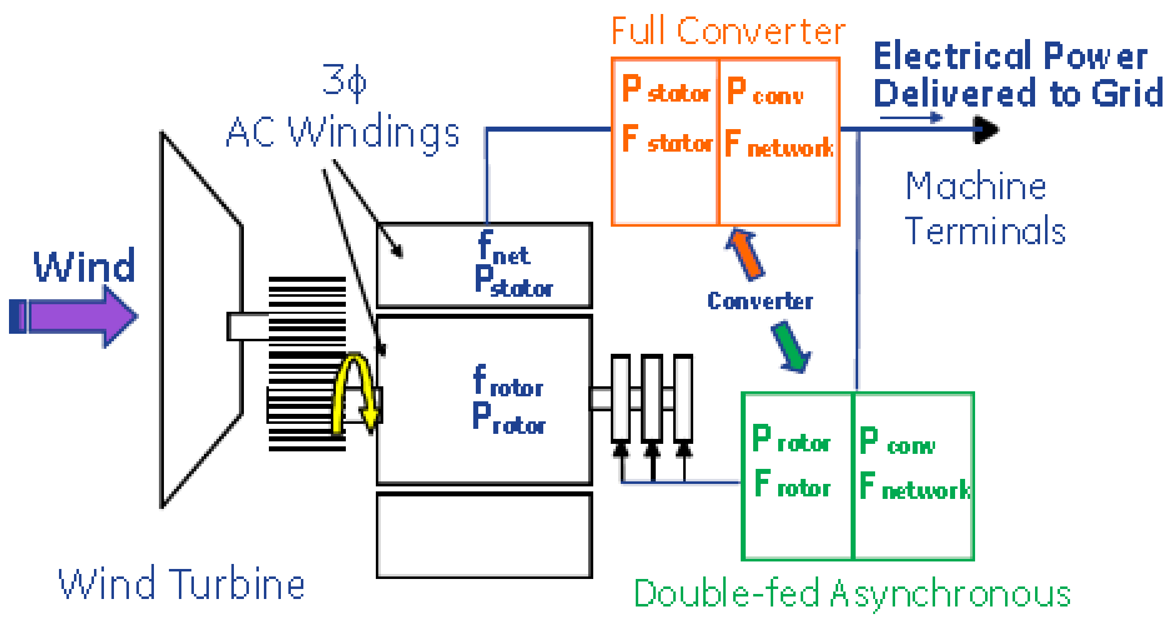
GE Energy

Voltage And Reactive Power Control

Nicholas W. Miller

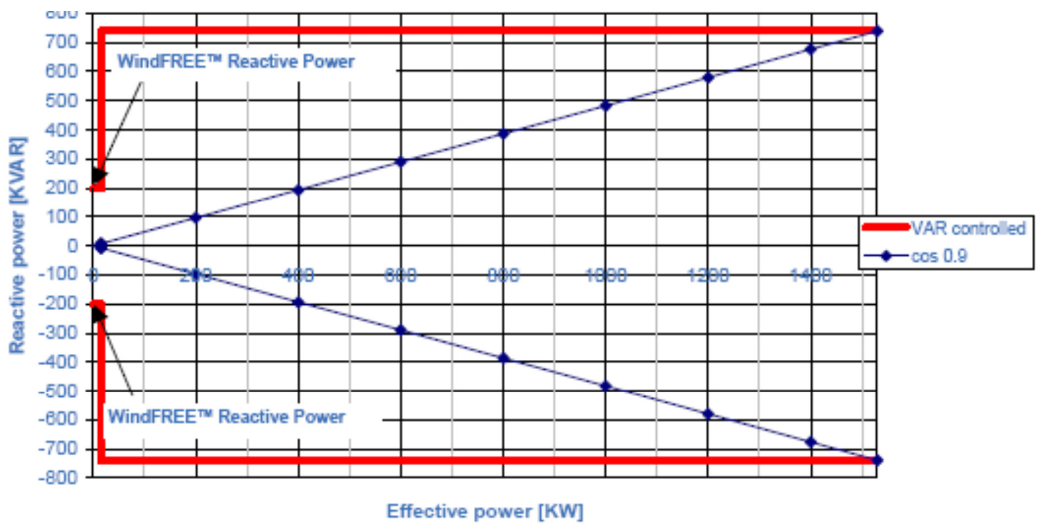
August 23, 2011
BPA Voltage Control Technical Conference

GE WTG Dynamic Models



Two classes of models: DFG and FC

WTG Reactive Power Capability

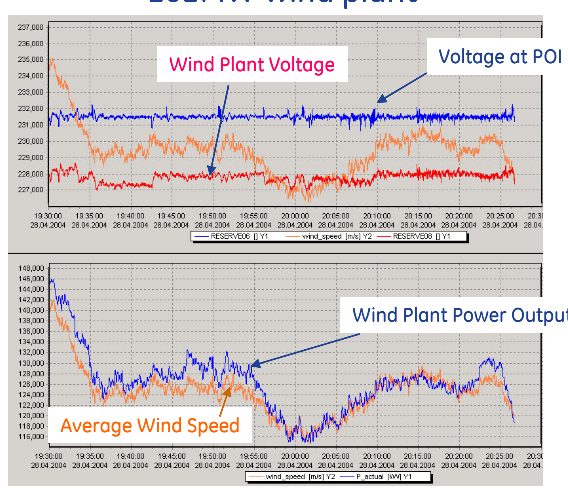


- Full leading and lagging range over full power range
- Faster reactive response than synch. generator
- Capability of reactive compensation with no wind
- Behavior like a FACTS devices

Voltage & Reactive Power Controls

- Regulates Grid Voltage at Point of Interconnection
- Minimizes Grid Voltage Fluctuations Even Under Varying Wind Conditions
- Regulates Total Wind Plant Reactive Power through Control of Individual Turbines

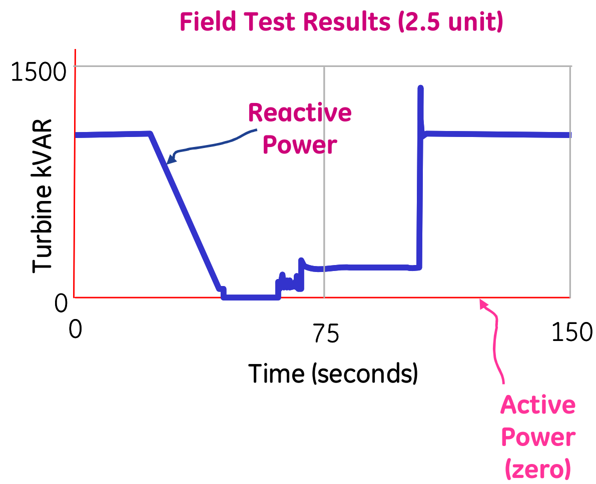
Actual measurements from a 162MW wind plant



