Proceedings of the Korean Nuclear Society Spring Meeting
Gyeongju, Korea, May 2004

Statistical Analysis for Rhodium Fixed Incore Detector Performance of KSNP

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Abstract

In most of PWR plants with the self-powered fixed incore detector system, there is no direct method to confirm the accuracy of fixed incore detector. However, by analyzing a large number of detector snapshot data obtained from normal plant operation, it is possible to infer what each fixed incore detector response should be. The snapshot analysis was done by BEACON/SPNOVA that are Westinghouse core monitoring tools. This paper describes the evaluation method of gross variability and measurement variability using statistical analysis of the rhodium fixed incore detector signals to validate the BEACON/SPNOVA functionality and the detector performance. From the results of this analysis, we have concluded that the BEACON/SPNOVA can be used for the snapshot analysis of Korean Standard Nuclear Power (KSNP) plants.

Ⅰ. Introduction

A self-powered fixed incore detector (FID), such as Rh detector, is widely used for the power distribution measurement both in PWR and BWR. The detector is manufactured under a tight quality control environment for the uniform sensitivity within a specified allowance. However, the real detector sensitivity including its electronic devices can be estimated only in the real operating environment of the reactor, because the detector sensitivity changes as the neutron exposure progresses. In BWR, the fixed incore detectors are periodically calibrated against the movable fission chamber, where its signals are known as a standard fission power distribution. On the other hand, PWR plants traditionally use the FID with a fresh detector sensitivity supplied by vendors with a prescribed sensitivity correction due to the neutron exposure.

The power distribution measurement by BEACON[1] is performed through comparing the measured and predicted detector signals. The deviation can come from the following areas; i) detector relative sensitivity, ii) noise of detectors and electronic devices, iii) detector signal prediction model, and iv) global power distribution prediction.

During reactor operation, it is desirable to check the functionality of the FIDs periodically.

The detector functionality can be checked by RMS error related to the first three areas. This RMS error represents how accurately the detectors can measure the local power density and is defined as the 'measurement variability'.

If the detector system is working well and the predicted power distribution is in a good quality, root mean square (RMS) of percent deviation between the predicted and measured detector current over the entire detector elements, defined as the 'gross variability', should be typically less than 3%.

It happens occasionally that the gross variability shows higher values than measurement variability. In most cases, this is due to the fourth component such as the radial in-out tilt in the prediction. The BEACON functionality can be checked by observing the gross variability, and also the detector performance can be checked by observing the measurement variability.

II. Evaluation Method of Measurement and Gross Variability

The important step of the measurement variability evaluation is to know what the detector response should be if the detector is working correctly. This information can be achieved if a simultaneous reference measurement by a precision detector, such as movable fission chamber system, is available. Generally, there is no measurement device in PWR that can be used for the detector calibration. Therefore, the most likely or the best estimate (BE) detector responses need to be inferred by utilizing all available information; detector responses at the symmetric locations, and the predicted responses, etc. By analyzing a number of duplicated or redundant measurements collectively, one can infer the BE detector response. To do this, FID snapshots need to be collected for the SPNOVA analysis. These FID snapshots are selected from nearly HFP, ARO, equilibrium core and free from quadrant flux tilt core conditions. All the FID snapshots are analyzed by the SPNOVA[2] and the output files are processed to check the Rh FID performance and BEACON functionality.

The FIDs are subdivided into several groups where a group contains some detectors at symmetric position. If there is no quadrant tilt in the core, all the detectors of a group should have the same responses. If there are differences in their detector depletion histories, the measured currents can be normalized to the same age by using the predicted currents. The first member of the group is used as a reference.

The normalization is done by

$$J^{m}_{i,j,k} = C_{i,j,k} \cdot I^{m}_{i,j,k}, \tag{1}$$

$$C_{i,j,k} = {I^{p}_{1,j,k}} \big/ {I^{p}_{i,j,k}}, \tag{2}$$

where, I is a nominal detector current, J is an age-normalized detector current, C is an age normalization factor, m means measurement, p means prediction, i is the member ID in a symmetric group, j is the symmetric group ID, and k is the snapshot ID of FID.

