

GRID FORMING IN DFIG-BASED WIND TURBINES

ESIG Fall Technical Workshop, Providence, RI

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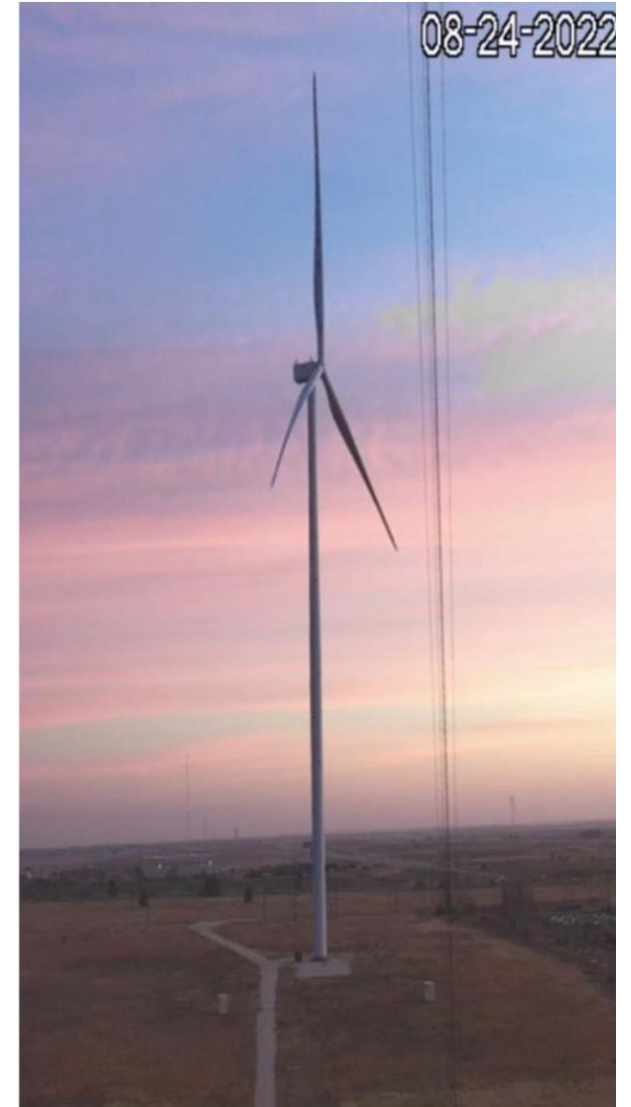
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Agenda

- Wind GFM Prototype Testing
- GFM Response in DFIG Wind Turbines
- Inertial Capability of GFM DFIG
- Conclusions

