Technology and Reliability Improvements in GE’s 1.5MW Wind Turbine Fleet

Wind Turbine Reliability Workshop
Sandia National Labs
Albuquerque, NM

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GE Wind Energy

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GE and GE Wind

GE’s Infrastructure Businesses

Energy
- Thermal
- Nuclear

- Renewables
  - Wind
  - Solar
  - Biomass
  - Hydrogen

Rail
Financial Services
Water
Aircraft Engines
Oil & Gas
GE Energy’s Start in Wind Power

• Formed May 2002…Purchased from Enron
• Foresee significant long term, global demand for Wind Turbines
• Continue growth with...
  - **Technology** - integrate with GE to improve on starting point...reliability, capacity factor, cost
  - **Supply Chain** – more turbines, with predictability
  - **Permitting & Transmission** – more turbine locations
  - **Policy** - support Long-term commitment
• **Ecomagination**

“Green is Green”...For Everyone
GE Wind Growth and Investment

Accelerating global deployment

GE Wind since 2002:

$600MM+ technology investment ...
- Unit production: 400 to 2500+
- Key suppliers: up 3x
- 2007 Revenue: $4.5B+
- Fleet size: 2000 to 8000

• Continued within 2-3 years ...
  - Expect policy issues to stabilize
  - Continue to grow supply chain
  - Expand capacity
  - Becoming GE’s largest Energy product business

It All Depends on Reliability

James Maughan, GE Wind

Wind Turbine Reliability Workshop
Why Reliable Operation is Everything

Customer View

- Price + Capacity Factor + Availability + Operating Costs = Customer Rate of Return
- Reliability issues directly cut production
- Reliability issues increase operating costs
- Reliability issues are aggravating

Reliability and Availability

- Reliability...component focused
  - Failure rates, MTBF, MTBT, starting reliability, etc
- Availability...operator focused
  - Fraction of time system is able to operate as intended
  - Includes impact of failure on operation
  - Failure rates, faults, outage length, planned repair, maintenance, etc
  - Ties to lost production, lost revenue

The Fuel is Free. The Turbine Needs To Run.
1.5sle Availability Summary - Customer Fleet View

Engineering Availability

- Includes downtime for any reason (except grid outages)
  - Duration from coming off-line to return to service
  - Faults, repairs, maintenance, upgrades, etc
- Lost production calculated from wind speeds during downtime
Availability Analysis By Fault Count and Duration

- More frequent but shorter events from system, thermal, integration, and operation issues
  - impact is primarily lost production

- Less frequent but longer events from component failures
  - impact is lost production and cost of component
Fleet Relative Cost of Component Failure

Failure Data - Weibull Predictions

- Lost Production and replacement cost data
- Failure data and predictions for continuous product improvement
Typical Failure Root Cause Analysis Process

**Failure Analysis**

- Mechanical Wear of Brushes
- Old Style to new style transition in design
- Inadequate Brush Replacement
- Slip ring cleaning procedures
- Maintenance

**Analytics**

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**RCA Fishbone, Identification, Validation**

- Root Cause Contributor
- Eliminated

- Above rated pitch motor currents (Temperature/Wear)
- Protection devices CB for slip ring 400 V, 50 A

**Material Analysis**
Availability Analysis By Fault Count and Duration

- More frequent but shorter events from system, thermal, integration, and operation issues
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Availability Analysis by Return to Service Process Step

Return to Service Process Steps
1. Identification, remote diagnostics, waiting period (if required)
2. Assemble needed teams, tools, and parts
3. Repair time
Typical fault and availability data

- Lost production guides technical effort, field solutions, component redesign, system improvement.

- Unavailability, hours
- Lost production, MWhr

- Blade angle asymmetry, Battery charging voltage, planned repair, rotor CCU collective faults, rotor CCU fault current, main switch released, motor protection, yaw runaway, weather downtime, gearbox oil pressure, planned maintenance.
Wind Turbine Blade Angle Asymmetry

**Background**

- Electronic pitch control system sets blade angle during high load wind control
- Under some conditions on some units, one blade lags behind, unit shuts down
Anatomy of a Blade Angle Asymmetry Fault

1. Blades all following setpoint
2. Blade 3 begins to lag behind
3. Unit shuts down due to potential asymmetric loads
4. Blades return to feathered position on grid or battery power. Unit restarts.

Blade Angle 1 - Actual
Blade Angle 2 - Actual
Blade Angle 3 - Actual
Blade Angle Setpoint
BAA - Root Cause Analysis

Root Cause Analysis
- Variability in torque requirements not seen in prototype data
- ~4% of bearings outliers
- Cause of variation not definitively identified

System Solution
- Torque applied to bearing increased with use of higher ratio gearbox
- Loads, lifing, response time all validated

Possible Corrective Action
- Uprate pitch gearbox
- Avg 87% reduction in impact validated
Cabinet Over Temperature Faults

**Background**
- Energy dissipated in pitch motors and hub increases cabinet temperatures
- Temperature protection shuts down unit if necessary...
- ... in some cases below spec of 40°C outside ambient

**Impact**

<table>
<thead>
<tr>
<th>Hub Axis Cabinet (3)</th>
<th>Hub Battery Cabinets (3)</th>
<th>Hub Center Cabinet</th>
<th>Top Box</th>
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</thead>
</table>

Lost Production, MWhrs

- FW01
- FW10
- FW19
- FW28
- FW37
- FW46
Hub Ventilation Schematic

Root Cause Analysis
- Vendor cabinets tightly sealed
- Hub is stagnant and unventilated
- Internal hub temperature can peak higher than ambient

Possible Corrective Action
- Create consistent air flow through hub with vent
- Screen and deflectors to limit water, snow, debris, etc
Typical Hub Temperature Data With Ventilation

- Hub temperature within a few degrees of outside ambient temperature
Typical Fault and Availability Data

Lost Production (MWhr)

Unavailability (hrs)

Field Solutions Developed

New System Designs

Typical Fault and Availability Data

Lost Production, MWhr
GE Pitch Control System

System Redesign
- Higher torque and temperature capability
- Improved batteries and chargers
- PWM conversion, reduced slip ring current
- Digital control, fewer components
- Ethernet-based diagnostics

Validation
- Fault counts at validation site
- Half old system, half new
1.5 MW DFIG IGBT-based Power Converter

Power Converter
- Replaces multiple vendors
- Based on GE’s motor drive and generator exciter technology
- Enhanced diagnostics, capability, reliability
- Operates under authority of legacy main control

Low Voltage Ride Through
- Digital monitoring and control technology
- Remains connected during grid disturbance
- Uses reactive power flow to ride through disturbance
Electrical System Simplification and Integration

System Redesign

- Integrates converter, main controller, and power distribution into a single cabinet
- Ethernet diagnostics and control across converter, pitch, control, generator, all electrical
- Modernized software, blockware, and toolkit, identical to Mark VIe control in gas turbines
- Discrete components in top box replaced with circuit boards
- Prototypes in installation now
Summary - Improving GE’s Fleet Reliability

Summary

- Focus on total reliability - component failure rates and system faults
- Increase production and revenue
- Reduce operating costs
- Grow the industry

It All Depends on Reliability