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ON-LINE CALCULATION OF 3-D POWER DISTRIBUTION

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ABSTRACT

The 3-D power distribution synthesis scheme was implemented in Totally Integrated Core Operation Monitoring System (TICOMS), which is under development as the next generation core monitoring system. The on-line 3-D core power distribution obtained from the measured fixed incore detector readings is used to construct the hot pin power as well as the core average axial power distribution. The core average axial power distribution and the hot pin power of TICOMS were compared with those of the current digital on-line core monitoring system, COLSS, which construct the core average axial power distribution and the pseudo hot pin power. The comparison shows that TICOMS results in the slightly more accurate core average axial power distribution and the less conservative hot pin power. Therefore, these results increased the core operating margins. In addition, the on-line 3-D power distribution is expected to be very useful for the core operation in the future.

1. INTRODUCTION

The ABB-CE developed the digital computer based on-line core operating limit supervisory system (COLSS) in mid 1970. It was developed using the fixed incore detectors and was based on the philosophy of maintaining the plant margin within the acceptance criteria assumed by the safety analyses rather than maintaining each plant variable within specific limits. COLSS [1] monitors the core power and axial power distribution and performs on-line DNB and LHR margin calculations using the pseudo hot pin power based on the pre-calculated radial peaking factors. This monitoring approach was used in the plants which were equipped with a digital protection system and first used in 1980's. COLSS has been used in many ABB-CE digital plants including YGN Units 3 and 4. Westinghouse has developed a

PWR core monitoring system, BEACON, which employs a fast three dimensional nodal code, SPNOVA [2]. However, BEACON is not used in the on-line core monitoring up to date.

After the initial development of COLSS, there have been tremendous advances in instrumentation, computer software and hardware. The advances in computer hardware enables the on-line synthesis of the 3-D power distribution using the fixed incore detectors which were first used to provide off-line 3-D power distribution surveillance capability by CECOR [3]. Thus, in this study, the 3-D power distribution scheme in CECOR was applied to TICOMS in order to remove the additional conservatism in COLSS (i.e., to increase operating margins) and to provide more useful information for core operation.

2. ON-LINE IMPLEMENTATION

The 3-D power distribution logic in CECOR was utilized in TICOMS for the on-line implementations. TICOMS converts the fixed incore detector readings to local box power using the neutron flux-to-power factors for instrumented assemblies at each axial detector level by

$$P_{in} = E_{corr,\,in} \times CALIB_{in} \times W_{in}' \tag{1}$$

where P_{in} is the power in the instrumented assembly i over the detector level n, $E_{corr,\,in}$ is the sensitivity and background corrected detector flux, W_{in}' is the ratio of power in assembly i of detector level n to the Rhodium activation in detector level n and $CALIB_{in}$ is a factor to convert from flux to activation. Full core planar power distribution at each detector level are obtained through the use of level dependent pre-calculated coupling coefficients, <CC>, which are defined as

$$<CC>_{in} = \frac{1}{N_i}\sum_{j=1}^{N_i}\frac{P_{jn}}{P_{in}}, \tag{2}$$

where $<CC>_{in}$ is the coupling coefficient for assembly i of detector level n, N_i is the number of neighboring assemblies to assembly i, P_{jn} is the power in the neighboring assembly j of detector level n, and P_{in} is the power of assembly i of detector level n. Writing this equation for every uninstrumented assembly to include the complete set of uninstrumented and instrumented assemblies, U_{ln} and I_{ln}, respectively, a system of equation of order U_n are obtained, i.e.,

$$N_l <CC>_{ln} P_{ln} - \sum_{j\in U_{ln}} P^l_{jn} = \sum_{j\in I_{ln}} P^l_{jn}, \qquad l = 1, \ldots, U_n, \tag{3}$$

where the summation on the left hand side is over uninstrumented neighbors, and the summation on the right hand side is over instrumented neighbors. When all the equations for each uninstrumented box are written and grouped, the following $U_n \times U_n$ matrix equation results;

$$A\,\underline{P} = \underline{S} \qquad (4)$$

where A is a matrix with n times the coupling coefficients for the uninstrumented assemblies on the diagonal and -1's in the off-diagonal elements to indicate the neighbors to the uninstrumented assemblies; $\underline{P}$ is a vector containing the uninstrumented box powers and $\underline{S}$ is a vector containing the sum of the neighboring box powers. Axial power distributions are obtained by a five mode Fourier expansion using the above assembly powers like COLSS. Once the assembly power is obtained, hot pin powers are calculated by multiplying the assembly power at each height by assembly-normalized local peaking factors. The W′, <CC> and peaking factors are obtained from fine-mesh, diffusion theory calculations with transport corrections.

