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Risk Analyses of Charging Pump Control Improvements for Alternative RCP Seal Cooling

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1. Introduction

Recently, Korea Hydro & Nuclear Power Company (KHNP) reviewed the probabilistic safety assessment (PSA) models of their nuclear power plants and inspected the accident sequences with high risk in terms of system designs and operator actions during the accidents. For Kori Unit 2 (K2), its PSA results demonstrate that the risk from the total loss of component cooling water (TLOCCW) comprises a large portion of the entire plant risk [1]. There are two events that significantly affect the plant risk during a TLOCCW event. One is an event in which the seal assembly of a reactor coolant pump (RCP) fails due to heating stress from the loss of cooling water; the other is an event in which the operators fail to conduct alternative cooling for the RCP seal during the accident. KHNP reviewed the replacement of the RCP seal with a qualified shutdown seal in order to remove the risk due to RCP seal failure during a TLOCCW. As an optional measure, a design improvement in the alternative cooling method for the RCP seal is being considered. This analysis presents the alternative RCP seal cooling improvement and its safety effect.

2. Risk Evaluation

The RCP seal of K2 is a hydrostatic seal assembly, and operators should shutdown the plant within 30 minutes during a TLOCCW event because continuing operation is impossible due to seal failure [2]. Therefore, operators need to provide alternative cooling water from sources other than the failed CCW system or inject refueling water storage tank (RWST) water into the RCP seal using the auxiliary charging pump in order to maintain the integrity of the RCP seal during a TLOCCW event. Because the K2 PSA results explain that the risk importance of alternative cooling of the RCP seal is very high, a design improvement plan to reduce this risk and its effects on the PSA results are reviewed through this evaluation.

2.1. Configuration of the Pump Startup Circuits

K2 has two operating charging pumps that provide RCP seal water, and one auxiliary charging pump that performs a backup function during the failure of these two pumps. This auxiliary charging pump is started by an operator using a manual switch in the main control room (MCR), and it has a circuit configuration that can close or open the power circuit breaker for a pump through related switch contacts (refer to Fig. 1). The auxiliary charging pump is equipped with an air-cooling design and can inject seal water into the RCP during a TLOCCW, which is a different characteristic compared with the main charging pumps that have a water-cooling design.

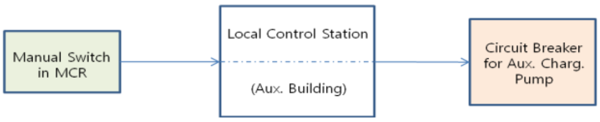

Fig. 1. Manual control circuit configuration to start an auxiliary charging pump (before improvement)

Operators should take action to transfer the suction line of the auxiliary charging pump from the volume control tank (VCT) to the RWST, as well as start the pump during a TLOCCW event. This action enables the pump to inject cold water into the RCP seal during an accident. Therefore, installing an automatic control circuit, which starts the auxiliary charging pump and transfers the pump suction from the VCT to the RWST during a TLOCCW event, can reduce the probability for operators to fail to take appropriate actions (refer to Fig. 2).

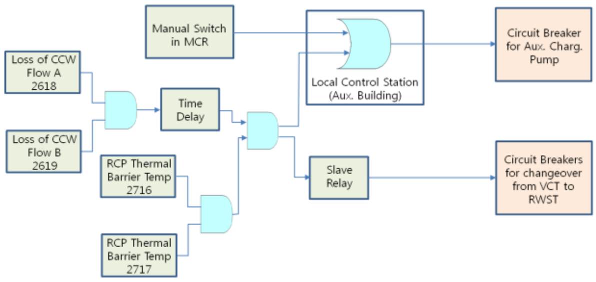

Fig. 2. Automatic startup circuit configuration for an auxiliary charging pump

This automatic circuit actuates a bistable when a flow signal from the sensor in the CCW pipe reaches a set point, and it creates an "AND" logic between the channel A signal and the channel B signal through the isolation cards. This circuit determines whether an actual TLOCCW event is occurring or not based on the low flow signals after a time delay from both the cooling water flow channels and the high temperature signals from the RCP thermal barrier. In addition, the circuit initiates an actuation signal to the local control station in the auxiliary building and a slave relay conducting a valve control in order to transfer the pump suction during the TLOCCW event. The CCW flow measurement circuit and the slave relays for transferring the pump suction are previously installed components. The logic relays and a time delay relay should be added in order to configure the CCW flow signals and thermal barrier temperature signals to build the "AND" logics.

2.2. Fault Tree Establishment

In order to understand the safety effects of this improvement from a PSA perspective, a fault tree for the auxiliary charging pump was constructed.

Table 1. Reliability data of components in the circuit

Components	Failure Rate	Failure Probability	CCF Factor (2/2)	CCF Probability	Failure Mode
Transmitter	1.76E-06/h	4.22E-05	5.00E-02	2.11E-06	Fail to op.
Loop Power	9.15E-06/h	2.20E-04	1.00E-01	2.20E-05	Fail to op.
Bistable	9.20E-04/d	9.20E-04	1.00E-01	9.20E-05	Fail to op.
Actuation Card	1.25E-05/h	3.00E-04	1.00E-01	3.00E-05	Fail to op.
Logic Relay	1.00E-04/d	1.00E-04	-	-	Fail to op.
Slave Relay	9.59E-05/d	9.59E-05	1.00E-01	9.59E-06	Fail to op.