Using the above equations, the best estimate measured current at the symmetric locations for the 'age-normalized detector current' is considered to be

$$K^{m}_{j,k} = \underset{i}{\mathrm{AVG}} \left(J^{m}_{i,j,k}\right), \tag{3}$$

where, $\underset{i}{\mathrm{AVG}}$ is the average over i detectors within group j. If the number of detector within a symmetric group is less than 2, $I^{p}_{i,j,k}$ is added as an additional member of the measured detector current.

Now let's define an ur-measurement variability, $\sigma^{u}_{i,y}$. If the best estimate value has no uncertainty, $\sigma^{u}_{i,y}$ can be represented as following.

$$\sigma^{U}_{i,y} = \underset{k}{\mathrm{RMS}}\left[\left(\frac{J^{m}_{i,j,k}}{K^{m}_{j,k}} - 1\right)\cdot 100\right], \tag{4}$$

where, $\underset{k}{\mathrm{RMS}}$ is the root-mean-square for k-th snapshot.

And the uncertainty of the best estimate, σ^{BE}_{j}, can be obtained by

$$\sigma^{BE}_{j} = \underset{i,k}{\mathrm{RMS}}\left[\left(\frac{J^{m}_{i,j,k}}{K^{m}_{j,k}} - 1\right)\cdot 100\right], \tag{5}$$

where, $\underset{i,k}{\mathrm{RMS}}$ is the root-mean-square for augment i and k.

Therefore, the measurement variability, $\sigma^{m}_{i,j}$, is defined by convoluting the equation (4) and (5).

$$\sigma^{m}_{i,j} = \sqrt{\left(\sigma^{U}_{i,j}\right)^{2} + \left(\sigma^{BE}_{j}\right)^{2}} \tag{6}$$

To verify that the SPNOVA model for Rh FID of KSNP is capable of predicting the magnitude of the detector current, the ratio of predicted current to measured current should be determined over all FID measured data. The gross variability, $\sigma^{GV}_{i,j,k}$, is defined by

$$\sigma^{GV}_{i,j,k} = \mathrm{RMS}\left[\left(C\frac{I^{p}_{i,j,k}}{I^{m}_{i,j,k}} - 1\right)\cdot 100\right], \tag{7}$$

where, I^{p} is a predicted current, I^{m} is a measured current, C is a multiplier to I^{p}, and the subscript of (i,j,k) means the detector location.

If the predicted current is accurate, gross variability provides the measurement variability. However, the prediction has the uncertainty related with model itself. So the model related portion should be removed for the measurement variability.

III. Statistical Analysis of Rh FID Performance of YGN4 Cycle 5

Currently, fourteen rhodium snapshots were taken from April 19, 2000 to March 22, 2001 of the YGN 4 Cycle 5 and have been analyzed by BEACON/SPNOVA to verify the functionality of BEACON for the Korean Standard Nuclear Power (KSNP) plants[3]. The reactor was mostly at HFP, ARO conditions during the snapshot collections. The plant condition and file ID for each snapshot are summarized in Table 1.

If a prediction model is perfectly correct and the detector measurement has no uncertainty, the predicted and the measured detector currents agree well. But differences are observed all the time. For example, RMS of the % deviation between predicted and measured current is shown in Fig. 1. From those results alone, it is not possible to determine which one of the predicted and measured current is correct.

The uncertainty evaluation for the measurement data can be performed by using duplicated detector currents, which are basically from the symmetric partners as shown in Fig. 2. If there is no quadrant power tilt and all detectors have the same relative sensitivity, the detectors of symmetric partner must show the same responses. When measurements are made in multiple symmetric locations, the most likely value will be the average of all the symmetric partners. Individual current deviation from the average is considered to be the measurement error of that detector. On the other hand, some detectors may not have any symmetric partner. In that case, the prediction will be used instead of the symmetric partner.

These calculational procedures for the statistics of the measurements are implemented in a FORTRAN program. The program reads the output of SPNOVA snapshot analysis, validates the measured currents of Rh fixed incore detector, and evaluates the gross and measurement variability.

The final result is summarized in Table 2. It is concluded that the measurement variability of this plant is 1.514, much less than the gross variability of 2.3172. Although there is no criteria about measurement variability and gross variability, those two values are low enough at the point of generality. So one can say that the SPNOVA model of Rh fixed incore detector of YGN4 is well modeled, and the functionality of BEACON monitoring of Rh FID performance has been checked as a good one.

