NextEra Energy is a premier U.S. power company primarily comprised of two strong businesses

- Fortune 200 company
- 42,179 MW in operation
- $64 billion in total assets

One of the largest U.S. electric utilities
- Vertically integrated, retail rate-regulated
- 4.6 million customer accounts
- 24,626 MW in operation

Successful wholesale generator
- U.S. leader in renewable generation
- Assets in 26 states and Canada
- 17,771 MW in operation

A growing, diversified, and financially strong company
For the 7th consecutive year, NextEra Energy, Inc. is ranked No. 1 on Fortune’s list of “Most Admired Companies” among gas and electric utilities.
NextEra Energy Resources is the largest wind and solar energy provider in North America

NextEra Energy Resources Facilities

17,771 MW\(^{(1)}\) located across 24 states and Canada

---

1) As of March 1, 2013
NextEra Energy Resources is the largest wind owner operator in North America

Wind has grown quickly and repairing components is a big effort
Wind power from energy capture to your home

\[ P = \frac{1}{2} C_p \rho A V^3 \]

- Where \( C_p \) is the power coefficient
- \( \rho \) is the air density
- \( A \) is the rotor swept area
- \( V \) is the wind speed

1 Turbine powers about 300 homes
Wind turbines produce power on a design power curve

Standard Power Curve Rev 1

The calculated power curve data are valid for standard air density conditions of 15 deg.C air temperature, 1013 hPa air pressure and 1.225 kg/m3 air density, clean rotor blades, substantially horizontal, undisturbed air flow, normal turbulence intensity and normal wind shear.

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<thead>
<tr>
<th>Wind [m/s]</th>
<th>Power [kW]</th>
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<td>6</td>
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<td>25</td>
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</table>

![](chart.png)
In reality the power has a lot of variability and this data is used to pick out troubled turbines.

- Underperformance Example
  - Callahan Divide: Parameter change caused underperformance.

![Graph showing power output variability with data from April 30 to May 30, and then from September 2 to September 27, with a highlighted period from September 1 to September 26, 2013. A parameter correction is noted on September 26.]
Weibull data is used to forecast the annual failures of gearboxes for the year based on failures and aging.

![Distribution Overview Plot for Years]

We repair 33 different gearbox models and there are 67 in our wind fleet.

![Major Component Tracker]

Confidential Information

<table>
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<tr>
<th>Gearbox</th>
<th>Budget Qty</th>
<th>Transfer Qty</th>
<th>Actual Qty</th>
<th>Remaining Qty (End-Column)</th>
<th>%</th>
<th>Budget $</th>
<th>Transfer $</th>
<th>Actual $</th>
<th>Remaining $ (End-Center)</th>
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</table>
Experienced technicians operate and maintain our 100+ wind sites in the United States and Canada.

- Experienced technicians on site
- On-going training and mentoring programs
- Supported by 24/7 fleet monitoring and diagnostic center
NextEra Energy Resources Iowa Service Business Units

Generation Repair & Service
- 27 Employees
- $20 MM Investment
- $30 MM Inventory

North American Parts & Services
- $2 MM Investment
- $17 MM Inventory

Local Sourcing $2 MM in 2011
Our Story City, Iowa location is a critical component of our North American wind fleet operations

- **Fleet Gearbox Repairs**
  - 254 gearboxes repaired, 150 annually by 2015
  - 33 technologies - proprietary procedures and techniques developed in-house
  - Regenerative Test Stand
  - Repair cycle reduce from 118 to 34 days
  - Up-tower Repair Center of Excellence

- **Fleet Part & Services**
  - Supports NextEra’s fleet of approximately 10,000 wind turbines
  - Significant increase to inventory capacity and processing over the next 5 years
GRS looks at gearboxes from all angles

Exterior casing and auxiliary equipment (brakes, oil pumps, instrumentation and case deflection)
Look at bolting, cover and inspection plates

Borescoping is critical to seeing inside a gearbox prior to failures
Look at gearing and bearings

Inspect loading patterns, wear patterns and lubrication performance
Look at disassembly and reassembly processes

What is the most efficient, low cost way to repair failed gearboxes? NextEra uses quality tools - Kaizen events, 6 sigma, and lean - 5S techniques to understand the root cause of failures and implement proper countermeasures.
Effective Gearbox maintenance is based on maximizing the “5R“ Concepts

5R’s - Replace, Reuse, Reverse, Regrind, Repair, are all steps in the assessment of a gearbox overhaul
GRS reviews many engineering drawings

Reviews for bills of materials, specifications, and dimensions
AGMA (American Gear Manufactures Association) standards are used

The following table shows the difference in manufacturing tolerances between gearing.

Old 90’s vintage wind gearboxes were class 8. New gearboxes are at least class 12.

Gear Tolerances - Fine Pitch Spur and Helical Gears

<table>
<thead>
<tr>
<th>AGMA Quality No.</th>
<th>Number of Teeth and Pitch Diameter</th>
<th>Diametral Pitch Range</th>
<th>Tooth-to-Tooth Composite Tolerance</th>
<th>Total Composite Tolerance</th>
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<td>Up to 20 teeth inclusive</td>
<td>20 to 80</td>
<td>0.0037</td>
<td>0.0052</td>
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<td>Over 20 teeth, up to 1.999&quot;</td>
<td>20 to 32</td>
<td>0.0027</td>
<td>0.0052</td>
</tr>
<tr>
<td></td>
<td>Over 20 teeth, 2&quot; to 3.999&quot;</td>
<td>20 to 24</td>
<td>0.0027</td>
<td>0.0061</td>
</tr>
<tr>
<td></td>
<td>Over 20 teeth, 4&quot; and over</td>
<td>20 to 24</td>
<td>0.0027</td>
<td>0.0072</td>
</tr>
<tr>
<td></td>
<td>Up to 20 teeth inclusive</td>
<td>20 to 200</td>
<td>0.0027</td>
<td>0.0037</td>
</tr>
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</table>
Forensics of failures is caused by up to 2,210 BHP of energy.

