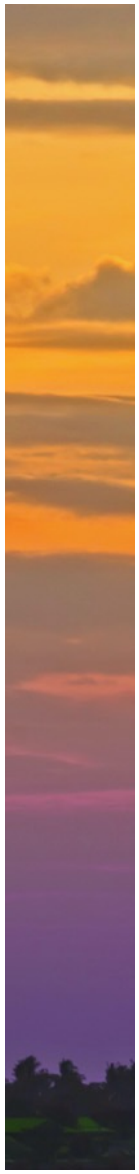

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PNNL-SA-174437

PMAPS MANCHESTER 1824 2022

Panel Session T1A: Future Grid

Chairs: Prof. Joe Dong & Prof. Junhua Zhao

Power Electronics for Large-Scale Renewable Integration

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Research Professor, Washington State University

June 14, 2022

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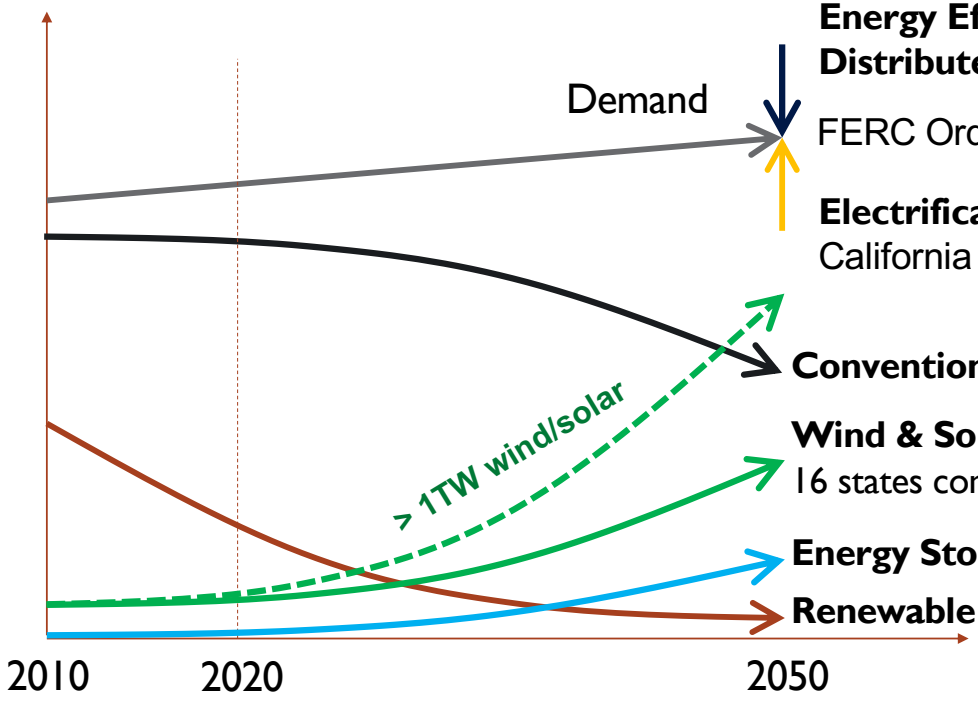
A future of clean electricity towards a Power Electronics-dominated power systems



Energy Efficiency: Buildings ⬆ 45%|$_{2030}$
Distributed Solar: 40%|$_{2019}$ of total solar

FERC Order 2222: DERs in market

Electrification: EV Sales 0.2 M|$_{2019}$ ⬆ 2 M|$_{2050}$
California ending gasoline car sales by 2035

