Evaluation of Automatic Control System for Long Term Load Following Operation using Control Rod for a SMR

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1. Introduction

Increasing global energy demand coupled with the need to reduce carbon and other greenhouse gases make investments in new carbon-free energy technologies more important than ever. One promising new technology is light water small modular reactors (SMRs), which are on the verge to be commercially available and are raising increasing public interest. Their relatively small size, modular design, reduced construction times, enhanced safety and other features make them a potentially attractive energy source. In addition, SMRs are usually designed to have flexible load maneuvering capabilities to cope with rapid load changes in an isolated or a small grid system. SMR's load maneuvering capabilities becomes critical if it is coupled with relatively large renewables in a limited grid system.

Therefore , in order to cope with such a large change in output, a control logic using a control rod was applied to the SMR. It was confirmed through other papers[1][2] that the control method using the control rod enables operation at a level that does not exceed the safety limit for 48 hours. However, through the European Utility Requirement (EUR)[3][4], it could be confirmed that the load-following operation condition required for SMRs is higher than the 48-hour level. The conditions that the EUR requires for SMRs are as follows.

"a unit must be capable of continuous operation between 50% and 100% of its nominal power (Pn), […]. Load scheduled variations (should be) 2 per day, 5 per week and 200 per year" [3]

Through this, it is necessary to check whether the SMR could operate normally even with the demanded load that changes frequently over a longer period of time. Therefore, it was confirmed through this study whether there were any problems even when driving under the calculation conditions of the EUR required level.

In this paper, it was confirmed that the control logic works normally through a load similar to that of the existing 48-hour demand load. In addition, a new control logic was also offered. And it was checked whether it was possible to operate under a random demand load and whether it was possible to operate by reflecting the demanded load for a week or a month.

2. Methods

In order to automatically control the core power, the selection of the control method of the core, the appropriate control algorithm, and the selection of the core characteristics factor to be considered when evaluating the load following are described. And the calculation conditions used in the load following calculation and the preliminary evaluation of the control algorithm for each core characteristics factor through the code are described.

2.1 Automatic Evaluation Algorithm using CR

Among the core control logic, the position of the control rod was adjusted with the highest priority and the load following operation was performed. In the case of boron concentration, it was considered as a level reflecting the boron letdown curve generated according to the degree of depleted core, and the algorithm was constructed so that the boron concentration was changed only in situations where load following was difficult with only the control rod.

Based on the coolant outlet temperature, the existing control rod insertion/withdraw algorithm that inserts/withdraws the control rod only when it exceeds the limit of the outlet temperature was analyzed [1].

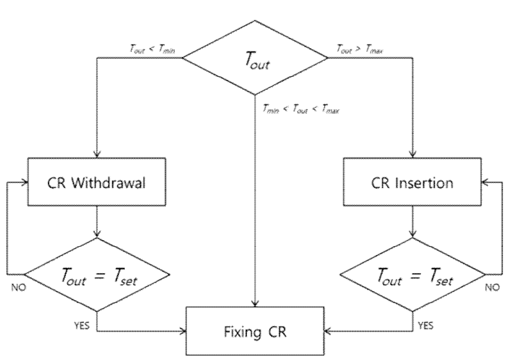

Fig. 1. Control of CRs based on Outlet Temperature Control Algorithm.

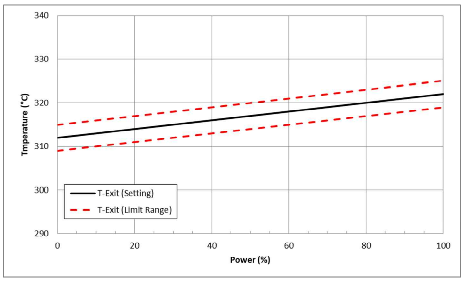

Fig. 2. Settings of Outlet Temperature Range

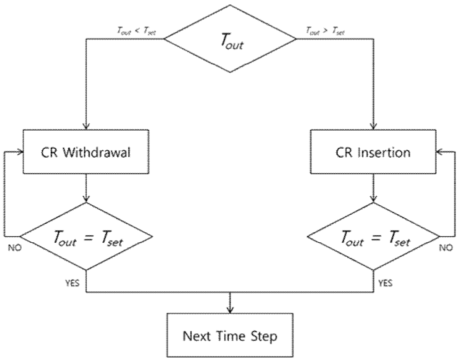

Fig. 3. Control of CRs based on Setting Temperature Control Algorithm.

