Performance Characteristics of State of the Art Wind Plants

Jovan Bebic, Ph.D.
GE Energy Consulting

SEVENTH ANNUAL CARNEGIE MELLON CONFERENCE ON THE ELECTRICITY INDUSTRY 2011

Pittsburgh, March 9, 2011

imagination at work

Energy Consulting... Since Early 1900's

Power Economics

Strategic Planning

Asset Valuation

Investment Analysis

Generation Solutions

Optimization of Thermal Systems

Concept & Design Engineering

Generation Performance

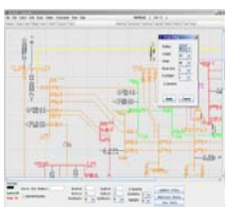
Power Systems

**** Equipment Applications ****

Testing & Grid Compliance

Systems Engineering & Performance

Smart Grid



Market Models & Tools

Power Market Models

Power Systems Models

Asset Valuation Tools

Power Systems Engineering Course (PSEC)

Standardized Training

Customized Courses

Global Reference

Enabling >20% Renewables… GE Studies

Studies commissioned by utilities, energy commissions, ISOs, …

- Examine feasibility of 100+ GW of new renewables
- Consider operability, costs, emissions, transmission

2008 Maui
70 MW Wind
39% Peak Load
25% Energy

2010 Oahu
500 MW Wind
100 MW Solar
55% Peak Load
25% Energy

2004 New York
3 GW Wind
10% Peak Load
4% Energy

2005 Ontario
15 GW Wind
50% Peak Load
30% Energy

2006 California
13 GW Wind
3 GW Solar
26% Peak Load
15% Energy

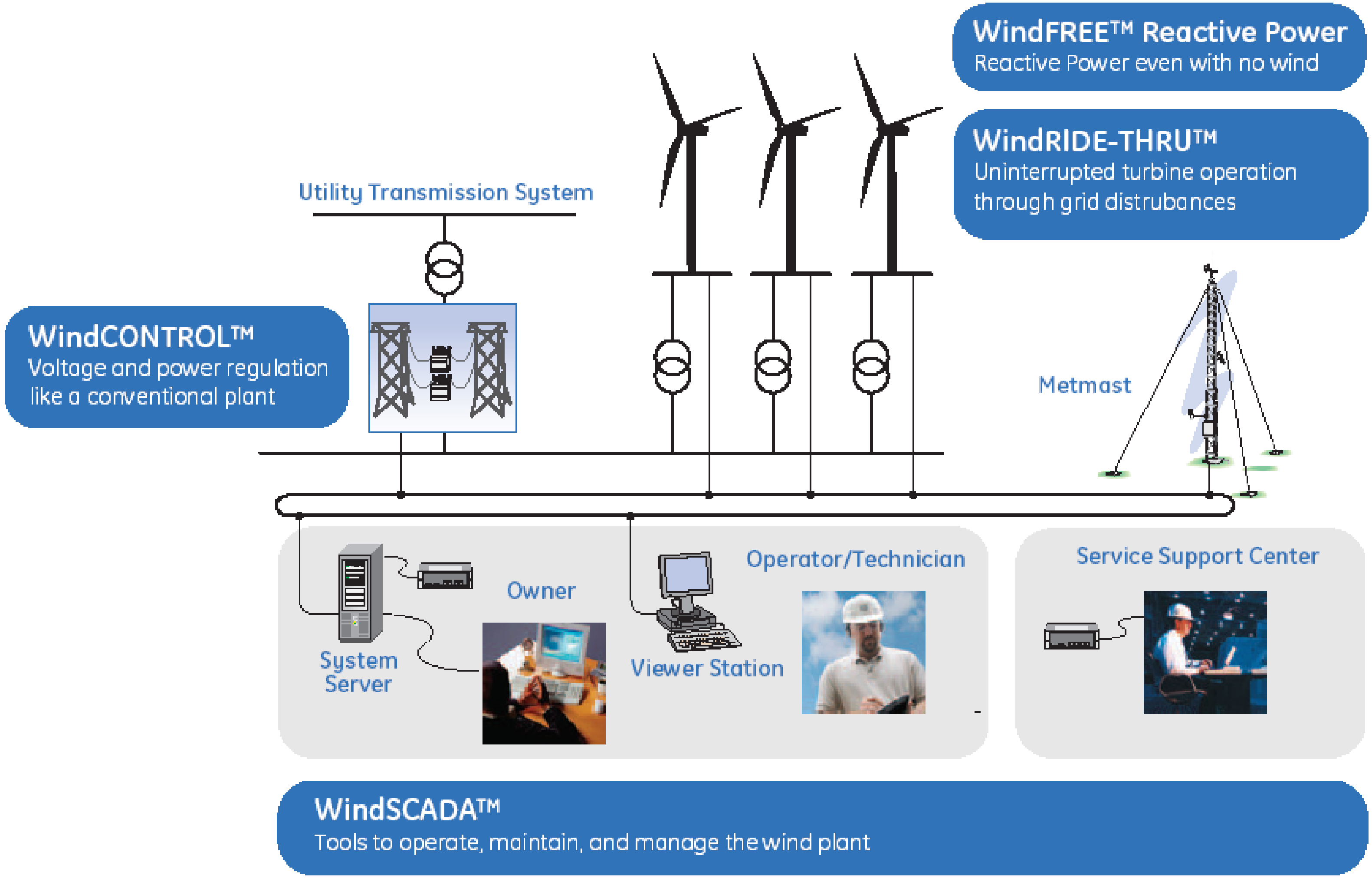
2007 Texas
15 GW Wind
25% Peak Load
17% Energy

