Application of Load Follow Operation to Equilibrium Cycle of OPR1000

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1. Introduction

All nuclear power plants in Korea are operated at a base load, that is 100% rated power, and do not rely largely on power tracking control except for startup, shutdown, and some minor problem occurrences. However, if the electricity from nuclear power plants exceeds 50% of total electricity generation according to national energy plan, load follow operation is necessary to efficiently use the electrical energy. But it is very difficult to control the axial power distribution and reactor core reactivity at the same time as needed because of variations in nuclear system parameters [1]. In 1990s, an advanced reactor control algorithm, Mode-K, was developed [2,3] which uses regulation banks, boron control, and a heavy-worth bank (H-bank). The regulation banks and boron control are used for core reactivity control and the H-bank is used for the control of axial power shape. In this study, reactor core simulations with HELIOS/MASTER code system using Mode-K strategy are applied to the daily load follow operation in equilibrium cycle of OPR1000.

2. Computer Code System

For the design of OPR1000 equilibrium cycle and the simulation of load follow operation, HELIOS/MASTER code system is used in this paper. AURORA, HELIOS and ZENITH are computer codes to produce multi-group group constants for reactor core analysis. These three codes exchange input and output data through a common data base file (HRF file). The output file produced by ZENITH is processed into library files (cross section library and form function library) by HOPE and PROLOG code for the MASTER code and the MASTER code will be used to perform the simulation of 24 hour daily load follow operation at the beginning of equilibrium cycle.

3. Simulation of Load Follow Operation

3.1 OPR1000 Equilibrium Core

In this study, an equilibrium core of OPR1000 is loaded with 16x16 PLUS7 fuel assemblies in 3 batches. The cycle length is 475 EFPDs and the PLUS7 assembly has 5 guide tubes of 2x2 rods size. The uranium enrichments of the fuels are 4.0w/o and 4.5w/o. Gadolinia is used as burnable poison for the control of initial excess reactivity.

3.2 Daily Load Follow Operation of OPR1000

The power maneuvering for the 24 hours is shown in Fig. 1. The reactivity control of the core for the load follow operation was achieved by the movements of regulating banks, part strength banks and change of boron concentration.

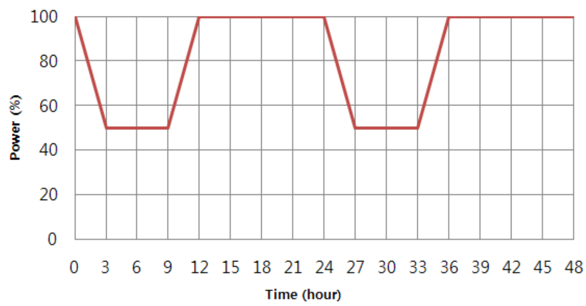

Fig. 1. The power varies from 100% to 50% in 3 hours, holds at 50% for 6 hours, then rises back to 100% in 3 hours and holds at 100% for 12 hours.

During the daily load follow operation, the core needs to satisfy several operating limits such as core inlet temperature, power dependent insertion limit (PDIL), axial offset (AO), and pin peak power (Fq). The PDIL of OPR1000 is shown in Fig. 2. The part strength rod has no PDIL. In this study, only the regulating banks R4 and R5 will be used to control the power level because the range of power level in the load follow operation is between 50% and 100%.

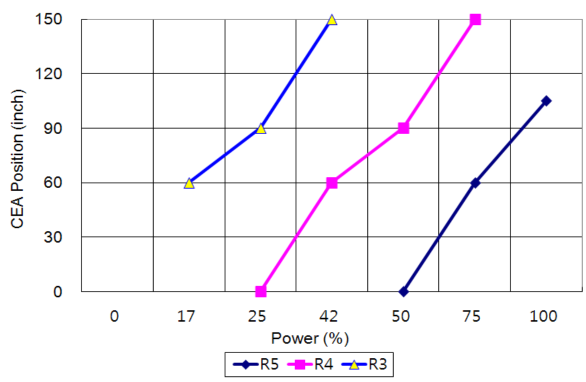

Fig. 2. PDIL of OPR1000

Also, axial offset and pin peak power should be within the limits of ±0.27 and 2.578, respectively.

