GE Energy

Asia Development Bank
Wind Energy Grid Integration Workshop:

Wind Plant Interconnection Studies

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GE Energy Consulting

Beijing
September 22-23, 2013

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ADB topic list

Technical studies for impact of wind plant on the grid (International Expert)

- Methodologies for determining impacts on the reliability, safety, (transient, voltage, and frequency) stability and thermal loading capacity of the power system
- Best practices for modeling power flow, analyzing stability and short circuit
- Approaches to determine the grid improvements and upgrades triggered by the proposed wind farms, and develop cost estimates

Interconnection Issues – Dynamic Performance

- Voltage Regulation
  - Dynamic voltage response
  - Flicker
- Fault Tolerance/Low-Voltage Ride-Through
- Stability
  - Maintaining Synchronism
  - Damping
  - Voltage Stability
- Active Power Control
  - Frequency Regulation
  - Intertie Flow Regulation

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Wind Turbines and Reactive Power Control

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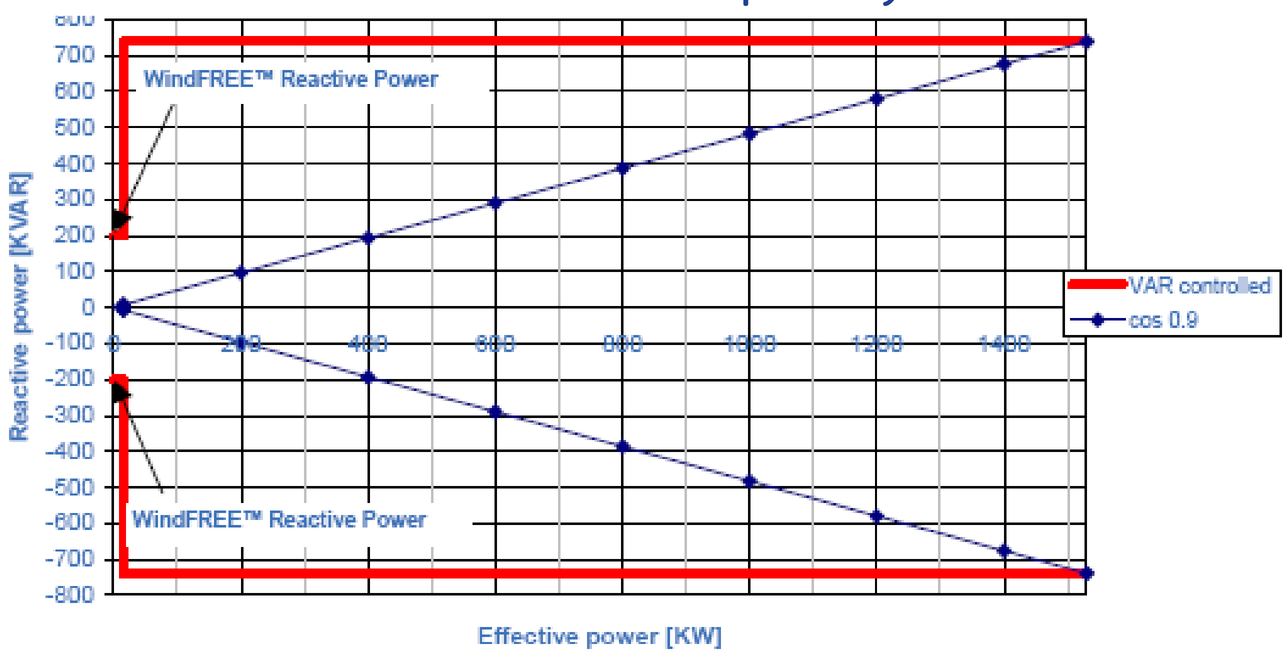
WTG Reactive Capability

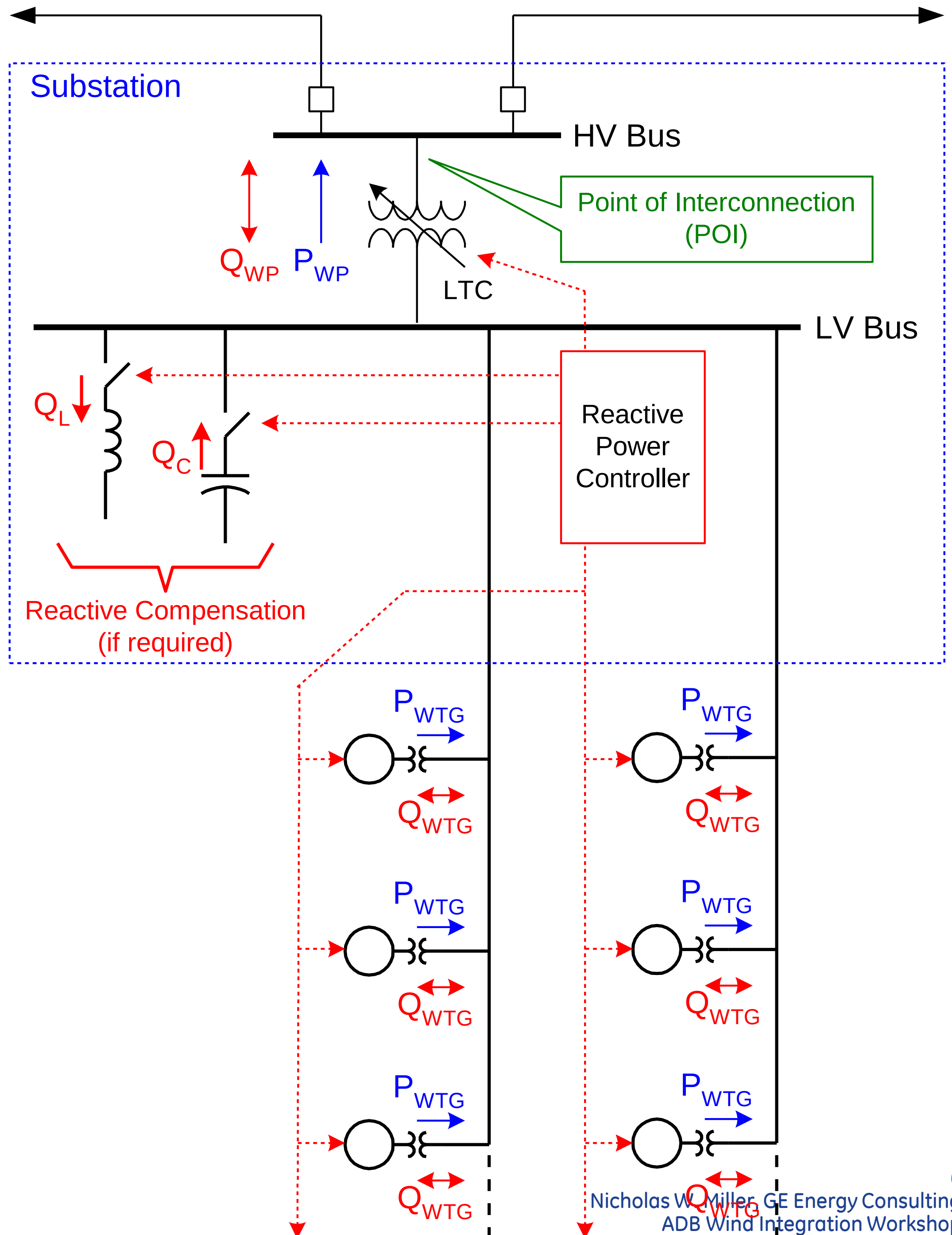
- GE 1.5 MW Reactive Capability



- Most modern (type 3 and type 4) wind turbines have some reactive capability
- Varies greatly by OEM
- Critical to intereconnection

Plant Level Control System

- Coordinated turbine and plant supervisory control structure
- Voltage, VAR, & PF control
- PF requirements primarily met by WTG reactive capability, but augmented by mechanically switched shunt devices if necessary
- Combined plant response eliminates need for SVC, STATCOM, or other expensive equipment
- Integrated with substation SCADA



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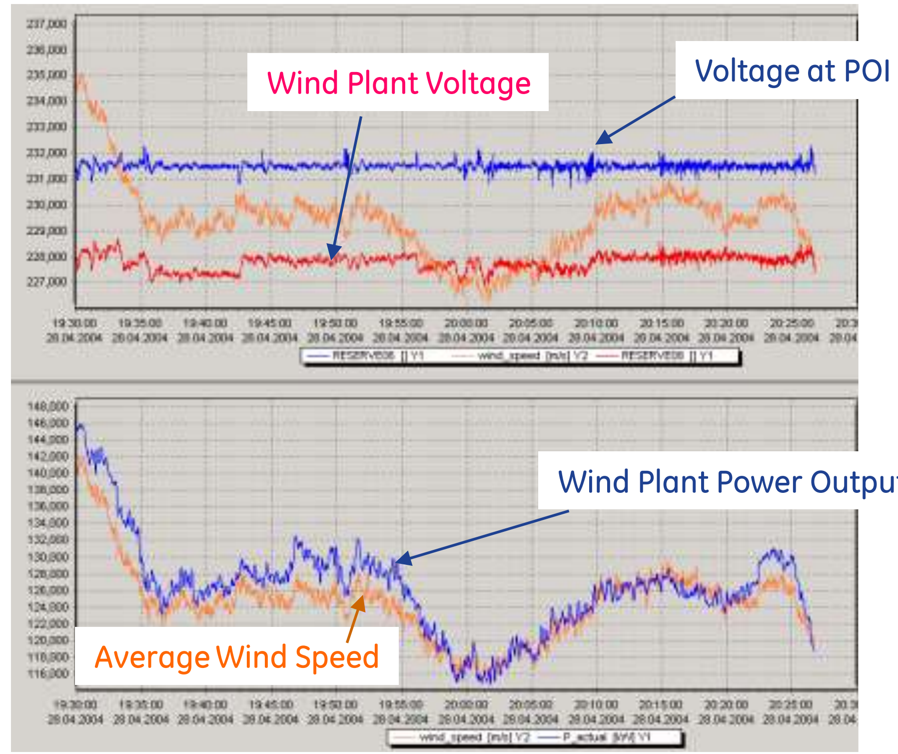
Voltage & Reactive Power Controls

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

Actual measurements from a 162MW wind plant



Voltage and Reactive Power Regulation Like A Conventional Power Plant

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System Strength

What is it?