Failure forensic analysis. Why did it fail?

- Overloaded
- High cycle fatigue
- Low cycle fatigue
- Material inclusion
- Grind temper
- Heat treating error
Ring gear pinion secondary damage from previous slide

Fig. 2 View of the sun pinion gear mesh. Note, only secondary fractures were observed.
Macro pitting of a spherical roller planet gear bearing race

Typical bearing analysis, indications of overloaded bearing due to higher loads than expected. Bearing selections that work in other industry do not work in wind.
Gear tooth overloading associated with a tolerance problem
High cycle fatigue – wear over life of the component
Catastrophic Failure

Salvage some gearing and send gearbox to scrap vendor
Plastic deformation of a pair of tapered roller bearings
Bearing race white etching prior to spalling of race

Root Cause is the transient vibrational loading seen in high speed bearings

Up tower repair was perfected in the GRS shop then deployed to the field
Failure pictures
Gearbox case bolt failure after about 50% of the diameter was cracked the bolt sheared off causing a failure.
Broken Gear and Ring Gear – cracked in two pieces
Failure debris pictures

Planet gear tooth

2 ring gear teeth cold welded together due to the energy of the failure
Intermediate pinion – Double helix or herringbone design

Overloading failure
Inclusion failure

Non metallic inclusion usually aluminum or silica
Macro spalling

One sided spalling can suggest an alignment issue
Planet carrier with 5 planet gears
Wind turbines commonly have 3 planets
Load modeling for analysis

$\alpha = 22.9^\circ\text{ Rotorside}$

$\alpha = 24.1^\circ\text{ Generatorside}$

Bore in carrier rotorside

Bore in carrier generatorside

$DUY = 0.10978\text{mm}$

Pin length

$\text{mm}$

File: PP-ge-1-5-120grad

File: PM-ge-1-5-120grad

NEXTera ENERGY RESOURCES
### Design Calculations

<table>
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<tr>
<th>Gear Ratio</th>
<th>Center Distance</th>
<th>No. of Teeth</th>
<th>Phase Displacement</th>
<th>Normal Module</th>
<th>Profile Shift Coef.</th>
<th>Face Width</th>
<th>Helix Angle</th>
<th>Tip Diameter</th>
<th>Contact Ratio</th>
<th>Spec. Sliding</th>
<th>B/Sun Diameter or B/Pinion Diameter</th>
<th>B/Annulus Diameter or B/Center Distance</th>
<th>Load Distribution</th>
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<td>i</td>
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<td>z</td>
<td>Delphi</td>
<td>m</td>
<td>x</td>
<td>h</td>
<td>p</td>
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<td>m3</td>
<td>m3</td>
<td>b/sun</td>
<td>b/annulus</td>
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<td>-1,55</td>
<td>1,245</td>
<td>1,15</td>
<td>1,13</td>
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</tbody>
</table>

**GE Wind Energy 1,5 60Hz i=71,76595 planetary stage**

- T-Rotor = 790,000 Nm
- n-Rotor = 20,065 rpm
- n-Gen = 1,440 rpm
- Pellemch = 1,500/1960 kW
- Oil: synthetic CLF3221 FZG-LS 12 SKS n GFT: 10 Oil temperature 85°C
- Gearwheel material: 18CrNiMo7-6 (1,6587) SigHlim = 1510 N/mm² SigFlim = 520 N/mm²

**RMS = 0 (AGMA rec.)**

<table>
<thead>
<tr>
<th>Flank</th>
<th>Root</th>
<th>Flank</th>
<th>Root</th>
<th>Flank</th>
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<td>(FVA45 III)</td>
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**RMS = 0 (upgrade)**

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**RMS = +91 (upgrade)**

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**RMS = -91 (upgrade)**

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**Limits (AGMA) (2003)**

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<th>SH</th>
<th>SF</th>
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<tbody>
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<td>1,58</td>
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</table>

**As of 1999**

![Image of a page from a design document]
Design calculations associated with load sharing of multiple gears

Timing of gears is critical to some gear train designs
GRS engineers use many contractors to assist in failure analysis.
Design Calculations for contact stress after operation at full load

High speed gear after gearbox incremental tests to 100% rated torque

Bluing is often used to check tooth contact for rebuilt gearboxes
Typical jobs around the shop

Assembly/Disassembly

Flipping

Measuring

Cleaning

Freezing

Heating
All > 1MW gearboxes get load tested at the shop

Torque Feedback Test Stand

Test Gearbox

Location where Consolidation gearbox is installed

Absorber

Drive Motor

Drive Gearbox
All > 1MW gearboxes must pass the load test prior to installation.

All bearing vibrations and oil flows are monitored.
Electronic repairs will start at the facility next year
Motor and pump repairs will also start at the facility next year.
Job opportunities with NextEra can be found at

www.nexteraenergy.com/careers/

Hiring Heros

From engineering and communications to nuclear science and more, our opportunities will allow you to transfer your skills to shape the future of clean and renewable energy. At NextEra Energy, we value the leadership training, technical skills and discipline you gained while serving our country, and we will challenge you to use them to the fullest.

Learn More ▶
Questions?
Some Assembly Required
Installing Foundations

- 54 feet, 6 inches wide
- 8 feet deep
- 330 cubic yards of concrete
- 53,200 pounds of rebar
- Foundation above ground is about 14 feet in diameter