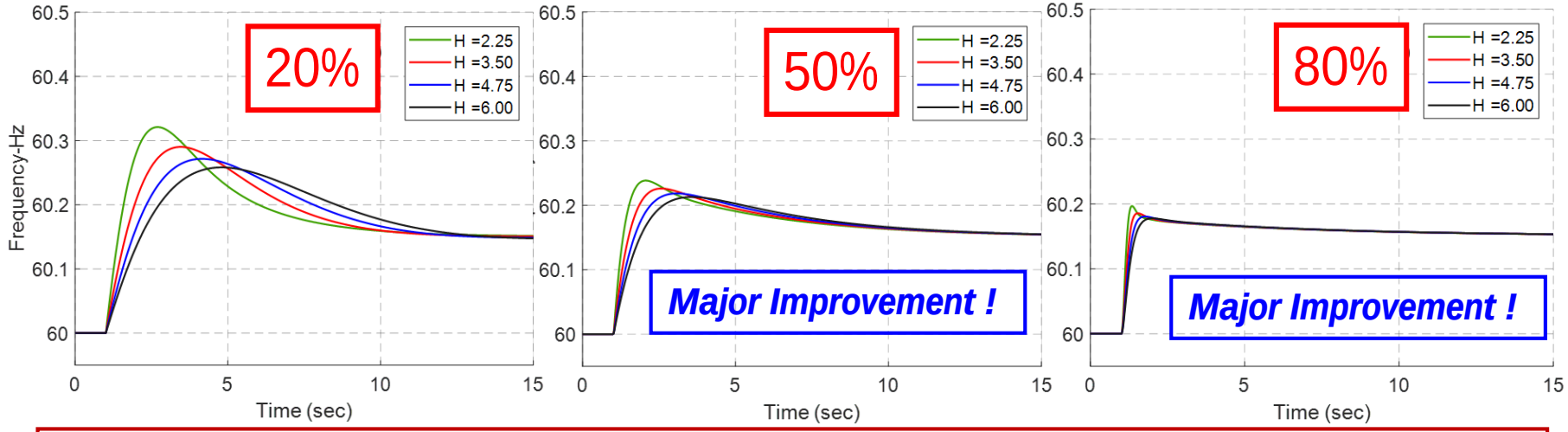
Grid-Following Sources

Inertia of remaining synchronous generators



5% Load Decrease

Grid-Forming Sources

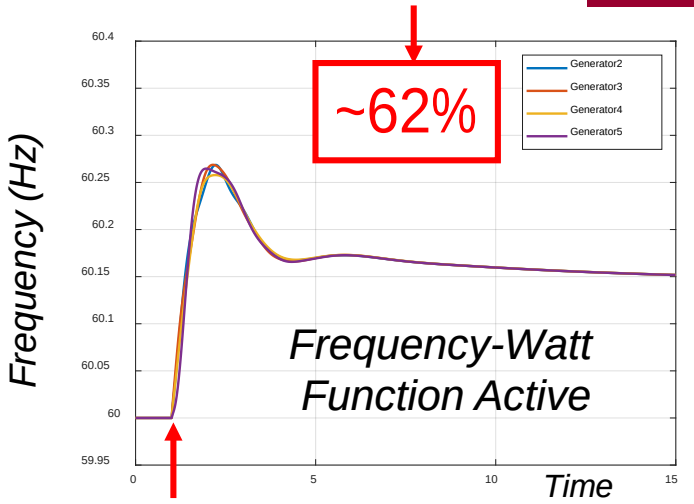


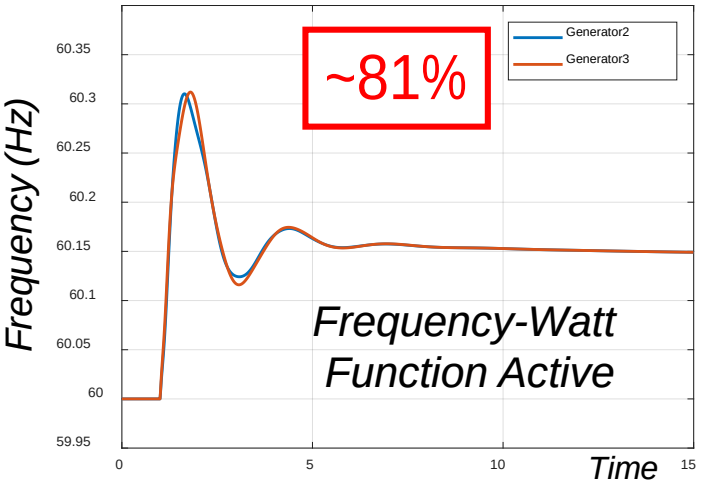
Dynamic response with GFM sources improves as penetration level increases

