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A Simple Concept for Real-time ROP setpoint Evaluation system for CANDU-6

Eun-ki Lee, Yong-Bae Kim, Dong-Whan Park, Yong-Kwan Lee
Nuclear Power Lab, Korea Electric Power Research Institute, 103-16 Munji-dong Yusung-Gu, Daejeon, KOREA
lek@kepri.re.kr, ybkim@kepri.re.kr, dwpark@kepri.re.kr, yklee@kepri.re.kr

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's periodic primary side cleaning can increase the ROP TSP about 5%. The detail TSP gain depends on each plant's operation history. However, within 2~3 years, the TSP goes back to the level before the SG cleaning. 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 for every design-basis core condition there is as least one detector in each safety channel satisfying less than the required value, TSP. Naturally and logically, TSP depends on the worst core condition. It means that if one calculates TSP using nominal core conditions only instead of whole design-basis condition, he/she will get higher TSP. Therefore, the next best way to recover ROP TSP is to change the evaluation methodology and hardware. If power shapes and thermal-hydraulic characteristics due to changes in device configuration or xenon changes are calculated in real-time, one can obtain the exact TSP corresponding to each reactor condition. Therefore, KEPRI developed conceptual four different real-time online ROP systems. At first, this paper discusses the general problems to be solved by real-time ROP system and, then, shows the merits and defects of each candidate.

2. Real-time ROP systems

If one wants to create a real-time ROP system, he/she has to determine which measured site data should be used to reflect core condition at real-time; ROP detector signals, reactivity device configurations, thermal-hydraulic detector signals and vanadium detector signals, etc. The real-time ROP system should compute channel power distribution, critical channel power shape, and trip setpoint within given time criteria.

2.1 Flux Distribution

It is possible for the current core simulator, RFSP[1], to compute the channel power (CP) shape within ~sec. However, the RFSP code cannot simulate cores at transient state and is too heavy because of other function not required for real-time core calculation. Although it considers reactivity device configuration at given point for specific time step, more information to show actual flux distribution are needed; detector readings. Especially, 102 Vanadium detector readings are good for that purpose although they are classified as a non-safety system. Therefore, one has to slim and modify the RFSP code to treat continuous burnup effects and simulate transient core conditions. One also should solve how to use the non-safety system problem. The ROP Pt-detector readings are also an alternative idea. However, in this case, it is possible to increase the overall uncertainty because of its inaccuracy of readings.

2.2 TH model

Another key process in real-time ROP system is to obtain the Critical Channel Power (CCP) distribution based on the axial bundle powers transferred from the RFSP, because TSP consist of channel-wise CCP over CP values and relative detector readings. Basically, a specific module of the thermal-hydraulic code for primary heat transfer system (PHTS), NUCIRC[2], computes the CCPs based on the well-designed TH model satisfying measured boundary conditions. At present, it takes about 10 min. to calculate whole 380 CCPs in Pentium 4 3.0GHz PC. Therefore, a computer system containing about 10 parallel processors is a good solution for this problem. It means there is a need to modify and slim the NUCIRC code to meet time interval criteria of real-time ROP system, which will be determined.

2.3 TSP calculation

One can use the current probabilistic method for computing TSP. In real-time system, computing time for running ROVER-F[3] code will be very short because there are only ~10 flux cases and a ripple case. However, detail number of flux cases should be determined according to the specific real-time ROP TSP system. Because KEPRI has well trained persons in this field, code modification or development will be conducted by KEPRI itself.

2.4 Several Candidates of Real-time ROP system

Figure 1 shows the typical data flow diagram to estimate TSP of a CANDU-6 reactor. If one wants to control TSP itself, the real-time system diagram in Figure 2 is a representative one. This system calculates and updates TSP itself with various plant data including vanadium detector signals, if possible. There is no need of detector calibration factor because required information is already used to determine the real-time TSP. When the core is maintained at normal condition, the real-time TSP might go up to ~10% higher than that of conventional one determined to protect the worst and rare occasional flux shape. However, this system has lots of problem. Typical problem is that all ROP electric systems should be changed, i.e. hardware replacement. On the other side, a simple method with minimum change of the current system exists. If one can control the detector calibration factor with real-time, then one can get the same effect to treat the TSP itself. In this case, the fixed TSP should be determined in advance but with normal or economic flux cases only.

