GE Energy

Wind Technology and Windfarm Overview

Forum on Renewable Energy Development in Myanmar

November 1, 2012
saumil.shah@ge.com
Topics for discussion

- Introduction to Wind Power technology
- Windfarm design
- Windfarm construction
- Windfarm operation
GE Renewables ... wind business

World’s most efficient & reliable wind turbine fleet

- 28GW+ installed ... ~18+k WTGs in 22 countries
- 98+% availability ... ↑15%
- Energy capture ↑52%

GE Onshore Product strategy
- Portfolio flexibility ... value where you need it
- Evolutionary development strategy ... world’s best running fleet
- Continual investment ... focused on increasing customer value

Invested $2B in technology ... GE is changing the game
GE’s Installed Wind Fleet

USA
(12,617 units/19,202 MW)

Canada
(1,070 units/1,619 MW)

Brazil
(59 units/94 MW)

Europe + Turkey – 16 Countries
(3,533 units/5,900 MW)

China
(792 units/1,188 MW)

Japan
(290 units/478 MW)

Over 18,000+ WTGs, 28GW+ installed ... 22 countries

As of 2Q 2012
Wind technology overview
Wind Turbines ... a highly engineered product

- 103 meter blade diameter is larger than a Boeing 747 wing span
  ... Swept Area = 8332 sq m = 2.05 acres

- Tip speed of GE wind turbine is 322 km/h
  ... F-18 Hornet at take off is 225

- Thrust load is greater than 2 X F-18 in max after burn

- Power Electronics 18,000 switching events per second
  ... GE converter fleet = 200M switches/sec

- Input torque is >2,000 kNm, (~1.5M ft-lbs)
  ... ~2,400 times torque from an Indy car engine

- Pitch bearing supports >6,000 kNm
  ... 7 ton Mack dump truck at a lever arm more than a football field
Modern Wind Turbines – Onshore & Offshore

80 – 110+ meter hub height onshore

Rotor diameter 50 – 120m

Output 0.75 – 5MW

Operates between wind speed of typically 6 – 25m/s

Tubular steel towers

Remote operation through web based instrument control

Note: 1MW equivalent to energy for approximately 1,300 homes in Thailand
Components of a Wind Turbine
(Model shown is Vestas V80 - onshore wind turbine)

- Rotor blades
- Gearbox
- Main shaft
- Hub controller
- Electrical generator
- Yaw gears
- Nacelle
- High voltage transformer
- Ultrasonic sensors
- Hydraulic system
- Tower
- Oil cooler
1.6-100, 96m HH, 4-Section Tower

Improvements

- Increased AEP 4% to 9% depending on site
- Improved manufacturability and Internals Assembly
- Optimized design against resonance and buckling limits
- Logistics – Fewer sections to ship and Erect
- Decreased installation & Transportation

Comparison with 100mHH Tower

- Same robust top flange design
- Longer Individual Sections
- 100m Natural Frequency Optimized
- 96m Buckling and Frequency Optimized
- 96m Tower approx. 20% lighter, 68 MTs

Reduced frequency vibrations, large tower & fast spending rotor, not tower buckling such as crushing a can
GE Component Test Lab – Greenville, SC

Main Bearing

Pitch Bearing

Bedplate

Gearbox

Setting the standard on reliability

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Quality and performance critical ... the downside of getting it wrong

Cross-section of wind blades

Bond joint critical to blade life

Blade life?

Chinese OEM blade

20yr+ life

GE designed blade

Poor quality can reduce wind farm value by 80%+

Long term asset ... customers buy quality

Source: Karen Newby, Journal Star; GE Marketing
Evolution of GE wind products

GE Wind Products ... proven performance and reliability

<table>
<thead>
<tr>
<th>GE Wind Products</th>
<th>'02</th>
<th>'12</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEP (GWh/yr)*</td>
<td>6.0</td>
<td>12.6</td>
</tr>
<tr>
<td>Capacity Factor (%)**</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>Availability (%)</td>
<td>85</td>
<td>98</td>
</tr>
</tbody>
</table>

*2.5-120@8.5m/s, **1.6-100@8.5m/s, EOY '12

GE enters wind industry

LVRT introduced

GE 37c blade

GE 40m blade Mark VIe controller

HALT Introduced

GE Pitch

WindBOOST

Enhanced controls

Next Gen Grid

Model introduction

1.5i (65m) 1.5s (70.5m)

2.5 (88m)

1.5sle (77m)

2.5xl (100m)

