# Wind Generation Challenges & New Technologies

Matthew Richwine
March 4, 2015

imagination at work

# Agenda

- Introduction
- Grid Integration Challenges
- "New" Technologies
- Conclusions

# Introduction

# Matt Richwine

## Education

BS, Electrical & Computer Engineering, Cornell University, 2008

MEng, Systems Engineering, Cornell University, 2009

## Work Experience

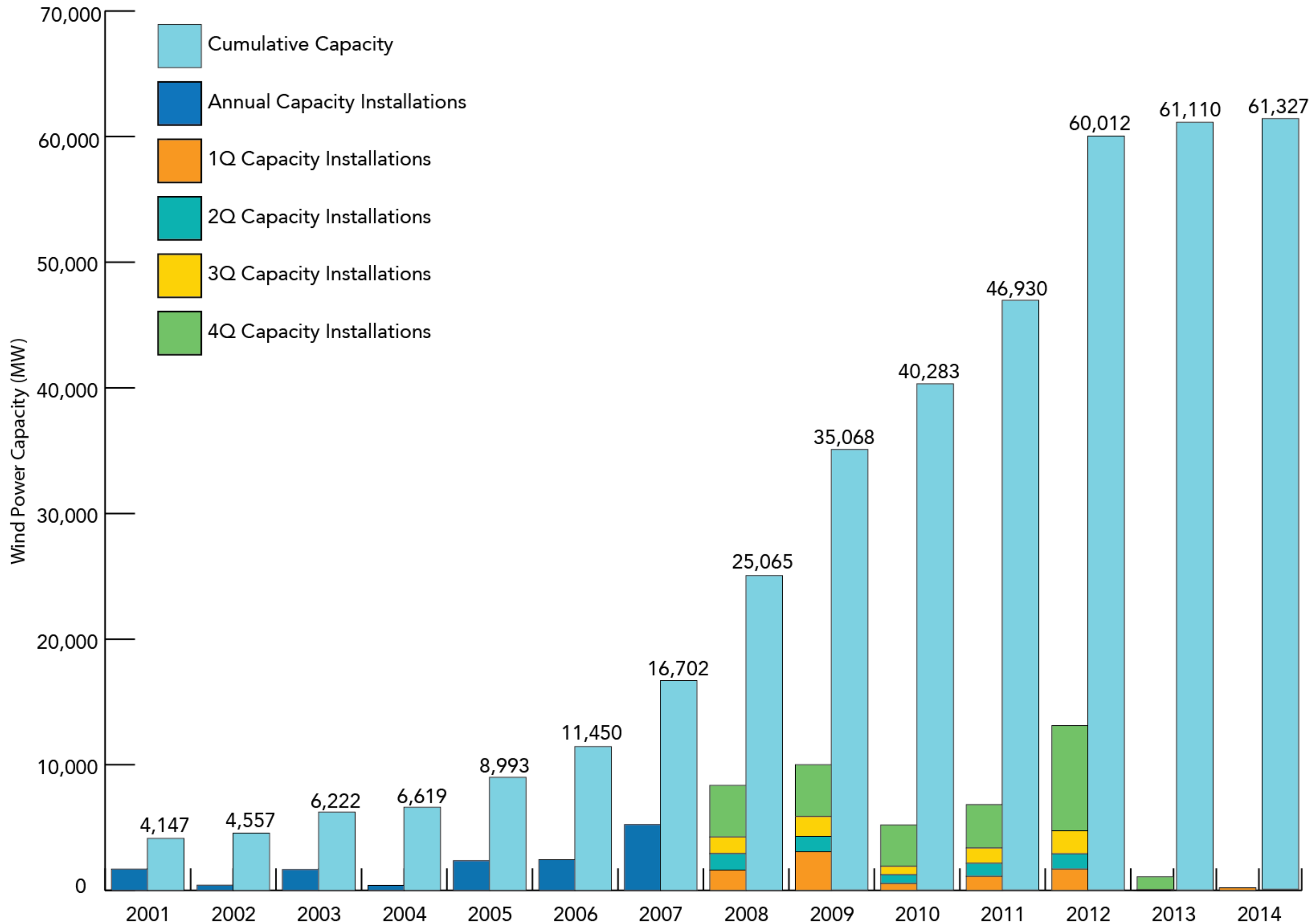
GE Energy Consulting, 2013 – Present

- Leading sub-synchronous resonance and torsional interaction studies
- Analyzing renewable generation integration on existing island systems
- Testing and modeling thermal and renewable plants for grid code compliance

GE Wind Generator & Electrical Systems Engineer, 2009 – 2013

- Specified, developed, and validated a new DFIG for a new electrical system
- Introduced a thermal control strategy for wind generators to optimize output

# Growth of the Industry




Source: AWEA, 1Q 2014 [1]

# Wind Integration Challenges

# Looking Ahead

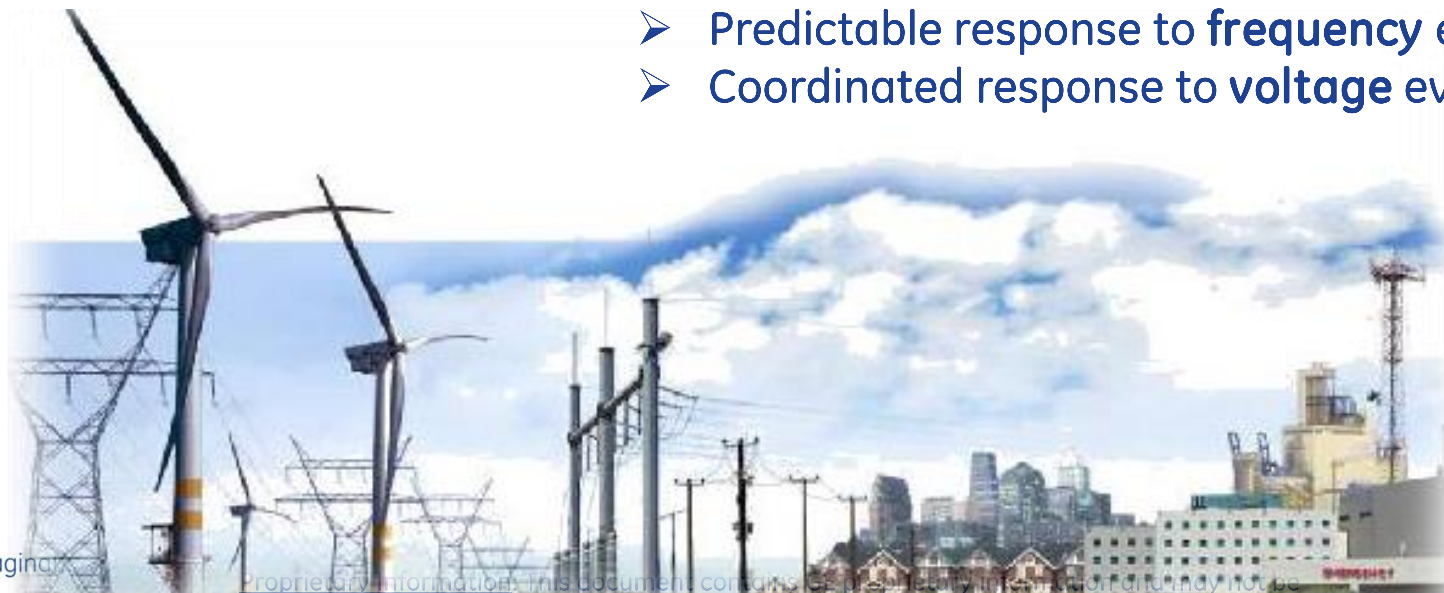
**As renewable energy increases, it will:**

- Have a greater impact on the grid;
- Displace other generation;
- Become essential to grid reliability; and
- Need to be more predictable during disturbances

**Renewable energy must be a good citizen on the grid**

# Strategies to Improve Integration

- Wind power forecasting to improve unit commitment
- Refine up reserve requirements based on wind power forecast
- Increase thermal unit ramp rate capability
- Advanced wind turbine technologies to support the grid when it is stressed
  - Predictable response to **frequency** events
  - Coordinated response to **voltage** events