Prototype Tests

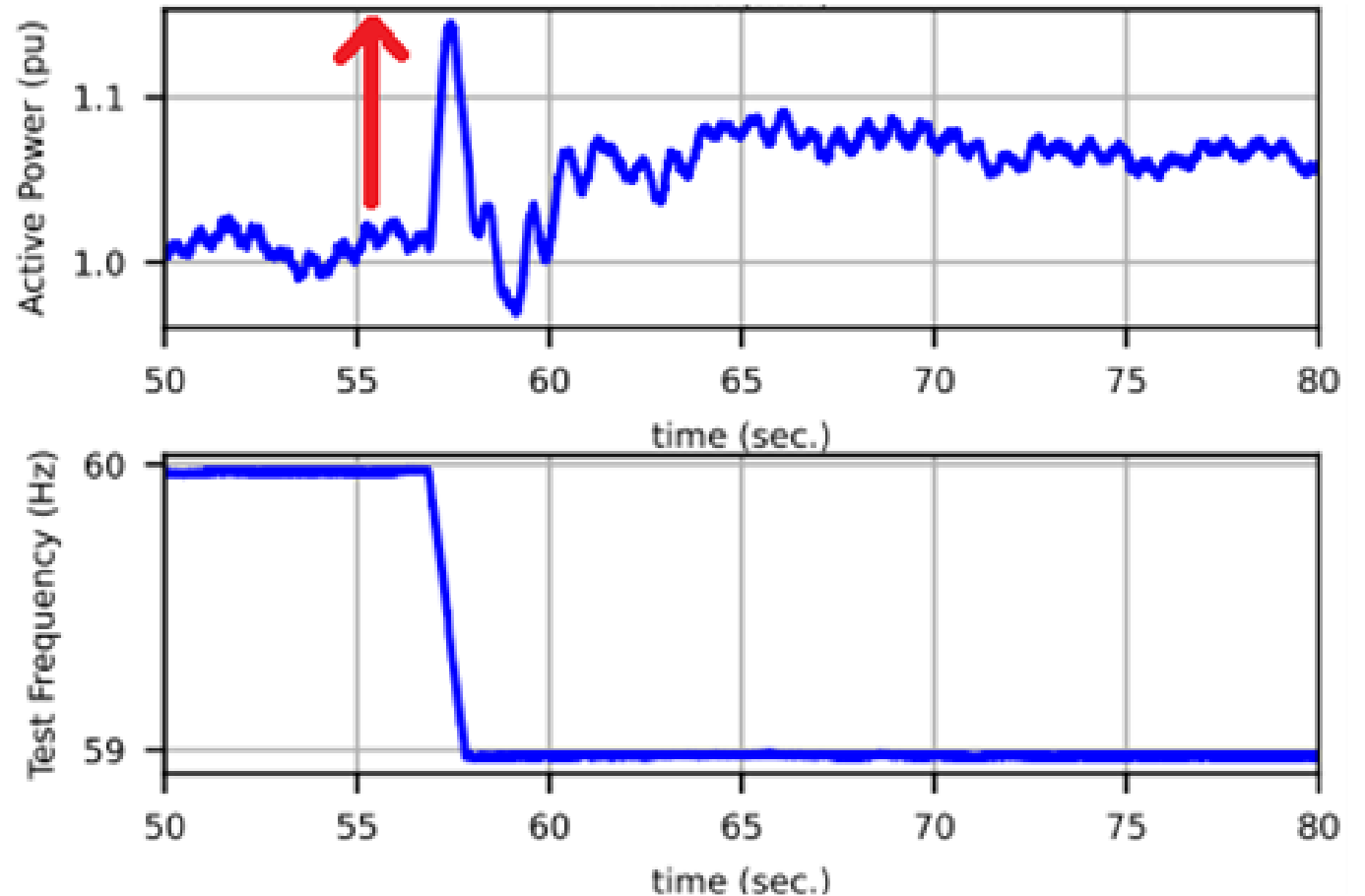
- Turbine Prototype (Lubbock, TX, USA)
 - Standard GE 2.8 MW DFIG
 - Prototype GFM Controls
 - Connected to Local Grid
- Preparation Steps (~2-3 years)
 - GFM Control design and careful coordination with equipment/energy limits of particular turbine hardware
 - Rigorous simulation validation on multiple simulation platforms
 - Electrical subsystem testing
 - Regression testing
 - Creation of test plan
 - Review/approval with engineering leadership



2.8MW Prototype Turbine, Lubbock TX, USA

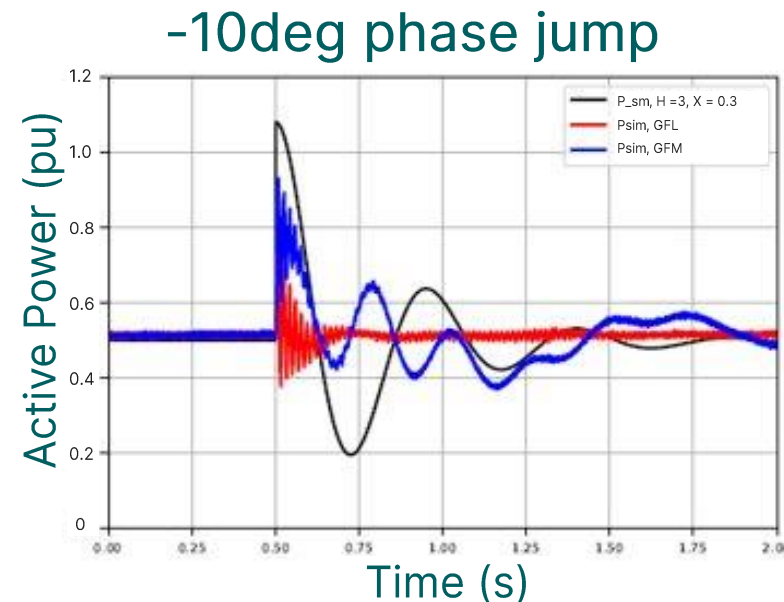
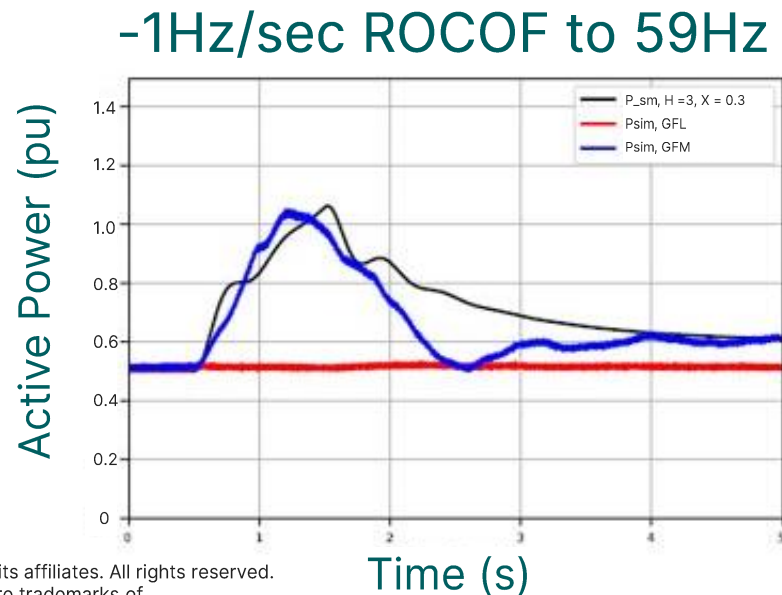
Prototype Results