- Usually measured in short circuit MVA
- $MVA_{sc} = kV_b^2/X_{sc} = 3^{½}kV_b kI_{sc}$

Why is it the single most important factor?

- Maximum short circuit (I.e. max kI_{sc} or min X_{sc}) dictates breaker duties, many equipment ratings
- Minimum short circuit (I.e. min kI_{sc} or max X_{sc}) dictates worst sensitivities, e.g. dV/dC, dV/dP, etc.

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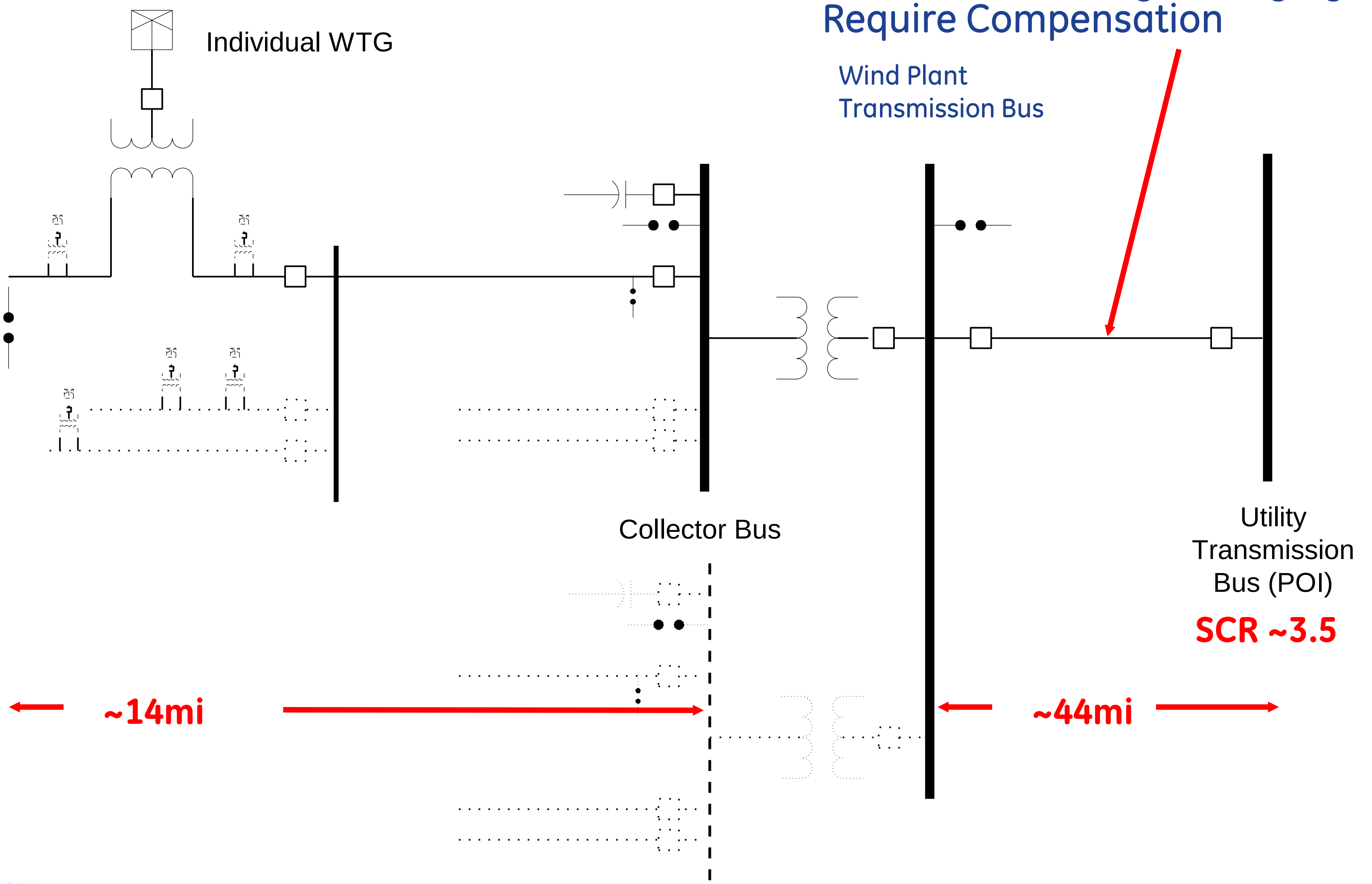
Crisp Voltage Regulation Essential in Weak Systems

Long Radial Connections (especially cable runs with high charging) Require Compensation



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Wind Plant vs. Wind Turbine Reactive Capabilities

Wind Plant pf capability ≠ wind turbine pf spec

Reactive Losses

- I^2X of unit transformer
- I^2X of collector lines and cables
- I^2X of substation transformer

- V^2B_L of shunt reactors
- Q_L of dynamic compensator

Reactive Gains

- V^2B_C of collector cables
- V^2B_C of harmonic filters

- V^2B_C of shunt cap banks
- Q_C of dynamic compensator

Extra compensation provided to make up the difference

- Switched caps and reactors all step-wise compensation
- Dynamic compensation needed for smooth control unless WTG has variable reactive capability

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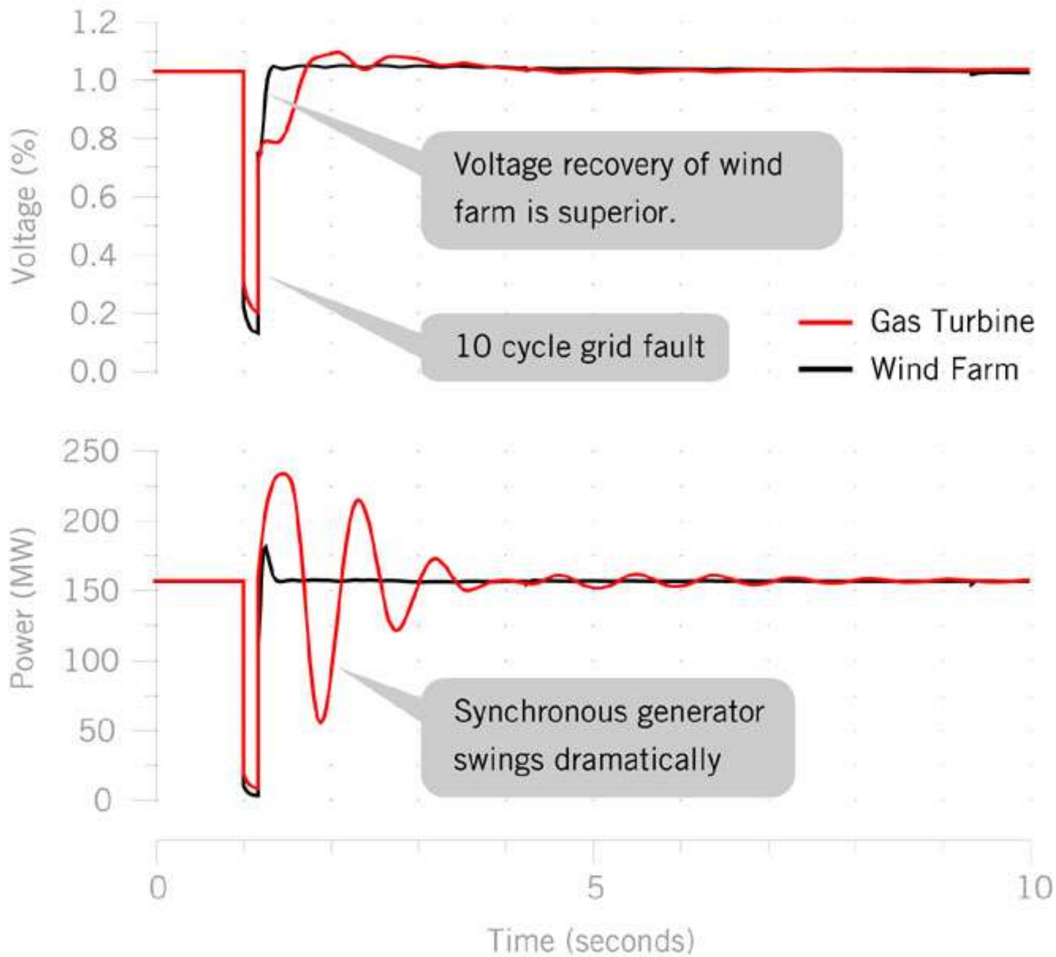
Transient Stability

Transient Stability

DFG wind farms are more stable than conventional synchronous generators.