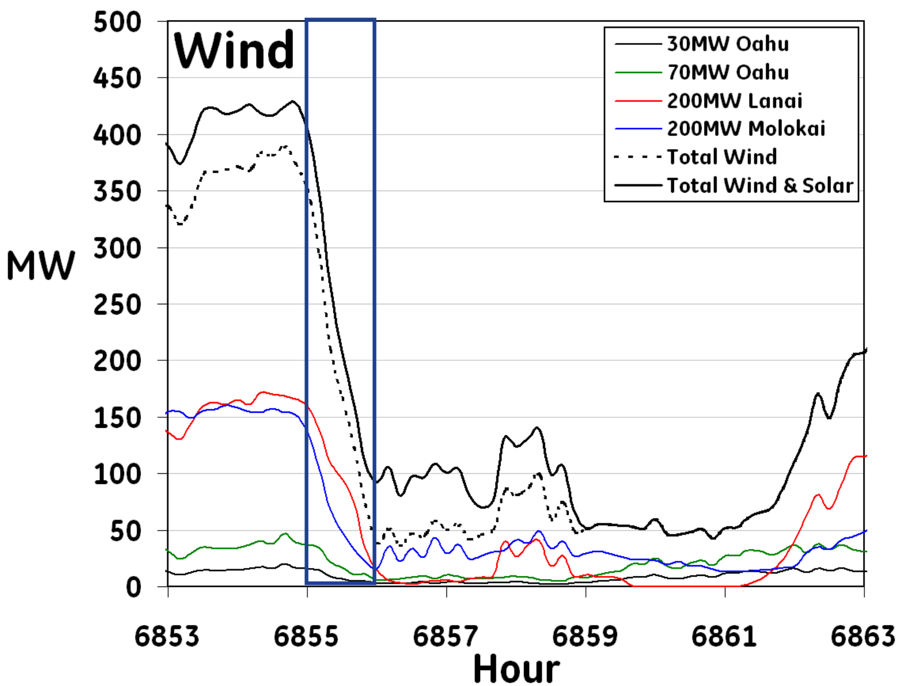
# Frequency Response

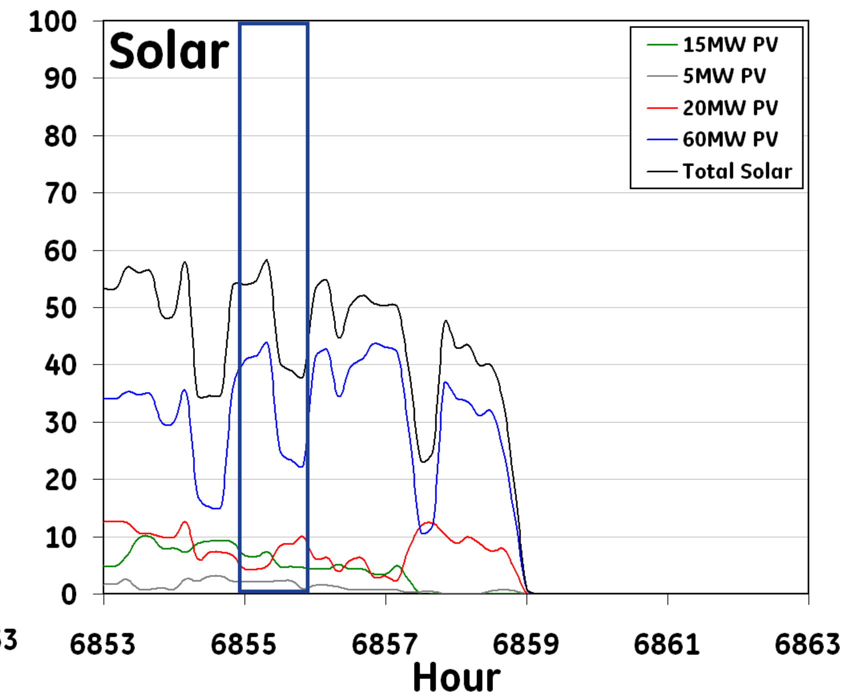
imagination at work

# Sustained Wind Power Drops

## Planning for Challenging System Events

Largest hourly wind power drop, three large baseload units on outage, largest wind power forecasting error, rapid sub-hourly solar variability.

