Wind Turbine Participation for Microgrid Frequency Control

Matthew Chu Cheong Zheren Ma Dongmei Chen

THE UNIVERSITY OF TEXAS AT AUSTIN

Advanced Power Systems and Control Laboratory

INTRODUCTION

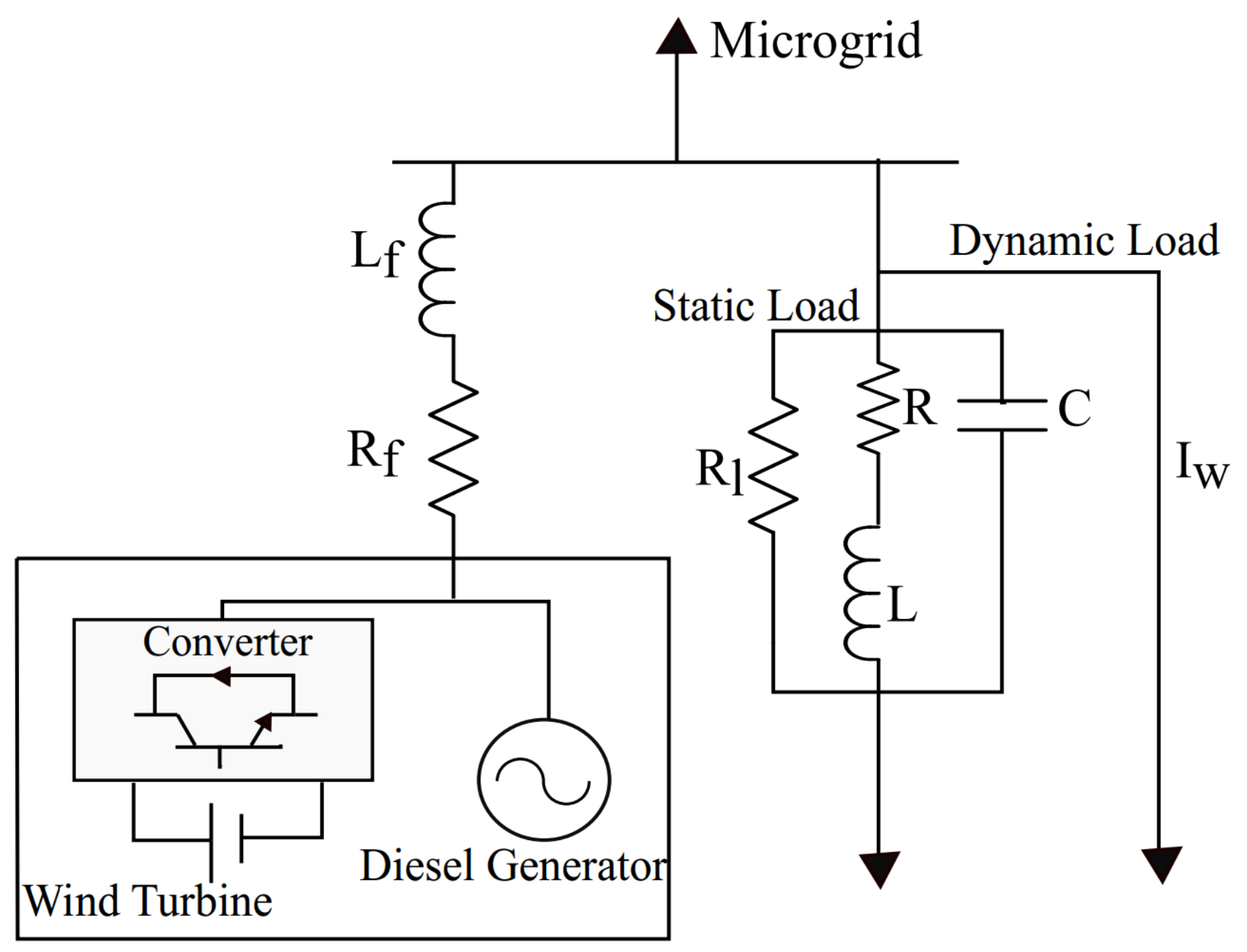
One of the most abundant renewable and clean energy sources on earth is wind energy. With advancements in wind turbine technology, and investments into clean energy, wind energy penetration has dramatically increased over the last decade. It requires the grid to be resilient against the intermittence of the wind energy generation.