IEEE 39-Bus System Simulations

Grid-Following Sources

Inverter Penetration Level





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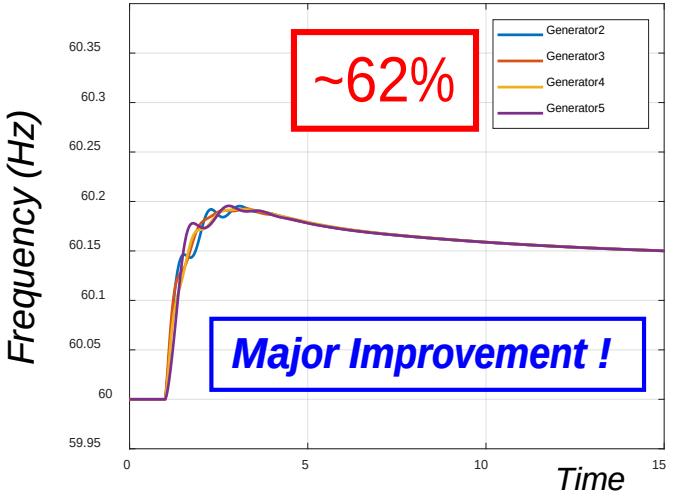
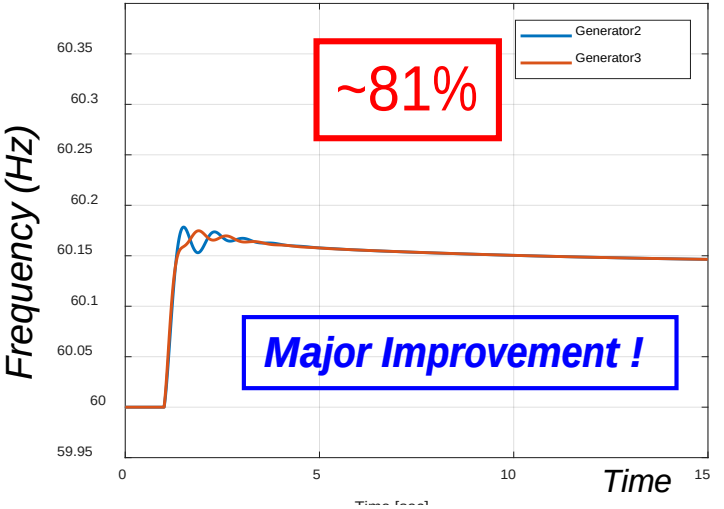
Grid-Forming Sources



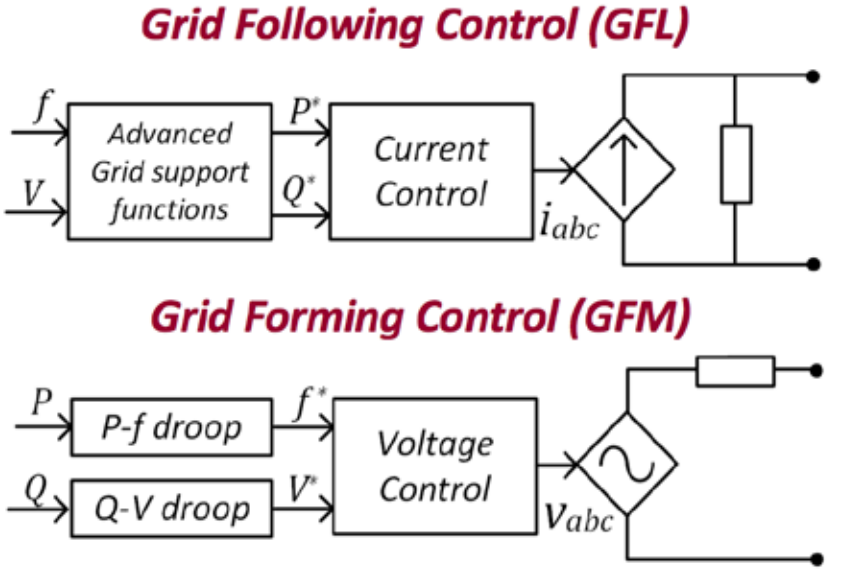


Same advantages of Grid Forming sources emerge from 39-bus simulations

Concluding Observations

- Increasing the "smarts" of future RE inverter-based sources can significantly improve the grid's stability and dynamic characteristics as RE penetration % increases
- Performance of grid-following (GFL) sources can be improved by introducing frequency-watt function, but value degrades as penetration level increases
- In stark contrast, grid dynamic performance *improves* as penetration level of grid-forming (GFM) sources increases
  - Depends on assumption that GFM sources have head-room capacity to accommodate dynamic load requirements
- IEEE 1547 (2018) does not address grid-forming sources

Smarter power electronics can make a big difference!



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