Wind Farm Modeling and Prognostic Opportunities

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&

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Purpose & Overview

• Purpose: Provide an overview of the reliability analysis approach used by SNL and encourage dialogue with industry in order to improve reliability, efficiency, and costs

• Overview
  – Objectives
  – Analysis approach
  – Reliability tools
    • Raptor - Dynamic reliability block diagram simulation
    • Pro-Opta - Static fault tree analysis tool with improvement optimization
  – Prognostics
    • Where it makes sense
Program Objectives

- Establish industry benchmarks for reliability performance
- Improve system performance of wind assets through better asset management
- Identify reliability trends
- Provide high quality information to support operational and maintenance practices
- Targeted efforts to address important component reliability problems

Providing an independent and objective perspective
Analysis Approach

• Data Analysis
  – Investigate existing failure & maintenance data sources
  – Recommend reliability data elements

• Wind Turbine System Baseline ("as is") Model
  – Populate with existing failure & maintenance data
  – Analyze & compare against current system performance

• Optimize Plan ("best bang for the buck")
  – Predict impacts of component & subsystem modifications, changing maintenance practices, etc.
  – Evaluate other cost and availability drivers identified by the baseline model

- Maintenance Data
  - Field data
  - Inspection data

- MTBF Update
  - Data correction
  - New components

- Objectives & Constraints
  - Performance objectives
  - Cost constraints

- Maximize Availability
- Minimize Cost

RESULTS

Annual Cost Reduction

Estimated RECAP Cost

Millions

Thousands
Reliability Toolkit

• Numerous techniques are available
  – Failure modes and effects analysis (FMEA)
  – Failure modes and effect and criticality analysis (FMECA)
  – Reliability block diagram (RBD)
  – Reliability, Availability, Maintainability, and Safety, (RAMS)
  – Etc.

• Numerous tools available
  – Reliasoft
  – Itemsoft
  – SCADA reporting and analysis tools
  – Winsmith
  – Raptor
  – Pro-Opta
Approach

• **Data**
  – Global Energy Concepts (GEC) Reliability and Cost Model for Generic 1 MW Wind Turbine
    • Generic 1 MW Wind Turbine
    • Random & wearout failures modeled
  – Modified based on wind farm owner and operator feedback
  – Further modified to illustrate optimization methodology

• **Reliability software demonstration - come to our booth for in-depth information**
Raptor analysis

- Commercially available Reliability Block diagram software package
- Simulation allows for “scenario testing” or “what if” analysis
Raptor analysis

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- Simulation allows for “scenario testing” or “what if” analysis

Inputs
- Preventive maintenance
- Costs, resources
- Spares strategy
- Maintenance delays
- Dependency

Inputs
- Failure, repair
- Costs, resources
- Spares strategy
- Maintenance delays
- Dependency
### Raptor scenario analysis

#### Block Input Tables

<table>
<thead>
<tr>
<th>Block Name</th>
<th>Failure Distro</th>
<th>Param1</th>
<th>Param2</th>
<th>Param3</th>
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Raptor scenario analysis
Raptor scenario building

What if we could cut the time to do crane repairs in half?
Raptor scenario building

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Pro-Opta Toolset

- Sandia’ reliability optimization tool
  - Maintenance events or summarized data
  - Improvement option optimization
  - Army’s Apache, Navy’s LCAC, ABL, etc.
Pro-Opta Toolset

Field Data
- Turbine #
- Type of “failure” event
- Failure date & time
- Downtime & costs
- Etc.

Data Manager

Data Analyzer

Fault Tree Interface

Summary Data
- Subsystem, component, etc.
- Type of “failure” event
- Failure rates / distributions
- Downtime & cost distributions
- Etc.

Summary Data
(i.e., Failure Distributions)

Optimizer

Improvement Options
- Change in MTBF
- Change in downtime
- Costs for each change
- Etc.

Field Data
(i.e., Maintenance Events)
Pro-Opta Toolset

Field Data (i.e., Maintenance Events)

Data Analyzer

Data Manager

Fault Tree Interface

Summary Data (i.e., Failure Distributions)

“Best bang for the buck”
- Minimize annual cost
- Maximize availability
- Minimize weight
- Etc.