Voltage and Reactive Power Regulation
Like A Conventional Power Plant…with FACTS speed

WindFREE Reactive Power

- Wind Turbine converter can deliver reactive power (kVAR) without wind (kW)
- Benefits weak grids and systems with high wind penetration
- Voltage support continues without active power generation...even following trips



Reactive Power - *even without wind:*
A valuable option – An unreasonable requirement

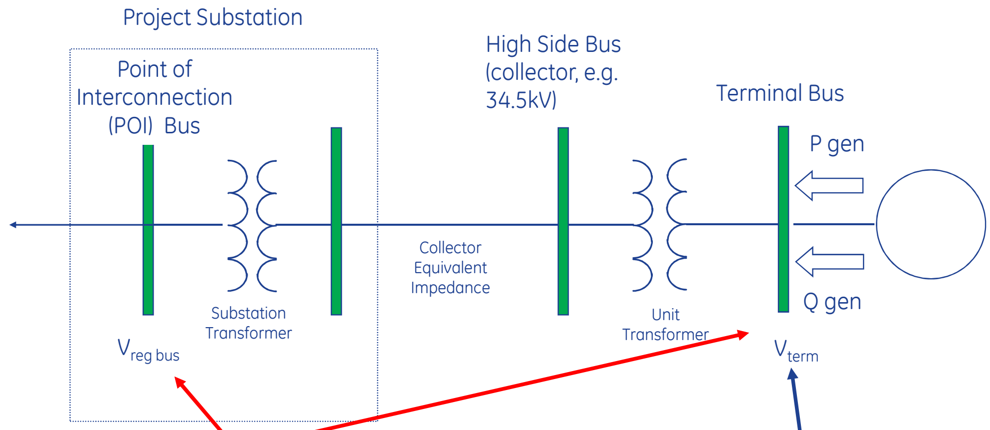
The following 11 figures are from IEEE panel session paper:
“Validation of GE Wind Plant Models for System Planning Simulations

Electric Machinery Committee
IEEE Power & Energy Society General Meeting

Jason MacDowell
Kara Clark
Nick Miller
Juan Sanchez-Gasca

July 25, 2011, IEEE General Power Meeting Detroit

Volt/Var Control for **Application Studies**



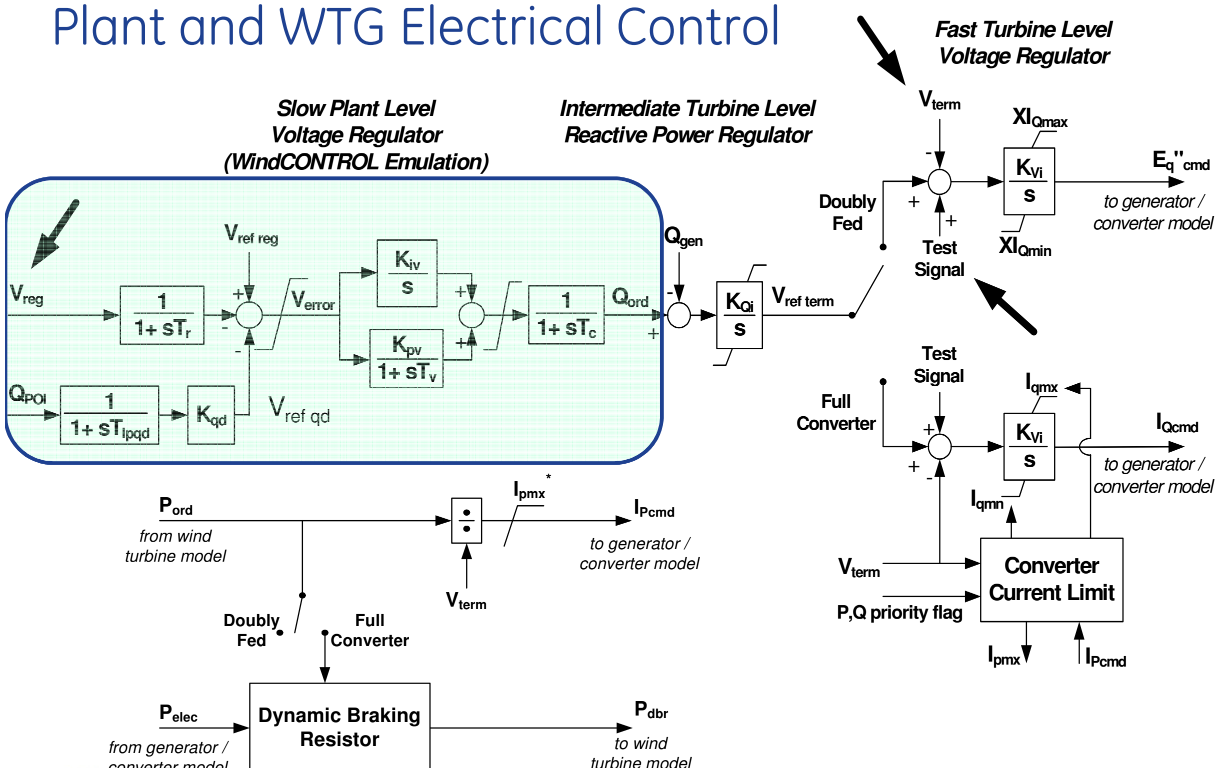
The supervisory control will instruct individual machines to adjust their reactive power output in order to regulate system voltage; normally at the point-of-interconnection

GE 1.5 MW machines offered in a range of steady-state reactive power capabilities at their terminals.
A common range:

- 0.90 pf overexcited (delivering 730 kVARs to the system)
- 0.90 pf underexcited (drawing 730 kVARs from system)

