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A Statistical Approach to determine the optimal ROP detector location for CANDU-6

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1. Introduction

Because of plant aging effects due to the flow accelerated corrosion (FAC) of a CANDU-6 reactor, the Regional Overpower Protection (ROP) Trip setpoint (TSP) has been decreased every year so that some utilities should operate their CANDU-6 reactors less than the licensed power. To solve this problem, AECL, the CANDU-6 designer, has developed several ways for plants to restore the ROP TSP. For an example, the steam generator primary side cleaning periodically can increase the ROP TSP about 5%, which depends on the plant operation history. However, even those ways, the TSP goes back to the level before the SG cleaning within 2~3 years. The best way is to replace old and aged pressure tubes with new ones, but it takes a long time and requires full-scale safety analysis as well as new TSP evaluation with the current probabilistic methodology.

The ROP requirements is that, for any core condition including core operation history, each safety channel must trip before the power in any fuel channel reaches the critical channel power. Therefore, TSPs should be setup in such a manner that there is at least one detector in each safety channel satisfying less than the required value, TSP, for every design-basis core condition. Naturally and logically, TSP depends on the worst core condition as well as the detector location. It means that if one evaluates TSP using optimized detector location corresponding to the aged core condition, the higher TSP may be possible. The object of this paper is to propose an advanced method to determine the optimal detector location based on the aged core condition. This new method is basically based on the deterministic approach developed by AECL. At first, this paper discusses the general deterministic method for selecting three safety channels from independent one channel list, and shows the some results based on the new approach.

2. Deterministic Detector Layout Optimization

The deterministic detector layout optimization module works in several stages.[1]

2.1 Determination of Initial Trip Setpoint

The first step is to set trip setpoints of detectors so that each ROP case must be seen by at least three detectors, one per safety channel. The result of this process is a matrix of integer values (0 or 1) indexed by case and detector, where “1” indicates that the case is covered by that detector and “0” not covered by the detector.

2.2 Matrix Reduction

At the second stage, the matrix is reduced in two steps. First, any case that is covered by a set of detectors, for which a subset of detectors can be found as the tripping detectors for a second case, is considered redundant and the case is removed. This step is taken because any trip that would occur for the case using the smaller number of detectors would also occur for the case using the larger number of detectors.

After reducing the number of cases, the number of detectors is reduced. Any detector that trips for a number of cases that are a subset of the cases that trip for a different detector is considered redundant so that the detector is removed. The justification is that the detector covering the larger number of cases makes the other detector redundant. The exception to this rule occurs when the removal of the redundant detector would reduce the number of detectors tripping for any case below the lower limit (at least three detectors).

2.3 Selection of Three Safety Channels

All potential independent three safety channels for each shutdown system may be determined by generating a logic tree and building individual safety channels on a case-by-case basis. Each single safety channel solution is generated so that they satisfy every case, by proceeding sequentially through the cases and adding detectors, as necessary. This procedure results in a group of potential single channels that are examined in turn for completeness. If a detector set with N detectors covers all cases, then any solutions with the same detectors plus others are obviously non-optimal. The result from this process will be a list of potential solutions using a minimum number of detectors, spread over three safety channels, each covering every case specified. The process can be set to look for solutions of at least a certain size or below a certain setpoint.

3. Stochastic Detector Layout Optimization

3.1 Problems in the Deterministic Approach

The most weakness in the deterministic approach is that it could not give any optimized three-channel solution. Designers have to select one of the cases contained in the final list, prepare the detector signal file corresponding to be chosen detectors, calculate the case’s TSP based on the conventional statistical method, and do these all process repeatedly until to find reasonably high TSP. But no one knows or guarantees the solution is optimal. Generally the statistical TSP is different from the deterministic TSP, while all deterministic results satisfy the pre-determined TSP of the first stage.