2.2 Core Characteristic Factor Limit for a Load Following Operation

The axial offset (AO) and the three-dimensional and two-dimensional peaking factors(Fq, Fr) were selected as the main safety variables to be considered in the load following evaluation, and the highest priority was evaluated whether each value deviated from the safety limit during the load following evaluation. In this control concept, the operator does not directly control the core during load following operation. Therefore, when applying the steady state control concept of base load operation the load following operation capability is evaluated by analyzing the change of the nuclear characteristic factor that affects the thermal margin of the core during load following operation and proving that the effect is within the thermal margin secured by design.

During the daily load follow operation, the core needs to satisfy several operating limits such as core outlet temperature, power dependent insertion limit (PDIL), axial offset (AO), and pin peak power (Fq, Fr). In this study, only the regulating banks R3 will be used to control the power level because the range of power level is huge but control bank worth is enough to control the excessive reactivity. Core outlet temperature limit range was calculated through the Figure 2. The upper limit of peaking factor was 2.1 for Fq and 1.5 for Fr. The lower limit of AO was -0.3. The limit line for each core characteristic factor was shown in figure for each graph.

When the core transient calculation is performed, the change state of the core according to the time period is simulated through the transient calculation and the quasi-static calculation. In the case of transient calculation, the time-dependent diffusion equation and the delayed neutron equation are used as the governing equations in small time intervals and are mainly used when simulating an accident situation. In the case of quasi-static calculation, transient calculation is performed as a result of steady-state calculation, and a relatively large time period is used, and it is used when simulating the effect of xenon or depletion calculation. When the size of the time interval was within 5 minutes, it was confirmed that the results of the quasi-static calculation and the results of the transient calculation were almost similar. The figure 4 showed the result of simple quasi-static calculation with load following calculation with MASTER code[5].

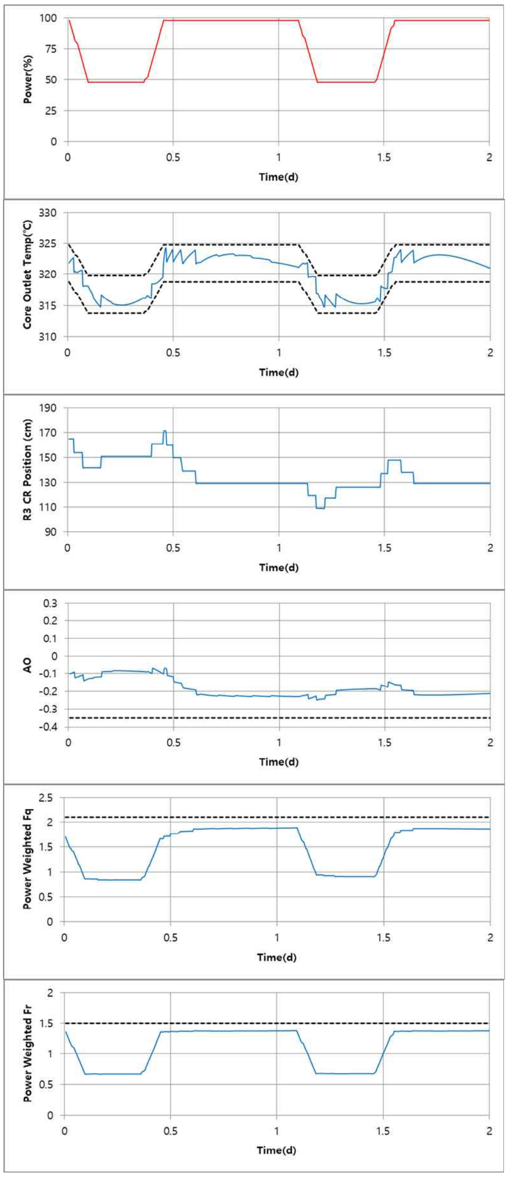

Fig. 4. Core characteristics factor to be considered when evaluating the load following (2 days)

3. Results

The evaluation of load following was performed with the core design code (MASTER) and preliminary evaluation was performed with various load demand.