2009 Western U.S.
72 GW Wind
15 GW Solar
50% Peak Load
27% Energy

2010 New England
12 GW Wind
39% Peak Load
24% Energy

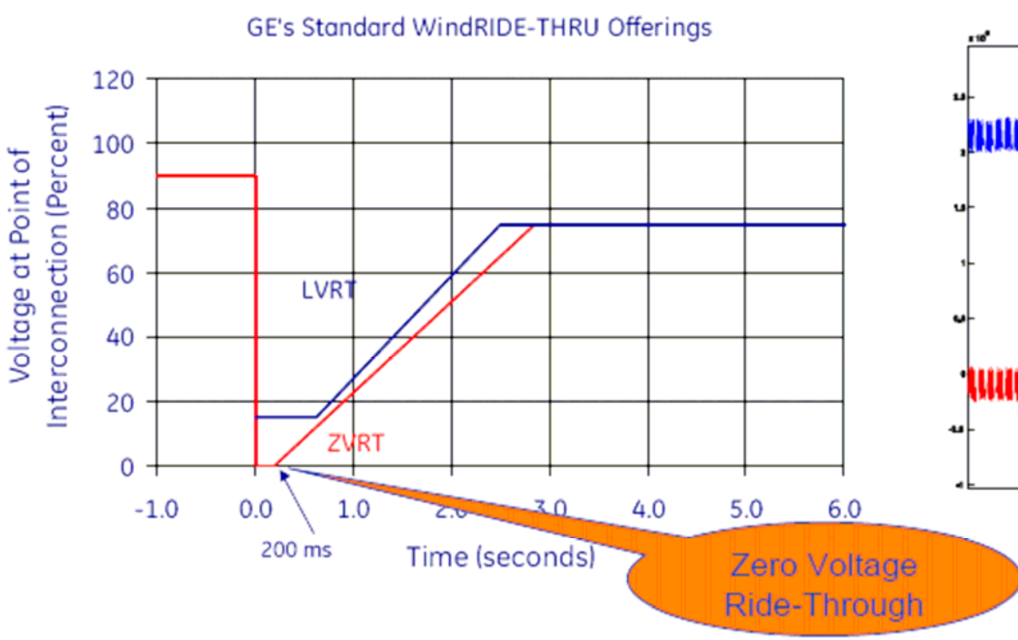
Need for operational flexibility, new operating strategies and markets, transmission reinforcement, grid friendly renewables.

