U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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Process-Constrained Data Analytics for Sensor Assignment and Calibration

Advanced Sensors and Instrumentation Annual Webinar

November 6, 2019

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Argonne National Laboratory

Project Overview

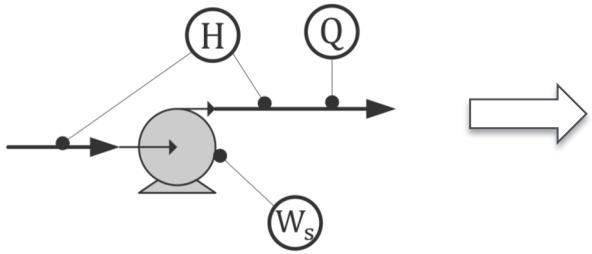
- Goal and Objective
  - Determine the minimum sensor set required to diagnose equipment faults (sensors/components) in a system in a nuclear facility
  - Solve using data analytics and physics-based methods
  - Deploy in an industry setting to solve a meaningful O&M problem
- Participants (2019)
  - Richard Vilim, Alexander Heifetz – Argonne, Marc Anderson – Xcel Energy, Brendan Kochunas – Univ. 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

Accomplishments

- Deliverables
  - *Development of Process Constraints for the Sensor Calibration Problem*, ANL/NSE-19/4, March 29, 2019.
  - *Development of Methods for Solution of Sensor Calibration and Assignment Problem*, ANL/NSE-19/24, August 30, 2019.
  - *First Annual Progress Report on Process Constrained Data Analytics for Sensor Assignment and Calibration*, September 30, 2019.

Accomplishments Y1

- Developed Method and Programmed Algorithm
  - Digital twin of the components in a system serves as a reference against which to generate anomaly signatures
  - Anomaly signatures consist of measurement residuals that map into a table of residual/fault pairings
  - Identify fault by using measurement residuals to read out of a table of residual/fault pairings
  - Algorithm operates at the system level



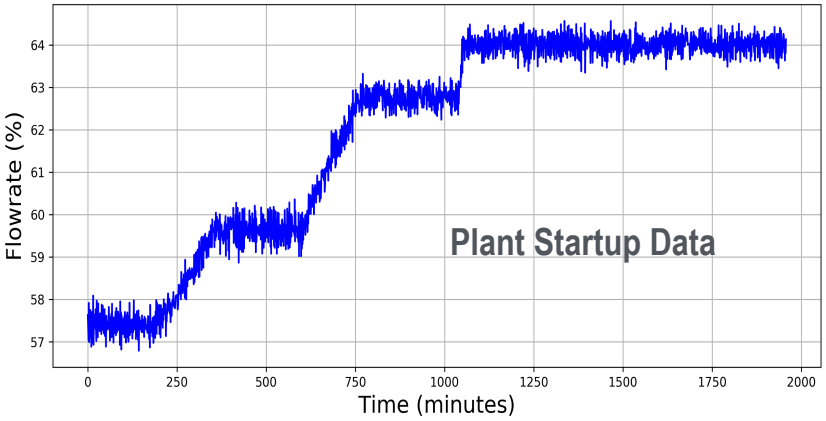
Feedwater (FW) Pump

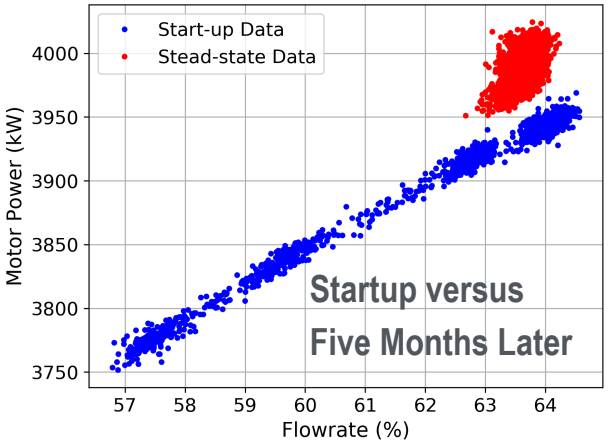
FW Pump Measurement Residuals and Associated Faults

Residual	Pump Fault	H_m sensor fault	τ_m sensor fault	n_m sensor fault	Q_m sensor fault
r_H	1	1	0	1	1
r_τ	1	0	1	1	1
r_3	1	1	1	1	0
r_4	1	1	1	0	1

