A Feasibility Study to Prevent Unnecessary CEA Movement due to RCS Hot-leg Thermal Stratification

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1. Introduction

By adopting low leakage, loading pattern in OPR1000, the power deviation between inner and outer parts of reactor core became greater than as it was and it increases thermal stratification in hot-leg of reactor coolant system (RCS). Thermal stratification is generally occurred in the beginning of cycle (BOC) operation due to burnup deviation between the fuel assemblies. Due to thermal stratification, the measured temperature of hot-leg shows hunting phenomenon. If the magnitude of the hunting exceeds the band of the reactor regulating system (RRS) setpoint of ±1.1 ℃, unnecessary control element assembly (CEA) movement can be occurred.

In this study, sensitivity study was performed to prevent unnecessary CEA movement by adjusting lead time constant (τ1) of lead/lag filter in RRS. Thereafter, analyses of the performance related transient events were performed to verify feasibility of the selected lead time constant.

2. Control Functions of RRS

RRS provides a mechanism to improve the capability of the reactor to follow turbine load changes. It controls the CEA movements through the control element drive mechanism control system (CEDMCS) to maintain the average coolant temperature (T_{avg}) within specified values. [1]

As shown in Figure 1, temperature error between the T_{avg} and the reference temperature (T_{ref}) is compensated with the dynamic filters. These filters have capability to adjust performance by changing the time constant. Thus, unnecessary CEA movement can be prevented by adjusting time constant of the filters. For that purpose, adjusting lead time constant of lead/lag filter is suitable because amplification of temperature error signal can be decreased by adjusting lead time constant.

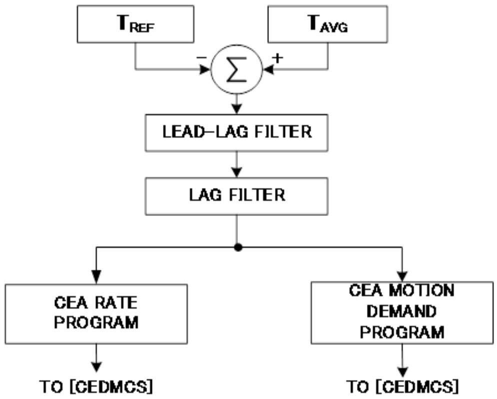

Figure 1. Simplified Block Diagram of RRS

3. Hunting Phenomenon and Time Constant Analyses

3.1. Simulation Code

To simulate the hunting phenomenon and the performance related transient events, the KEPCO E&C integrated system performance analysis code (KISPAC) was utilized. The KISPAC is best-estimate simulation code to analyze performance of plant including control system.

3.2. Initial Conditions and Assumptions

To simulate hunting phenomenon in BOC, it was needed to determine the range of T_{avg} variation. Table 1 shows the measured data of maximum and minimum hot-leg control channel temperatures and their maximum deviations during 100% power steady state operation at about 5,000 MWD/MTU burnup obtained from OPR1000.

Table 1. Max & Min Temperatures of Hot-leg Control Channel and Their Max Deviations

	Hot-leg 1	Hot-leg 2
Max. value	326.805 ℃	(A) 326.878 ℃
Min. value	324.703 ℃	(B) 324.349 ℃
Max. deviation	(A) - (B) 2.53 ℃	

Based on the OPR1000 operation data, core inner and outer temperature difference in BOC was 10% bigger than those in Table 1. Therefore, it seems reasonable to assume that the maximum hot-leg temperature deviation in BOC can be expected as 2.78 ℃. As a result, maximum T_{avg} deviation is calculated to be 1.39 ℃ because the cold-leg temperature is constant as it designed.

3.3. Hunting Simulation

To simulate hunting phenomenon, Gaussian random number were generated and added to T_{avg}. Figure 2 shows T_{avg} distribution and Figure 3 shows steady state T_{avg} hunting simulation using the KISPAC. The maximum T_{avg} deviation is 1.39 ℃ as discussed in section 3.2.

