Development of Load Following Operation Tracer for SMR

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1. Introduction

As interest in load following operation grows in domestic reactor research, a load follow operation capability evaluation and study with the Small Modular Reactor (SMR) is being actively pursued [1-2]. In evaluating load follow operation capability, assessing a reactor's load in real-time and defining an ordered approach for the control method following the measurement are crucial. In addition, the control system for performing automatic and real-time operation on control rods of a reactor without intervention of human operator is important [3].

In this study, we want to improve the load following control algorithm that was previously developed for a study on automation strategy and automatic control system for load following operation of SMR, as well as develop a load follow evaluation code to analyze the algorithm's effectiveness and user-friendly interface to perform an effective study on the future improvement of the automatic strategy.

2. The Load Following Control Algorithm

Based on the coolant outlet temperature, the load following control algorithm involves in the control rod movements only when the coolant temperature exceeds the limit band of the outlet temperature as shown in Fig. 1. The load following control algorithm shown in Fig. 1, takes the axial offset (AO) as an additional control parameter to minimize AO variations (caused by control rod movements and xenon redistributions) for the extended load maneuvering operations and quick return-to-full power from the load following operation. Addition of AO to the control parameters is required when the AO resulted from the arbitrary load following operation is close to its limit value. So therefore, the control algorithm is made to check the AO value and its limit to trigger boration/dilution operation. Any changes in boron concentration incur changes in core criticality, outlet temperature and subsequent control rod position. In addition, since the control rods are designed to move within the range of power dependent insertion limit (PDIL) to all-rod-out (ARO) positions, a supplementary control mechanism is required if the control rod movement is limited.

The control algorithm is shown in Fig. 1 that accommodates control mechanisms for AO, boron concentration, control rod position and outlet temperature. Note that, this algorithm assumes that there is no lag time of boron concentration change effect, which is not true in real reactor operation.

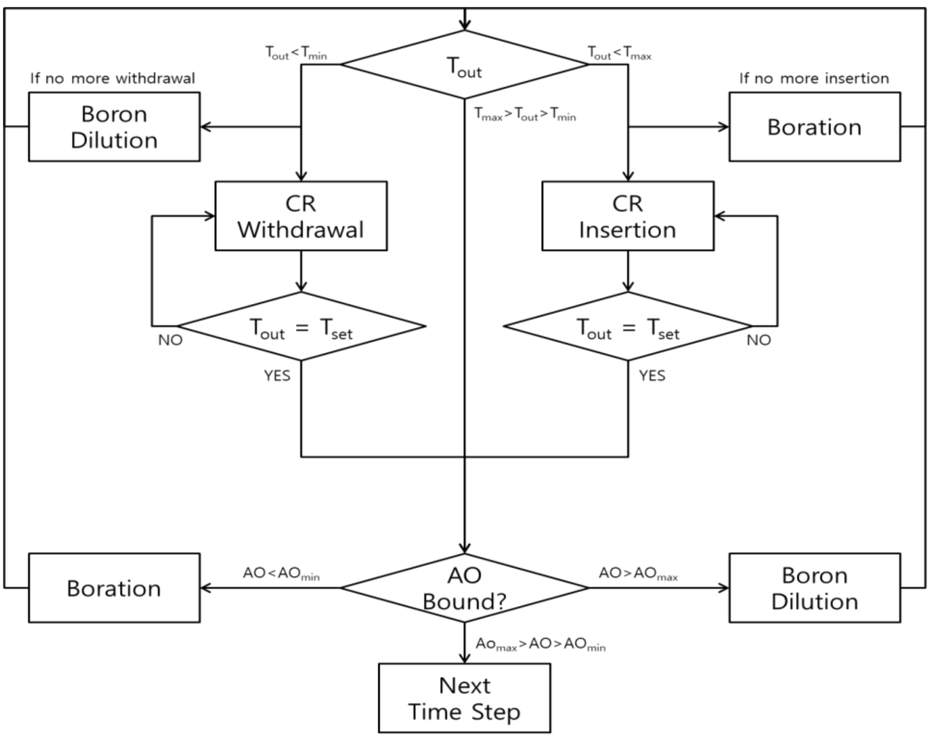

Fig. 1. The load following control algorithm.

3. The Application for the System

The code developed in this study is the application that applies the load following control algorithm to the MASTER code developed at KAERI [4] for the application to reactor physics analyses for pressurized water reactors. This application implements the automatic control system of control rods for SMR by analyzing the load evaluation results of the MASTER executed in previous time and reflecting it to next time input of same code. The code includes the module that changes input value according to load following control algorithm whenever the MASTER is executed, and then executes the code.

The SMR load follow evaluation of more than a day runs at least 48 hours, and accordingly, which is expected to take more than 10 minutes for the actual process of the code. Therefore, this code includes the module of updating the evaluation results from receiving at predetermined time intervals in real time and visualizing data as text and graphs.

4. Results

The implementation of the code is the application for Windows OS. The calculation module that executes the MASTER in the background process and implements load following control algorithm is developed by using FORTRAN, and the input/output interface and visualization module to assist the calculation module are developed by using C# and WPF. The application was named the Load Follow Tracer (LF Tracer).

