SORO Prediction of High Response NOP Detectors

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ABSTRACT

This paper compares two approaches for predicting high response in-core NOP detectors. Results were compared against those generated and the station measurements. The analysis was carried out by using the core-tracking SORO program and the PI system with Bruce B Unit 6 data. The conclusions show that the current approach in use is effective and provides accurate prediction of high response NOP detector(s) to avoid unplanned reactor trips.

1. INTRODUCTION

The Neutron Overpower Protection (NOP) system is designed to initiate trips to shutdown the reactor whenever the neutron flux reaches an unacceptably high level anywhere in the reactor core. A set of self-powered in-core NOP detectors are installed to constantly monitor the neutron flux at high power levels during operation. Conditions such as a Large Break Loss of Coolant Accident (LBLOCA) event or a Loss of Regulation (LOR) event involving a loss of control of the bulk power and/or the spatial power distribution in the reactor could lead to increase of NOP detectors response.

The core tracking SORO program has been used in operation on Bruce Site to predict high response NOP detectors prior to fuelling. Fuelling any channels in the close proximity of these high response NOP detectors will likely cause low NOP margin-to-trip (MTT). The NOP MTT is the difference between the operating point and trip set point of the in-core NOP detector reading. During operation, adequate NOP trip coverage should be maintained. The smaller the MTT is, the more likely that spurious trips will occur. If the MTT is too small, the reactor may be derated to improve the margin. Accurate prediction of high response NOP detectors foresees the risk of having reduced MTT so that appropriate responses could be made to avoid the adverse scenario to happen.

This paper presents the results from two different SORO calculation methods to predict NOP detector responses to fuelling operations. Comparisons of the results from the two SORO calculation methods against the historical station measurements extracted from PI are also shown.

2. COMPUTER PROGRAMS

Simulation Of Reactor Operation (SORO)

The 3-D steady state core tracking SORO program is used at Bruce Power by fuelling engineers and analysts for: (i) channel selection for fuelling, (ii) generating reports for monitoring performance and compliance, and (iii) archiving reactor core history.

The SORO program includes the following:

- Lattice cross-sections generated from WIMS-IST version 2-5d with ENDF/B-VI library
- 2-Group approximation
- Local fuel temperature effects
- 7 saturating fission products (Rh105, Cd113, Xe135, Sm149, Sm151, Eu155, and Gd157).
- Coarse mesh

SORO repeatedly performs Shift, Flux, Burn, Flux to simulate the reactor operation, where Shift denotes the fuelling of the channels, Flux is the calculation of the flux, bundle and channel powers, and Burn burns the core at constant power.

The most important use of SORO is to track the actual reactor operation through simulations and show compliance with Maximum Channel Power/Bundle Power. This is referred to as production SORO. The production data are kept indefinitely. SORO is also used by fuelling engineers to make predictive runs for future fuelling, which is referred to as predictive SORO. The predictive data are of limited use and in practice are kept for approximately three months for all the Bruce reactors since it is of no real use after actual production data has been obtained.
Production data and predictive data are referred to as data from production and predictive SORO runs, respectively.

Plant Information System (PI)

Plant Information (PI) system is a PC tool for storing station information and displaying the data through the PI ProcessBook or the PI DataLink. The PI ProcessBook allows users to construct surveillance ProcessBook for one of their systems. The PI DataLink allows users to extract station measurements from the PI Server for one of their systems into an MS Excel spreadsheet which are then analyze through plots and calculations.

3. METHODOLOGY

NOP Detector Response Ratios

Three fuelling cases of Bruce B Unit 6 that caused spurious detector responses were selected for this analysis. The simulation data was extracted from SORO and the station measurements are from PI. Detector responses due to perturbations in general, or fuelling operations in particular are expressed by the ratio of detector responses before and after perturbation. This is shown in the following equation, which was used to calculate the simulated and actual detector response with SORO simulation data and station measurements from PI, respectively.

$$DET_{response} = DETFLUX_{after\ perturbation} / DETFLUX_{before\ perturbation} \qquad \textit{(Eqaution 1)}$$

where $DET_{response}$ is the detector response, $DETFLUX_{after\ perturbation}$ is the detector flux after perturbation, $DETFLUX_{before\ perturbation}$ is the detector flux before perturbation.