Figure 3 shows TSP variation for each ripple data, where just a few normal core flux shapes are used. The difference between minimum TSP and installed TSP is about 5%.

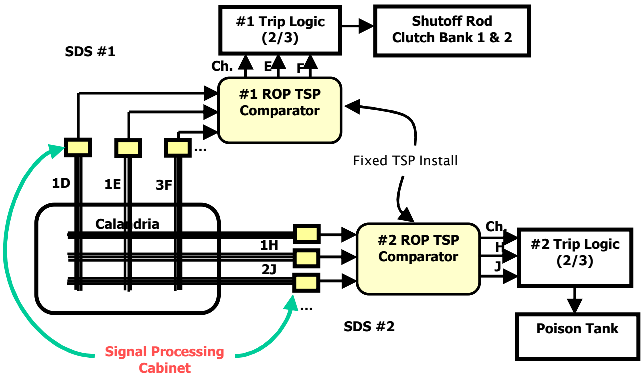

Fig. 1. TSP installation in the current ROP system

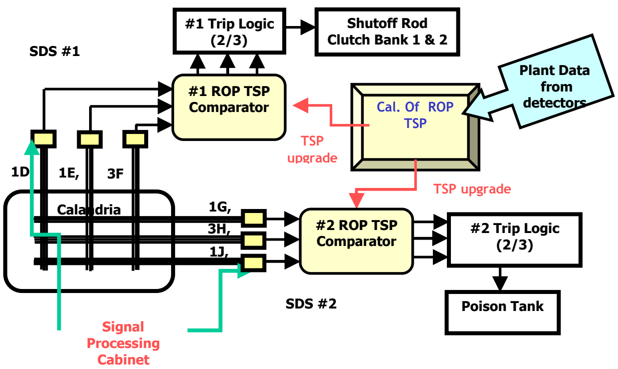

Fig. 2. TSP itself updating system

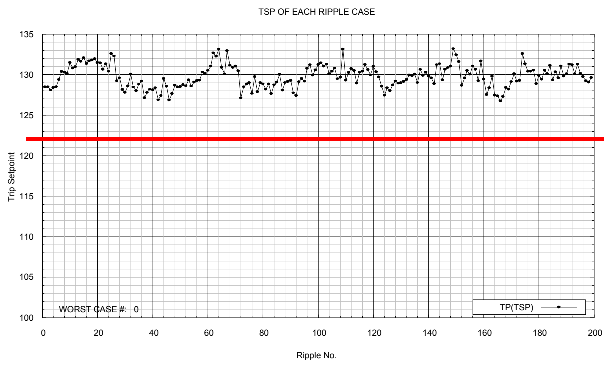

Fig. 3. TSP variation in case of using normal cases only

3. Conclusion

The conceptual design comparison for real-time ROP TSP evaluation system was performed. We found several critical problems; how to treat non-safety system signals in a safety system, determination of appropriate time interval for real-time TSP control, and which approach for real-time TSP calculation is the best, etc. Basically, ROP TSP was designed to protect the fuel in the worst case of the slow loss of regulation accident. It means there is no need to control the TSP at real-time. However, if one obtains 5% higher TSP form a new real-time ROP system, then the plant is able to maintain the licensed power during 5 years without power degrading. If some economical or operational benefits are guaranteed from the real-time ROP system, the feasibility and applicability of the system to the real world should be performed.

REFERENCES

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[3] V. Caxaj, "ROVER-F version 2-04 Manual," AECL Report CW-117390-MAN-003,2005 April.