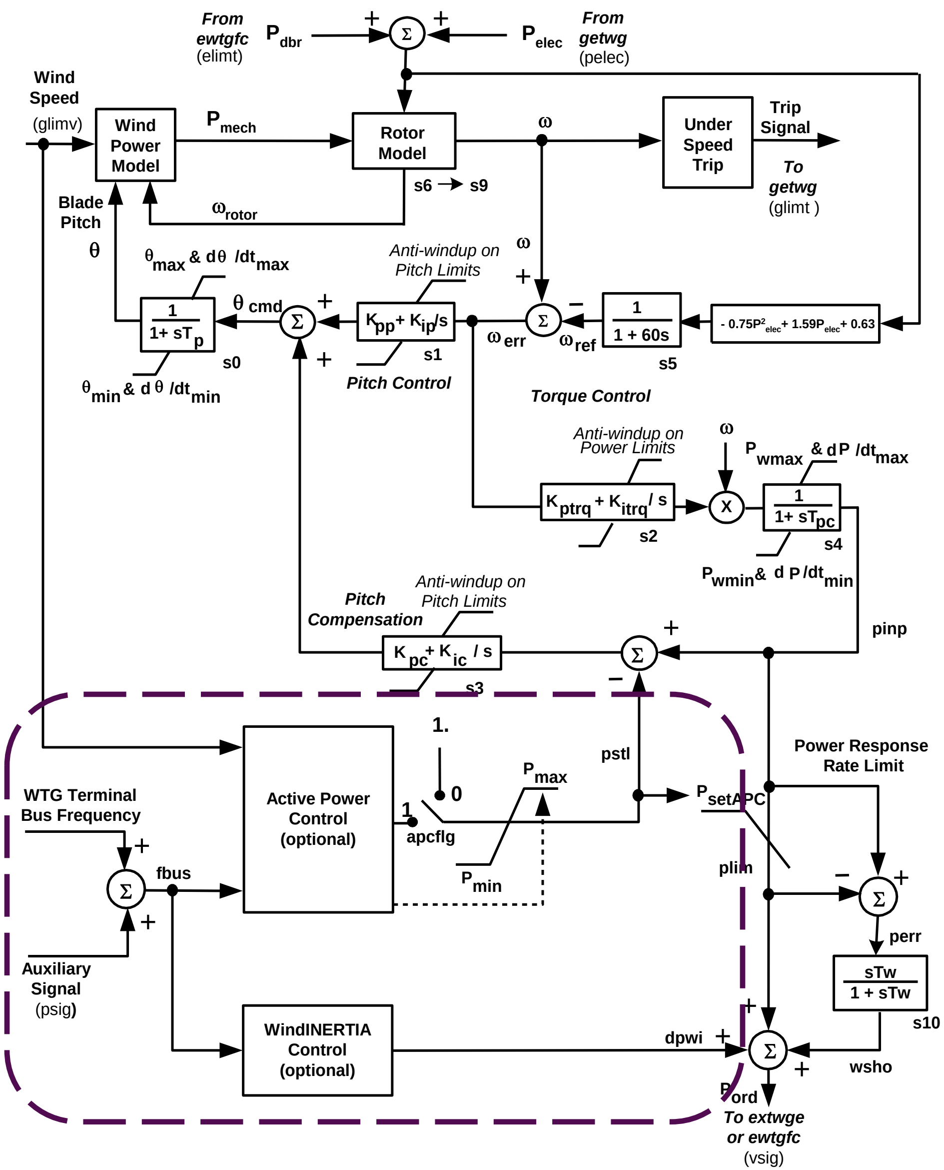


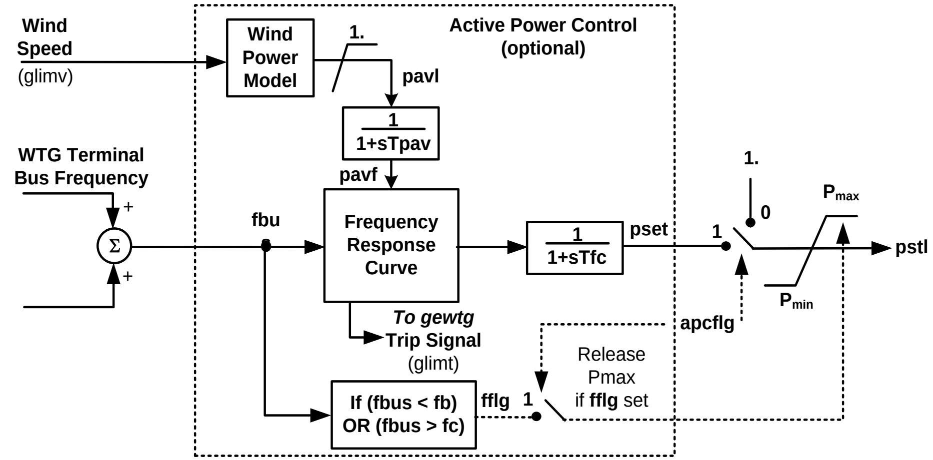



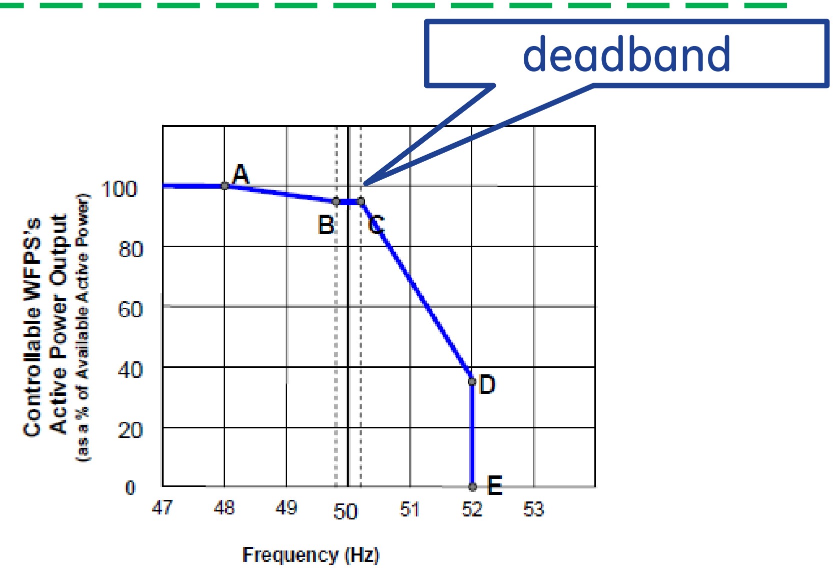

Sustained drops in wind power could consume the available up reserve on the system and/or challenge the systems ramp rate capability

imagination at work

# Active Power Control Stability Model

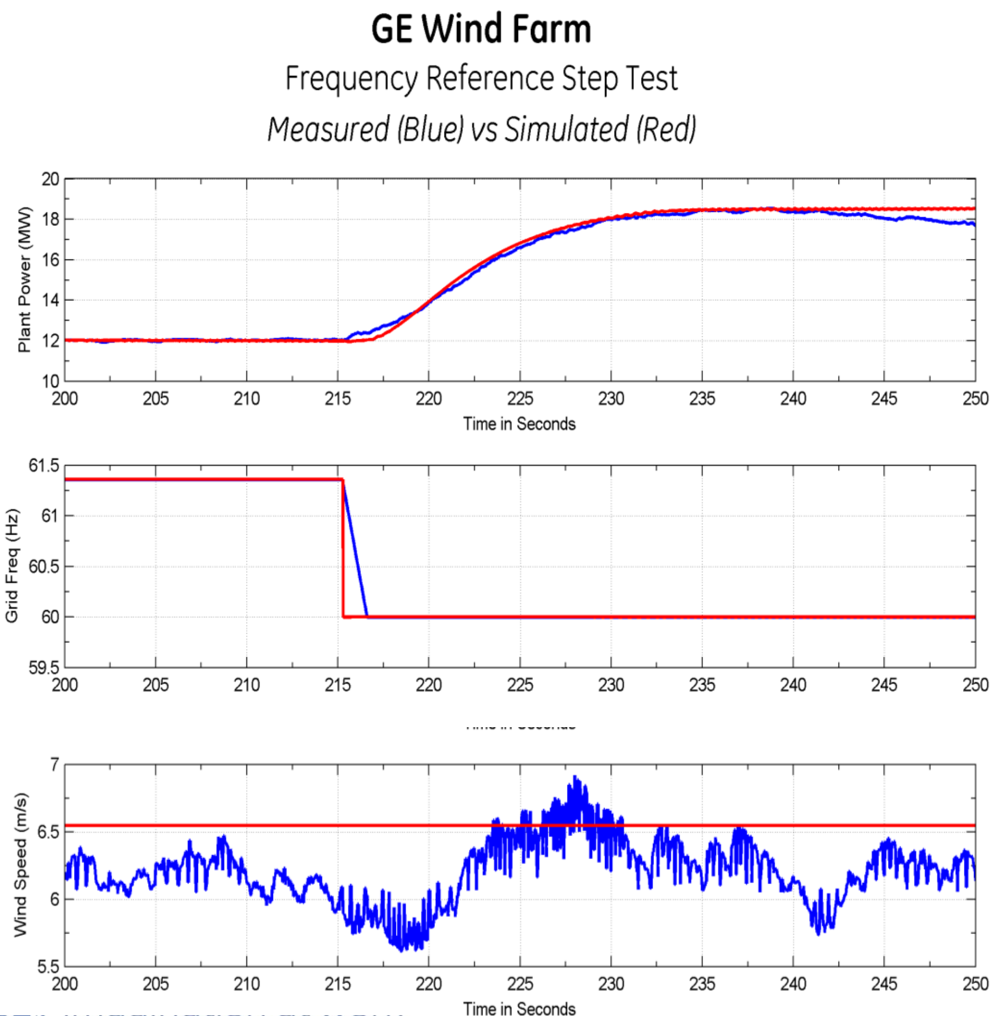



Clark, N.W. Miller, J. J. Sanchez-Gasca, "Modeling of GE Wind Turbine-Generators for Grid Studies," version 4.5, April 16, 2010. Available from GE Energy.

# Field Test and Model of GE Wind Plant Frequency Response




- 83 MW plant in Alberta
- Test is *release* of high frequency input
- Std GE WTG model (wndtge); parameters tuned for this plant