- Turbine Prototype
 - Standard GE 2.8 MW DFIG
 - Prototype GFM Controls
 - Connected to Local Grid
- ROCOF Test
 - WTG Running at Rated Power before ROCOF
 - Immediate Increase in Power to ~1.15 pu due to Inertial Response
 - Power Reverts to Higher than Initial Conditions due to Droop



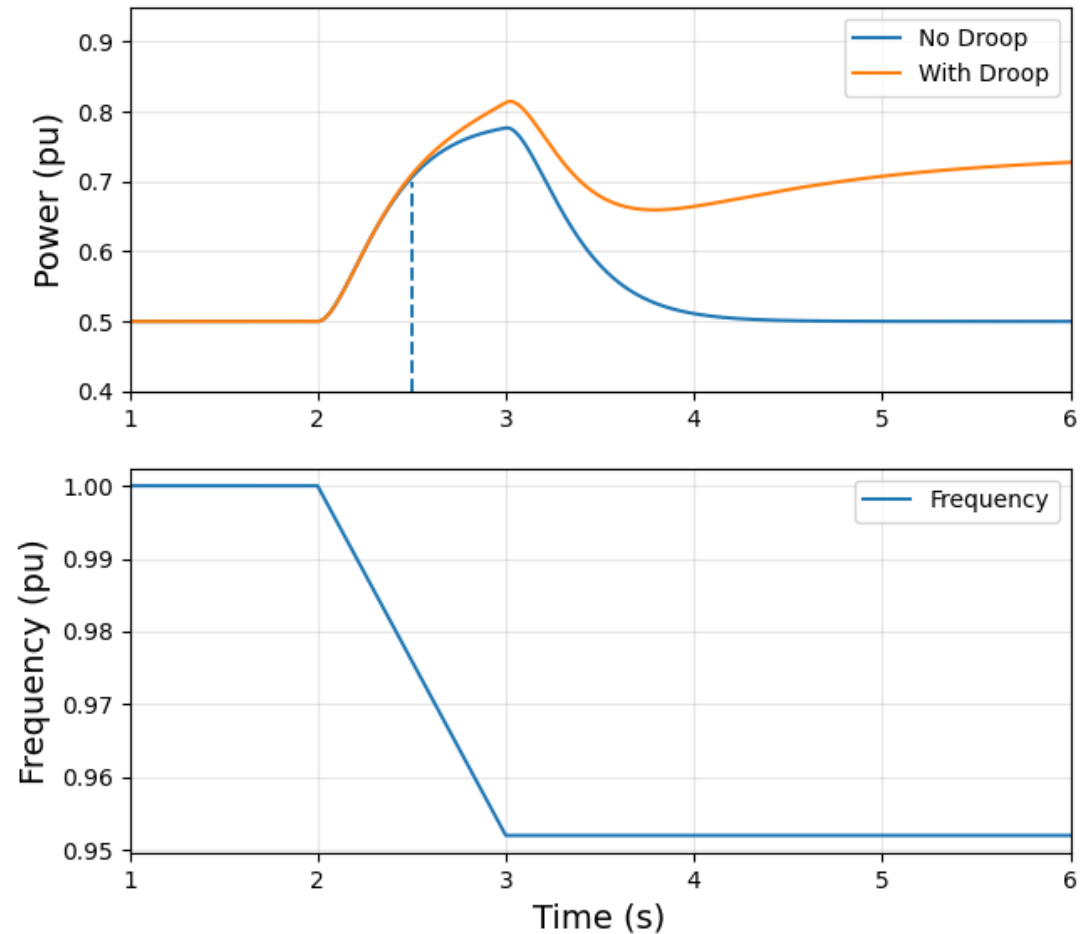
GFM Grid Strengthening