Accomplishments Y1

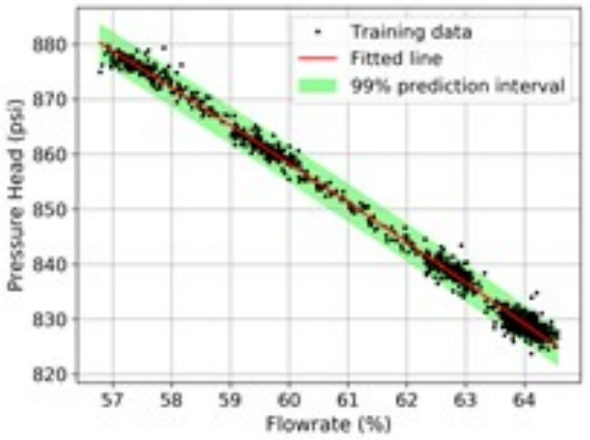
- Worked First Test Problem with Nuclear Utility
  - Received FW pump data from utility partner
    - Speed, pumping power, mass flowrate, head
    - Data from startup data and from five months later
  - Pump appears to have undergone degradation over five-month interval



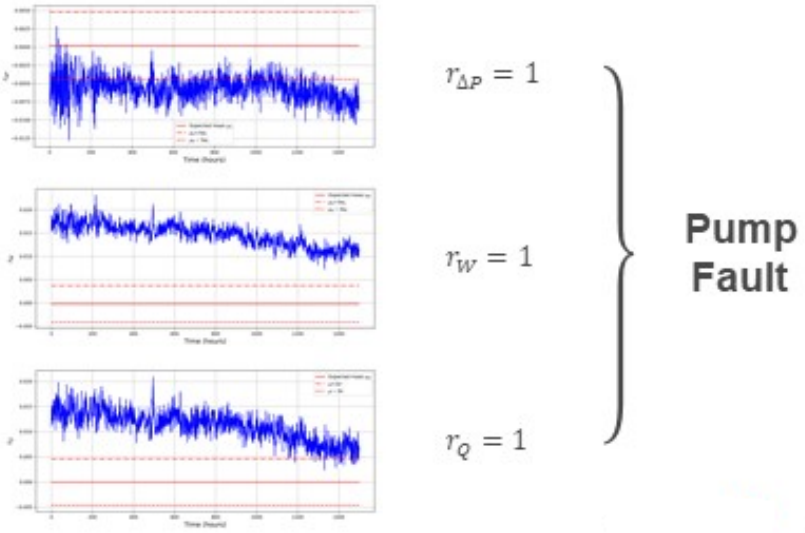


Accomplishments Y1

- Results for FW pump test problem
  - Calibrated physics-based model against startup data
    - Model engineering parameters (deterministic)
    - Model uncertainty and sensor noise parameters (stochastic)

