Collaboration Plan for the Development of Diagnostics and Prognostics Methods, and Self-Powered Sensing Techniques for Sustainability of Safety Critical Functions

Jung-Taek Kim [a*], Belle R. Upadhyaya [b], Sang-Jung Lee [c] and Seop Hur [a]
[a] *Korea Atomic Energy Research Institute, 1045 deokdaero, Yuseong-gu, Daejeon, Republic of Korea,* *jtkim@kaeri.re.kr*
[b] *University of Tennessee, Nuclear Engineering Department, Knoxville, TN 37996-2300,* *bupadhya@utk.edu*
[c] *Electronics Engineering Department., Chung-Nam National University, Goong-dong 220, Yusong-gu, Daejeon, Republic of Korea*

1. Introduction

Since the accident at the Fukushima Dai-ichi Nuclear Power Station, attention has been given to accident mitigation during possible beyond design-basis accidents. This safety issue is elaborated in the July 2011 US NRC report[1], Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident [1].

As a part of the International Nuclear Engineering Research Initiative (INERI) Project, University of Tennessee (UTK) and KAERI are investigating diagnostics and prognostics methods for sustainability of Nuclear Power Plant Safety Critical Functions [2]. The objective of this collaborative INERI project is to develop and demonstrate advanced technologies for condition monitoring, diagnosis, remote sensing, sensor network design, self-powered sensors, and safety actuation during beyond design-basis events in operating nuclear plants and next generation reactors.

2. Scope of I-NERI Project

A nuclear plant consists of several safety-related standby equipments. These equipments are tested periodically in order to verify their functionality when they are called upon to perform. The data acquired during periodic testing provide information about possible degradation of the equipment or device under test. Performance related parameters can be trended in order to determine possible degradation and to estimate the remaining useful life. Thus, prognostics, plays an important role in avoiding the loss of functionality of critical equipment.

A major task of the project is to develop self-powered sensors that can function under a loss of power event, and to incorporate them with plant communication for data transmission and remote actuation. Design of a sensor network to optimize fault monitoring will be part of the research effort with applications to a typical PWR. A simulation model of a new-design reactor will be used for the generation of plant operational data.

Figure 1 shows a typical configuration of the proposed system. It consists of an intelligent monitoring, diagnostic & prognostic system, remote sensing, sensor network, and self-powered sensing modules.

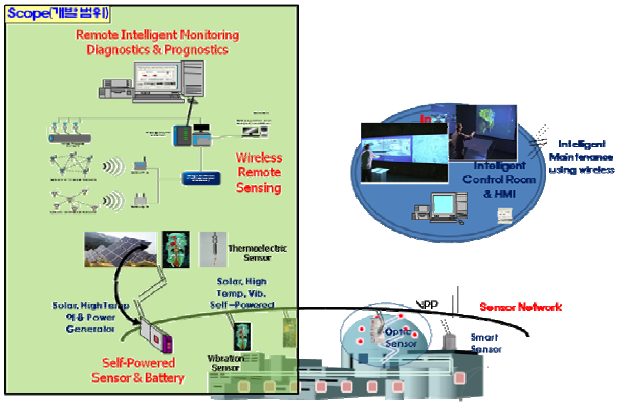

Fig. 1 A typical configuration of the proposed system.

3. Development Plan of I-NERI Project

3.1 Review of operability of safety critical functions and components

This task will focus on the review of several safety critical components, their functions, and operational history in typical light water reactors. Examples of these components are emergency diesel generators, motor-operated valves, motor-driven pumps, turbine-driven pumps, air-operated valves, and others. It also includes sensor and actuator to monitor and maintain safety critical functions under severe accidents. Several NUREG reports describe the performance characteristics of these equipments. From this list, three important components will be selected for further analysis and the need to improve their performance. Several measurements and sensors needed for monitoring and sustaining safety critical functions under severe accidents will be reviewed and identified.

Deliverable: Review and Evaluation Report identifying operability of safety critical components and measurements for monitoring and sustaining safety critical functions under severe accidents.

