On-line Power Distribution Generation for SMART Core

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1. Introduction

The SMART core monitoring system (SCOMS) produces an on-line 3-D power distribution by using a direct 3-D power connection method (3DPCM) [1]. This paper describes the direct 3DPCM and examines the effectiveness of the developed method. Also this paper estimates the uncertainty of the generated 3-D power distribution by applying the direct 3DPCM to various core conditions.

2. Methods

2.1. Detected Node Power from Detector Power

Generally, the size of a detector is greater than that of an axial node, and a detector includes a few neutronics nodes. The detected node power can be reproduced from the detector power by using a power sharing factor as:

$$P^d_{l,k} = F_{l,kk'} P^d_{l,k'}\,, \tag{1}$$

where

$P^d_{l,k}$ = detected node power at node (*l,k*),

$F_{l,kk'}$ = power sharing factor of node (*l,k*) to detector (*l,k'*),

$P^d_{l,k'}$ = detector power at (*l,k'*).

k' and *k* are indices for the detector and the neutronics node and superscript *d* means the detected signal.

The exact power sharing factor can not be determined if all the neutronics power of $P^d_{l,k'}$ are not directly detected by using incore detectors. Therefore, an approximated power sharing factor is introduced in the 3-D power calculation module based on the neutronics solutions as:

$$F_{l,kk'} \approx F^C_{l,kk'} = \frac{w_{kk'} P^C_{l,k}}{P^C_{l,k'}}\,, \tag{2}$$

where

$F^C_{l,kk'}$ =approximated power sharing factor,

$P^C_{l,k}$ = node power calculated by neutronics code,

$P^C_{l,k'}$ = detector power calculated by neutronics code,

$w_{kk'}$ = ratio of the included size of neutronics node *k* to detector *k'* to the whole size of detector *k'*.

The usefulness of Eq. (1) depends on the accuracy of the estimated $F^C_{l,kk'}$.

2.2 3-D Power Connection Factor

The 3-D Power Connection Factor is defined by the ratio of the power of a node (*l,k*) to the power average of the neighboring nodes as:

$$C_{l,k} = \frac{1}{P_{l,k}\left(N_l + N_k\right)}\left(\sum_{j=1}^{N_l} P_{j,k} + \sum_{j=1}^{N_k} P_{l,j}\right), \tag{3}$$

where

N_l, N_k = the numbers of radially and axially neighboring nodes to node (*l,k*).

The exact 3-D Power Connection Factor can not be determined for the same reason as the power sharing factor. Therefore, an approximated 3-D Power Connection Factor is introduced in the 3-D power distribution module based on the neutronics solutions as:

$$C_{l,k} \approx C^C_{l,k} = \frac{1}{P^C_{l,k}\left(N_l + N_k\right)}\left(\sum_{j=1}^{N_l} P^C_{j,k} + \sum_{j=1}^{N_k} P^C_{l,j}\right), \tag{4}$$

The accuracy of the generated power distribution also depends on the accuracy of the estimated $C^C_{l,k}$.

2.3 Core 3-D Power Distribution

The governing equation for the power of node (*l,k*) can be written from the definition of the 3-D Power Connection Factor of Eq. (3) as:

$$C^C_{l,k}\left(N_l + N_k\right)P_{l,k} = \left(\sum_{j=1}^{N_l} P_{j,k} + \sum_{j=1}^{N_k} P_{l,j}\right). \tag{5}$$

The right hand side (RHS) of Eq. (5) includes not only the determined node powers from Eq. (1) but also the undetermined node powers as $P_{l,k}$ of the left hand side (LHS).

Eq. (5) can be rewritten by moving the undetermined node powers to LHS as:

$$C^C_{l,k}\left(N_l + N_k\right)P_{l,k} - \sum_{j\in U} P_{j,k} - \sum_{j\in U} P_{l,j} = \sum_{j\in I} P^d_{j,k} + \sum_{j\in I} P^d_{l,j}\,. \tag{6}$$

Groups *U* and *I* mean the undetermined and detected node groups.

The final governing matrix equation for the undetermined node powers can be established as:

$$\mathbf{AP} = \mathbf{S}\,\cdot \tag{7}$$

Eq. (7) is a fixed source problem, and it can be solved easily by applying an iterative scheme. The final 3-D power distribution is produced by applying a normalization procedure to the solution of Eq. (7).

3. Benchmark Calculation

The coefficient of the direct 3DPCM that consists of the power sharing and the 3-D power connection factors varies with the core burnup and the control rod position and the core power. The sensitivity study showed that the 3DPCM coefficient varies severely with the control rod position, but smoothly with the core burnup and the core power [1]. Form the results of the sensitivity study, the 3DPCM coefficient is expressed as a function of these parameters and the data library containing the power sharing and the 3-D power connection factors is generated from the neutronics core calculation.

