Application of Periodic 3DPCM for Core Monitoring System

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1. Introduction

The online monitoring system has become one of important elements for commercial nuclear power plants due to the growing requirements for the safety with efficient operation. The key point of this system is how to estimate the state of the core from measured operation data. The OASIS (Online core Analysis and Simulation System) was developed for WH type PWR which has movable in-core detector [1]. 3DPCM (3D Power Connection Method) was also developed to measure 3D core power distribution using the fixed in-core detector signals [2~3] and tested for KSNP (Korea Standard Nuclear Plant) such as OPR1000 and APR1400. According to previous study, 3DPCM coupling with neutronics code shows high accuracy. However, this method requires the neutronics code results at each calculation. Therefore, the long calculation time makes it impractical in the online monitoring system requiring the real-time 3D power distribution.

In this paper, the 3DPCM based alternative methodology which called periodic 3DPCM is proposed to reduce the calculation time within the reasonable accuracy. Then the offline core monitoring is conducted applying plant operation data by periodic 3DPCM.

2. Methodology

The 3DPCM estimates the core power distribution by coupling the measured data and the predicted core power distribution calculated by neutronics code whenever the in-core detector signals are available. The predicted values associated with core power distribution from neutronics code such as 3D-PCF(3D Power Connection Factor), W', and hot pin factor are generated following the core conditions. W', power to fixed in-core detector activation rate, is used to measure the assembly power of the axial detector region with in-core detector signal. The hot pin factor is multiplied to assembly power to calculate the peak fuel rod power in assembly. The 3D-PCF is the core factor to estimate whole core 3D power distribution from the measured assembly power. Based on these parameters and measured incore detector signal, the measured power at in-core detector existing node is calculated then other unknown power distribution is calculated from known measured power according to the predicted power distribution. The use of neutronics code which is able to generate predicted values following operating core condition eliminates the synthesis errors caused by applying the burnup dependent fixed function or constants generated in advance before the plant operation. In this paper, ASTRA (Advanced Static and Transient Reactor Analyzer) [4] is adopted as the neutronics code. But the nuetronics code takes high possession to the total calculation time. Therefore, periodic 3DPCM is proposed to decrease calculation time for application of online core monitoring system.

The main object of this method removes neutronics calculation with reasonable accuracy. It means that the parameters are not modified during reasonable period and the power distribution is estimated by coupling the updated measured data and the previous parameter values. Also, the power distribution of actual core during normal operation is not changed dramatically because the base load operation is main strategy. Then, the update time of prediction values is the most important factor affecting accuracy and effectiveness of the estimation.

3. Sensitivity Analysis

The errors caused by fixed prediction values are analyzed in various cases such as power increasing/decreasing, ASI change by Xe oscillation, and control rod insertion, which is able to be occurred during normal operation. The analysis for these cases is performed for a KSNP. For sensitivity analysis, the prediction values which are generated from initial ASTRA calculation are fixed while the ASTRA generated snapshot files which are expected to be almost same as real snapshot files are updated at each calculation steps. This means that the 3D power distribution is estimated with fixed prediction values and updated snapshot file at each calculation steps. The adoption of the snapshot file generated by ASTRA enables the elimination of errors caused by differences between state of actual core and predicted core as a result of neutronics code calculation. Therefore, the error which means differences between regenerated power distribution and ASTRA result is only caused by the fixed prediction values. The analysis procedure is summarized in Fig. 1.

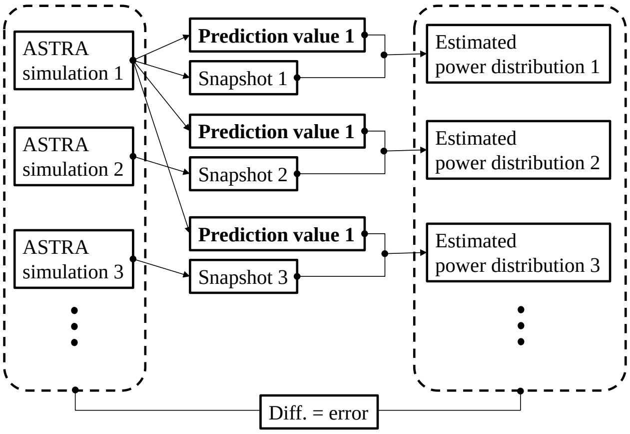

Fig. 1. The procedure of the sensitivity analysis.

