Evaluation of 3-D Power Distribution Synthesis Method for SMART Core Monitoring System

Bon-Seung Koo, Jin-Young Cho and Dae-Hyun Hwang
Korea Atomic Energy Research Institute, 1045, Daedeokdaero, Yuseong-gu,Daejon, 305-353, Korea
bskoo@kaeri.re.kr

1. Introduction

A 3-dimensional power distribution synthesis method, named DPCM3D[1] has been developed by KAERI. SMART core monitoring system, SCOMS[2] adopted this method instead of Fourier expansion method for the digital monitoring system of conventional PWRs. The DPCM3D method produces a synthetic 3-D power distribution by coupling a neutronics code and measured in-core detector signals. In DPCM3D, instrumented node powers are determined from the detector powers by using power sharing factors and the un-instrumented node powers are determined by using power connection factors. A coefficient library for the 3-D power synthesis is functionalized as a function of the burnup, core power and control rod position.

In this paper, performance of SCOMS 3-D power distribution synthesis method for SMART initial core was evaluated.

2. Methods and Results

In this section, 3-D power connection method (DPCM3D) is explained briefly, and SCOMS 3-D power synthesis performance for SMART initial core is evaluated. Also, sensitivity test for the number of failed detector is performed.

2.1 DPCM3D

In DPCM3D, a node power is determined from the neighboring node powers using the 3-D power connection factors.

$$C_{l,k}(N_l^{nb}+N_k^{nb})P_{l,k}-\sum_{j\in U}(P_{j,k}+P_{l,j})=\sum_{j\in I}(P_{j,k}^d+P_{l,j}^d) \quad (1)$$

where, groups U and I mean the un-instrumented and instrumented node groups, respectively. N_l^{nb} and N_k^{nb} are the number of neighboring nodes in the radial and the axial directions. $C_{l,k}$ means the 3-D power connection factor which couples the node (l,k) power with the neighboring node powers. The right hand side (RHS) in Eq. (1) is given as a source for the node (l,k), which produces a fixed source problem. The left hand side (LHS) of Eq. (1) couples the node power of (l,k) to the undetermined neighboring power. This equation can be solved by an iterative scheme and then 3-D power distribution can be determined.

If the 3-D power distribution is given, the coupling coefficient of $C_{l,k}$ in Eq. (1) can be determined by using the neighboring powers.

$$C_{l,k}=\frac{1}{P_{l,k}(N_l^{nb}+N_k^{nb})}\left(\sum_{j=1}^{N_l^{nb}}P_{L_l^{nb}(j),k}+\sum_{j=1}^{N_k^{nb}}P_{l,K_k^{nb}(j)}\right) \quad (2)$$

where, $L_l^{nb}(j)$ and $L_k^{nb}(j)$ are the neighboring node and plane indices for node *(l,k)*, respectively. However, the 3-D power distribution can not be given until the solution of Eq. (1) is obtained. Therefore, DPCM3D uses an approximated coupling coefficient of $C_{l,k}^C$ instead of rigorously defined one in Eq. (2).
The detected node power in Eq. (1) is determined by using a power sharing factor (PSF) and a detector signal. An approximated power sharing factor $F_{l,kk'}^C$ is provided by neutronics code, as like coupling coefficient.

$$P_{l,k}^d=\frac{1}{w_k}\sum_{k'}F_{l,kk'}P_{l,k'}^d \quad (3)$$

where,
$P_{l,k}^d$ = detected node power of node *(l,k)*
$F_{l,kk'}$ = PSF from detector k' to node k ($=\frac{w_{kk'}P_{l,k}}{P_{l,k'}}$)
$P_{l,k'}^d$ = in-core detector power of detector unit k'
$w_k = \sum_{k'}w_{kk'}$ ($w_{kk'}=h_{kk'}/h_{k'}$)
$h_{k'}$ = height of detector unit k'
$h_{kk'}$ = height of plane k included in detector unit k'

2.2 3-D Power Distribution Synthesis

3-D power distribution is synthesized for the SMART initial core by using the coefficient library and in-core detector signals. The library constants of $F_{l,kk'}^C$, $C_{l,k}^C$ and detector signals are generated from the reference power distribution of MASTER neutronics code. Fig. 1 and Fig. 2 show the synthesis result. As shown in Fig. 1, radial power distribution error (axially integrated 2-D power) shows the maximum 0.006% at BOC condition which is negligible value. In addition, synthesized axial power shape is exactly match with reference shape. These trivial errors are less than the truncation error of about 0.02% caused by the number of digits for the power distribution and detector signals[3].

