Progress of Design Improvements for APR1400 Computerized Procedure System from HFE V&V results and Design Experience

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1. Introduction

APR1400 Computerized Procedure System (CPS) has been applied to Shin-Kori Nuclear Power Plant (SKN) 3&4 units, Shin-Hanul Nuclear Power Plant (SHN) 1&2 units and Baraka Nuclear Power Plant (BNPP) 1, 2, 3&4 units. Since APR1400 CPS is a first-of-a-kind (FOAK) human machine interface (HMI) for executing a computerized procedure in the nuclear power plant's main control room in South Korea [1], it has been continuously improved through a) the human factor engineering (HFE) verification and validation (V&V), b) the internal design review and c) prototype tests [2]. Human engineering discrepancies (HEDs) can be identified by the HFE V&V activity [3]. Some HEDs of APR1400 CPS for SKN 3&4 and SHN 1&2 have been adopted as a role of design improvement in the CPS system while others were regarded as an operator training requirement or part of task contents. This study shows major already improved design features from the above three processes and a design proposal for to-be-improving items.

2. Design Modifications from HED

The HFE V&V is planned by HFE experts and it should be prepared with properly trained users, generally NPP operators, and almost real facility with specific tasks. HFE experts select HEDs in all of problems or opinions during the V&V test. Most HEDs should be resolved before getting NPP operating license through three ways. One of them is design modification, training program or procedure development. In this section, design modifications for SKN 3&4 CPS are presented.

2.1 Procedure Execution History Popup Window

1) HED description: In order to recognize the procedure execution history of the CPS in the digital main control room, related information should be provided in a proper way.

2) Design improvement: This problem plays an important role of reviewing current executed procedures in a sequential series. To solve it, the CPS should provide an operator's valid control command into the CPS execution with its generating time. So, current design specification of the CPS has two kinds of methods to provide the procedure execution history.

One is the procedure execution history popup window as shown in Fig. 1. This popup includes operator's control command in the lowest (instruction evaluation) level. The other is online hardcopy procedure which is printing continuously at the same time of processing user's control command. The online hardcopy includes only step level's control command such as completing, re-executing and postponing.

Fig. 1. Example of Procedure Execution History Popup

2.2 Backup Paper-based Procedure (PBP)

1) HED description: The initial design of the backup PBP is the A3 landscape size and one side binder books as Fig. 2. The empty space for its doubled size is necessary to execute the backup PBP in the operator console and safety console. Therefore, there is no sufficient space and disturbance with the various interface devices for its use.
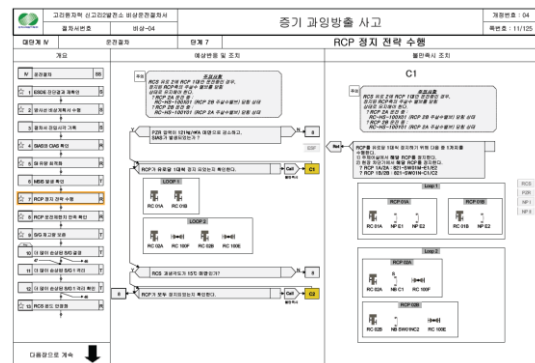

Fig. 2. Previous A3 Layout of backup PBP

2) Design improvement: Paper-based procedure should have some specific features for convenient uses such as weight and size. Typically, A4 portrait book is preferred for handling on operator hand or desk. The CPS has following two specific features. One is that a screen is not used for displaying both a normal procedure flow and its contingency at the same time. Each contingency is connected with its associated normal procedure content so that operator can access a specific contingency on a linked point. The other is that the CPS always provides current position of a procedure and the procedure overview status. In according to this feature, operator can be easily aware of overall

