Implementation of Multigroup Calculation for Commercial Reactor Core

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1. Introduction

KNF has made an effort to develop a set of codes for designing commercial reactor core as a part of the project "Development of Core Design Codes for Nuclear Power Plants". ASTRA (Advanced Static and Transient Reactor Analyzer), one of the codes, is for three dimensional reactor core analysis and the other code is ECHO (Equivalent Cross-section and HFF Organizer for ASTRA) which can generate a set of microscopic cross-sections and homogenized power form functions from results of assembly-wise calculation using KARMA which had been developed by KAERI.

Since ASTRA should be a commercial reactor design code for the MOX-fueled reactor or fast reactors as well as PWR, core analysis based on multigroup structure was one of important requirements. For this reason, we had to introduce the modern methodologies applicable to nodal and pin power reconstruction calculations. ECHO also has been developed for multigroup cross-section and constants with Equivalent theory. In this work, we are going to introduce their multigroup methodologies simply and verify multigroup calculation capability by solving commercial core problem.

2. Methodologies

2.1 Multigroup CMFD methodologies

Recently, the coarse mesh finite difference (CMFD) method is widely used to reduce the calculation time for the higher solutions like whole core transport methods as well as nodal methods. In this work, we have optimized a performance of ASTRA with a nodal calculation accelerated by CMFD calculation. Especially, SENM (source expansion nodal method) based on two-node scheme that is one of the modern semi-analytic nodal methods and developed by Seoul National University has been employed into ASTRA as a main nodal method solving multigroup problems. A solution of SENM is expressed with a set of trigonometric and polynomial functions as following. It is a result of expanding the right hand side of neutron balance equation to 4th order Legendre polynomial.

$$\begin{aligned}\phi_g(\xi) &= \phi_g^H(\xi) + \phi_g^P(\xi) \\ &= A_g \sinh(\kappa_g \xi) + B_g \cosh(\kappa_g \xi) + \sum_{i=0}^{4} c_{gi} P_i(\xi)\end{aligned} \quad (1)$$

where $\kappa_g = (h\sqrt{\Sigma_{rg} / D_g}) / 2$.

The five polynomial coefficients (c_{gi}) of the solution are easily obtained by employing the method of undetermined coefficient and the remaining two trigonometric coefficients are obtained with boundary conditions.

The best advantage of the source expansion nodal method is the use of source iteration scheme that predetermines the right hand side of the one dimensional neutron balance equation using an initial or the previous general solution so that the group-coupled neutron balance equations is divided into the decoupled equations. With this iteration scheme, time taken by nodal calculation isn't increased exponentially but linearly with respect to the number of energy groups. Moreover, the source expansion nodal method achieved good convergence and stability by applying two-node nodal scheme.

In the multigroup calculation, multigroup CMFD calculation is essentially necessary to update the global neutron flux but it can't provide good performance compared to twogroup calculation due to more energy groups. To resolve this issue, two-level CMFD calculation that accelerates multigroup calculation with twogroup calculation is introduced.

2.2 Multigroup Pin Power reconstruction

For the multigroup core calculation, multigroup pin power reconstruction method should be also implemented as well as multigroup CMFD method. Seoul National University developed a method of the multigroup pin power reconstruction with source expansion approach that was same thing applied to source expansion nodal method. The method is based on a polynomial expansion of the right hand side of the axially averaged two-dimensional neutron balance equation. Expanding to fifteen term polynomials, the general solution is expressed with a set of polynomial and trigonometric functions. The fifteen polynomial coefficients of the particular solution are determined with the method of undermined coefficient and the eight trigonometric coefficients of the homogeneous solution are determined with eight boundary conditions which consist of four surface currents and four corner fluxes.

A feature of this method is to consider corner discontinuity as well as assembly discontinuity. Modern PWR fuels are optimized with zoning technique that place low-enriched rod to edges or corners of an assembly. Since flux discontinuity at corners can become very large in these cases, this method employed a corner discontinuity factor to reduce the discontinuity.

2.3 Homogenization Process in ECHO

ECHO performs a role that generates assembly-wise homogenized micro cross-sections and constants from the results of pin-cell calculation which is done by KARMA.

$$\sigma_G^N = \sum_{n \in N} \sum_{g \in G} \sigma_g^n \phi_g^n \Big/ \sum_{n \in N} \sum_{g \in G} \phi_g^n \qquad (2)$$

Where N and n is pin-cell and assembly index, respectively and G and g is many-group and multigroup index, respectively.

3. Estimation of Multigroup Calculation

For the purpose of estimating effects of multigroup calculation for commercial pressurized water reactors, a depletion calculation was performed for Cycle 1 of Yonggwang Unit 3.

3.1 Depletion Calculation

First of all, depletion calculation results were compared to verify the multigroup implementation. As shown in Fig 1, the multigroup result is almost same to the twogroup result.