Also, sensitivity test for the number of failed detector is tested. Detector signals are made to 0.0(zero) compulsorily to simulate failed detector and then 3-D power distribution is synthesized. The number of failed detector is increased to almost 100% failed condition. Table 1 shows calculational result for 3-D power synthesis errors as a function of failed detector numbers. For the most severe case (only 1 detector available), maximum 3-D error is less than 3% compared with reference result. This demonstrates that SCOMS 3-D power synthesis algorithm is robust and less sensitive to the number of available detectors compared with conventional COLSS algorithm. Also SCOMS can synthesize 3-D power distribution exactly with a minimum available detector numbers.

```
MASTER                      1        2        3
SCOMS                    0.8413   1.0048   0.8413
ERROR(%)                 0.8413   1.0048   0.8413
                         0.0033   0.0023   0.0034
                  4        5        6        7        8
               0.8390   1.1176   1.1735   1.1176   0.8390
               0.8390   1.1176   1.1735   1.1176   0.8390
               0.0026   0.0039   0.0010   0.0040   0.0026
         9       10       11       12       13       14       15
      0.8390   1.0995   1.0008   1.0669   1.0008   1.0995   0.8390
      0.8390   1.0996   1.0008   1.0670   1.0008   1.0996   0.8390
      0.0026   0.0060   0.0054   0.0047   0.0054   0.0060   0.0026
  16       17       18       19       20       21       22       23       24
0.8413   1.1176   1.0008   1.0475   1.0015   1.0475   1.0008   1.1176   0.8413
0.8413   1.1176   1.0008   1.0476   1.0015   1.0476   1.0008   1.1176   0.8413
0.0026   0.0038   0.0054   0.0039   0.0018   0.0039   0.0054   0.0040   0.0034
  25       26       27       28       29       30       31       32       33
1.0048   1.1735   1.0669   1.0015   1.0341   1.0015   1.0669   1.1735   1.0048
1.0048   1.1735   1.0670   1.0015   1.0341   1.0015   1.0670   1.1735   1.0048
0.0021   0.0010   0.0047   0.0018   0.0025   0.0018   0.0047   0.0010   0.0022
  34       35       36       37       38       39       40       41       42
0.8413   1.1176   1.0008   1.0475   1.0015   1.0475   1.0008   1.1176   0.8413
0.8413   1.1176   1.0008   1.0476   1.0015   1.0476   1.0008   1.1176   0.8413
0.0034   0.0040   0.0054   0.0039   0.0018   0.0039   0.0054   0.0038   0.0027
        43       44       45       46       47       48       49
      0.8390   1.0995   1.0008   1.0669   1.0008   1.0995   0.8390
      0.8390   1.0996   1.0008   1.0670   1.0008   1.0996   0.8390
      0.0026   0.0060   0.0054   0.0047   0.0054   0.0060   0.0026
                 50       51       52       53       54
               0.8390   1.1176   1.1735   1.1176   0.8390
               0.8390   1.1176   1.1735   1.1176   0.8390
               0.0026   0.0038   0.0010   0.0040   0.0026
                          55       56       57
                        0.8413   1.0048   0.8413
                        0.8413   1.0048   0.8413
                        0.0027   0.0022   0.0034

      MAX. ERROR =    0.0060( 48)
```

Fig. 1. Axially Integrated Power Distribution of SMART Initial Core at BOC (MASTER vs. SCOMS).

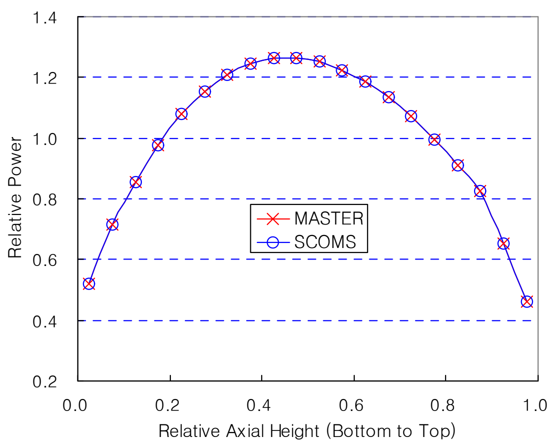

Fig. 2. Axial Power Distribution of SMART Initial Core at BOC (MASTER vs. SCOMS).

Table 1. 3-D Power Synthesis Errors as a Function of Failed Detector Numbers.

Case No.	No. of Det.		Failed Det.(%)	Max. Error(%)[a]	
	Avail.	Failed		Error(a)[b]	Error(b)[c]
1	116	0	0	0.0156	0.0060
2	110	6	5	0.0157	0.0062
3	104	12	10	0.0155	0.0071
4	99	17	15	0.0152	0.0075
5	93	23	20	0.0150	0.0074
6	87	29	25	0.0150	0.0074
7	81	35	30	0.0153	0.0073
8	75	41	35	0.0152	0.0078
9	70	46	40	0.0154	0.0079
10	64	52	45	0.0194	0.0081
11	58	58	50	0.0197	0.0079
12	52	64	55	0.0191	0.0074
13	46	70	60	0.0188	0.0068
14	41	75	65	0.0185	0.0070
15	35	81	70	0.0180	0.0072
16	29	87	75	0.0173	0.0074
17	23	93	80	0.0195	0.0076
18	17	99	85	0.0210	0.0092
19	12	104	90	-0.0237	0.0094
20	6	110	95	-0.0608	-0.0181
21	1	115	99	-0.2756	-0.0297
22	0	116	100	-	-

a) error(%) = (SCOMS-MASTER)/MASTER·100
b) max. error for 3D node-power
c) max. error for 2D node-power (axially integrated)

3. Conclusions

The performance of a 3-dimensional power distribution synthesis method (DPCM3D) was evaluated for the digital core monitoring system (SCOMS) of SMART initial core. SCOMS shows negligible power distribution errors and less sensitive to the number of available detectors compared with COLSS. By employing a DPCM3D method in SCOMS, it is demonstrated that a core power distribution could be synthesized more accurately by eliminating the fitting error with a minimum available detector numbers.

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