The two sets of resultant detector responses were compared to examine how accurate the results from the SORO simulation data are, depending on how well the results from SORO simulations match the station measurements.

Logic Trip Channel for Shutdown Systems SDS1 and SDS2

There are two shutdown systems, SDS1 and SDS2, in a CANDU reactor. Each of the two shutdown systems has three logic trip channels. For Bruce B reactors specifically, SDS1 logic trip channels D, E, and F each has 18 in-core detectors in; SDS2 logic trip channels G, H, and J each has 16 in-core detectors in. Either SDS1 or SDS2 initiates a reactor trip when two out of three channels receive in-core detector signal exceeding the trip limit. These in-core detectors for SDS1 and SDS2 are referred to as NOP detectors.

Higher detector response to perturbations reduces MTT. In this analysis, the maximum detector response ratios in response to fuelling operations for each channel were selected for comparisons, since such detectors challenge the MTT and have higher operational impact especially if the predictive SORO runs do not identify them beforehand.

SORO Data

SORO prediction data are preferred for this analysis since the objective is to examine effectiveness of the results from predictive SORO runs prior to actual fuellings. However, as mentioned in Section 2, SORO prediction data at Bruce site is only kept up to three months, which is not long enough to provide sufficient data for this analysis. Therefore, production data were used instead. In general, fuelling engineers provide the fuelling list by running predictive SORO. The fuelling list is in alphabetical order so that fuelling is performed from top to bottom of the core. This is to protect the fuelling machines from wearing out by minimizing unnecessary moving distance and time. When the fuelling list is implemented in the control room, Authorized Nuclear Operators (ANOs) usually try to stick with the order of the fuelling sequence on the given fuelling list if possible. However, there are occurrences when the fuelling order needs to be changed depending on particular operational circumstances (for example, to keep the liquid zone controller level at an optimum level). Detectors may respond differently if the fuelling order is shuffled, but this difference is not expected to have significant impact on the analysis results, as shown by the following sample case in Section 4.

The frequency of flux calculation in SORO is user-defined. The flux calculation can be done as frequent as following each fuelling activity. This is referred to as single-channel fuelling method. In practice for current reactor operation predictions, flux calculations are performed for every several fuelling activities to provide key parameters (e.g. Channel Power, Bundle Burnup) to monitor the reactor core behaviour. This is referred to as multi-channel fuelling method. In general, more frequent flux calculation produces more accurate results since in the case of multi-channel fuelling, flux shape is affected by multiple channel fuellings. One of the purposes of this analysis is to find out whether the multi-channel fuelling is sufficient for predictive SORO runs to provide accurate prediction on high response NOP detector(s).

Predictive SORO run produces a summary report showing the highest three detector gains yielded following each flux calculation, through a special script written for predictive fuellings. Detector gain is the same idea as detector ratio (for example, a gain of 6% is the same as a detector ratio of 1.06), but it is presented in the form of percentage reflecting the delta of detector readings before and after fuelling. A detector gain higher than 6% is usually considered as unacceptable and is referred to as high detector gain (or high detector response if in the form of 1.06). The associated detector will be flagged and fuelling is not preferred around this particular detector. If fuelling in the proximity of the flagged detector is not avoidable, the reactor may be derated to maintain the MTT. With the multi-channel fuelling method, when a detector gain higher than 6% is captured for a specific Shift card, the fuelling engineers are usually able to identify the fuelling causing the heavily increased gain by the known detector(s). This is because that there are not too many channels to be fuelled each day, and neighbourhood channels are usually not fuelled together to avoid higher than usual channel and bundle powers, as well as flux tilt. If the fuelling introducing high gains is not explicit, or the third highest among the top three detector gains on the summary report is still higher than or very close to 6%, additional flux calculations would be performed on each single fuelling activity in between the two flux calculations to identify the fuelling corresponding to the high detector gains. With the single-channel fuelling method, extra simulations are not needed since the detector response for each fuelling activity is provided.