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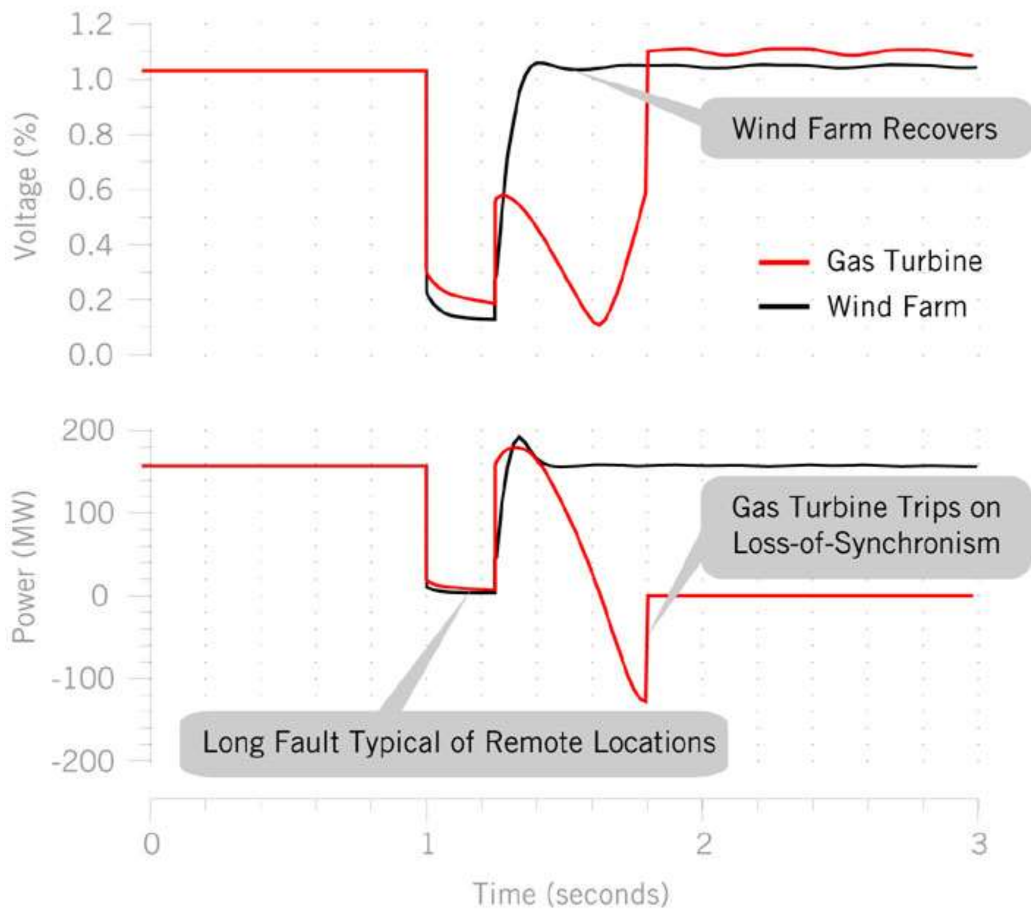
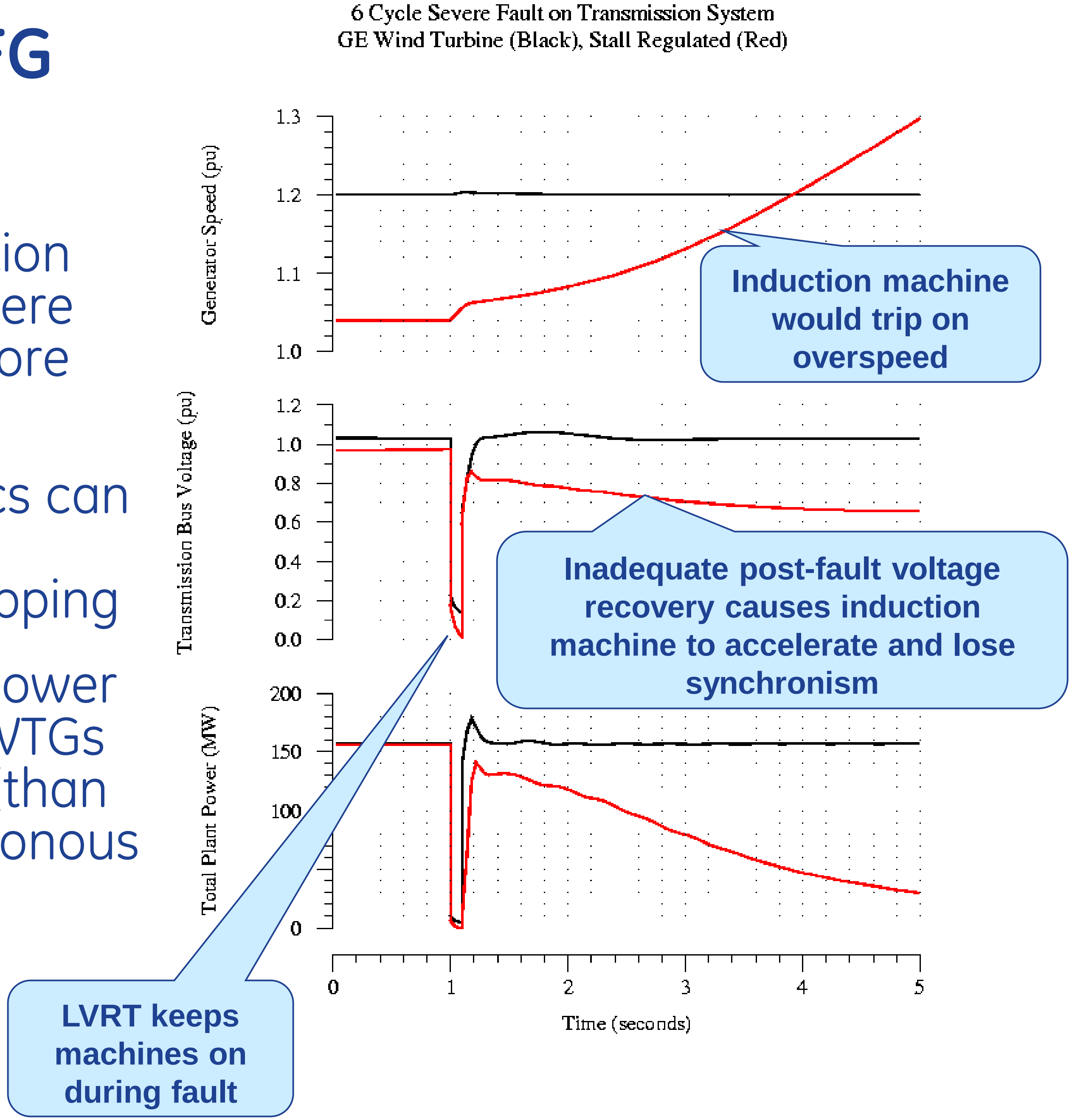
Transient Stability

In fact, wind farms will survive some disturbances that trip conventional synchronous generators.



Induction vs DFG Dynamics

- Recovery of induction generators from severe faults can involve more than LVRT
- Post-fault dynamics can result in loss of synchronism and tripping
- Wind plants with power electronic enabled WTGs can be more stable (than conventional synchronous generators.)



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Wind Turbine Fault Tolerance

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Disturbance tolerance

- In the event that wind plants:

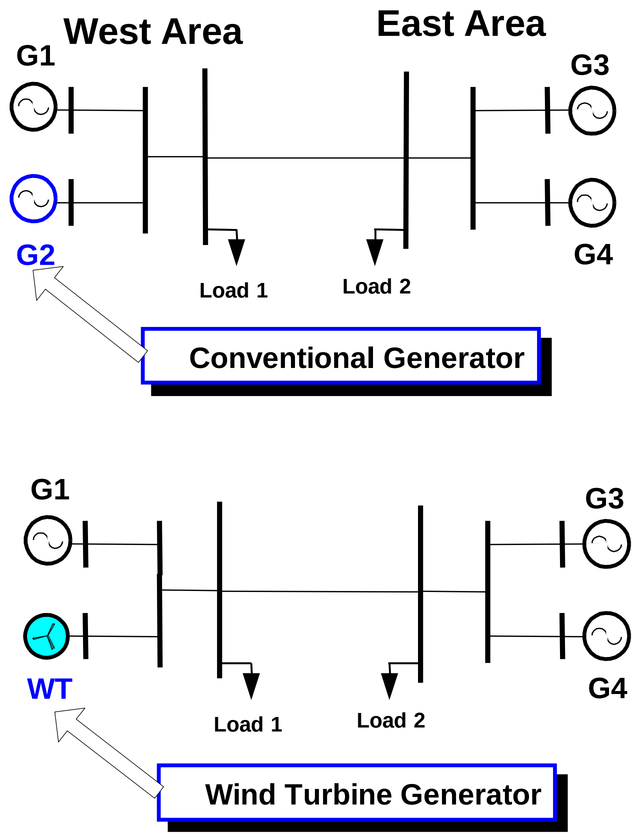
1. Do not have ZVRT
2. Have credible N-1 transmission events that isolate the plant
3. Have credible high voltage events that exceed HVRT
4. Have credible low/zero voltage events that exceed LVRT

