Risk assessment of improved reactor shutdown signal redundancy for RCP breaker opening

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1. Introduction

Some nuclear power plants use a RCP breaker auxiliary contact as a reactor trip signal. This paper evaluated the risk of the proposal of design change to reactor shutdown signal redundancy for RCP breaker opening.

2. Risk Assessment

In a reactor protection system related to the RCP trip signal, only one device of each loop is installed, those devices are RCP circuit breaker auxiliary contact, fuse, input relay, etc. A reactor trip occurs when these single devices fail. To improve for this, the following design changes were proposed and analyzed in terms of system unavailability and risk. In these proposals, RCP breaker auxiliary contacts and input relays could be additionally used to implement a 2/2 (1st proposal) or 2/3 (2nd proposal) logic circuit to prevent reactor shutdown when a single device malfunctions.

2.1 Review 1st proposal

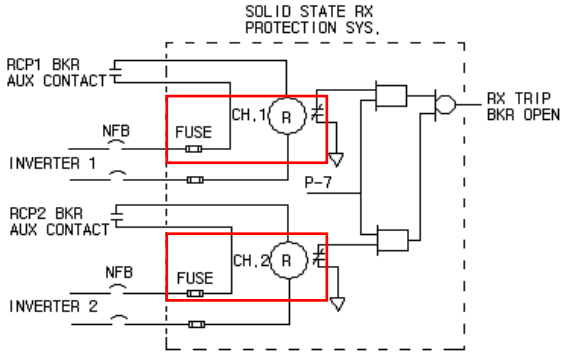

Fig. 1. Before improvement

In the existing design, a reactor shutdown signal is generated when ch1(the loop for RCP1) or ch2(the loop for RCP2) operates singly. [Fig. 1]

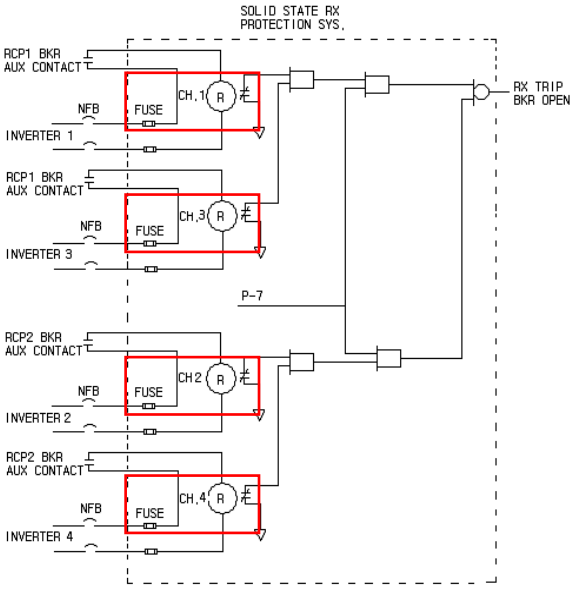

Fig. 2. 1st proposal

The 1st proposal is to generate a reactor shutdown signal when ch1 and ch3 are operating simultaneously or when ch2 and ch4 are operating simultaneously. (2/2 coincidence) [Fig. 2]

Assuming that the probability of failure of each channel is 0.1, the probability of a reactor trip signal occurring due to circuit failure is reduced, but the probability of failure of the reactor shutdown signal is increased.

Table 1. Simple unavailability of 1st proposal

Failure effect	Circuit	Combination	Probability	Result
Reactor trip signal, spurious output	Before	CH1 + CH2	0.1+0.1 = 0.2	Decrease
	After	CH1*CH3 + CH2*CH4	0.01+0.01=0.02	
Reactor trip signal, no output	Before	CH1*CH2	0.1*0.1 = 0.01	**Increase**
	After	(CH1+CH3)* (CH2+CH4)	0.2*0.2 = 0.04	

- Neglecting common cause failure (CCF)