1.5xle (82.5m)

2.75-100

1.6-82.5

2.75-103

1.6-100

2.5-120

2.85-103

1.85-82.5

1.7-100

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WindBOOST

Enhanced controls

Next Gen Grid
GE 4.1-113 World’s highest output shallow water (offshore) turbine

Solid electrical system design...
- Enhanced reliability... modular generator & converter design
- High efficiency... PM Generator
- Direct-drive

Simple mechanical design...
- Protected from offshore environment... sealed nacelle containing all components
- Robust & reliable... up-scaled components from proven 1 – 3 MW models

Designed with service in mind...
- Serviceability... In place tower exchange for converter and generator parts
- Spacious nacelle with internal hub access

Proven direct drive technology ... over 5 years operating experience
Large machines...
Bigger is not always better

<table>
<thead>
<tr>
<th>WTG</th>
<th># WTGs</th>
<th>MW Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5-77</td>
<td>66</td>
<td>99.0</td>
</tr>
<tr>
<td>1.6-82.5</td>
<td>62</td>
<td>99.2</td>
</tr>
<tr>
<td>1.6-100</td>
<td>62</td>
<td>99.2</td>
</tr>
<tr>
<td>2.5-100</td>
<td>40</td>
<td>100.0</td>
</tr>
<tr>
<td>2.75-103</td>
<td>36</td>
<td>99.0</td>
</tr>
</tbody>
</table>

100 MW wind farm production
Windfarm design
Wind Project Technical Challenges

Energy yield assessment
- Data acquisition
- Wind modeling
- Layout design
- Uncertainty analysis

WTG technology selection and specification

Electrical system design

Foundation and road design

Environmental assessment

Maximising operating performance
Site data requirements

≥12 months site data for seasonal balance

Mast set up to IEC or equivalent standard
- Location representative of whole site
- As close to hub-height as possible (at least ¾ advisable)
- Free from sheltering
- Instruments calibrated and correctly configured

Wind speed
- Collected from several heights to assess wind shear
- 10 minute averages from high frequency samples
- Standard deviation (to calculate turbulence)
- Max 3 second gust

Wind direction
- 10 minute averages from high frequency samples
- Standard deviation
## Wind Resource Assessment Inputs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual mean wind speed @98m - $V_{avg}$</td>
<td>6.7 – 7.0 m/s</td>
</tr>
<tr>
<td>Extreme wind – $V_{ref}$</td>
<td>33 m/s</td>
</tr>
<tr>
<td>Flow angle</td>
<td>3°</td>
</tr>
<tr>
<td>Shear measured (40-60m)</td>
<td>0.25</td>
</tr>
<tr>
<td>Characteristic Turbulence Intensity</td>
<td>13%</td>
</tr>
<tr>
<td>Air density</td>
<td>1.210 kg/m³</td>
</tr>
</tbody>
</table>

All parameters below IEC IIIb
**Optimum Product Mix**

- Several factors impact turbine suitability
- Comparing avg. wind speed (site vs. wind class) not sufficient
- Any parameter below IEC standard creates design margins

<table>
<thead>
<tr>
<th>IEC 61400 Design Envelopes (TC)</th>
<th>Ia</th>
<th>Ib</th>
<th>IIa</th>
<th>IIb</th>
<th>IIIa</th>
<th>IIIb</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{ave}$ [m/s]</td>
<td>10</td>
<td>10</td>
<td>8.5</td>
<td>8.5</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>$V_{ref}$ [m/s]</td>
<td>50</td>
<td>50</td>
<td>42.5</td>
<td>42.5</td>
<td>37.5</td>
<td>37.5</td>
</tr>
<tr>
<td>$V_{e50}$ [m/s]</td>
<td>70</td>
<td>70</td>
<td>59.5</td>
<td>59.5</td>
<td>52.5</td>
<td>52.5</td>
</tr>
<tr>
<td>$T_{I15}$ [%]</td>
<td>18</td>
<td>16</td>
<td>18</td>
<td>16</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>Air density [kg/m$^3$]</td>
<td>1.225</td>
<td>1.225</td>
<td>1.225</td>
<td>1.225</td>
<td>1.225</td>
<td>1.225</td>
</tr>
<tr>
<td>Vertical wind shear exponent [-]</td>
<td>0.2/0.11</td>
<td>0.2/0.11</td>
<td>0.2/0.11</td>
<td>0.2/0.11</td>
<td>0.2/0.11</td>
<td>0.2/0.11</td>
</tr>
<tr>
<td>Flow inclination [$^\circ$]</td>
<td>8°</td>
<td>8°</td>
<td>8°</td>
<td>8°</td>
<td>8°</td>
<td>8°</td>
</tr>
</tbody>
</table>

