GE Energy

Wind Plant Functionality and Emerging Grid Codes

Nicholas Miller

GE imagination at work

As Wind Power Plants increase in size and number …

- Wind plants have a greater impact on the grid
- Displace other generation, so wind needs to provide its share of system support
- Continuity of wind generation contribution becomes essential to grid reliability
- Behavior during disturbances needs to be predictable

“Grid friendliness” is essential to wind energy’s continued growth

What makes a Wind Plant "Grid Friendly"?

- Provide inertial response to large under-frequency events: *WindINERTIA*^{TM}

Inertial Response:

System Needs:

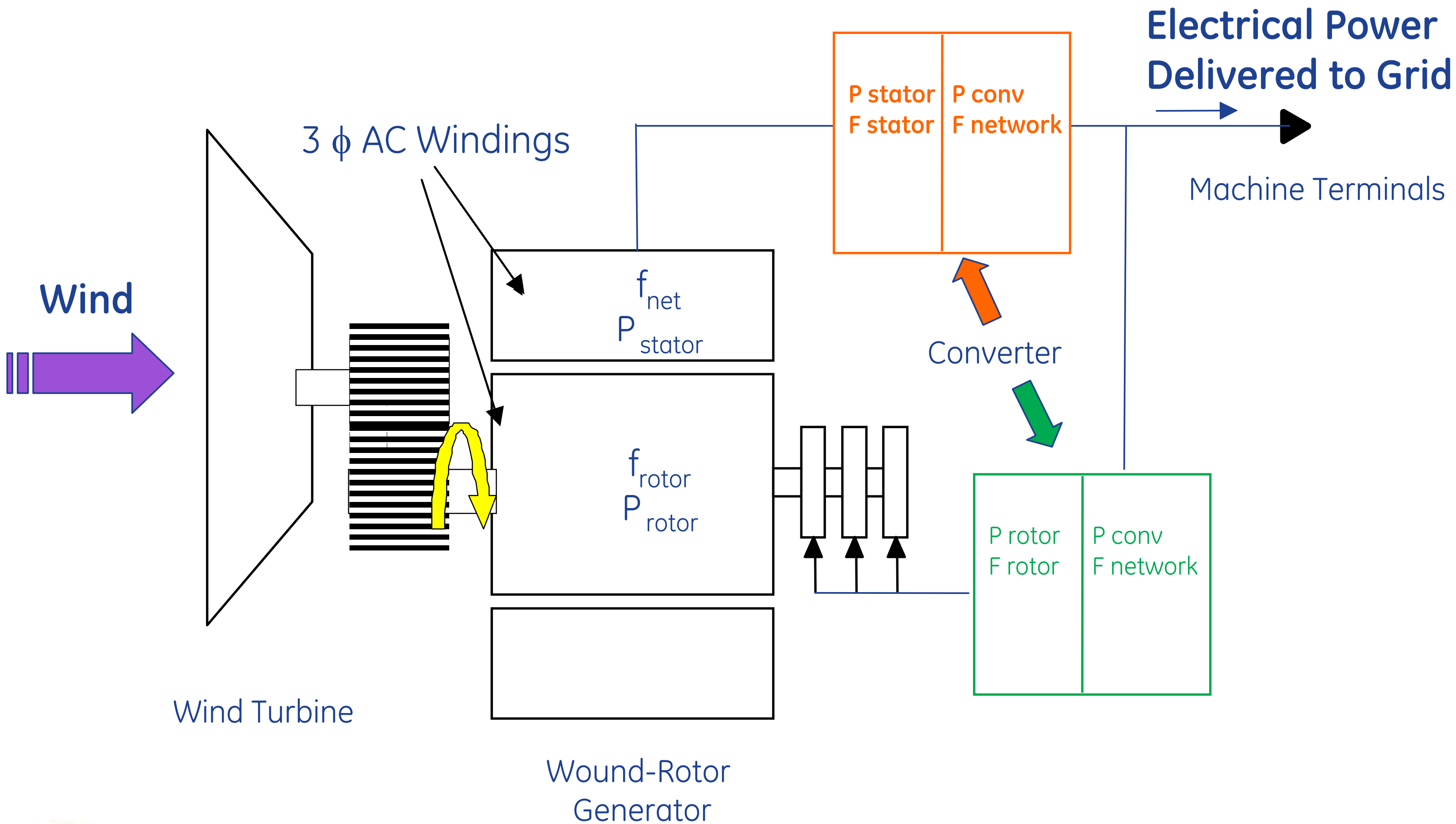
- Modern variable speed wind turbine-generators do not contribute to system inertia
- System inertia declines as wind generation displaces synchronous generators (which are de-committed), resulting in deeper frequency excursions for system disturbances, and increased risk of Under-frequency load shedding (UFLS) and Cascading outages