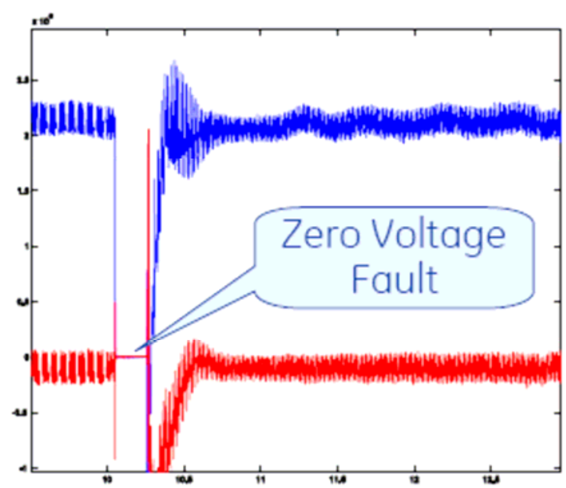
Grid Friendly Wind Power Plant



Ride-Through Capabilities

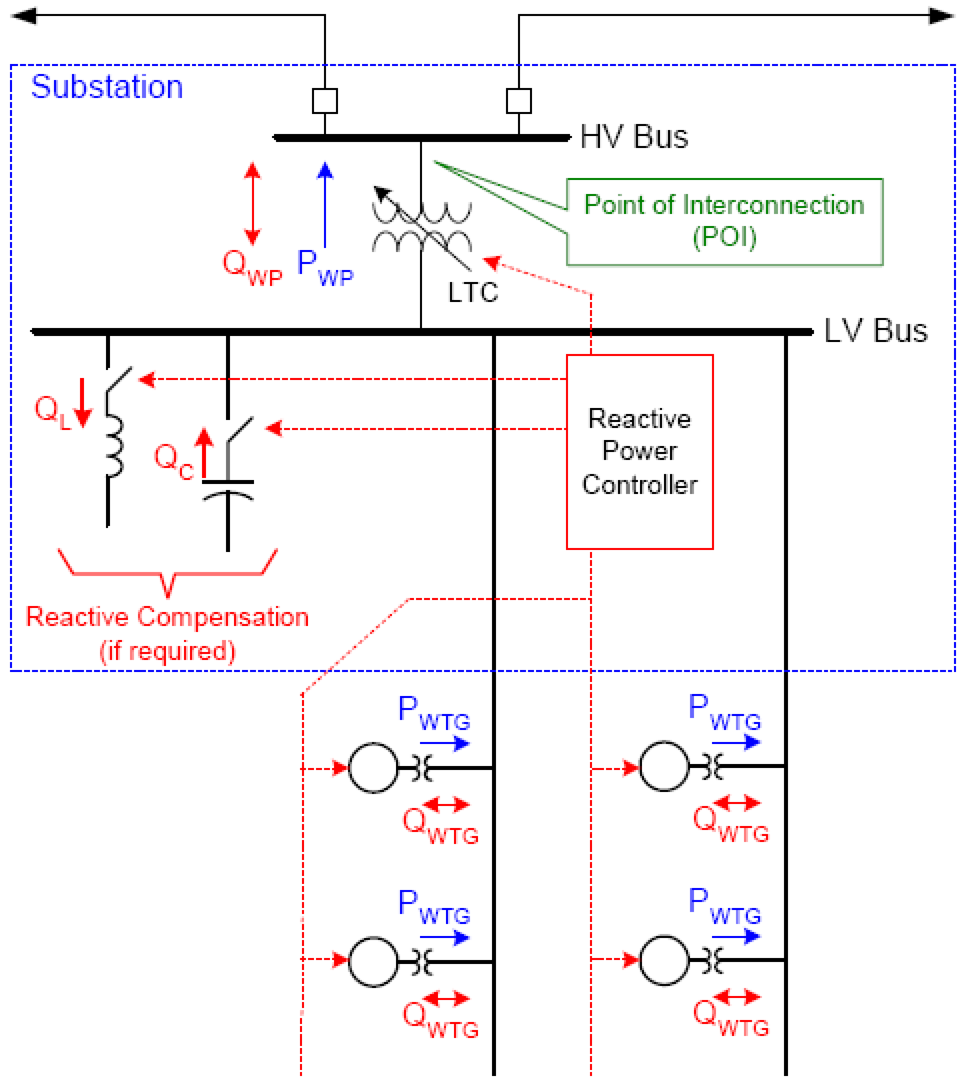
- Wind plant remains on-line and feeds reactive power through system disturbances
- New ride through capabilities are engineered to meet global needs
- Designed for faults on any combination of phases
- Zero voltage ride through offering new standard





Wind Control - Voltage