Conventional Generation: 90%|$_{2019}$ ⬇ 70%|$_{2050}$

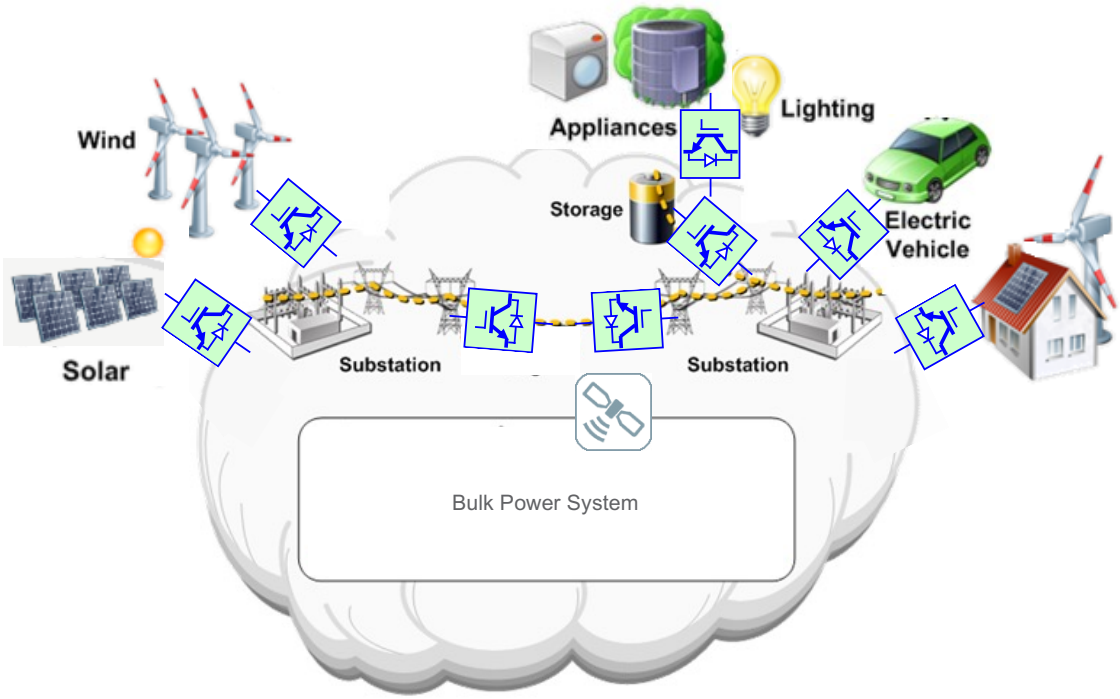
Wind & Solar: 10%|$_{2019}$ ⬆ 30%|$_{2050}$
16 states committed to 100% renewable/clean energy

Energy Storage: California 1.325GW|$_{2019}$

Renewable Production Cost: Solar 3¢/kWh|$_{2030}$

DERs = Distributed Energy Resources
EV = Electric Vehicle
FERC = Federal Energy Regulatory Commission

Ubiquitous power electronics at all levels
– Power electronics are the glue if the grid is the fabric



HVDC/SST: National transmission

MVDC/DC Breakers: Offshore wind and regional transmission

Low Frequency AC: Offshore wind integration and reconductoring

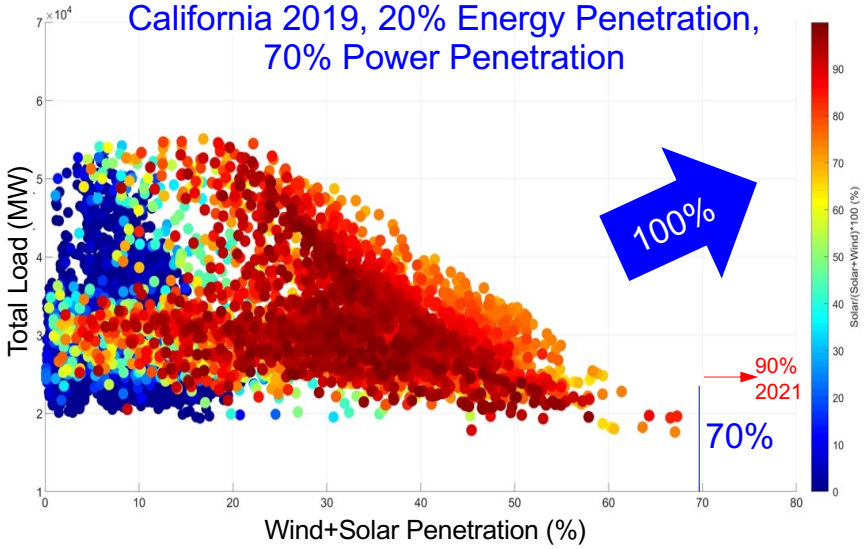
LVDC: Inverters for renewables, data centers, buildings, …

