GE Perspective on Wind Systems Engineering

2nd NREL Wind Energy Systems Engineering Workshop

Patrick Riley
GE Global Research
Renewable Energy Systems Lab
GE Global Research
Market-focused R&D

- Global Research Center
  Niskayuna, NY
- India Technology Center
  Bangalore, India
- China Technology Center
  Shanghai, China
- Global Research Europe
  Munich, Germany
- Advanced Manufacturing & Software Technology Center
  Ann Arbor, MI
- Global Software Center
  Silicon Valley, CA
- Brazil Technology Center
  Rio de Janeiro, Brazil

• ~2000 scientists/engineers, nearly two-thirds PhDs.
• 3,615 US patents filed by GE in 2011
• One of the world's most diversified industrial research organizations, providing innovative technology for all of GE's businesses

Cornerstone of innovation for GE
Goal: Assess the system-level value of new technologies & next-generation product designs

- Many system-level trades
  - rating & rotor diameter
  - hub height
  - control strategies (loads vs. AEP)
  - component technologies (cost vs. perf)
  - rotational speed (noise, DT size, loads)

- Need system-level approach to optimize
  - performance
  - capital cost
  - operation & maintenance

- Non-obvious interactions abound

Optimizing technology development & product moves around lifetime value to wind farm
## System Value Optimization

### Key Metrics

<table>
<thead>
<tr>
<th>Component Level</th>
<th>Turbine Level</th>
<th>Farm Level</th>
<th>Fleet Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifecycle Costs</td>
<td>Lifecycle Costs</td>
<td>LCOE, NPV, IRR</td>
<td>Fleet Operations</td>
</tr>
<tr>
<td>Rotor Diameter &amp; Rating</td>
<td>Overall turbine O&amp;M cost</td>
<td>Balancing Costs</td>
<td></td>
</tr>
</tbody>
</table>

### Operation & Maintenance

<table>
<thead>
<tr>
<th>Component Level</th>
<th>Turbine Level</th>
<th>Farm Level</th>
<th>Fleet Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned maintenance</td>
<td>Overall turbine O&amp;M cost</td>
<td>Servicing strategy</td>
<td></td>
</tr>
<tr>
<td>Failure rates</td>
<td>Wind Resource</td>
<td>Grid Integration</td>
<td></td>
</tr>
</tbody>
</table>

### Annual Energy Production

<table>
<thead>
<tr>
<th>Component Level</th>
<th>Turbine Level</th>
<th>Farm Level</th>
<th>Fleet Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component efficiency</td>
<td>Turbine power curve</td>
<td>Wind Resource</td>
<td>Forecasting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wake &amp; cable losses (siting)</td>
<td></td>
</tr>
</tbody>
</table>

### Capital Cost

<table>
<thead>
<tr>
<th>Component Level</th>
<th>Turbine Level</th>
<th>Farm Level</th>
<th>Fleet Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localized loads</td>
<td>Full loads</td>
<td>BOP Costs</td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td>Operational limits</td>
<td>Logistics</td>
<td></td>
</tr>
</tbody>
</table>

**Technologists typical focus areas**

Complex multi-physics, multi-dimensional optimization at farm and fleet levels.

---

February 8, 2013
Technology Development Example

Fabric Covered Blades
GE (lead), NREL, & Virginia Polytechnic Institute
Wrapping architectural fabric around metal wind turbine blades

Component Level
- Reduce mass and cost of blade
- Aero performance
- Required maintenance

Turbine Level
- Turbine loads
- Operational limits such as noise
- Turbine power curve
- Overall turbine O&M

Farm Level
- Logistic costs
- Foundation Size
- Installation costs
- Wake losses

Specify turbine parameters
Specify market & environment parameters
Optimize Technology Development & Turbine Architecture
Technology Value to Customer
Evaluate Technology Options Example

**DFIG Drivetrain**
GE moving multi-MW turbines to DFIG

**Component Level**
- Gearbox & generator cost (material costs)
- Gearbox & generator efficiency
- Required maintenance

**Turbine Level**
- Structural costs (bedplate, tower, etc.)
- Converter cost & efficiency
- Grid requirements
- Turbine power curve

**Farm Level**
- Logistic costs
- Foundation size
- Installation costs

**Technology Value to Customer**

Specify turbine parameters
Specify market & environment parameters

Evaluate Technology Options via Lifecycle Value to Customer
Next Generation Product Designs

Inputs to Next-Generation Product Design

• Environmental Conditions
  Wind speed distribution …most popular
  Wind shear
  Air density
  Farm size

• Market Conditions
  location …logistic costs
  Incentives …reduces impact of capital or
  increases impact of generation
  Financing & target rate of return …influences
  customer value

• Technology Options

Requires system engineering to optimize new products decisions
Next Generation Product Example

### 1.X Products

<table>
<thead>
<tr>
<th>Year</th>
<th>IEC Class II</th>
<th>IEC Class III</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>1.5-70</td>
<td>1.5-82.5</td>
</tr>
<tr>
<td>2006</td>
<td>1.5-77</td>
<td>1.6-82.5</td>
</tr>
<tr>
<td>2009</td>
<td>1.6-70</td>
<td>1.6-100</td>
</tr>
<tr>
<td>2012</td>
<td>1.6-77</td>
<td>1.6-100</td>
</tr>
</tbody>
</table>

### Conditions leading to 1.6-100

**Wind Resource:**
- Increased market in IEC Class III … lower wind speeds

**Technology:**
- Better blade design … lower mass & cost
- Better control technologies … reduced loads
- Noise reduction technologies … allows rotor scaling

→ New Optimal for this Combination

### Constraints leading to 1.6-100

Minimize component modifications:
- Proven aerodynamics from 2.5MW rotor
- Proven high performance, reliability, & availability from existing turbines
- Fast product development … market & technology changing at a faster speed
- Minimize impact on supply chain
- Optimize current equipment

→ Many New Products are Evolutionary

Typical system-engineering

Industry specific design objectives
Join the conversation

GE Global Research website
www.ge.com/research

Edison’s Desk – GE’s longest running blog
www.edisonsdesk.com

Edison’s Desk on Twitter
twitter.com/edisonsdesk

Youtube account
www.youtube.com/grcblog

GE’s Genius of the Day
www.ge.com/genius

We’re on Facebook too!

Engage with GE scientists and engineers about innovation and science