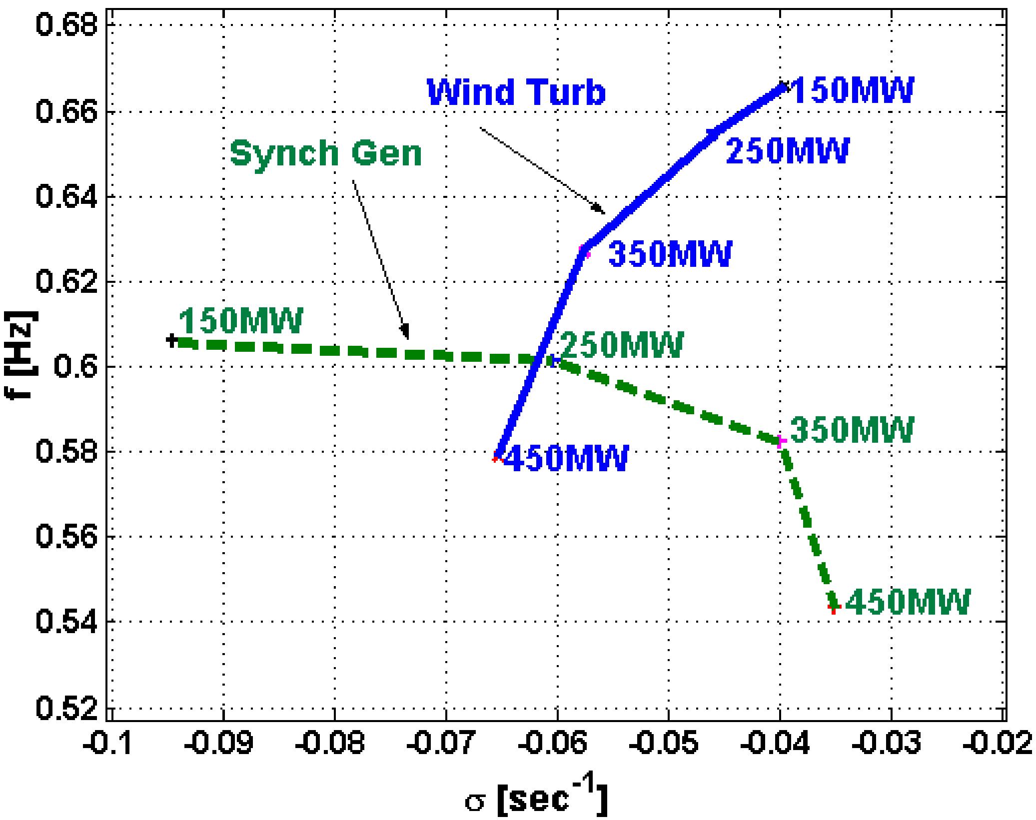
Grid transient and frequency stability must be studied for loss of the plant

Damping

Damping

DFG wind farms don't tend to aggravate system oscillations





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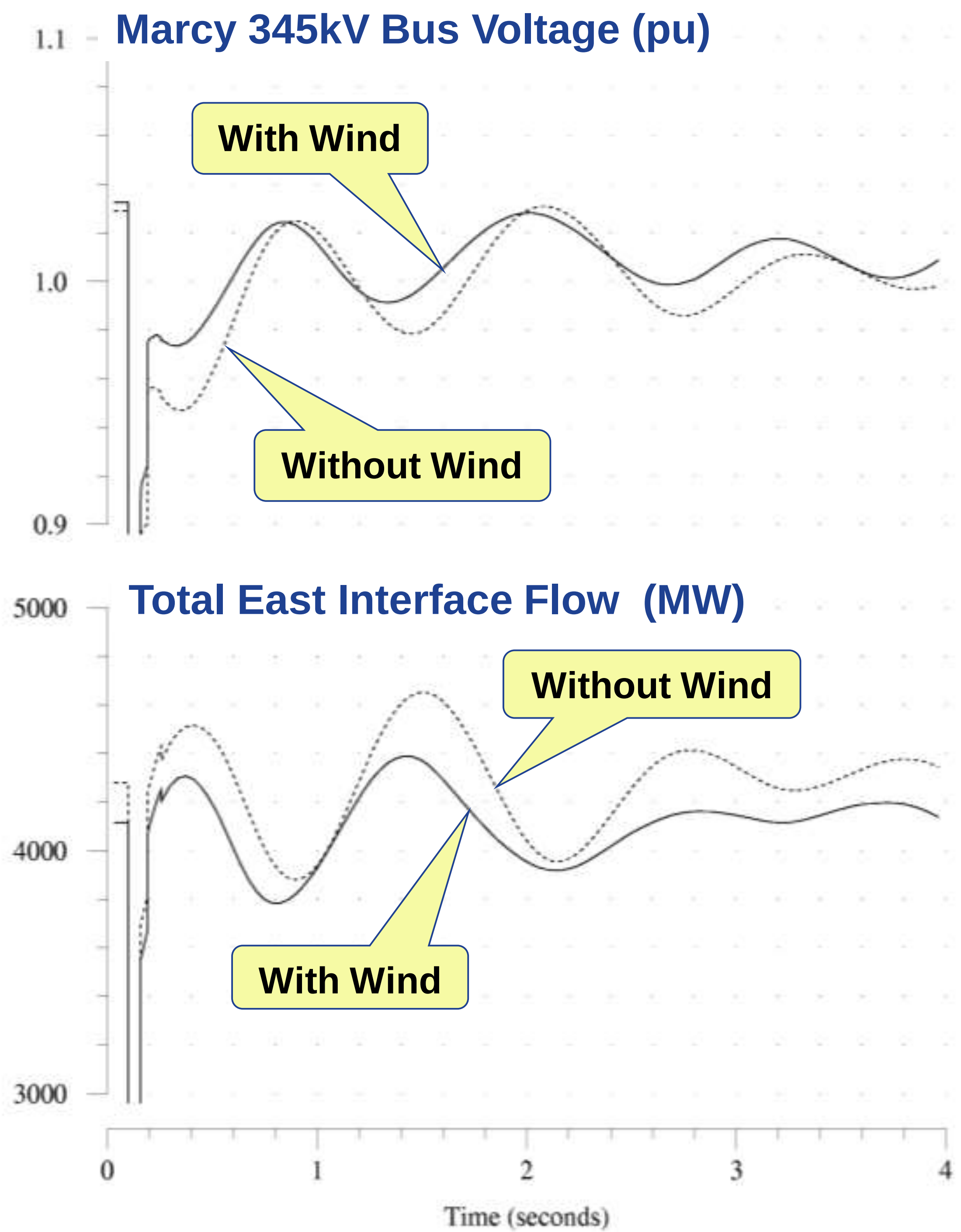
Impact of Wind Generation on System Dynamic Performance

- Fault at Marcy 345 kV bus
- Severe contingency for overall system stability
- Simulation assumes vector-controlled wind turbines
- Wind generation improves post-fault response of interconnected power grid



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Wind Turbine Active Power Control

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Active Power Controls

Advanced plant controls power response to variations in wind and system frequency