Challenges: low inertia

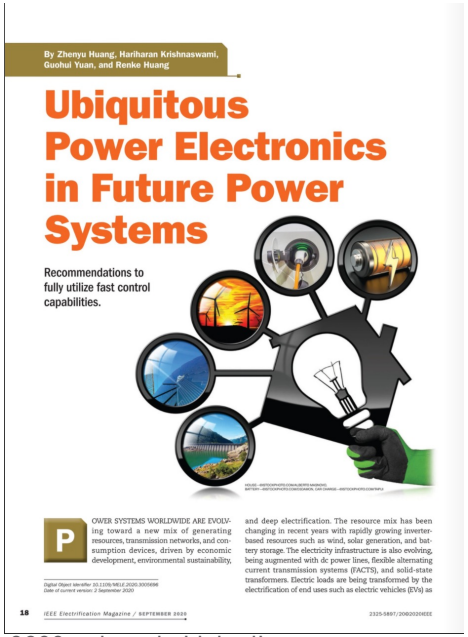
Opportunities: controllability and flexibility

Challenge: PE-based power system reliability

- Inverter-based generation and resources (building loads, EV charging, etc.) displaced conventional ones, resulting in low system inertia and fast dynamics. Instantaneous wind/solar penetration approaches 80-100%!



Data Source: EIA Hourly Data 2020



8600+ views in LinkedIn

Huang, Krishnaswami, Yuan, Huang, "Ubiquitous Power Electronics in Future Power Systems", IEEE Electrification, September 2020.

Challenge: PE-based power system flexibility

- Net load in California “Duck” curve approaching 0, need 80-100% ramping! Plus, no longer unique to California – a bigger system-level challenge.
- Many resources to optimize for maximum flexibility. Significantly larger number of active participants. 2.3 M solar generators on the U.S. distribution system today ➔ 2.3 M inverters, and increasing rapidly.

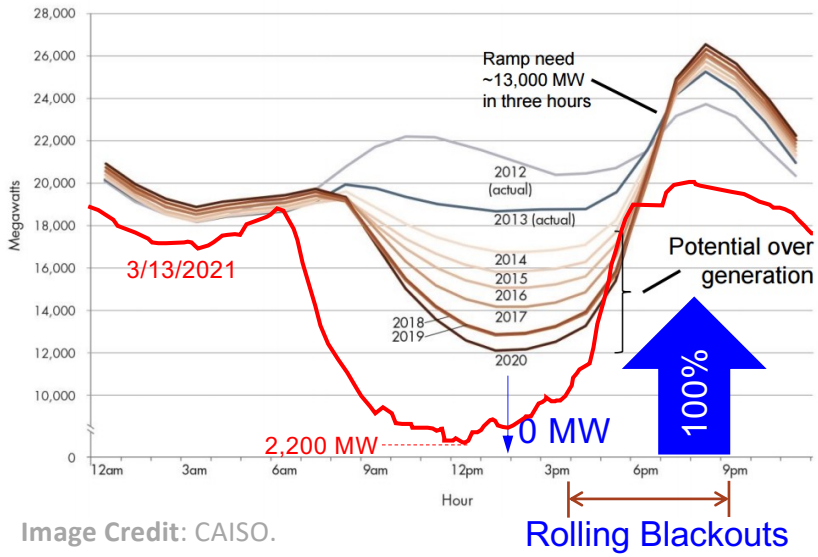


Image Credit: CAISO.

