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Applicability Evaluation of Enhanced Functions of APR1400 Feedwater Control System to OPR1000

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1. Introduction

The Feedwater Control System (FWCS) in Nuclear Power Plant (NPP) is an important control system that regulates the feedwater (FW) flow to steam generators (SGs) by adjusting the economizer valves, downcomer valves and main feedwater pumps in order to maintain the SG level at a predetermined setpoint.

In comparison with OPR1000, APR1400 FWCS embraces various compensation logics and algorithms to improve the transient responses of SG level, and their performance was proven through the power ascension test in Shin-Kori NPPs Units 3 and 4.

While many efforts have been made to control the SG water level more stably in the APR1400 FWCS, the existing OPR1000 FWCS has not been improved because of lack of process sensor signals, proof of new design features, low need for urgency and so on. However, it is important to adopt the advanced functions for the old power plants with the increasing demands for replacement of obsolete equipment.

In this paper, the enhanced functions of APR1400 FWCS was incorporated into OPR1000 FWCS logic, and implemented on the distributed control system (DCS) controller to evaluate applicability to OPR1000. The performance was analyzed with the dynamic simulation, and the prototype controller and simulator showed the enhanced dynamic responses against two major performance related design basis events (PRDBEs).

2. Enhanced Functions of the FWCS

2.1 Three (3) element level control at low power

The FWCS controls SG level using 3 process variables such as main steam flow, total feedwater flow and SG level during high power operation of NPP. That is, it can improve the transient responses to disturbances through the feed-forward control algorithm which compensates for the difference between main steam flow and total feedwater flow to reject disturbances before they affect the SG level [1].

Table 1. Level control inputs at low power

Function	OPR1000	APR1400
level control at low power	SG level only	SG level, calculated steam flow, downcomer FW flow

During low power operation in which the reactor power is less than 20%, the FWCS in OPR1000 uses only SG level, which is unstable due to low feedwater temperature and unreliable steam flow. Consequently, in OPR1000, the SG level at low power is being manually controlled by the experienced operators during plant startup operation and it imposes a burden on the operators.

In APR1400, the FWCS was improved to utilize 3 elements even during low power operation so that automatic level control can be extended over the full range of reactor power.

During low power condition, the steam flow signal is calculated from summation of the turbine load index and the steam bypass modulation demand, and the total feedwater flow is replaced by the downcomer feedwater flow.

2.2 Differential pressure (DP) control for FW valve

When FW pumps goes into on/off or when other events that can affect feedwater or steam pressure occur, this disturbance can cause SG level to fluctuate. As controllability of this fluctuation is weakened by the differential pressure change of both ends of the FW valves, normal regulation of the FW valves is difficult to supply appropriate FW flow and SG level goes through a transient process prior to steady state.

If a desired differential pressure across the FW valves is not maintained during plant operation when a disturbance occurs, SG level can become unstable and the mechanical integrity of the FW valves can be negatively affected.

Meanwhile, APR1400 FWCS has a differential pressure compensation algorithm to maintain a differential pressure across the FW valves and to cope with the SG level transient condition [2].

Table 2. FW valve DP control inputs

Function	OPR1000	APR1400
FW valve DP control	N/A	main steam header pressure, FW common header pressure, main steam flow

As the FW valves are located between SG and FW pumps, the differential pressure of the FW valves is obtained by difference between the main steam header pressure in the downstream of the FW valves and the

FW common header pressure in the upstream of the FW valves. The measured differential pressure is compared to a desired pressure generated by a function of the main steam flow, and the error signal is used to provide adequate bias value to the FW pump speed demand which subsequently adjusts or maintains the differential pressure of the FW valves.

2.3 Feedwater temperature compensation control

When low temperature FW is supplied to SG during low power operation, SG level is affected by a process of shrink and swell effects. For example, cold FW makes two phase fluid in the SG shrink and thus the FWCS increases the FW flow demand to recover the SG level. If the supplied FW is heated from primary side, the SG fluid swells and results in considerable overshoot in SG level.

For this reason, APR1400 FWCS has a FW temperature compensation logic to adjust SG level error gain depending on the FW temperature.

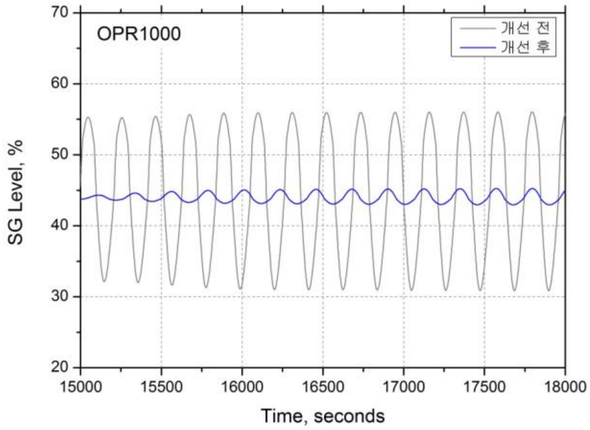
Table 3. FW temperature compensation input

Function	OPR1000	APR1400
FW Temp. compensation	N/A	FW temperature

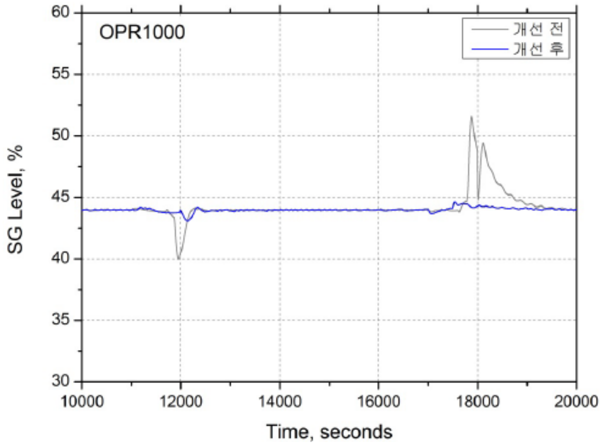
When the SG level is lowered with the fluid contraction, the excessive flow increase due to a large level error is reduced by decreasing the error gain into the FWCS controller.