Fig. 1 shows the maximum node power errors for the library base point test. The node power distribution at the library base point should be the same as the reference power distribution because the coefficient of the direct 3DPCM is generated using the reference power distribution. However, Fig. 1 shows trivial errors. These trivial errors results from the limited decimal point of the library data and the detector power signals. Therefore, it can be concluded that 3DPCM is developed correctly and the 3-D power distribution module works soundly.

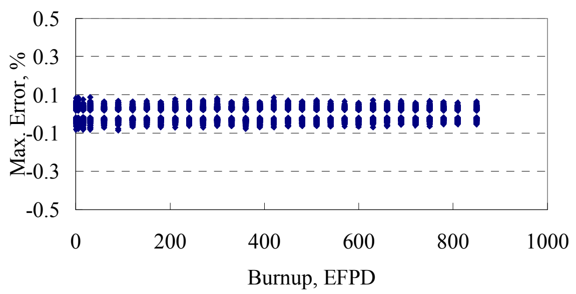

Fig.1 Maximum Node Power Error for the Library Base Point Test

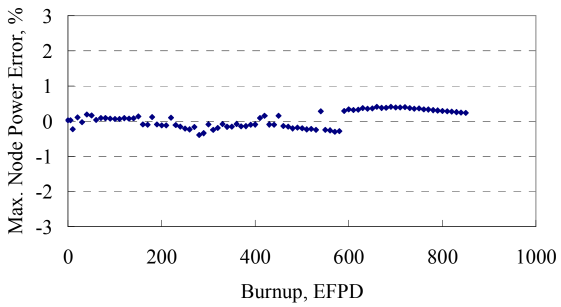

Fig.2 Maximum Node Power Error for the Core Burnup Variation Test

Figs. 2, 3 and 4 shows the maximum node power errors for the core burnup, the control rod position and the core power variation tests. In the burnup and rod position variation tests, the 3-D power distribution module shows less than 0.5 % of the maximum node power error for all the burnups and for all the control rod positions of the SMART core. In the core power variation test, this module shows less than 0.5 % for the core power of greater than 30 %, but it shows up to 2.5 % for the core power of less than 30 % where the extrapolation scheme is applied for the coefficients of the direct 3DPCM. Therefore, it can be concluded that the 3-D power distribution module should consider about a 1.5 % node power uncertainty including the core burnup and the control rod position and the core power variation effects if the core power is greater than 30 %, and about 3.5 % uncertainties if the core power is less than 30 %.

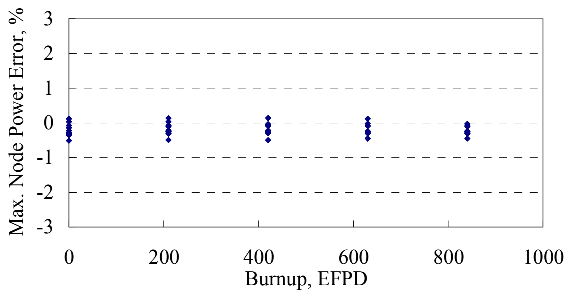

Fig.3 Maximum Node Power Error for the Control Rod Position Variation Test

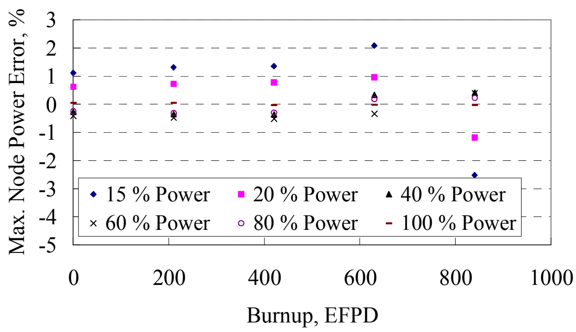

Fig.4 Maximum Node Power Error for the Core Power Variation Test

4. Conclusion

In this paper, an on-line 3-D power distribution module that uses a direct 3DPCM is generated and examined for the library base point, and the burnup, rod position and core power variation tests. From the results of these tests, it is concluded that the 3-D power distribution module works soundly and needs to consider about 1.5 % and 3.5 % node power uncertainties for a core power of less than and greater than 30 % including the core burnup and the control rod position and the core power variation effects.

Acknowledgement

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REFERENCES

[1] J. Y. Cho, et al., "3-D Power Synthesis Methodology for SMART Core Monitoring System," KAERI/TR-3399/2007, 2007