IV. Conclusion

In this paper, to validate the detector performance and the BEACON/SPNOVA functionality, the statistical analysis for the currents of rhodium self powered fixed incore detector in YGN 4 Cycle 5 was introduced. By analyzing a large number of snapshots, KEPRI has confirmed that both gross variability and measurement variability of BEACON/SPNOVA system are reasonably low for one to adopt the system as a new tool to analyze the snapshots of KSNPs. Basing on this conclusion, BEACON/SPNOVA system can be used to design a brand-new self-powered fixed incore detector.

References

[1] BEACON Core Monitoring and Operations Support System (WCAP-12472-P-A), Addendum 1, Jan. 2000.

[2] Westinghouse Electric Company, "User's Manual for SPNOVA," CMP-03-15.

[3] Kyoon Ho Cha et al., "Snapshot Analysis for Rhodium Fixed Incore Detector using BEACON Methodology," May 2004, Korean Nuclear Society Spring Meeting (to be published).

Table 1. YGN Unit 4 Cycle 5 Rhodium Fixed Incore Detector Snapshot Information

NO	Snapshot File	Date	Burnup (MWD/MTU)	Power (%)	Boron (PPM)	ASI	Lead Bank Pos.(cm)
1	Z28604BC	04/19/00	537.2	99.7	1089.	-015	381
2	Z286F675	05/04/00	1094.2	99.7	1044.	-.009	379
3	Z28844B1	05/25/00	1858.4	99.6	998.	-.002	379
4	Z288EA4A	06/04/00	2244.2	99.7	968.	.004	377
5	Z289D4B2	06/19/00	2776.9	99.6	931.	.005	377
6	Z28AC4C1	07/04/00	3328.1	99.7	915.	.013	375
7	Z28BB667	07/19/00	3884.7	99.7	875.	.023	374
8	Z28CA4B1	08/03/00	4430.2	99.7	833.	.019	374
9	Z28D9654	08/18/00	4986.5	99.6	799.	.021	375
10	Z28F84B1	09/18/00	6119.5	99.8	724.	.018	377
11	Z29344B1	11/17/00	8323.5	99.6	597.	.028	381
12	Z29524B0	12/17/00	9424.8	99.6	519.	.020	379
13	Z29934B1	02/20/01	11812.0	99.9	315.	.025	369
14	Z29B14B1	03/22/01	12914.4	99.7	198.	.024	373

Table 2. Result of YGN4 Cycle 5 Snapshot Analysis

Gross Variability	No of Samples	2940 (14) snapshot
	% Deviation Avg	0.1916
	Standard Deviation	2.3093
	RMS	2.3172
Ur-Measurement Variability by BE Symmetric Average	No of Samples	2940 (14) snapshot
	% Deviation Avg	-0.0712
	Standard Deviation	1.0551
	Ur-Measurement Variability*	1.0650
Measurement Variability	RMS of Infered BE Sym Avg	1.076
	Measurement Variability**	1.514

* The ur-measurement variability is defined as the detector's measurement variability if the best estimate value has no uncertainty.

** Measurement variability relates to the measurement accuracy, if measurement variability goes high, the detector measurement accuracy goes down.