Optimizer

Sandia National Laboratories
Wind Turbine Availability

“... a day in the life of a wind turbine”

Operating & Operable

Repair, Inspection, Supply & Admin

Contributors to Availability:

- No suffix – parts replacement only
- “- Mx” – maintenance performed with no parts replacement
- “- Crane” – crane required to repair or replace component
- “- Can” – parts cannibalized from another turbine
- “- SchMx” – scheduled maintenance
- “- Insp” – planned inspection

A systems approach assesses key availability drivers
Baseline Model Results

Availability = 93.88%

Annual Cost = $59,813
Optimization Setup

- Optimization Setup
  - All TTF and downtime improvements and costs are “notional”
  - 9 improvement options result in 288 combinations of possible solutions
    - Genetic algorithm helps find the optimal or near optimal solution
    - Multiple top solutions available
  - Approximately $100K to spend in improvement options

<table>
<thead>
<tr>
<th>Improvement Option Name</th>
<th>% TTF Improvement</th>
<th>% Downtime Improvement</th>
<th>Implementation Cost</th>
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Optimization Results
Optimization Results

Annual Cost History

Summary Information

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<td>Total</td>
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Prognostics & Health Management (PHM)

- Prognostics & Health Management:
  - A technology to accurately predict the remaining useful life of a system or component
  - Produces time-to-failure (TTF) estimates which could be projected for long periods of time to assist in maintenance planning.
  - Requirement of every major new military hardware acquisition: FCS, JSF, etc.

**System Health Condition**

- **Functioning**: Loss of life and/or system due to catastrophic failure
  - **Prescriptive replacement of functioning “good” item**: $\$\$
- **Degrading**: Optimum
  - $\$$ Optimum
    - Replace item with maximum usage before failure
  - Associated Cost with Time of Replacement
  - $\$\$
- **Failing**: Loss of life and/or system due to catastrophic failure
  - $\$$\$$\$$\$$\$

- Time

---

[Image of a diagram illustrating the health conditions, costs, and decisions related to system maintenance.]
Sandia PHM System Architecture

Data Fusion: Bayesian Belief Networks

Evidence Engine (System Health)
- System
- Subsystem
- Component

Data Analysis
- Raw Sensor Data
- Sensor Feature Extraction
- Sensor Feature Interpretation (NN, SHT, SET)

Consequence Engine
- Maintenance Scenarios
- Consequence Analysis
- Optimal Ops / Maintenance Recommendations

Consequence Engine
- Updated TTF Distributions
- Estimates of Remaining Useful Life

- Environmental Conditions
- Maintenance History
- Physics of failure
- Aging and Time-to-Failure
Sandia PHM Research

• Nuclear Power Plant “Smart” Equipment
  – DOE Nuclear Energy Research Initiative (NERI) with MIT, etc.
  – Introduce PHM to selected power plant equipment

• Manufacturing Facility PHM
  – DOE funded program
  – Implement PHM in manufacturing facility

• Machine Tool PHM
  – DOE funded program
  – Implement PHM on SNL machine tools

• F-16 Accessory Drive Gearbox (ADG)
  – Joint Shared Vision program with LM Aero
  – Extend replacement intervals

• Airborne Laser (ABL)
  – Program with MDA and Industry
  – Implement PHM on fluid flow systems (COIL)

• MEMS-Based PHM for Internal Combustion Engines
  – Predict failures in internal combustion engines and other rotating machinery
  – Low footprint PHM hardware & software solution
Sandia PHM Research

- Develop a low-footprint PHM solution (MEMS) for rotating machinery
  - Sandia 3-year internally funded research (finishing 1st year)
  - Predict failure through vibration analysis & oil properties

**Wind Turbine Gearbox Application**

**Maintenance Computer**

**MEMS PHM Sensor Node**

- Integrated IR Spectrometer, IR Source, Accelerometer, DSP, Wireless Comm., Long-life battery

**Real-Time Monitoring Software integrated in onboard display**

**Sensor mounted in oil pan.**
Summary

• **Program Objectives**
  – Establish industry benchmarks for reliability performance
  – Improve system performance of wind assets through better asset management
  – Identify reliability trends
  – Provide high quality information to support operational and maintenance practices
  – Address important component reliability problems

• **Multiple reliability analyses tools**
  – Assess wind turbine top contributors to availability
  – Determine optimal component improvement options

• **Investigate PHM applications**
  – Evaluate applicable technologies
  – Examine cost / benefit