Power Ramp Rate – Limits the rate of change from variations in wind speed

Startup and Shutdown – Control the insertion and removal of large power blocks

Frequency Droop – React to changes in system frequency

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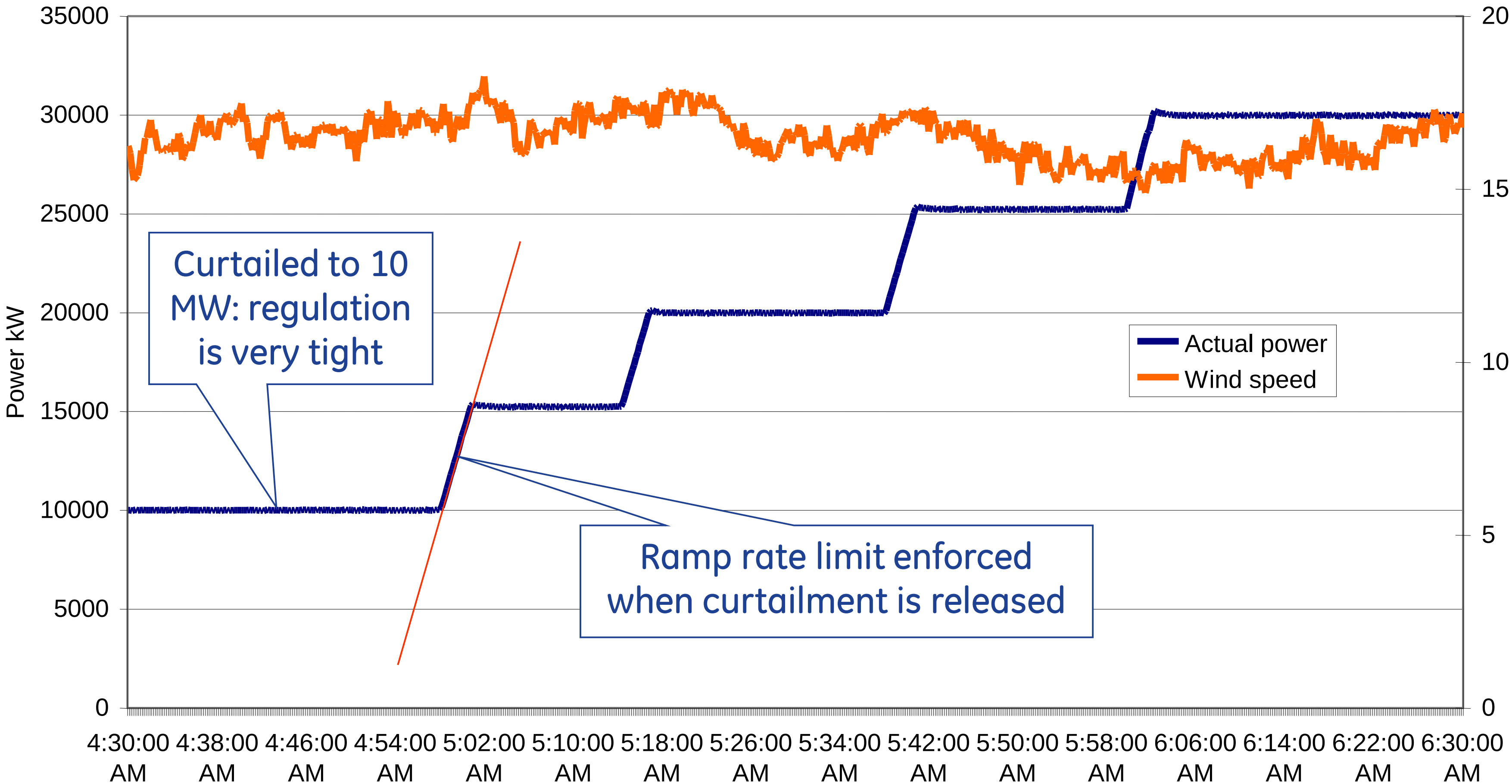
Curtailment and Ramp Example (30 MW plant)



2 Hours

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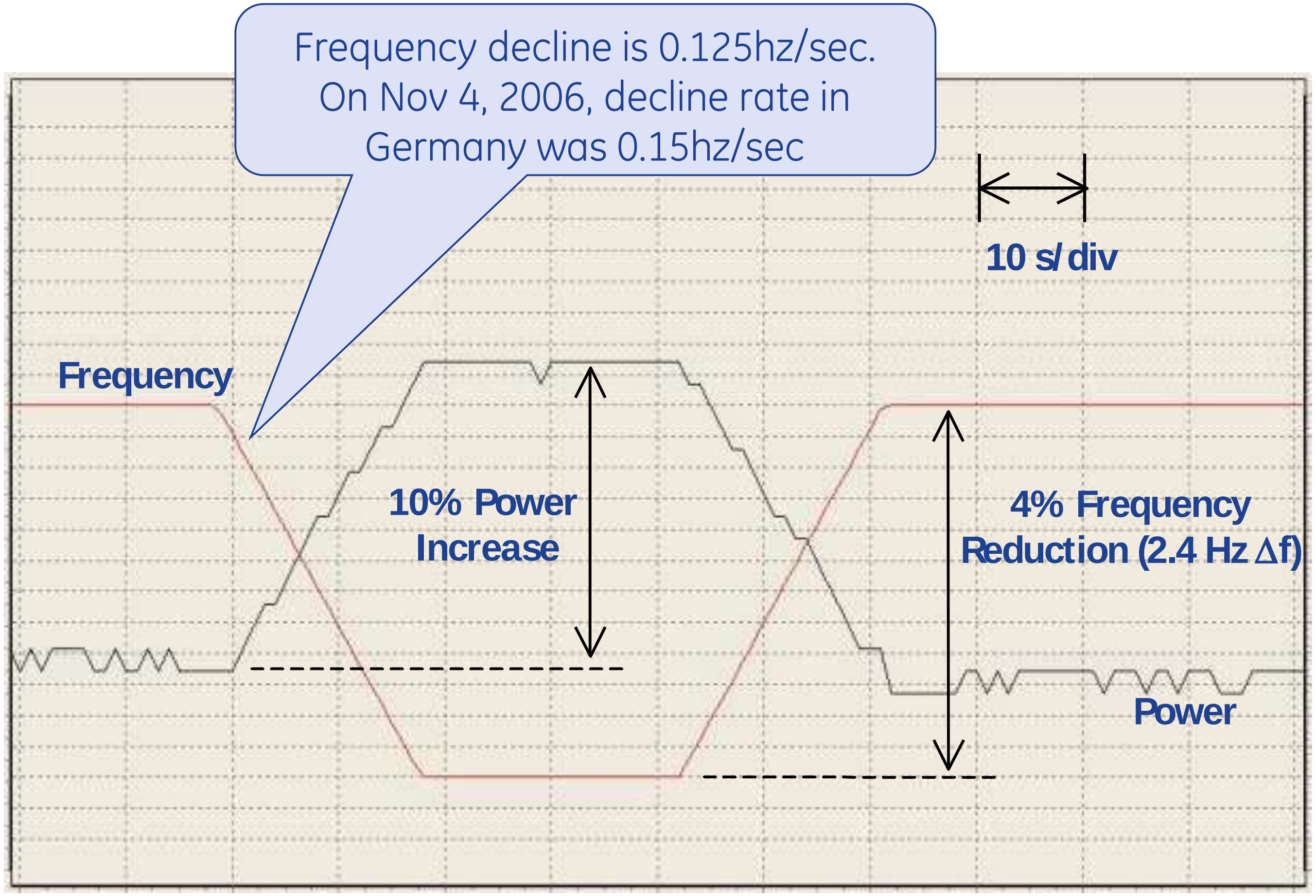
Under-Frequency Droop Response

Settings:

90% wind capacity

4% droop

4% frequency step
@0.125Hz/sec



10% Increase in plant watts with 4% under-frequency

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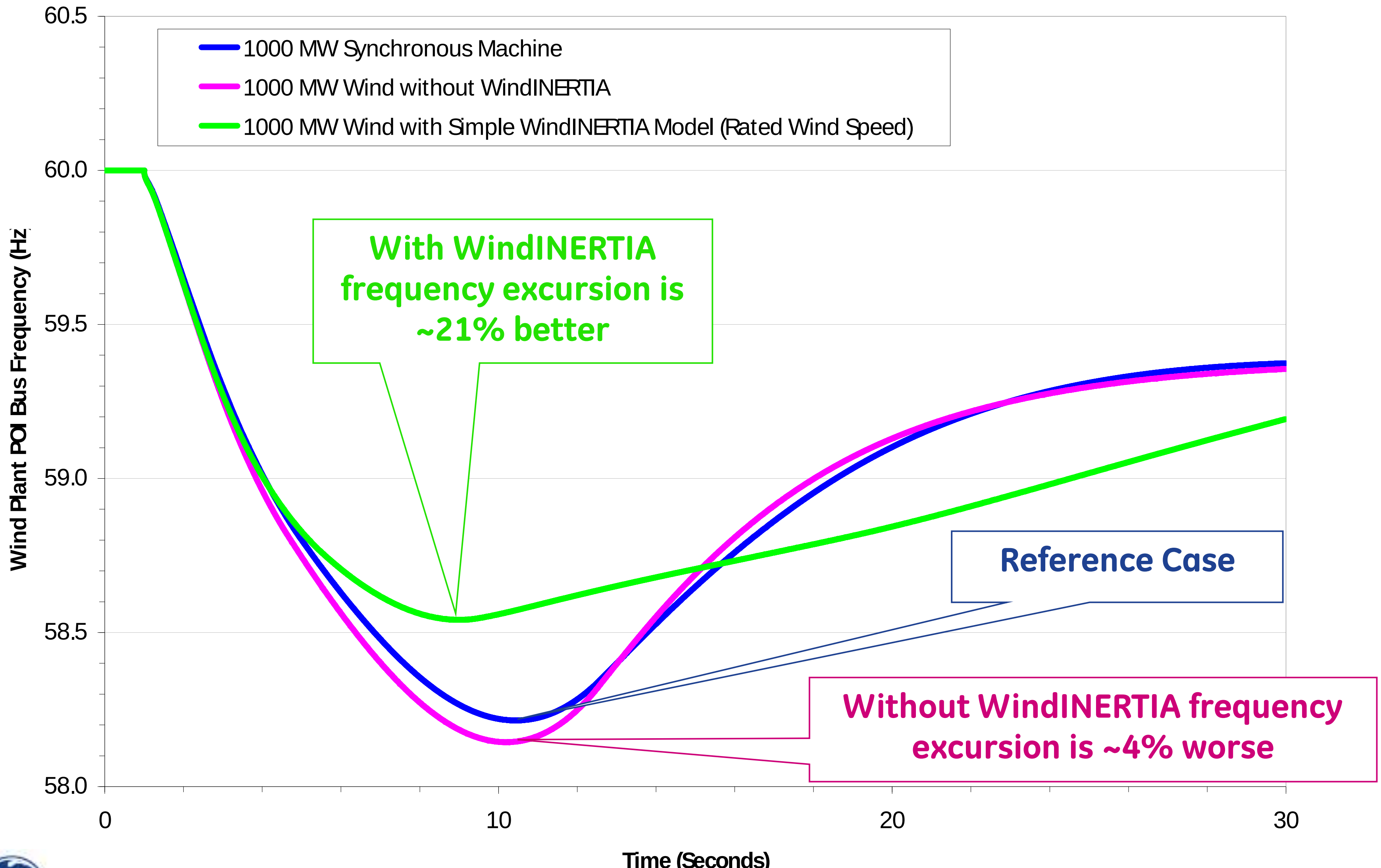
Wind Turbine InertialControl

