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CSEE JPES Forum

Enabling Inverter-Based Resource Stability Control in Power Systems with High Converter Penetration

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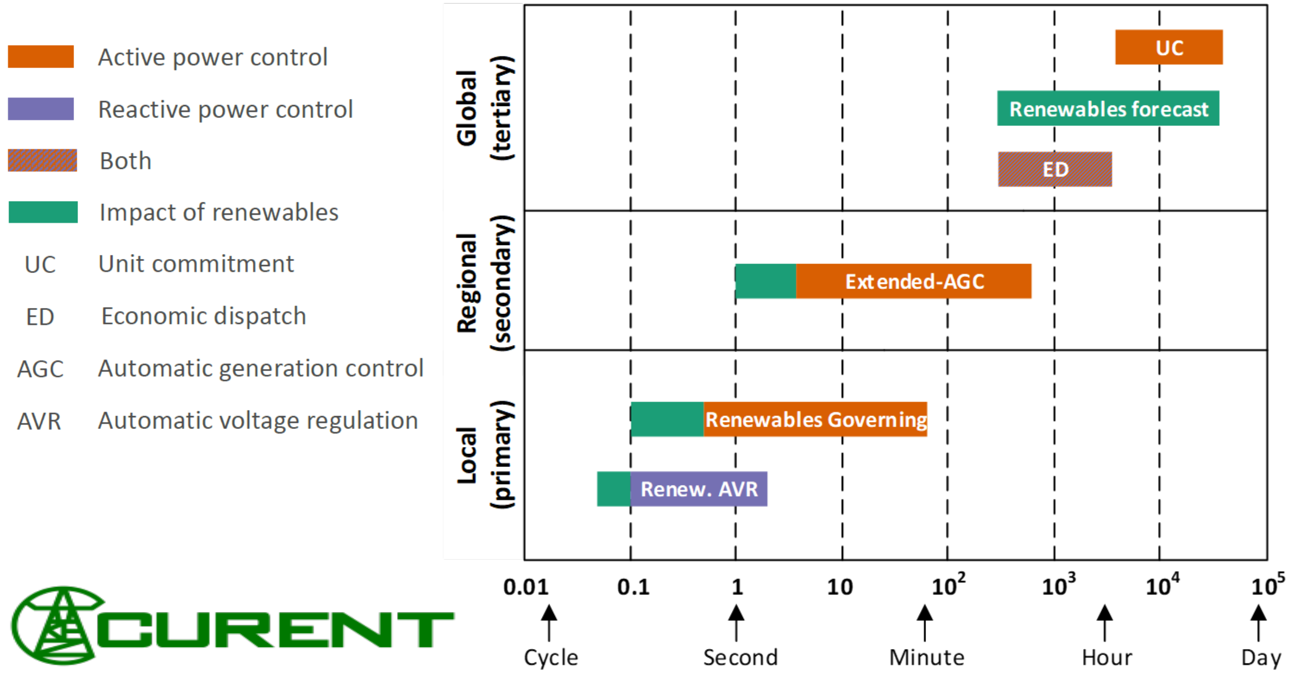
Topics

Opening remarks

- Conventional AC power system relies on generator inertias and reactive power support to allow *time* for relays and control to operate reliably
- In future grid with large penetration of inverter-based resources, converters need to overcome low inertias and weak grid issues
- However, there is good news, as inverters can provide fast active power and reactive power control (time-scale figure below)
  - Active power – changing I_p within a few cycles
  - Reactive power – known from STATCOM control



This presentation

- Inverter control examples
  - Frequency regulation
  - Transient stability enhancement
- Disturbance propagation in systems with inverters
- Concluding remarks

Acknowledgement:

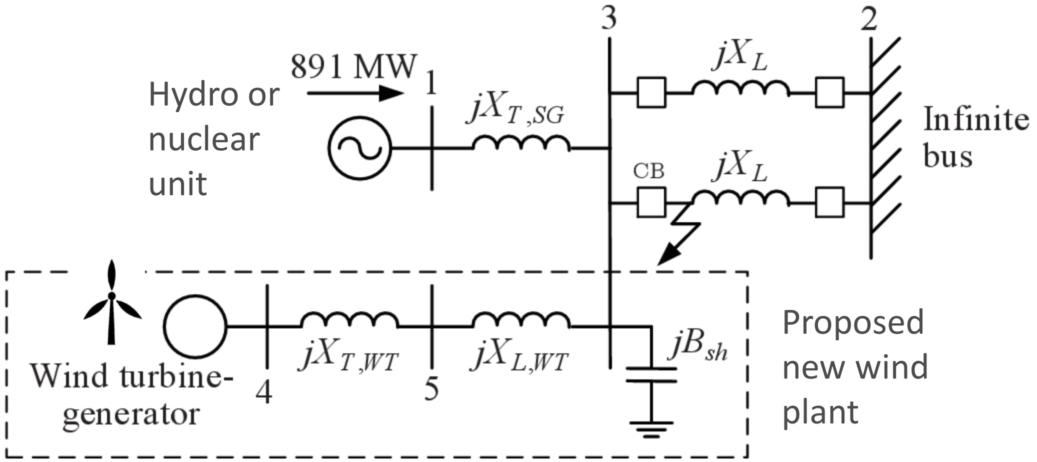
- Funding support from the NSF/DOE CURENT ERC
- ERCOT (Texas) slides (Dr. Pengwei Du)

This talk is condensed from a seminar at Iowa State University, April 6, 2022. Complete set of slides available upon request.

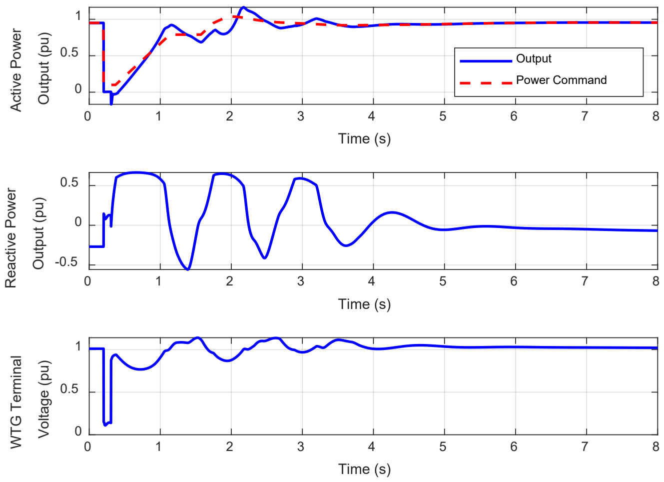
D. Osipov and J. H. Chow, “Operation Paradigm for Power Systems with High Penetration of Renewables and Effects of Climate Change,” IEEE PES General Meeting, August 2021.

WTG Active Power Control for Transient Stability Enhancement

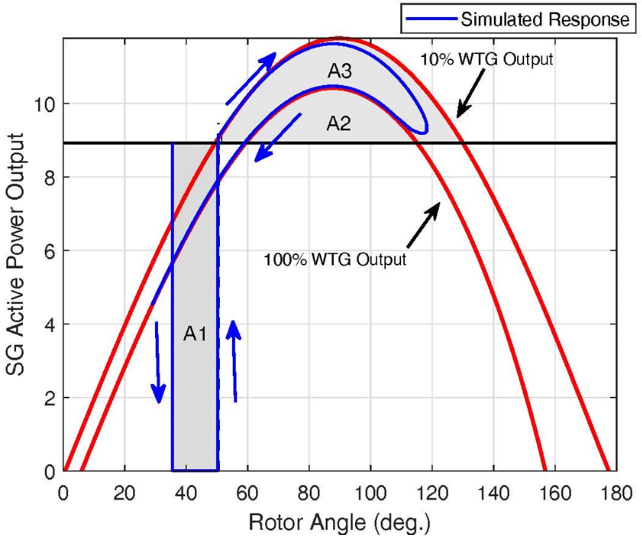
- Synchronous machines operating in a high renewable penetration grid still need to be transiently stable to large disturbances.
- The ability to change active power injection quickly can enhance transient stability, and pushes more power on an already constrained transmission line
- Consider an existing synchronous machine supplying power to a load center on a congested transmission path, as determined by a contingency of a fault for 5.5 cycles, cleared by line trip (see figure)
- Can we install a new wind farm of Type-3 wind turbines to use the same congested transmission path, without SM power curtailment?
- A possible control is to reduce WTG active power output during the fault and ramp it back gradually to full power so that it acts like a braking resistor (like BPA's Chief Joseph braking resistor in Pacific NW)



- Three elements of the proposed adaptive Dynamic Power Reduction (aDPR) control
  - The red dashed line shows WTG reduces WTG active power to 10% and ramps back up to full power in 2 sec
  - Active power ramping is paused at about 1.2 sec as the synchronous generator is accelerating – the frequency measurement of a PMU can be used
  - Reactive power is used to damp power swing from the synchronous generator.