GE Energy

# WindINERTIA™: Inertial Response Option for GE Wind Turbine Generators

Nicholas Miller
Kara Clark
Robert Delmerico
Mark Cardinal

GE imagination at work

# 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**

# Control Concept

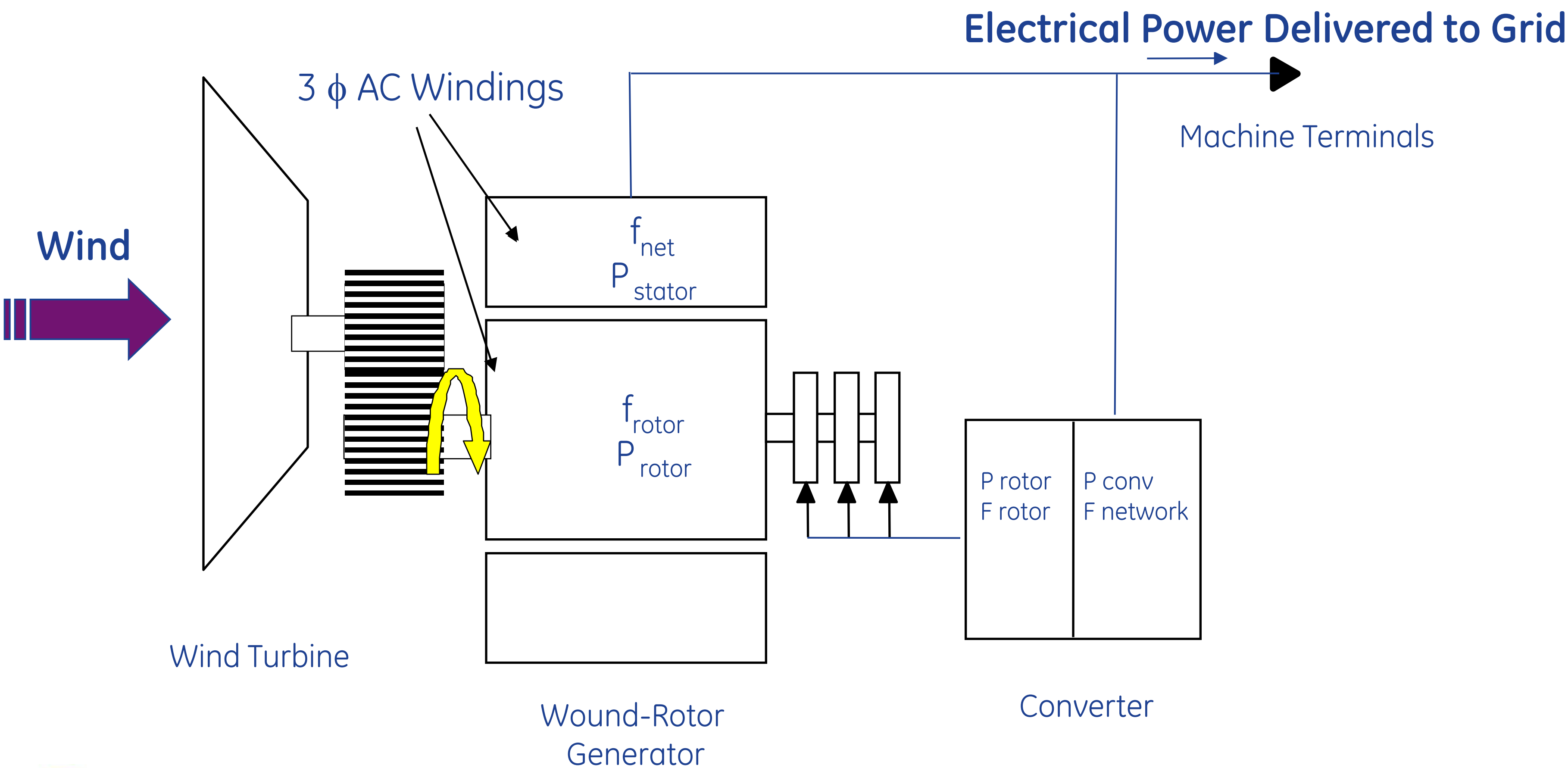
- Use controls to extract stored inertial energy
- Provide incremental energy contribution during the 1$^{st}$ 10 seconds of grid events;
  - Allow time for governors and other controls to act
- Target incremental energy similar to that provided by a synchronous turbine-generator with inertia *(H constant)* of 3.5 pu-sec.
- Focus on functional behavior and grid response: do not try to exactly replicate synchronous machine behavior

# Constraints

- 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

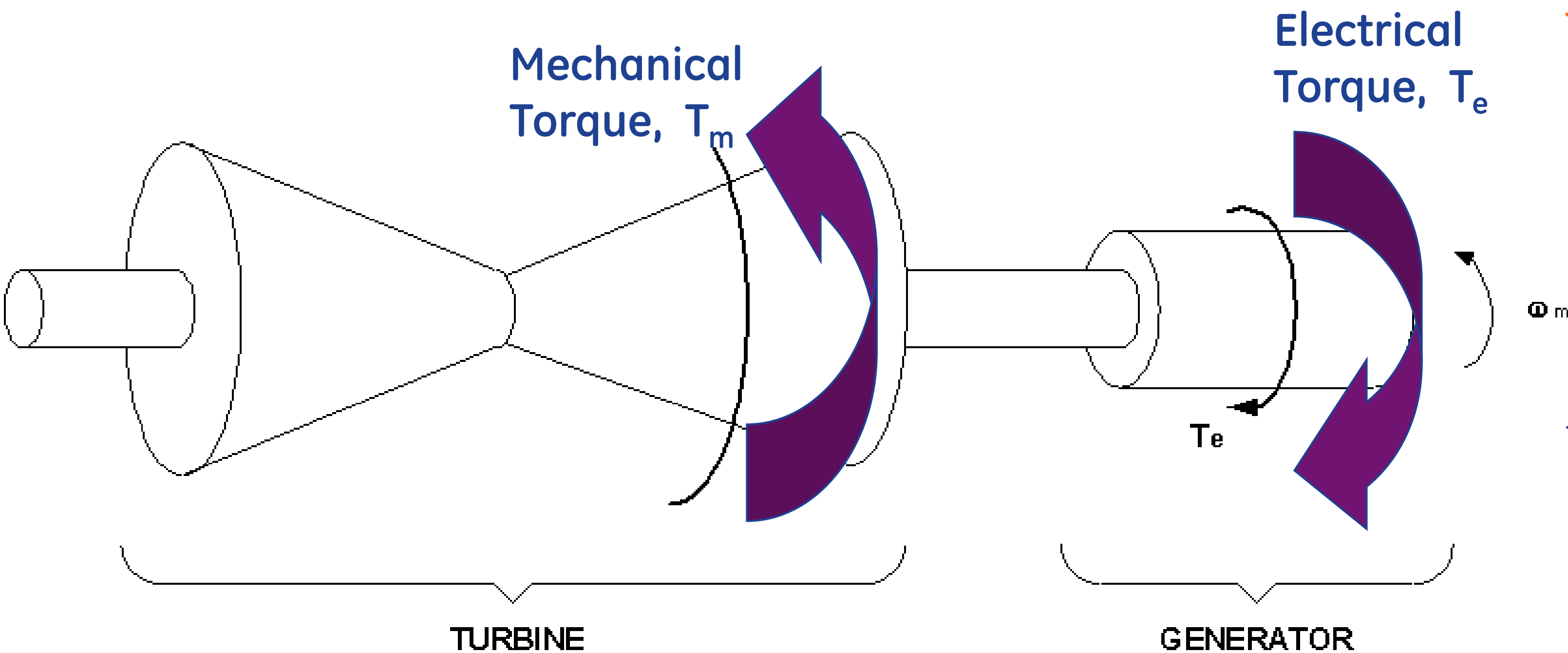
# How does it work?

## Basic components of a GE Double-Fed Asynchronous Wind Turbine Generator:



# How does it work? Part 2

## Basic machine equations for all rotating machines




$$J\frac{d\omega}{dt} = T_a = T_m - T_e$$

$$\mathbf{H} \equiv \frac{1}{2}\frac{\mathbf{J}\,\omega_{mo}^2}{\mathbf{VA_{base}}}$$

$$\mathbf{H} = \frac{\text{Kinetic Energy Stored in the Rotor (Watt-sec)}}{\mathbf{VA_{base}}}$$

Basic Notation:

*J* is the inertia of the entire drive-train in physical units

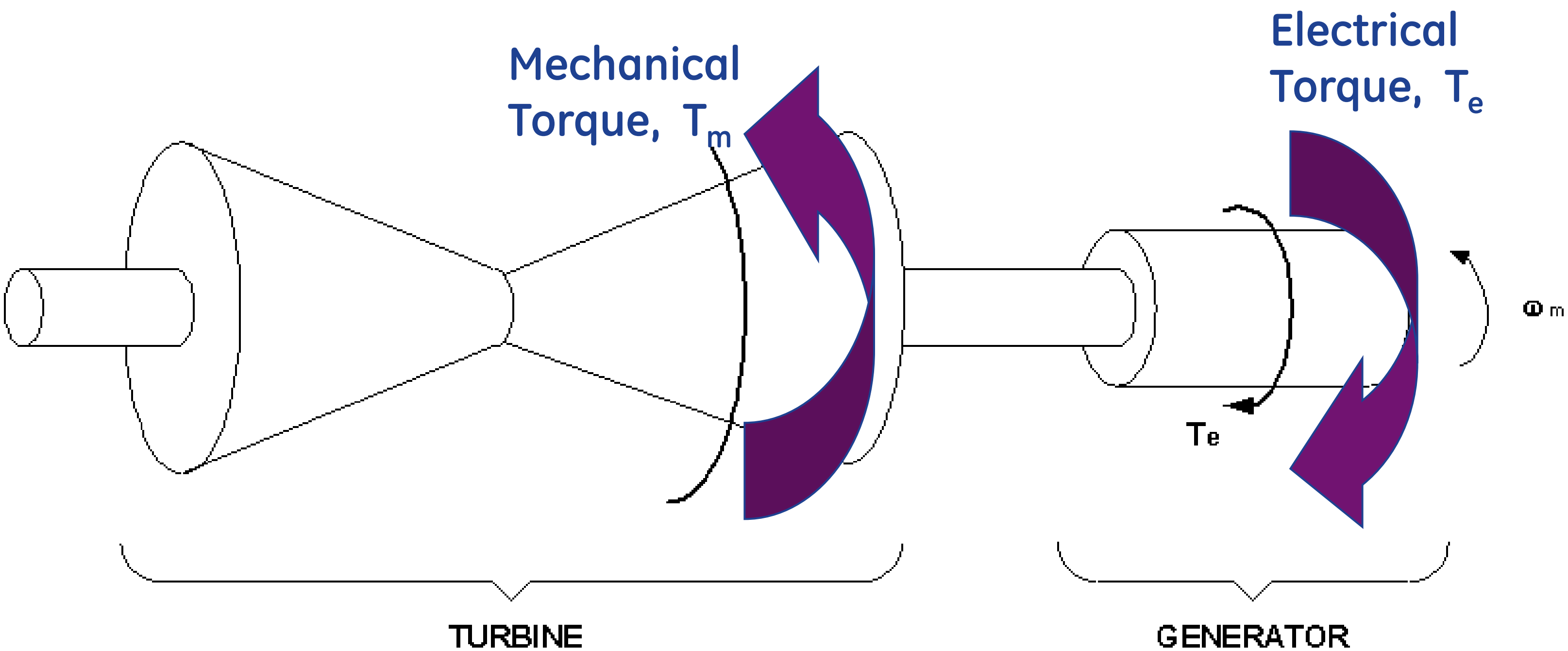
*H* is the inertia constant – it is scaled to the size of the machine.