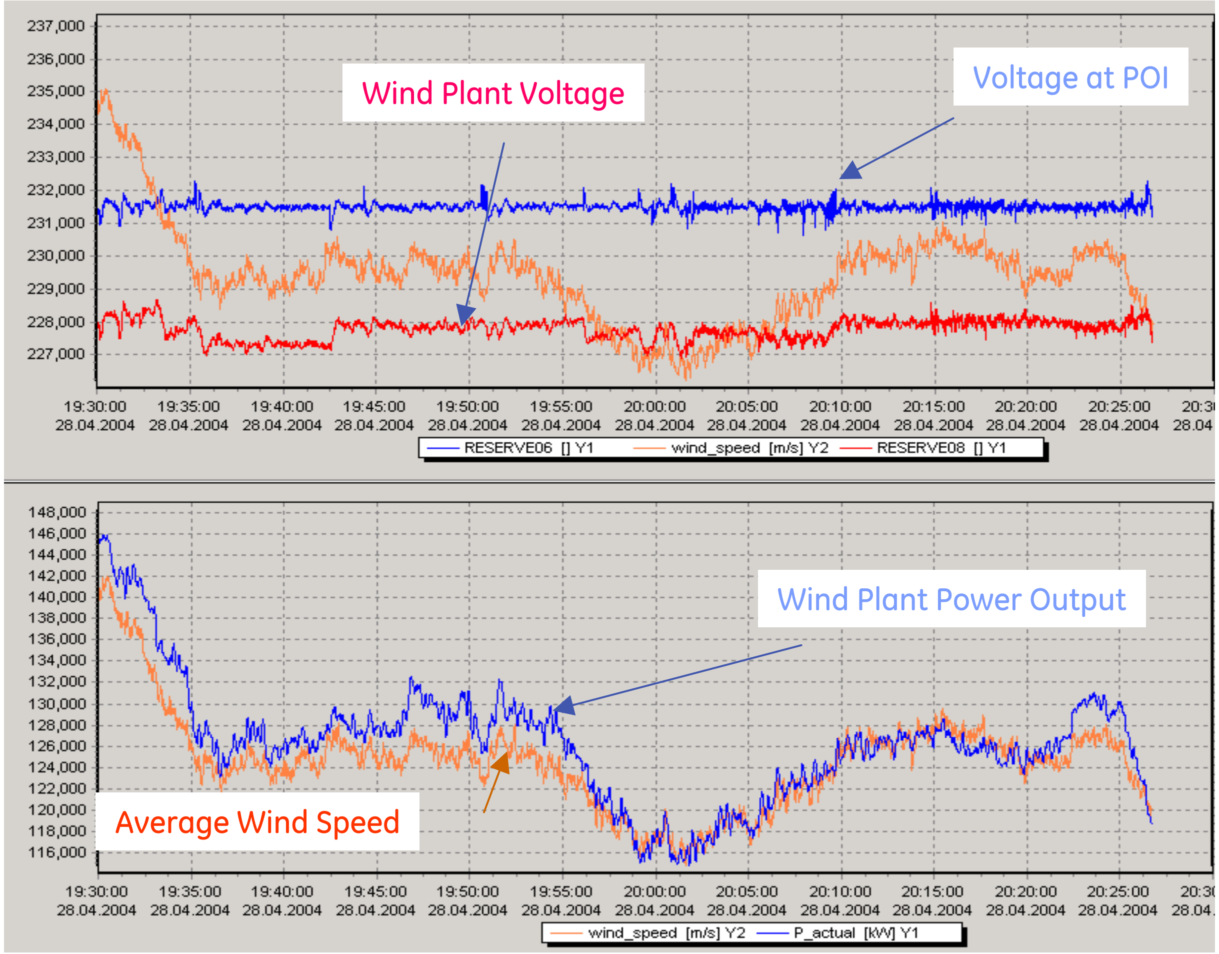
- Coordinated turbine and plant supervisory control structure
- Voltage, VAR, & PF control
- PF requirements primarily met by WTG reactive capability, but augmented by mechanically switched shunt devices if necessary
- Combined plant response eliminates need for SVC, STATCOM, or other expensive equipment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