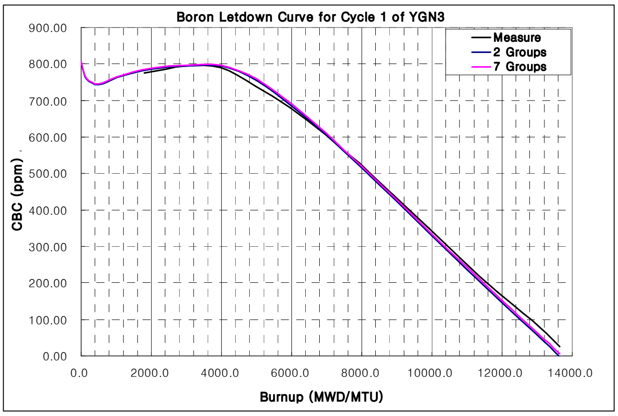

Fig 1. Boron Letdown Curve for Cycle 1 of YGN 3

3.2 Power Distributions at BOC, MOC & EOC

We compared predicted power distribution with measured power distribution that is calculated by CECOR to estimate multigroup effects. In this calculation, CECOR constants generated by ASTRA were used. Fig 2 shows a comparison between a predicted power distribution with two-group structure and a measured power distribution of CECOR. From Table 1 that shows summary of the comparison at BOC, MOC and EOC, we observed multigroup calculations gave smaller differences than twogroup calculations. This improvement of multigroup results was due to reduced error near reflectors.

		2012 (MWD/MTU)	7080 (MWD/MTU)	13651 (MWD/MTU)
2G	RMS[1]	-3.46%	4.11%	3.43%
	MAX[2]	1.53%	1.31%	1.23%
MG	RMS	-3.12%	2.61%	-2.39%
	MAX	1.12%	0.97%	0.99%

- RMS[1] : Root mean square of relative errors

- MAX[2] : Maximum relative error

Table 1.Summary of comparing power distributions

	A	B	C	D	E	F	G	H	J
1						B 01 0.549 0.544 1.045	C 0.814 0.811 0.476	D 0.947 0.944 0.366	C 02 0.813 0.810 0.300
2				B 0.546 0.550 -0.751	D 03 0.949 0.949 -0.018	D2 1.104 1.094 0.893	C1 04 1.179 1.165 1.221	C1 1.231 1.216 1.310	C1 1.171 1.166 0.488
3			C 0.644 0.653 -1.401	D1 07 1.059 1.066 -0.689	D2 1.231 1.221 0.809	A 0.888 0.880 0.938	B2 1.221 1.202 1.518	B1 1.120 1.103 1.603	B2 1.205 1.202 0.243
4		B 0.537 0.551 -2.671	D1 1.054 1.070 -1.468	C1 1.157 1.154 0.274	A 08 0.885 0.866 2.185	C1 1.213 1.183 2.479	A 09 0.920 0.896 2.676	B2 1.213 1.198 1.223	A 0.894 0.896 -0.203
5		D 0.921 0.952 -3.315	D2 12 1.187 1.224 -2.996	A 0.864 0.868 -0.446	C1 1.192 1.165 2.292	A 0.885 0.869 1.902	D2 1.317 **1.288** 2.282	A 0.911 0.902 0.955	D2 1.294 1.288 0.498
6	B 0.529 0.544 -2.718	D2 14 1.064 1.097 -3.049	A 0.868 0.881 -1.473	C1 1.197 1.185 0.979	A 15 0.895 0.869 3.011	C1 1.234 1.198 2.994	A 0.921 0.905 1.802	B2 16 1.231 1.201 2.488	A 0.906 0.905 0.167
7	C 0.798 0.810 -1.481	C1 1.164 1.166 -0.164	B2 19 1.216 1.202 1.208	A 0.902 0.896 0.615	D2 1.314 1.288 2.084	A 20 0.932 0.905 3.007	B 1.251 1.225 2.088	B1 1.105 1.079 2.486	B 1.233 1.225 0.690
8	D 22 0.930 0.944 -1.451	C1 1.222 1.216 0.536	B1 1.116 1.103 1.221	B2 1.202 1.198 0.326	A 0.901 0.902 -0.106	B2 1.215 1.201 1.211	B1 1.102 1.079 2.198	A 23 0.916 0.887 3.236	B1 1.096 1.079 1.628
9	C 0.806 0.811 -0.545	C1 1.175 1.165 0.846	B2 1.212 1.202 0.829	A 0.891 0.896 -0.508	D2 25 1.271 1.288 -1.277	A 0.900 0.905 -0.484	B 1.236 1.225 0.892	B1 1.102 1.079 2.130	B 26 1.241 1.225 1.335

Fig 2. Comparison measured and predicted power distributions of twogroup calculation at BOC

4. Summary

A capability of multigroup calculation has been implemented into ASTRA and ECHO to design MOX-fueled core and fast reactor core as well as commercial reactor core. In this work, we performed a depletion calculation for Cycle 1 of YGN3 with twogroup and multigroup constants that were generated by ECHO to verify the capability of multigroup calculation. In the comparison of boron letdown curves, multigroup calculation shows slightly better results but not noticeable. In the comparison of power distributions, multigroup calculation produced better results than twogroup calculation because multigroup structure should simulate large gradient of thermal flux near reflector region.

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