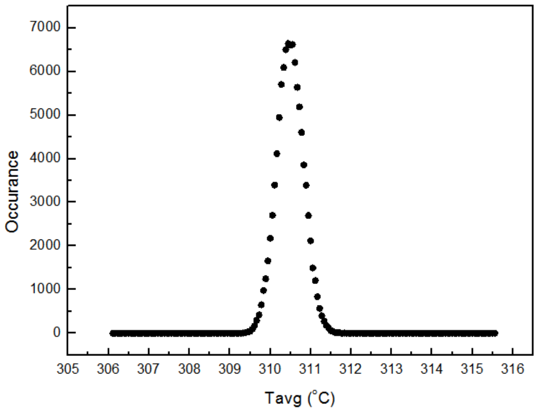

Figure 2. T_{avg} distribution for Hunting Simulation

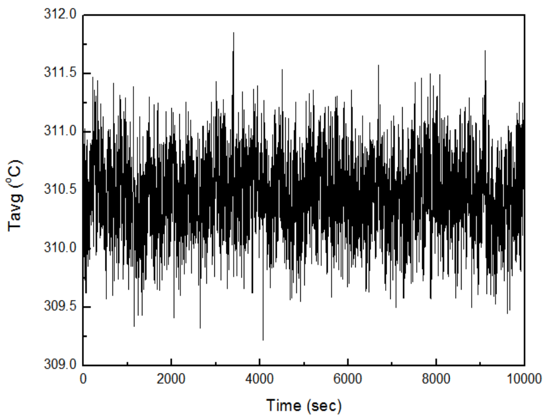

Figure 3. KISPAC Simulation of Steady State T_{avg} Hunting

3.4. Determination of Time Constant

Sensitivity study on lead time constant of lead/lag filter in RRS was performed to find out the effects on CEA movement during 100% power steady state operation. Table 2 shows the results of study.

Table 2. Sensitivity Study Result of Lead Time Constant

Case	τ1	Max Amplitude of CEA Movement (cm)
01	30	4.52
02	28	4.29
03	26	3.94
04	25	3.02
05	24	3.15
06	22	2.44
07	20	2.01
08	18	1.60

In the actual plant, the movement unit of CEA is a step of 1.905 cm. However, the KISPAC is not embodied like that. Thus, if the amount of CEA movement in the KISPAC exceeds ±1.905 cm, it can be considered that CEA is moved. Therefore, if the amplitude of CEA movement is greater than 3.81 cm in the KISPAC, it is determined that unnecessary CEA movement is occurred.

As a result of study, unnecessary CEA movement can be prevented when τ1 is smaller than 25. Figures 4 and 5 show the CEA movements of case 01 and 08, respectively. As shown in the figures, movements of the CEA became smaller as lead time constant decreased.

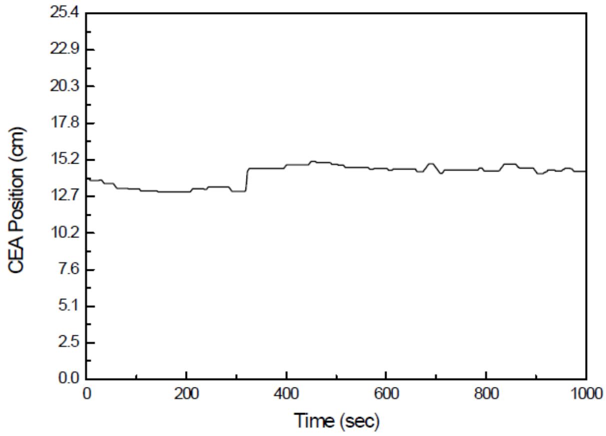

Figure 4. CEA Movements (τ1 = 30)

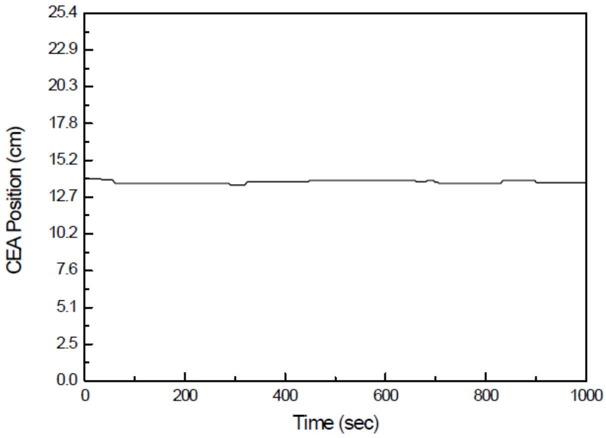

Figure 5. CEA Movements (τ1 = 18)

4. Transient Analysis

Adjustment of time constant would have an effect on the response of CEA movement. Therefore, feasibility of time constant was verified by analyzing performance related transient events. Three cases were selected as present (τ1=30), optimized (τ1=24) and minimum (τ1=18). For three cases, the most limiting performance related transient events for CEA movement which are load rejection at 75% power and loss of a main feedwater pump at 100% power were analyzed to verify system performance.

