Qualitative Evaluation of Single Point Vulnerability in Domestic NPPs

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1. Introduction

Although operating skills of domestic nuclear power plants are improved and various efforts are being made to prevent the unexpected reactor scram, the plant trip due to SPV (Single Point Vulnerability) still occurs. Unplanned plant trip leads to the generation loss which means economic loss and this is why the detailed review, systematic risk evaluation and countermeasure establishment on the SPV of the plant are needed in the domestic Nuclear Power Plants (NPPs).

In the same manner, U.S. nuclear industry makes an effort to remove the SPV of their plants. For example, Arkansas Nuclear One made a list of SPV whose failure results in plant transient including de-rate or reactor scram and corrected the difference between lists for the unit 1 and 2 through the cross check of the expert group which is called Unit Reliability Team. Shearon Harris is also one of the utilities which organized the task force to resolve SPV problems and they focused on the major 4 systems which resulted in plant trip during recent 14 years. Exelon identified SPV components through the review of MR (Maintenance Rule) functions and DC Cook performed the detailed fault tree modeling of the plant BOP system.

Recently, KHNP encourages their plants to make an effort to drive the plan which could reinforce the control of SPV components. The plants have developed their SPV lists to establish further actions and NETEC (Nuclear Engineering & Technology Institute), which is responsible for an engineering part as a subsidiary of KHNP, is performing the verification of the SPV lists and FMEA (Failure Mode Effect Analysis) and fault tree modeling of major systems related with plant transient.

2. Goal of SPV Evaluation

The goal of this SPV evaluation can be divided into qualitative respect and quantitative respect separately. First, the goals of qualitative SPV evaluation are to complement the current SPV list and to provide domestic NPPs with management methods of SPV components. The goals of quantitative SPV evaluation are to perform the FMEA (Failure Mode Effect Analysis) and to develop the detailed logic model using FTA(Fault Tree Analysis) tool, finally to establish the countermeasures according to the resultant importance of the SPV component. FMEA and FT modeling are performed with respect to major 4 systems which caused the transient conditions such as reactor scram, unplanned T/G (Turbine/Generator) trip.

After development of the prototype trip monitoring program has been completed, the final trip monitor including entire plant systems which affect plant power generation would be developed. To accomplish this long term plan, the detailed trip logic model should be developed system by system and from the PWRs to CANDU plants.

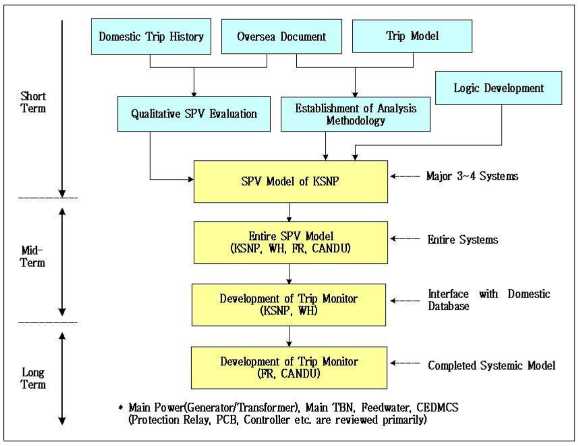

Figure 1. Steps for SPV and Trip Risk Evaluation

3. Qualitative SPV Evaluation

The domestic plants which consist of KSNP 8 units, Westinghouse type plant 5 units, Framatome type plant 2 units and CANDU type plant 4 units made their SPV lists using previous draft SPV lists. These lists include the SPV components which the plants have managed on the basis of experience since their commercial operation. The components are the ones which can cause reactor scram, T/G trip, and de-rate of more than 50% if single component fails.

To compare the difference between the experience based SPV lists of the same reactor type plants, the interview with the component maintenance crew in the plants was performed. Consequently, omitted SPV components were identified through a cross-check between the SPV lists of the same type units. Besides, it was revealed that several additional components had single point vulnerability through the plant scram history review and they were added to the SPV list.

The criteria to remove unrelated components from the initial plant SPV list were established. For example, redundant components such as analog safety channel components were excluded. Relays and solenoid valves with normal de-energized characteristic were also removed from the SPV list. The following figure shows mechanical, electrical and I&C component occupancy ratio in the specific plant SPV list. There was only small discrepancy between two same type plants (i.e. Yonggwang unit 1&2 and Kori unit 3&4) due to the slight system design difference.

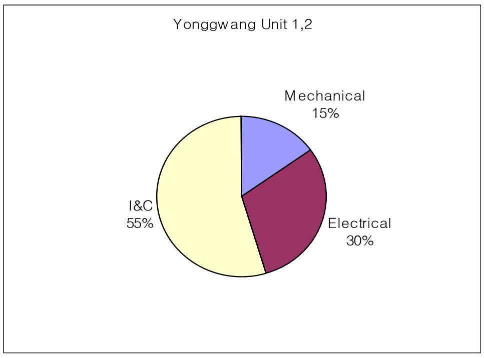

Figure 2. Maintenance Area in the SPV List

Since the failure of mechanical SPV components are generally related with aging mechanism, it is determined that mechanical component improvement to remove SPV is unreasonable, that is, very difficult or high cost. Electrical SPV components are mostly protection relays and their improvement methods becomes simple if the digital 2 out of 3 protection technology is employed. Since I&C SPV components still have a potential improvement opportunity such as additional redundancy, it is expected that additional design changes could prevent unnecessary plant trip.

The below figure explains the SPV management policy of this evaluation. In the short term, the SPV list is made according to the qualitative SPV evaluation results and after that, field inspection, operation procedure improvement, design change etc. are followed as the corrective actions. In the long term, the quantitative evaluation including FMEA will be performed to identify the logic combination which can cause the plant transient and the system single point vulnerability also will be analyzed and modeled through this activity.

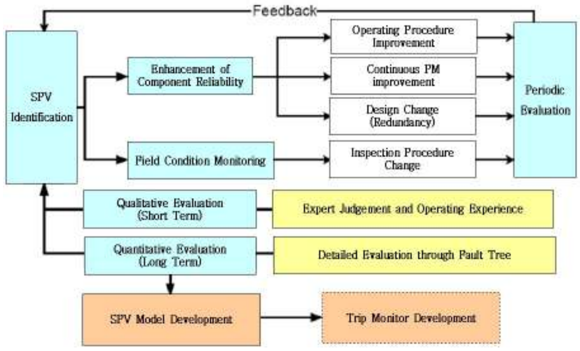

Figure 3. SPV Evaluation Scheme

5. Conclusion

The KSNP has many SPV components, which include electronic circuit cards, coils, position detectors etc., in the control rod drive system but there will be few SPV components in the secondary system if the feedwater controller such as a positioner is changed into a redundant configuration. Control Rod System (RCS) of Westinghouse type plant has a design which is robust to plant trip due to the single failure because a negative flux rate trip signal has been removed through a design change but many circuit cards of Reactor Protection System (RPS) remains as SPV components. It was revealed that CANDU plants had single failure vulnerability in the primary reactivity control system including the moderator system. The function transfer relay for plant control computers also was identified as a SPV component of CANDU unit.

Some domestic plants performed a design change which replaced traditional analog electrical protection relays with the digital relays containing the 2 out of 3 coincidence logic to prevent the generator or transformer trip due to the protection relay failure or its spurious actuation. Consequently, the SPV evaluation and its application like above examples are being performed aggressively as a part of the efforts to reduce unexpected plant trip and it is expected that these activities would give a positive effect on the plant safety also as well as prevention of generation loss in the domestic NPPs.

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