Motivation

Conventional synchronous generators have a physically spinning rotor that is coupled to the grid frequency. Following a grid disturbance, the inertia in this rotor means that the frequency response in the grid is slowed. Meanwhile wind turbines are physically decoupled from the grid's frequency, and do not contribute to the inertial frequency response of a power system. With a higher proportion of wind energy, particularly for microgrid

ncy regulation is more

erators.

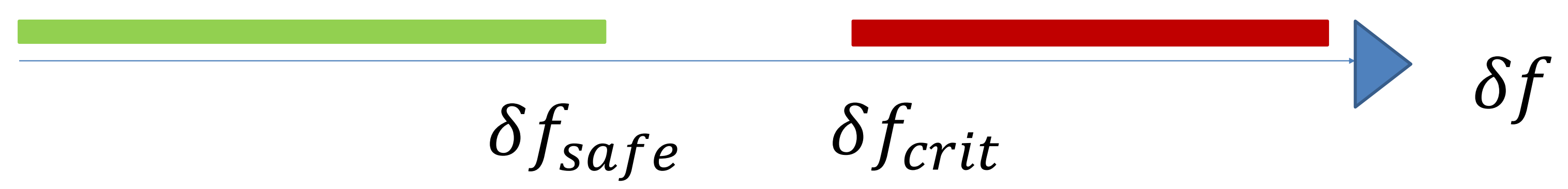


Proposed hybrid setup, where the wind turbine can provide fast power injections

Proposal: Wind Turbine Frequency Support

- Wind turbines do not normally participate in frequency control, but they do have a heavy, spinning rotor- can we use this to emulate an inertial response?
- Fast power electronics allow the generator torque to rapidly change, and draw power from the rotor's inertia.
- This idea is not fundamentally new, but has not been implemented effectively in practice. Previous methodologies have either been inefficient (deloaded control), or lack robustness/stability

METHODOLOGY



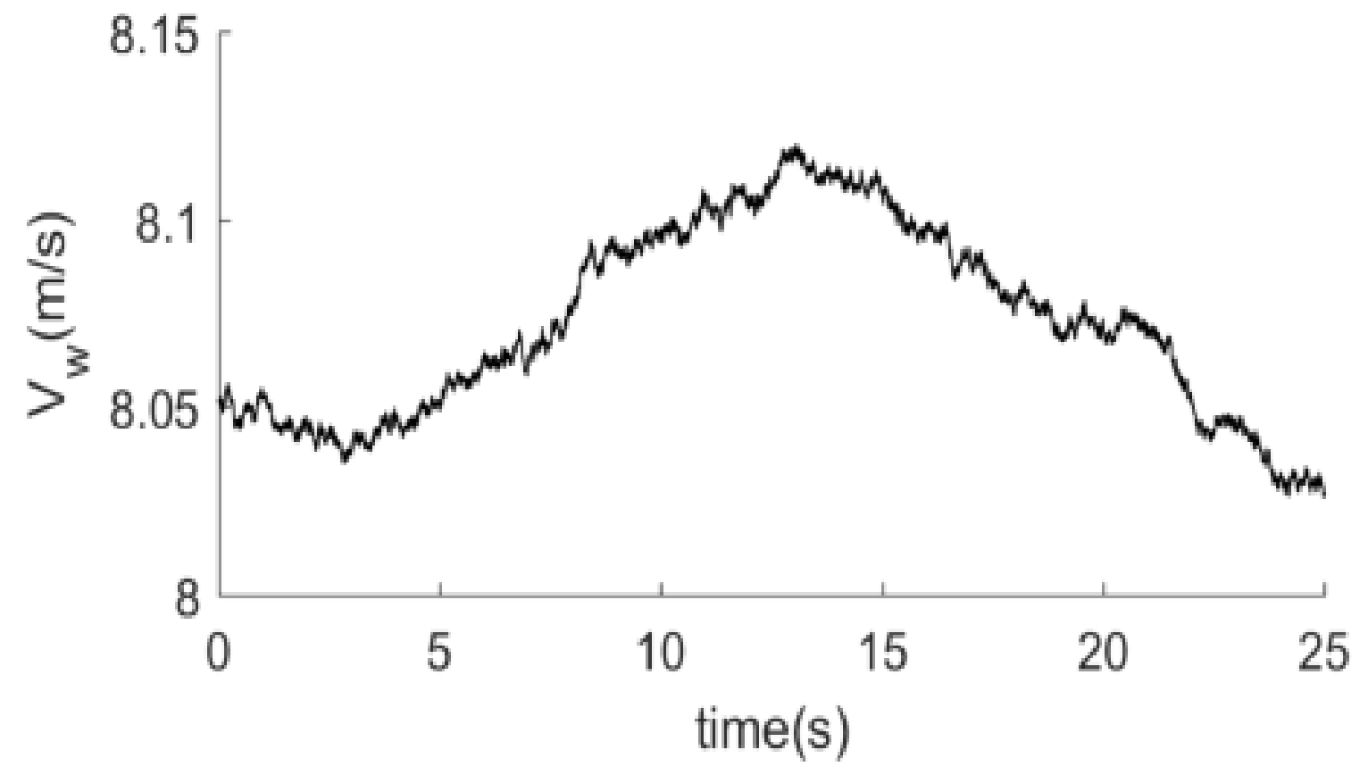
- If frequency error is less than critical threshold, wind turbine operates as a "normal" wind turbine:
    - If available wind cannot meet the nominal power setpoint, the wind turbine maximizes power delivery to the grid.
    - Otherwise the turbine tracks its power setpoint.
- If frequency error exceeds the critical threshold, the turbine supports the grid frequency
- "Gap" is to avoid limit cyclic behavior; control modes are linearly interpolated to avoid discontinuous switching