Control Concept:

- Use controls to extract stored inertial energy
- Provide incremental energy contribution during the 1st 10 seconds of grid events;
  - Allow time for governors and other controls to act

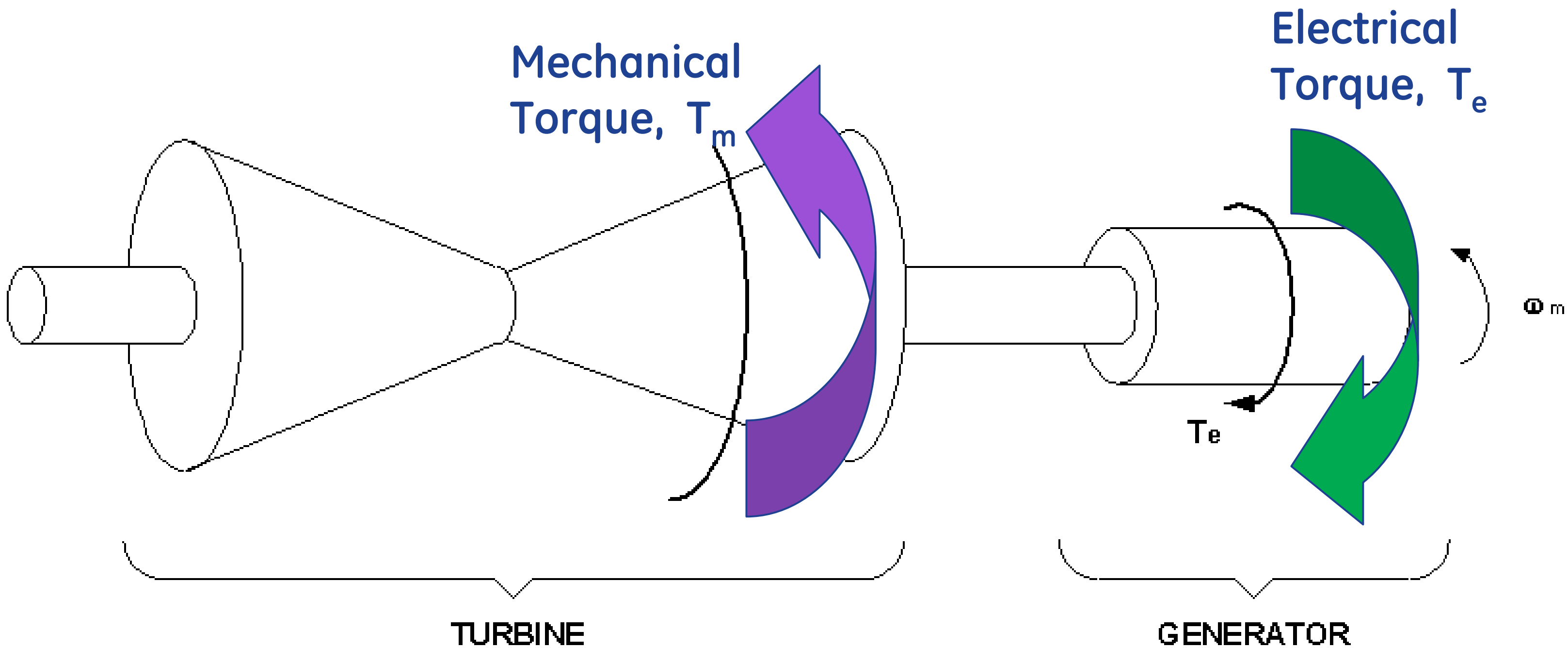
How does it work?

Basic components of a GE Full Converter or Double-fed Asynchronous Wind Turbine Generator:



GE imagination at work

How does it work? Part 2



- 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 uses controls to increase electric power during the initial stages of a significant downward frequency event

What's Different?