A typical synchronous turbine-generator has an H of about 3.5 MW-sec/MW.

imagination at work

# How does it work? Part 3

## So what?




- 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

# What's Different?

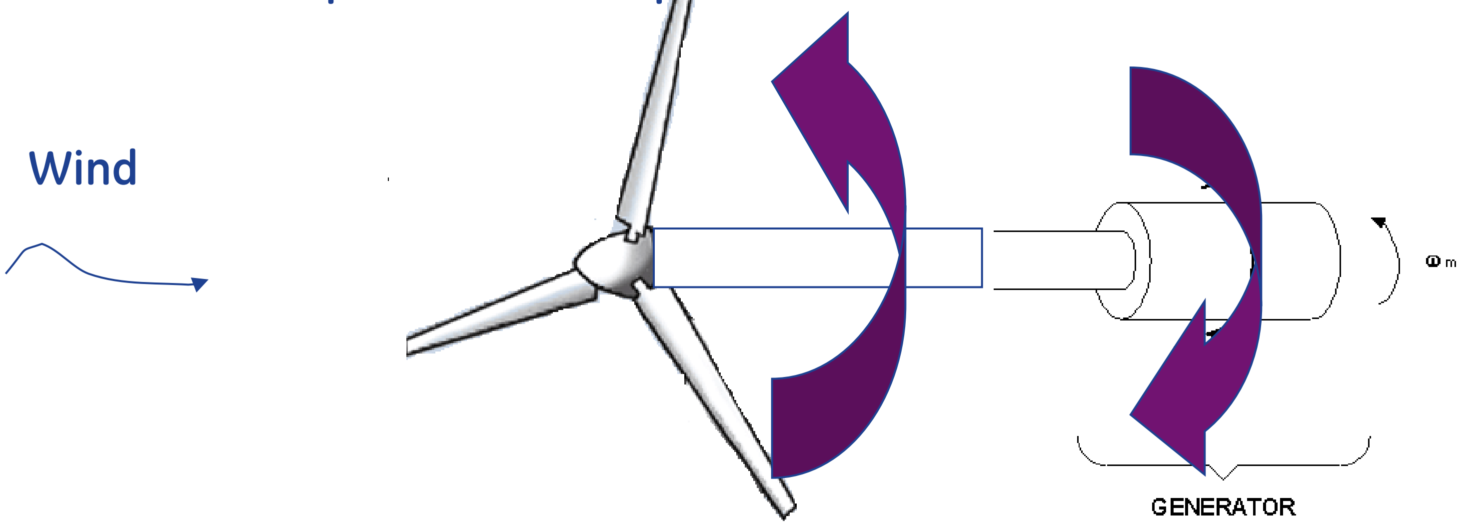
| | Synchronous Generator | Wind Turbine* |
|---|---|---|
| **Mechanical power** | Governor Response / Fuel Flow Control | Pitch Control / Uncontrolled Wind Speed |
| **Electrical Power** | Machine Angle (d-q Axis) / passive | Converter Control / active |
| **Inertial Response** | Inherent / Uncontrolled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

* Variable speed, pitch controlled WTGs

# How does it work? Part 4

Mechanical Torque is a function of:
(1) Wind Speed
(2) Blade Pitch
(3) Blade Speed ( ά Rotor Speed)

Electrical Torque is a function of:
(1) Converter Control
(2) Commands from Turbine Control

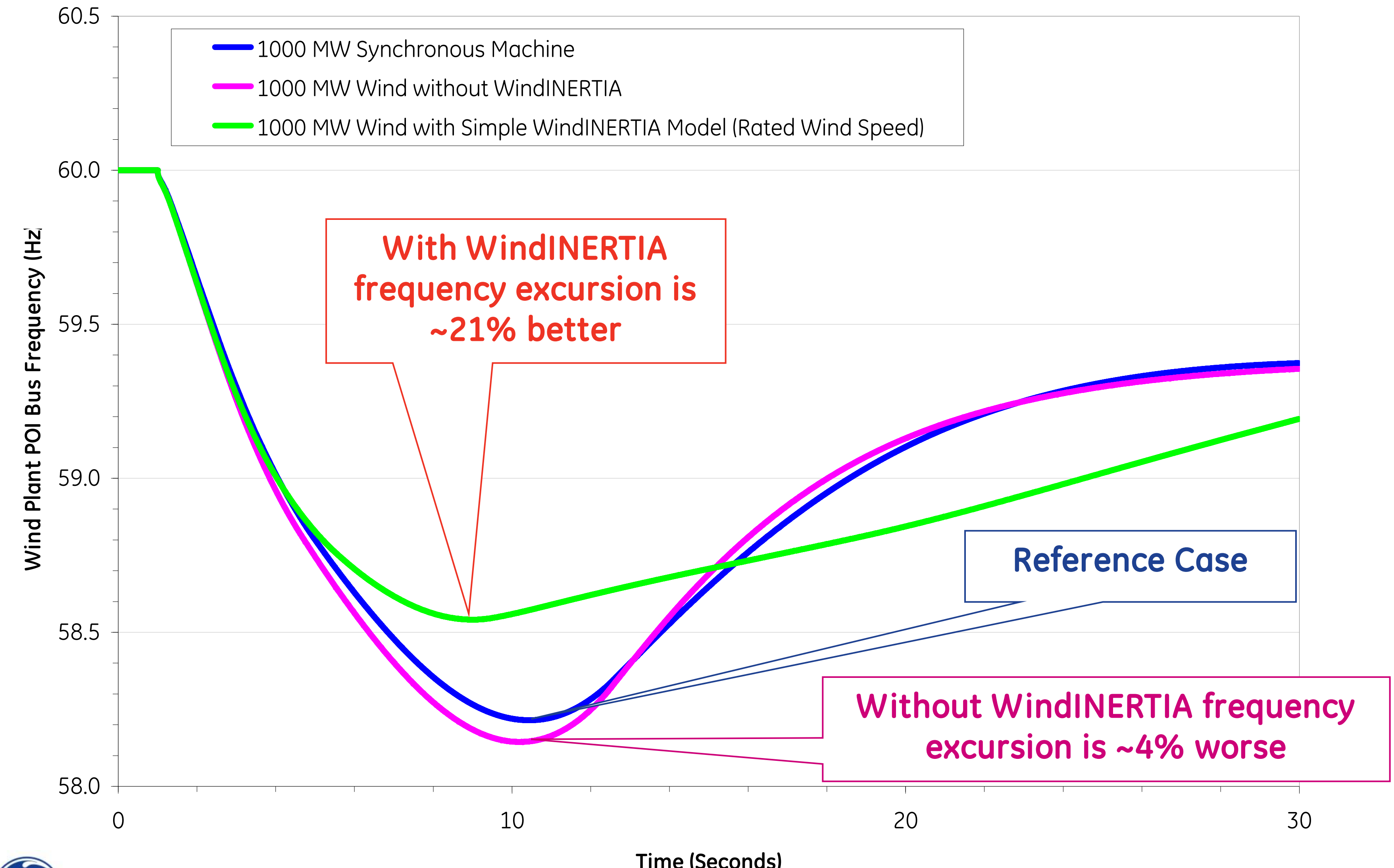



**WindINERTIA uses controls to increase electric power during the initial stages of a significant downward frequency event**

