Performance Monitoring Function for Autonomous Startup Operation in Nuclear Power Plants

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1. Introduction

Artificial intelligence, one of the key aspects of the Fourth Industrial Revolution, focuses on the ability of computers for human tasks by doing the same thing as a human being with intelligence [1]. Artificial intelligence is attracting attention in many industries, and new technologies that utilize it are emerging. As a representative example, there is an autonomous vehicle that enables driving without human intervention. This aims to minimize human intervention, which can reduce human error.

The International Atomic Energy Agency (IAEA) reports that human errors are significant in the operation of nuclear power plants and the Korea Institute of Nuclear Safety has also reported about 24% of the incidents [2]. Under this circumstance, the autonomous operation system that minimizes operator intervention in the operation of nuclear power plants (NPPs) is recognized as one of the ways to reduce human error. This system is also expected not only to improve the safety, but also improve the economic efficiency and allow access to places where human access is difficult.

This study suggests a conceptual design of performance monitoring function (PMF). This function has been developed as a part of autonomous startup operation system. First, this paper introduces a structure of autonomous startup operation system. Then, the requirements of function are defined through the analysis of GOPs. Finally, the objectives and functions of the performance monitoring system are suggested.

2. Structure of Autonomous Startup Operation System

The structure of the autonomous startup operation system is shown in Fig.1. Operational conditions of nuclear power plant can be largely divided into normal, abnormal, and emergency operation. Typical examples of normal operation are startup, shutdown, and power operation. This system is focused on the startup operation. The overall framework has a hierarchical structure and is divided into execution, coordination, and management levels. The execution level consists of safety systems and sub systems. These are the various devices that represent the display system, control system, and safety system in the control panel of NPPs main room. The coordination level consists of the function to control and diagnose the accident during the startup operation of NPPs. The management level consists of the function to select the operation strategy and interact with the operator and monitor the performance.

The PMF of management level monitors whether the control function is performing the correct control in the startup operation of NPPs. As a result, it provides the performance status to the strategy selection function so that the strategy selection function can determine the continuation and modification of the current autonomous operation strategy. It can also provide operator interaction function with the information about current nuclear power plant status and control status of the autonomous operation system. At this point, the general operation procedures (GOPs) should be analyzed to determine the good performance criterion in startup operation.

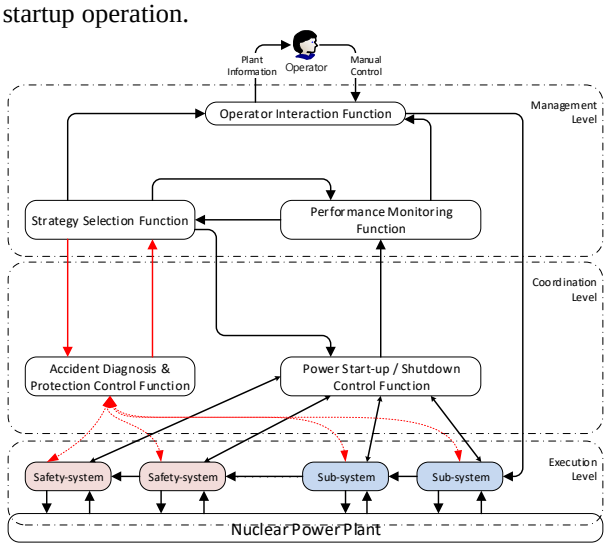

Fig.1. The structure of the autonomous startup operation system.

3. Functional Requirements through the analysis of GOPs

The requirements for PMF functional definition can be found through analysis of GOPs. These requirements include the criterion for evaluating the performance of the autonomous operation system.

For the operation of NPPs, the operators in the main control room carry out the operation through the documented procedure and the various devices of the main control panel. The procedure provides directions and instructions to the operator so that they can respond

appropriately to their operation situation. In addition, operators rely on procedure to perform cognitive and device control behaviors such as checking and monitoring the operation status and judging the application of procedure [3]. Therefore, the analysis of the procedure provides requirements of the PMF and the criterion for evaluating performance.

Requirement 1

The first requirement is to monitor whether the operator is operating NPPs in accordance with the instruction of the procedure. The GOPs consist of three parts, namely the initial conditions, the precautions and limitations, the procedures. Generally, the operator confirms the initial conditions, performs the monitoring, and control according to the procedure. At this time, the operator should continue to monitor the limitations and precautions.

Requirement 2

The second requirement is to monitor whether the operators are operating NPPs with observing the trend of the parameters. Mainly instructions in the GOPs are described as 'Turn on the device or turn off the device or make sure the device is turned on and off'. However, some instructions are not described in this way, but required confirmation that the parameters were within the described range. Fig.2 shows the actual trend of the parameters that require confirmation to be within the described range in the GOP. These parameters are constantly changing from cold shutdown to full power operation. This means that operators have difficulty determining the correct value or predicting the values before/after. In addition, operators are required to have an understanding of the parameters trend throughout the operation to evaluate that the NPPs are operation properly. In practice, about 5~7 main parameters are selected by the skilled operator for the performance evaluation of NPP and selected parameters evaluate success/failure by confirming whether the parameter is operating within the operational upper/lower limit [4].

