Availability Verification of Information for Human-System Interface in Automatic SG Level Control Using Activity Diagram

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1. Introduction

Steam Generator (SG) level control system in OPR 1000 is one of representative automatic systems that falls under the Supervisory Control level in Endsley's taxonomy [1]. Supervisory control of automated systems is classified as a form of out-of-the-loop (OOTL) performance due to passive involvement in the systems operation [2], which could lead to loss of situation awareness (SA).

There was a reported event, which was caused by inadequate human-automation communication that contributed to an unexpected reactor trip in July 2005 [3]. A high SG level trip occurred in Yeonggwang (YGN) Unit 6 Nuclear Power Plant (NPP) due to human operator failure to recognize the need to change the control mode of the economizer valve controller (EVC) to manual mode during swap-over (the transition from low power mode to high power mode) after the loss-of-offsite-power (LOOP) event was recovered.

This paper models the human-system interaction in NPP SG level control system using Unified Modeling Language (UML) Activity Diagram. Then, it identifies the missing information for operators in the OPR1000 Main Control Room (MCR) and suggests some means of improving the human-system interaction.

2. Operation of SG Level Control

This section describes the operation of SG level control based on [4]. The SG level can be controlled by using a Master Controller that commands the Downcomer Valve Controller (DVC) and EVC. In automatic mode, the SG level is regulated by setting the SG level setpoint through the Master Controller. In manual mode, the SG level is regulated by controlling the downcomer or economizer valve positions through the Master Controller, or through the individual EVC or/and individual DVC.

From Hot Standby (0% reactor power), the SG level setpoint is set to be within the narrow range (NR) of 20% to 40% to prevent SG level fluctuation due to swap-over or electrical grid synchronizing. The SG level would then be kept within the NR of 20% to 40% while the reactor power is increased to 5%.

Above 5% reactor power, the Feedwater Control System (FWCS) control mode is then changed from manual to local automatic mode. The local automatic mode can be changed back to manual mode if there was any SG level fluctuation.