procedure status and flow. In the design improvement as Fig. 3, the backup PBP is A4 portrait layout. The normal procedure content and small amount of procedure flows are presented on every left-side while its associated contingency content is presented on every right-side if necessary. A whole procedure flow and status for operator manual check are provided independently at each backup PBP. Therefore, the usability of the backup PBP has been increased and satisfied with operators' request.
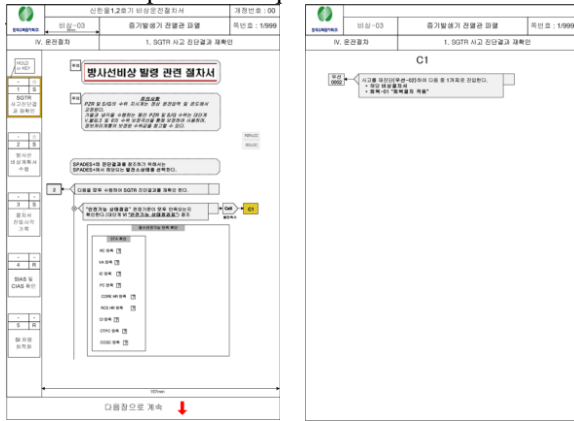

Fig. 3. Improved A4 Layout of backup PBP

2.3 Input of Procedure Entry Time

1) HED description: The function of input field for procedure entry time is too general that operator uses only virtual soft-keyboard or physical keyboard connected to an operator console to input some value. Fig. 4 shows the typical example. According to its functionality and non-specific text format, operator feels difficulties and it takes long time to do that.
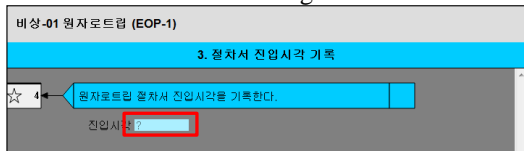

Fig. 4. Typical Example of Procedure Entry Time

2) Design improvement: The functionality of keyboard has not been considered much into the human machine interface (HMI) of APR1400 main control room. Human actions such as selection should be as simple and correct as possible on the software-based HMI. To input current time (ex. "13:21:49 2015-08-27") in the text field, many selections are necessary. Some corrections during the human actions are expected. Therefore, an alternative function to input current system time has been implemented by one-click button ("자동입력") in the SKN 3&4 CPS as shown in Fig. 5. This button is created at the CPS client software by interpreting and displaying procedure contents.
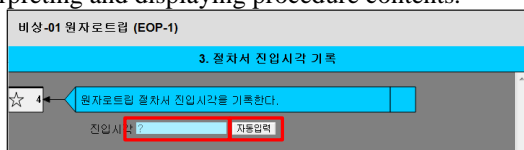

Fig. 5. Example of Improved Procedure Entry Time

3. Design Modifications from Internal Review

In the NPP construction project, there are several publications of design document for a system. According to the project phase, system design document should be continuously refined by various requirements and reviews. This section presents design modifications and proposals of APR1400 CPS.

3.1 Distinction between Disabled and Enabled of Input Field

1) Review description: Some input fields are adopted in the APR1400 CPS such as Boolean, Numeric and Text inputs. It is too difficult to distinguish whether each input field is activated or not. The reason is that the background color of their shapes is always same. Operators may not even aware whether he or she has completed the input field or not.

2) Design improvement: The shape rules of the user interface including input and output field for operators input and internal variable display are established as Table I. These rules are adopted into the as-built design and final product of SKN 3&4 CPS.

3) Design proposal: When an operator completes entering a value in the input fields, current APR1400 CPS does not check whether the entered value is valid or not. The validation check function can be an important tool to be aware of operator input error before handling the value. In addition, the size of Input/Output Fields should be adjusted with its value from the default size. The input value should be used for the CPS internal system as procedure local variable or system global variable.

Table I. Input/Output Field's Shape Rule

UI Conditions			UI Shape
Enabled	For Input	Null	Numeric In [?] kg/cm2
		Not Null	Numeric In [11] kg/cm2
	For Output	Null	Numeric In [?] kg/cm2
		Not Null	Numeric In [11] kg/cm2
Disabled	For Input	Don't Care	Numeric In [?] Kg/cm2
	For Output		Numeric In [?] Kg/cm2

3.2 Out-going Destinations in the Overview Diagram

1) Review description: Some labels of out-going destination from one container, i.e. GrossStep, are duplicated among abbreviated words in other engineering document such as 'EOG' and 'EOP'. They mean 'End of GrossStep' and 'End of Procedure'. In addition, some out-going destinations in a contingency content are omitted but they can be checked in more detailed pages.