# What happens during a grid event?

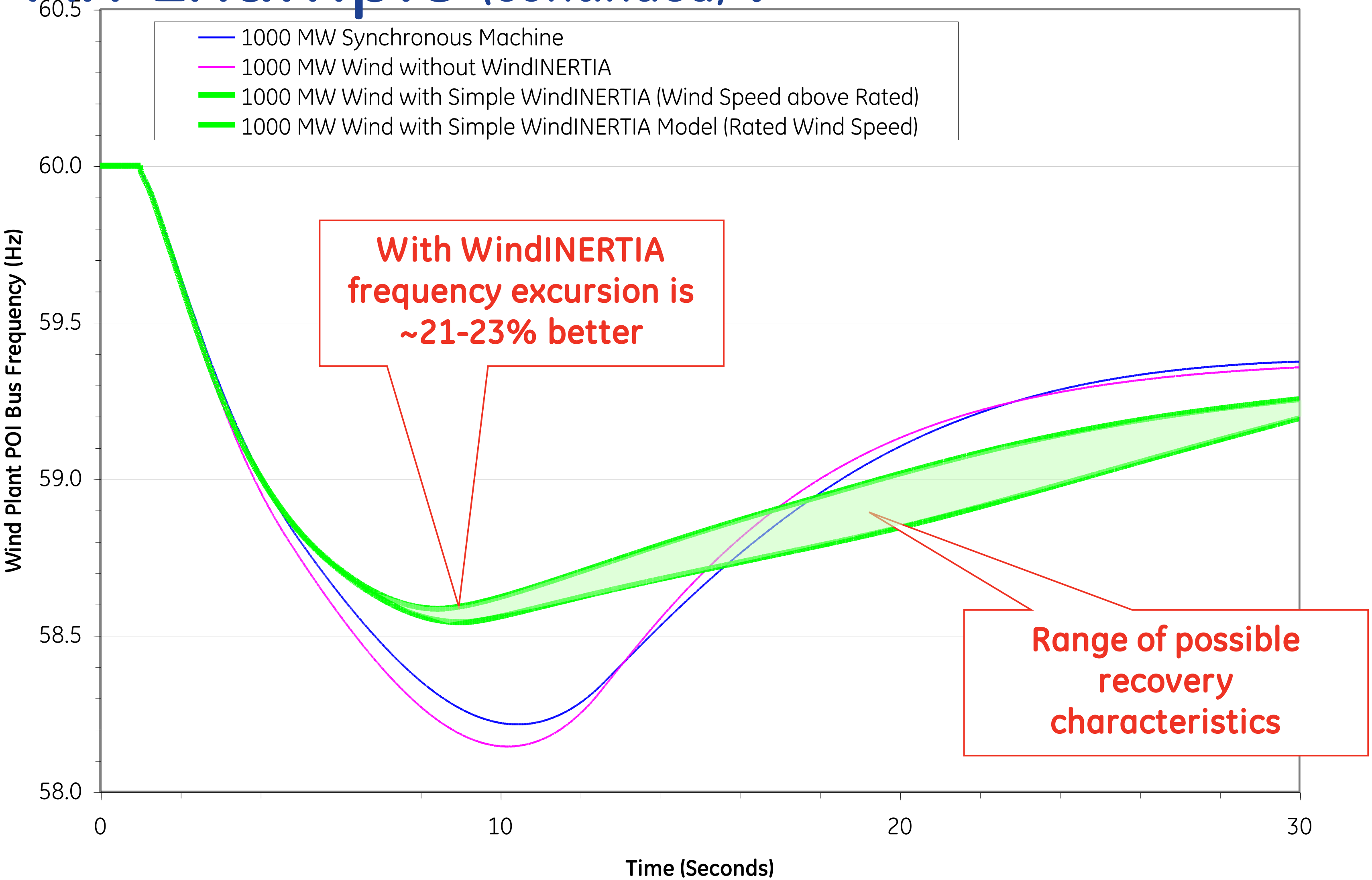
1. Disturbance (e.g. generator trip) initiates grid frequency decline
2. WindINERTIA detects significant frequency drop
3. Instructs WTG controls to increase electrical power
4. Additional electric power delivered to the grid
5. Rate and depth of grid frequency excursion improves
6. WTG slows as energy 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




Minimum frequency is the critical performance concern for reliability

# An Example (continued) :



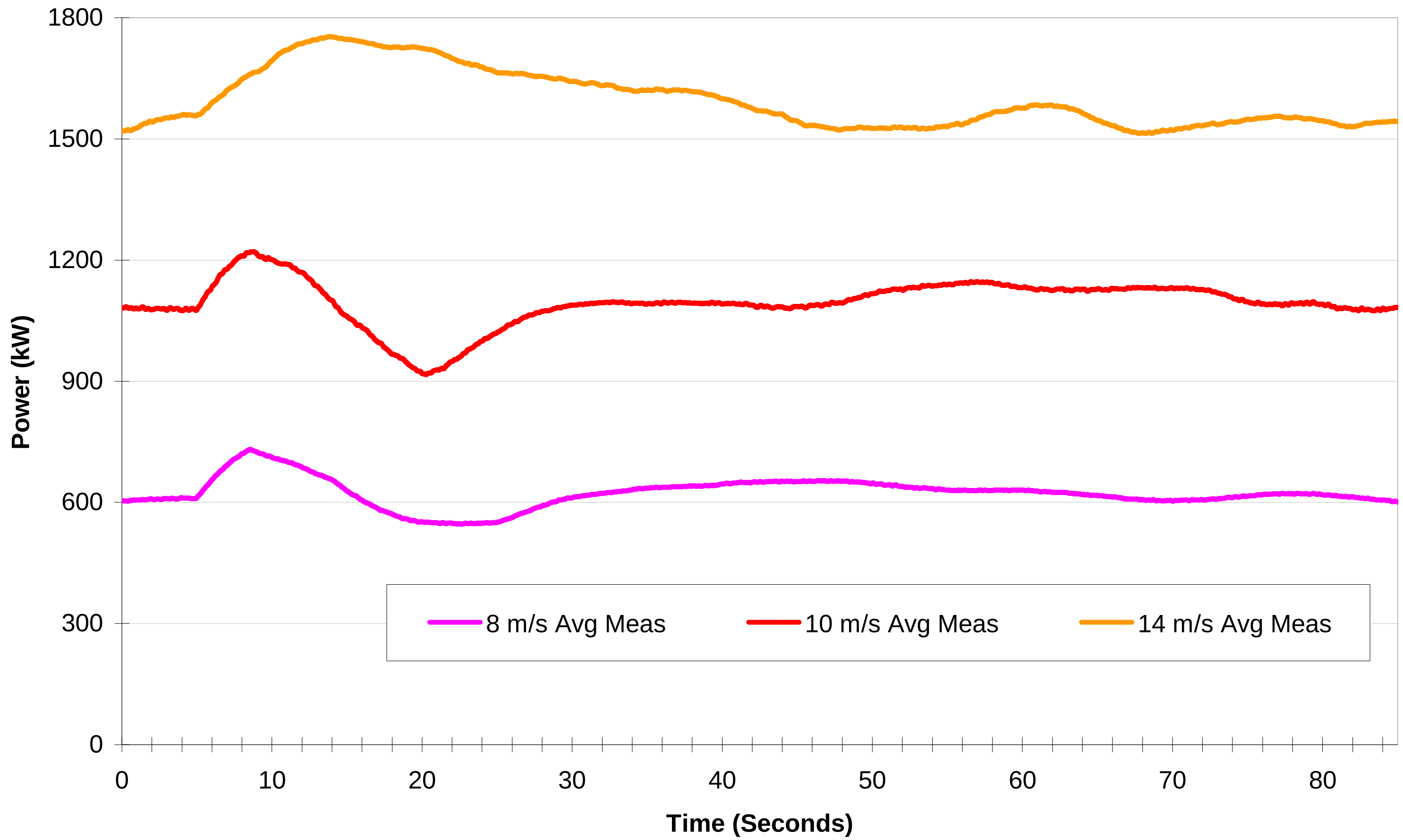

Performance is a function of wind and other conditions: not perfectly deterministic like synchronous machine inertial response