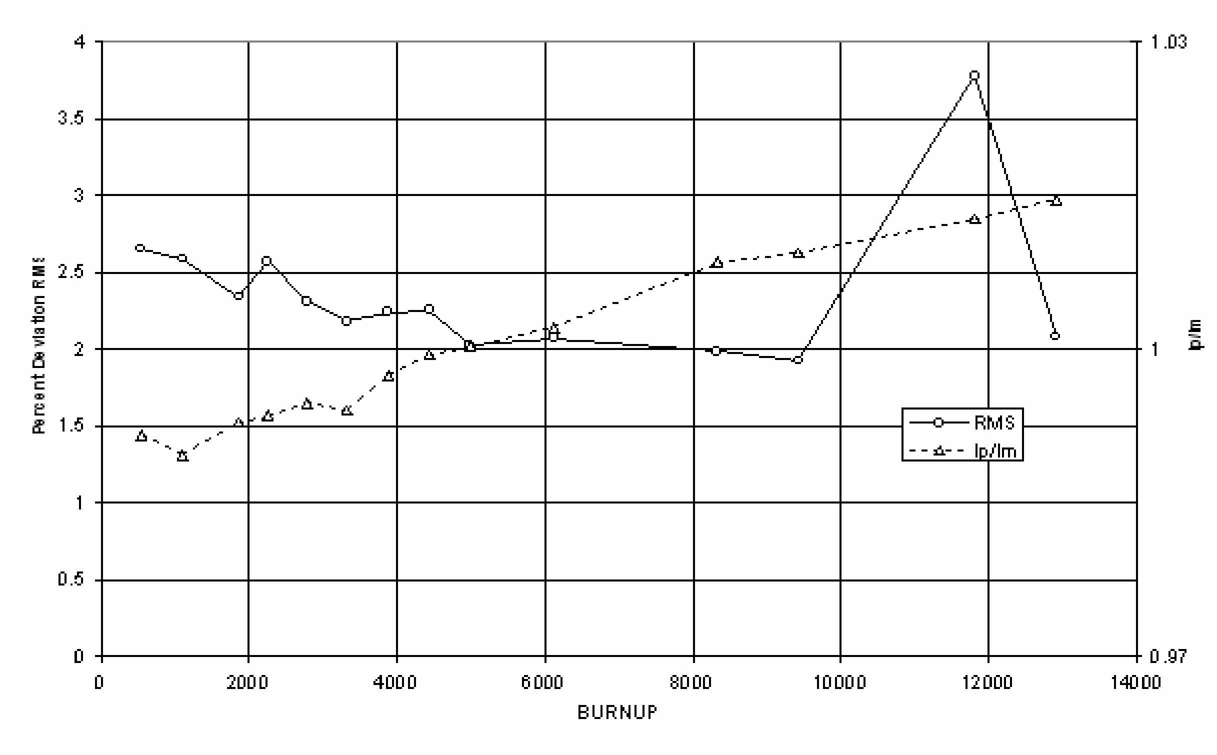

Figure 1. Yonggwang Unit 4 Cycle 5 Core Average Ip/Im Ratio and RMS of % Deviations

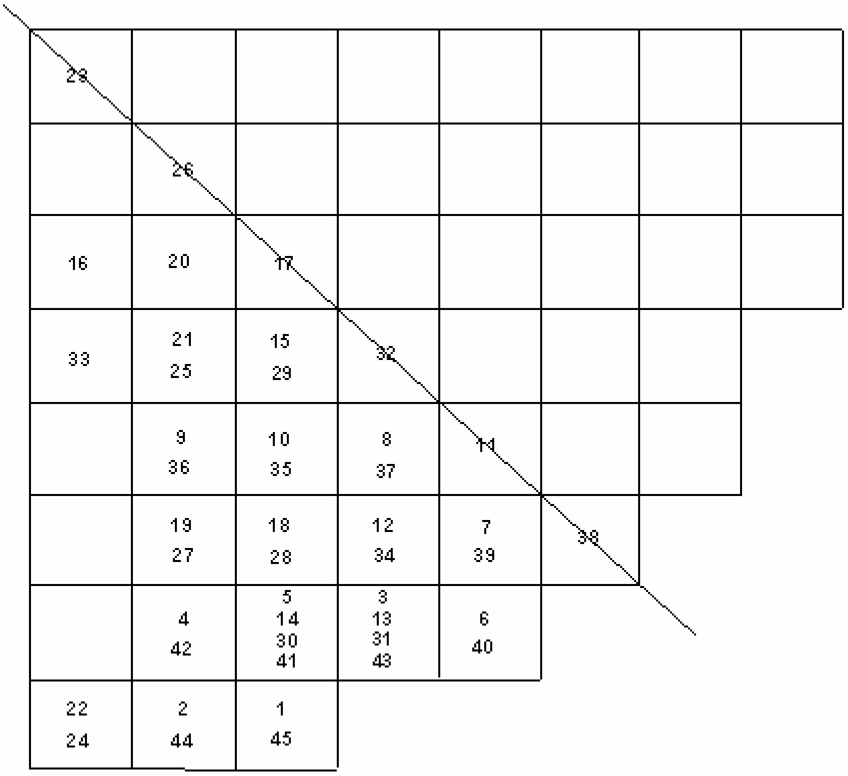

Figure 2. Yonggwang Unit 4 Incore Detectors in One-Eight Core