ROP Case Identification using group-wise ROP detector signal variation

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1. Introduction

The aging process in the heat transport system (HTS) of an aged CANDU-6 reactor results in the decrease of regional overpower protection (ROP) Trip setpoint (TSP) because the aging process make the unwanted flow distribution in the fuel channel and increase the possibility of fuel failures in the worst ROP case. It means that the aged CANDU-6 reactor should reduce the operating power level less than 100% at normal operation to prevent fuel failures. To make less decease of operating power level, several methods were applied such as a steam generator tube cleaning to restore efficient heat transfer, an application of new hand switch rules coupled with alarm system, and the adoption of a new TSP evaluation methodology. However, those methods are not permanent solution. The tube cleaning of a steam generator is very expensive work but will be lost its effect within three or four years. The new hand switch position (HSP) rule has been applied to a CANDU reactor by a utility in CANADA but not yet in KOREA. There is a possibility for a site to lost normal operational margin due to the new rule. New ROP TSP evaluation method, i.e., the Extreme Value Statistics (EVS) method [1], was submitted to Canadian Nuclear Safety Commission (CNSC) and final acceptance is anticipated by end of 2010. However, the successful application of EVS method to CANDU-6 reactors in KOREA maybe require more time because EVS is theoretically different and more complex method compared with the current ROP TSP calculation process.

However, if operator can be aware of the core status accurately, then a utility uses the TSP corresponding to the current core status instead of the ROP TSP based on the worst ROP case, which is installed in sites at present. If one can use the TSP against a normal condition, it means the reactor maintains the licensed power or the utility can minimizes the decrease of ROP TSP.

The problem is how to get the information about the reactor status accurately. The best way to solve this problem is to make an on-line system help operator be well-informed about the reactor status. The similar system to COLSS[2] coupled with ROVER-F code [3] is required to do this. However, it is nearly impossible to apply that system to a CANDU-6 reactor because lots of control system should be changed as safety system. In addition, it takes long time to acquire license and needs huge initial investment.

This paper suggests a simple but practical method to identify the core status; it uses the ROP detector signals itself but different approach. The key point of the method is of grouping the ROP detectors and using the averaged detector signal of each sub-group.

Chapter II and III show the method more detail, and Chapter IV will discuss an example of the new method's application to a CANDU reactor where operator had replaced 16 fuel bundles over two hours. From the test result, we have reached that the new method is useful to prevent the power reduction under 100% in an aged CANDU reactor without any modification of existing system because it can point out the core status and help to set the appropriate TSP corresponding to the core condition.

2. ROP TSP Determination and Detector Grouping

The ROP TSP is calculated by the probabilistic method[4] based on ~900 channel power shapes (or ROP cases) derived from nuclear design, critical channel powers reduced from the recently measured thermal-hydraulic data, well-defined uncertainty values, several hundred ripple data reflecting operational history, and calculated 58 ROP detector signals. Each ROP case belongs to one of three hand-switch positions (HSP). For each HSP, the trip probability of shutdown system T is calculated according to the following Eq.;

$$P_T(k) = 1 - \int Q_{CM}(k,x) \cdot P_{NT}(k,x)dx \qquad (1)$$

where $Q_{CM}(k,x)$ means the common-mode probability density, and $P_{NT}(k,x)$ is the non-trip probability of k th ROP case and x reactor power. To solve Eq. (1), one needs several design code such as RFSP[4], NUCIRC[5], and ROVER-F. As for ROP detectors, their readings are calculated by RFSP code for each ROP cases and used to get $P_{NT}(k,x)$, where channel power peaking factor (CPPF) extracted from ripple data are multiplied to simulate detector signal variation in a site. An individual ROP detector just point out a local flux. It cannot give us any information about the core status even though it protects the reactor during normal and abnormal operation. However, if there are several detector-groups (DG) consisting of 3~4 individual ROP detectors, then one can extract the information about core status from DG's characteristics. For an example, if DG_1 consists of 2D, 2E, and 9F, then the maximum reading of DG_1 occurs at No. 399 ROP case, while the minimum reading at No. 344 ROP case. The minimum value is also important because it is a clue for check the core status. Fig. 1 shows an example how to group individual detectors. DG_2 can reflect the regional flux behavior at quadrant four.