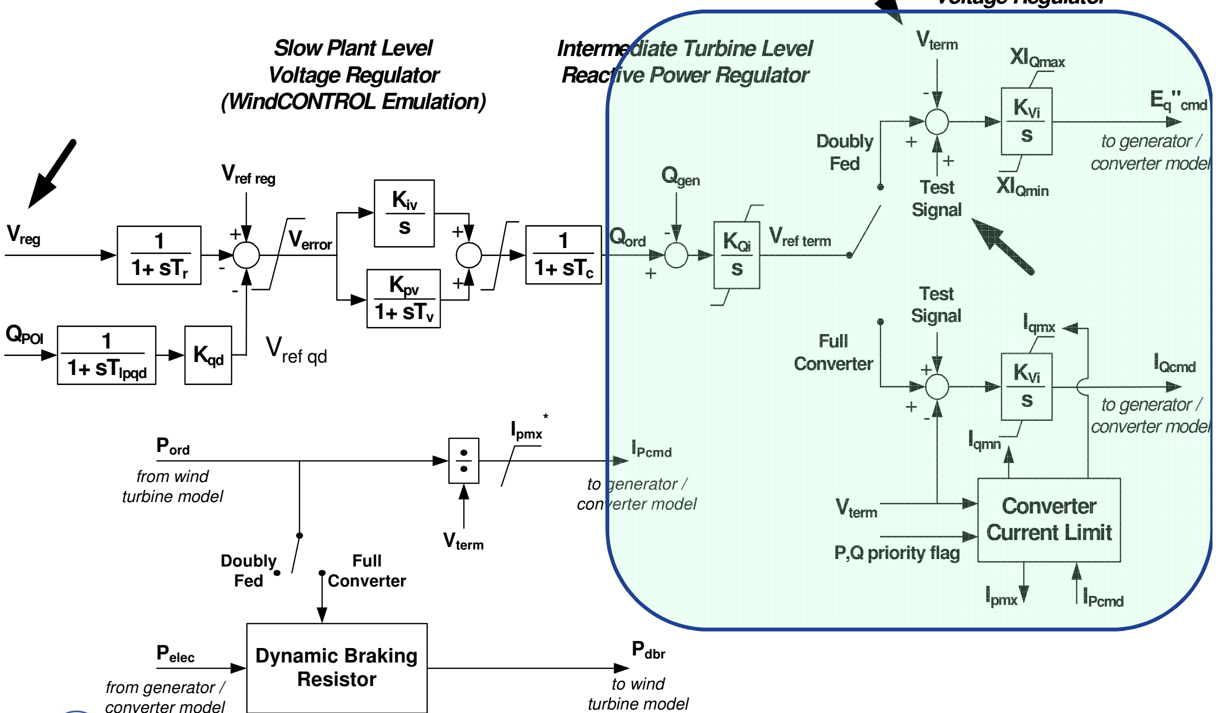
Frequently provides +/- 0.95 pf at POI

Plant and WTG Electrical Control



* Ipmx is fixed for the doubly fed model, or calculated by the converter current limit function for the full converter model.

Plant and WTG Electrical Control



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Model Validation – Field Test Results

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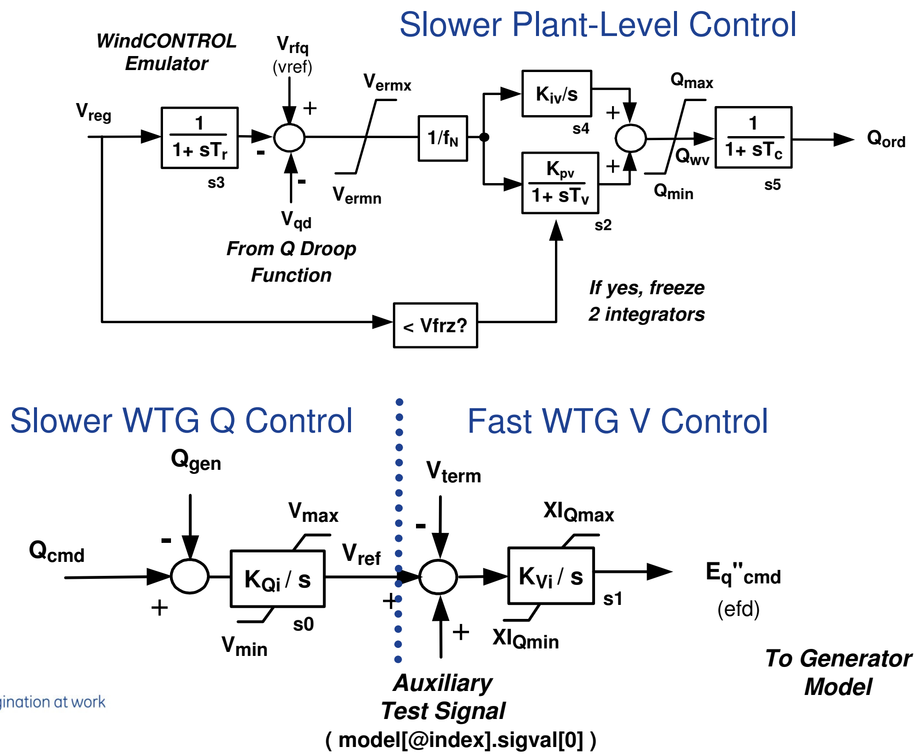
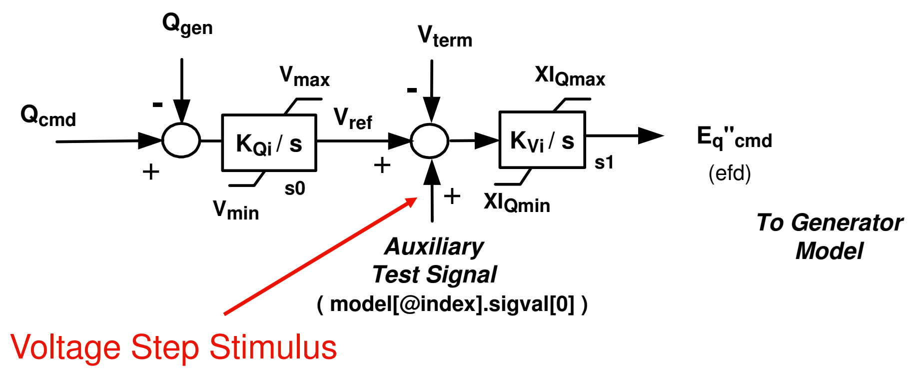
Volt/Var Control