3. Performance and Test Results

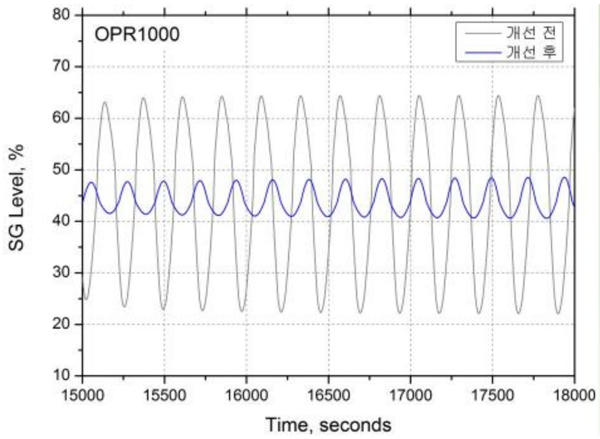
The improved control algorithms of APR1400 FWCS described above were applied to OPR1000 FWCS prototype and simulated. Based on each function, the dynamic performance was enhanced in comparison with the existing OPR1000 system as shown Figure 1.



(a) 3 element level control



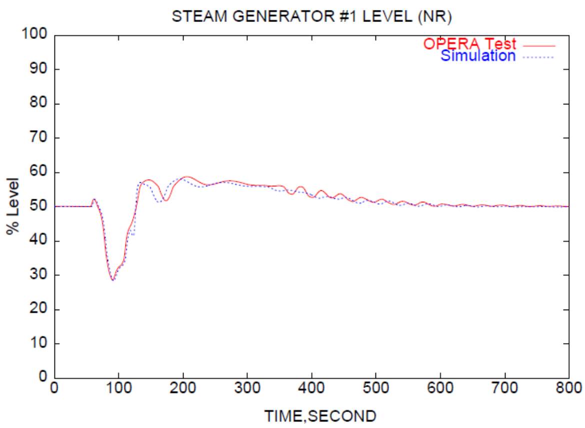
(b) FW valve DP control



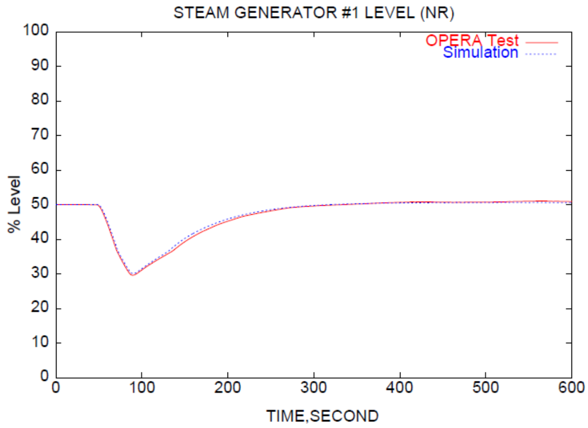
(c) FW temperature compensation

Figure 1. Performance of improved functions

With 3 element level control, SG level oscillation was alleviated by compensating the flow error during low power operation. In application of the FW valve DP control function, overshoot and undershoot in SG level were mitigated through well-maintained FW valve DP. Also, the FW temperature compensation logic reduced the SG level oscillation by decreasing the level error during low temperature FW supply condition.



(a) Load rejection to house load



(b) Loss of a main feedwater pump

Figure 2. Test results for design basis events

In addition, the analysis for two major PRDBEs was performed using a simulator and a test prototype controller. The simulator is the Nuclear Plant Analyzer (NPA), which is used to design and analyze the control systems of the nuclear power plants. The prototype controller is implemented with a commercial DCS, OPERA SYSTEM®.

The load rejection to house load and loss of a main feedwater pump events are chosen as major PRDBEs, because the events give a considerable impact on SG level. For the two PRDBEs, the improved FWCS functions worked well on the prototype controller as well as the simulator without any reactor trip in terms of agreement of parameter trends and values as shown in Figure 2.

4. Conclusions

For enhancing the control performance of OPR1000 FWCS, the improved APR1400 FWCS functions such as 3 element level control at low power, FW valve DP control and FW temperature compensation were incorporated into OPR1000 FWCS logic and implemented in the prototype controller to be simulated using the NPA. The simulation result showed that oscillation or transient responses of SG level were outstandingly improved per each control function. Also, the prototype controller revealed the enhanced dynamic responses similar to the simulator against two major PRDBEs. It is concluded that these enhanced functions can be actually applied to the OPR1000 NPP sites and this feature will contribute to the operational control performance of the power plants, if the additional process signals and algorithms are acquired and implemented by the design change for the logic cabinets, the transmitters and the cabling.

ACKNOWLEDGEMENT

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[2] Registered Patent, "Feedwater Control System in Nuclear Power Plant Considering Feedwater Control Valve Pressure Drop and Control Method thereof," KEPCO Engineering & Construction Co., 2006.