Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22, 2009

Online Core Monitoring Method in WH type PWR

Hae-Chan Lee, Do-Ik Chang, Sung-Min Choi and Tae-Je Kwon
Korea Nuclear Fuel Company, Ltd., Core Engineering Department
1047 Daedukdaero, Yuseong-gu, Daejeon 305-353, Korea
hclee@knfc.co.kr; dichang@knfc.co.kr; smchoi@knfc.co.kr; tjkwon@knfc.co.kr

1. Introduction

Measurement of 3D power distribution in Westing-house type PWRs is performed every 31 EFPD to verify the vaildity of the nuclear design. Nuclear safety parameters are confirmed through the measured 3D power distribution per the Technical Specifications. This surveillance warrants the next one month operation with only axial flux deviation monitoring using ex-core detector.

The aggressive core operation, for example long cycle length and power up-rate, makes the reduction of safety margin. So, online core monitoring is necessary for safe operation and advanced nuclear fuel vendors have their unique system.

In the case of WH type PWRs, the plants have thermocouples and ex-core detectors which are online monitored and the signals are stored at plant main server and web server. Real time 3D core power distribution can be generated using thermocouple and ex-core detector signal and the 3D power distribution is calibrated by monthly flux measurement.

Therefore nodal calibration method using monthly measured power distribution, radial power shape calibration method with thermocouple signal and axial power shape calibration method with ex-core detector are studied and the online core monitoring program is developed on this paper.

2. Online Core Monitoring Method

2.1. Nodal Calibration Method

Online core monitoring system should have 3D nodal code which has almost same core calculation results as those of the reload core design. But, the real time 3D power distribution is different from the shape of 3D core analysis code although the core follow calculations are well performed using detail core conditions. Thus, nodal calibration based on measured 3D power distribution should be done for the generation of realistic 3D power distribution.

We can easily take the nodal calibration factors from the monthly flux mapping. INCORE code calculate the factors at the movable detector location as follow[1];

$$NCF(i,j) = MRR(i,j)/PRR(i,j)$$

where,
MRR = Measured Reaction Rate
PRR = Predicted Reaction Rate

Unmeasured assembly powers are predicted through the empirical fitting method in INCORE code. However, surface spline fitting(SSF) method which is an improved radial power fitting technology is applied in this study. It's confirmed that the accuracy and smoothening of prediction for unmeasured assembly powers are improved by SSF[2,3].

2.2. Radial Power Calibration Method

In the case of WH type 3-loop PWR, 39 fuel assemblies have core exit thermocouples installed above them to measure assembly average outlet temperature. This information can be translated into the enthalpy rise up the fuel assembly. If the thermocouple correctly measures the average temperature of coolant in that assembly, the axially integrated radial power distribution is proportional to the thermocouple signal. So, radial power calibration factor can be calculated as follow;

$$RPC(i,j) = \frac{\frac{\Pr\cdot\overline{\Delta H}}{z}\int_0^z P(i,j,k)dz}{H(T_{out}(i,j)) - H(T_{in})}$$

where,
Pr = Relative Power
H = Enthalpy

Initial inverse RPCs at thermocouple location are used to fit the RPCs at whole core location with SSF and then these inverse RPCs at all assemblies are used to predict real time radial assembly power until next model update.

Real time RPCs can be get continuously from the online database which is in the plant main server or web server and these real time RPCs are fitted for whole core by SSF and then real time radial assembly power can be calculated as follow;

$$P_{xy}^{Real}(i,j) = RPC_o^{-1}(i,j)\cdot RPC^{Real}(i,j)\cdot P_{xy}^o(i,j)\cdot NCF(i,j)$$

2.3. Axial Calibration Method

Axial Offset(AO), the power difference of top and bottom core power, is monitored by ex-core detector. If the measured AO differ from the predicted AO, the axial power shape of the model is adjusted by Furier correction term as follow;

$$P_{xy}(z) = P_{xy}^R(z) + \Delta AO\int P_{xy}^R(z)dz\cdot\frac{\pi}{2h}\sin\left(\frac{z+h/2}{h+2\delta}\pi\right)$$

where,
P_{xy}^R = *calibrated radial power*
δ = *extrapolation length*

2.4. Model Update Method

Above real time adjusted 3D power distribution can be used for online core monitoring after normalization.

The plant operator can easily monitor the real time assembly wise FQ, FΔh, AO and core tilt through online core monitoring program. However, the core analysis model should be updated to exactly predict the subsequent core condition, for example AO control, critical position after trip because above calibration factors are only used to adjust 3D power distribution not reactivity.