The core power distribution routines in CECOR were extracted and combined with COLSS to create TICOMS. It was confirmed that the 3-D power distribution of TICOMS agrees well with those of CECOR.

3. RESULTS AND DISCUSSIONS

The core average axial power distribution and the hot pin power in TICOMS based on the calculated 3-D power distribution were compared with those of COLSS and ROCS [4] for YGN 3 Cycle 1. Figure 1 shows the comparisons of the core average axial power shapes at typical three burnup points (BOC, MOC, and EOC), respectively. The results from ROCS are used as the reference values. TICOMS gives slightly better axial shapes than COLSS but the difference is judged to be insignificant to the operating margins. Table 1 shows the hot pin power information. As expected, the integrated radial peaking factor (Fr) and the three-dimensional peaking factor (Fq) values of TICOMS are much lower than those of COLSS because the TICOMS hot pin power is determined from the 3-D power distribution at a given burnup. However, the COLSS (pseudo) hot pin power is determined by the combination of core average axial power and the pre-calculated cycle-maximum planar radial peaking factor (Fxy). The hot pin power significantly decreases from BOC to EOC because the cycle-maximum Fxy occurs at BOC for YGN 3 Cycle 1. Hence, the on-line 3-D power distribution in TICOMS can eliminate the conservatism of the pseudo hot pin power in COLSS by the on-line credit of the Fxy burndown effect.

The available overpower margins (AOPMs) on LCOs of DNBR and LHR are compared in Table 2. It should be noted that the AOPMs in Table 2 do not include the associated uncertainties such as modeling uncertainty and instrument uncertainties. The TICOMS AOPM on DNBR LCO (DNB-OPM) increases from 3.53% at BOC to 12.31% at EOC mainly due to the decrease of the integrated radial peaking factor (Fr) in Table 1. Similarly, the TICOMS AOPM on LHR LCO (LHR-OPM) also increases from BOC to EOC due to the decrease of the three-dimensional peaking factor (Fq).

4. CONCLUSION

The on-line 3-D power distribution scheme using the fixed incore detector readings was implemented in the next generation core monitoring system, TICOMS, and compared with the current on-line power distribution in this study. The use of the on-line 3-D power distribution results in the slightly more accurate core average axial power shape and eliminates the conservatism of the pseudo hot pin power in COLSS. These results would increase the core operating margin in the event. In addition, the on-line 3-D power distribution monitoring is expected to be very useful for plant operation and further for the predictive core maneuvering with the on-line xenon information in the future.

REFERENCES

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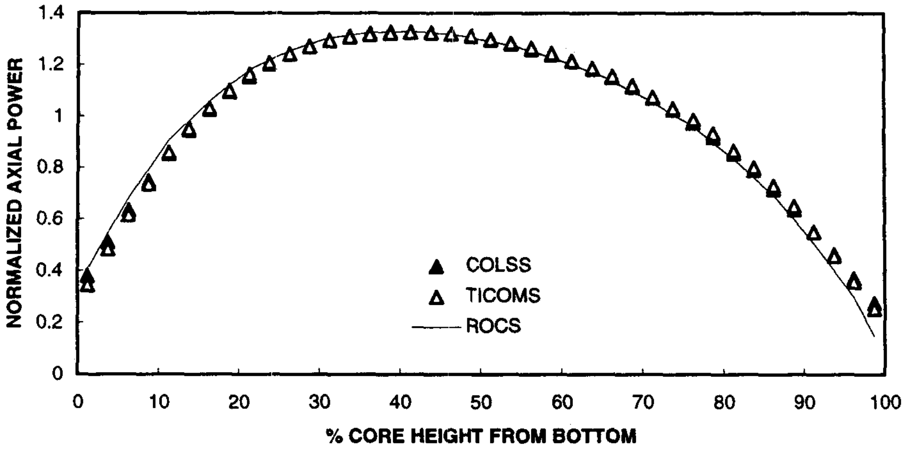
Table 1 Comparisons of the Integrated Radial Peaking Factor (Fr) and the Three-Dimensional Peaking Factor (Fq)