WTG active and reactive power and terminal voltage for a 3-phase short-circuit fault at Bus 3

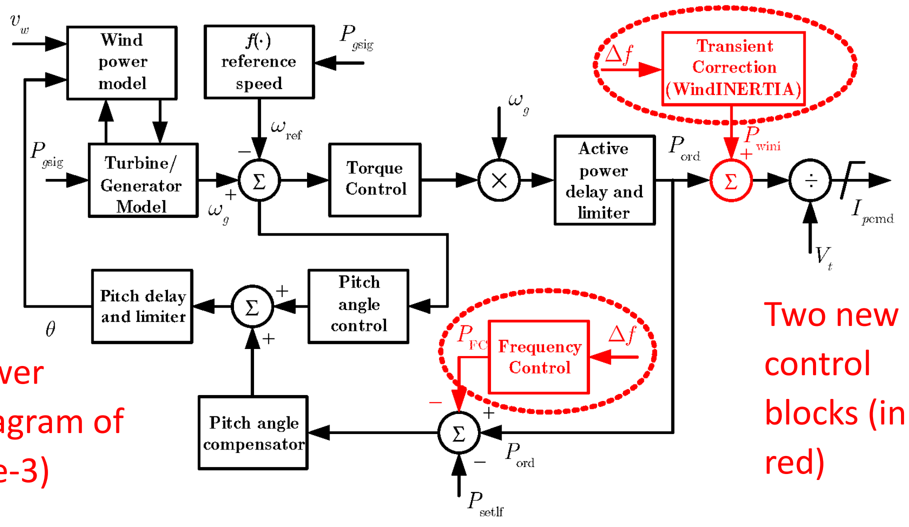


SG power-angle curve and equal-area criterion for 200 MW WTG full and curtailed power output.

S. Konstantinopoulos and J. H. Chow, "Active Power Control of DFIG Wind Turbines for Transient stability Enhancement," IEEE Open Access Journal of Power and Energy, published 2022/7/29

Wind Turbine-Generator Frequency Control

- Requires WTGs to perform frequency regulation – control is designed to be activated when a large generator is tripped and causes a drop in system frequency
- Proposed control – require the WTG to pitch back the wind turbine blades to spill power and create a headroom
  - **Governing control:** blade pitch angle made to respond to frequency variations
  - **Transient correction:** fast power adjustment similar to wind inertia emulation