Power increasing/decreasing case analysis is performed as 3% power change per hour. Fig. 2 shows the error propagation when power is increased during 2 hours from 15% to 21% at BOC with 15 minute of time intervals. Fig. 3 shows the error propagation when power is decreased during 2hours from 100% to 94% at BOC with same interval. As shown in Fig. 2 and 3, the error is bounded within 0.25% without the update of prediction values during 2 hours.

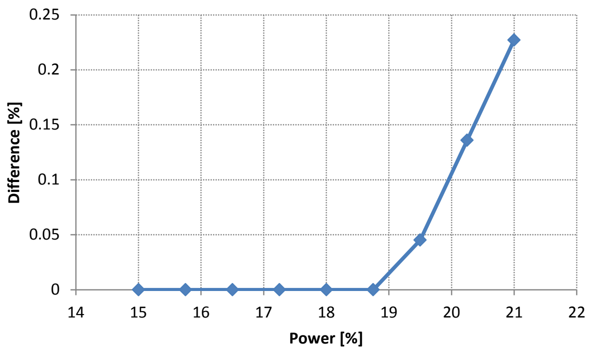

Fig. 2. Fq difference for power increasing operation.

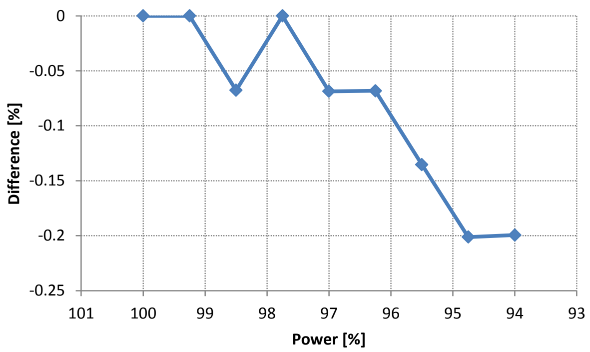

Fig. 3. Fq difference for power decreasing operation.

The free xenon oscillation at EOC is simulated to change the axial power distribution. The target period for the analysis is selected when it has highest ASI changing rate during free xenon oscillation. Then the calculation is performed at the selected period with 15 minute of time intervals. Fig. 4 shows the error propagation trend. It seems that the error propagation trend is changed twice. It seems that the location change where Fq is occurred affects the change of error propagation trend. Although the location of Fq is changed at those times when generate the snapshot files, the prediction values are fixed with initial ASTRA calculation case. This kind of inconsistency makes the change of error propagation trend. As shown in Fig. 4, the error is bounded within 0.64% and 1.07% during 1 and 2 hours, respectively.

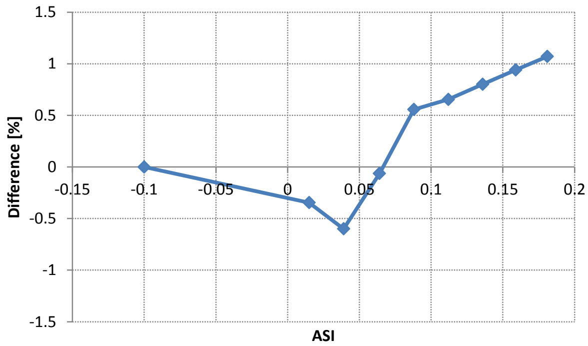

Fig. 4. Fq difference for Xe oscillation at EOC.

Fig. 5 shows the error due to the lead control rod insertion at BOC, HFP. In this analysis, only rod position is changed without time interval. As shown in Fig. 5, the error is bounded within 1.15%. Meanwhile, the result shows that the trend of Fq error propagation is changed twice when 30% and 70% insertion by same reason of Fq occurring position change.

