Process-Constrained Data Analytics for Sensor Assignment and Calibration

Advanced Sensors and Instrumentation Annual Webinar

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Project Overview

• **Goal**
  – Determine the minimum sensor set required to diagnose equipment degradation (sensors/components) in a system in a nuclear facility

• **Objectives**
  – Solve using data analytics and physics-based methods
  – Deploy in an industry setting to solve a meaningful O&M problem

• **Participants (2020)**
  – Richard Vilim – Argonne; Xcel Energy; University of Michigan

• **Schedule**
  – Y1: Develop Method and Algorithms and Engage a Nuclear Utility
  – Y2: Perform Sensitivity Studies on an Application Selected by Nuclear Utility
  – Y3: Install at Utility Site for Their Assessment
Summary of accomplishments (FY20)

• Deliverables

• Journal Paper

• Patents
  – Three patent applications are being written
Summary of accomplishments (FY20)

• Extended Algorithms and Methods
  – Added uncertainty treatment to automated reasoning algorithm

• Added Pump/Motor/Bearing Models to Component Library
  – Centrifugal pump, synchronous induction motor, and shaft bearing model added to PRO-AID library

• Validated Methods Using Blind Data from Utility Partner
  – Received FW pump normal operation data and blind fault data
  – Successfully diagnosed sensor biases superposed on plant measurements
  – successfully diagnosed blind faults

• Deployed Cluster-Based Executable for Sensor Assignment
  – Delivered executable to University of Michigan for subcontract task
  – Started software quality assurance upgrade
Technology Impact (1/3)

• Advancement of state of the art for nuclear application
  – Improves the reliability of nuclear plant health monitoring technology by including physics-based information as an adjunct to sensor data
  – Increases situational awareness among plant engineering staff by providing early identification of equipment degradation
  – Improves plant efficiency by providing a technical basis for determining when scheduled maintenance is unnecessary and can be bypassed
  – Facilitates the new paradigm of a remote monitoring center aimed at improving overall efficiency of a utility’s nuclear fleet
  – Provides a techno-economic basis for designing the plant health-monitoring sensor set for an advanced reactor
Technology Impact (2/3)

• Support for the DOE-NE research mission
  – Improves the economic competitiveness of nuclear power by reducing O&M costs
  – Leverages national laboratory expertise to advance commercial sector capability
  – Improves U.S. energy security through development of science-based technology that furthers the viability of nuclear power for electricity production

• Impacts the nuclear industry
  – Targets improved O&M efficiency in the current fleet with evaluation underway by two U.S. utilities in coordination with a U.S. energy services company
Technology Impact (3/3)

• Commercialization
  – Presently in early phase evaluation/ adoption by two utilities developing remote monitoring centers
  – A U.S. nuclear energy service company has committed to adopting (industry partner on TCF awards) the method as a front-end plugin to maintenance optimization and asset management tools they are developing through EPRI sponsorship
  – Proceeding with three patent applications to protect U.S. taxpayer investment
Accomplishment #1 – Developed Algorithms and Methods

• Automated reasoning algorithm extended to include uncertainty treatment

• Sensor assignment algorithm developed and programmed

```plaintext
// Pseudo code for finding sensor set that yields optimal maintenance
// and asset management scheduling strategy
while  // iterate on sensor set
    spawn sensor_set
    generate virtual_sensors    // Subtasks 1.2 and 1.3
    generate Current_Likelihood_Component_Faults  // Subtask 2.2
while    // Subtask 2.5
    spawn PM_schedules
    evaluate maintenance_asset_cost_function
    exit_if maintenance_asset_cost_function < epsn
exit_if maintenance_asset_cost_function < epsn
print cost, sensor set, PM schedules
end
```
Accomplishment #2 – Developed Component-Library Models

- First-principles models for generic nuclear plant components were developed
  - Centrifugal pump, synchronous induction motor, shaft bearing
  - Added to the component library of the PRO-AID engineering-system health-monitoring code

Centrifugal Pump Performance Maps  Synchronous Induction Motor Equivalent Circuit

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_1$</td>
<td>Stator phase supply voltage (V)</td>
</tr>
<tr>
<td>$I_1$</td>
<td>Stator phase current (A)</td>
</tr>
<tr>
<td>$I_2$</td>
<td>Rotor phase current (A)</td>
</tr>
<tr>
<td>$I_m$</td>
<td>Magnetizing current (A)</td>
</tr>
<tr>
<td>$s$</td>
<td>Slip (-)</td>
</tr>
<tr>
<td>$n_r$</td>
<td>Rotor speed (rpm)</td>
</tr>
<tr>
<td>$n_s$</td>
<td>Synchronous speed (rpm)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>Stator leakage reactance (Ω)</td>
</tr>
<tr>
<td>$X_1$</td>
<td>Stator leakage reactance (Ω)</td>
</tr>
<tr>
<td>$R_2$</td>
<td>Rotor resistance at standstill (Ω)</td>
</tr>
<tr>
<td>$X_2$</td>
<td>Rotor leakage reactance (Ω)</td>
</tr>
<tr>
<td>$X_m$</td>
<td>Magnetizing reactance (Ω)</td>
</tr>
</tbody>
</table>

Variable $s = \frac{n_s - n_r}{n_r}$
Accomplishment #3 – Validated Methods Using Blind Data from Utility Partner

• Received FW pump/motor normal operation data and blind fault data

• Successfully diagnosed sensor biases superposed on plant measurements

• Successfully diagnosed blind faults

Timeline of Blind Data

Electric Power Generation

Diagnosis of feedwater pump bearing degradation
Accomplishment #4 – Release of Cluster-Based Executable

• Brought in software engineer to help with life-cycle management of PRO-AID code

• Developed and delivered cluster-based alpha version of PRO-AID code for use by Univ. of Michigan
Conclusion

• Algorithm and methods work was largely completed
  – Uncertainty treatment added
  – Component models added
• Validated algorithms and methods for feed water pump use case in collaboration by partnering utility
  – Successfully diagnosed sensor bias errors superposed on normal operating plant data
  – Successfully diagnosed blind faults in three plant event cases
• Released an alpha version of the code for use in sensor assignment problem
• Contact Information
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