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Load Follow Control Algorithm Improvement through Optimizing Weighting Factors

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1. Introduction

Korea Hydro & Nuclear Power Co., LTD (KHNP) has been developing automatic load follow controller as a part of Advanced Power Reactor Plus (APR+) development. The developing controller is composed of three algorithms which could control reactor power and axial power shape. One is a model predictive control algorithm and another is a parameter estimation algorithm providing model predictive control algorithm with real-time reactor models and the other is a genetic algorithm in order to optimize the cost function of the controller [1, 2, 3, 4, 5]. And various simulations on daily load follow operation were performed using this controller [6, 7]. In addition, new study results came out, identifying the effect of weighting factors in control algorithm [8].

This paper aimed to optimize the weighting factors based on boron concentration changes. So, we made representative scenarios of boron concentration changes which can consider xenon transient effects. And we modified load follow algorithm for optimizing the weighting factors and we evaluated the control performance improvement simulating daily load follow operation.

2. Boron Change Scenarios

The core maneuver capability for load follow operation is provided by use of the control rods and boron concentration changes which compensate for reactivity changes associated with changes in power level. Typically, it is unable to fast change reactor power using the boron concentration because of its long time constant. And it's very hard to change the boron concentration low at the end of the cycle because too much water should be needed and the charging pump speed is limited. For this reason, the developing control algorithm [6] only uses two kinds of control rods based on typical boron concentrations. In this study, the maximum boration and dilution rates are conservatively set as about 30.0 and 10.0 ppm/hr considering the boron concentration about 200 ppm at the end of the cycle. Figure 1 shows the limitation rates of boration and dilution in APR+. In addition, the boron change scenarios based on the poisoning effects of xenon buildup, burnout, and decay in conjunction with power level changes were developed within the maximum boration and dilution rates. That is to say, boron concentrations are changed in direct opposition to the xenon reactivity. Figure 2 shows the developed boron change scenarios at two core average burnups during daily load follow operations.

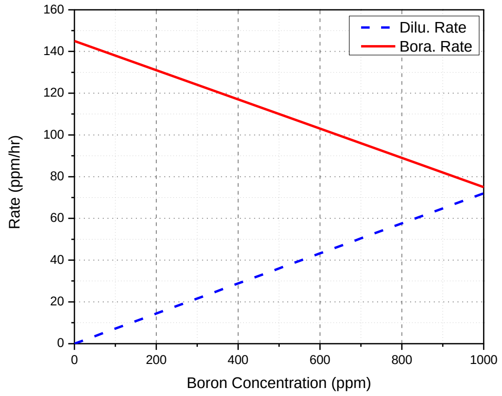

Fig. 1 Maximum Boration and Dilution Rate vs. Boron Concentration in APR+

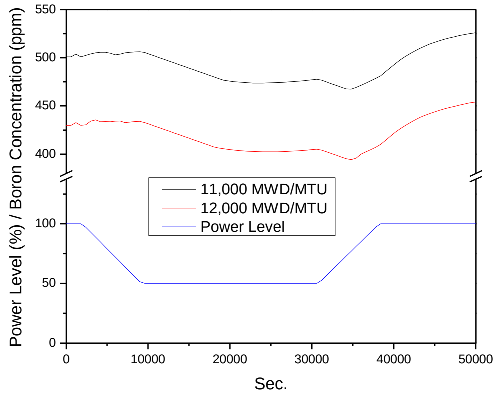

Fig. 2 New Boron Concentration Changes during Daily Load Follow Operations

3. Weighting Factor Control Logics

In the previous study [8], it was found that proper selection of weighting factors is important to the controller performance and it took too long and difficult to find proper weighting factors. So, it was needed to automate the selection process for the purpose of optimizing the weighting factors. In this study, new logics of selecting weighting factors were developed and they were embedded into the optimization algorithm in the main automatic load follow controller. The key logics of them are to change weighting factors as the need arises. That is, the weighting factor of the power increases when it has priority for the control and it decreases when the other is important. Table 1 summarizes the key statement of selection logics. In Table 1, minimum and maximum weighting factors are from the previous study [8] and detailed values are shown in the table.

Table I: Key Logics for Selecting Weighting Factors

```
If(WF≥min && WF<max)
{
   IF( (output – target)≥value1 and (output – target)≤value2 )  WF=freeze
   IF( ABS(output – target) < value1 )  WF=decrease
   IF( ABS(output – target)> value2 )  WF=increase
}
  *WF : two kinds of weighting factors
  *min : minimum weighting factors from previous study [8]
  *max : maximum weighting factors from previous study [8]
  *value1 : min. deadband of power and ASI(axial shape index)
  *value2 : max. deadband of power and ASI(axial shape index)
  *output : power and ASI
  *target :  power and ASI
```

4. Performance Simulation Results

The simulation pattern of a daily load-following operation is selected in order to evaluate the performance of the modified control optimization algorithm with automatic selecting weighting factors logics. In the simulation, plant power decreases from 10 0 to 50% power in two hours after simulation starts, is maintained at 50% power for six hours, increases to 100% power for another two hours and then remains for 4 hours. Figure 3 shows the simulation results of controlled power level such as core average temperature (Tavg) at the burnup of 11,000 MWD/MTU and 12,000 MWD/MTU. During a day, controlled temperatures are controlled better than previous results [8] and they are all within 1°F.

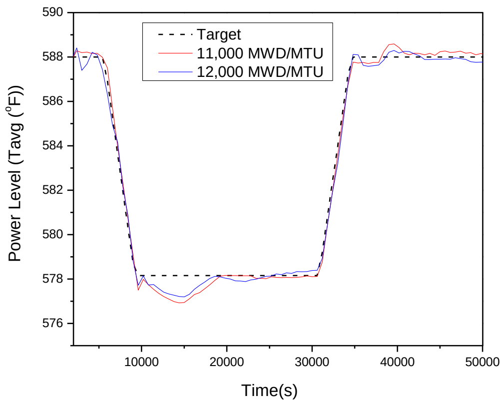

Fig. 3 Simulation results of controlled power level

Figure 4 depicts the change of weighting factors of Tavg. Comparing two Figure 3 and 4, we can find out weighting factor increases at the time when the deviation between target and controlled Tavg is getting bigger. Especially, this tendency is more pronounced when the power change stops and the weighting factor remains at the maximum value from 10,000 to 15,000 seconds.

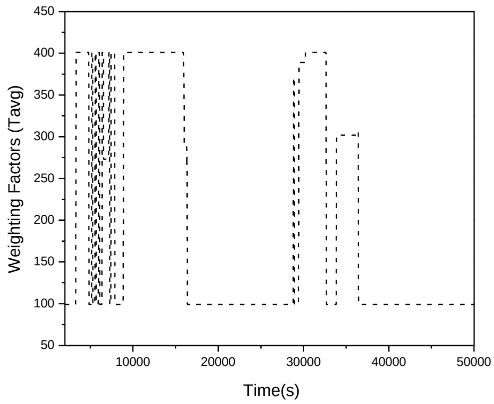

Fig. 4 Tendency of Weighting Factor Change for controlling Tavg

5. Conclusions

In this study, the new selection logics for weighting factors were developed and embedded into control algorithm and its control performance was evaluated. According to the simulation results, the new selection logics improved the control performance and saved much time to find proper weighting factors.

In the near future, based on this study, hardware applicability test will be performed using the load-following control algorithm embedded this logic

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