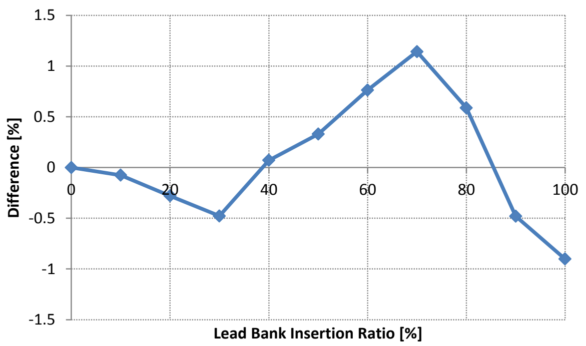

Fig. 5. Fq difference for lead bank insertion at BOC.

4. Application

The online core monitoring system, called OASIS is being developed in KNF. The flow chart of OASIS program for KSNP is shown in Fig. 6.

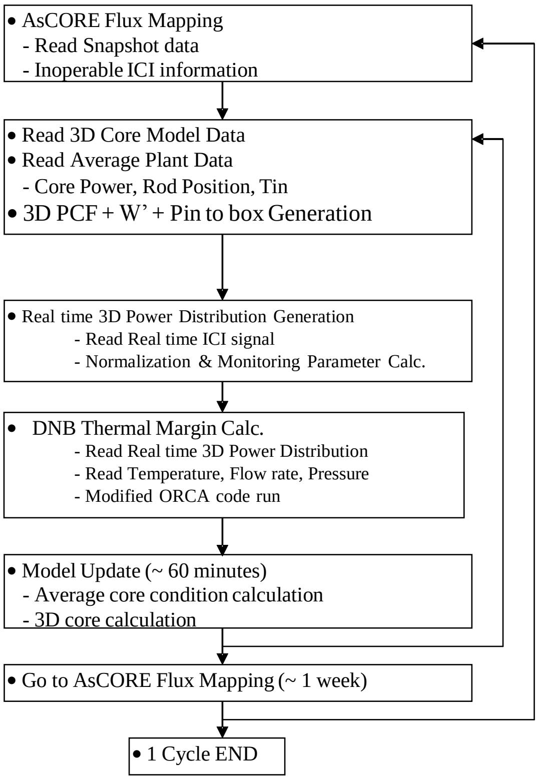

Fig. 6. The flow chart of OASIS program for plant operating simulation.

According to the plant data update strategy of OASIS program, the offline core monitoring simulation has been conducted with plant operation data to estimate the applicability of 3DPCM for the core monitoring program. In this application, the prediction values from neutronics code is updated at each hours or at that time of 30% change of any control rod position applying the result of sensitivity study. The target nuclear plant data such as power, ICI signals, inlet temperature, pressure, moderator mass flow rate, etc. is obtained at intervals of one minute during 45 days at BOC of a commercial OPR1000 plant. The power change history at starting operation is shown in Fig. 7.

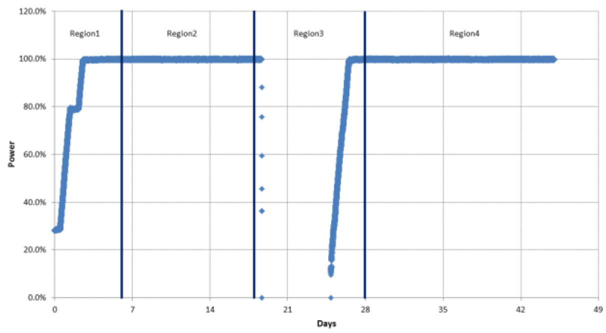

Fig. 7. Relative power change at BOC of a commercial OPR1000 plant.

