Autonomous Algorithm for Start-up Operation of Nuclear Power Plants based on Operating Procedure

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1. Introduction

In recent years, the core technologies of the forth-industrial revolution are attracting attention in the world due to the increased computing power as well as the development of improved software algorithm. The forth industrial revolution includes many technologies such as internet of things (IoT), artificial intelligence (AI), machine learning, big data, and cloud computing. Especially, autonomous operation, which is one of the technologies in the forth industrial revolution, is a combination of technologies in the digital field [1].

Autonomous control, which is a high level of automation, is having the power or ability of self-governance in the overall system without human intervention. It can have many advantages such as safety improvement through a highly automatic system, optimal control in the system, adaptability even with changing environment, reliability of operating system, and cost saving. Due to the advantages of autonomous operation, it has been applied in many industrial areas, especially in those areas that require high-level of precision and can reduce human burden.

Nuclear power plants (NPPs) are operating with manual control and control by the operator as well as automatic control by an automatic algorithm in the system. The digital technology provides advantages such as processing of numerous data, improvement of system reliability, flexibility of adding new functions, automation of periodic tests, self-diagnostics and improved operation [2]. As a result, NPPs have been able to increase safety and efficiency as well as to reduce operator's burden by applying digital automation system. However, the level of automation for controlling NPPs during start-up does not reach the autonomous control, because the intervention by operators is still important in a large portion of control.

In the case of rod position control during the start-up operation, the automatic control, which is combined with digital technology, is activated at the specified NPPs condition based on operating procedure. On the other hand, all of the operations are manual control before reaching a specified NPPs condition. It means that the manual operation based on operating procedure is required before NPP can use an automation algorithm to control the system.

Start-up operation is one of the important operational modes of NPPs. It is normally performed by operators using operating procedures in order to raise power of NPPs from 0% to 100%. In this operation mode, the burden of operators is more than during normal operations, because the operator has to determine the control strategy of components by monitoring many physical parameters in the NPP. Therefore, to decrease the burden of the operators the automation level of NPPs, there is a need for an autonomous control.

This study is a part of developing autonomous control during start-up/shutdown operation. The system includes control, diagnosis, self-validation, decision-making, and adaptation. Fig. 1 shows the suggested framework of autonomous operation system. It consists of functions such as power start-up/shutdown control function, accident diagnosis/protection control function, performance monitoring function, strategy selection function and operator interaction function. This study is focused on the power start-up/shutdown control function.

This study aims to develop the power start-up/shutdown control function by using AI method. In order to apply AI method, the requirements based on general operating procedure as well as the operating strategy of current NPPs need to be developed. Therefore, this study suggests a model of the algorithm based on procedure and operating strategy.

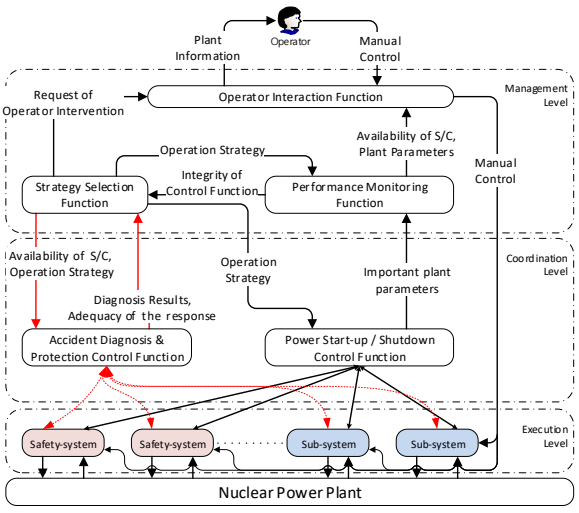

Fig. 1. Autonomous control framework during start-up/ shutdown operation

2. Analysis of Current Operation Strategy for Startup and Shutdown

In order to develop the power start-up/shutdown control function, it has to reflect the operating process in current NPP. Current NPPs are operated with automatic system and manual control by operators. The operation team in the main control room (MCR) of the power plants in Korea are composed of 5 operators, including a senior reactor operator (SRO), a shift technical advisor (STA), a reactor operator (RO), a turbine operator (TO), and an electrical operator (EO). The SRO supervises the operation situation in the MCR; the RO is in charge of operating the reactor system; the TO is in charge of operating the turbine system; and the EO is in charge of operating the electricity system [3]. Also, the operators can control systems based on procedures to operate the NPPs. Procedures are essential to plant safety because they support and guide personnel interactions with plant systems and personnel responses to plant-related events [4]. In the case of start-up/shutdown operation, procedures consist of several ones according to operation mode. Fig. 2 shows the overview of the operating procedures from start-up to shutdown operation. Each operating procedure has elements that include defining operating mode, checking precaution/limitation, checking initiation condition and performing procedure steps.

