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The Daily Load Follow Operation Capability of SMART

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1. Introduction

SMART (System-integrated Modular Advanced Reactor) has been developed by Korea Atomic Energy Research Institute (KAERI). SMART is Small Modular Reactors (SMRs) which accommodates fuel assemblies, steam generator, reactor coolant pumps and pressurizer inside of the reactor vessel and soluble boron in primary coolant. The core power control of SMART is based on the pre-determined core outlet coolant temperature as a function of the core power [1].

The capability of the load follow operation is evaluated for a daily load follow scheme of 2-6-2-14, the power variation from 100% to 50%. The evaluation is performed by MASTER [2]. MASTER is a neutron diffusion nodal code for a nuclear design of PWRs including SMRs and it has the capabilities to analyze the steady-state and transient core behaviors in 3-dimensional geometry based on the two-group diffusion theory.

In this paper, the major parameters – radial and 3-dimensional power peaking factors (Fr and Fq) and axial offset (AO) are evaluated for evaluation of load follow operation capability. This evaluation shows that the control rod worth within power dependent Bank Insertion Limit (BIL) is capable of sufficiently controlling the reactivity change due to the core power change and all of major parameters are controlled within limits with enough margin, without the change of the soluble boron in the primary coolant but with the control rod movement only.

2. Methods and Results

2.1 Evaluation of Required Reactivity

In order to evaluate the required reactivity for load follow operation, the reactivity change during load follow operation in All Rods Out (ARO) condition is evaluated. Fig. 1 shows the core power change during load follow operation and a daily load follow scheme.

For the power control without the change of soluble boron in the primary coolant, the control rod worth should be greater than the most positive and negative reactivity introduced during load follow operation. The reactivity change is affected by the power defect and xenon variation. Fig. 2 presents the reactivity change due to the core power change and xenon variation during load follow operation in ARO condition, and Fig. 3 shows the xenon variation. In the part of power change (0-2, 8-10, 24-26, 32-34 hours), the reactivity change due to power change is dominant than xenon variation effect. However, in the part of constant power region (2-8, 10-24, 26-32, 34-48 hours), the reactivity change is affected by xenon variation only.

Table I shows the required rod worth during load follow operation in ARO condition. The most positive and negative reactivity are compared with the R3 bank worth. The lead bank minimum insertion position is determined in such way that the inserted lead bank worth is greater than the inserted most negative reactivity during load follow operation. On the contrary, the lead bank maximum insertion position is determined so that lead bank worth to the BIL can be greater than the inserted most positive reactivity. Finally, the initial position of lead bank should be selected between these limits.

