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

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Analytics-at-Scale of Sensor Data for Digital Monitoring in Nuclear Plants

Advanced Sensors and Instrumentation Annual Webinar

October 29, November 5, November 12 , 2020

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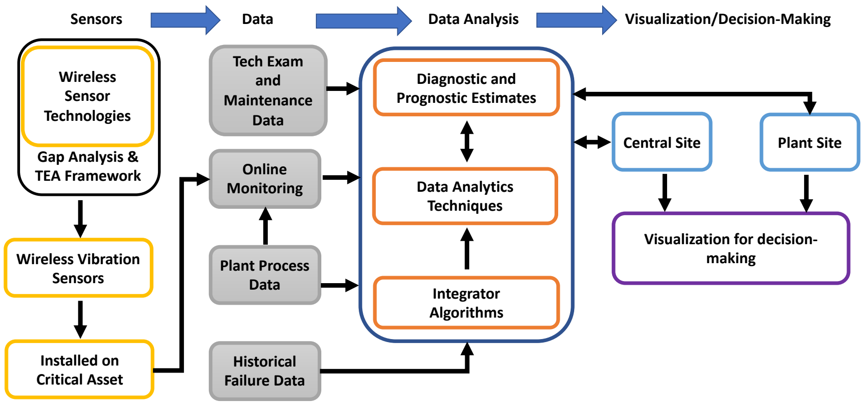
Project Overview

- **Goal:** Advance online monitoring and predictive maintenance in nuclear power plants to enhance plant performance (i.e., efficiency gain and economic competitiveness)



- **Team:** Vivek Agarwal (INL), Pradeep Ramuhalli (ORNL), Michael Taylor (EPRI), Charlotte Geiger and Scott Greenlee (Exelon). **Others @ INL:** Cody Walker, Koushik A. Manjunatha, Nancy Lybeck, Ahmad Al Rashdan, and Ronald L. Boring.

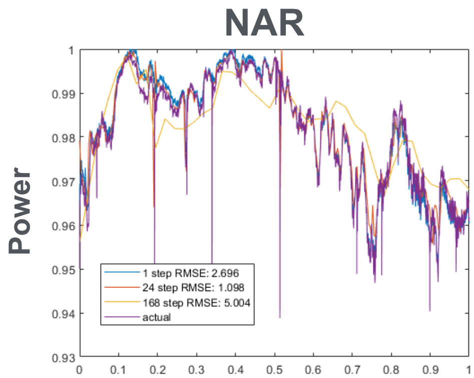
- **Schedule:**

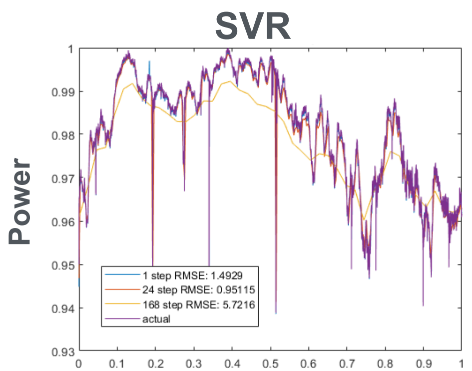
Year	Objective	Task	Responsibility
1	Develop a generalized techno-economic analysis (TEA) of a wireless infrastructure	Multi-band heterogeneous wireless communication architecture	Vivek Agarwal and Koushik A. Manjunatha
2	Develop diagnostic and prognostic models for identified balance of plant asset	Feedwater and Condensate System: BWR and PWR	All participants
		Diagnostic modeling and data integration	V. Agarwal, N. Lybeck, and C. Walker Pradeep Ramuhalli
		Prognostic modeling	Pradeep Ramuhalli, C. Walker, V. Agarwal, and N. Lybeck
3	Development of visualization algorithms	User-centric visualization scheme for monitoring and diagnostic center	Ronald L. Boring
	Validation of developed models and TEA methodologies	Numerical validation using ns-3 simulator	Koushik A. Manjunatha and Vivek Agarwal
		Data driven validation of models	All participants