- **Voltage Angle Strengthening:** Maintain positive-sequence phase angle approximately fixed during transient conditions and when equipment limits are not being reached
- **Voltage Magnitude Strengthening:** Maintain positive-sequence voltage amplitude approximately fixed during transient conditions and when equipment limits are not being reached

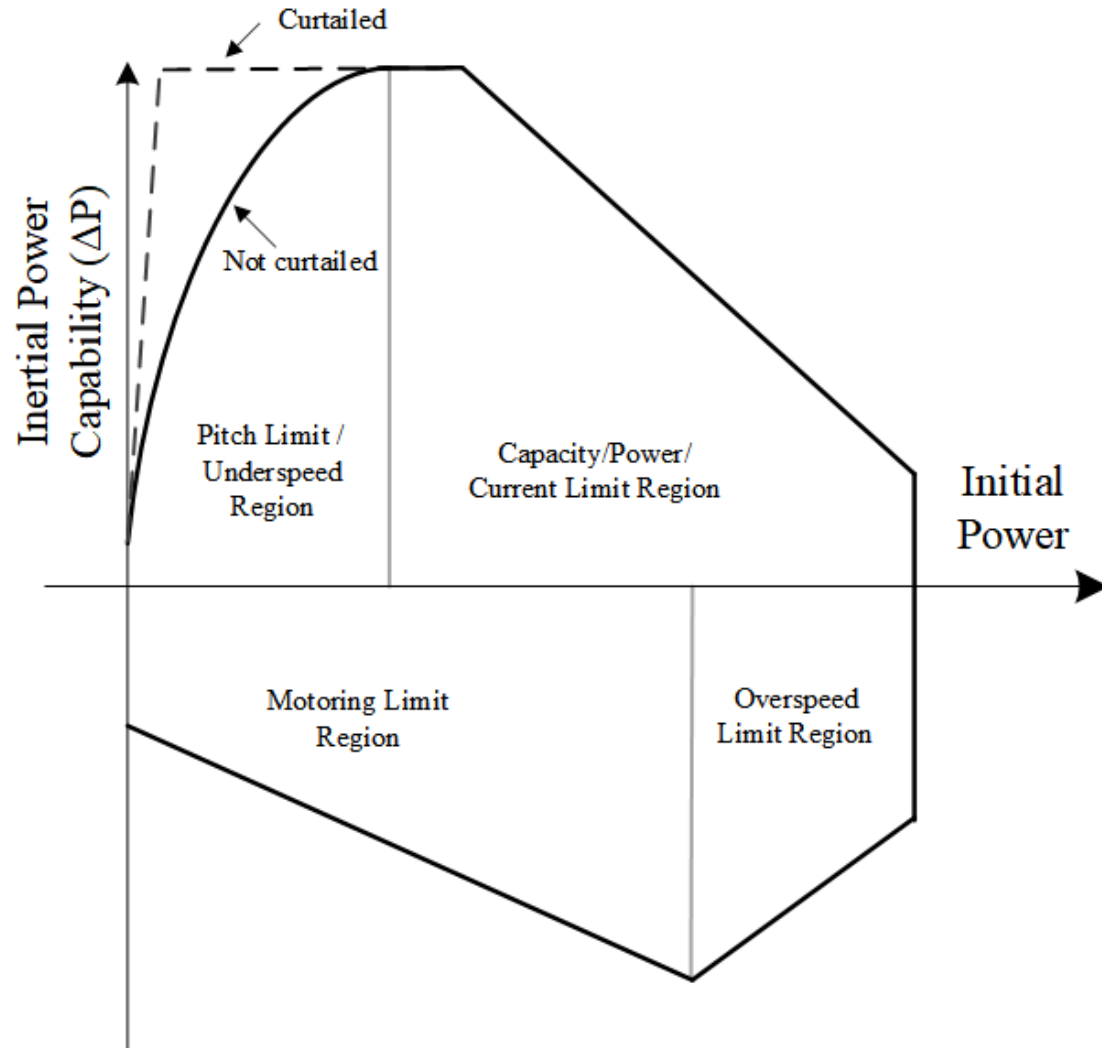


How to Define Inertial Contribution?