imagination at work

Wind Control – Voltage (continued)

- 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

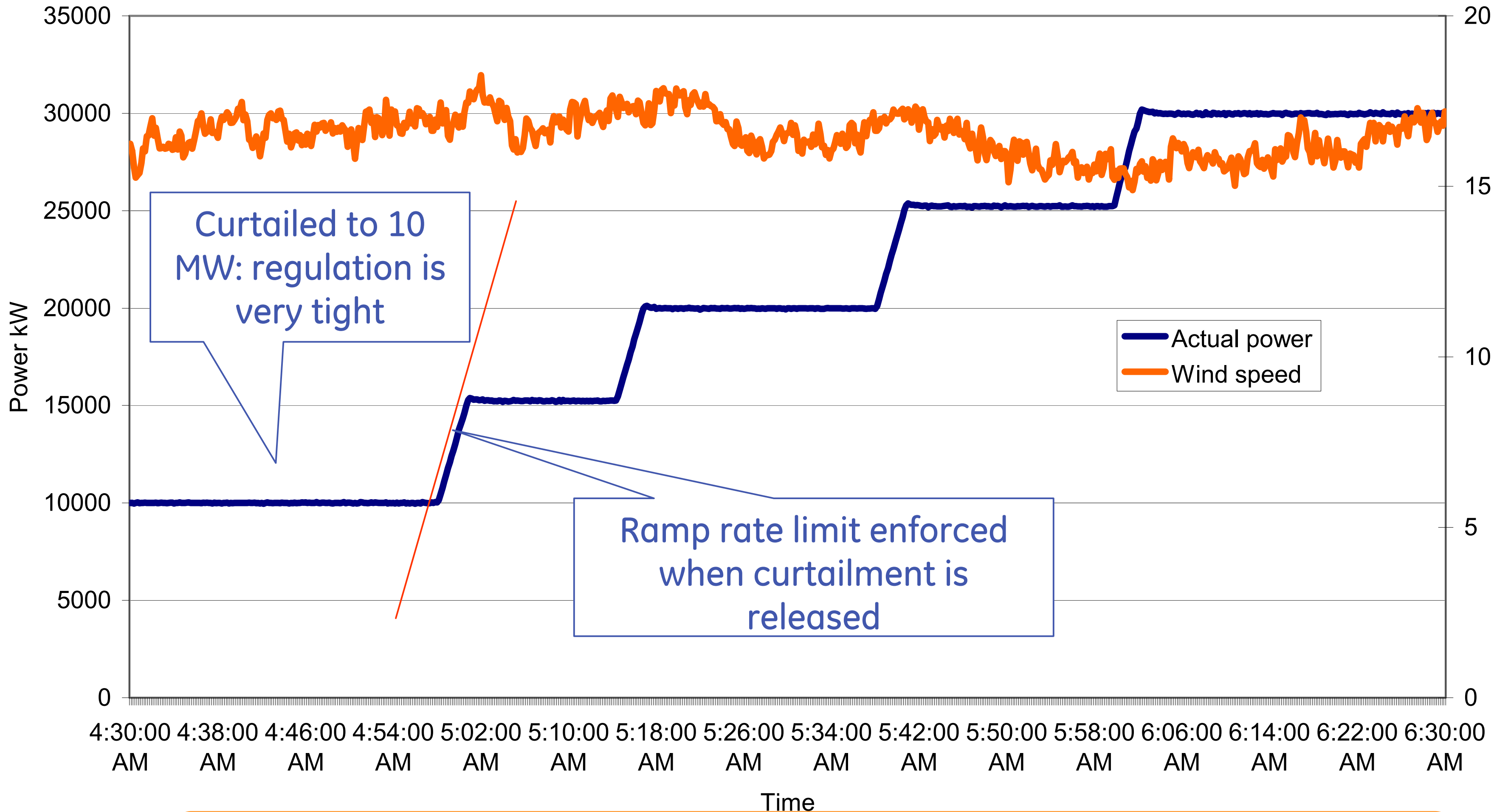


Actual measurements from a 162MW wind plant

imagination at work

Wind Control – Power

Curtailment and Ramp Rate Limits



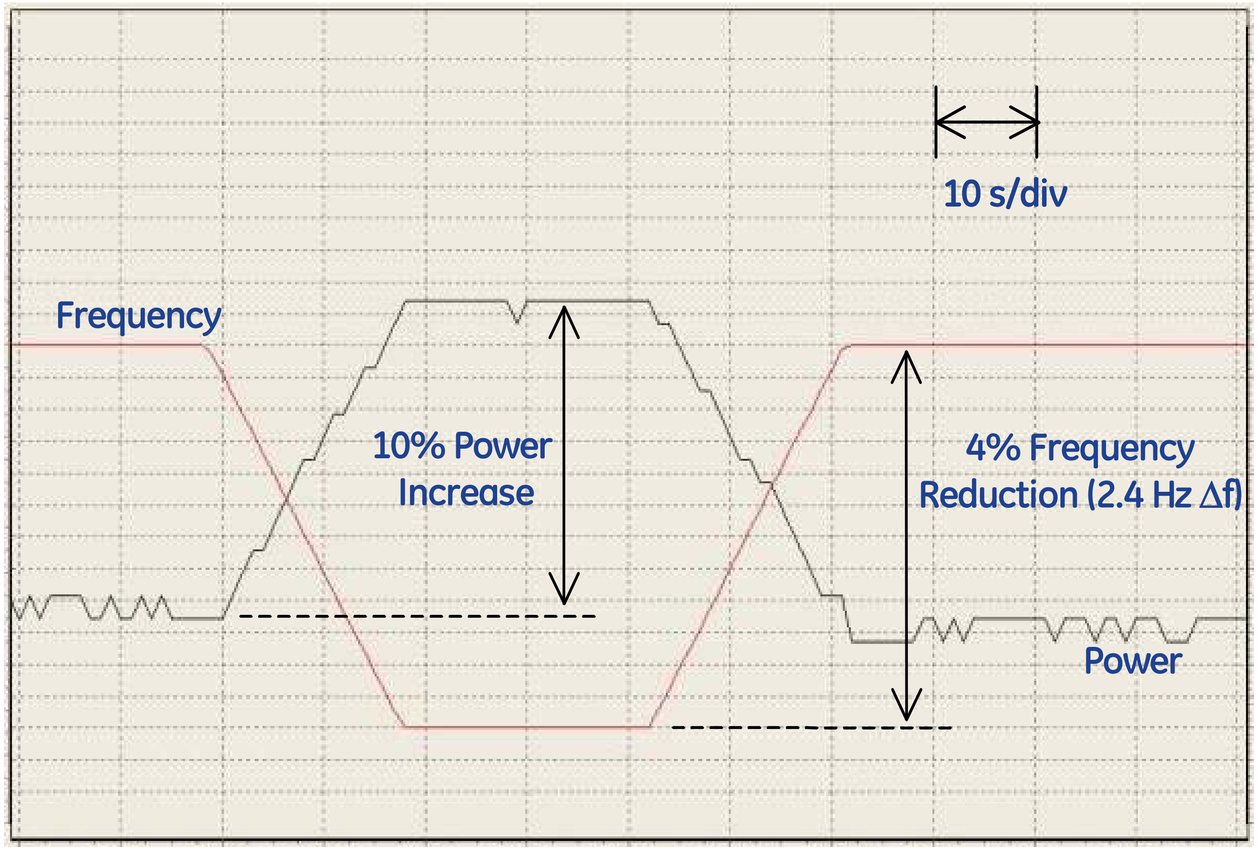
Dispatching of Wind Plants Becoming More Common

imagi

Wind Control – Power
Under-Frequency Droop Response

Initial Conditions:
- Power curtailed to 90% of available wind
- 2.5% power increase for 1% frequency drop

Test:
- 4% frequency ramp-down @0.125 Hz/sec
- 10% increase in plant power with 4% under-frequency



