Simulation of Core Axial Power Distribution During Coastdown Operation

Sang-Rae Moon[*]
Nuclear System Safety Lab., KHNP Central Research Institute
70, 1312-gil Yuseongdae-ro Yuseong-gu Daejeon, 34101 Korea
*[*]Corresponding author: **srmoonsr@khnp.co.kr***

1. Introduction

It is very important to control the core axial power distribution in nuclear power plant. And core axial burnup profile is closely related to the integrity of nuclear fuel assembly.

Most of the Westinghouse type plants in the Korean NPP apply RAOC (Relaxed Axial Offset Control) methodology but Westinghouse 2 loop apply CAOC (Constant Axial Offset Control) methodology. Because CAOC operation has axial offset margin less than RAOC operation, operators have a difficult in control the core axial power.

Recently, Westinghouse 2 loop plant has experienced Coastdown operation for about 3 weeks in end of 29 cycle and had a hard time in control axial flux difference within target delta I(ΔI).

In this paper, simulation of core axial power distribution during coastdown operation was performed using core design code(ANC).

2. Analysis Method and Code

General nuclear design methodologies for WEC type PWR were used for this analysis and ANC was utilized in practice for axial power simulation. ANC is an advanced nodal code capable of two-dimensional or three-dimensional calculation. ANC asbuilt database provided by fuel vendor for production of nuclear design report(NDR) was used for the axial power analysis and simulation .

3. General theory of axial flux difference

At power operation the reactivity feedbacks causes the flattening of the flux distribution, because the feedbacks acts stronger on positions, where the flux is higher. It follows there must be differences also in an axial direction.

For example, let assume the inlet temperature (Tin), which is determined by the pressure in the steam generators, therefore the inlet temperature changes minimally as thermal power changes. It follows the outlet temperature must change significantly as the thermal power increases. When the inlet temperature remains almost the same and the outlet changes significantly, it stands to reason, the average temperature of moderator will change also significantly. It follows the temperature of top half of the core increase more than the temperature of bottom half of the core. Since the moderator temperature feedback must be negative, the power from top half will shift to bottom half. Hence the axial flux difference, defined as the differences in normalized flux signals between the top and bottom halves of a two section excore neutron detector, will decrease.

Note that the allowable operating band limits are defined in terms of axial flux difference (AFD), or ΔI, which is defined as the power in the top half of the core minus the power in the bottom half of the core, (PT - PB), relative to the core's rated thermal power. To convert to axial offset, which is defined as :

$$\text{AO}(\%) = \left(\frac{Pt-Pb}{Pt+Pb}\right) \times 100\% \qquad (1)$$

$$\Delta\text{I}(\%) = \text{AO}(\%) \times \text{Power} \qquad (2)$$

4. Objectives of Power Distribution Control

The basic operational procedure for following load changes, as is required by the technical specification, is Constant Axial Offset Control (CAOC).

There are two objectives of power distribution control. These are licensability and operability. For licensability, we need to demonstrate that there is adequate margin to Safety limits, directly related to power distribution control, to which we must show margin: For operability, we must assure that margin exists between the expected operating conditions and the monitored safety limits. At the same time, we must avoid overly complex operating instructions and technical specifications. In addition, every NSSS contract includes statements about the load change capability of the plant(i.e., the flexibility of the plant to meet the utility's grid demands).

5. CAOC and RAOC Methodology

For CAOC, the allowable space is the ΔI band about the target AO. The band limits must then be added to the HFP target AO to obtain the operating space. For RAOC plants, the operating space is the band limits, independent of the target AO. For example, for a CAOC plant with an allowable AFD band of +/-5% and a target axial offset of -2% (determined at HFP, ARO, equilibrium Xe and applicable for all power levels), the allowable axial offset range would be -7% to +3% at HFP and -12% to +8% at 50% power. Axial offset is unrestricted at HZP.

For RAOC technical specifications, there is usually no limit below 50% RTP. Therefore, the axial offset should be skewed as positive as reasonably possible below 50% power.

6. Related Technical Specification

Technical Specification of Westinghouse 2 loop about power distribution limits is as follows:

The indicated axial flux difference (AFD) shall be maintained within the following target band (flux difference units) about the target flux difference. If core average accumulated burnup is less than or equal to 3,000 MWD/MTU, target difference shall be maintained within ±5 percent. If core average accumulated burnup is greater than 3,000 MWD/MTU, target difference shall be maintained within +3 percent, -12 percent. This limiting condition for operation is applied MODE 1 above 50 percent of rated thermal power.