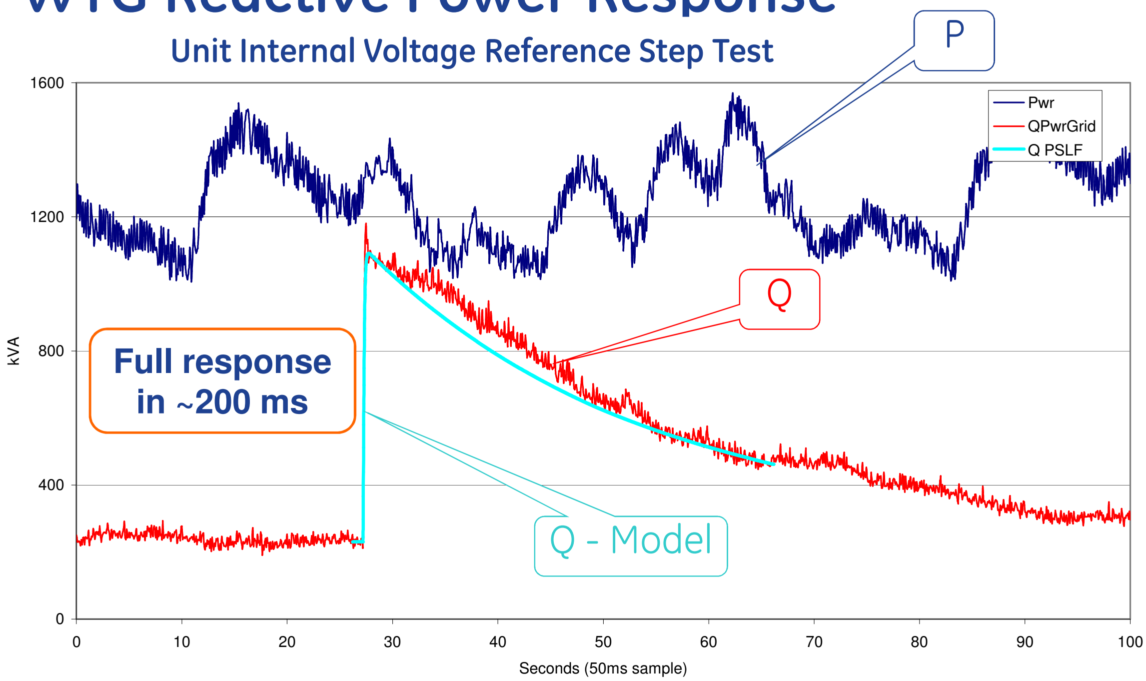


Individual WTG Test

- Test fast response of individual turbine
- 3% positive step, slow reset



WTG Reactive Power Response



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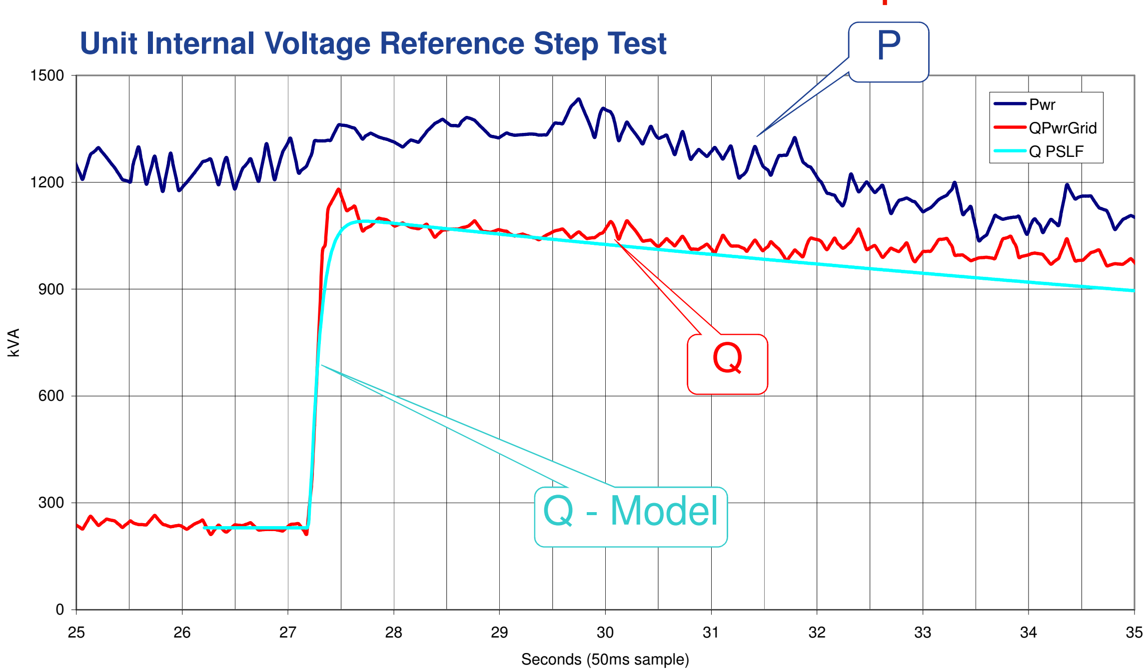
Model replicates equipment response