Wind Turbine Control for Frequency Support

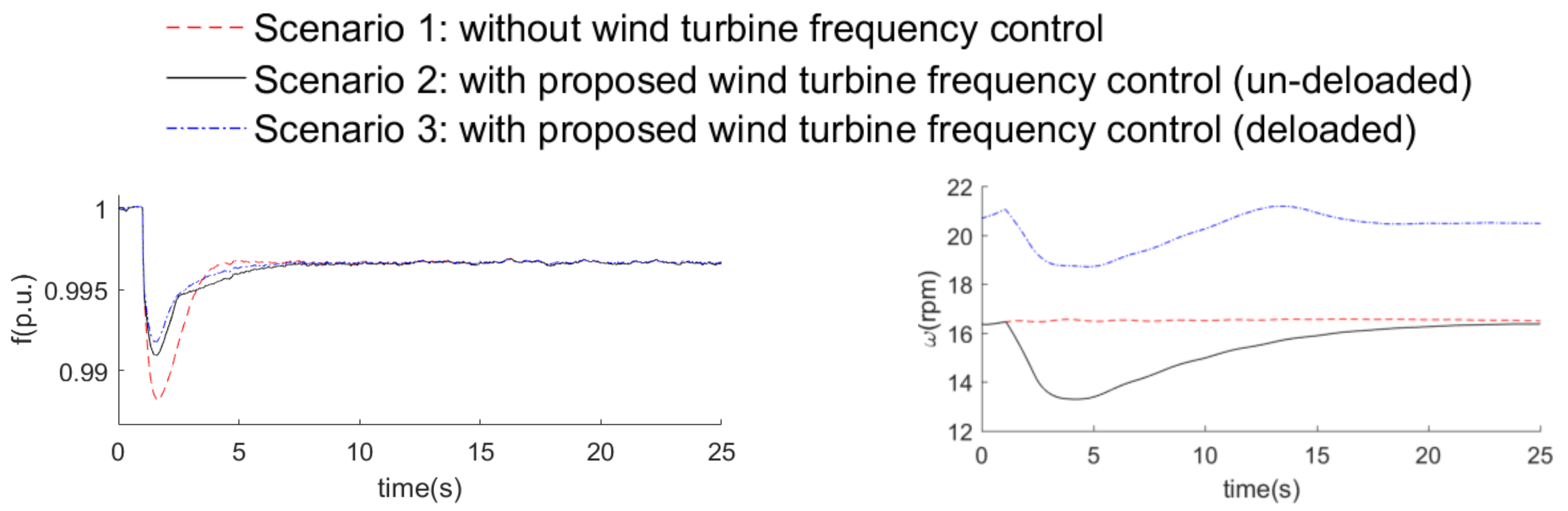
- A wind turbine can rapidly inject power, but this power cannot be sustained; synchronous generators can sustain the necessary power output, but cannot ramp up as quickly.
- For a synchronous generator connected to the network, mechanical power must increase in response to a frequency deviation:
    - $\Delta P_m = m\Delta\omega$
    - P_m is limited in its ramp rate
- Can add power injections from the wind turbine:
    - $\Delta P_m + \Delta P_w = m\Delta\omega$
- If the turbine rotor is at a stable operating frequency, can increase the torque to match this power differential:
    - $\Delta P_{command} = m\Delta\omega - \Delta P_m$
- Turbine power is tracked using an H-2 optimized blade pitch angle controller
    - Standard gain-scheduled pitch control is not robust enough for this application, particularly in variable wind conditions
    - Cost function: $J = W\left\|\frac{\Delta\omega(s)}{d(s)}\right\|_{\mathcal{H}_2}^2 + \left\|\frac{s\beta(s)}{d(s)}\right\|_{\mathcal{H}_2}^2$
    - Blade pitch angle controller gains (PI-gains) obtained by optimizing the cost function.
- If the rotor critically slows, the wind turbine maximizes power capture to increase rotor frequency.