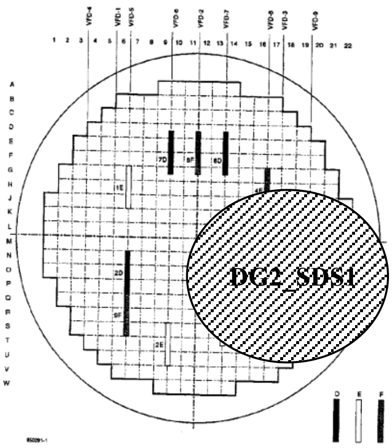

Fig. 1 An Example of new detector-group (DG)

3. ROP Case Identification method

From several detector-groups, one can obtain more information about the core status. However, it is impossible to identify ROP case with DG signal itself. There should be something for identifying ROP case from DG signals. We developed a simple and intrinsic method. We allocate a serial and unique number to each DG from 1 to 10, and then set criteria for the signal variation of a DG. The reason variation is used instead of absolute signal strength is to reflect noise and fluctuations in actual signal behavior.

For an example, |5%| variation from the normal condition may be introduced. If DG signal exceeds the criteria, set the status of DG as '1', otherwise set '0'. Then, the final DG chain looks like '01100101' and that binary value can be converted to an integer, or representative number (RN), easily. Table 1 shows an example how to get DG status and RN from eight DGs of SDS1 for each ROP case.

Table 1. An example of DG and its status number

Case	DG1	DG2	DG3	DG4	DG5	DG6	DG7	DG8	RN
499	0	0	0	1	1	1	0	0	28
510	0	0	0	1	1	1	1	0	30
1	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0
399	1	1	1	0	1	0	0	0	232

Table 1 shows the new method can be failed to indicate individual ROP case because of large criteria. However, there is no doubt RN can indicate the normal and abnormal core condition. If one use the RN, TSP corresponding to RN = 0 is increased to about 5% compared with the TSP based on the worst case

4. Test Result and Conclusion

The new ROP case identification method was applied to a CANDU-6 reactor. Because 58 ROP detector signals were measured during two hours refueling process, the off-line analysis was conducted to investigate the applicability of new method despite heavy fluctuation caused by noise. Fig. 2 shows DG4_SDS2 reading and three detector readings belong to DG4_SDS2.

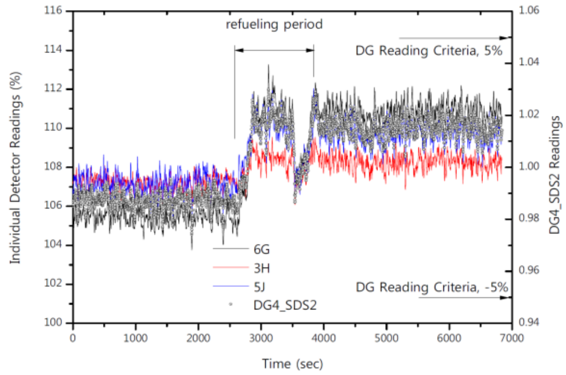

Fig. 2 Detector reading variation during refueling process

As the core status during refueling process were at the normal operation, the RN should be zero theoretically even there were heavy fluctuation. The test result for total 3,423 data point verified the performance of our suggestion. There was no case of RN > 0. Table 2 shows an example of RN history of 10 sec.

Table 2 Test results in case of refueling process

Time(sec)	DG1	DG2	DG3	DG4	DG5	DG6	DG7	DG8	RN
3000	0	0	0	0	0	0	0	0	0
3002	0	0	0	0	0	0	0	0	0
3004	0	0	0	0	0	0	0	0	0
3006	0	0	0	0	0	0	0	0	0
3008	0	0	0	0	0	0	0	0	0
3010	0	0	0	0	0	0	0	0	0

The RN monitoring system based on the new method can figure out the detail values of DG4_SDS2 in every second so that the installation of an alarm is very easy. If RN = 0 is sustained during the operation and DG histories are known, the utility can get enough information to adjust TSP corresponding to normal condition and to maintain the operating power level without reduction. Further study will be focused on the on-line ROP case identification test and introduction of real time reactivity computer catching reactivity alternation induced by the slow loss of regulation.

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