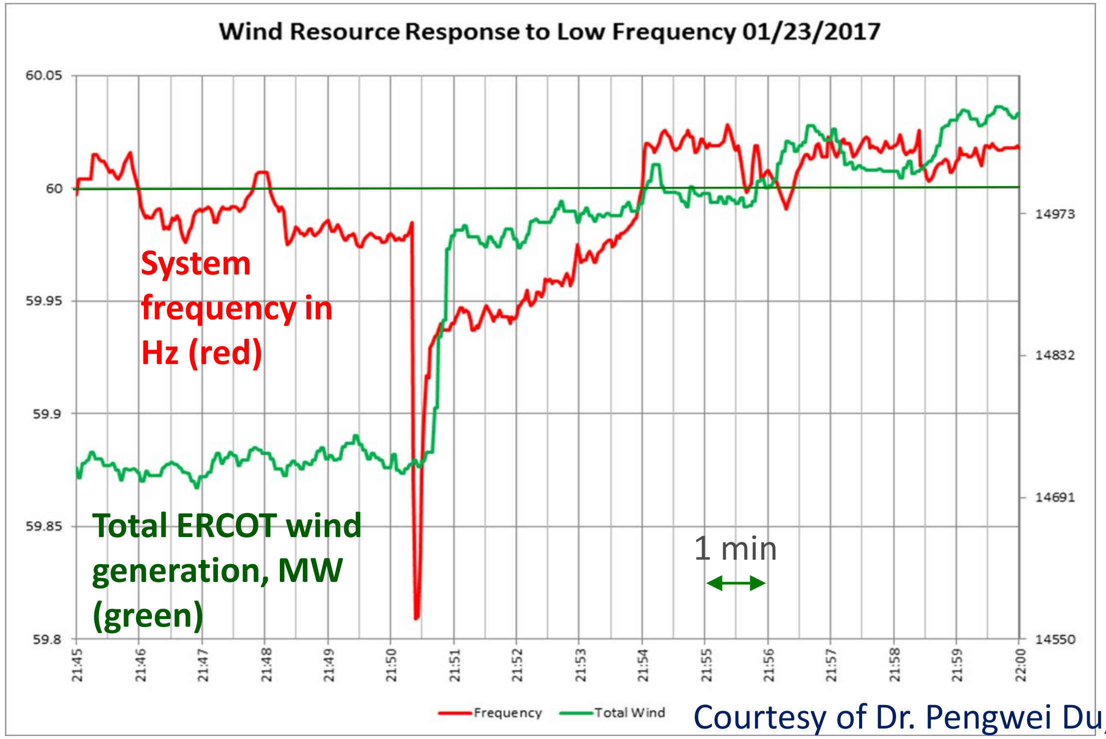


Active power control diagram of DFIG (Type-3) model

Two new control blocks (in red)

Design results and simulation can be found in Felipe Wilches-Bernal, "A Fundamental Study of Applying Wind Turbines for Power System Frequency Control," *IEEE Transactions on Power Systems*, 2015

- ERCOT (System Operator of Texas) requires all generators including WTGs to provide frequency support (5% droop with deadband of 17 mHz); WTGs can hold back 3% of generation for frequency reserve market
- The activation of reserve is dispatched by AGC setpoint signals
- The SCADA data chart (public info) below shows a 150 mHz drop in frequency (red curve) with WTGs (green curve) responding with a 210 MW increase (210/14,700 = 1.4%).



Courtesy of Dr. Pengwei Du, ERCOT

- PMU measurements will enable fast inverter frequency regulation control

Disturbance Propagation in One-Dimensional Radial Systems

- Tripping of Gen 0 (open breaker CB) results in a frequency drop electro-mechanical wave (EMW) from Bus 1 to Bus 11
- The swing equation of the uniform system is modeled as a partial differential (wave) equation

$$\frac{\partial^2 \delta}{\partial t^2} = \frac{k\Omega}{m}\frac{\partial^2 \delta}{\partial x^2} = c^2 \frac{\partial^2 \delta}{\partial x^2}$$

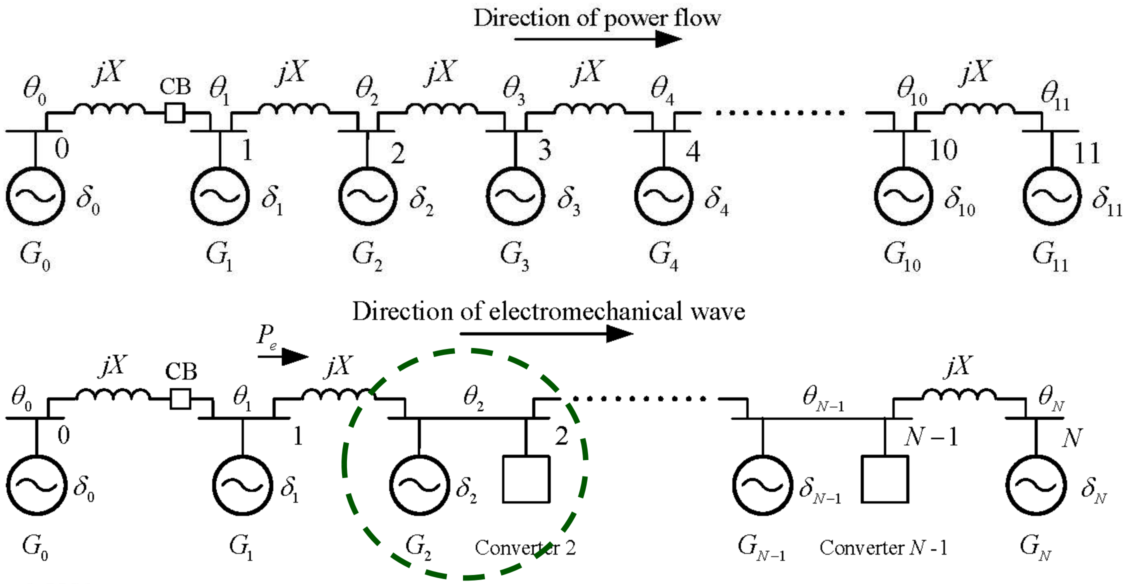
  δ is rotor angle, k and m the susceptance and inertia pu length, and Ω conversion factor from Hz to rad/sec.
- The EMW propagation speed is (Semlyen 1973)