Function has High Opportunity Cost: To Be Used Sparingly

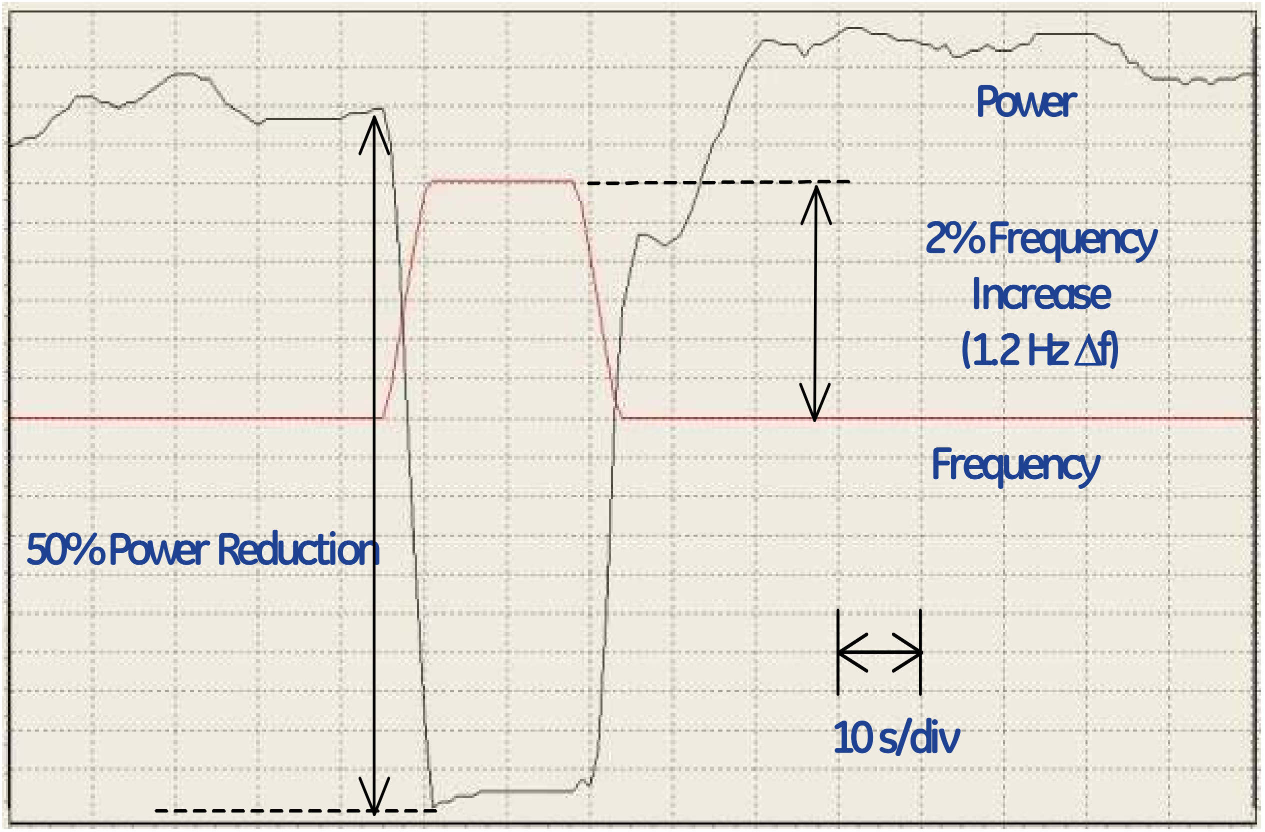
Wind Control – Power
Over-Frequency Droop Response

Initial Conditions:

- 25% power reduction for 1% frequency increase

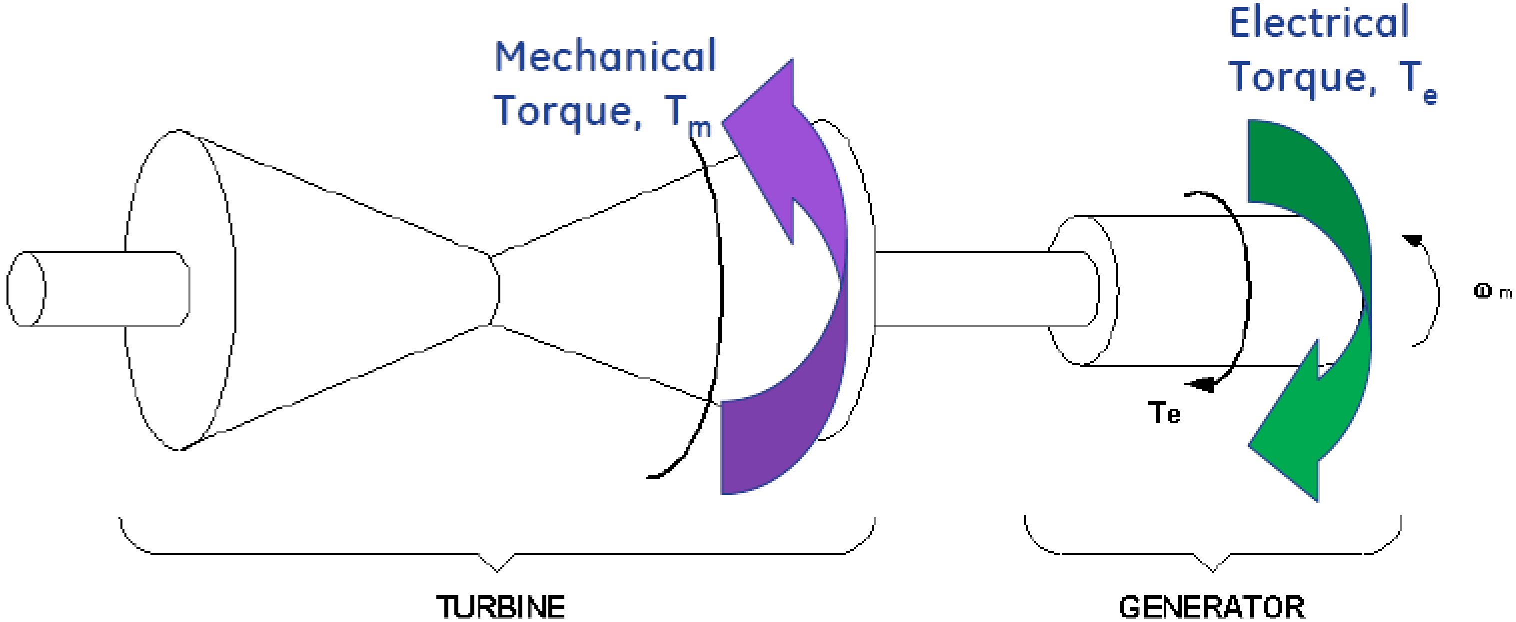
Test:

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



Function has Little Opportunity Cost: A Reasonable Request

WindINERTIA – Inertial Response



System Needs:

- Modern wind turbine-generators do not contribute to system inertia
- System inertia declines as wind generation displaces conventional generators (de-committed)

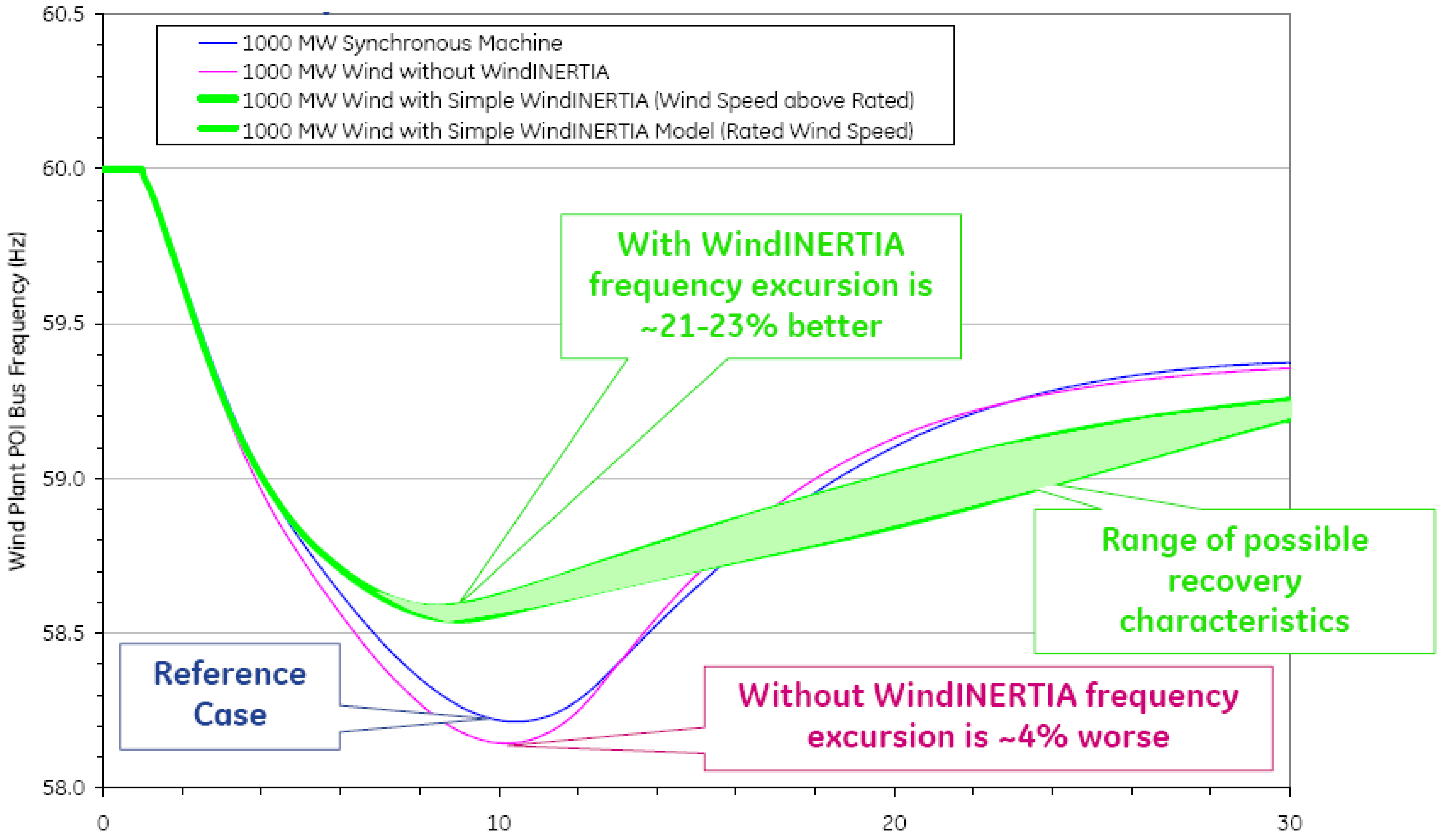
Control Concept:

- Use controls to extract stored inertial energy
- Provide incremental energy contribution during the first 10 seconds of grid events

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

WindINERTIA – Example

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



Performance is a function of wind and other conditions, less deterministic than synchronous machine inertial response

imaginati

Wind Power On Series-Compensated Lines

Why use series compensation?