Firstly, comparative calculations were performed at the BOC, MOC, and EOC by the automatic CR control algorithm with the core demand load. Through the figure 5, 6, 7, the core characteristic factor results were shown. There were two kinds of values which were black one is the first algorithm and the blue one is the second algorithm except the first graph. And the red line was design limit value. The design limit values(Fq, Fr, AO) were not exceeded in all cases.

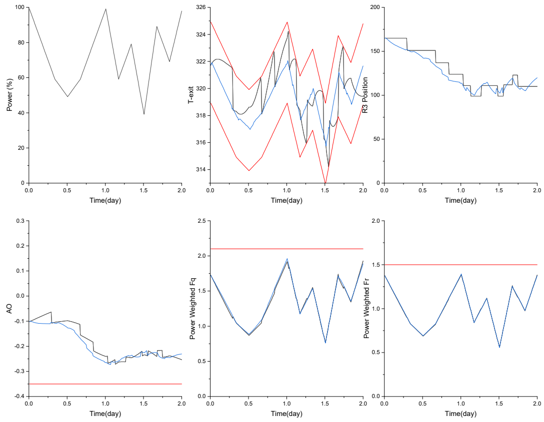

Fig 5. Load Following Operation Core Characteristic Factor at BOC condition

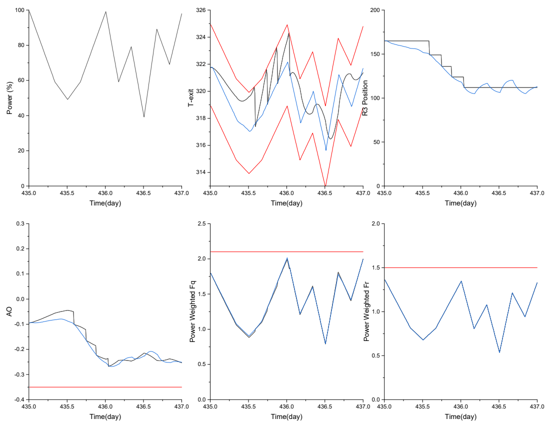

Fig 6. Load Following Operation Core Characteristic Factor at MOC condition

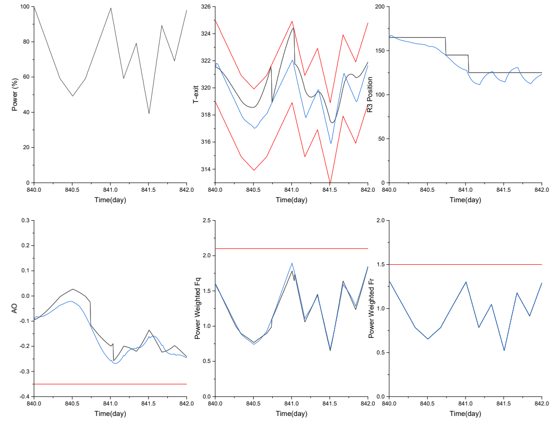

Fig 7. Load Following Operation Core Characteristic Factor at EOC condition

Secondly, comparative calculations were performed by the automatic CR control algorithm with the random demand load. Through the figure 8, 9, the core characteristic factor results were shown. There was one line with the first algorithm. And the horizontal line was design limit value. In case of random demand load, the design limit was not exceeded. However, these results were only for the nuclear core part not for the thermal hydraulic part or BOP.