	Synchronous Generator	Wind Turbine*
Mechanical power	Governor Response / Fuel Flow Control	Pitch Control / Uncontrolled Wind Speed
Electrical Power	Machine Angle (d-q Axis) / passive	Converter Control / active
Inertial Response	Inherent / Uncontrolled	By Control Action

* Variable speed, pitch controlled WTGs

GE imagination at work

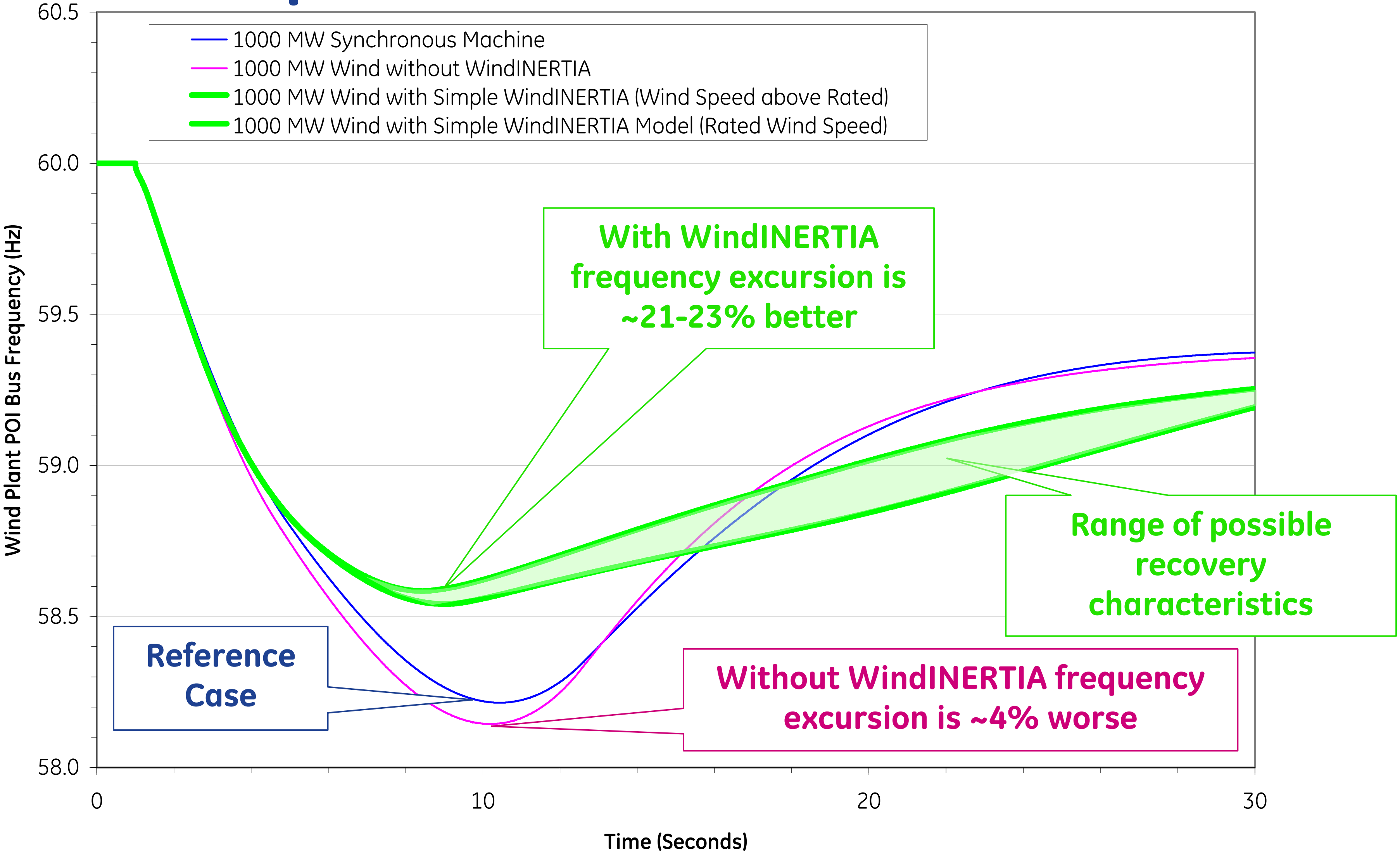
Objectives and Constraints

- 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

What happens during a grid event?

