A Study on Improving the Level of Automation for Small and Modular Reactor Operation using Computer-based Operating Procedures

Sa Kil Kim*, Kwang Il Jeong, Joon Ku Lee
SMART Reactor Technology Development Division, Korea Atomic Research Institute, Daejeon, Korea
Corresponding author: sakilkim@kaeri.re.kr

1. Introduction

Computer-based operating procedures were developed for effective management of existing paper-based operating procedures. The Computerized Procedure (COMPRO) developed by Westinghouse in the United States, the computer-based operating procedures applied to the N4 power plant developed by EdF in France, and the Emergency Operating Procedure Tracking System (EOPTS) that computerized the emergency operation procedure of EPRI BWR are computer-based operating procedures applied in the early days. Afterwards, the Computerized Procedure System (CPS) applied to APR1400 in Korea was developed with Westinghouse in the United States. Korea Hydro & Nuclear Power Co. localized the CPS for the first time in Shinhanul Units 1 and 2 and applied it to the field.

The computer-based operating procedure is continuing to develop innovatively as a digital system that effectively provides procedure information to the operator by supplementing the inconvenience of the existing paper-based procedure. However, there have been voices of concern that the human factors considerations for the expected cognitive burden and cognitive error of the operators so that the use of computer-based operating procedures should be sufficiently reflected in the design stage (Reason, 1988; Rasmussen, 1986; Dien, Montmayeul, and Beltranda, 1991; Roth, Mumaw, and Lewis, 1994; O'Hara, Stubler, and Nasta, 1997 etc.). Therefore, the NRC documented design reviews for computer-based operating procedures as a reference guide for regulators (NUREG-0700, Rev. 2, 2002).

NUREG-0700 refers to the level of automation of the computer-based operating procedure system as the following four levels.

- Manual: The operators perform the function with no assistance from the CBP.
- Advisory: The CBP gives advice only. For example, the CBP may advise the operator that Pump A should be started but does not perform the action.
- Shared: The CBP and the operators both perform the function. For example, a CBP system could monitor a process but be unable to access all necessary information about the system (e.g., valve position) caused by lack of instrumentation. When this type of information needs to be monitored, the operator obtains the information.
- Automated: The CBP performs the function automatically without direct intervention from the operator. This may or may not involve notification to the operators of the automated actions taken.

Design review items for computer-based operating procedures differ according to the above four levels. Therefore, when the computer-based operating procedure is applied to the operation of a nuclear power plant, it is necessary to ensure that the regulatory guidelines according to the level of automation of the applied system are closely secured.

In the case of small and modular reactors, it is advantageous to secure international competitiveness only when the safety and economics of the nuclear reactors are innovatively proven compared to domestic and foreign large nuclear power plants (e.g., APR1400). In the case of SMART, the first small and modular reactor in Korea, which is being developed by the Korea Atomic Energy Research Institute, safety is dramatically improved through the application of a passive safety system to an integrated reactor. However, in terms of construction cost and operation and maintenance costs, there is still room for debate over the competitiveness of large-scale nuclear power plants. Meanwhile, in the case of the NuScale small and modular reactor in the United States, the design was certified by the NRC, a nuclear safety regulator, with full support from the government for the revival of the nuclear industry in the United States, and a demonstration reactor is currently being built in Idaho.

This study is being conducted for the purpose of improving global competitiveness through innovative technical use of computer-based operating procedures in terms of operation and maintenance of SMART for small and modular nuclear reactors in Korea. The purpose of this study is to maximize the level of automation of computer-based operating procedures by applying the latest 4th industrial revolution technology in the system design stage of computer-based operating procedures. The improvement of the automation level of the computer-based operation procedure is expected to improve the safety of the power plant operation by significantly reducing human errors that may occur during operation of the power plant by minimizing the cognitive load on the operator. In addition, it is expected to reduce power plant operation and maintenance costs by minimizing and optimizing operator duties related to maintenance during operation, including start-up

operation, electric power generation operation, and shutdown operation.

2. Research Method and Content

The computer-based operating procedure may be developed as a concept that supports or replaces the operator's decision-making, as well as a case where it is simply developed as a computerized system of paper-based procedures according to the control room operating concept. IEC has established a standard for computer-based procedures (IEC 62646), and the approaches are divided into three groups as shown in Figure 1 according to the degree of operator support in computer-based procedures.