Detail - WTG Reactive Power Response

10x expanded time scale



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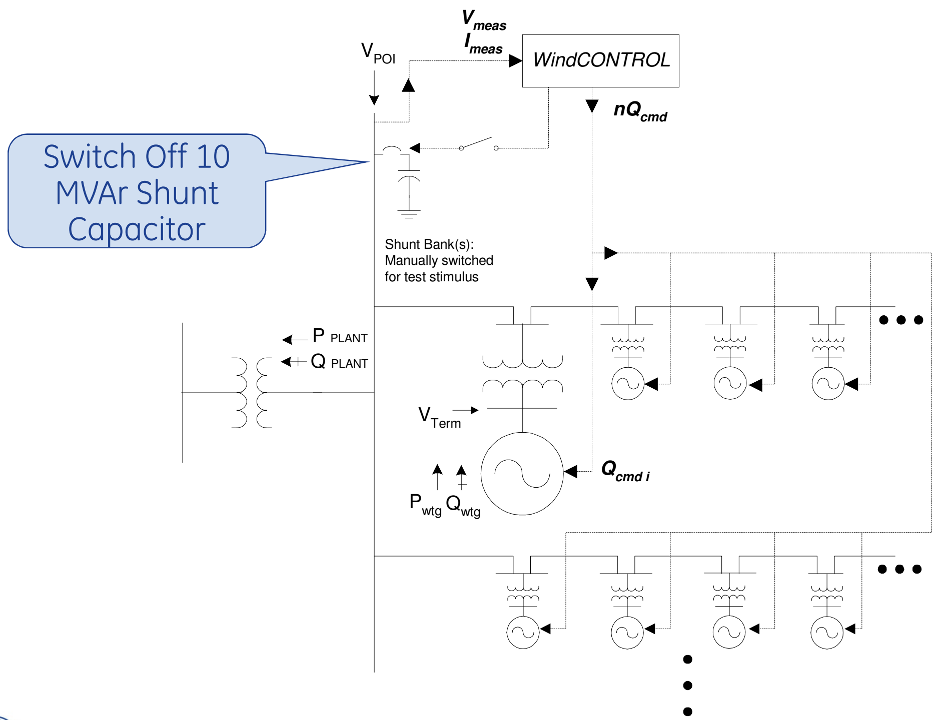
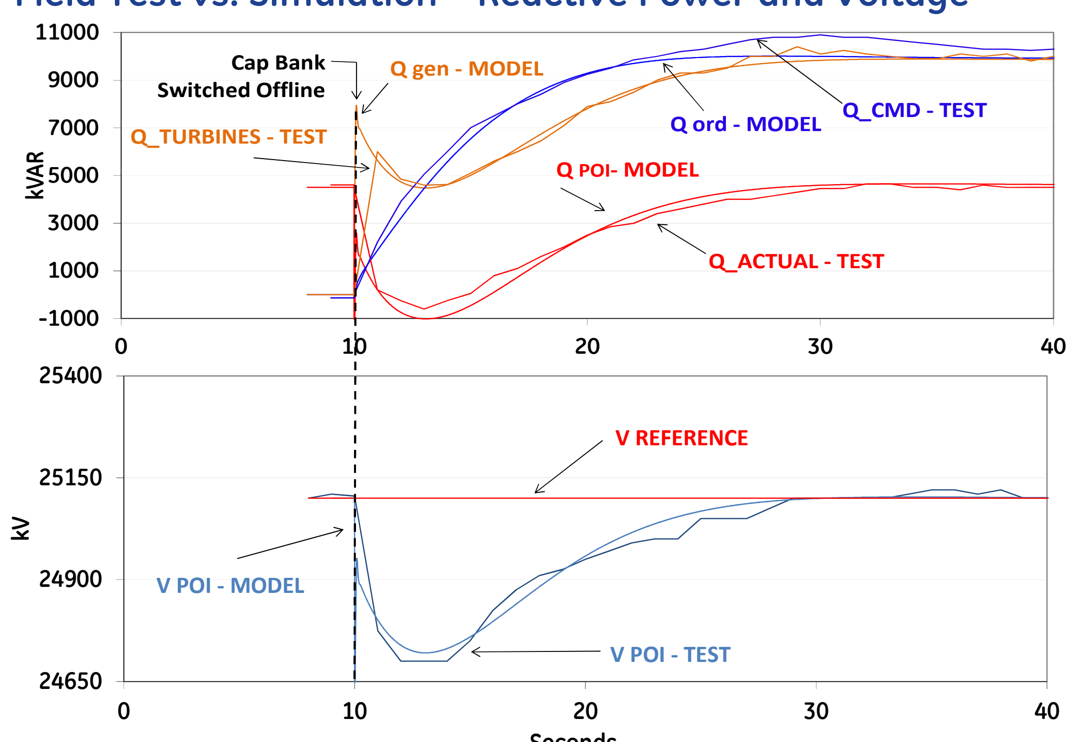
Full response in ~200 ms

Plant Level Volt/Var Test



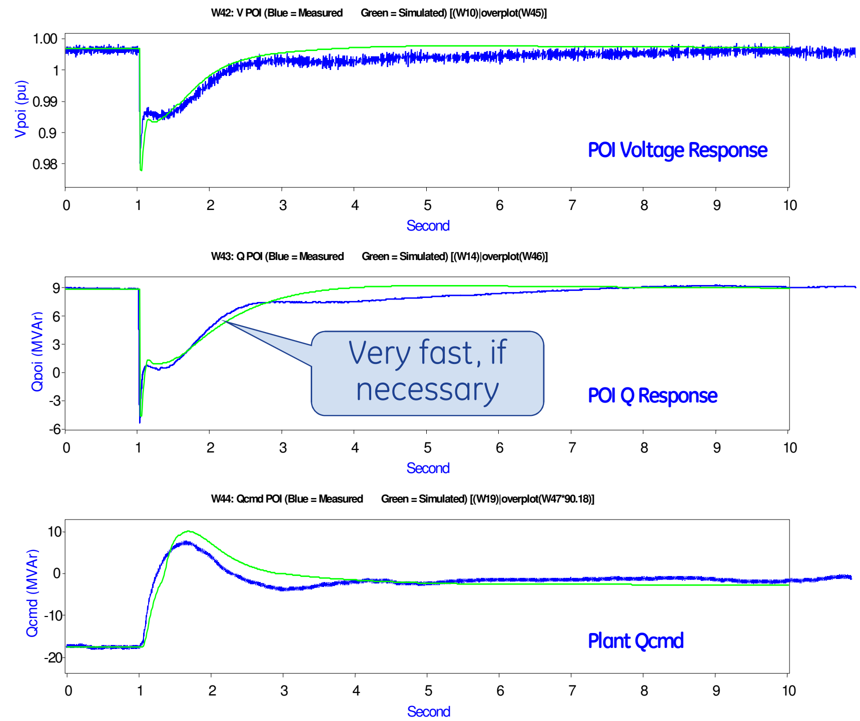
Field Test vs. Simulation – Reactive Power and Voltage



Model closely replicates field response

Cap Switching Test vs. Model – (100 MW Plant)

BLUE = MEASURED GREEN = SIMULATED



Conclusion

Voltage and Reactive Control of GE Wind Plants:

- In many respects are more flexible and faster than conventional plants
- Flexibility means attention to basic planning and operation engineering needs to be applied
- Blind application of default control settings without consideration of local requirements has, upon occasion, caused problems
- Field tuning of plant supervisory control to be relatively slow (~30 seconds) has generally resulted in good grid performance; faster is possible, *if necessary*
- We have NEVER encountered a voltage/reactive issue than can't be corrected

Conclusion

The GE wind models presented here are based on:

- Currently available design and test data
- Extensive engineering judgment
- The models represent actual equipment/plant behavior appropriate for bulk planning studies and have been validated via type and field tests.