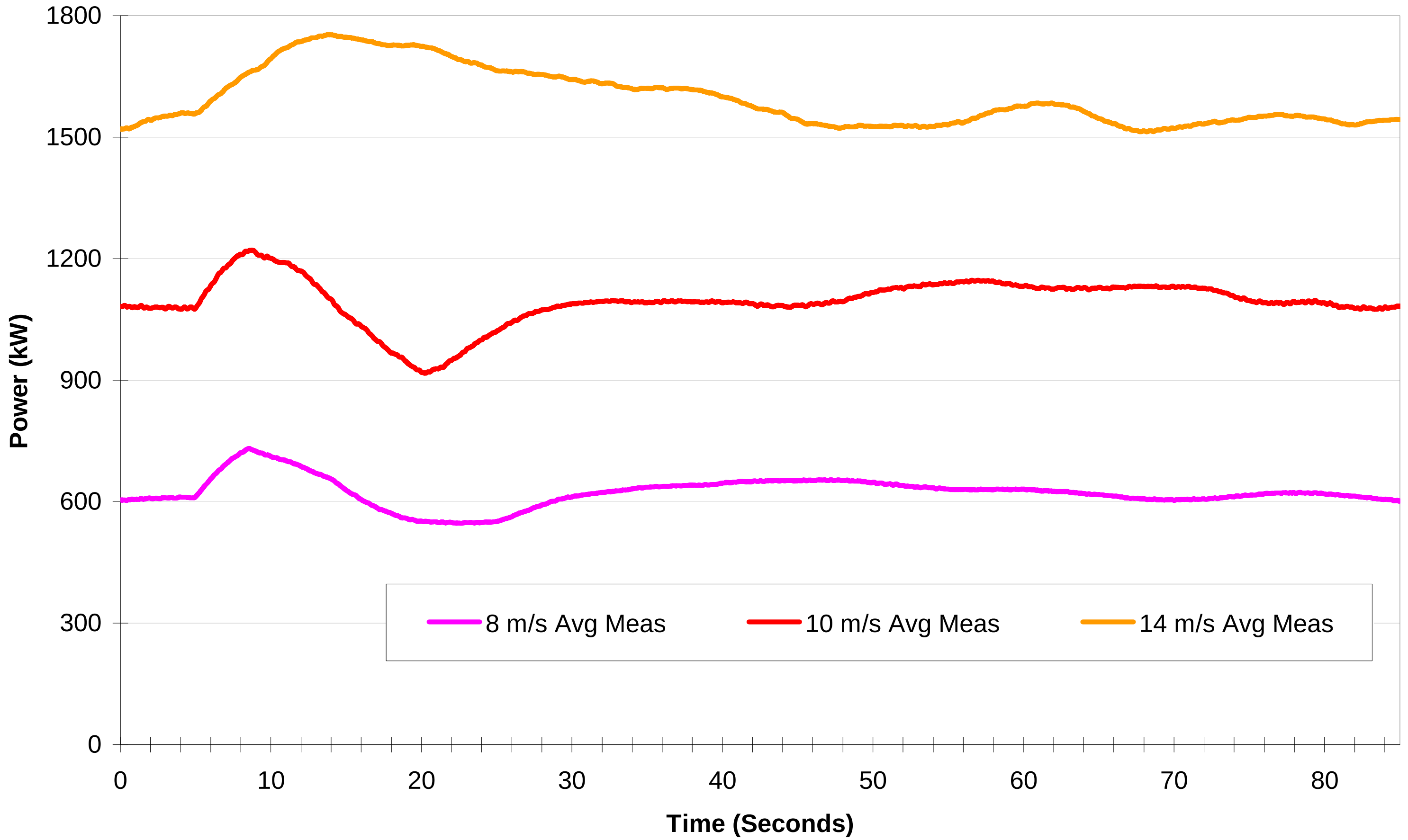
1. Disturbance (e.g. generator trip) initiates grid frequency decline
2. WindINERTIA detects significant frequency drop
3. Instructs WTG controls to increase electrical power
4. Additional electric power delivered to the grid
5. Rate and depth of grid frequency excursion improves
6. WTG slows as energy extracted from inertia; lift drops
7. Other grid controls, especially governors, engage to restore grid frequency towards nominal
8. WindINERTIA releases increased power instruction
9. WTG electric power drops, to allow recovery of rotational inertial energy and energy lost to temporarily reduced lift
10. Transient event ends with grid restored