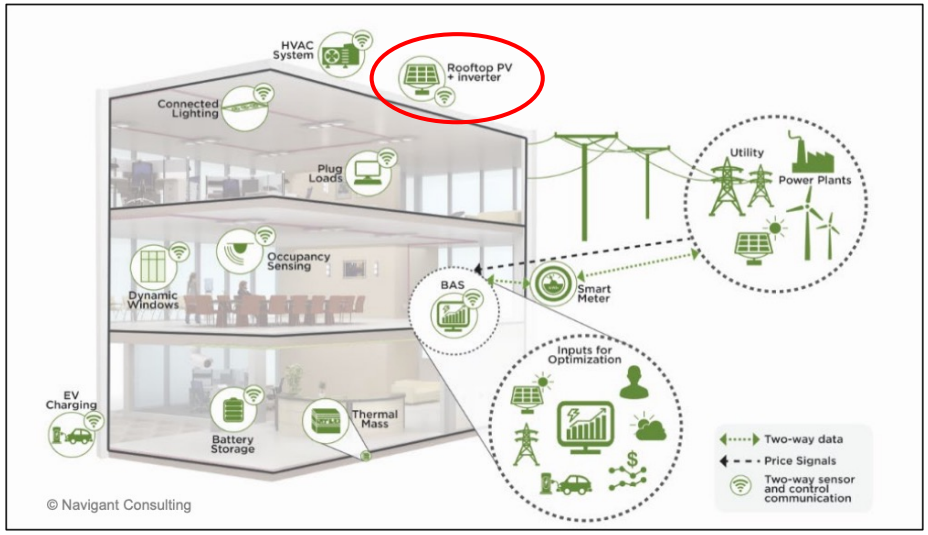
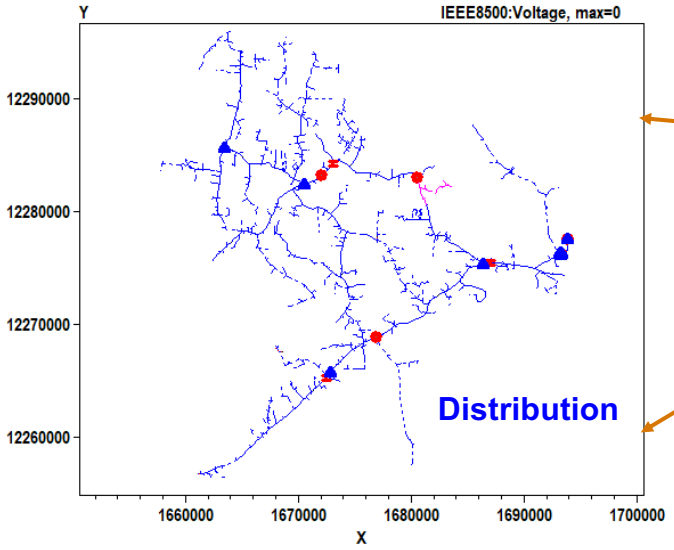
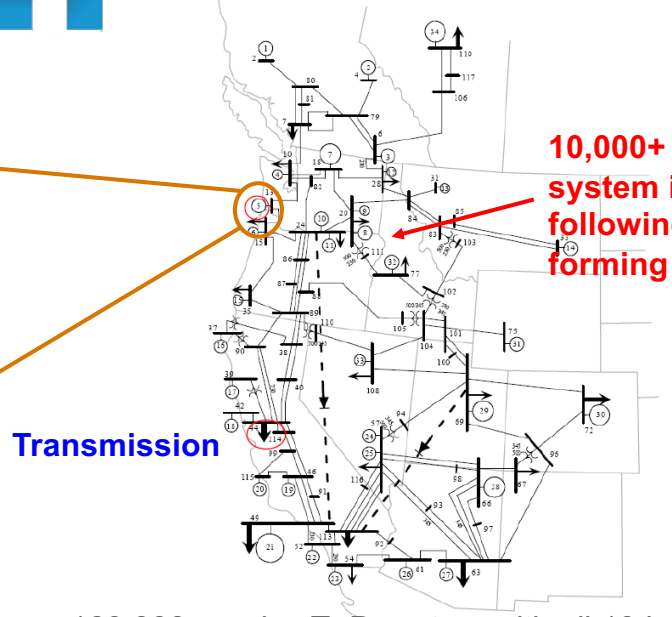