These models are:

- Evolutionary and continuously updated as experience and test data are obtained
- Open and publicly available
- Able to be shared and distributed as required

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Active Power Control

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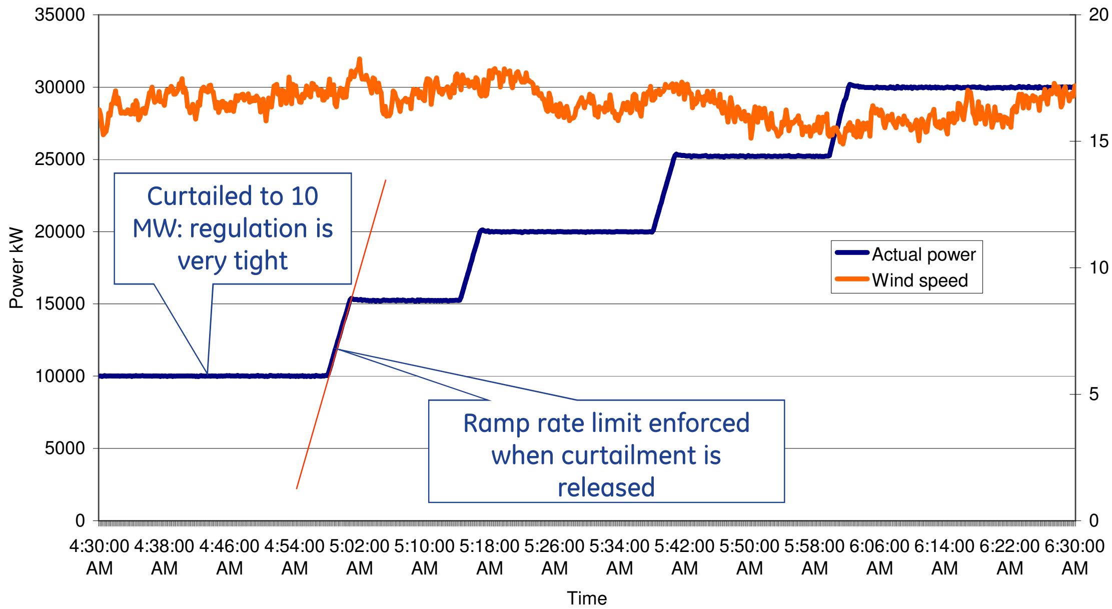
Curtailment and Ramp Rate Limits

(Example 30 MW Plant)



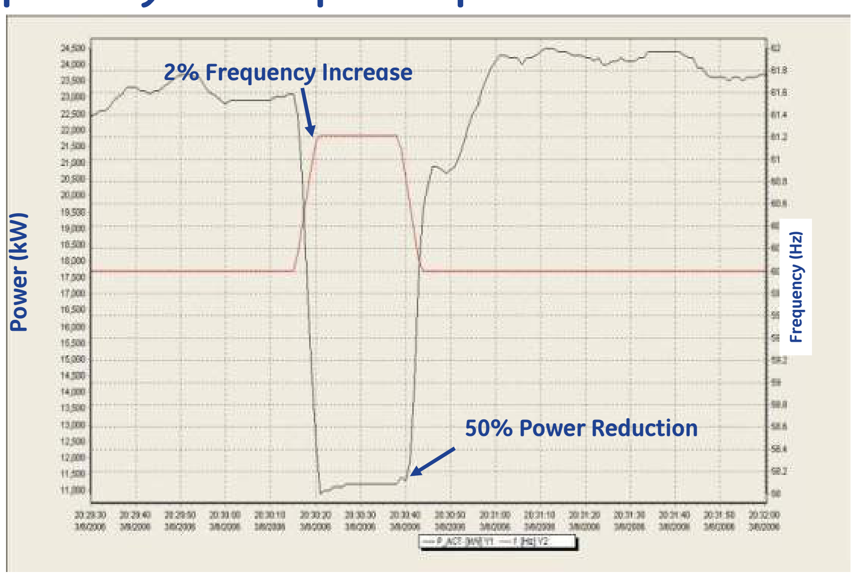
Over-Frequency Droop Response

Initial Steady-State Conditions:

- 25% power reduction for 1% frequency increase

Test:

- 2% frequency ramp-up @ 0.125 Hz/sec
- 50% reduction in plant watts with 2% over-frequency



Function is Grid Friendly with Little Opportunity Cost: A Reasonable Request

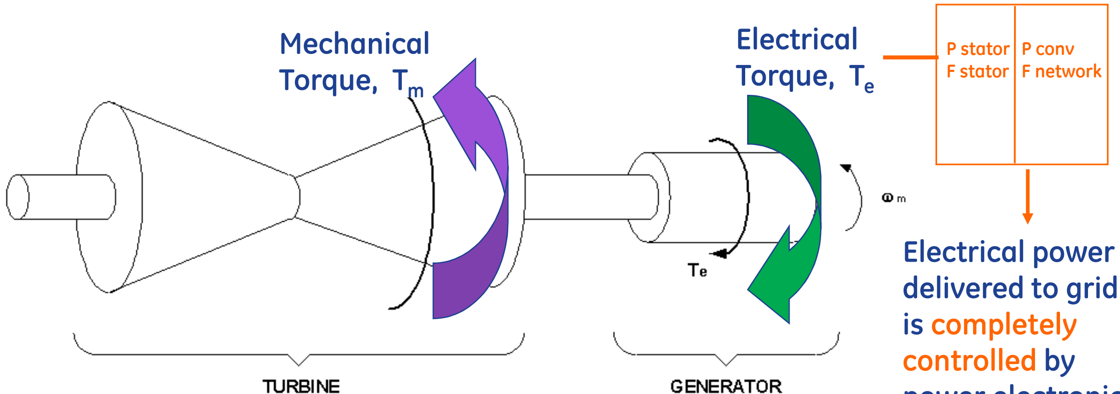
Equivalent Under-frequency Function has High Opportunity Cost: To Be Used Sparingly

Why Inertial Response: System Needs

- Increasing Dependence on Wind Power
  - Large Grids with Significant Penetration of Wind Power
- Modern variable speed wind turbine-generators do not contribute to system inertia
- System inertia declines as wind generation displaces synchronous generators (which are de-committed)
- Result is deeper frequency excursions for system disturbances
- Increased risk of
  - Under-frequency load shedding (UFLS)
  - Cascading outages

Inertial response enabled by power electronics enables CONTROLLED performance (not just Park's equations!)

How does it work?



