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

Clean. Reliable. Nuclear.

Design of Risk-Informed Autonomous Operation for Advanced Reactors

Advanced Sensors and Instrumentation Annual Webinar

November 12, 2020

PI: Michael Golay

Massachusetts Institute of Technology

Project Overview

- Goal and Objective
  - *to develop and demonstrate artificial reasoning systems for operator decision support for advanced reactors*
  - *to advance nuclear capabilities for operator advice and approach to autonomous control*
- Participants (2020)
  - Michael Golay (MIT, PI), Paul Hunton (INL, TPOC), Hyun Gook Kang (RPI, Co-PI), Sacit Cetiner (ORNL, Co-PI), Pradeep Ramuhalli (ORNL, Co-PI), Xingang Zhao (MIT/ORNL), Junyung Kim (RPI), and Kyle Warns (RPI)
- Schedule
  - Project start date: 10/1/2019; end date: 9/30/2022
  - Milestones status: on schedule

Accomplishments in FY20

- Milestone #1: complete (10/1/19-7/30/20)
  - Topic: **formulation of symptom-based conditional failure probabilities for selected structures, systems, and components (SSCs)**
  - The primary goal is to aid plant personnel in deducing the probabilistic performance status of the monitored SSCs and in detecting impending faults/failure. Our focus is upon failure-prone and risk-important balance-of-plant assets, especially cases having strong operator involvement. Bayesian network (BN) models are used.
  - An illustrative example case study is conducted on the failure of a motor-driven centrifugal pump to demonstrate the usefulness and technical feasibility of the proposed artificial reasoning system using an expert system shell.
  - Deliverables: milestone report submitted, 1 conference paper expected in 2021
- Milestone #1 follow-up tasks: in progress
  - Discussion is on-going with utility partners for accessing field data and expert knowledge of SSC failures. Lack of real, useful data has been our no.1 challenge.
  - Associated advisory models are being developed for providing operator decision support on alternative actions to be executed for the most beneficial performance.
  - BN capabilities are being extended to incorporate time-dependence (via a dynamic treatment) and to connect with system/plant-level risk assessment.

Accomplishments in FY20

- Milestone #2: complete (10/1/19-9/30/20)
  - Topic: **development of an emulator-based software verification and validation (V&V) toolkit for safety-critical programmable logic controller (PLC) platform**
  - Software failure of digital I&C systems is one of the major risk issues for autonomous control. The software V&V of PLC-based action implementation systems is of high importance.
  - The proposed toolkit includes software testing input generation algorithms and the emulator environment. Software testing time is effectively reduced and exhaustive testing capability is achieved. Our focus is upon V&V of binary-outcome software, which will be used in the action implementation phase of our project.
  - Deliverables: milestone report submitted, 1 conference paper expected in 2021
- System simulation and data-oriented modeling: in progress
  - Time-discretized system transient modeling is under development using simulated data from RELAP (and later TRANSFORM) and eventually collected field data.
- Integrated artificial reasoning algorithm development: in progress
  - Combine functional modeling (multilevel flow modeling), unsupervised machine learning (clustering analysis) and dynamic BN
  - Deliverables: 1 journal article published, 3 conference papers accepted

Technology Impact

- The ultimate outcome of this project will be a demonstration of improved monitoring and control capabilities of nuclear energy systems, which will enable reduction of O&M costs and reliance on human labor by enabling key operational decision-making autonomously.
- The developed artificial reasoning systems will enable routine operator oversight of autonomous control actions while providing specific operator action options for more complex scenarios, optimizing plant availability and reliability while maintaining safety margins.
- The proposed work is expected to improve the knowledge base and specific lore to a convincing level of assurance, and through such progress to strengthen its foundation. The greatest need is demonstration of the feasibility of such operator support to the point that others can be confident in using the ideas demonstrated. Without such progress in supporting nuclear power plant (NPP) operations hopes of reducing operator errors and staff size will remain frustratingly difficult.

Conclusion

- Our project aims to develop and demonstrate artificial reasoning systems for operator decision support, aided by autonomous control technology, for advanced nuclear reactors.
- The work scope is concerned with demonstrating the principles of NPP systems monitoring and diagnostics, creation of operational recommendations for purposes of operator decision support, and illustration of the use of NPP protection system software for such purposes.
- During FY20, the following accomplishments have been achieved:
  - Symptom-based conditional failure probability estimation for selected SSCs (complete)
  - Emulator-based software V&V toolkit for safety-critical PLC platform (complete)
  - System simulation and data-oriented modeling (in progress)
  - Integrated artificial reasoning algorithm development (in progress)
- This work is desired in order that improved monitoring and control capabilities will become available at the time when the next wave of advanced reactor technologies will need them, particularly should nuclear energy be required within the portfolio of options for climate change mitigation.
- Contact information: Michael Golay (golay@mit.edu)