3.2 Statistical Concepts to find better single channel

To find the optimal three-channel solution, one has to know the statistical TSP value for each possible safety channel solution. Therefore, additional subroutines computing the statistical TSP of each safety channel were developed. To minimize the TSP computing time, the integral regions of non-trip and common-mode probabilities for each safety channel and ROP case were adjusted.

If one get the possible single channels after the second stage, ROVER-K[2] calculate the channel-wise TSP using well defined uncertainty and ripple data. Even only 58 ROP detectors could be exist in CANDU-6 instead possible 425 detector locations (278 for SDS1, 147 for SDS2), the number of possible single safety channels goes up to several ten thousand. Therefore, the potential number of combined three independent channel which can be treated as a shutdown system is greater than 10^{11} order($_{\sim 10000}C_3$). If all 425 detector location candidates are used, the order of combined cases maybe 10^{14}. Therefore, sometimes huge computing time will be required to search the optimal three-channel case. Fig. 1 shows the new algorithm using statistical approach, compared with the conventional deterministic one.

4. Test Results and Discussion

To test the performance of new method, we investigate the detector location changes for initial core and aged(~6800 EFPD) core where current 58 ROP detector locations only are considered. All information required to calculate statistical TSP were prepared based on the site measured data, i.e., critical channel power cases and uncertainties corresponding to two core conditions. Because of using 58 detectors only, the TSP may be not changed if one use re-arranged safety channels.

Table 1 shows how many cases and detectors are required for two test problems in case of SDS1 & 2, and Table 2 shows the final TSP variations according to different core condition as well as without channel relocation when just SDS1 detector variations are considered. After DLO, the required detector number is decreased except that of SDS2 because no rule to treat the compensated and compensating detectors was setup. But Table 2 also shows that by using statistical detector layout optimization technique one can preserve the TSP implemented in the site with less ROP detectors. From Table 1 and 2, one can observe the new statistical approach is able to search the optimal number of detectors and safety channel combination.

5. Conclusion and Further Study

This paper just has considered the effect of statistical approach of detector layout optimization for the given 58 detector problems. It shows that without variation of the TSP one can decrease the number of detectors required to trip CANDU-6 reactor with 98% trip probability.

In case of reflecting less than 30,000 single channel lists, the direct search technique was useful to find the best three-channels. However if 425 detector locations are used, the computing cost of direct searching is much expensive so that other optimal technique like as GA algorithm should be applied, and one should investigate the effect of TSP variation itself according to the optimal detector locations.

REFERENCES

[1] V. Caxaj, "ROVER-F version 2-04 Manual," AECL Report CW-117390-MAN-003,2005 April.
[2] E. K. Lee, "Development of ROVER-K code to Determine Regional Overpower Trip Setpoint in CANDU 6 Reactor," KNS Spring Meeting, May 26 – 27, Jeju, 2004

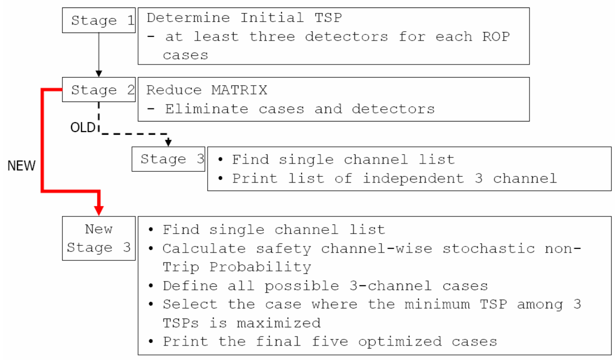

Fig. 1. TSP installation in the current ROP system

	Before DLO	After DLO
Initial Core	34/24/212	25/18/25
Aged Core	34/24/212	26/25/23

Table 1. Essential number of Detectors (SDS1 & 2) and ROP Cases of Two Core Conditions

	DLO (re-allocation)	Sustaining the current safety channel but reduce the number of detectors
Initial Core	No change	- 4.5%
Aged Core	No change	No change

Table 2. TSP Changes corresponding to core condition in case of applying SDS1 DLO results