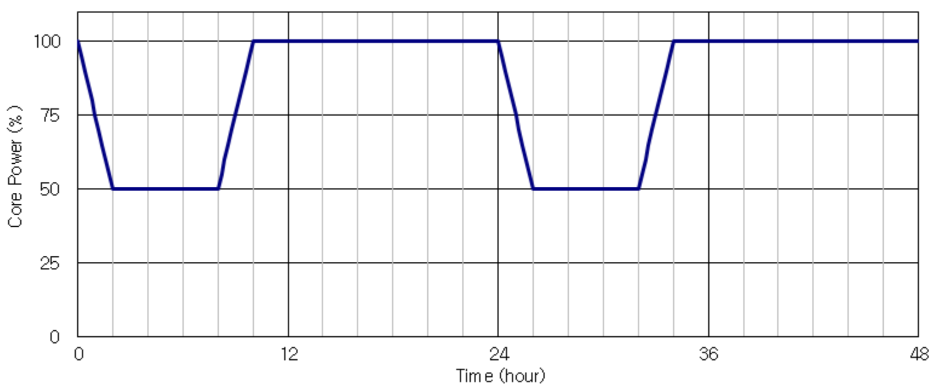

Fig. 1. Core Power Change during Daily Load Follow Operation

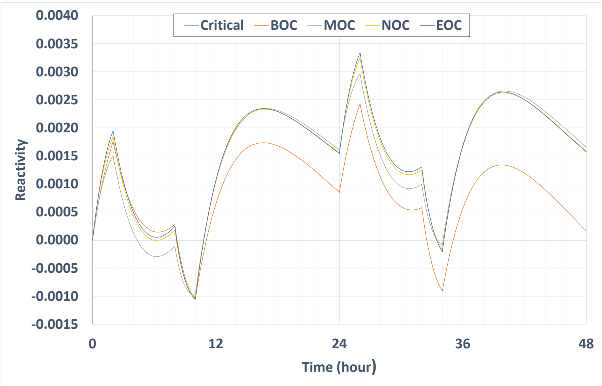

Fig. 2. Reactivity Change during Load Follow Operation in ARO Condition

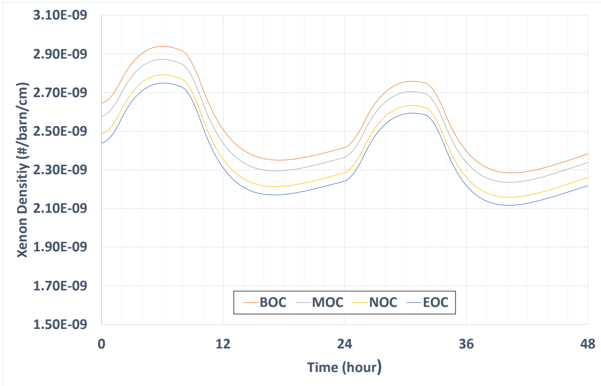

Fig. 3. Xenon Variation during Load Follow Operation in ARO Condition

Table I: Required Rod Worth during Load Follow Operation in ARO condition

	Required Rod Worth (Δρ)			
	BOC	MOC	NOC	EOC
Most Positive	0.002425	0.002966	0.003250	0.003340
Most Negative	-0.001043	-0.000965	-0.001015	-0.001054
Most Positive in Constant Power Region	0.001743	0.002655	0.002623	0.002638

2.2 Evaluation of Load Follow Operation

The core power control of SMART is based on the pre-determined core outlet coolant temperature (T_h) as a function of the core power. The load follow operation capability is evaluated for SMART core in which the reactivity is controlled by the control rod only (without soluble boron change), and the core outlet coolant temperature (T_{out}) range allowance is ±2.0°C. Therefore, if the difference between T_h and T_{out} is greater than 2.0°C, the control rod moves so that the T_{out} equals the T_h.

Fig. 4 shows the concept of the control rod movement strategy. SMART core is protected and supervised by the limitations of the 3-dimensional power peaking factor (Fq) and departure of nucleate boiling ratio (DNBR), and the operation is limited within the allowable axial offset (AO) range [3].

Since the operating parameters that affect the DNBR (such as the system pressure and the mass flow rate of the primary coolant) will not be changed during the normal operation, the DNBR can be estimated by the radial power peaking factor (Fr) [1]. Therefore, the evaluation can be performed by checking the variations of Fr, Fq, and AO during the operation.