2.2 Review 2nd proposal

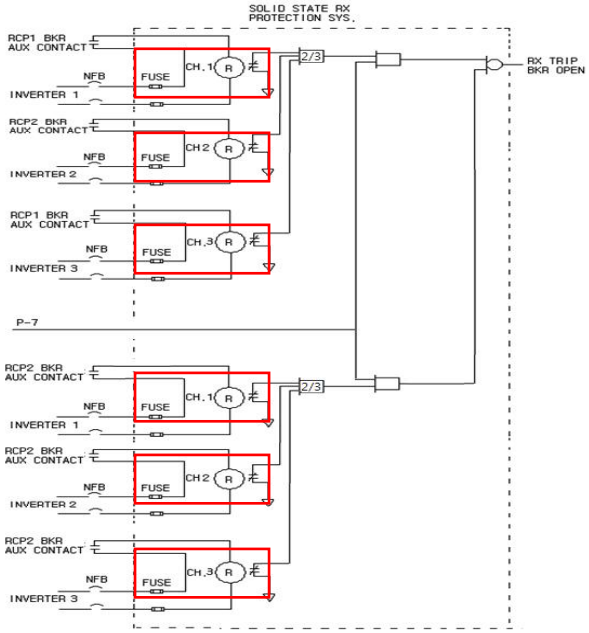

Fig. 3. 2nd proposal

The 2nd proposal is to add two auxiliary contacts and input relays per RCP loop to change the reactor trip logic by the RCP breaker contact to 2/3 coincidence. The unavailability of the circuit and core damage frequency due to design change are analyzed as follows.

Table 2. Device-specific reliability data[1]

Component	Failure rate	Mission Time (hr)	Failure probability	CCF fraction	CCF probability
Universal Logic	1.09E-05	24	2.62E-04	-	-
Undervoltage Output	3.35E-04	24	8.04E-03	-	-
Flow Transmitter	1.76E-06	24	4.22E-05	2.50E-02 (3/3)	1.06E-06
Press Transmitter	8.69E-07	24	2.09E-05	5.00E-02 (2/2)	1.04E-06
NIS Channel	1.28E-05	24	3.07E-04	2.25E-02 (4/4)	6.91E-06
Bistable	-	-	9.20E-04	4.50E-02 (4/4)	4.14E-05
				5.00E-02 (3/3)	4.60E-05
				9.20E-04 (2/2)	9.20E-05
RPS Logic Relay	-	-	1.00E-04	4.50E-02 (4/4)	4.50E-06
				5.00E-02 (3/3)	5.00E-06
				1.00E-01 (2/2)	1.00E-05
Circuit Breaker (contacts)	-	-	2.99E-04	5.00E-02 (3/3)	1.50E-05
				1.00E-01 (2/2)	2.99E-05

Unavailability analysis of the reactor shutdown signal was performed by a fault tree method (Table 3). When only the RCP circuit breaker contact point was considered, unavailability due to circuit malfunction decreased by 67% after 2/3 redundancy improvement. However, the unavailability of the entire reactor shutdown circuit due to the RCP low flow rate was reduced by 0.001%. As a result, the improvement effect is not significant.

The final reactor shutdown signal output, such as UV output etc., which has a major influence on unavailability, is not affected by this design change because it still doesn't have redundancy

Table 3. Unavailability changes

Division	Before	After	Rate of change
Reactor trip circuit by RCS low flow	8.818326E-03	8.818235E-03	-0.001%
RCS low flow by RCP circuit contact	4.388539E-04	1.451686E-04	-66.92%

For the 2nd proposal, core damage frequency (CDF) was re-evaluated with reference to the PSA report of the related power plant. The evaluation results show that there is no risk change before and after the proposed design change. It is considered that the effect of redundancy in the proposed on the CDF is small due to the slight change in unavailability.

3. Conclusion

To improve a reactor protection system in which a reactor shutdown occurs due to single device failure, one plant proposed the redundancy of the RCP circuit breaker auxiliary contact in the input circuit. However, adding RCP circuit breaker auxiliary contacts and relays for this redundancy has a limited effect in terms of preventing a reactor trip caused by the failure of a single device. The final output card that outputs the reactor shutdown signal still remains single point vulnerability, therefore it has minor effect on safety and the prevention of spurious reactor trip.

REFERENCES

[1] Korea Hydro & Nuclear Power CO., LTD(KHNP), Probability Safety Analysis(PSA) report for reference plant.