Image Credit: US DOE EERE BTO GEB Overview, 2019

Established large-scale modeling and simulation capabilities for power electronics

GridLAB-D + GridPACK™





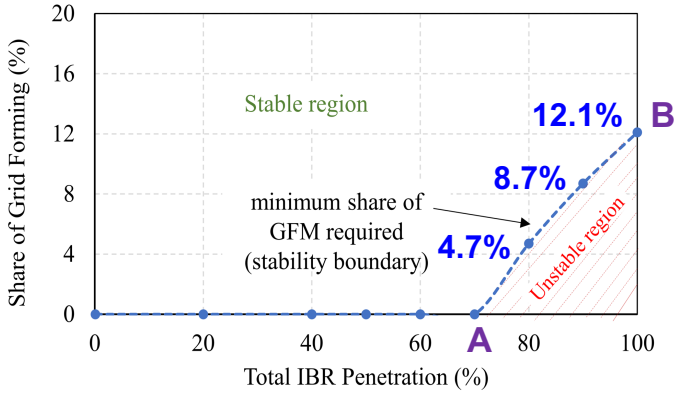
10,000+ IBRs in the T&D system including both grid-following (GFL) and grid-forming (GFM) inverters

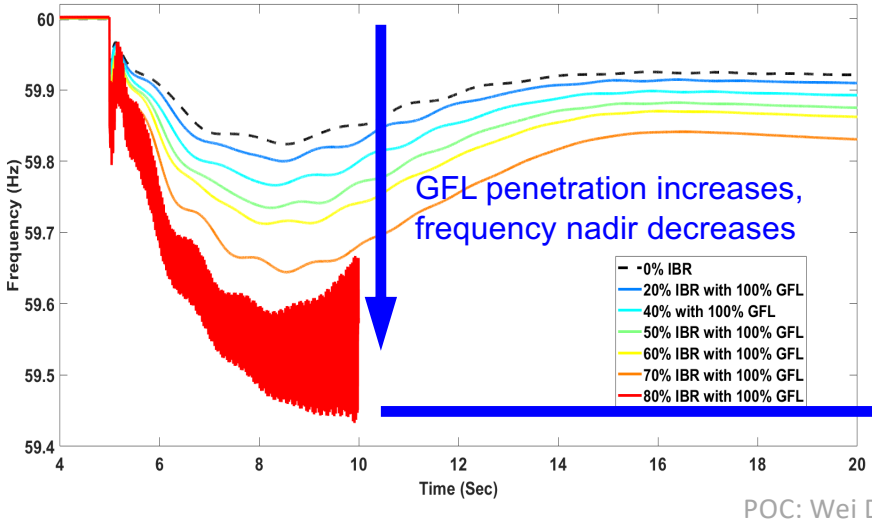
Dynamic simulation of the modified IEEE 8500-Node Test Feeder with 550 IBRs in GridLAB-D.

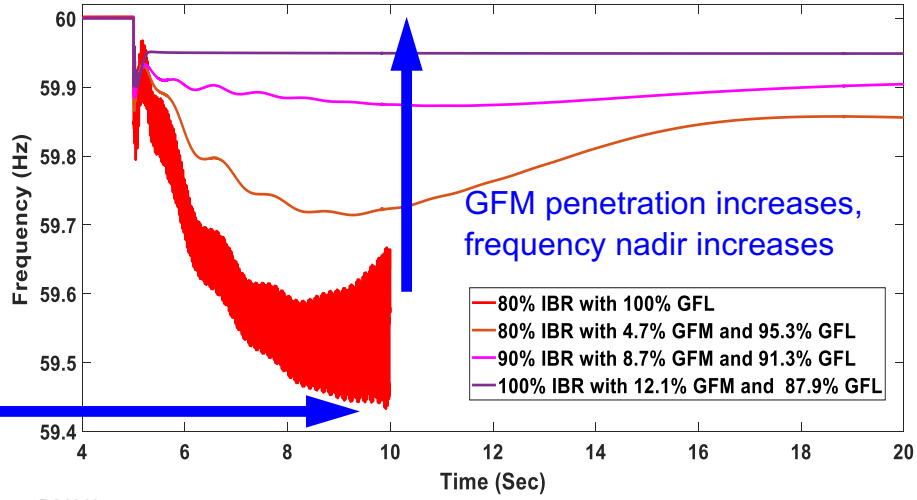
160,000+ nodes T+D system with all 19 load buses replaced with the 8500-node test feeder (19*550=10,450 IBRs)