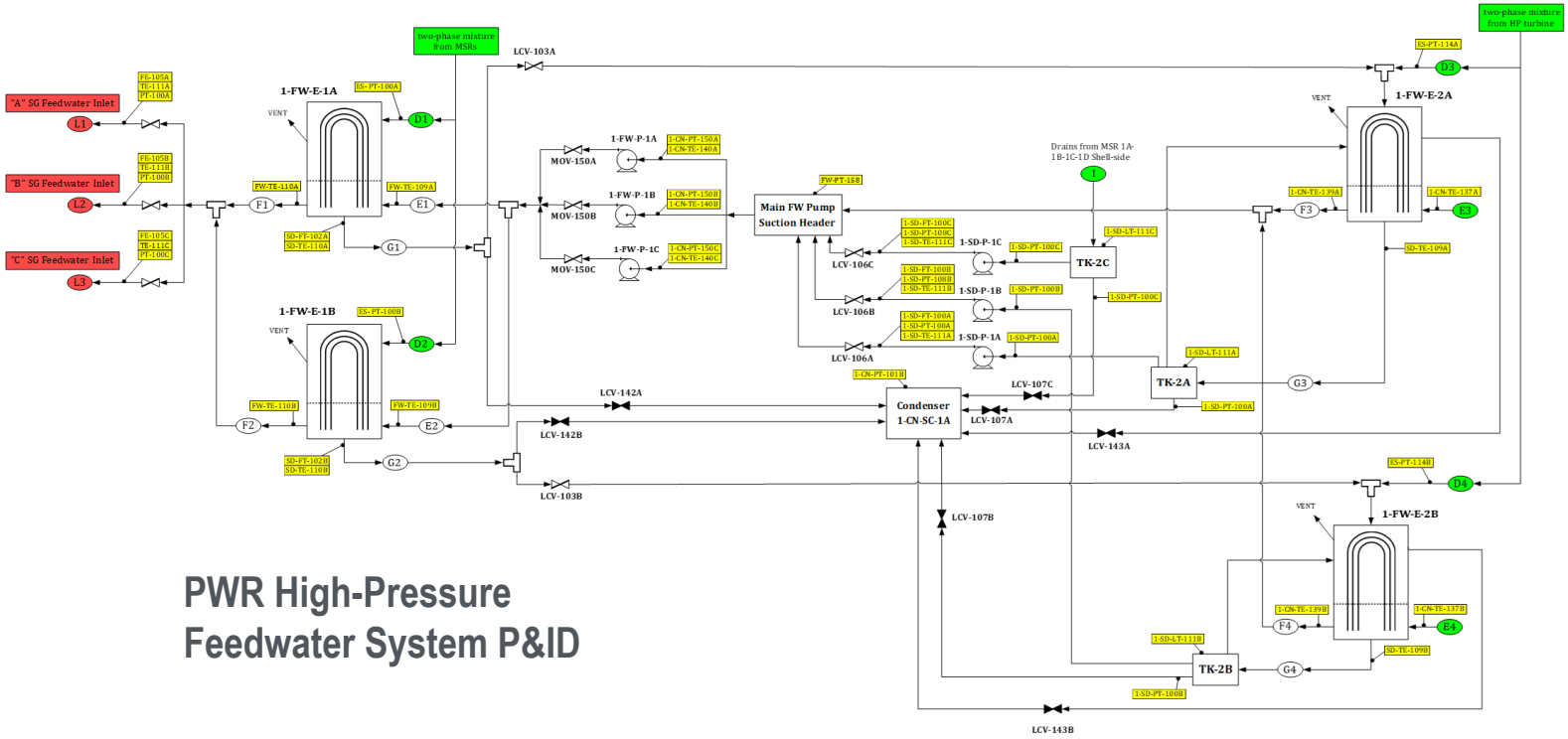


  - Residual statistics clearly indicate pump fault and no sensor faults
  - Loss in mechanical efficiency was about one percent indicating high sensitivity



Accomplishments Y1

- Working on system-wide application with utility partner
  - First test problem was standalone component (FW pump)
  - But method works at system level using concept of virtual sensors extracted from physics-based model
  - Presently working HP Feedwater heater system for PWR



PWR High-Pressure Feedwater System P&ID

Accomplishments Y1

- Publications/Presentations
  - **A Probabilistic Model-Based Diagnosis Framework for Fault Detection and System Monitoring in Nuclear Power Plants**, *Knowledge-Based Systems,* submitted October 2019
  - **Automating O&M Monitoring Using Physics-Based Qualitative and Quantitative Reasoning**, Pacific Council Nuclear 2018 conference, San Francisco, CA, October 2018
  - **Machine Learning – Equipment Diagnostics, presentation, Purdue University & ANL workshop, Argonne IL, March 2019**
  - **Machine Learning – Equipment Diagnostics**, presentation, Purdue University & ANL workshop, Argonne IL, March 2019
  - **A Software Package for On-Line Monitoring of Sensor and Equipment Degradation: Application to FW System**, presentation, BWR Owners Group Meeting, Oak Ridge TN, July 2019

Technology Impact

- *Advances the state of the art for nuclear application*
  - *Facilitates remote diagnosis of equipment performance degradation using concepts of digital twin and virtual sensors*
- *Supports the DOE-NE research mission*
  - *Advances technology to enable nuclear power as a viable option in the US energy landscape*
- *Impacts the nuclear industry*
  - *Reduces O&M costs for commercial and advanced nuclear power plants*
- *Will be commercialized*
  - *Plans are being developed to install in a facility of the partnering utility*

Conclusion

- *Developed and demonstrated an approach for determining the calibration status of sensors and the fault status of components in a system in a nuclear facility*
  - *Developed and applied seamless digital twin to the problem of diagnosing performance problems in LWRs*
  - *Sets stage for mechanistic approach to follow-on predictive maintenance prospects – uncertainty reduction*
  - *First adapters in the commercial power plant industry can use to improve efficiency of O&M procedures*
- *Contact Information*
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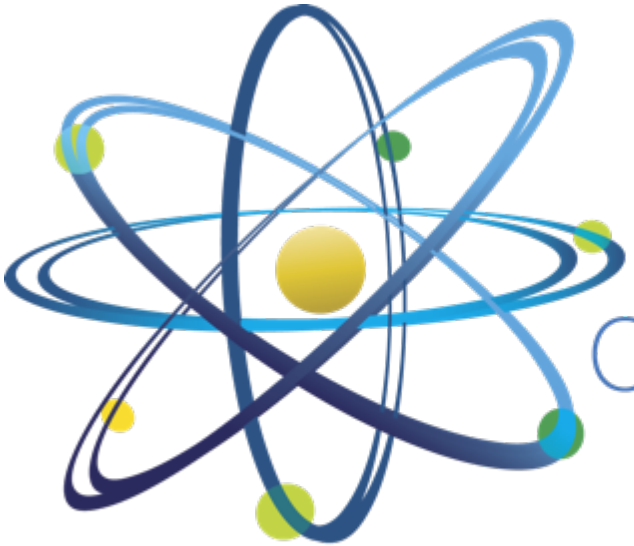
  - *630-252-6008*



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