An Example: 14GW, mostly hydro system, for trip of a large generator



Performance is a function of wind and other conditions: not perfectly deterministic like synchronous machine inertial response

Field Tests Results:



8 m/s - 19 tests
10 m/s – 19 tests
14 m/s – 52 tests

WindINERTIA simulation models are openly available

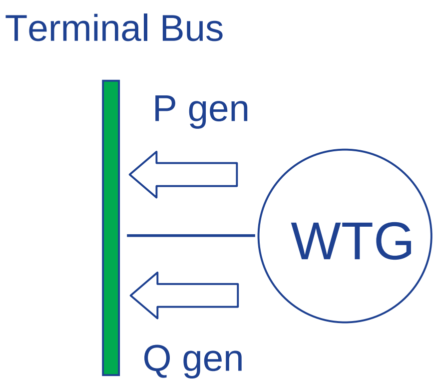
What makes a Wind Plant “Grid Friendly”?

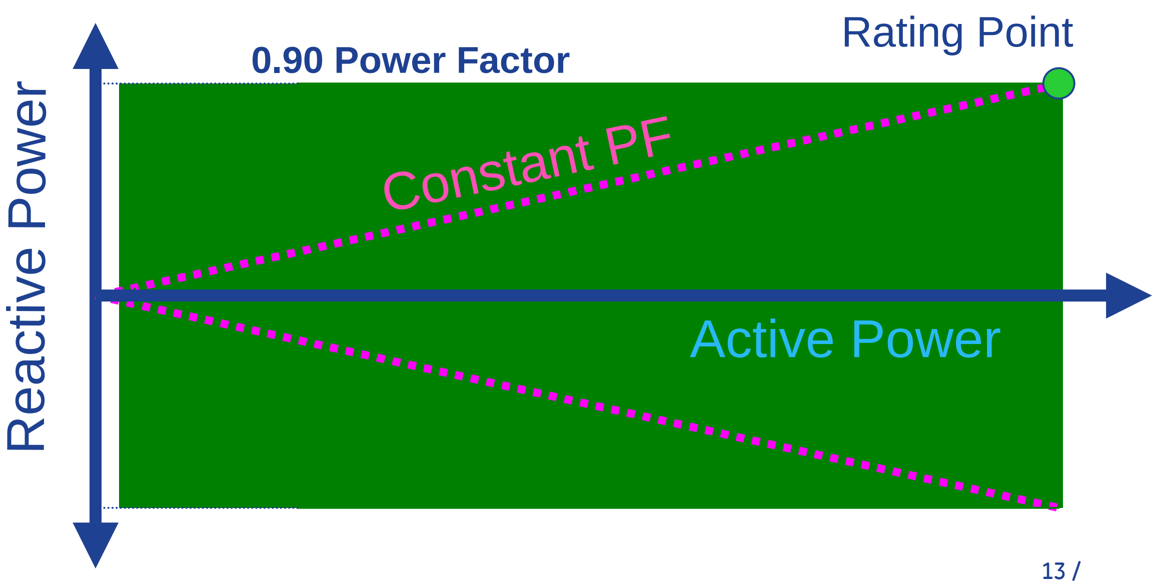
- *Provide inertial response to large under-frequency events: WindINERTIA™*
- Regulate plant voltage & reactive power : WindCONTROL™

WTG Reactive Power Capability

Reactive Power for Voltage Support

- Steady-state PF range - 0.90 under-excited/0.90 over-excited
- Dynamic range meets or exceeds steady-state range
- WTG reactive capability often sufficient to satisfy PF requirements at POI
- VAR capability reduced at low power due to reduced generator cooling and units cycling off-line