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 will increase system security and aid large scale integration of wind power: starting to be required in some systems

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



Minimum frequency is the critical performance concern for reliability

Frequency Control – System Example

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Frequency response to loss of generation for the base case

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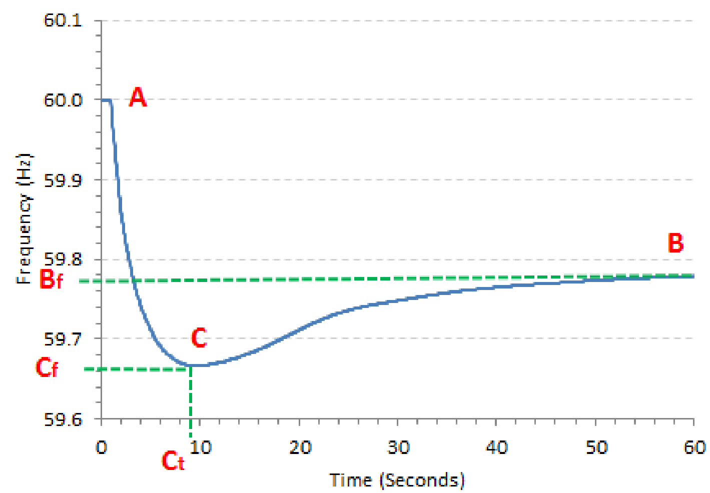
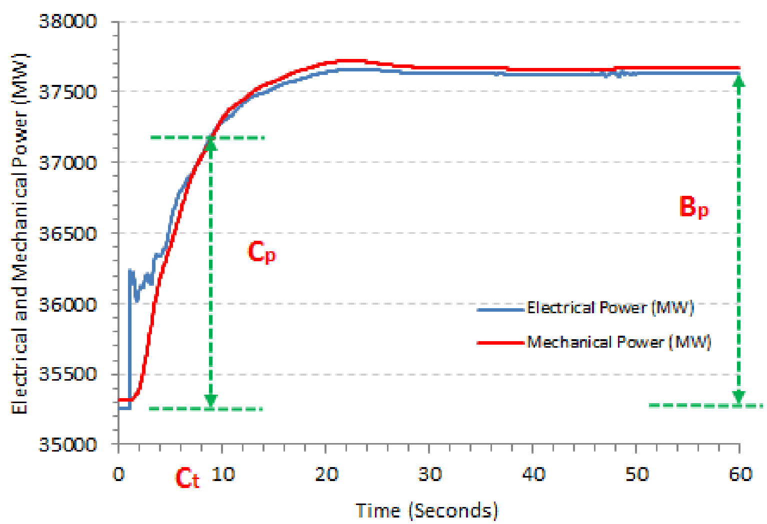
2012 San Diego,CA
New Energy Horizons
Opportunities and Challenges





- **Frequency Nadir (Cf)**
- **Frequency Nadir Time (Ct)**
- **LBNL Nadir-Based Frequency Response (MW Loss/Δf_c*0.1)**
- **GE-CAISO Nadir-Based Frequency Response (Δ MW/Δf_c *0.1)**
- **Settling Frequency (Bf)**
- **NERC Frequency Response (MW Loss/Δf_b*0.1)**
- **GE-CAISO Settling-Based Frequency Response**
- **(Δ MW/Δf_b*0.1)**

Frequency Nadir (Hz)	59.67
Frequency Nadir Time (Seconds)	9.8
LNBL Nadir-Based Frequency Response (MW/0.1Hz)	806
GR Nadir-Based Frequency Response (MW/0.1Hz)	641
Settling Frequency (Hz)	59.78
NERC Frequency Response (MW/0.1Hz)	1218
GR Settling-Based Frequency Response (MW/0.1Hz)	968

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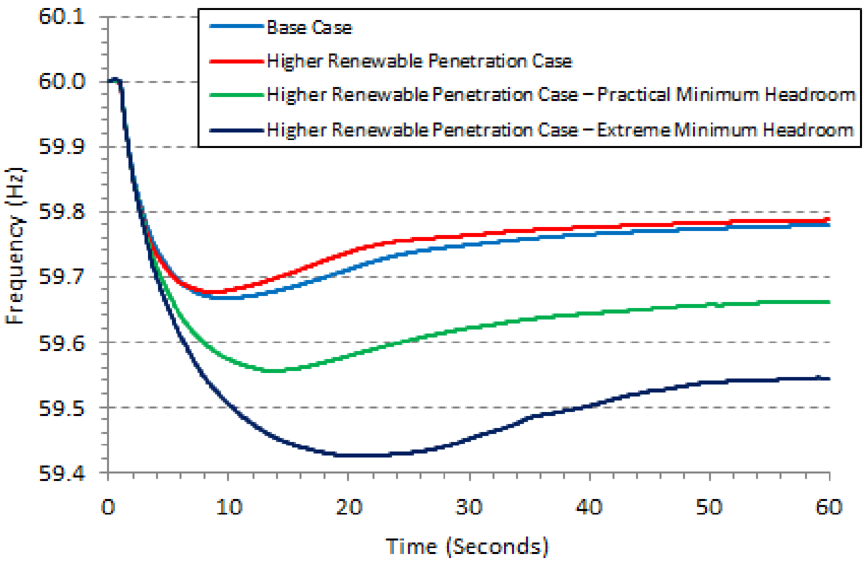
Frequency response for the three higher renewable penetration and reduced headroom cases



	BC	HR	HR-PH	HR-EH
Frequency Nadir (Hz)	59.67	59.68	59.56	59.42
Frequency Nadir Time (Seconds)	9.8	9.1	13.4	20.7
LNBL Nadir-Based Frequency Response (MW/0.1Hz)	806	839	605	467
GR Nadir-Based Frequency Response (MW/0.1Hz)	641	675	464	336
Settling Frequency (Hz)	59.78	59.79	59.66	59.54
NERC Frequency Response (MW/0.1Hz)	1218	1272	794	590
GR Settling-Based Frequency Response (MW/0.1Hz)	968	1024	609	424

BC: Base Case
HR: Higher Renewable penetration case
HR-PH: Higher Renewable penetration and Practical Headroom case
HR-EH: Higher Renewable penetration and Extreme Headroom case

Mitigation Measures – Governor-Like Response (Frequency Droop) from Wind Plants

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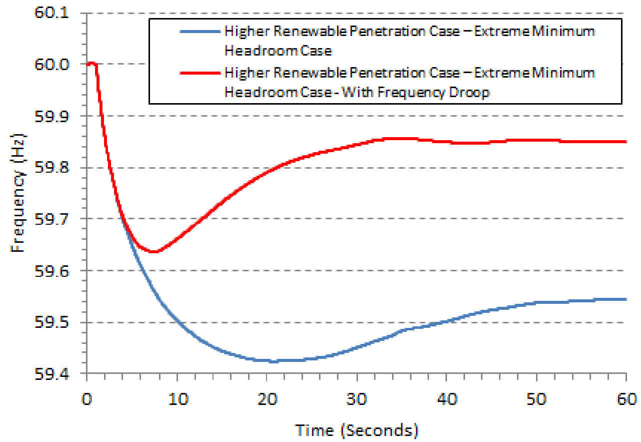
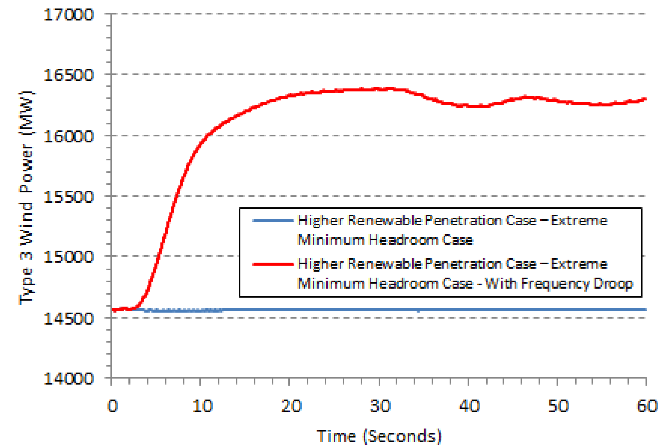
Approximately 41% of all the WTGs in WECC are provided with standard 5% droop, 36mHz deadband governors. This condition adds a total of 1812 MW of headroom.





Primary frequency response from wind generation has the potential to greatly improve system frequency performance of the entire WECC grid.

