An Integrated Scheme for Anomaly Identification and Automatic Control of Nuclear Power Plants

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INTRODUCTION

Nuclear Power Plants (NPPs) are complex systems with many variables that require adjustment to achieve efficient and safe operation over the entire operational envelop. Performance, reliability and safety of NPPs depend upon validity and accuracy of sensor signals that measure plant conditions for information display, health monitoring and control. Validity of measurements are important because a sensor failure can have severe consequences. It is essential to regularly ensure correct operation of sensors, in particular for those having great importance for operating safety, in order to locate and identify any possible degradations and faults [2].

NPPs are operated and monitored by human operators. When faced with an unplanned anomaly, the operators have to carry out diagnostic and corrective actions. However, even an experienced operator may be overwhelmed by signals and readings of a large number of sensors and alarms in case of unpredicted and abrupt events [3]. In this circumstance, anomaly identification system is critical to assist the operator to indentify the transients at the incipient stages and minimize or even mitigate the negative consequences [4]. Furthermore, when unanticipated adverse conditions occur, the primary objective of the control system is to ensure the safety of the plant rather than the performance [1].

The objective of this research is to develop an integrated scheme for anomaly identification, and automatic control of NPPs. In the anomaly identification system, the signals from the sensing system of the NPPs should be firstly calibrated to remove potential faults, and then the calibrated signals are processed by a classifier to identify the exact anomaly classes. The automatic control system should contain a supervisory controller which is able to choose an appropriate controller from a controller bank based on specific situation. The transition between two controllers should be smooth and bumpless to avoid impact to the NPP.

METHODOLOGY

This proposed integrated scheme consists of three inter-related subsystems: Nuclear Power Plant, Anomaly Identification system, and Automatic Control system. The structure of the proposed scheme is shown in Fig. 1.

Anomaly Identification

The proposed anomaly identification is comprised of two parts: sensor calibration and anomaly classification. The sensor calibration part calibrates the important measurements of the NPP if redundant measurements are available. The purpose of sensor calibration is to ensure correct measurements even if some of the sensors exhibit abnormal behaviors (drifting, fluctuating, and etc.). The anomaly classification part uses the calibrated signals (if the redundant measurements are available) and the uncalibrated signals to identify the exact class information of anomaly based on the patterns extracted from the selected measurements. Support Vector Machine (SVM) is used as the classifier. The feasibility of anomaly identification in NPPs using SVMs has been investigated in [3]. To avoid misclassification when the input is untrained, a hierarchical structure of SVMs consisting of two stages was introduced [5]. It firstly applied an one-class SVM to detect the novelty of the signals and then applied a multi-class SVM to recognize the anomaly class. This reduces the risk of misclassification and the associated danger of applying incorrect emergency procedures which follows a wrong diagnosis.

Automatic Control

The Automatic Control system is comprised of a Supervisory Controller, a Bank of Robust & Resilient Controller, and Activator & Filter part.

The supervisory controller is essentially a discrete event controller [6] which makes decision based on the discrete event generated by the anomaly identification system, activates the selected robust or resilient controllers, and changes the set points of the selected controller.

The Bank of Robust & Resilient Controllers consists of pre-designed controllers that aim to operate under various conditions. The role of a robust controller is to enhance insensitivity of the control system to exogenous disturbances, internal faults, and uncertainties in the plant. The role of a resilient controller is to enhance recovery of the control system from unanticipated adverse conditions and faults as well as from emergency situations by altering its operational envelope in real time. The concept of resilient control has been successfully applied to both

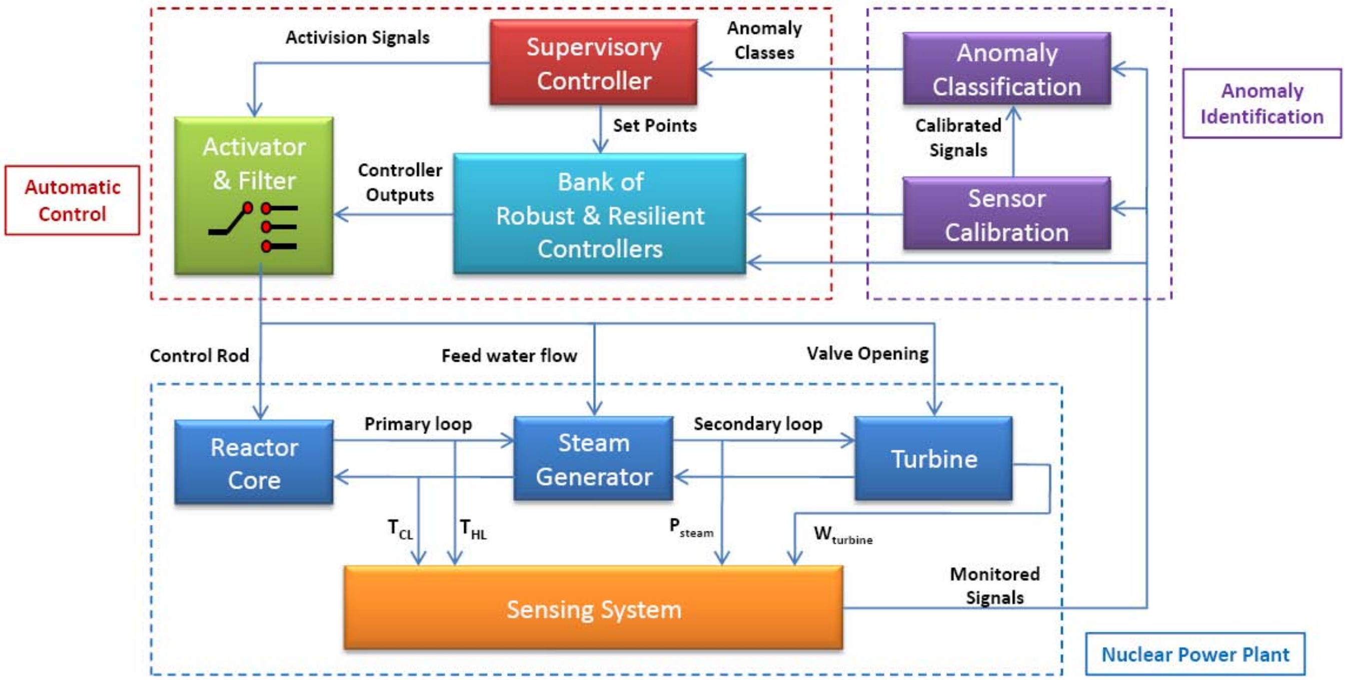

Fig. 1. An integrated scheme for anomaly identification and automatic control of nuclear power plants.

aerospace and nuclear engineering [1].

The activator & filter part performs as a switch that connects the chosen controller from the NPP. To ensure smooth transition during the transition stage between the two controllers, the filters with (exponentially decaying or increasing) weights are connected in cascade with the controller outputs. The bumpless control actions are then fed into NPP for feedback control.

SUMMARY AND FUTURE WORK

Due to the limited time, the integrated system has not been completely tested. However, simulation results of individual system are available. The resilient and robust control strategy for NPP is reported in [1], and sensor calibration results are reported in [2].

Because this proposed framework is relatively new, many issues still need to be investigated. The following topics are recommended for future research:

- Anomaly Identification using two-stage hierarchy structure SVM
- Integration of all subsystems to test the overall performance

ACKNOWLEDGMENT

This research is supported by a U.S. Department of Energy NERI-C grant with the Pennsylvania State University and the University of Tennessee, under grant DE-FG07-07ID14895.

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