3.3 Description of Mode-K Operation

The Mode-K utilizes a heavy worth bank (H-bank) dedicated to axial power distribution control independently of the existing regulating banks. Therefore, it is possible to provide a monotonic relationship between the motion of H-bank and the axial power shape change, which makes it easy to control axial power shape automatically. There are three stage flags: ORS (Overlap Restoring Stage), FOS (Fixed Overlap stage) and ARS (ASI Restoring Stage) in the Mode-K. These are the measures representing the degree of ASI deviation from target ASI. The ASI is defined as $(P_b - P_t)/(P_b + P_t)$, where P_b and P_t are normalized power of bottom and top halves of the core, respectively. The reactor regulation system (RRS) selects a bank or banks by using information of ASI deviation. Fig. 3 shows the concept of how to switch the stage flag. Soluble boron is the other means to control the core reactivity. Thus, it is unavoidable to adjust the boron concentration, and it is required to develop boron scenario which is predetermined through a lot of simulation to reduce the burden with the CVCS operation as well as the amount of liquid waste. In this study, the part strength bank is used instead of H-bank for the control of AO. At the beginning of daily load follow operation, mode-K uses a large amount of boron for axial power shape control.

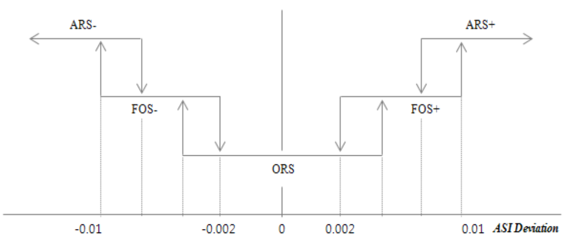

Fig. 3. Concept of stage flag for ASI control

3.4 Simulation Results

The following is the simulation results using the regulating banks, part strength banks and boron concentration control at the beginning of cycle (BOC) of OPR1000 equilibrium core (refer to Fig. 4, Fig. 5, Fig. 6).

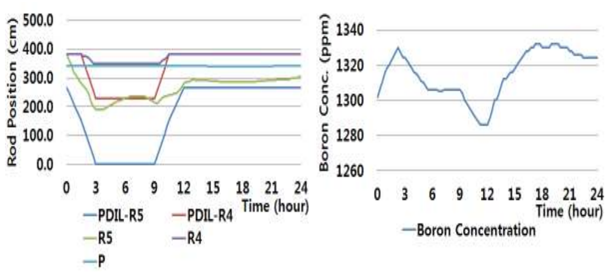

Fig. 4. Bank movements and boron concentration

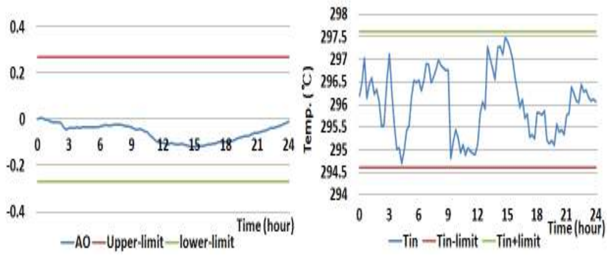

Fig. 5. Axial offset : $(P_t-P_b)/(P_t+P_b)$ [P_t : top power of core, P_b : bottom power of core] and core inlet temperature.

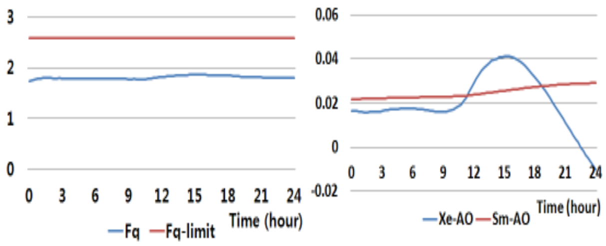

Fig. 6. 3-dimensional pin peak power (Fq) and AO of Xe and Sm

3. Conclusions

In this study, an equilibrium core of OPR1000 with 177 PLUS7 fuel assemblies is developed and the simulation of load follow operation reflecting Mode-K has been described. This paper shows the feasibility of load follow operation by adjusting the regulating bank, part strength bank and boron concentration at BOC of the OPR1000 equilibrium core. However, additional simulations need to be performed at the middle and end of cycle to demonstrate the safety of load follow operation for the entire cycle.

Acknowledgement

This work was supported by the Nuclear Research & Development program and Power Generation & Electricity Delivery program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (*No. 20111510100010 & No. 2011T100100241*)

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