	Winter Low Load – High WECC Wind Case – Extreme Minimum Headroom			Winter Low Load – High WECC Wind Case – Extreme Minimum Headroom – Frequency Droop		
	WECC	CA	Non-CA	WECC	CA	Non-CA
Frequency Nadir (Hz)	59.42	59.42	59.43	59.64	59.63	59.63
Frequency Nadir Time (Seconds)	20.7	18.8	20.7	7.4	8.3	7.2
LBNL-Nadir Based Frequency Response (MW/0.1Hz)	467	461	468	739	736	727
GE-CAISO Nadir Based Frequency Response (MW/0.1Hz)	336	118	213	538	106	415
Percent of Total (%)		35.1	63.3		19.3	77.5
Settling Frequency (Hz)	59.54	59.55	59.56	59.85	59.85	59.85
NERC Frequency Response (MW/0.1Hz)	590	592	606	1787	1794	1793
GE-CAISO Settling Based Frequency Response (MW/0.1Hz)	424	152	275	1301	258	1036
Percent of Total (%)		35.8	64.9		19.8	79.6

The California contribution to frequency response goes from an unacceptable 152 MW/0.1 Hz to a healthy 258 MW/0.1 Hz.

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Short circuit behavior of wind generators

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SHORT CIRCUIT

- Short-circuit analysis is necessary for:
  - Protection coordination
  - Assessment of fault-current withstand requirements
- Industry's short-circuit analysis practices and tools based on synchronous generators
  - Positive sequence represented by an ideal voltage source behind reactance
  - Negative sequence represented by a simple constant reactance
- Older wind turbines (Type 1 and 2) are generally compatible with existing short circuit analysis practices and tools
- Modern wind turbines and PV inverters are not
  - Modern WTGs use variable-speed generators
    - Doubly-fed asynch. generators (DFAG, aka DFIG) – **Type 3**
    - Full ac-dc-ac conversion – **Type 4**
  - PV inverters are like Type 4 wind turbines

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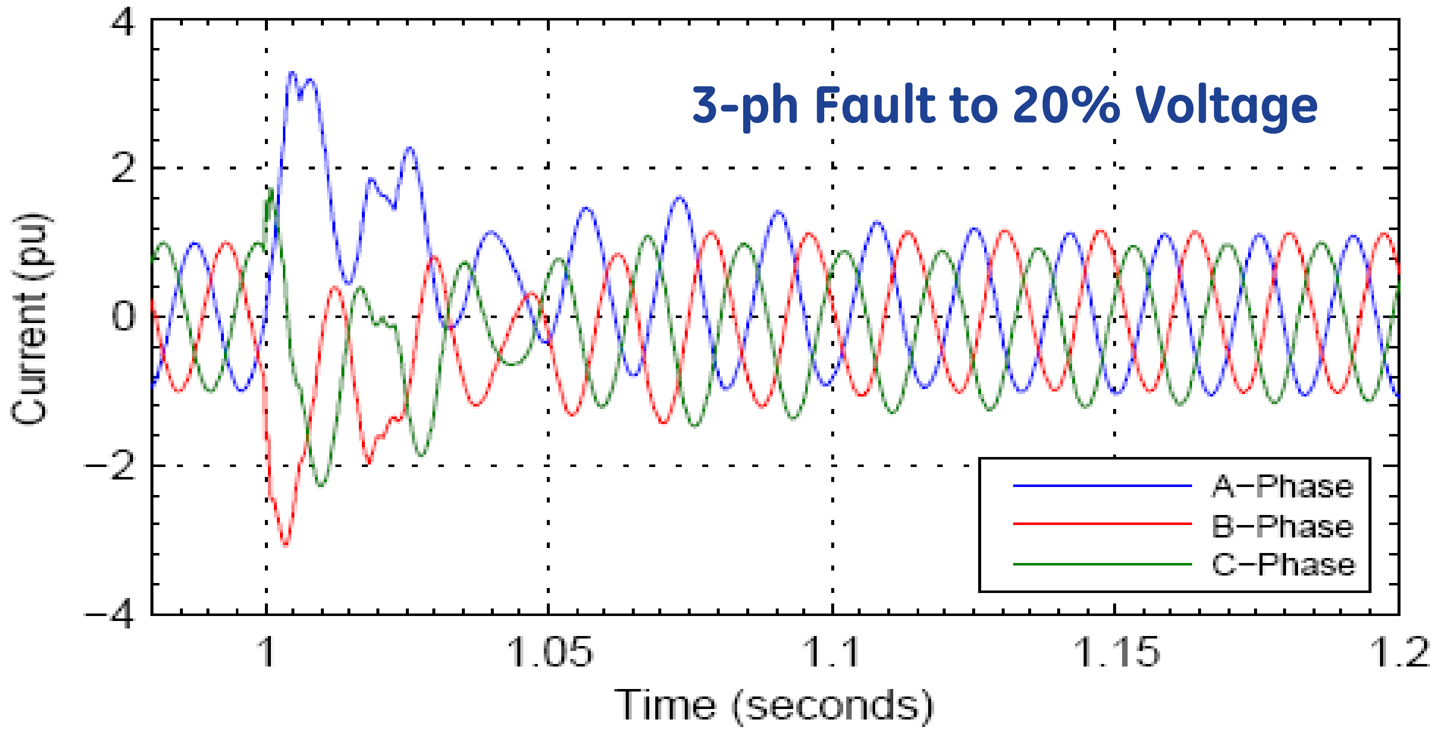
Type 3 WTG (Doubly Fed Generator)



- Initially, rotor circuit is “crowbarred” – acts like an induction generator – symmetrical current up to ~ 4 p.u.
- As fault current decreases, crowbar is removed
- Current regulator regains control

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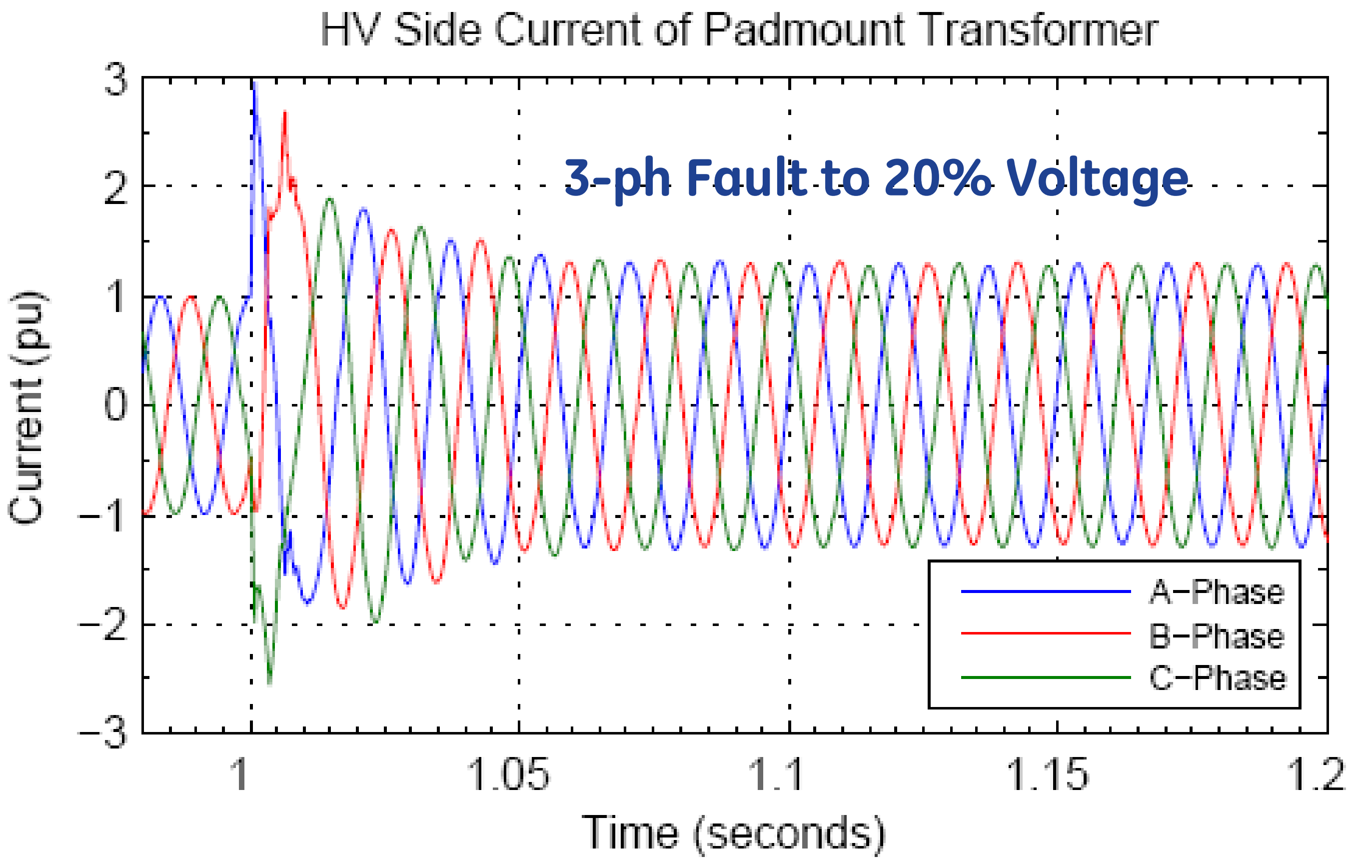
Type 4 WTG Short Circuit Current



- Initial transient current – ~ 2 p.u. symmetrical
- Current regulator quickly takes control
- Current order increased for grid support in this design

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Modeling Type 3 & 4 WTGs, and PV Inverters in Short Circuit Studies

Alternative #1: approximate modeling

- Type 3
  - Model as a voltage source behind subtransient reactance
  - Provides upper limit to short-circuit current
- Type 4 and PV Inverter
  - Model as a current-limited source
  - Current magnitude 2 – 3 p.u. for first 1 – 2 cycles
  - Longer-term current could be from pre-fault value to ~1.5 p.u., depending on control

Approximate models are quite inexact, but may be good enough because WTG contribution to grid fault current is usually much smaller than total

Inadequate where wind plant current contribution is dominant, and accuracy is important

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Modeling Type 3 & 4 WTGs, and PV Inverters in Short Circuit Studies

Alternative #2: detailed time-domain simulations

- Performed in an EMT-type program (EMTP, ATP, PSCAD, etc.)
- Requires detailed hardware and control model
  - Such data are usually considered quite proprietary
  - “Generic” models are quite meaningless
- Not well suited for large system studies
- Requires an expertise different from that of most short-circuit program users
- Considerable computational effort for each case

Technically superior alternative, but generally quite impractical.

