Transactions of the Korean Nuclear Society Autumn Meeting
PyeongChang, Korea, October 30-31, 2008

Information Flow Analysis for Human-System Interaction in the SG Level Control

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1. Introduction

Interaction between automatic control and operators is one of main issues in the application of automation technology. Inappropriate information from automatic control systems causes unexpected problems in human-automation collaboration. Poor information becomes critical, especially when the operator takes over the control from an automation system. Operators cannot properly handle the situation transferred from the automatic mode because of inadequate situation awareness, if the operator is out-of-the loop and the automatic control system fails. Some cases of unplanned reactor trips during the transition between the manual mode and the automatic mode are reported in nuclear power plants (NPPs) [1]. Among unplanned reactor trips since 2002, two cases were partially caused by automation-related failures of steam generator (SG) level control.

This paper conducts information flow analysis to identify information and control requirement for human-system interaction of SG level control. At first, this paper identifies the level of automation in SG level control systems and then function allocation between system control and human operators. Then information flow analysis for monitoring and transition of automation is performed by adapting job process chart. Information and control requirements will be useful as an input for the human-system interface (HSI) design of SG level control.

2. Human-system interaction in SG level control

Identification of the level of automation is the first step to design the interaction between system control and operators. Both function allocation and interaction between operator and system control can be defined after the level of automation is clearly defined. The level of automation in the SG level control systems of OPR1000-type plants (or feedwater control systems) belongs to Supervisory Control according to Endsley's taxonomy [2]. At the Supervisory Control, the system generates options, selects the option to implement and carries out that action. Operators mainly monitor the system control and intervene if necessary.

There are two modes in the SG level control: manual and automatic. In the manual mode, operators have the responsibility of controlling SG level by adjusting the speed of feedwater pumps and the position of control valves. In a stable state, operators transfer the control of pump speed and valve position to the system. Then system takes over the control to maintain the level. The system regulates SG level without any permission of operators. The operator intervenes when the level control by system fails. Then role of operators changes to controller from supervisor, as shown in Fig. 1.

Operator functions in the supervisory role are as follows:

- Monitoring SG level control
- Detecting failure of automation control

Operators monitor whether the system controls the SG level within a reasonable range, based on the information about SG level, steam flow, and feedwater flow. Then, operators also perform monitoring activities for the detection of failure of automatic control, based on the stability of SG level and deviation between setpoint and process value. If it is concluded that system control fails, operators resume manual control.

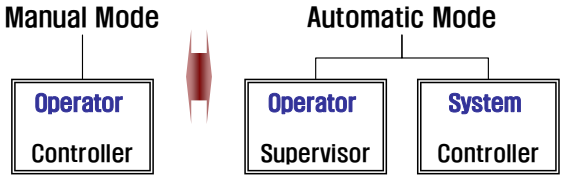

Fig. 1 Transition of operator role in automation

3. Information flow analysis using job process chart

This paper analyzes information flow for the human-system interaction of SG level control related to automation. The purpose of this analysis is to identify information and control requirement for designing HSI of SG level control system. This work uses job process chart for information flow analysis. Job process chart is a kind of task analysis method to show operational process [3]. The job flow chart is composed of the following columns:

- The left column is for system functions
- The central column is used to show the interface information and control flow between system and operators
- The right column is for operator functions

System should provide the following information for better operator situation awareness about system control:

- Informing what are performed by the system

- Providing information which operators want to know to understand a given situation (e.g., the reason why the operation by system is actuated).
- Alerting operators to conditions for automatic activation. Sudden activations by system which operators are not aware of can cause them to be confused or embarrassed. Operators need to be informed that an automatic control is or will be soon activated, especially when the operation is under manual control. (e.g., automatic transition of feedwater flow from downcomer line to combination of downcomer and economizer around 20% of reactor power)

Job process chart for monitoring of system control and transition between operators and system is shown in Fig. 2. This chart has been developed based on operating procedures related to SG level control [4-5]. The chart shows a flow from automatic mode to manual control. General operating procedure describes that operator switches to automatic mode at 5 % of reactor power during startup. In the automatic mode, operators obtain process value or alarms on SG level to monitor the performance of system control. They identify the appropriateness of SG level control. If the SG level is unstable, operators diagnose status of system control, i.e., failure of system control, to resume manual control. The decision is based on flow rates related to SG level (i.e., main steam flow and feedwater flow) and deviation between setpoints of automatic control and real process values. If system fails to control the level appropriately, operators take over control from system. For correct situation awareness in manual control, they need to obtain information about SG level, feedwater flow, steam flow, reactor power, feedwater pump speed, economizer valve position, and downcomer valve position. Then, operators control the SG level by adjusting pumps speed, control valves or master controllers.

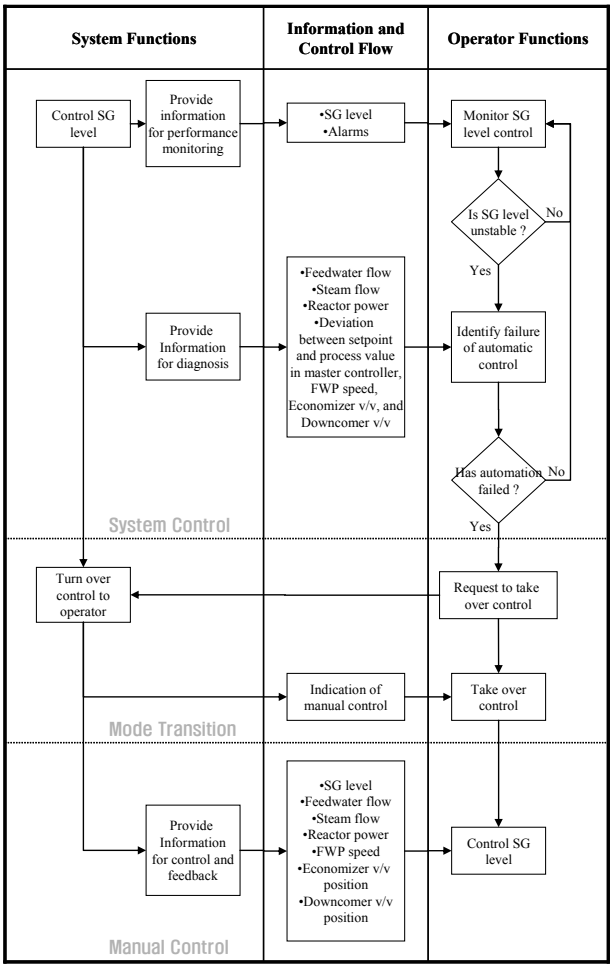

Fig. 2 Information flow analysis for monitoring and transition of automation

4. Future works

This paper identifies information and control requirements for human-system interaction in the SG level control. Transition of control authority from automation system to operators usually occurs in the time-pressed situation. Operators may not obtain all the information necessary for correct situation awareness. Therefore, HSI designers need to deliberate how to provide the information in the effective way.

Investigation into automation design and procedures for current SG level control systems is also required. Operators role in the automatic control mode should be clearly defined in operating procedures. Especially, criteria to evaluate the stability of level control by automation system need to be specified. Verification of automation-related design is also required to ensure whether the design provides relevant information for automation transition and monitoring in the effective way.

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