Electrical power delivered to grid is completely controlled by power electronics

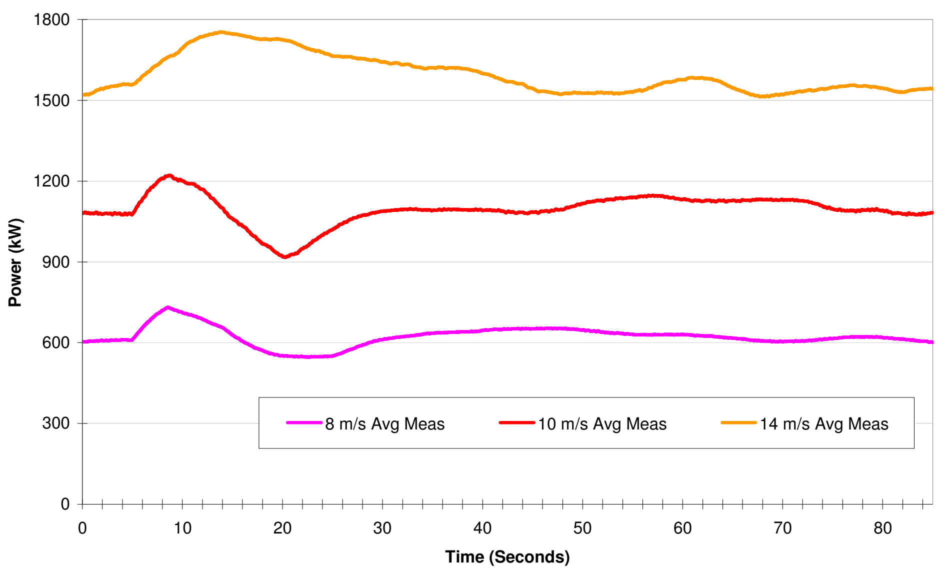
- In steady-state, torques must be balanced
- When electrical torque is greater than mechanical torque, the rotation slows extracting stored inertial energy from the rotating mass

WindINERTIA^{tm} uses controls to increase electric power during the initial stages of a significant downward frequency event

Objectives and Constraints on Inertial Controls

- Target incremental energy similar to that provided by a synchronous turbine-generator with inertia *(H constant)* of 3.5 pu-sec.
- Focus on functional behavior and grid response
  - do not try to exactly replicate synchronous machine behavior
- Not possible to increase wind speed
- Slowing wind turbine reduces aerodynamic lift
  - must avoid stall
- Must respect WTG component ratings
  - mechanical loading
  - converter and generator electrical ratings
- Must respect other controls
  - turbulence management
  - drive-train and tower loads management

Field Tests Results:

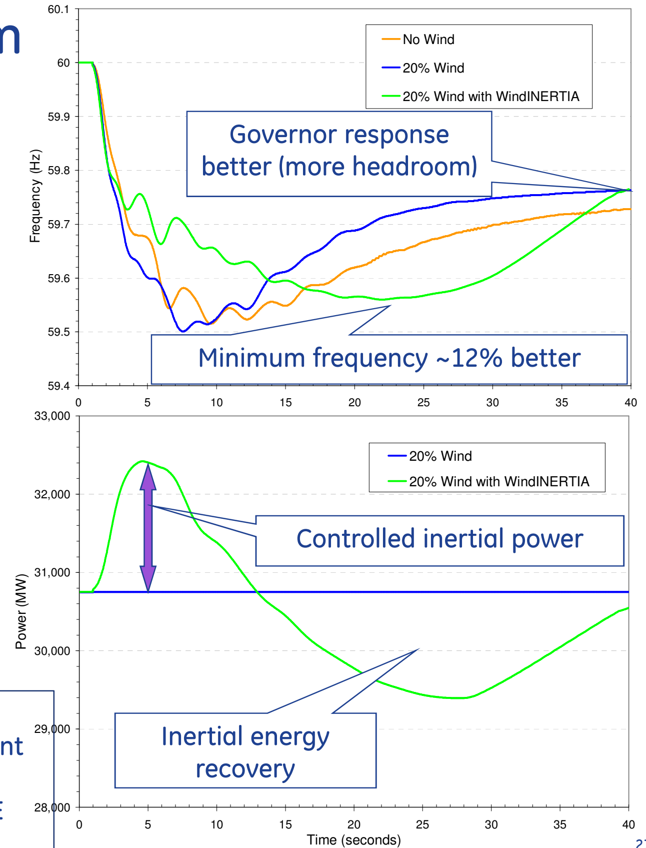


Test count:
8 m/s - 19 tests
10 m/s – 19 tests
14 m/s – 52 tests

Inertial Response from Wind Generation

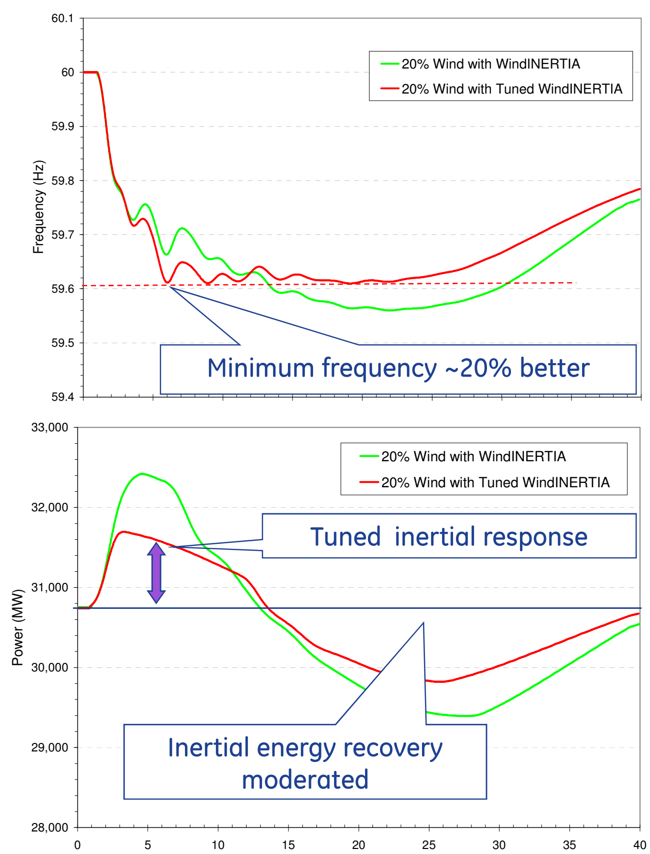
- Inertial response reduces and delays minimum frequency
- Margin above UFLS increases by about 40mHz
- Response in this case is overly aggressive: Inertia is now another control variable that can be tuned.