# Field Tests Approach and Constraints:

- Not possible to drive grid frequency
- Controls driven with an external frequency signal
  - (very similar to frequency of previous example)
- Performance a function of wind speed
  - (also, not possible to hold wind speed constant during tests)
- Since WTG must respect other controls
  - Turbulence & drivetrain and tower loads management affect performance of individual WTGs at any particular instant
  - Exact performance of single WTG for a single test is not too meaningful
  - Aggregate behavior of interest to grid

**WindINERTIA validation tests:**
**Multiple tests over varying wind conditions**

# Field Tests Results:




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

# Summary & Conclusions

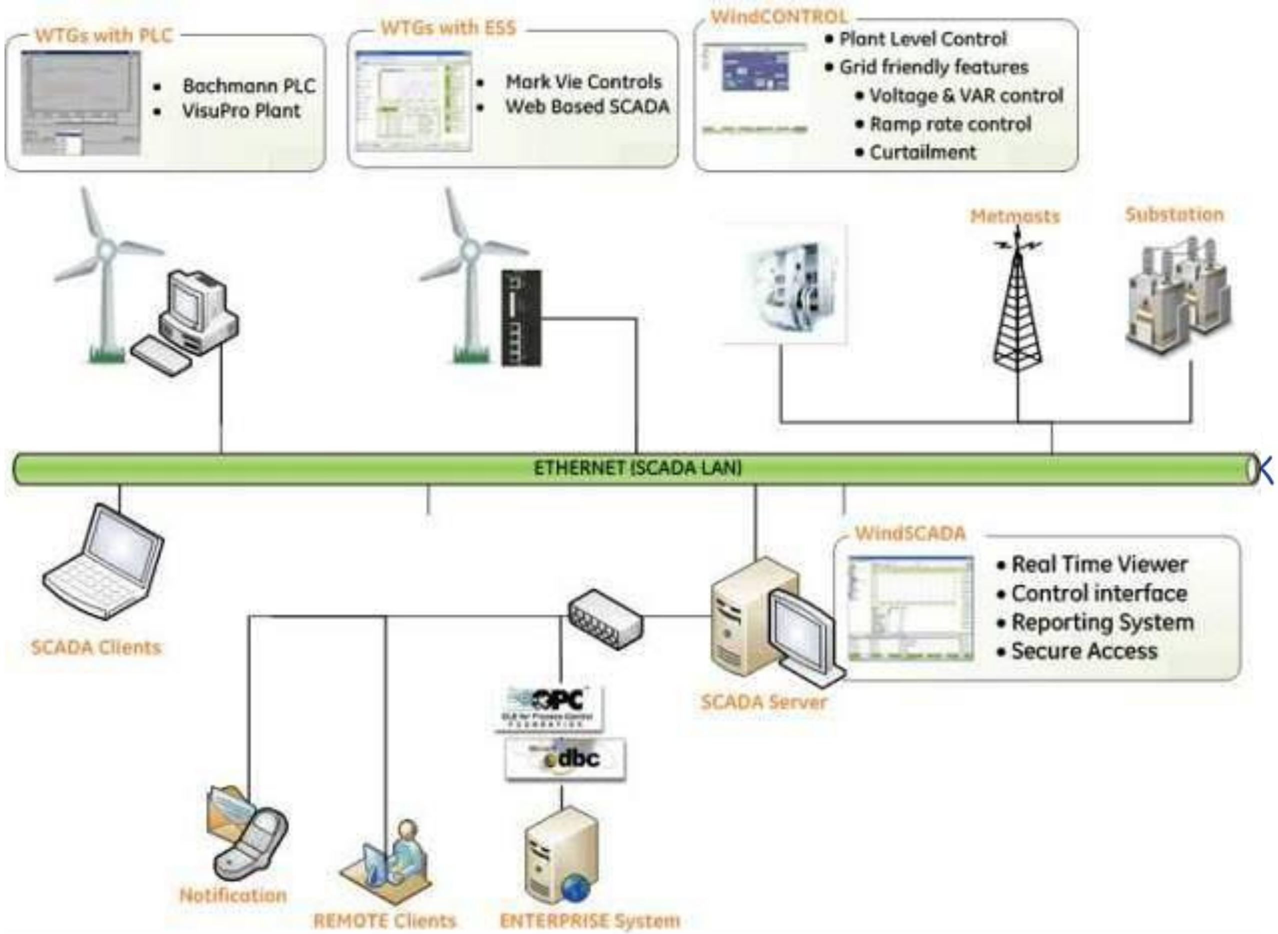
- Need and demand for inertial response from WTGs has been growing
- GE now offers a new, grid friendly feature to meet this need
- The feature has been field tested; a dynamic model has been created
- Fundamental physical differences in WTGs mean that inertial behavior is not identical to synchronous machines
- Future grid codes may require inertial response; they must recognize physical reality & constraints

**WindINERTIA™ - another aid to the continued successful large scale integration of wind power**

imagination at work

# Volt/VAR Coordination

# Key components of plant systems




## WindCONTROL

- Provide functions similar to conventional power plant
- Coordinated control of all WTG
- Integration with substation equipment
- 200+ systems in operation controlling 8000+ turbines

## WindSCADA

- Utility grade SCADA system
- Integrated monitoring & control of WTG, substation
- Tools for O&M operations
- Robust remote and local access
- Industry accepted protocols for data transfer

# 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

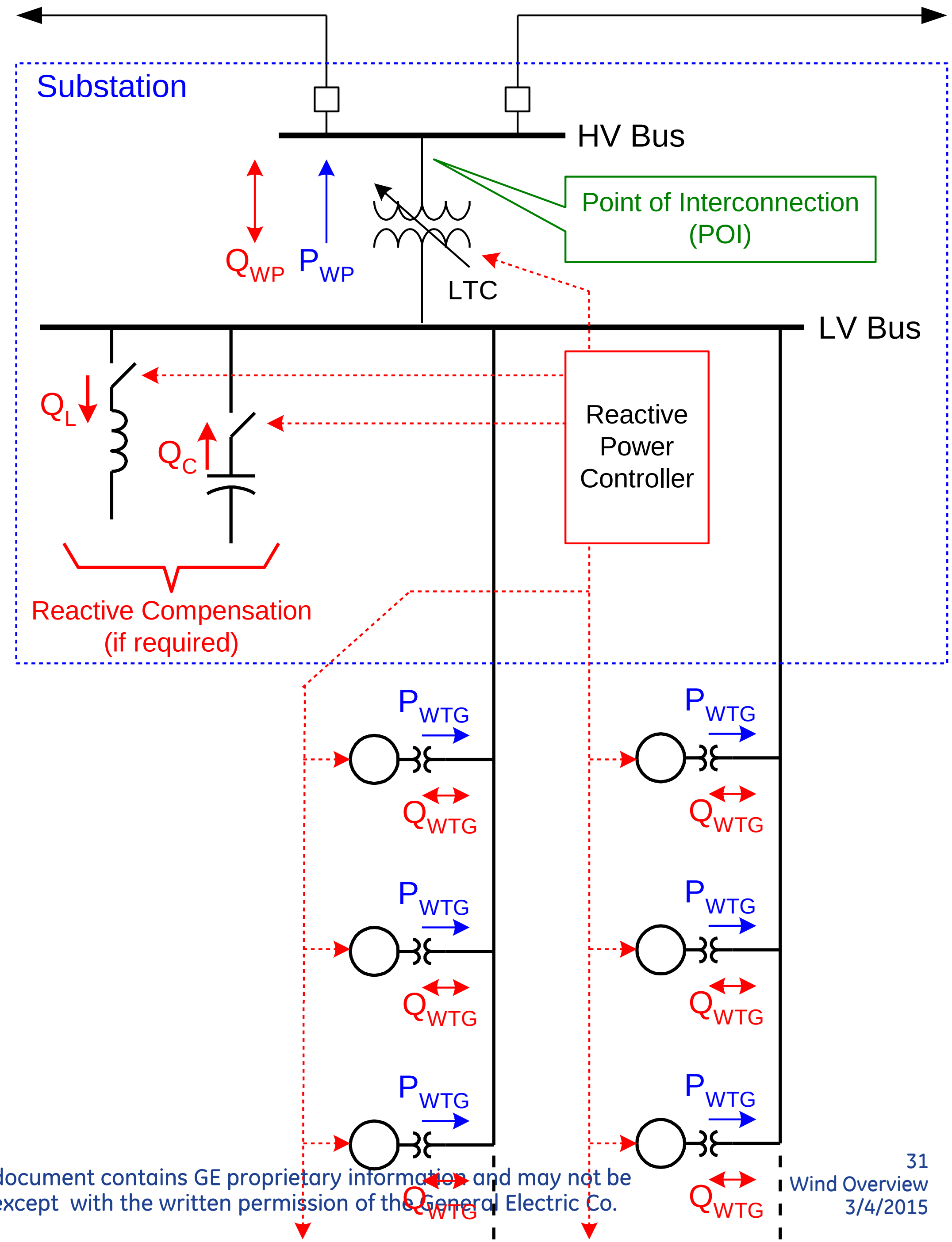
WindCONTROL provides plant-level controls to meet performance requirements (e.g., voltage regulation) at the point-of-interconnection (POI)