**Portfolio flexibility ...value where you need it**

- 1.6MW, 2.5MW, 2.75MW (3.5xMW 2015)
- 82.5m, 100m, 103m, 120m (120+ 2015)
- 75m, 80m, 85m, 96m, 98.3m, 123.5TT

GE wind turbine models offering flexible configuration for site specific optimization

Optimize your WF with GE’s product portfolio based on one core design architecture and an +15year evolutionary design strategy

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## Site wind conditions

<table>
<thead>
<tr>
<th></th>
<th>IEC TC IIIb</th>
<th>Site</th>
<th>Impact on loads</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LAYOUT</strong></td>
<td>--</td>
<td>31</td>
<td>--</td>
</tr>
<tr>
<td><strong>WRA:</strong></td>
<td>--</td>
<td>GE</td>
<td>--</td>
</tr>
<tr>
<td>Vavg [m/s]</td>
<td>7.5</td>
<td>7.3 - 9.3</td>
<td><strong>↑</strong></td>
</tr>
<tr>
<td>Weibull shape factor (k)</td>
<td>2</td>
<td>2.2 - 2.5</td>
<td><strong>↓</strong></td>
</tr>
<tr>
<td>CTI @ 15m/s [%]</td>
<td>16</td>
<td>8.7 - 11.6</td>
<td><strong>↓</strong></td>
</tr>
<tr>
<td>Vertical Shear exponent [-]</td>
<td>0.20</td>
<td>0.07 - 0.22</td>
<td><strong>↔</strong></td>
</tr>
<tr>
<td>Flow inclination angle [°]</td>
<td>8</td>
<td>0.6 – 6.3</td>
<td><strong>↓</strong></td>
</tr>
<tr>
<td>Air density [kg/m³]</td>
<td>1.225 / 1.269 / 1.452</td>
<td>1.038</td>
<td><strong>↓</strong></td>
</tr>
<tr>
<td>50-yr 10min gust [m/s]</td>
<td>40.0 / 37.5</td>
<td>34.1 – 46.5</td>
<td><strong>↑</strong></td>
</tr>
</tbody>
</table>

All site conditions rarely align across all modeled parameters. Site specific loads analysis performed always to confirm suitability.
GE’s rigorous Mechanical Loads Analysis model uses $V_{avg}$, $V_{ref}$, CTI, air density, shear, flow inclination angle, wake effects, and wind speed distribution to ensure site loads are within the design loads envelope of the wind turbine.

Selecting the correct WTG can increase AEP by as much as $1GW/yr = $1MMNPV*
Mechanical Loads Analysis, MLA, inputs

- Wind rose
- Wind speed distribution, $V_{\text{avg}}$
- Turbine spacing wake effect
- Extreme wind conditions, $V_{50}$
- Characteristic turbulence intensity
- Air density
- Flow inclination angle
- Wind shear
Wind farm layout – Pole or land constrained

- Phase 1 of the project is limited to **XX** fixed turbine positions.
- Phase 2 open in terms of number and size of turbines to reach a total project capacity of 300MW.

**Phase 2**: optimized for different product scenarios
- Number of turbines based on the Rated Power -> 200MW
- Different HH and RD possible + Wind Reserve Option

2000m
Calculating gross yield

The wind flow model is used to calculate the gross energy yield of the wind farm, using:

- Wind turbine measured power curve
  - Adjusted for site air density
  - Warranted by manufacturer
- Wind turbine thrust curve (for calculating wake effects)

Methodology

- Wind speed distributions for each direction sector, at each turbine location and are extracted from wind flow model and integrated across power curve.
- Wake losses are calculated using specialist software models
Calculating net energy yield

- Net yield is reduced from gross yield to account for efficiency factors, availability, planning constraints (e.g. shadow flicker / noise) or manufacturer imposed curtailments

<table>
<thead>
<tr>
<th>Loss Factor</th>
<th>Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine availability</td>
<td>0.960</td>
</tr>
<tr>
<td>Blade degradation</td>
<td>0.985</td>
</tr>
<tr>
<td>Blade icing</td>
<td>0.990</td>
</tr>
<tr>
<td>Wind hysteresis</td>
<td>0.990</td>
</tr>
<tr>
<td>Electrical efficiency</td>
<td>0.970</td>
</tr>
<tr>
<td>Substation availability</td>
<td>0.997</td>
</tr>
<tr>
<td>Grid availability</td>
<td>0.997</td>
</tr>
<tr>
<td><strong>TOTAL adjustment</strong></td>
<td><strong>0.894</strong></td>
</tr>
</tbody>
</table>
Windfarm construction
Windfarm elements