3.2. Development of plant monitoring, diagnostics, and prognostics algorithms

Several well-developed algorithms are available for monitoring and diagnostics of plant sensors, equipment, and field devices. These are generally data-based techniques that develop empirical models to characterize the relationship among a set of plant measurements. The models developed using normal operation data may then be used to track plant operation by predicting one or more variables of interest. Both simulation and experimental data will be used to validate the prognostic algorithms. The final goal is to provide the ability to make reliable decisions about component/system status.

Deliverable: Algorithms and a toolbox to perform component monitoring, fault diagnostics, and prognostics.

3.3. Development of low-energy self-powered process sensors, sensor networks, and optimal sensor placement strategy

3.3.1. Low-energy sensor development

The loss of off-site power (due to earthquake) and onsite AC power (due to tsunami) combined with the rapid discharge of the DC batteries leads to a complete station blackout. The station blackout makes it difficult to monitor critical parameters (e.g. reactor water level, pressure, temperature, etc.) and open critical safety valves (e.g. safety/relief valves, isolation condenser return valves, containment vent valves), which in turn lead to fuel and containment overheating and damage. Self-powered (charged) low-power sensors for remote sensing, together the passive and active electric power supply systems are desirable to overcome the station blackout scenario. These sensors are self-charged low power equipment or have self-powered batteries that charge themselves using vibration energy, deviation of temperature or pressure, and solar energy. Currently, thermoelectric sensors that self-charge using thermoelectric power generation, and some commercial sensors incorporating self-charged batteries using small solar cells, are available in the process industry.

Deliverable: Design and Evaluation Report for low-energy self-powered process sensors.

3.3.2. Development of advanced techniques for remote sensing and sensor network systems

Remote sensing and communication technologies are typically concerned with the transfer of data and information sensed from multiple different sensors. Some of these technologies have limited implementation in NPP, though have seen applications in other industries. Since the accident at the Fukushima Dai-ichi Nuclear Power Station, remote sensing and communication technologies have been strongly considered for monitoring the state of accident mitigation during a *beyond design-basis* accident. The networked systems for remote sensing and data communication have enhanced the small, low-power, wireless devices. There are fully contained wireless sensors which include both the sensor and the transmitter in the same module. To achieve this effectively, issues of remote sensing, communication and transmission (radio frequency (RF), microwave and wireless), noise reduction, and fusion of multiple and functionally different sensors must be addressed.

Deliverable: Report on advanced techniques for remote sensing, sensor network, and communication

3.4. Development of plant simulation models for data generation

The dynamic model developed using normal operation data may then be used to track plant operation by predicting one or more variables of interest. The dynamic model will be used to develop algorithms for monitoring and diagnosis of the plant behavior during transients and validate a technology for remote sensing and communication. In order to accomplish this task, dynamic simulation of the operation of a next generation light water reactor (LWR) will be used to generate data needed for validation of the proposed monitoring and diagnostic technologies

Deliverable: Report of development for plant simulation and model for data generation.

3.5. Demonstration of the technologies

The techniques and algorithms developed in the technical tasks will be demonstrated by application to selected safety-critical components. Data from the simulation of a pressurized water reactor will be used for validation of the various algorithms. Several new equipment, devices, sensors, and communication being developed, will also be validated and demonstrated to ensure sustained functioning for monitoring safety critical functions under severe accidents. Some of the devices will be installed in the KAERI test bed.

Deliverable: Test bed demonstration of new technologies.

4. Conclusions

As a part of the International Nuclear Engineering Research Initiative (INERI) Project, the collaborative activity plans to integrate monitoring and diagnostics methods developed by the international team of Korean and US collaborators and demonstrate the techniques and measurement strategies for three selected safety-related equipment.

Acknowledgement

This work is supported by the Ministry of Science & Technology.

REFERENCES

[1] C.L. Miller et al., Recommendations for Enhancing Reactor Safety in the 21st Century: Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident, Report by the U.S. Nuclear Regulatory Commission, July 2011.

[2] Belle R. Upadhyaya, Jung T. Kim et al., Proposal for the International Nuclear Energy Research Initiative U.S. – ROK Collaboration, "Development of Diagnostics and Prognostics Methods for Sustainability of Nuclear Power Plant Safety Critical Functions", Nov. 2011