Long lines have significant impedance to current flow

- Limits power transmission capacity

Series capacitors "cancel" part of line impedance

- Permits desired power transmission

But, impedance-cancellation has an important side-effect…

Electrical resonance introduced to grid

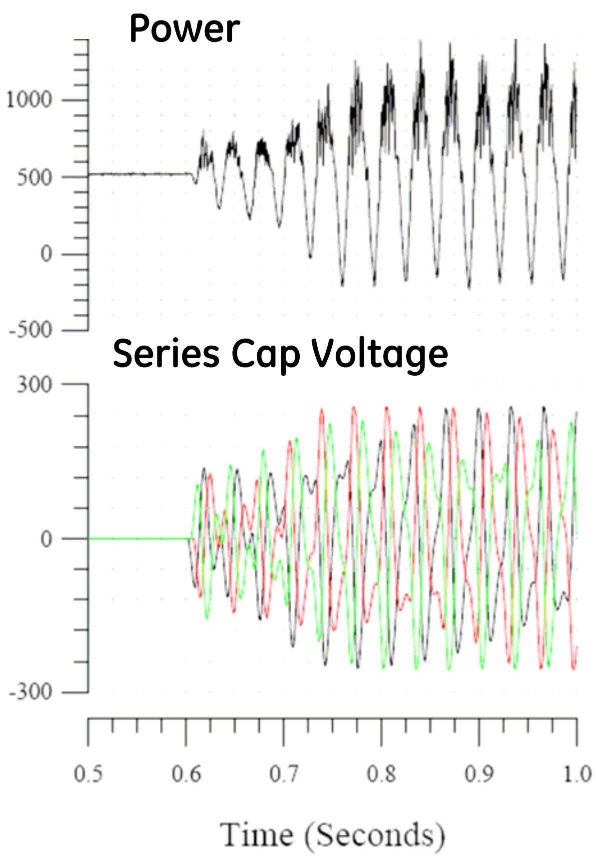
- Very small damping, due to low-loss grid
- Interacts with electrical equipment on grid
- Some interaction mechanisms create instability

Subsynchronous Interactions (SSI) is a generic term for various interaction mechanisms with series capacitors

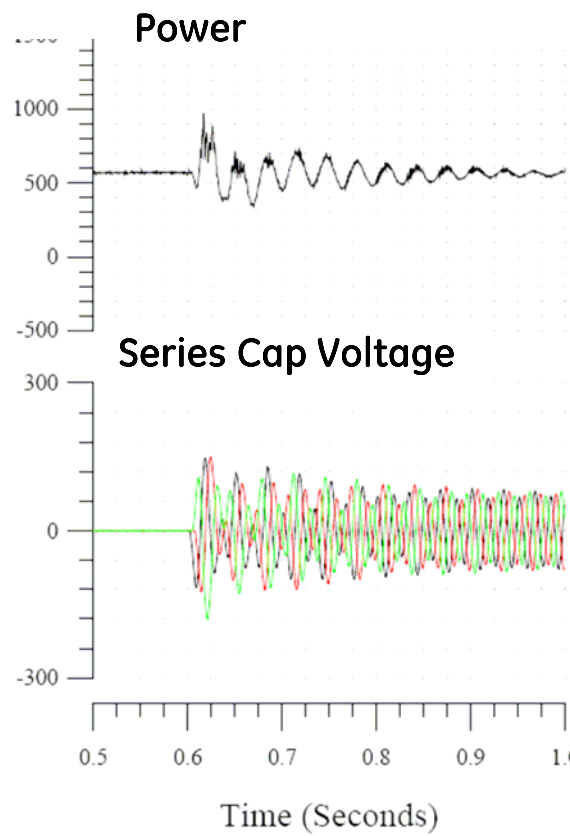
Wind Power On Series-Compensated Lines

Example: Insertion of series capacitor, wind plant based on doubly-fed asynchronous generator

Baseline control



Modified Control



Mitigate by control, but protect as well.
At turbine and at series capacitor…

Wind Power On Series-Compensated Lines

Suggested Best Practice

Grid entity responsibility

- Determine exposure of wind plants for both extreme and planned grid conditions
- Provide grid-level protection for SSI events
- Provide some modest grid-level damping of series resonance
- Inform wind plant owners of exposure

Wind plant owner responsibility

- Engage turbine vendor and share grid information
- If needed, engage independent consultant with SSI expertise
- Define actions needed within wind plant, if any
- Arrange to implement any needed actions

Wind turbine vendor responsibility

- Evaluate application information, and propose solutions if needed
- Support independent consultant if needed

Protection prevents damage – always prudent
Mitigation prevents protective action – not always necessary

Thank you.

Jovan Bebic
bebic@ge.com