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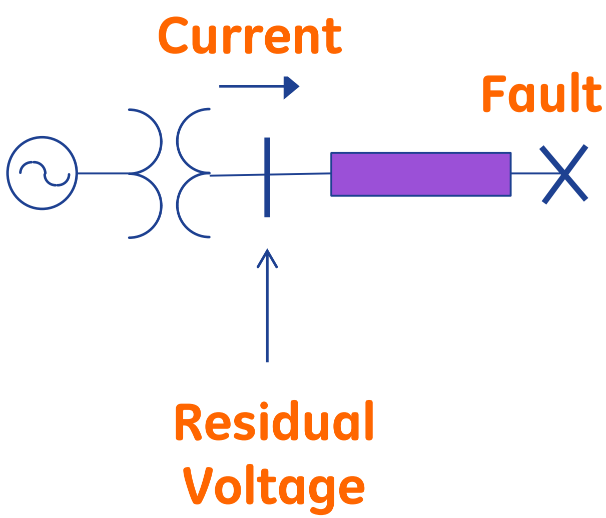
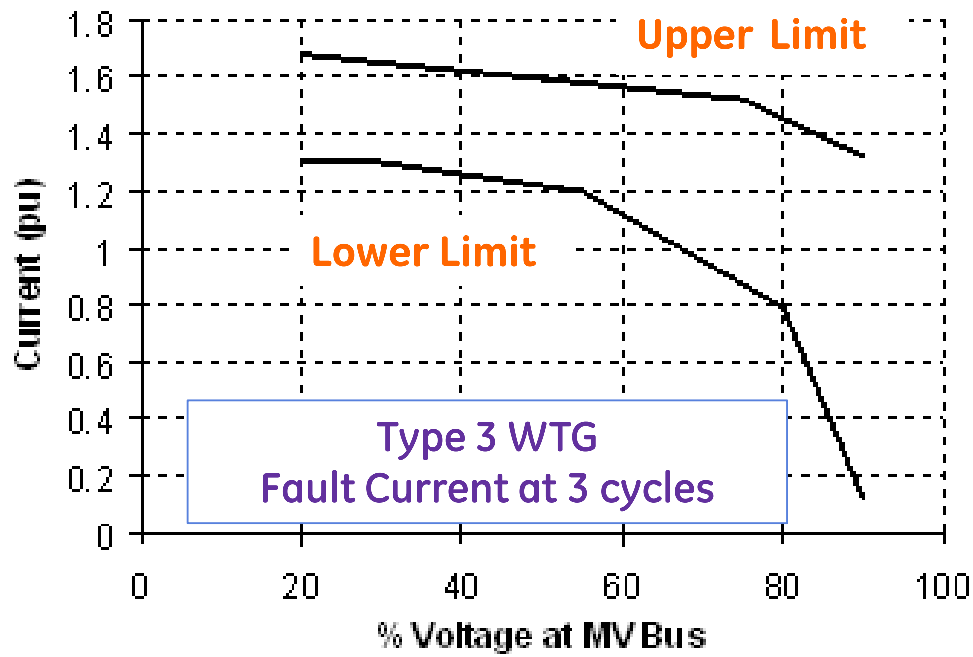
Modeling WTGs in Short Circuit Studies

Alternative #3: modified phasor approach

- Wind turbine manufacturer provides tables or graphs of current versus residual fault voltage for certain times
- Network short circuit analysis solved iteratively

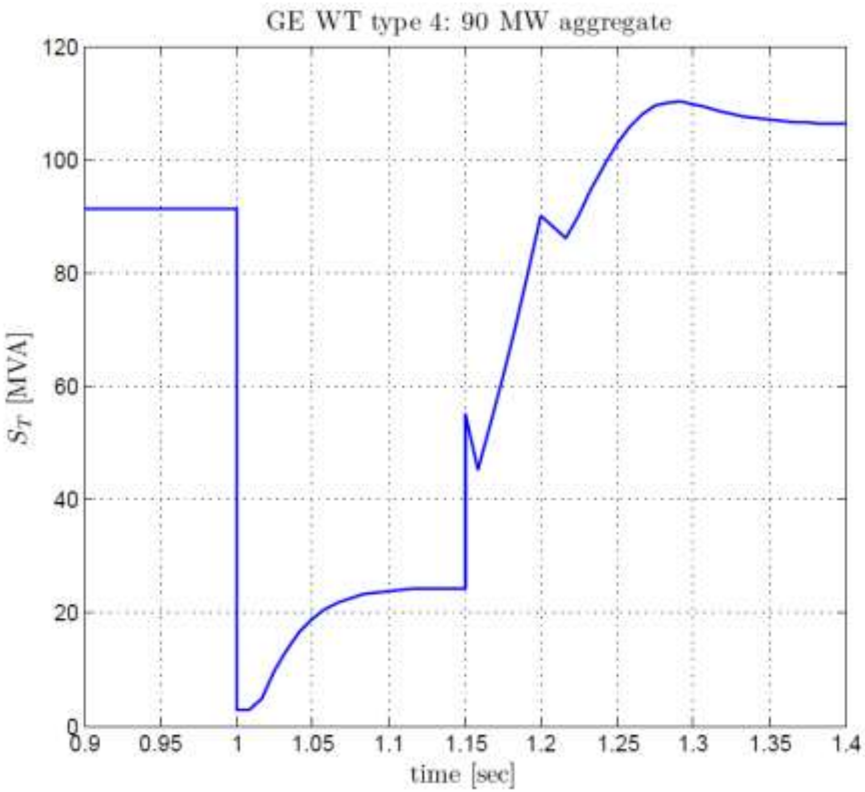


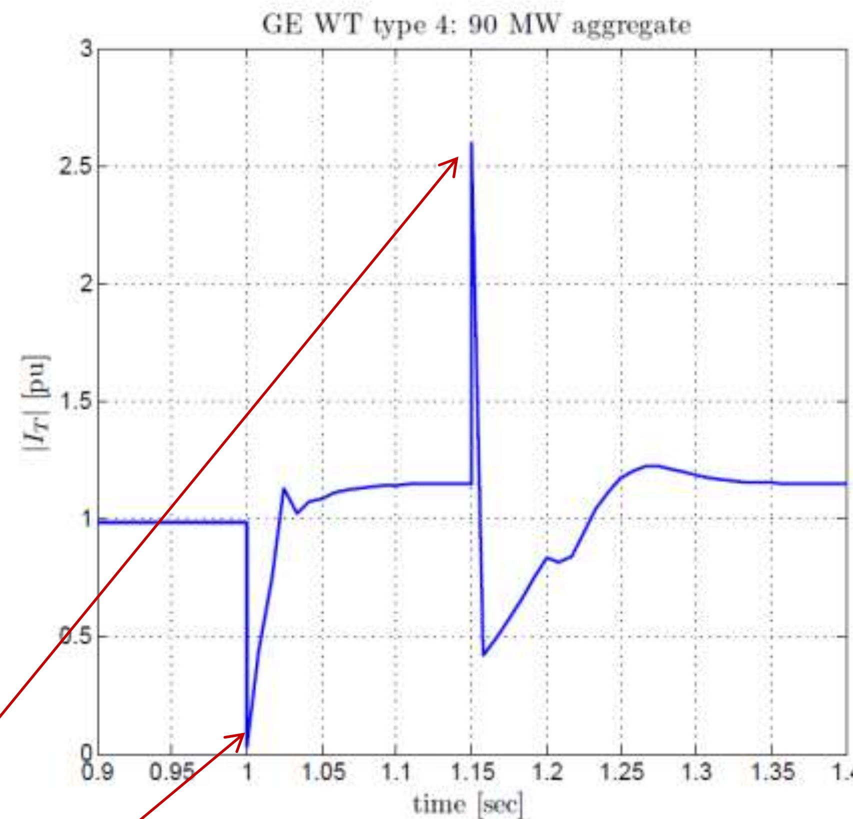


Most feasible option at this time; short circuit software needs to be modified

Examples from PSS/e stability runs

GE WT Model, type 4, 90 MW aggregate





Not relevant

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Thank you!

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