4.1. Load Rejection at 75% Power

Load rejection at 75% power event is very critical for the performance of CEA movement because reactor power should be stabilized by RRS without RPCS actuation. Figures 6 to 8 show reactor power, turbine power and CEA position during load rejection at 75% power for each case. Reactor power was stabilized to be equivalent to turbine power and turbine bypass energy. And CEA was controlled well to achieve equivalence of reactor and turbine power.

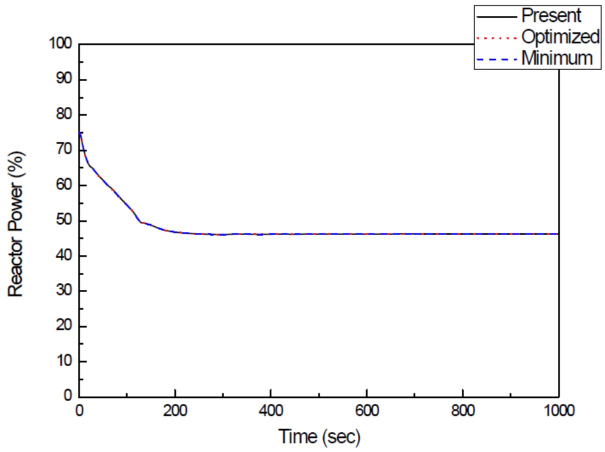

Figure 6. Reactor Power (Load Rejection at 75% Power)

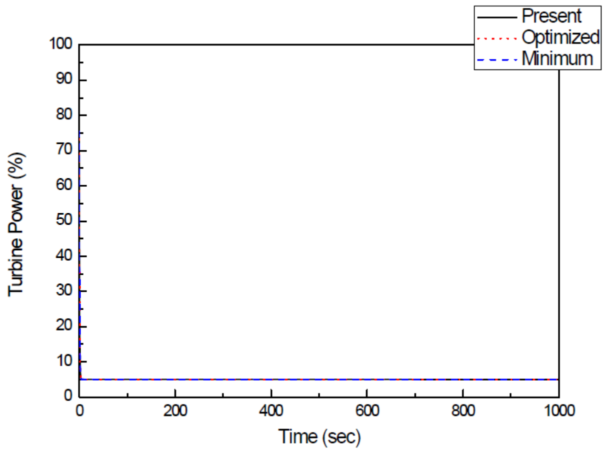

Figure 7. Turbine Power (Load Rejection at 75% Power)

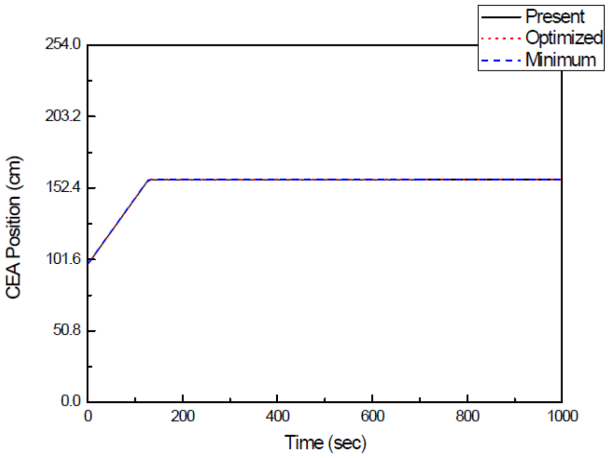

Figure 8. CEA Position (Load Rejection at 75% Power)

4.2. Loss of a Main Feedwater Pump at 100% Power

The performance of CEA movement is also important to loss of a main feedwater pump at 100% power event. Because the power mismatch due to RPCS actuation and turbine setback can cause turbine over-runback so that CEA is controlled to achieve power balance. Figures 9 to 11 show reactor power, turbine power and CEA position during loss of a main feedwater pump at 100% power. Reactor power was stabilized with turbine power and the performance of CEA movement is acceptable for all cases.