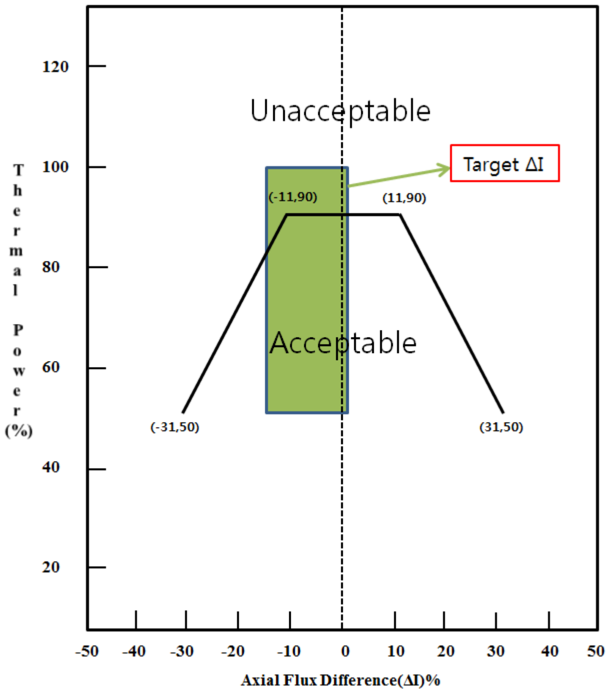

Figure 1 Technical Specification Limits of AFD

On the other hand, target difference of RAOC plants is within +8 percent, -14 percent at full power and is within +22 percent, -24 percent at below 50% power.

7. Simulation of Core Axial Power Distribution

7.1. Assumption for simulation

Various operational methods were reviewed to find scenarios that meet the target delta I during Coastdown operation at the end of cycle. Design burnup of 29 Cycle is 19,910 MWD/MTU and burnup window is ± 500 MWD/MTU. Adjustment control rod position and boron concentration was used as a operational methods. Measured core average burnup is 19,779 MWD/MTU and measured boron concentration is 11 ppm at the beginning of simulation. To avoid influencing on subsequence cycle design results, final shutdown core average burnup should be depleted within 20,410 MWD/MTU [(19,910 + 500) MWD/MTU]. Coastdown operation without reactivity insertion was applied at the rate of 1.38% power per day from full power to about 82% power. And then, Power descension rate was controlled less than 3% per hour to ensure fuel integrity and satisfy the request of utility.

7.2. Strategy of ΔI Control

To satisfy the shutdown margin(SDM) and initial condition of safety analysis, power dependent rod insertion limit(RIL) must be complied.

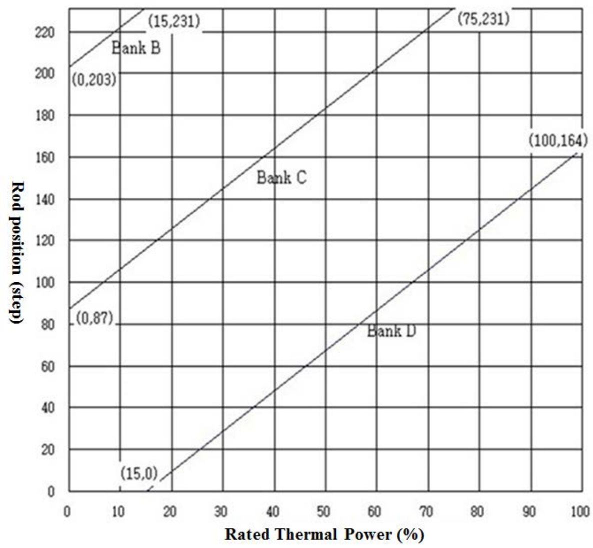

Figure 2 Power dependent rod insertion limit

Since boron concentration was very low at the end of cycle, D bank (Leading bank) was used to satisfy the target delta I at first. Allowable range of delta I is -13% ~ 1.6% at 50% power. That is more limiting when the upper power of core is greater than the lower power. Therefore, the lower power of core was controlled as large as possible. When the core power is down by boron injection, the upper power of core is rapidly increased due to negative MTC effect by temperature decrease of upper core. In this case, control rod insertion operation is required. Since xenon oscillation occurs for one week after arrival at 50% power, operator must insert or withdraw the control rod properly for delta I control. Finally, reactor can be shut down by boron injection or rod insertion because there is no delta I limit below at 50% power.

7.3. Results of ΔI Simulation

The results of simulation for satisfaction of target ΔI during Coastdown operation at EOC shows that it is difficult to meet the Tech Spec limit. Because the value of MTC at the end of cycle is more negative, it is expected that operators will be pressured to control the axial power distribution.

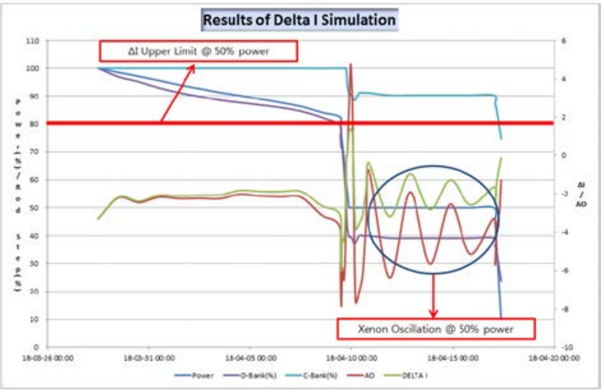

Figure 3 Results of Delta I Simulation

8. Conclusions

The Westinghouse type plants applying the CAOC Methodology have essentially less operational margin for delta I than RAOC plants. In particular, it is difficult to satisfy the target delta I during Coastdown operation at the end of cycle. Because the value of MTC at the end of cycle is more negative, it is more difficult to control the axial power distribution than beginning of cycle. In conclusion, in case of Coastdown operation at the end of cycle, the simulation of core axial power distribution must be performed in advance.

REFERENCES

[1] METCOM Chap 6, “Safety Analysis”, rev 63. 2012
[2] ANC Code User Manual