- Fast and Slow Dynamics
 - Phase Jump Response
 - Plant Droop, Pitch Blade Angle
- Testbed for Inertial Contribution Limits
 - Apply ± 3 Hz/s ROCOF with Strong Grid
 - Measure Inertial Power at 500 ms
 - Keep Applying ROCOF to Determine Limits
- Example of Synchronous Generator With and Without Frequency Droop
 - Frequency Droop Washes out by 500ms



Qualitative Inertial Capability Curve

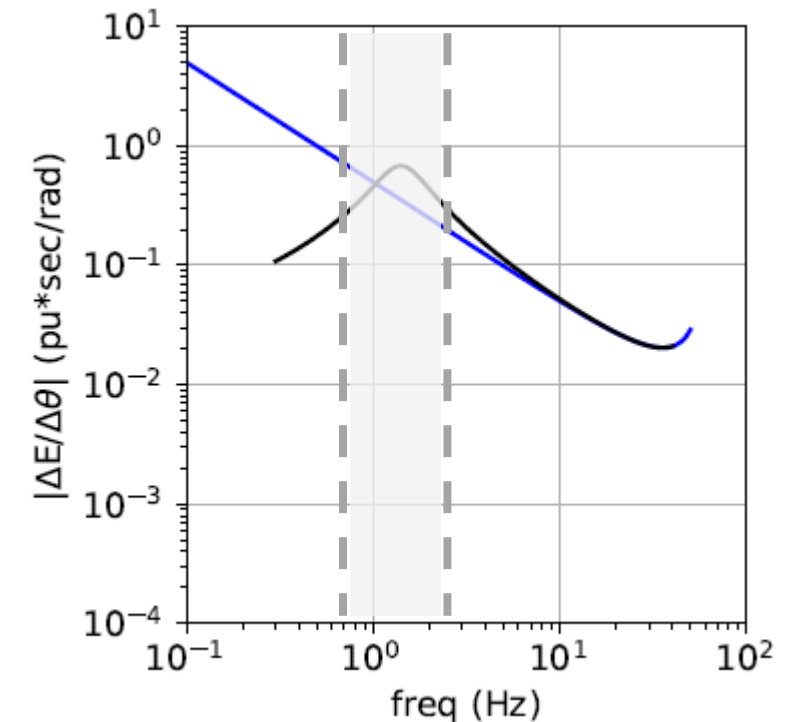


- Inertial Capability Curve of DFIG
 - Does Not Represent Specific Product or Configuration
- Different Than BESS or Other WTGs
 - E.g. BESS Contributes Maximum Inertia at Zero Initial Power
 - DFIG Doesn't Operate in Sustained Negative Initial Power
- Curtailed vs Not Curtailed Limits
- Capability Limiting Factors
 - Overspeed/underspeed limits,
 - Blade pitch angle response time,
 - Hardware Capacity Limits

Practical Power/Energy Limitations

- DC Energy – Constrained Devices
 - DC storage is negligible in typical IBR
 - Without curtailment or specially designed hardware with additional storage, DC-Energy constrained IBR cannot meet the $\Delta P/\Delta\theta$ characteristics of V behind X for dynamics relevant for positive-sequence
 - Example DC – Constrained Devices: solar, statcoms, wind turbines operating in ‘statcom’ mode
- Resonance – Constrained Devices
 - Mechanical systems often have resonances in certain frequency ranges that may require frequency “exclusion zones” to avoid overstimulation of resonance
 - Outside this exclusion zone, IBR may exhibit V behind X characteristics (even without curtailment)
 - Example Resonance-Constrained IBR may include: wind turbines, pumped hydro

- V behind X
- GFM without Power/Energy Constraints
- - - Example frequency “exclusion zone” for resonance-constrained IBR



Conclusions

- Fault Ride-Thru Performance of GFM Wind Largely Similar to GFL Wind
- Inertial Contribution Needs to be Carefully Defined so it Does Not Exclude Equipment Beneficial for Grid Stability
- Mechanical limitations, in addition to current limitations, should be considered in GFM requirements to avoid making GFM IBR with rotating machines overly expensive