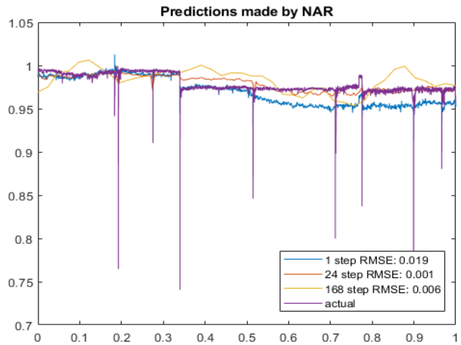
This task will be completed in Year 3

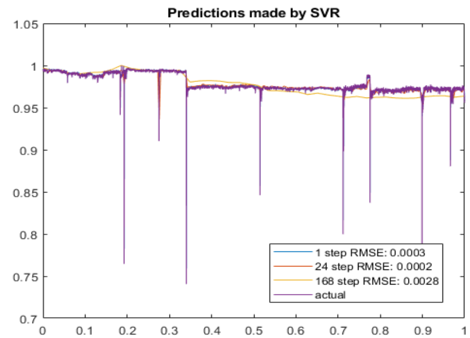
Accomplishments

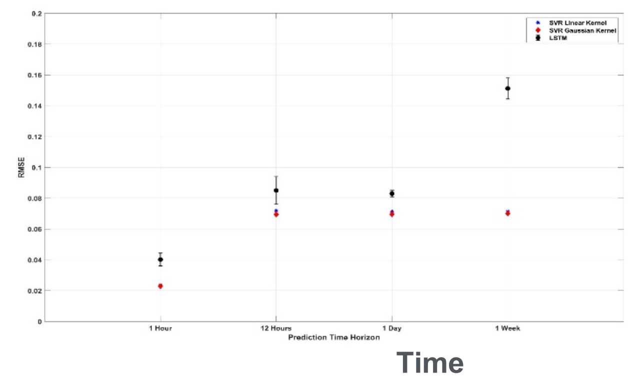
- Condensate and Feedwater System
  - Feedwater pump, condensate pump, booster pumps, gross load
  - Plant process data and work order information from Exelon-owned BWR and PWR power plants were obtained
- Milestone: Development of Prognostic Models using Plant Asset Data
  - Development of three Prognostic Models: Nonlinear Autoregressive (NAR) neural network, Long Short-Term Memory (LSTM), and Support Vector Regression (SVR).
  - SVR outperformed both the LSTM and NAR models when predicting the reactor power, system flow, and temperature of individual components.
  - Results indicate multiple factors influence prediction accuracy, with performance optimization necessary during model development phase.







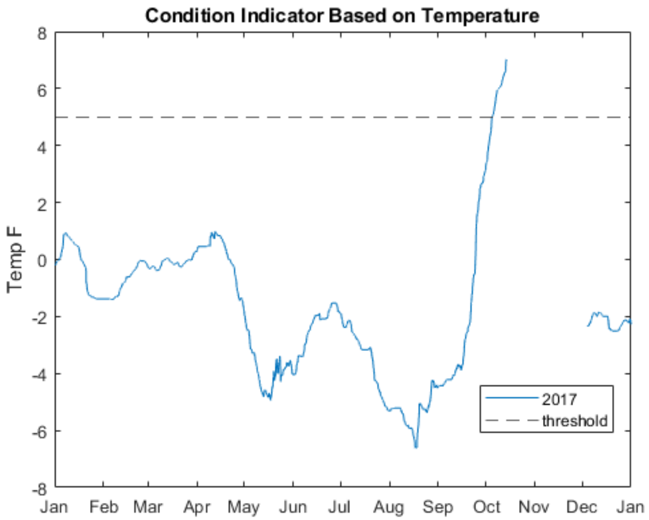




Accomplishments II

- Milestone: Wireless sensor modalities to collect vibration data
  - With inputs from Exelon, INL identified range of wireless vibration sensors that could be installed on condensate and feedwater system pumps and motors
  - Identified wireless vibration sensors could be integrated with the multi-band heterogeneous wireless architecture proposed by INL in Year 1
  - Petasense, Bently Nevada wireless vibration sensor and Bently Nevada proximity vibration probe

- Milestone: Fault diagnosis and data integration (delayed)
  - Maintenance logs were utilized to locate previous faults within the condensate and feedwater system.
  - Condition indicators based on temperature were created to predict when the component was operating in a degraded state.
  - INL is currently in development of a fault diagnostic clustering and integration of new signals.



- Publications:
  - Manjunatha et al., "ISM band Integrated Distributed Antenna Systems for Industry 4.0: A Techno-Economic Analysis." Presented at Virtual IEEE Global Communication, December 2020.
  - Manjunatha et al., "A Multi-Band Heterogeneous Wireless Network Architecture for Industrial Automation: A Techno-Economic Analysis," IEEE Trans. of Industrial Informatics (under review)
  - 2 additional journal papers in preparation.

Technology Impact

- *Advances the state of the art for nuclear application*
  - Advances online monitoring at a nuclear plant site for different plant assets
  - Provides machine learning approaches to integrate and analyze heterogeneous structured and unstructured data (i.e., analytics-at-scale)
  - Visualization of information to make informed decision-making
- *Supports the DOE-NE research mission*
  - Enable economical long-term operation of existing fleet of reactors
  - Research outcomes can be utilized to develop maintenance strategy for next generation of advanced reactors
- *Impacts on the nuclear industry*
  - Enable industry to transition from preventive maintenance strategy to predictive maintenance strategy
  - Enhance reliability and economic operation of domestic existing fleet
- *Commercialization*
  - Project team will develop a transition plan to enable transfer of research outcomes to an industrial partner

Conclusions

- *Advanced machine learning and related data analysis methodologies enables*
  - *Utilizing heterogeneous data collected over different temporal and spatial resolutions to assess system state*
  - *Detect anomalies in equipment conditions*
  - *Develop prognostic models to assess future operational states*
- *Prognostics models were developed to predict process measurements over different time horizons*
  - *Prediction accuracy were evaluated for different learning models and architectures*
  - *Data exhibiting only steady-state conditions, i.e., without transient challenges, were used to date. Transient conditions are part of Year 3 activity along with validation of models.*
- *Different wireless vibration sensor modalities were identified*
  - *Wireless vibration sensors communication protocols can be easily integrated with the multi-band heterogeneous wireless communication architecture proposed by INL*
- *Diagnosis and data integration research*
  - *Focusing on understanding what additional sensor measurements could enhance diagnosis of motor and pump condition*
- *Questions*
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