The fault tree includes additional components for circuit improvements, which are flow sensors, temperature sensors, loop power supplies, bistables, actuation cards (isolation cards) in the process control systems, logic relays for the "AND" configuration, a time delay relay, a relay in the local control station, and slave relays for transferring the pump suction. The reliability data are presented in Table 1. This table includes the same values as the data in the K2 PSA report [1].

The fault tree of the auxiliary charging pump startup circuit for this analysis is depicted in Fig. 3. Common cause failures (2/2) were considered because there were two signal channels to measure the process parameters.

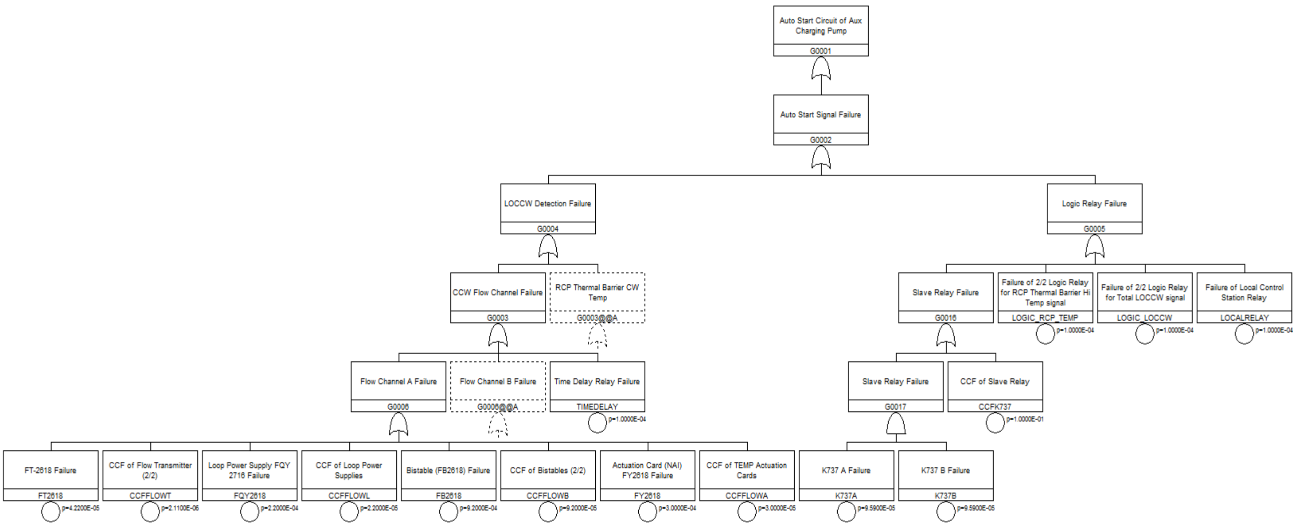

Fig. 3. Fault tree for the automatic startup circuit of the auxiliary charging pump

2.3. Risk Evaluation

A fault tree for the automatic startup circuit of the auxiliary charging pump was integrated in the PSA model in order to evaluate core damage frequency (CDF). The resultant CDF was reduced by approximately 28% compared with the value prior to the design improvements. This resulted from the operator action failure probability being reduced through adding the automatic control circuit. For example, an operator action failure occurs with a probability of 3.98E-2 during a manual seal injection with a backup charging pump. This value decreased by 89% to 4.26E-3 when the control circuit was supplemented by the automatic startup function.

Table 2. PSA effects of the circuit design change

Risk Measure	Before Design Change	After Design Change	Change (%)
RCP seal injection failure using aux. charging pump	3.98E-2	4.26E-3	-89.30%
CDF	1.89E-05/RY	1.37E-05/RY	-27.51%

3. Conclusions

K2 is a nuclear power plant with a Westinghouse design, and it has a relatively high CDF during TLOCCW events because it has a different CCW system design and difficulty in preparing alternative cooling water sources. This analysis confirmed that an operator action providing cold water to the RWST as RCP seal injection water during a TLOCCW event is very important in K2. The control circuit improvement plan for the auxiliary charging pump was established in order to reduce the failure probability of this operator action. This analysis modeled the improvement as a fault tree and evaluated the resulting CDF change. The consequence demonstrated that the RCP seal injection failure probability was reduced by 89%, and the CDF decreased by 28%.

In conclusion, it was proved that adding automatic startup circuits to the auxiliary charging pump can reduce the operator action failure probability due to human error during accidents and can create positive effects in plant safety based on this evaluation result.

References

[1] PSA Final Report for Kori Unit 2, KHNP, 2007.
[2] WCAP-15603, RCP Seal Leakage Models, W., 1999.