Node wise macroscopic cross section correction in 3D core analysis code is the best way to adjust node power to real time 3D power distribution for model update. But, the average core conditions, for example control rod step, Tin, etc, are simply used for model update without cross section correction in this paper. The method which artificially adjusts the power shape of the 3D core model to keep consistency with real time core power shape predicts the subsequent core condition worst than node wise macro-scopic cross section correction method.

3. Development of Online Core Monitoring Program

Online core monitoring program has been developed to realize the online 3D core power distribution and to perform the sensitivity study on each plant data. The detail program flow chart is shown in Figure 1. Initial INCORE output and 3D core model at the same burn-up point are necessary to run this program. The 3D core model is updated after 15 minutes for the calculation of the initial inverse RPC and the INCORE output is replaced with new one after one month to revise the NCF.

Sample run is done for K3C17 and started from 174 MWD/MTU. The plants data of sample run are edited as ASCII file which is taken from web server MS SQL DB. The results of the program are shown in Figure 2. The safety core parameters are summarized in the left section and the radial power, temperature distribution and core tilt are displayed in the right section.

4. Conclusions

Nodal calibration, radial and axial power calibration method are applied in the online core monitoring program to get the real time 3D power distribution. The safety parameters of Westinghouse type core can be online monitored using the thermocouple and ex-core detector signals. According to the results, real time 3D power distribution based on INCORE measurement is reasonable and this program can be applied in plant operation as a support tool.

As the further study, node wise cross section correction method will be applied in the 3D core analysis code to predict the subsequent core condition perfectly. The sensitivity study will be done for the plants signals.

REFERENCES

[1] Baek, J. H., et al., Procedure for INCORE/CARIN Constant Generation, July, 1990.
[2] Harder, R. L., et al., Interpolation Using Surface Splines, Journal of Aircraft, October, 1971.
[3] Lee, H. C., et al., Improved Radial Power Distribution Fitting Method in INCORE Code, KNS, May, 2007.

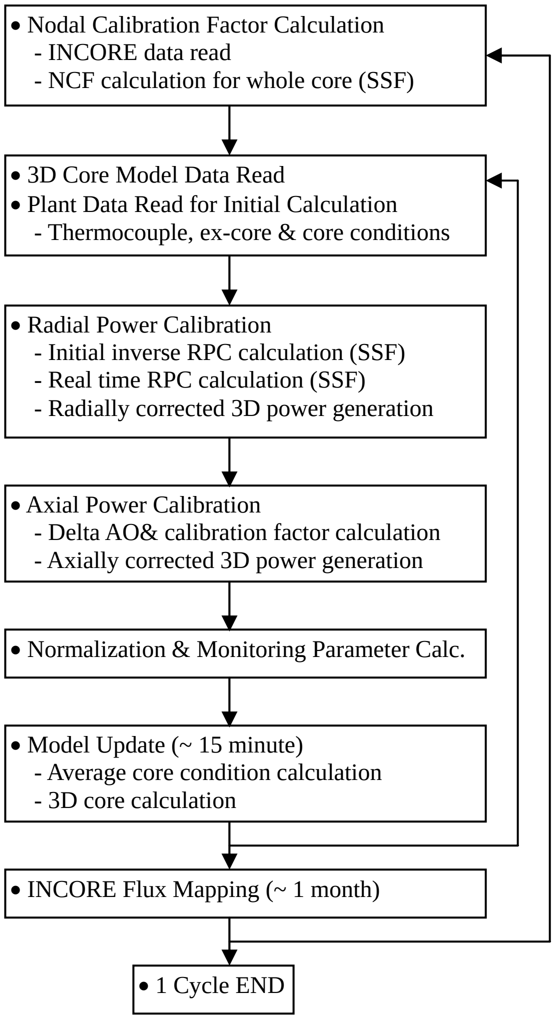

Figure 1. Online Core Monitoring Program Flow Chart

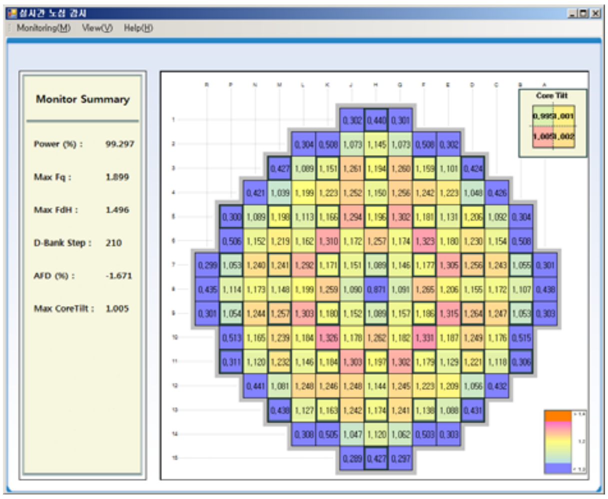

Figure 2. Online Core Monitoring Program Results for K3C17