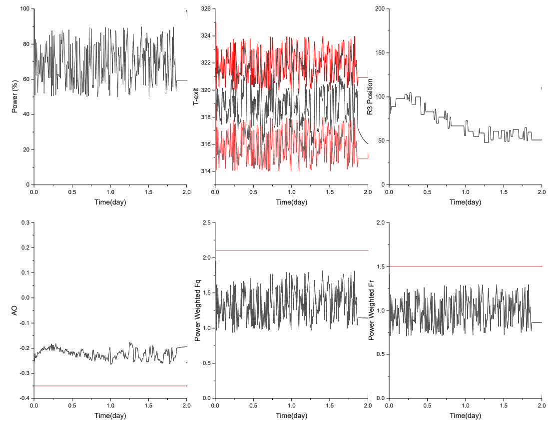

Fig 8. Load Following Operation Core Characteristic Factor with random demand load(small)

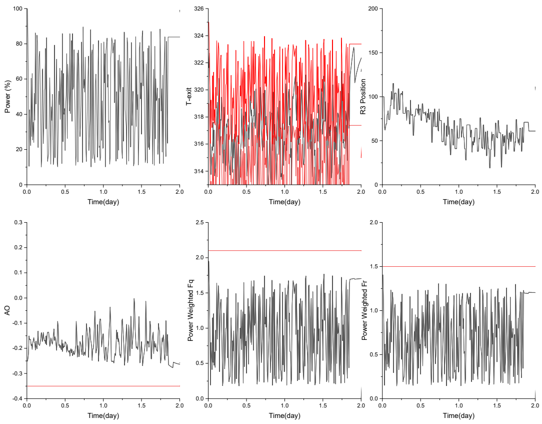

Fig 9. Load Following Operation Core Characteristic Factor with random demand load(large)

Finally, comparative calculations were performed by the automatic CR control algorithm with the normal demand load. Through the figure 10, 11 the core characteristic factor results were shown. There were two kinds of value except the first graph. And the horizontal line was design limit value. In case of long term cycle, the design limit was not exceeded. For long term cycle cases, the control rod was continuously withdrawn. To mitigate the withdrawal of control rod, the CBC letdown curve can be reflected with different core power.

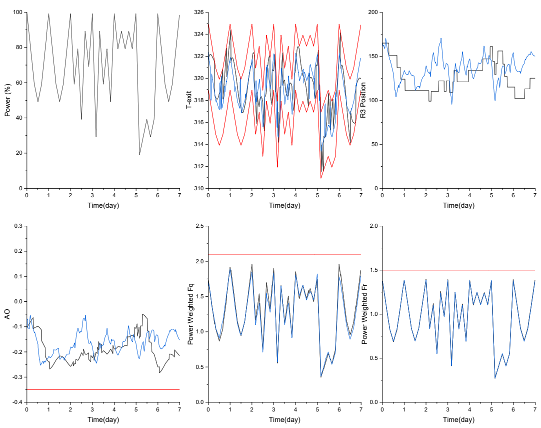

Fig 10. Load Following Operation Core Characteristic Factor with weekly demand load

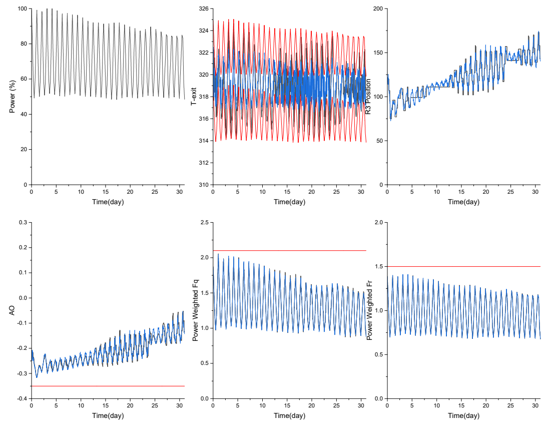

Fig 11. Load Following Operation Core Characteristic Factor with monthly demand load

4. Summary

In this study, the simulation of load follow operation reflecting both algorithms has been described. This paper shows the feasibility of load follow operation by adjusting the regulating bank at BOC, MOC, EOC and random load demand. Additionally the weekly and monthly core simulation was performed. For the entire simulation the core characteristic factor was satisfied with limit range. However, additional simulations need to be performed for the long term cycle to demonstrate the safety of load follow operation for the entire cycle.

Acknowledgement

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