Voltage Regulation

Hierarchical Control Philosophy

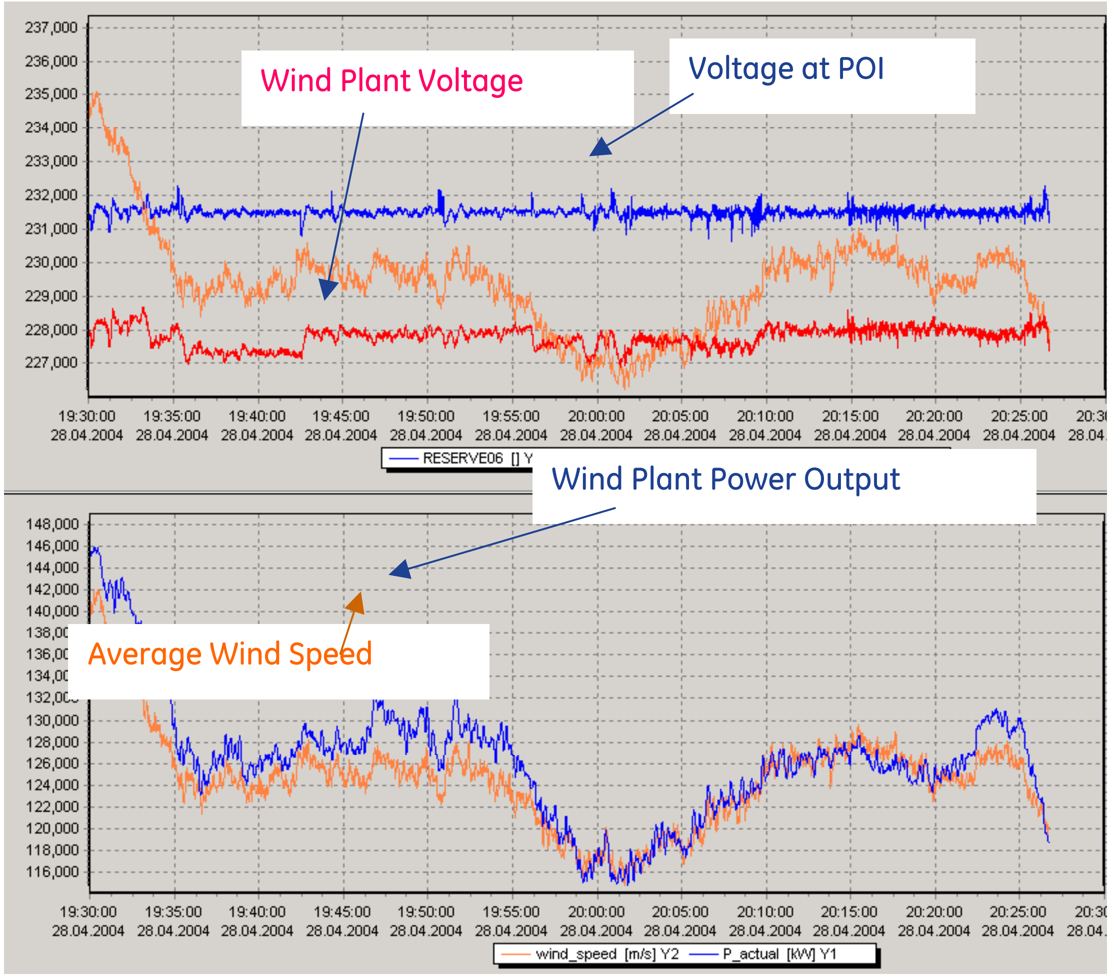
Individual WTGs have fast, autonomous, self-protecting regulation of their terminal voltages

- Individual WTGs will always respond rapidly and correctly for grid voltage events

WindCONTROL™ provides plant-level controls to meet performance requirements (e.g., voltage regulation) at the point-of-interconnection (POI)

- Sends supervisory reactive power commands to individual WTGs to 'trim up' initial individual WTG response
- Coordinates other substation equipment (e.g., switched shunt capacitors)
- Interfaces with utility SCADA
- Accepts commands (e.g., voltage reference setpoint) from utility system operator