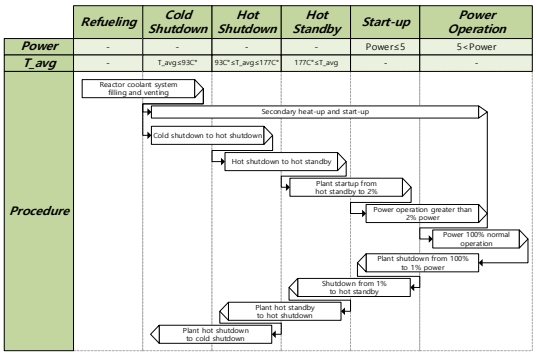

Fig. 2. Overview of the operating procedures from start-up to shutdown operation

3. Design of the Power Start-up/shutdown Control Function

The power start-up/shutdown control function is designed as sub-functions that is based on elements in operating procedure. Sub-functions are consist of manual/autonomous mode function, operation mode definition function, precaution/limitation monitoring function, initiation condition check function and procedure control/monitoring function. The manual/autonomous mode function selects the operation strategy according to the output of a strategy selection function, which is high level in the autonomous control framework. The operation mode definition function provides the calculated operation mode with other sub-functions through current NPPs state. The precaution / limit monitoring function monitors whether the control of the procedure control/monitoring function is proceeding while observing the precautions and limitations. The initiation condition check function is providing information of initiation condition to check before operation of the procedure control/monitoring function. The procedure of control/monitoring function, which is based on procedure steps, is offering operation steps to achieve the goal of the current operation mode.

Power start-up/shutdown control also takes into account the role of the operators in current NPPs. During the start-up/shutdown operation, the operators can control the system according to the steps specified in the operating procedure. Each step specifies an operator to perform the step according to the purpose of the procedure. Therefore, all operating steps, which include contents of performing procedure steps, defining operating mode, checking precaution/limitation and checking initiation condition, are classified according to the role of operators. Fig. 3 shows a block diagram of power start-up/shutdown control function according to the defined functions.

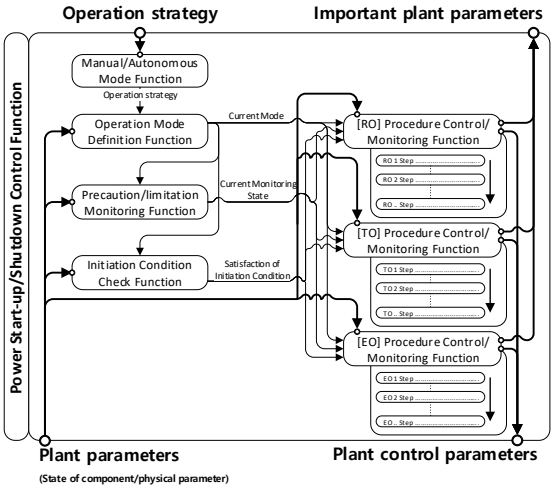

Fig. 3. Block diagram of power start-up/shutdown control function

4. Verification and Result

In this study, the designed power start-up/shutdown control function is implemented by using Python, which is a programing language. Each step in procedure is composed of the if-then logic. Therefore, the procedure control/monitoring function in power start-up/shutdown control function is written as programing scripts using if-then logic. A compact nuclear simulator (CNS), which simplifies complex NPP models, is used as a test-bed to validate designed features in real time.

Fig. 4 shows the parameter trend of CNS by using power start-up/shutdown control function during start-up operation from 2% to 100% power. It consists of physical parameters such as reactor power, turbine power and turbine speed revolutions per minute (RPM).

It also consists of control parameters, which include rod control, pump control and turbine control, to increase the reactor power based on operating procedure. The result of the graph shows that the designed power start-up/shutdown control function can generate the output signal of the plant normally while keeping the operating procedure.

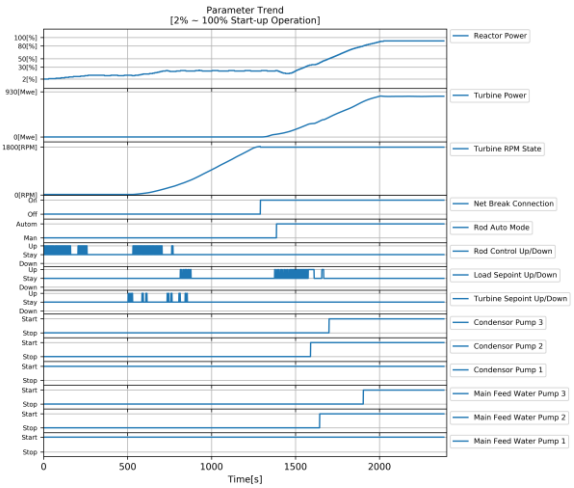

Fig. 4. Parameter trend during start-up operation from 2% to 100%

5. Discussion

The validation results indicate that the designed control function could manage the plant system without manual control by the operator during start-up operation. In the case of pump operation, it is sequentially controlled according to the priority of operating procedure. On the other hand, rod control and turbine set-point control are processed simultaneously. It means that the designed control function has the capacity to handle sequential processing as well as parallel processing. This capacity can compensate for situations that cannot be handled simultaneously by the operator.

6. Conclusion

This study attempted to design power start-up/shutdown control function in the autonomous operation framework. In addition, the designed control function is implemented by using Python which is a kind of programming language. To verify the control function in real time, CNS is used as the test-bed. The result shows that the designed control function could manage the plant system without manual control by operator during start-up operation.

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