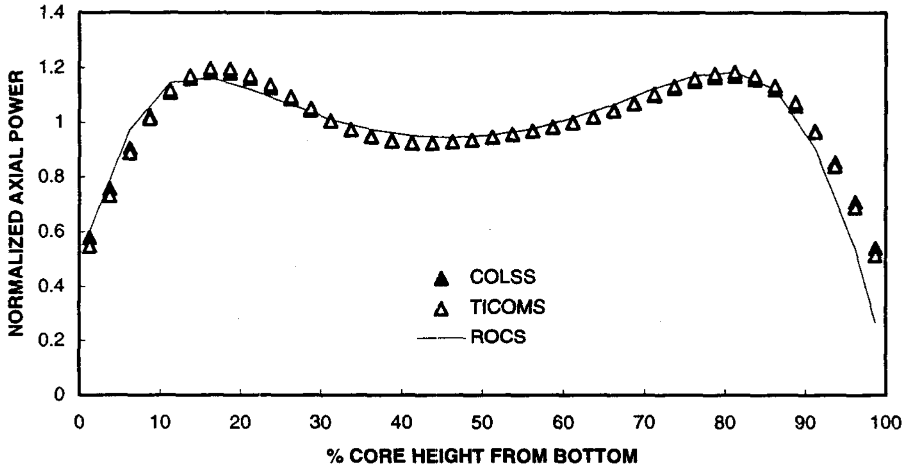
Parameter	TIL	COLSS	TICOMS	% Difference (T-C)/C×100
Fr	BOC	1.5459	1.5008	-2.92
	MOC	1.5012	1.4112	-6.00
	EOC	1.5044	1.3554	-9.90
Fq	BOC	2.0512	2.0021	-2.39
	MOC	1.7734	1.6911	-4.64
	EOC	1.7939	1.5429	-13.99

Table 2 Comparisons of Available Overpower Margins

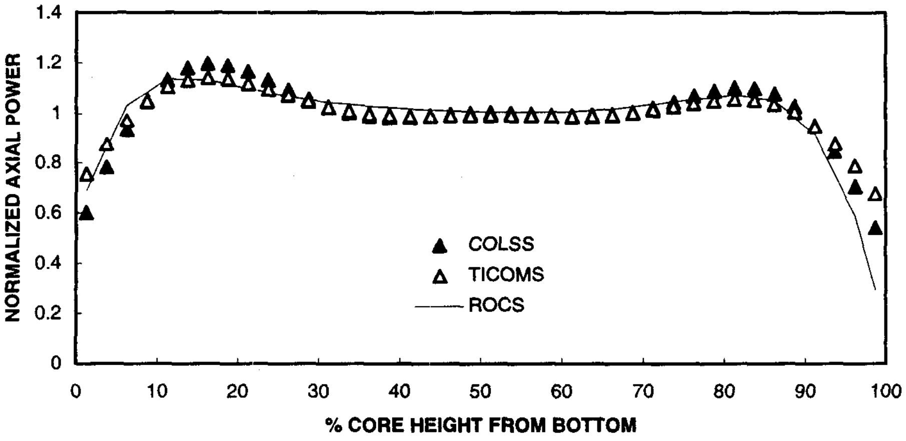
Parameter	TIL	COLSS	TICOMS	% Difference (T-C)/C×100
DNB-OPM (% Power)	BOC	117.31	121.45	3.53
	MOC	114.19	121.92	6.77
	EOC	115.96	130.23	12.31
LHR-OPM (% Power)	BOC	125.70	128.78	2.45
	MOC	145.39	152.47	4.87
	EOC	143.73	167.11	16.27



(A) BOC



(B) MOC



(C) EOC

Figure 1 Average Axial Shapes at Typical Burnups