
Virtual Sensing Framework with Hybrid Measurement Technique for Real-Time Monitoring of Advanced Reactors

PI: Syed Bahauddin Alam – University of Illinois Urbana-Champaign **Collaborators:** N/A

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ABSTRACT:

DOE-NE identifies enhanced sensor technology/capability with suitable artificial intelligence (AI) and machine learning (ML) techniques as a key to filling the gap of novel and real-time measurement techniques for nuclear plant components to handle new challenging operational environments. The project's research objective is to develop a novel virtual sensing framework with a hybrid measurement technique (combination of physical sensor and AI-driven virtual sensor) with extended physical sensing coverage for real-time monitoring of advanced reactors. It will capture details not achievable by conventional point sensors or traditional fiber optic technologies, offering real-time, unmeasurable data from challenging environments and hard-to-instrument locations. The research objectives and outcomes will be tightly integrated with education and leadership activities. By integrating these educational and leadership components, the project ensures that the research on real-time monitoring and AI/ML techniques for nuclear systems is not only groundbreaking but also contributes to the development of a skilled nuclear workforce.

Research Plan: The research focuses of this integrated research-education-leadership project are to:

1. Integrate an experimental facility with distributed fiber optic sensing (DFOS) to obtain high-resolution measurement along with high-fidelity simulation data for developing virtual sensors for real-time monitoring under different operating conditions.
2. Integrate the DFOS data with virtual sensors to monitor inaccessible areas and infer unmeasurable parameters. It will also extend the physical sensing coverage to overcome limitations such as sensor absences, faulty sensors, and low sensor density.
3. Implement adaptive calibration using ML algorithms and develop early anomaly detection mechanisms.
4. Conduct lab-scale tests and demonstrations at UIUC, full-scale trials at INL's SPHERE facility, and ANL's METL to validate the proposed methodologies.

Integrated Research and Education Plan: The project will tightly integrate research with education by:

1. Transformative learning approach through developing a new course and textbook and supporting a nuclear newcomer country on sensors and AI for nuclear systems.
2. Designing high school curricula and workshops on AI for nuclear energy to engage students-parents.
3. Providing undergraduate research opportunities, particularly for underrepresented minorities, through summer internships and collaborative projects on proposed research components.

Integrated Leadership Plan: PI will integrate leadership activities with education and research by:

1. Supporting nuclear newcomer countries through educational partnerships and International Atomic Energy Agency (IAEA) activities on proposed research thrusts.
2. Joining the OECD/NEA Task Force to advance AI/ML in nuclear energy.
3. Leading sessions and panels at national and international conferences on "Sensors, AI/ML and digital Twins in Nuclear Engineering" to increase visibility in the nuclear community.
4. Committing to open access for all research outputs, fostering wider dissemination of knowledge.

This holistic and tightly integrated *research-education-leadership* approach positions the project at the forefront of nuclear energy innovation, ensuring that the research outcomes have a lasting impact on the technological advancement, education, and workforce development of the nuclear energy sector.