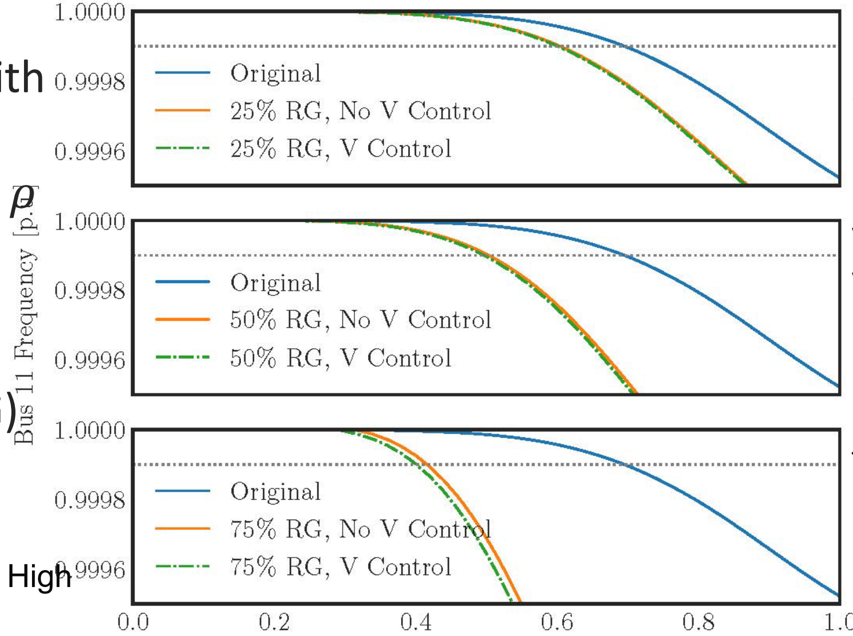
$$c = \sqrt{\frac{k\Omega}{m}} \quad \text{pu-length/sec}$$

- **With inverter penetration:** pair a grid-following converter with every generator to keep system uniformity with the same inverter portion ρ. EMW propagation speed will speed up as ρ is increased from 0 to 1 according to

$$c = \sqrt{\frac{k\Omega}{(1-\rho)m}} \quad \text{pu-length/sec}$$

- Grid-forming inverters in virtual synchronous generator (VSG) mode will slow down the propagation speed
- Inverter control can stop disturbance propagation





Opening of circuit breaker CB – the resulting frequency wave propagation with various levels of renewable generation penetration: increased EMW speed for ρ=0.25, 0.5, 0.75.

H. Cui, et al. "Disturbance Propagation in Power Grids with High Converter Penetration," IEEE Proceedings (2022/5/18)

Concluding Remarks

- New paradigm on power system operation and control time-scale – PMU data and communication will be critical in carrying out such control actions (0.1 – 2 seconds)
- In traditional AC power systems, only reactive power can be controlled quickly, and transmission line flow (FACTS) controllers can affect the active power line flow, but not power injections. With inverters backed by energy sources (wind, solar, battery, …)
  - Inverters can rapidly change active power injections and provide potential benefit to many stability situations for AC power systems.
  - Weak grid problems including inadequate reactive power support – SG retirement/replacement implies loss of inertia and reactive power support – uprate the inverters. For example, a 100 MW WTG equipped with a 110 MVA converter rating can provide 45 MVar at full active power of 100 MW (square-root effect).
- Future research directions
  - Field demonstration of benefits of advanced inverter stability control
  - Renewable siting and transmission planning accounting for inverter transient stability control
  - Coordination of smaller renewable resources to achieve active power control design on bulk power system
  - Reliable operation of protection systems in high inverter penetration systems