Actual measurements from a 162MW wind plant

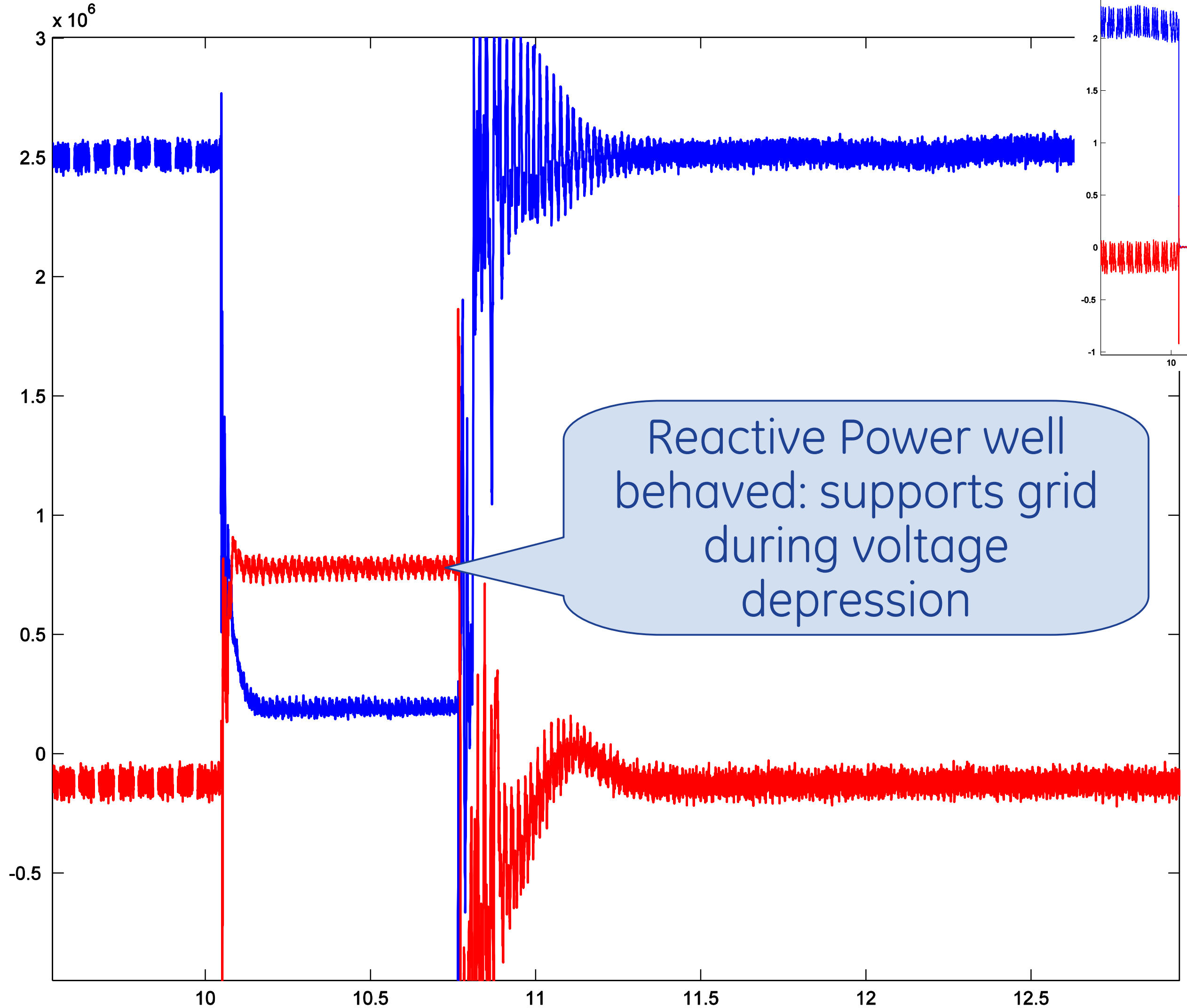


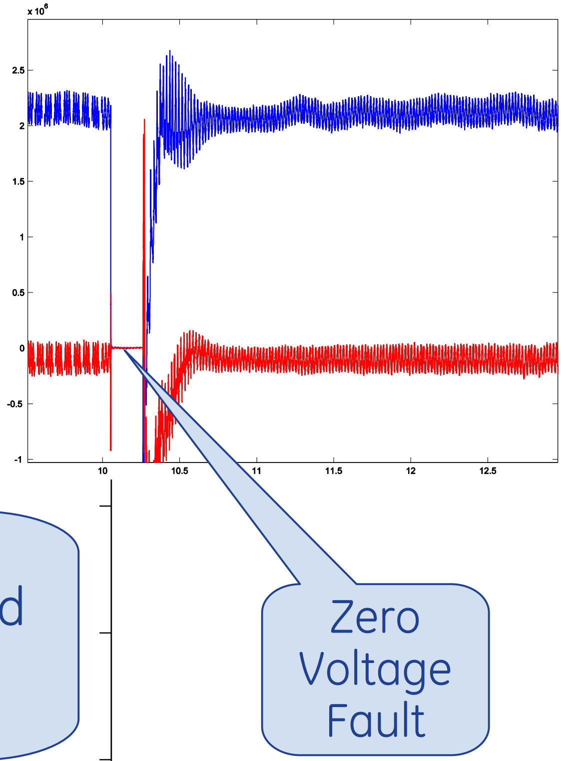
Voltage and Reactive Power Regulation
Like A Conventional Power Plant

What makes a Wind Plant "Grid Friendly"?