In this analysis, the result is discussed focusing at region 1 when the core power is ascending to HFP and region 4 when the core power has arrived at HFP as expressed in Fig. 7. Fig. 8 and 9 shows the core maximum Fq at region 1 and 4, respectively. In Fig. 8, it seems that the trends of the periodic 3DPCM are well matched with those of the measurement data, but the values are somewhat different from the results of AsCORE [5]. It is caused by the difference between node-wise and point-wise. The results of periodic 3DPCM are expressed by node-wise values but AsCORE results are given by point-wise by expansion from node-wise values. It is confirmed that the difference becames negligible when the results are compared with the same node-wise values. Also, the axial power distribution is well matched with other flux mapping code results as shown in Fig. 10. Therefore, it is able to infer that the core power distribution by periodic 3DPCM is well done although given prediction values come from different axial power distribution. The peaking factor at HFP lies between design and measured values as shown in Fig. 9.

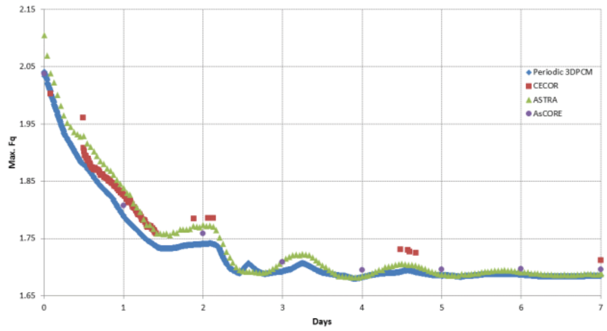

Fig. 8. Fq during the power ascending for a commercial OPR1000 plant in region 1.

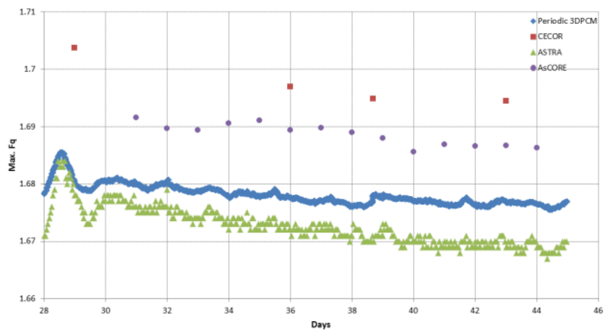

Fig. 9. Fq at BOC HFP operation of a commercial OPR1000 plant in region 4.

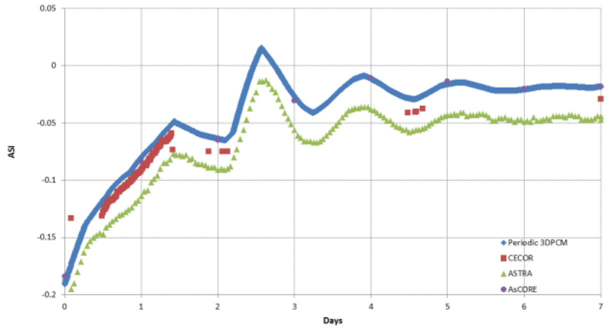

Fig. 10. ASI during the power ascending for a commercial OPR1000 plant in region 1.

5. Conclusion

The 3DPCM is one of powerful option for regenerating core power distribution utilizing measured data from in-core detector and prediction values from neutronics code. The periodic 3DPCM is proposed to reduce the number of neutronics calculation with reasonable accuracy for the application to the online monitoring system development. The periodic 3DPCM is analyzed by 3 cases of sensitivity studies. The errors for the results of power changing operation, ASI changing simulation, and lead control rod insertion are bounded in 0.25%, 1.07%, and 1.15%, respectively. If the update time is shorten as 1 hour, the errors for power changing operation and ASI changing simulation are bounded in 0.07% and 0.56%, respectively. As a result, the update time of 1 hour and prompt update at 30% control rod position change are reasonable considering both conservativeness and effectiveness to update the prediction values.

OASIS program utilizing periodic 3DPCM is verified using the plant measurement data and snapshot files which were generated during 45 days operation. The result shows that the results of OASIS are well matched with the other flux mapping results such as AsCORE and CECOR.

ACKNOWLEDGMENTS

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