2) Design improvement: The 'EOG' and 'EOP' has been changed as 'End.G' and 'End.P' to reduce the

operator perception error. These are adopted into SHN 1&2 CPS design.

3) Design proposal: The Overview Diagram of APR1400 CPS presents overall status and flow of each GrossStep in a procedure. It can play an important role for operator to understand and navigate current procedure. Omitted out-going destinations in a contingency content should be displayed in the Overview Diagram and its associated normal content.

3.3 Information of Override Reset Popup

1) Review description: A procedure should be handled by operator manual actions originally. APR1400 CPS has a function to aid operator's judgment based on acquired plant state. It is so-called as system evaluation. When the operator evaluation is different from system evaluation, override symbol is provided at that position, i.e. Instruction. As time passes, the system evaluation can be the same as operator's one. At that time, Override Reset Popup is provided to the operator. In the initial design, it has not sufficient information to be aware of.

2) Design improvement: In the SKN 3&4 as-built design, the popup has the reset location information in the title of popup window and operator's current view is changed automatically at the reset location.

3) Design proposal: The above improved design can interfere with operator's intention to continue executing current procedure because of view changing function. To resolve this problem, the reset popup should have a selection to change current view or not.

3.4 Synchronization with Other Operator Display

1) Review description: APR1400 CPS has a function to synchronize his or her CPS display with other operator's current procedure at a Step level under the same GrossStep. It is a strong tool to monitor or review other operator's action and progress in the real-time environment.

2) Design proposal: The level of the synchronization should be enlarged to a whole procedure so that operator does not need complicated selections of each GrossStep under a certain condition that a procedure executer changes his GrossStep. Moreover, the scope of the synchronization should include the scroll of each detailed page and contingency contents.

3.5 Opened Procedure Management

1) Review description: There is 'Desk' feature for managing opened procedure in the CPS system. In the current design, each operator can have maximum 10 procedures to be opened. According to this limitation, operator must monitor and consider the number of opened procedure. Especially, the CPS system closes a specific procedure to open another procedure at the maximum condition although operator wants to look at the specific procedure continuously. Procedures with 'Desk' status cannot have a difference between his or her procedures and others' procedures.

2) Design proposal: The 'Desk' status means that a specific procedure is displayed in the desk area of the CPS client. This status can be divided into more detailed status such as 'StandBy', 'Desk(me)' and 'Desk(other operator role)'. The 'StandBy' status means that this procedure is not necessary to be processed during considerable time so it does not need to be displayed. But its state and values are kept continuously. Without opening the 'StandBy' procedure, operator just change its state as 'Desk(me)'. The 'Desk(other operator role)' (ex. Desk(RO)) is necessary to distinguish the whole opened procedures in the CPS system and to select a correct procedure for monitoring and browsing other operator's procedure. Fig. 6 shows the example of this design proposal.

Fig. 6. Example of Procedure Status in the Procedure List

4. Conclusions

APR1400 CPS has been verified and validated by the HFE process, internal design review and site acceptance tests. Various requests for improving the CPS have been collected from those results. A HMI system should be improved continuously for removing potential defects. Some of introduced design features in this paper has been adopted for APR1400 nuclear power plants. Some of them are under the review in the CPS design team of KHNP. It has been identified that experiences of FOAK development and various tests can be a considerable role for design improvement and modifications.

REFERENCES

[1] KHNP, System Specification for the Computerized Procedure System of SKN 3&4 (as-built), 2013.
[2] KHNP, CPS Test Report of SKN 3&4, 2014.
[3] KEPCO E&C, HFE V&V Report of SKN 3&4, 2013.