- 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

# WindCONTROL

## 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

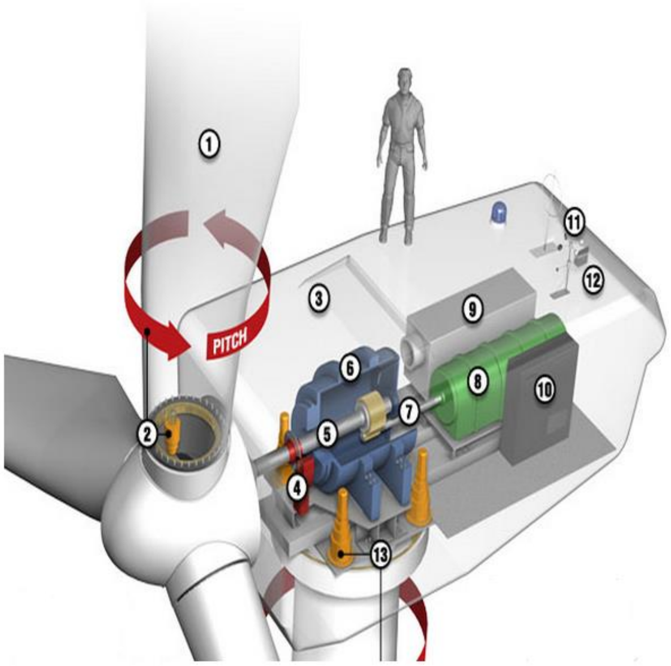


# “New” Technologies

imagination at work

# Challenges of Scale

Mass outpaces power capacity as wind turbine size increases for a given technology




Wind Turbine Component Overview
Source: AWEA [1]

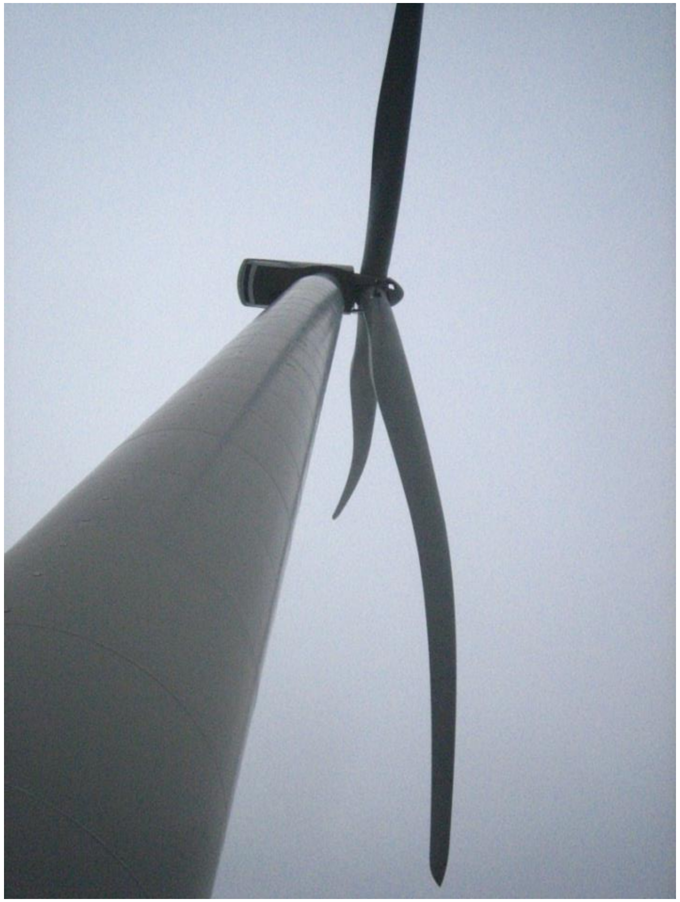
- Power increase is approximately quadratic (swept area)
- Mass increase is approximately cubic (material volume)

# Steel Tube Tower Design

4 20+m tube tower sections

Transportation challenges due to weight and size (diameter & length)

Tower cost is a significant portion of turbine cost



imagination at work

# Steel Tube Tower Limits

Imagine a 130+ meter tube tower…

- For structural integrity, tube thickness at the bottom must increase
- Increased thickness → increased weight … run into shipping constraints
- Shipping constraints for tube tower sections to be shorter
- More, thicker tower sections… cost increases quickly
- Shipping cost, assembly cost… not to mention raw material cost

imagination at work

# Enabler…Space Frame Tower

Weight savings: >25% for 96m tower height

100% on-site assembly

Shipping in standard containers

Large-diameter base increases stiffness

# Tower Assembly

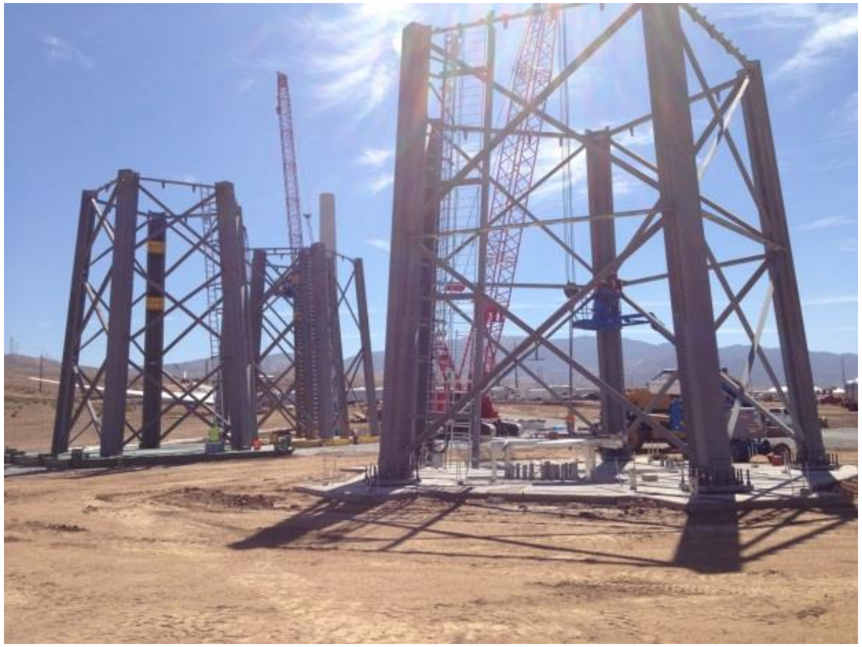
Economics hinges on efficient assembly

Sections built on ground, then stacked x8 (4 for tube) 96m towers

Key Components:

Structural fabric exterior with a tensioning system

Maintenance-free bolts – ~4000 fasteners on space frame tower



imagination at work

# Conclusions

imagination at work

# Elements of a Renewable Energy Era

- More capable, coordinated wind plants
- Improved forecasting
- Operational procedures (down-reserves)
- In creasing thermal unit flexibility (ramp rates)
- Driving cost effectiveness through technology


imagination at work