Inverters enhancing reliability in IBR-dominated power systems

- ***Question***: How many GFMs are needed to maintain the stability of future IBR-dominated systems? In 160,000-node mini-WECC system with 10,000+ inverters:
  - 12.1% in 100% IBR system
  - 8.7% in 90% IBR system
  - GFMs, if properly controlled, achieves better system reliability performance than conventional synchronous machines

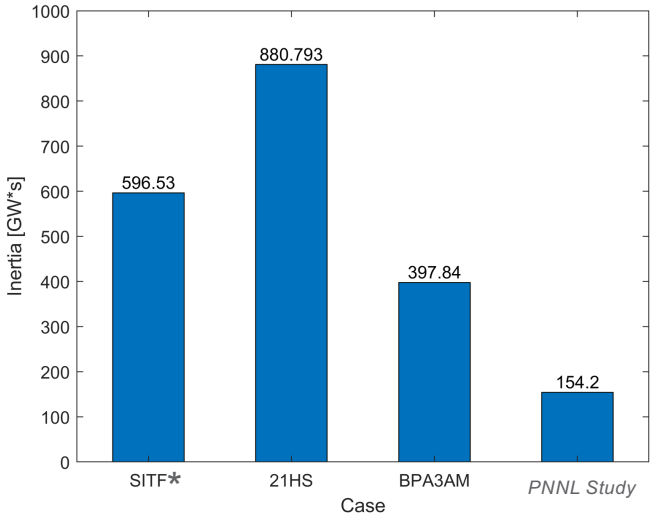




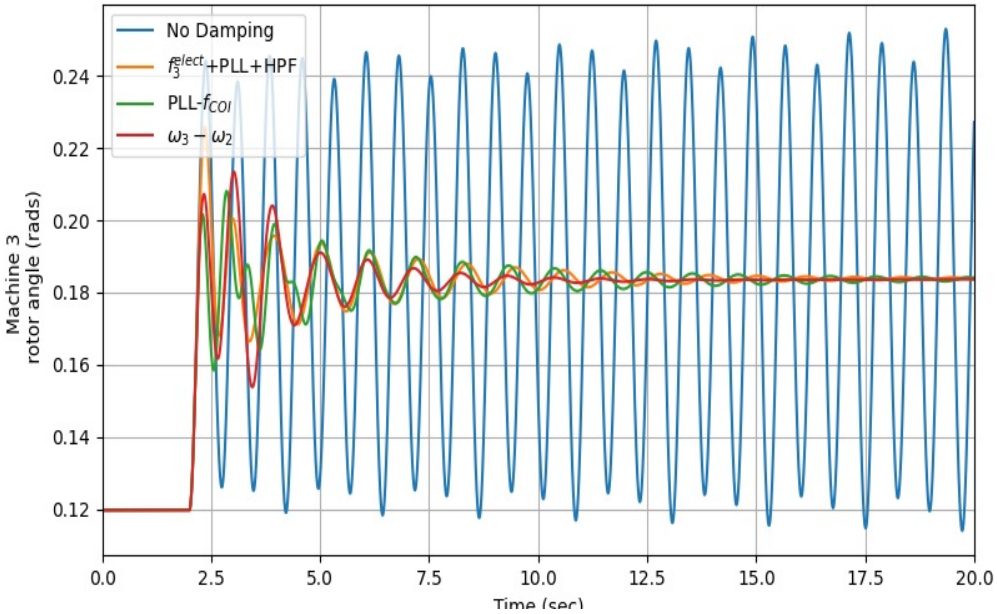


Mitigating reduced inertia with energy storage

- WECC study showed dramatic decrease in inertia for a < 50% RE scenarios
- Energy storage with Fast Frequency Response (FFR) can dramatically improve system damping against disturbance.