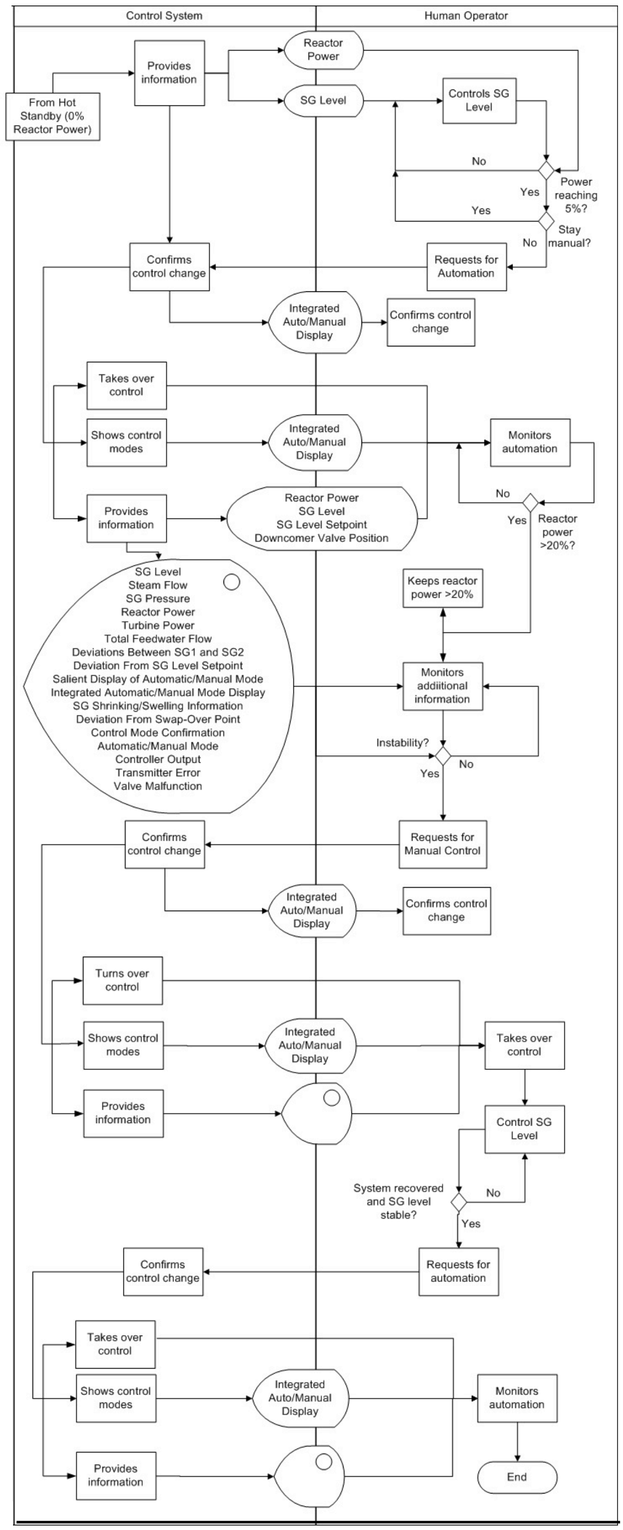

Fig. 1. Activity Diagram for the human-system interaction in SG level control.

The reactor power is then increased to about 11% to 12% and the SG level in this reactor power range (from 5% to 11%~12%) is controlled solely by the downcomer valve position. Before the power reaches 20%, the operator has to decide on how to change SG level control from using only downcomer valve to using both downcomer and economizer valves (changeover).

The FWCS mode should be in automatic mode when the SG level control mode changes from low power mode to high power mode but the operator can change to manual mode if necessary. After the swap-over, the setpoint is increased to about 44% and remained fixed as the power is increased to 100% reactor power.

3. Modeling of Human-Automation Interaction for SG Level Control by Activity Diagram

An Activity Diagram specifies the transformation of inputs into outputs through actions sequence and shows responsibilities for the activities using activity partitions [5]. Fig.1 shows the Activity Diagram of SG level control that contains all of the information needed to ensure economical and safe operation of the NPP.

4. Availability Verification of Information for Human-Automation Interaction

A list of necessary information for SG level control was identified using the Activity Diagram as depicted in Fig.1. The availability of the identified necessary information is attested for OPR1000 control room and summarized in Table I.

Table I: Analysis of availability of information needed for SG level control in OPR1000

Necessary Information	Availability
SG Level	O
Steam Flow	O
Total Feedwater Flow	O
SG Pressure	O
Reactor Power	O
Turbine Power	O
Deviations Between SG1 and SG2	X
Deviation from SG Level Setpoint	O
Controller Output	O
Transmitter Error	O
Valve Malfunction	O
Automatic/Manual Mode Indicator	O
Salient Control Mode Display	X
Integrated Control Mode Display	X
Control Mode Change Confirmation	X
SG Shrinking/Swelling Information	X
Deviation from Swap-over Point	X

This paper identified the information that needs to be added to the current OPR1000 control room for better human-automation interaction.

1) During the operation, one of the two SGs may go through a transient, resulting in deviations in terms of SG level, feedwater flow and steam flow in one SG with respect to the other. It is suggested that the deviations between the SGs are displayed so that the operator will not have to resolve the value differences by reading off each SG readings display when controlling the SG level manually.

2) A controller's control mode can be identified by a small LED indicator on the control mode request button in the existing MCR. This small indicator tends to be overlooked hence the suggestion to include a salient display of the controllers' control mode. In addition, an integrated display of all the controllers' control modes in one panel display would also be useful in keeping the operator aware of the controllers' control modes.

3) Confirmation of control mode change also needs to be displayed before, during and after the transition of control. This would help the operator to keep track of the control transition of the controllers.

4) The operator would need an indicator that shows the condition of each SG, whether it is in swelling or shrinking state, so that appropriate and accurate control action can be taken by the operator. The indicator could be text-based, for example an indicator that says "swell" would light up if the system evaluates that the SG is in swelling state.

5) Real-time deviation of reactor power from the swap-over point would also be useful for the operator to plan ahead on the changeover. Therefore, it is suggested that a display of the real-time deviation value to be present in the control room.

5. Conclusion

This paper suggests from the Activity Diagram and the analysis of information availability that there should be a need for design modification of the SG level control information display to include deviations between SG1 and SG2, salient control mode display, control mode change confirmation, SG shrinking/swelling information, deviation from swap-over point and integrated control mode display. Future works could include analyses on how to effectively integrate the missing information into the human-system interface system.

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