As a result, the functional requirements for startup operation are as follows.
1. Operator performance monitoring according to the procedures
- Check the procedure initial conditions.
- Pay attention the precautions/limitations.
- Match the procedure sequence.
2. NPP performance monitoring by observing the trend of the parameters

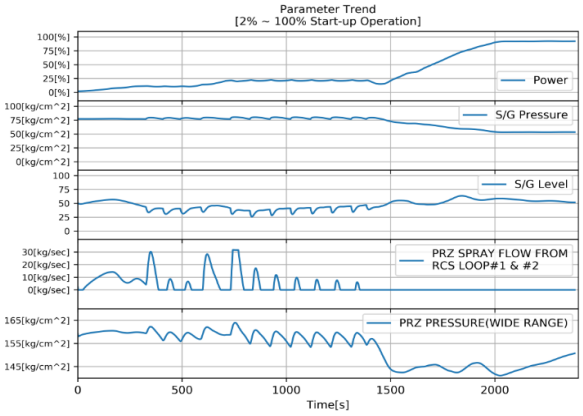

Fig.2. The trend of the parameters

4. Suggestion of Performance Monitoring Function

Through the analysis of the GOPs, functional requirements were defined. The PMF must have the capability to meet these requirements, and its goal is to ensure that the autonomous operation system is operating the NPPs well. Fig.3 shows the algorithm of the PMF. It is divided into GOP Module, NPP Module and Combination Module.

The GOP Module monitors whether the parameters are consistent with the values documented in the procedure. If not, it means that the control function did not follow the procedure.
- Procedure Selection: It chooses a procedure that matches operation goals. This is necessary because the initial conditions, precautions/limitations, and procedure sequence are different for each procedure.
- Initial Condition Monitoring: It monitors whether the parameters satisfy the initial condition described in the procedure.
- Precautions/Limitations Monitoring: It monitors whether the parameters meet the precautions and limitations described in the procedure.
- Procedure Sequence Monitoring: It monitors whether the parameters are operating in the sequence described in the procedure.

The NPP Module evaluates the state of the NPPs by monitoring the trend of the parameters. The Combination Module receives the results of the GOP Module and the NPP Module. If both modules are satisfied, the performance is evaluated as success, and if both modules are not satisfied, the performance is evaluated as fail. If the performance is evaluated as fail, it can provide additional information about which modules of the two modules are not satisfied.

The PMF integrates all detailed functions. GOP Module and NPP Module continue to monitor the NPPs parameters and provide the results to the combination module. Then combination module combines them to determine the performance of the autonomous startup operation system as success or failure.

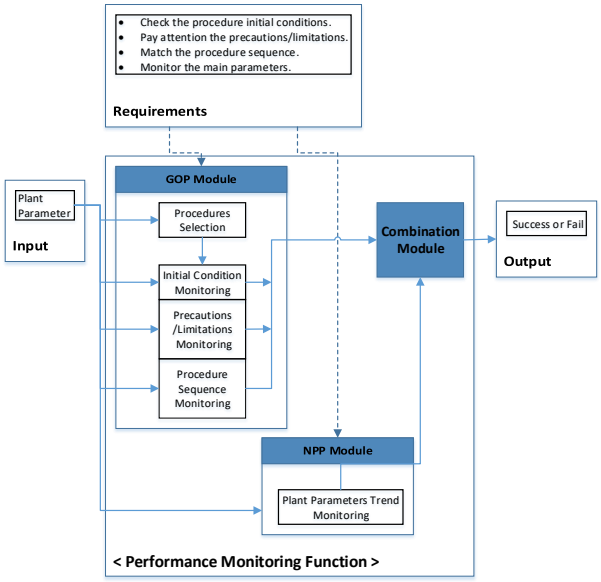

Fig. 3. The algorithm of the performance monitoring function

5. Conclusions

The goal of this study is to develop the performance monitoring function for autonomous startup operation of the NPPs. The PMF monitors the performance of the control function and status of the NPPs with the GOP, NPP, and Combination Modules. It evaluates whether autonomous operation system guarantees safe operation of the NPPs. This study includes the design process for functional development in the order of functional requirements analysis, and functional definition. Next, will be to do an analysis of potential approaches for implementing the function, apply it, and perform functional verification.

REFERENCES

[1] Seung Woon Kim, Intergrating Expert Systems and Artificial Neural Networks : A Theoretical Review, Chonbuk National University Institute of Industrial Economics, Vol. 26, pp.385-398, 1995.
[2] Yong Hee Lee, Tong Il Jang, Yeon Ju Oh, Seok Ho Kang, and Jong Hyun Yun, Research Activities and Techniques for the Prevention of Human Errors during the Operation of Nuclear Power Plants, Journal of the Ergonomics Society of Korea, Vol. 30, No. 1, pp. 75-86, 2011.
[3] Tae Young Huh, Eung Se Oh, and Chan Ho Sung, A Development of Computerized Procedure System MMI as Operator Aids System, Control Robot System Society Domestic Conference, Vol. 2, pp. 1161-1164, 1997.
[4] Jun Su Ha, Poong Hyun Seong, Development of Human Performance Evaluation Scale for Human Factor Verification, Korean Journal of Ergonomics, Vol. 25, No.3, pp.85-96, 2006.