Review of Operation Support Systems for Nuclear Power Plants

Ho-Bin Yim [a], Poong-Hyun Seong [a*]
[a]*Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology*
373-1, Guseong-Dong, Youseong-Gu, Daejeon, South Korea, 305-701
[*]*Corresponding author: phseong@kaist.ac.kr*

1. Introduction

Nuclear power plants have played a vital role many countries for several decades. Early those years, few accidents brought safety a critical issue, and economy also became another vital issue in a nuclear industry recently. Even if these two issues have been traditionally conceived to be trade-off matters, many researchers have tried to catch benefits from both issues. Various operation support systems (OSS) are one of the solutions to gain the favor. In this paper several techniques and features of OSS were reviewed, and future directions of development focus were discussed.

2. Review of OSS Techniques

2.1 Physical Models

Physical models especially First Principle models were first developed in early 1600s. The first principle model based approaches estimates the state of systems using mechanical, material, and other physical characteristics of systems. The main advantages of these models are presenting the behavior of systems from the beginning of plant running and showing the correlations among system parameters explicitly. However, these models are only valid for certain and simple problems. Kalman filter is also one of physical models. This method was firstly developed for spacecraft navigation. Later Kalman filter was discovered to be very useful to estimate the systems that were observed only indirectly. This method is not only fits well in practice but also appeals theoretically [1].

2.2 Empirical Models

Empirical models can only be developed for the systems that are operational because of their data-dependence. They do not provide analytical correlations among system parameters thus they are sometimes called black-box models [1]. The most important technical concept is 'regression'. To achieve robust regression model, outlier reduction has been an issue from the beginning. In order to reduce outliers, statistical tools such as low frequency pass filter using Fourier analysis are commonly used. While multivariate regression is based on parameters, kernel regression is one method for non-parametric regression. MSET (Multivariate State Estimation Technique) using kernel regression was developed by Argonne National Laboratory. For the nonlinear regression, Artificial Neural Networks are commonly used. The most important characteristics of neural networks is parallel computing capability that enables pattern recognition and function approximation.

2.3 Hybrid Models

Recently, hybrid models were presented to fill the gap between physical and empirical models. The idea is very simple that if the contribution of the un-modeled dynamics to the system behavior is observable, then a fitted function, which can be generated through an empirical model, can be used to minimize the discrepancy between the real and modeled system behavior [2]. There are not many rooms for research because these models are just a combination of theoretically matured models. However, optimization and implementation still need endeavor.

3. Review of OSS products

3.1 Computerized Procedure Systems

Most computerized procedure systems have been developed by individual companies because each company has its own optimized way to run. Korea Plant Service and Engineering developed e-Papyrus which can save operators real handwriting so that documents have legal force. Trend in computerized procedure systems contains graphical features and considers human factors to reduce errors which made by operators and maintenance personnel. Procedures are shown in small mobile devices such as Ultra Mobile PC and PDA. Thus, recently developed computerized procedures are based on theoretical backgrounds that show improvement of human cognitive activities.

3.2 Fault Detection and Diagnosis Systems

Fault detection and diagnosis systems are human oriented systems. They generate alarms and classifies event to reduce operators cognitive loads. Aladdin was developed by OECD HRP. It is based on empirical models, so initial normal data are essentially needed. EPI* Center and SHIELD by smart signal one of the

commercially available programs. The development trend of fault detection and diagnosis systems is including more and more intelligent features so that the system gives operators a complete understanding of the status of equipment.

3.3 Signal Calibration and Validation Systems

Signal validation is one of the basic functions of operation support system to ensure safety and economical operation of nuclear power plants. Without well calibrated instrument channels, the whole support system can be useless. PEANO (Plant Evaluation and Analysis by Neural Operators) by OECD HRP is one of the well-known programs for signal validation. As the name indicates, PEANO is based on neural network. Thus, there are two main disadvantages in PEANO; 1) large amount of process data are required. 2) The model does not extrapolate to unknown situations. Unlike PEANO, eCM^{TM} (equipment Condition Monitoring) developed by Smart Signal is also based on empirical models; however, unlike PEANO, eCM^{TM} uses actual process variable measurement only [3][4].

3.4 Core Monitoring Systems

The BEACON^{TM} (Best Estimate Analysis of Core Operation-Nuclear) core monitoring system has been developed by Westinghouse Electric Corporation and been in commercial operation since 1989[5]. This system is a real time core monitoring system which surveys core power thermal limits, including the minimum DNBR limit, as well as graphically shows core anomalies such as dropped/ misaligned rods, Flow anomalies and xenon oscillations. MAGELAN was developed by AREVA for 3D core monitoring. It has similar functions to those of BEACON^{TM}. The unique feature that distinguishes MAGELAN from other systems is in-core and ex-core parallel sensing of neutrons. Another system is called SCORPIO by OECD HRP. All the systems have nearly the same functions, and research focus nowadays is displaying core status in 3D.

3.5 Thermal Performance Monitoring Systems

There has been intensive research in the field of thermodynamic efficiency improvement over many decades. Most of the products are based on first principle models because thermal performance monitoring needs fiducial values. PEPSE® (Performance Evaluation of Power System Efficiencies) is one of the industry standard heat balance programs. PEPSE® monitors the thermodynamic performance of a plant to diagnose problems and abnormalities in operation and predict the effects when operating parameters have been changed [6]. For nuclear industry, TEMPO (Thermal Performance Monitoring and Optimization system) was developed by OECD Haden. In addition to the basic function of PEPSE®, TEMPO provides optimization of the thermal performance and simulations.

4. Conclusions

The more the nuclear power plant become pervasive, the more the system safety and efficiency issues are raised. To satisfy both safety and economy, smart operation support systems are needed. Various operation support systems have been developed since 60's. Unfortunately, not many of them are operational at the moment. Computational power has been drastically increased within a decade so implementation of more practical and robust operation support system is needed for now and the future.

REFERENCES

[1] Gyun Young Heo, Condition Monitoring Using Empirical Models: Technical Review and Prospects for Nuclear Applications, Nuclear Engineering and Technology, Vol. 40, No. 1, Feb, 2008.
[2] Bulent Alpay and Humberto E. Garcia, A Hybrid Model Combining First Principles and Data Driven Models for On-Line Condition Monitoring, NPIC&HMIT 2006, Albuquerque, NM, Nov, 2006.
[3] Robert E. Uhrig and J. Wesley Hines, Computational Intelligence in Nuclear Engineering. Nuclear Engineering and Technology, Vol. 37, No. 2, Apr, 2005.
[4] J. Wesley Hines and E. Davis, Lesson Learned from the U.S. Nuclear Power Plant On-Line Monitoring Programs, Progress in Nuclear Energy, Vol. 46, No. 3-4, pp. 176-189, 2005.
[5] William A. Boyd and R. Wade Miller, The BEACON On-Line Core Monitoring System: Functional Upgrades and Applications, Westinghouse Electric Corporation.
[6] J. Wesley Hines and R. Seibert, Technical Review of On-Line Monitoring Techniques for Performance Assessment, NUREG/CR-6895, U.S. Nuclear Regulatory Commission, 2006.