PI Data

Getting the results of detector response to fuelling operations from PI is not straightforward as that from SORO. The actual fuelling time is not documented and hard to be tracked precisely based on the available sources. However, the moment of each individual fuelling operation can be determined approximately based on the fuelling time stated in SORO and the change of reactor powers observed from the PI data if a derating happens.

According to station fuelling experience, it takes about 90 minutes to complete one fuelling. Data of detector readings and corresponding reactor powers were extracted two hours before and after the fuelling time stated in SORO with time step of 1 minute, in order to have a sufficient period covering related influence on detector readings due to a specific fuelling. The period of power derating is considered from the point when the reactor power starts to decrease till the point that the power is back to usual level. The average of detector readings obtained from PI, before power derating was then used as the detector response before perturbation, and the highest reading during the period of power derating was used as the detector response after perturbation.

4. RESULTS

SORO Simulation Data: Prediction and Production Data

Table 1 shows the maximum detector response among all the 18 or 16 detectors for each of the six logic trip channels (Channels D, E, F for SDS1 trip, and Channels G, H, J for SDS2 trip). The results were calculated by using detector flux readings from fuelling of channel E04 alone with predictive and production SORO data. The comparison shows that the percent differences are up to 0.54%. The small difference proves that the impact of using production data instead of prediction data is negligible on the analysis results.

SORO Simulation Results: Multi-Channel Fuelling Method v.s. Single-Channel Fuelling Method

Similar to Table 1, Tables 2-a to 2-c show the maximum detector response for each of the six logic trip channels from the three fuelling cases mentioned in Section 3, but with results from both single-channel and multi-channel fuelling methods. For all three tables, the highest detector responses obtained from each of the two methods were highlighted in yellow for comparison. The detector responses highlighted in orange are those than have a ratio after to before fuelling higher than 1.06 (or gain higher than 6%). As shown, the multi-channel fuelling method is as accurate as the single-channel fuelling method in terms of capturing the detector with highest detector response for all three cases examined.

Multi-channel fuelling method takes into account the effect from all the fuellings involved. In order to examine whether the multi-channel method captures the maximum detector response from the fuellings involved, the maximum detector response from the single channel fuelling are compared to the result from multi-channel fuelling for each logic trip channel. The differences are found to be in between -1.78% and 0.03% for the cases selected for this analysis. When the detector gain of 6% is applied on flagging high response detectors, this discrepancy in between the two SORO calculation methods is needed to be considered along with the 6% detector gain. If not, a high response detector may be missed as shown in Case 1 in Table 2-a. For Case 1, the result from multi-channel fuelling shows a highest detector response of 1.05, but the actual highest detector response, shown by the results from single channel fuelling, is 1.065. The three cases in this paper show a trend of small differences in between the results from the two approaches. However, further analysis is needed to figure out and to confirm the maximum difference in between multi-channel and single channel fuelling methods to ensure all the fuelling cases in the operation history are covered.

SORO Data v.s. PI Data

PI data provides the real-world measurements of the plant components, which can be used as a standard to examine how accurate the SORO simulation is. Table 3 provides the comparison of the resultant predictions from SORO against the PI data results. Both multi-channel and single-channel calculations match well with the PI data, within differences ranging from -1.89% to 0.16% and 0.25% to 1.39%, respectively.

5. CONCLUSION

In this analysis, the SORO predictions of high response NOP detectors are examined by comparing i) detector responses from SORO simulations by using the single-channel and multi-channel fuelling methods; and ii) detector responses from both SORO calculation methods against results from station measurements.