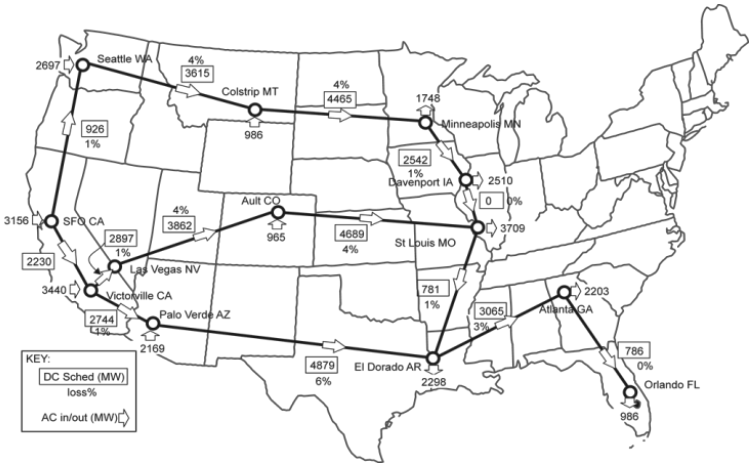
[*] Jon Jensen, Kent Bolton, Dick Simons, "Changes to System Inertia with High Renewable Implementation," WECC, February 2020



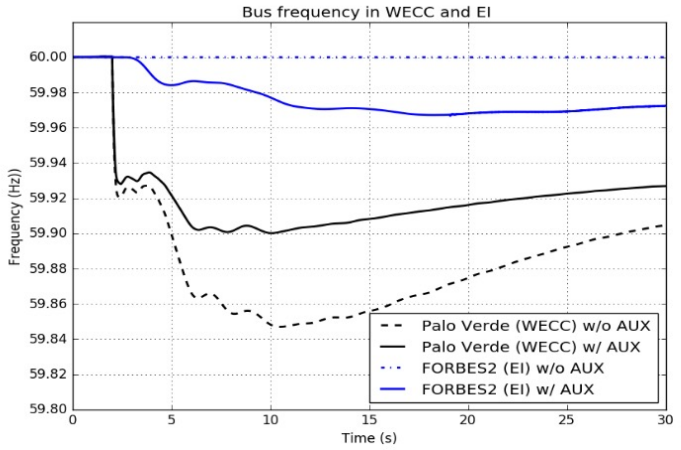
POC: Marcelo Elizondo, PNNL

HVDC: National transmission upgrades

- Developed continental-level combined modeling for the first time.
- Identified benefits such as shared frequency response through HVDC control.
- Such stability analysis complements many recent reports on macrogrid buildout for renewable integration and a clean electricity future.



