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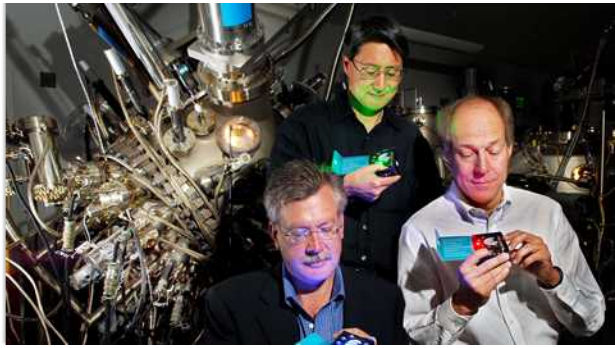

Wind Turbine Reliability Data Analysis

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Organization: 6121

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Purpose

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Key objectives:

1. Can data predict wind turbine failures?

2. How much data is really needed?

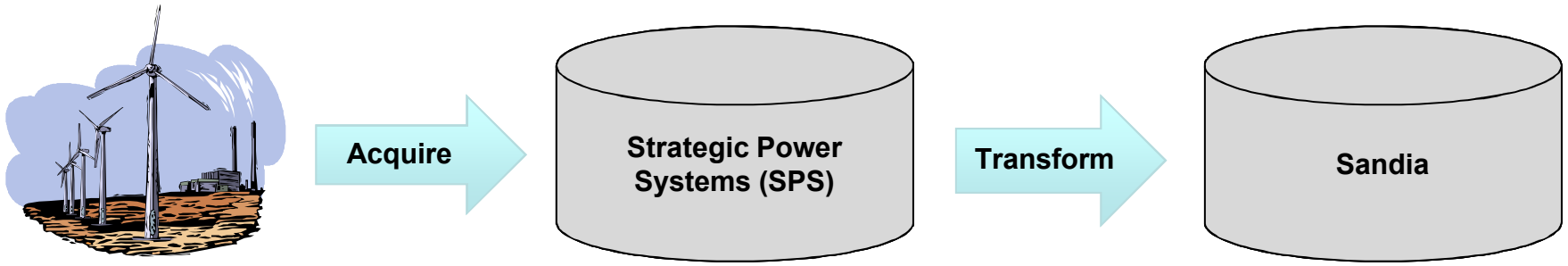
Role in energy surety:

- Reliability
- Cost effectiveness

Wind Turbine Reliability Data

- **Supervisory control and data acquisition (SCADA) data:**
  - Critical parameters for wind turbine reliability (47 total)
  - Acquisition fidelity based on parameter variability
  - Reduced to summarize 10-minute time intervals

- **Operational Analysis Reliability Program (ORAP) data:**
  - Discrete event-based data
  - Includes statuses as well as critical warnings and failures



Data Issues and Challenges

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- **Integrity:**
  - ***Completeness*: Often not fully or properly transmitted**
  - ***Accuracy*: Static values from server overload**
- **Collection and storage:**
  - **Expense increases exponentially with acquisition fidelity**
  - **Takes effort to ensure clean transmission of data**
- **Statistical:**
  - **High-dimensional data set, dependent variables**
  - **Relatively short history (< 2 years)**

SCADA Data Analysis Approach

- **Focus of analysis:**
  - **A specific, well-defined failure mode**
  - **Wind turbines with identical manufacturer and power capacity**
- **Failure mode: Drive train vibration**
  - **Acceleration exceeds a limit for a specified time interval**
  - **Results in immediate shutdown of turbine**
- **Use regression analysis to:**
  - **Identify significant predictors of drive train acceleration**
  - **Determine root cause of vibration spikes**

Regression Results

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- **Significant predictors of drive train acceleration**
  1. **Wind speed*****
  2. **Rotor speed**
  3. **Gearbox temperature**
  4. **Wind deviation (one second period)**
  5. **Change in torque**
  6. **Blade position**

- **Regression model:**
  - **Explains 55%-80% of acceleration variation (varies by turbine)**
  - **Wind speed is most important predictor**
  - **Does not predict the large observed acceleration spikes**