The results show that the SORO simulation with multi-channel fuelling method currently in use on Bruce Site provides reasonably accurate prediction of high response NOP detectors prior to fuelling. This foresees the adverse effect of fuelling activities causing reduced NOP MTT. Detector response results from both fuelling methods for SORO simulation are found to match well with the results from station measurements

Table 1: Comparison of Detector Responses from Predictive and Production SORO Runs

Channel Fuelled	Data Source	Max. Detector Response of Each Logic Trip Channel					
		D	E	F	G	H	J
E04	Predictive SORO Run	1.068	1.027	1.068	1.016	1.028	1.046
E04	Production SORO Run	1.069	1.027	1.074	1.020	1.031	1.051
Percent Difference		0.13%	0.07%	0.54%	0.40%	0.29%	0.48%

Table 2-a: Comparison of Single-Channel and Multi-Channel Fuelling on Detector Response Ratio Before/After Fuelling for Case 1 (Results are calculated from Production data)

	Channels Fuelled	Max. Detector Response of Each Logic Trip Channel					
		D	E	F	G	H	J
Single Channel Fuelling	J21	1.037	1.033	1.023	1.037	1.027	1.046
	O04	1.032	1.037	1.065	1.051	1.040	1.034
	Q14	1.030	1.024	1.010	1.017	1.010	1.015
Multi-Channel Fuelling		1.022	1.024	1.050	1.036	1.027	1.028
%Difference (Multi-Channel v.s. Single Channel)		-1.48%	-1.17%	-1.37%	-1.40%	-1.17%	-1.73%

* Both highlighted detector responses in Table 2-a are calculated from readings of detector AF8F

Table 2-b: Comparison of Single-Channel and Multi-Channel Fuelling on Detector Response Ratio Before/After Fuelling for Case 2 (Results are calculated from Production data)

	Channels Fuelled	Max. Detector Response of Each Logic Trip Channel					
		D	E	F	G	H	J
Single Channel Fuelling	P21	1.046	1.040	1.063	1.069	1.037	1.055
	F20	1.045	1.039	1.047	1.022	1.037	1.040
	M12	1.010	1.019	1.029	1.021	1.030	1.030
Multi-Channel Fuelling		1.042	1.038	1.062	1.065	1.037	1.051
%Difference (Multi-Channel v.s. Single Channel)		-0.43%	-0.17%	-0.09%	-0.35%	0.03%	-0.32%

* Both highlighted detector responses in Table 2-b are calculated from readings of detector AF9G

Table 2-c: Comparison of Single-Channel and Multi-Channel Fuelling on Detector Response Ratio Before/After Fuelling for Case 3 (Results are calculated from Production data)

	Channels Fuelled	Max. Detector Response of Each Logic Trip Channel					
		D	E	F	G	H	J
Single Channel Fuelling	U21	1.024	1.034	1.075	1.016	1.033	1.047
	J17	1.034	1.018	1.019	1.029	1.015	1.021
	N05	1.030	1.033	1.049	1.030	1.027	1.056
	P15	1.034	1.023	1.009	1.012	1.009	1.008
Multi-Channel Fuelling		1.030	1.023	1.060	1.020	1.020	1.037
%Difference (Multi-Channel v.s. Single Channel)		-0.38%	-1.04%	-1.34%	-0.95%	-1.21%	-1.78%

* Both highlighted detector responses in Table 2-c are calculated from readings of detector AF17F

Table 3: Comparison of SORO data and PI data

Source	Case1	Case2	Case3	Case4
SORO (Multi-channel fuelling)	1.050	1.062	1.060	1.050
SORO (Single-channel fuelling)	1.065	1.063	1.075	1.074
PI	1.050	1.060	1.070	1.070
%Difference (Multi-channel v.s. PI)	0.00%	0.16%	-0.90%	-1.89%
%Difference (Single-channel v.s. PI)	1.39%	0.25%	0.45%	0.35%