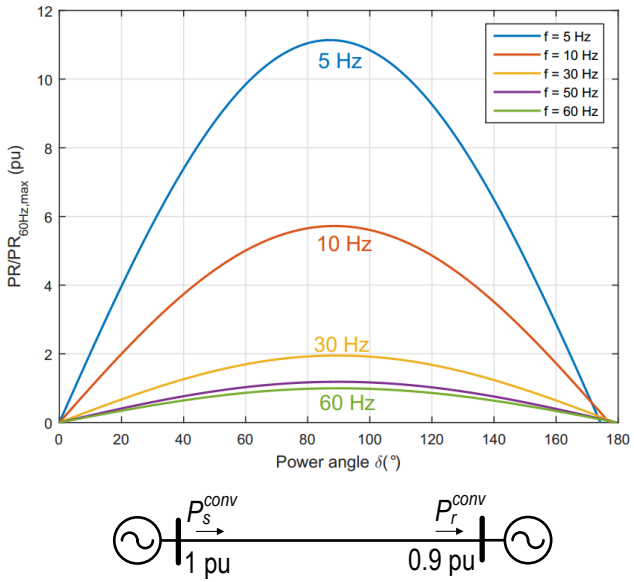
Credit: MISO

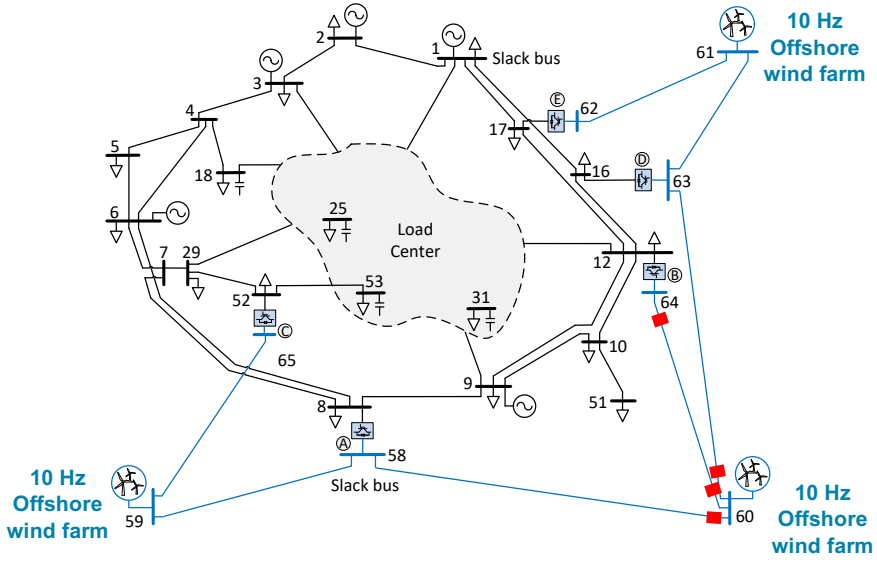


POC: Marcelo Elizondo, PNNL

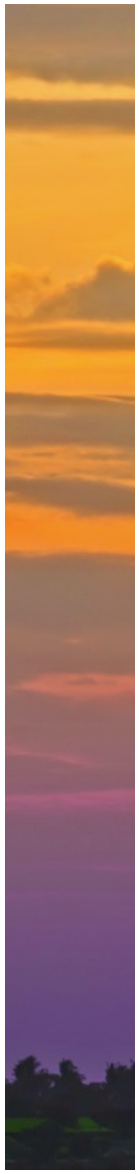
LF-HVac power electronics for network enhancement

- Low-frequency high-voltage alternating current (LF-HVac) to increase power carrying capabilities of existing transmission lines, leveraging existing technologies (e.g. circuit breakers).
- LF-HVac as a viable solution for offshore wind integration with better controllability.





POC: Quan Nguyen, PNNL



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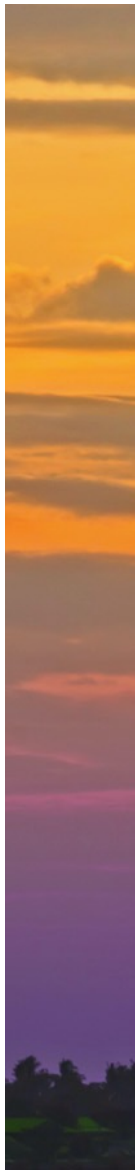
Summary: A more responsive and flexible future grid

- Power electronics are fundamentally changing the dynamics of the grid, at all stages and all scales, towards a clean electricity future.
- Power-electronics-based resources bring challenges, but more importantly, they bring an opportunity for a better future grid – more responsive and flexible!
- New methods, tools, and policies are needed to enable the full functions of power electronics for power system performance, especially considering the probability of renewables. Many efforts are ongoing, but significant needs exist!



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Questions?

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