SIMULATIONS AND RESULTS

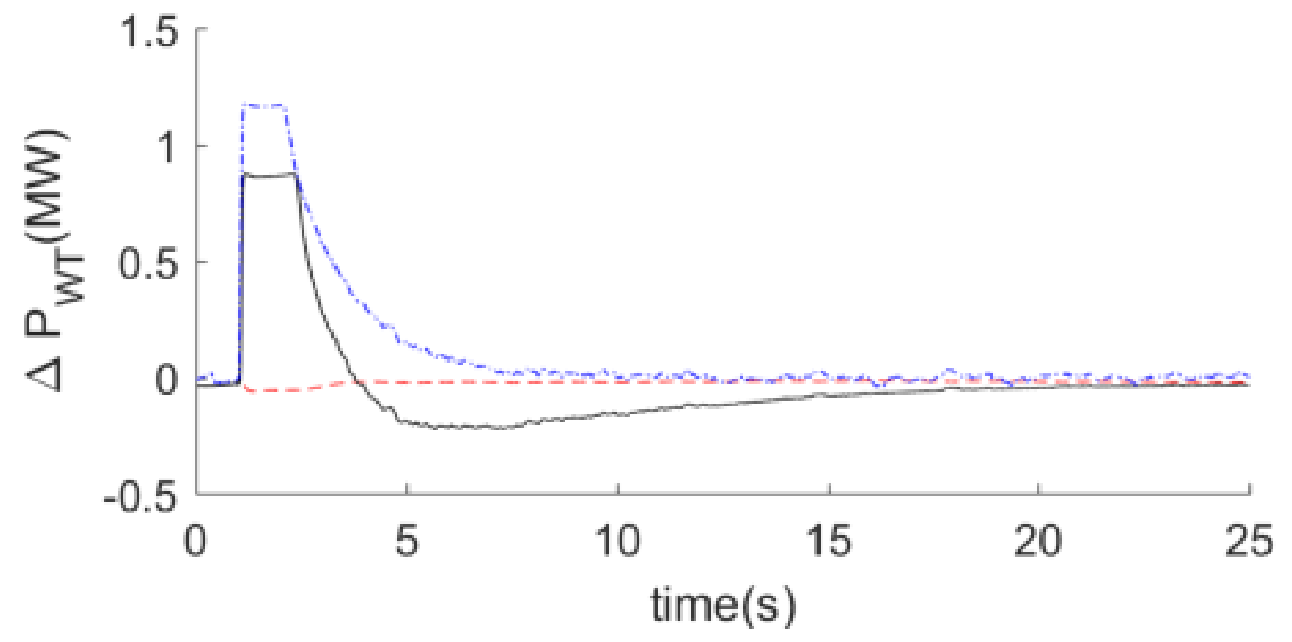
- How does this combined controller help mitigate the frequency deviation during an under-frequency event?
- Wind turbine modeled using NREL FAST code, wind profiles simulated with NRE turbsim code.
- Wind profile:



- We consider the cases where the wind turbine's power setpoint is (1) less than what is available (deloaded), (2) greater than what is available (undeloaded).



Grid Frequency Rotor Frequency



Wind Turbine Power Output

- We see that the addition of the wind turbine results in a notably mitigated frequency undershoot
- Overall power sharing is unchanged as intended: steady-state frequency offset remains the same
- Undeloaded operation (where the turbine does not have "extra power" to work with) can stably provide frequency support. After the disturbance, the turbine must then work to speed its rotor back to its nominal operating point.

Cockrell School of Engineering

Mechanical engineering department