- Turbine foundations
- Site roads
- Approach roads
- Inter-turbine electrical network
- Substation
- Grid interconnection
2.x Truck Examples
Turbine Erection
Windfarm operation
Windfarm Operation

- Key driver of windfarm performance is turbine availability
  - Turbine supplier should guarantee 95-98% availability for warranty period
  - Long-term 98% levels are achieved by some onshore portfolios internationally

- Typically operated without staff on site – remote operation and technical support
  - Cost savings for portfolio operators

- Need for owners to build a degree of in-house O&M capacity
  - Requires careful negotiation with turbine suppliers on operator training and turbine performance data access, in advance of placing new orders
  - Less of a critical issue if third-party O&M providers present
1.5/1.6MW availability trends

<table>
<thead>
<tr>
<th>Model Year Trends</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2Q 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5-82.5</td>
<td>95.6%</td>
<td>97.0%</td>
<td>97.0%</td>
<td>97.9%</td>
<td>98.2%</td>
<td>98.6%</td>
</tr>
<tr>
<td>1.6-82.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>98.5%</td>
</tr>
</tbody>
</table>

Improved design
Year over year

Improved service, resolved top issues 2Q 2012

Model year: The year in which a turbine is commissioned

First 12 weeks of operation excluded

World’s best running fleet defined
Remote Monitoring & Diagnostics ... maximized availability

✓ 24X7 customer support including strong collaboration with field engineers

✓ Centers - Salzbergen, Germany & Schenectady, NY – Hot Swap Capability

✓ 50+ customer service specialists

✓ 7,000+ turbines controlled remotely ... 98%+ availability

✓ Fleet analysis operating rhythm with engineering-based fault resolution, continuously evolved

✓ 12,700+ turbines w/ data connections

* As of EOY 2011
State-of-the-Art Training

- Technical Training
  - 2000 engineers
  - 1200 technicians
- High-Risk EHS Training
  - 1526 classroom
  - 1074 WEBEX
- Leadership Programs

World-Class EHS Training

- Digital Program Development
  - Simulated Demonstrations
  - Blended Training Solutions
  - Guided Self-Assessments
  - Interactive Animations
  - Video Analysis
  - Offline Learning Solutions

World-wide Productivity

1 million online completions
- 181 online EHS courses
- 20 different languages
- Tiered Structure Flexibility
  - Global
  - Country
  - Business
  - Site
O&M Contracts from Turbine Suppliers

Typically fixed price for a specified period with the option to renew – 2 or 5 years are typical terms

Guarantee for availability with damages based on lost revenue for non-performance

Availability needs to be carefully defined

Third party operators in the future?

- Historically lower-cost and can be higher performing (supply constraints, warranty incentives for supplier to fix worst performing, rather than optimise)
- Will likely take time to build up a third-party capability
GE multi-level support packages

Maintenance and Remote Operations
- Remote Monitoring & Troubleshooting
- Routine Services
- Preventative Maintenance

Extended Parts and Services
- On-Site Support
- Parts Package
- Availability Guarantee

Full Service Agreement
- Unplanned Maintenance
- Condition Monitoring
- Turbine Performance & Life Extension

Flexible options crucial to meeting unique customer needs

Providing defined scope of planned maintenance.

Ensuring highest standards of operation.

Worry-free operation & maintenance.
GE wind services experience

GE wind fleet

<table>
<thead>
<tr>
<th>Year</th>
<th>Cumulative Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>'03</td>
<td>2,000</td>
</tr>
<tr>
<td>'06</td>
<td>5,500</td>
</tr>
<tr>
<td>'09</td>
<td>13,500</td>
</tr>
<tr>
<td>'12F</td>
<td>21,000+</td>
</tr>
</tbody>
</table>

Mining the installed base

Technical fleet data and insight
- 18,000+ units operating globally
- 1,000+ technicians, 350 reliability engineers

Differentiated rigor and speed
- 80% of issues resolved within 10 mins
- Smart early warning algorithms

Upgrading fleet performance
- Driving new tech into fleet

World’s best running fleet ... 98%+ availability
GE’s wind services locations

Global resources, local support