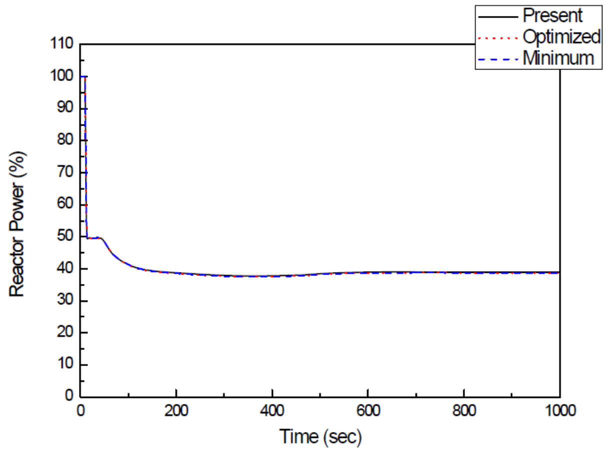

Figure 9. Reactor Power (Loss of a Main Feedwater Pump at 100% Power)

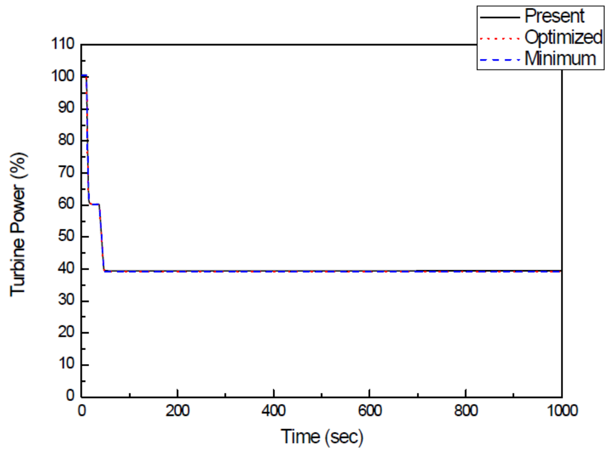

Figure 10. Turbine Power (Loss of a Main Feedwater Pump at 100% Power)

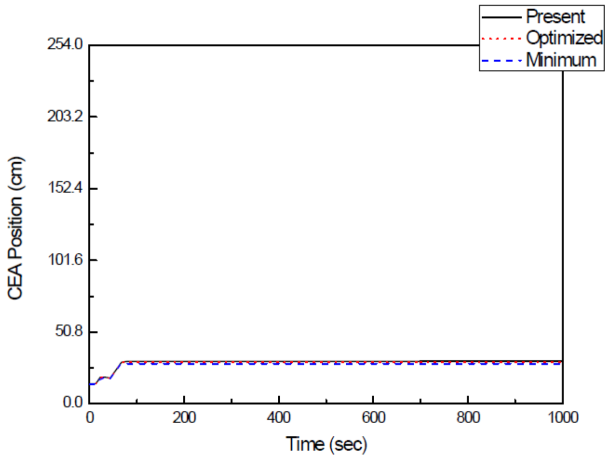

Figure 11. CEA Position (Loss of a Main Feedwater Pump at 100% Power)

5. Conclusions

To prevent unnecessary CEA movement due to thermal stratification in hot-leg of RCS, sensitivity study of lead time constant of lead/lag filter in RRS was performed in this study. It was concluded that unnecessary CEA movement could be prevented if $\tau 1$ is smaller than 25. Thereafter, load rejection at 75% power and loss of a main feedwater pump at 100% power were analyzed to verify the system performance with the selected time constants. As a result of analyses of transient events, all cases satisfied performance requirement with adequate movement of CEA. Consequently, unnecessary CEA movement during 100% power steady state operation can be prevented with acceptable performance when lead time constant is smaller than 25.

REFERENCES

[1] Hanul Nuclear Power Plant Units 5&6 Final Safety Analysis Report Chapter 7, Instrumentation and Control.