Regression Results

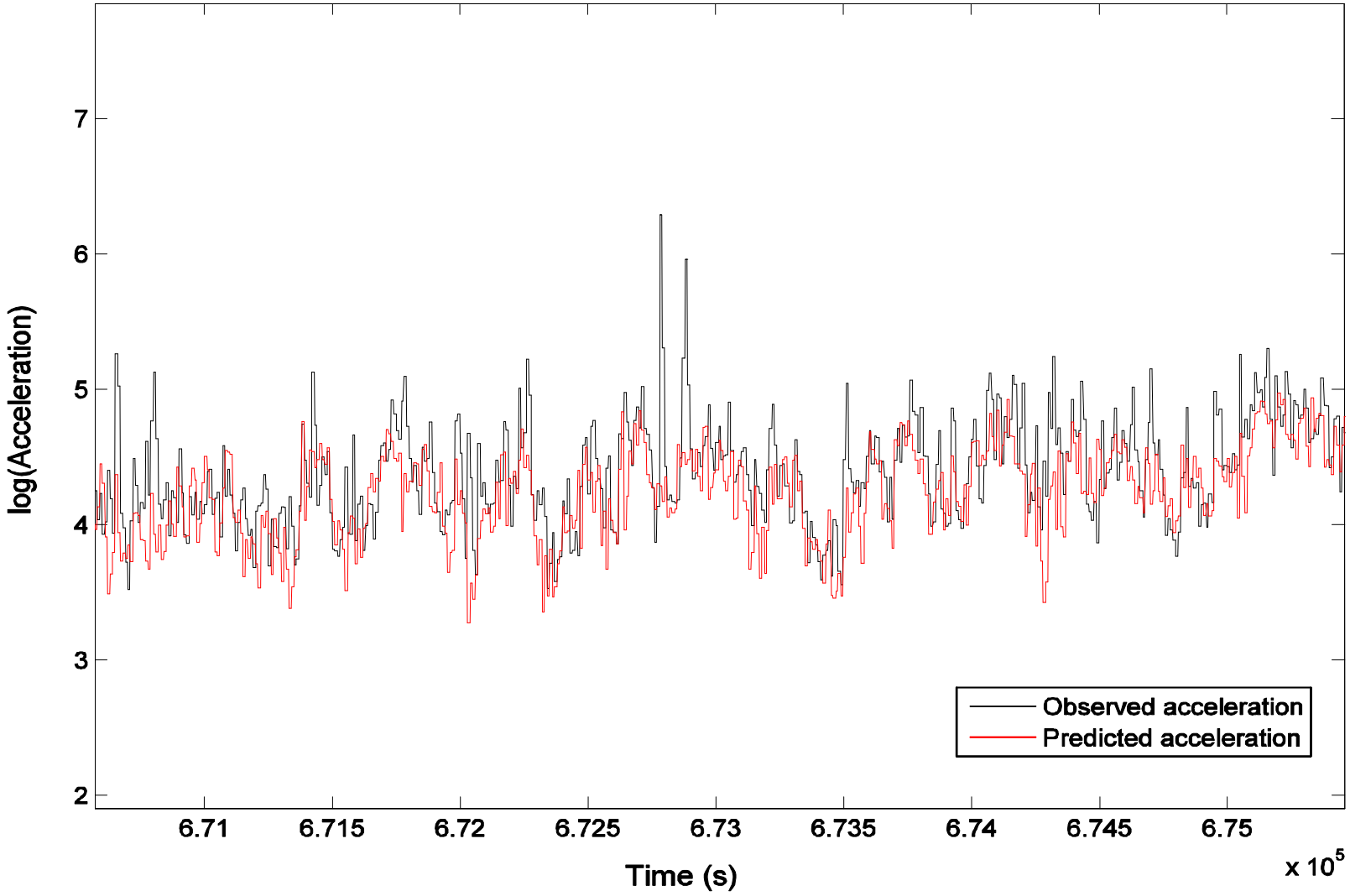

Figure 1: Plot of observed and predicted drive train acceleration.

Model Extensions and Hypothesis

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- **Regression using principal components analysis (PCA):**
  - **Based on transformed data using principal components**
  - **Can explain nearly 80% of acceleration variance, but not spikes**
  - **Pros: Multiple correlated variables utilized**
  - **Cons: Transformed variables lack intuitive interpretation**

- **Best Hypothesis: Wind gusts drive large accelerations.**

- **Attempts to verify hypothesis:**
  - **Meteorological tower data**
  - **Drive train and tower acceleration correspondence**

ORAP Analysis Approach

- **Objective: Identify associations between ORAP events**
  - **Determine root causes of failures**
  - **Reveal hidden system interdependencies**
- **Focus of analysis:**
  - **Warning and failure codes only**
  - **Limited to turbines with identical manufacturer and power capacity**
  - **Includes all ORAP data collected to present (~30,000 events)**
- **Technique: *Apriori algorithm***
  - **Iteratively identifies significantly associated events**
  - **Strictly data driven—makes no statistical assumptions**
- **Events partitioned into unique "turbine-month" bins**

ORAP Analysis Results

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Confidence	Association Rule			
1.0000	Collective fault pitch controller	Pitch overrun 90°	------>	Blade angle asymmetry
0.9474	Pitch overrun 90°	Pitch control deviation axis 3	------>	Blade angle asymmetry
0.9333	Pitch overrun 90°	Pitch control deviation axis 2	------>	Blade angle asymmetry
0.8889	Increasing speed with falling blade angle	Drivetrain vibration	------>	Tower vibration
0.8750	Increasing speed with falling blade angle	Low noise operation	------>	Tower vibration
0.8667	Generator Overspeed	Drivetrain vibration	------>	Tower vibration
0.8667	Generator speed implausible	Line CCU collective faults	------>	Line CCU fault voltage
0.8571	Response signal from CCU	Pitch overrun 90°	------>	Blade angle asymmetry
0.8571	Pitch overrun 90°	Line CCU collective faults	------>	Line CCU fault voltage
0.8462	Overtemperature pitch motor	Pitch control deviation axis 2	------>	Blade angle asymmetry

Table 1: A sample of some strongly associated ORAP events.

ORAP Analysis Results

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- ORAP analysis just beginning….
- Potentially a useful tool to identify failure root causes
  - Statistical results only for now
  - Engineering interpretation needed
- Advantages:
  - Requires no *a priori* data knowledge or assumptions
  - All available ORAP data utilized
  - Relatively quick to preform analysis
- Limitations:
  - ORAP data integrity not considered
  - Actionable information requires systems expertise
  - Association does not imply causality!

Questions

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