- *Provide inertial response to large under-frequency events: WindINERTIA™*
- *Regulate plant voltage & reactive power : WindCONTROL™*
- Not trip during faults and other system disturbances … *ride through capability:* WindRIDE-THROUGH™

3-phase 18.5% retained voltage, 700ms fault: P, Q (Mw,Mvar)





Field Test Results (2.5 unit)

What makes a Wind Plant "Grid Friendly"?

- Provide inertial response to large under-frequency events: *WindINERTIA™*
- Regulate plant voltage and power…: *WindCONTROL™*
- *Not trip during faults and other system disturbances … ride through capability: WindRIDE-THROUGH™*
- React to changes in grid frequency … *Frequency Droop*
- Limits the amount and/or rate of change of power from variations in wind speed … *Ramp Rate Control*
- Provide reactive power all the time: WindFREE™ Reactive Power

US Experience with Wind Grid Codes

US Grid Code Development

In the US, relationships between transmission system operators (TSO), generators and users of energy are governed by multiple entities:

- FERC (Federal Energy Regulatory Commission)
- NERC (North American Reliability Council)
- Regional Reliability Councils (e.g.:)
  - WECC (Western Energy Coordinating Council)
  - ERCOT (Electric Reliability Council of Texas)
- State Reliability Councils
- State Regulators
- Standards Organizations (ANSI/IEEE/NESC/NEC)
- A similar Federal/Provincial structure applies in Canada

GE imagination at work

Grid Code Development Debate…

- Should wind generation be treated differently?
- What is the obligation of generation to provide voltage control? frequency control?
- How should generation respond to system disturbances?
- How should generation prove it meets performance requirements?

These questions are still being debated in the US today.

GE imagination at work

Emerging US Consensus:

- Reactive Power: +/- 0.95 pf @ POI
- Voltage Control: required, with ISO voltage setpoints
- Frequency Tolerance: +/- 3 hz continuous
- Voltage Tolerance (Low Voltage Ride-Through): ZVRT
- Models and Data: required cooperation
- Telemetry and Metering: specific minima
- Power Quality: IEEE 519 for Harmonics and Flicker
- Frequency Control: debate underway, but not close to resolution
- Validation requirements: debate is raging

Wind: What's Next from GE

Onshore Wind - Continuing trend:
Bigger Rotor, Higher Hub Height, Larger Nameplate
- Capture more kinetic energy to create more electrical energy

1.x	'02	'09	
Rotor size (m)	70	82.5	+12.5m
Cap. factor (%)	39	52	+13 Pts
Availability (%)	85	98	+13 Pts

Evolving platform

- Introducing 1.6-100 to TCIII
- Introduced 100m tower
- Increased rotor on TCI model from 70.5m to 77m
- Advanced Controls

2.x	'04	'09	
Rotor size (m)	88	100/103	+15m
Cap. factor (%) 7.5m/s	**34.7**	**41.9**	+7 Pts
Cap. factor (%) 8.5m/s	**39.5**	**47.7**	+9 Pts
Availability (%)	92	97	+5 Pts

Evolving platform

- Increasing nameplate: 2.5+
- Increasing tower height: 100m+
- Increasing rotor: 103+
- Advanced Controls

GE imagination at work

Offshore Wind - Continuing trend:
Bigger Rotor, Higher Hub Height, Larger Nameplate
- 4.0-110 … the evolutionary next step

Direct-Drive MMW Introduction	SW 3 2005	SW 3.5 2007	GE 4.0 2010**
Rotor Diameter (m)	90	90	110
Capacity Factor* (%)	48	44	52
AEP (GWh)	12.7	13.4	18.3

+8 pts

+36%

SW: ScanWind

* Estimated AEP at 10 m/s and 98% availability

** Fleet Leader target COD

Evolving platform

- Commercial Launch: 2H12
- Grow rotor to 110m with advanced blade … In operation since mid 2009
- Advanced Controls
- Wind Power Plant solution for seamless grid integration

GE
Energy

Thank you!

imagination at work