Determining CBP family		Level of operator assistance		
		No step tracking/manual progress	Automatic step tracking	Guidance capability
Type of CBP signal interfaces	No input of process information	1	Not possible	Not possible
	Manual input of process information	1	Not possible	2
	Automatic input of process information	2	2	2 or 3
	Action on process	3	3	3

Figure 1. CBP Families (IEC 62646)

- Family 1: CBP which are essentially stand-alone replacements for paper based procedures, presenting linked pages of static information and operating steps.
- CBP of this Family do not receive any process information automatically and possesses no plant control capabilities.
- Family 2: CBP providing guidance to the operator based on information automatically acquired by the CBP system. Every item of information may be integrated into the display formats presented.
- Family 3: CBP presenting information and operating steps with full integration of on-line plant information, states and values, so that an actuator can be controlled by the operator from the CBP display, automatic control functions can be accessed from the CBP display, and automatic execution of sequences can be initiated by the operator from the CBP display.
- Decision support capability: depending on the complexity of the decision support capability the designer may choose to classify the CPB system as Family 2 or Family 3. This choice and the associated argumentation shall be documented.

In this study, we intend to develop a computer-based operating procedure in the form of Family 3 according to the IEC standard and apply it to SMART. Therefore, it was attempted to develop a Type 3 type of computer-based operating procedure by dividing the operating concept of the computer-based operating procedure into three types as follows.

- Type 1 (computerized system of paper-based operating procedures): A separate system that computerizes existing paper-based operating procedures using computer tools and effectively provides procedure information to operators.
- Type 2 (procedure and operator support information provision system): A separate system that computerizes existing paper-based operating procedures using computer tools and effectively provides procedure information and operator support information necessary for carrying out the procedure to the operator.
- Type 3 (integrated monitoring and control system): A system that integrates and provides information on procedures and operator support necessary for plant monitoring and control processes in monitoring and control tools.

Among the computer-based operating procedure documents, Type 3 does not provide a separate computer-based operating procedure system to the operator. In other words, it is a concept that provides procedure information and operator support information as one of the application functions of a computer-based monitoring and control system. Therefore, in this study, a procedure-based intelligent computer-based procedure platform is being developed to effectively provide procedure information and operation support information to a platform for plant monitoring and control.

The procedure-based intelligent computer-based procedure platform is being developed in a system engineering method based on the following intelligent functional requirements.

- Upon the operator's request, prior to executing the procedure, the expected results of the execution of the procedure are provided to the operator.
- When the operator automatically executes a procedure in a certain section, the automatic execution is stopped according to safety standards during the automatic execution of the procedure, and the operator's confirmation (continue the automatic execution or change the manual execution) is requested.
- By self-learning the history of procedure execution including automatic execution and manual execution of procedures, optimal procedure execution guidelines are created and guided to the operator.
- When an incident or accident diagnosis is required according to an incident or accident, the result of the preliminary diagnosis of the incident or accident is shown to the driver when requested by the operator.
- The operator can set and save the procedure section that needs automatic execution, and the result information after the automatic execution and execution of the procedure section set by the operator is provided to the operator.

- It provides an interactive interface for procedure search, section setting, automatic execution command, and automatic execution stop through voice recognition dialogue between the operator and the computer-based procedure system.
- It provides a face-to-face communication function between drivers by supporting video communication between operators.
- When an operator needs it, it provides control history and real-time control status information of other operators.
- A warning message is generated in case of violation of control authority (control authority priority setting) between operators.
- A warning message is generated when the AI agent monitors the powers' control behavior from the perspective of the third person and goes out of the context of the procedure.
- During the emergency operation procedure, when the conditions for emergency issuance are satisfied, the corresponding emergency (white, blue, red) is automatically issued.
- When an alarm occurs, the corresponding alarm response procedure is automatically executed and the result is provided to the operator, and if an action is not possible, an additional action is requested by the operator.
- In the event of a situation outside of the prepared procedure, the optimal operation procedure alternative and the expected result for each alternative are provided to the operator.

3. Conclusion

The procedure-based intelligent computer procedure platform will be developed as core element technologies so that it can be applied to SMART small and modular reactor under development as well as innovative small and modular reactors being promoted in Korea. The research results developed through this study are expected to be completed within the next four years.

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