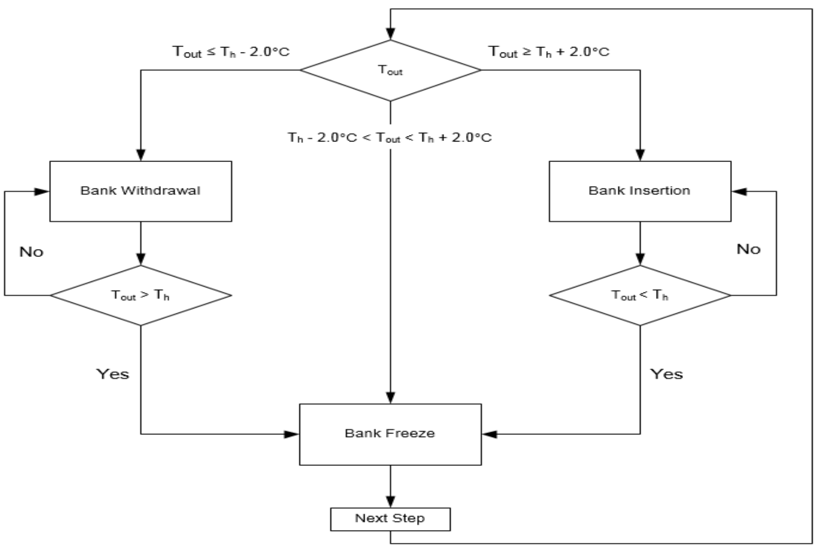

Fig. 4. Control Rod Movement Strategy for the Core Power Control of SMART

2.3 Results

2-6-2-14 daily load follow scheme is selected for a 48 hours simulation and the simulation starts from 100% power equilibrium state as shown Fig. 1. The concentration of the soluble boron in the primary coolant is fixed at the initial condition. In this load follow simulation, the core power changes over a period of 2 hours. The power is fixed for 6 hours and 14 hours for 50% and 100% power levels, respectively. The control rod should be moved for not only the part of the power variation but also the part of constant power region because of the xenon variation in the core.

Fig. 5 shows lead bank position during load follow operation at all of cycles. Dotted lines denote ARO and BIL. It shows that control rod movement is within the limits of all cycles. Fig. 6 presents core outlet temperature during load follow operation at all of cycles. It shows that core outlet temperature is within the allowance band of all cycles. Fig. 5 and Fig. 6 show the tendency for the changes in lead bank movement and core outlet temperature to be smaller as they are moved from BOC to EOC. This tendency is due to the difference in critical boron concentration (CBC). As the cycle goes on, the CBC decreases, and moderator temperature coefficient (MTC) becomes more negative. It means that there is a greater margin of reactivity for temperature changes.

Fig. 7 shows AO during load follow operation at all of cycles. Dotted lines denote upper and lower AO limits. It presents that AO is within the limits of all cycles. Since SMART is stable for any transients caused by Xenon-induced spatial oscillations [4], the effect of Xenon on AO is not evaluated in this paper.

Fig. 8 shows Fr and Fq during load follow operation at all of cycles, respectively. The red dotted line denotes limit of Fq and the blue dotted line denotes allowance of Fr. It shows that Fr and Fq are within the allowances and limits of all cycles, respectively.

These results show that all of those are varied within allowable ranges or limits with sufficient margins, without the change of the soluble boron in the primary coolant but with the control rod movement only.

