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Evaluation on the Effect of Load Follow Controller's Weighting Factors

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1. Introduction

Most of Nuclear Power Plants (NPPs) are operated on base-load source of electricity. This is the most economical and technically simple mode of operation. However the portion of electricity generated by NPPs is gradually increasing and the large-scale deployment of intermittent electricity sources is planned and NPPs have been required to implement or improve the maneuvering capabilities in order to adapt to a changing environment such as scheduled or unscheduled variation of the power demand.

Generally there are several important physical effects that limit the possibilities of power variations in NPPs. Some major effects are moderator and xenon effect. Moderator effect is relation with moderator density change and xenon effect is relation with the concentration change of Xe-135 which could affect axial power shape. These effects are more significant with large magnitudes of power variations and they are considered as major disturbances at the aspect of control method.

Due to the above physical effects, it is necessary to carefully change nuclear power considering power distribution change in the core. So, when nuclear plants are required to operate on load variation mode, we could control not only reactor power but also power distribution. Generally, power distribution is controlled by reactor operators who have enough experience, whereas reactor power is automatically controlled by automatic controllers. So, it is necessary to design an automatic controller that controls both reactor power and power distribution for frequent load following operation.

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].

This paper aimed to evaluate the effect of the controller's weighting factors. So, in this paper, we identify the meaning of the weighting factors and the controlled output weighting factors are selected among them. And we analyze the effects of them and evaluate what the proper ranges of weighting factors are for a daily load follow operation.

2. Identification of Weighting Factors

2.1 Cost function of optimization algorithm

The load follow controller has a major cost function like Eq(1).

$$J = \frac{1}{2}\sum_{j=1}^{P}(\hat{y}(t+j|t) - w(t+j))^T Q(\hat{y}(t+j|t) - w(t+j)) + \frac{1}{2}\sum_{j=1}^{M}\Delta u(t+j-1)^T R \Delta u(t+j-1) \qquad (1)$$

In Eq(1), y and w present a series of predictive control outputs and target outputs. And u presents those of manipulated variables selected to minimize the cost function that could consider the minimization of future control output errors and control effort. And R and Q are weighting factors composed of diagonal matrices used to adjust the control performance for the fine tuning. If Q is much bigger than R, the quantity of manipulated variables became much bigger. And the control outputs might diverge. So, it is important to adjust the ratio between Q and R. In this study, R is selected as a specific value and Q value is changed.

2.2 Power weighting factor

In Eq(1), Q weighting factor is again divided into power and axial shape index (ASI) weighting factor because the controller has two outputs variables such as power and ASI. Just like the ratio between Q and R, power and ASI weighting factor are also relative. So, if we need to control power strictly, the weighting factor of reactor power should be much bigger than that of ASI. In this study, we evaluate how much the power weighting factor could affect the performance of load follow controller. Table 1 shows weighting factor ranges for confirming the effect of weighting factor.

2.3 Axial power shape weighting factor

The ASI weighting factor is an axial power shape weighting factor and used to obtain well-controlled ASI performances. In this study, the effect of ASI weighting factor is also evaluated according to the Table I.

Table I: Weighting factor ranges of power and ASI

Weighting factor (WF)	Min. value	Max. value	Selected the other WF	The # of case
Power WF	10	600	1	12
ASI WF	100	800	1	8

4. Simulation and Results

According to the Table I, the power weighting factor is changed from 10 to 600 every 50 and ASI weighting factor is fixed as 1 in every case. And ASI weighting factor is changed from 100 to 800 every 100 and power weighting factor is also fixed as 1. A simulation pattern of a daily load follow operation is selected in order to evaluate the control performance according to the change of weighting factors. In the simulation, plant po wer decreases from 100 to 50% power in two hours afte r simulation starts, is maintained at 50% power for six h ours, increases to 100% power for another two hours and then remains for 4 hours.

Figure 1 shows the simulation results of representative 5 cases. When the power weighting factor is 10, the controlled Tavg which means the reactor power never follows the target one. On the other hand, controlled Tavg closely approaches target one when weighting factor is bigger than 200. However controlled Tavg seems to fluctuate quickly when weighting factor is 600 because optimized control rod speeds are very sensible in order to meet the target value. So, it is recommended to use power weighting factors from 200 to 400.

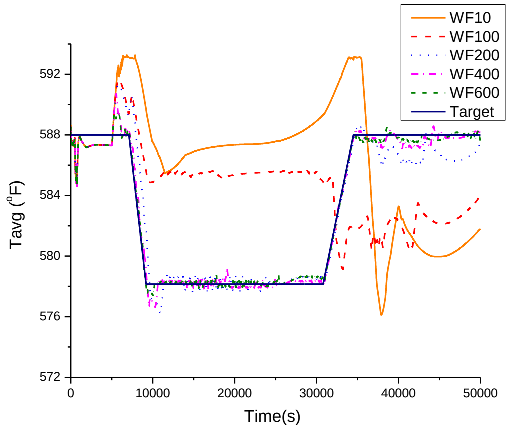

Fig. 1 Simulation results of power weighting factor variation

Figure 2 shows the simulation results of representative ASI weighting factor variation. When weighting factor is less than 100, none of control rods moves and ASI is not controlled. In the meantime, ASI is controlled using control rods when ASI weighting factor is bigger than 200. And it is seemed that the more weighting factor, the more controlled ASI is close to target one.

However reactor is tripped when weighting factor is 800 because steam generator pressure is lower than a trip set point at 15,580 second. So, it is proper to use ASI weighting factors from 200 to 600.

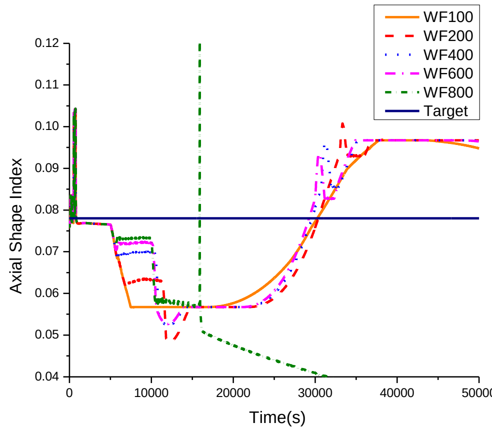

Fig. 2 Simulation results of power weighting factor variation

5. Conclusions

In this study, the effect of output weighting factors is analyzed. According to the simulation results, it is recommended that the weighting factor of power be between 200 and 400 and that of ASI be between 200 and 600. In the near future, based on the study, optimization of power and ASI weighting factors will be performed at the same time.

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