The following 4 figures are fully discussed in IEEE paper: "Frequency Responsive Wind Plant Controls: Impacts on Grid Performance N.W. Miller, K. Clark, M. Shao, GE Energy, IEEE General Power Meeting 2011, Detroit



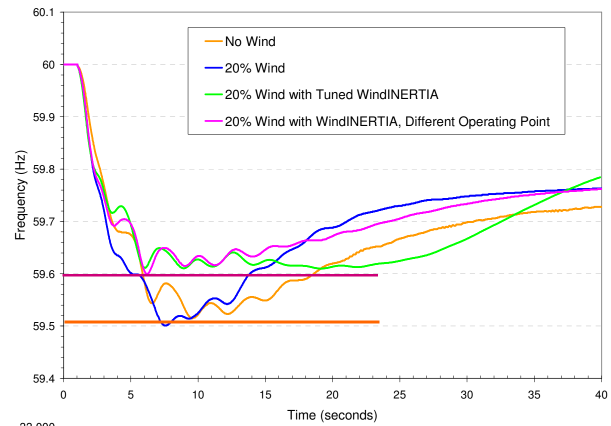
Tuning Inertial Response from Wind

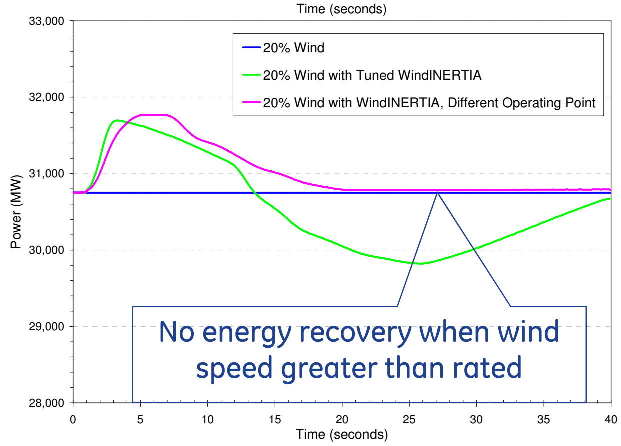
- Tuning inertial response further improves frequency nadir and reduces impact of recovery energy
- Margin above UFLS increases by about 80mHz
- (i.e. case without wind is about 20% worse than with wind)



Impact of Operating Point on Inertial Response

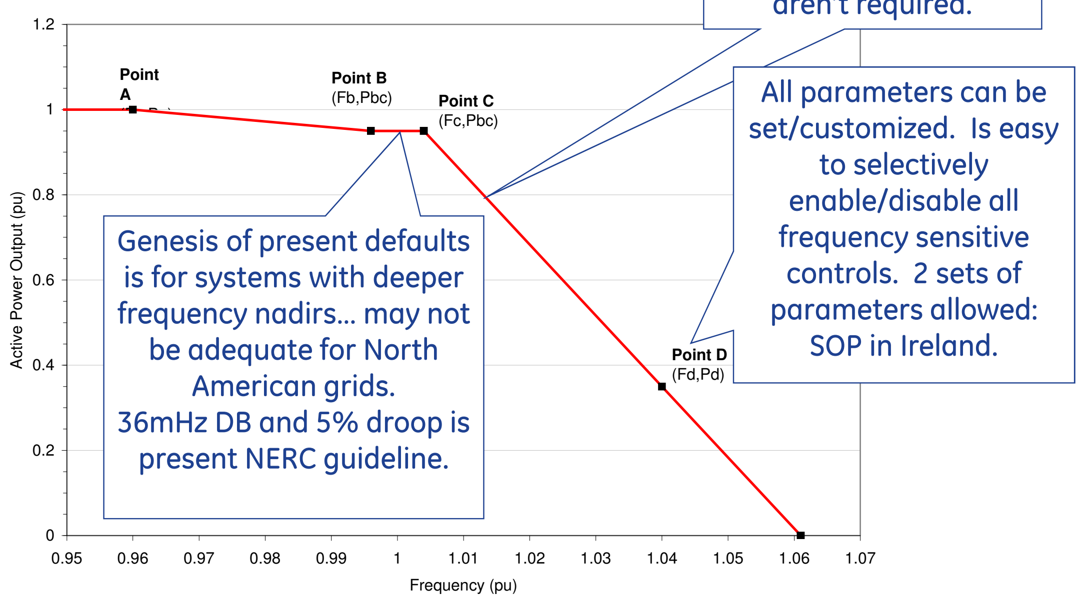
- Same initial loadflow condition: fewer WTGs producing the same MW at higher wind speed
- When wind speed is high, system response is superior throughout
- Frequency Nadir/Margin to UFLS improved by ~80mHz





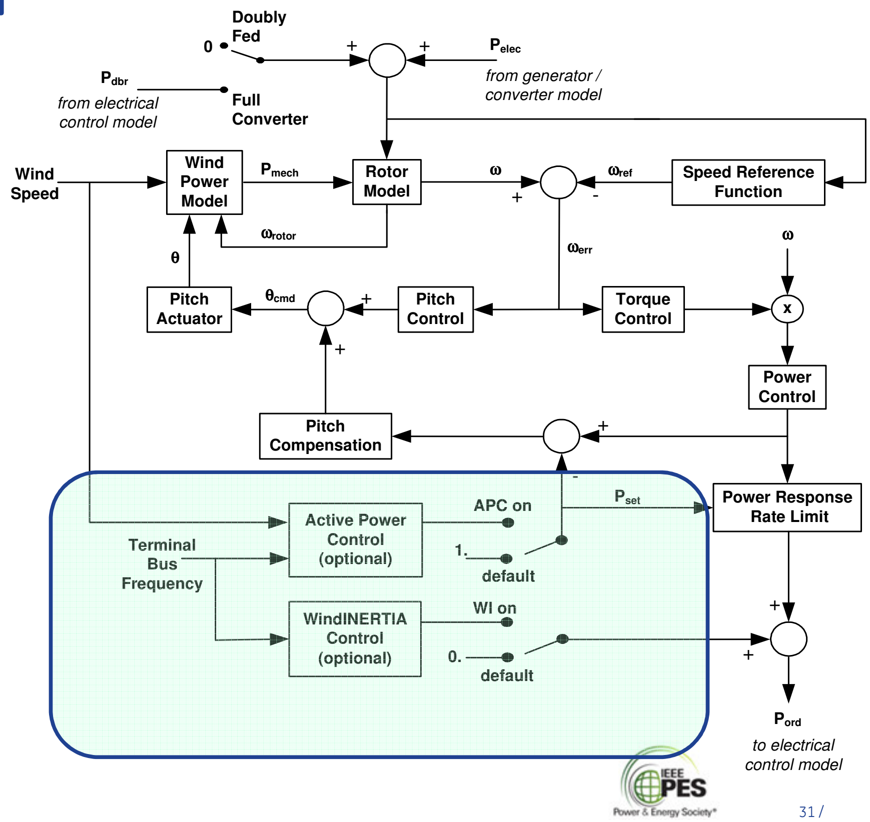
Frequency Response Curve

WTGs reduce power very effectively. Symmetric droops aren't required.



From PSLF manual

Turbine and Turbine Control



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