4.1 Real-time Process for Load Follow Evaluation

The real-time process for load follow evaluation is responsible for input and output of module implementing load following control algorithm with executing the MASTER code, and it prints calculation result as logs and graphs in real time. Input values of LF Tracer are edited in the LF INPUT tab, and initial values of the MASTER code are edited in the MAS INPUT tab. The user interface about input editor module is shown in Fig. 2. LF Tracer executes the MASTER code once every given time, and outputs the resulting data of the load follow evaluation for the given time at each end.

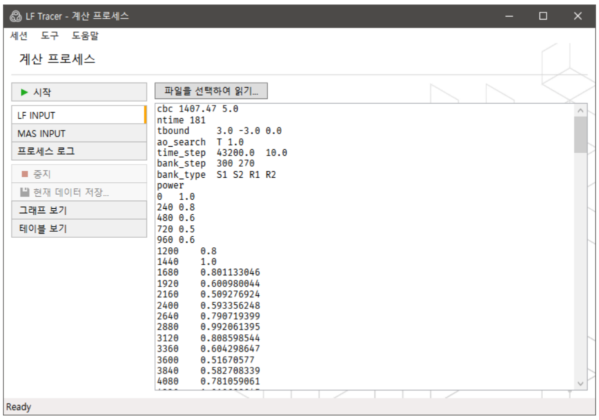

Fig. 2. The LF INPUT tab of the LF Tracer.

4.2 Visualization of Evaluation Result

The assessment results can be viewed in the real-time calculation module or the finished calculation result viewer module. In both modules, the visualization function is supported. It can support seven data graphs, including rod position, coolant outlet temperature, boron concentration, axial offset, peaking factors, Xe worth and A/P scatter plot. Other data may be added as needed. The important four of seven data graphs are shown in Fig. 3. The change in Xe worth according to the change in power weighted can be confirmed in Fig. 3. Except for the A/P scatter plot, the remaining graphs

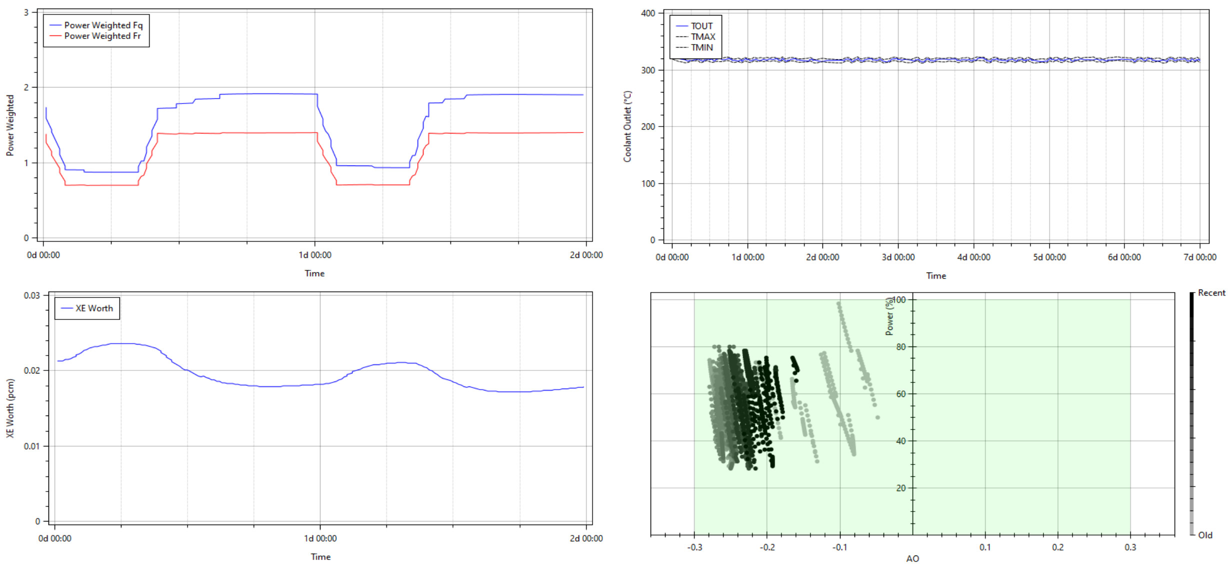

Fig. 3. The four data graphs of result visualization module. Power Weighted, coolant outlet, Xe worth and A/P scatter plot.

are the graphs with elapsed time as the X-axis. The A/P scatter plot is a distribution system plot over time using axial offset and power level as X-axis and Y-axis. In the A/P scatter plot, recent dots are marked in black and old dots are marked close to transparent, and it is possible to check a flow over time.

5. Conclusions

In conclusion, an execution handling module that executes the load following control algorithm in conjunction with the MASTER code and a real-time visualization module that logs and displays the vital load following simulation results were developed in this study.

It is expected that the code method developed in this study will be effectively used in the future to improve load following control algorithm and establish automation strategy for SMR operation control.

Acknowledgement

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REFERENCES

[1] W. Hwang, J. E. Kuh, H. R. Hwang, The Development of Load-Following Technology in Nuclear Power Plants, 1991.
[2] J. K. Park at el., The Analysis of Load Follow Operation for the KNGR, 1995.
[3] K. B. Park, T. K. Park, S. K. Zee, B. S. Koo, Evaluation of Automatic Control System for Long Term Load Following Operation using Control Rod for a SMR, Korean Nuclear Society, 2021.
[4] B. O. Cho, C. H. Lee, C. O. Park, C. C. Lee, MASTER – An Indigenous Nuclear Design Code of KAERI, Korean Nuclear Society, 1996.