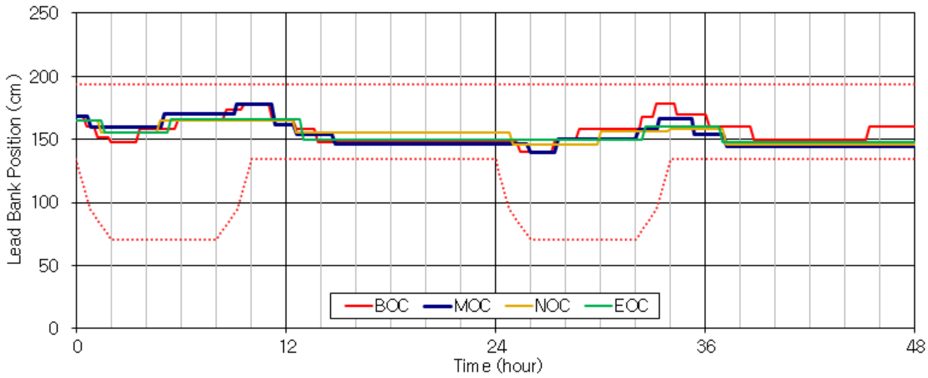

Fig. 5. Lead Bank Positon during Load Follow Operation

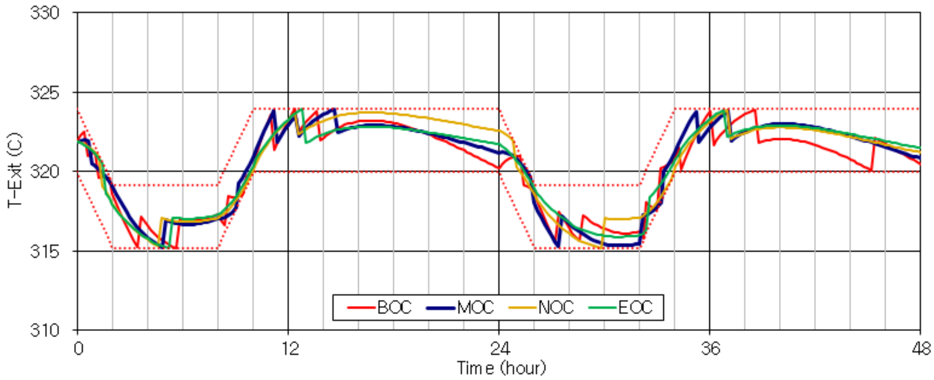

Fig. 6. Core Outlet Temperature during Load Follow Operation

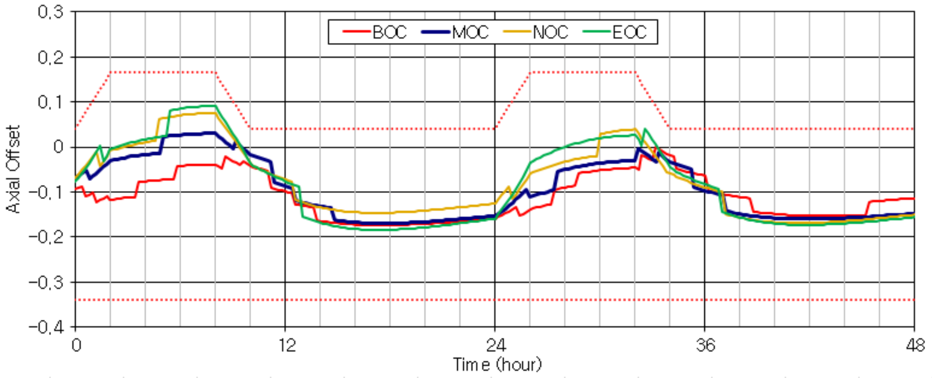

Fig. 7. Axial Offset during Load Follow Operation

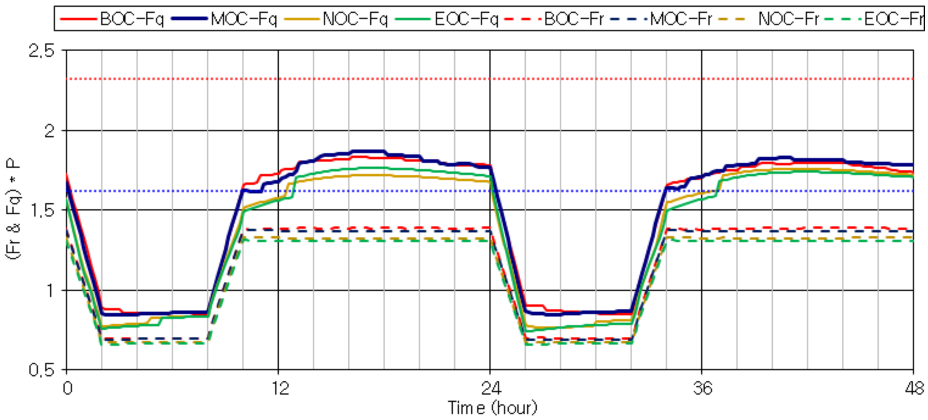

Fig. 8. Radial Power Peaking Factor and 3-dimensional Power Peaking Factor during Load Follow Operation

3. Conclusions

In this paper, the daily load follow operation capability of SMART core was evaluated using the MASTER code developed in KAERI. In order to evaluate the required reactivity for load follow operation, the reactivity change during load follow operation in ARO condition is evaluated and the initial position of lead bank should be selected between these required reactivity limits. The results of this evaluation show that the control rod worth within power dependent BIL is capable of sufficiently controlling the reactivity change due to the core power change and all of major parameter – axial offset (AO), radial and 3-dimensional power peaking factors (Fr and Fq) are controlled within limits with enough margin, without the change of the soluble boron in the primary coolant but with the control rod movement only.

ACKNOWLEDGMENT

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