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Reliability Improvement of Redundant Power Circuits for MFIV & MSIV SOVs

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1. Introduction

In nuclear power plants, solenoid valves (SOVs) for MSIV and MFIV fast close actuation are supplied by the uninterruptible power. But, in some cases, the power circuit related with the SOVs has a design susceptible to the single component failure such as the open fuse or bad contact which will cause the plant transients including reactor trip. The design change to prevent the unexpected plant transients is proposed by plant operational department. As a result, additional redundant fuses and diodes are installed within the power circuit. The redundant circuit design including the additional current path to the SOV will have a fault tolerance to reduce unnecessary plant transients. The reliability evaluation on the redundant circuit configuration is performed using the PSA technique and contained in this article.

2. Existing Power Circuit of MSIV/MFIV

2.1 Power circuit: MSIV

The MSIV(Fig.1) is closed when the power circuit components are failed to interrupt the current path to the SOV or SOV itself is failed. First, the cases (probabilities) resulting in the MSIV closing are considered to calculate the MSIV fail close probability.

(1) F1: Fuse(F1) is opened.
(2) $R_{I1}*R_{I2}$ [1] $+R_{CCF}$ [2] : Relay1(R1) and Relay2(R2) are failed.
(3) D1: Diode1(D1) is failed.
(4) $S_{I1}*S_{I2}+S_{CCF}$: SOV1(S1) and SOV2(S2) are failed.

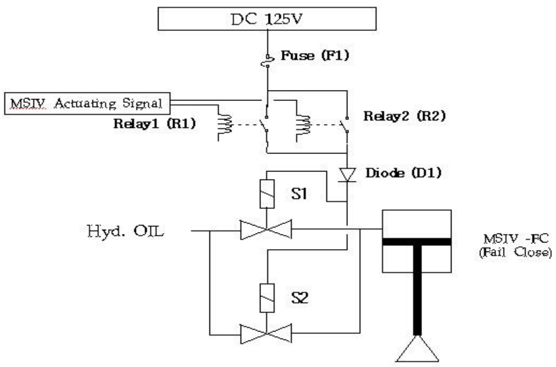

Fig.1 Original MSIV Power Circuit

2.2 Power Circuit: MFIV

The MFIV's power circuit design(Fig.2) is similar to the MSIV's, but, a single failure of SOV directly leads to the MFIV close because MFIV circuit has only one SOV to actuate the valve, while MSIV is actuated when all SOVs(SOV1 and SOV2) are failed.

In the MFIV case also, it is regarded that the MFIV is closed when the power circuit components are failed to interrupt the current path to the SOV or SOV itself is failed. The cases (probabilities) resulting in the MFIV closing are considered to calculate the MFIV fail close probability as follows.

(1) F1: Fuse 1(F1) is opened.
(2) $R_{I1}*R_{I2}+R_{CCF}$: Relay 1(R1) and Relay 2(R2) are failed.
(3) D1: Diode 1(D1) is failed.
(4) S1: SOV(S1) is failed.

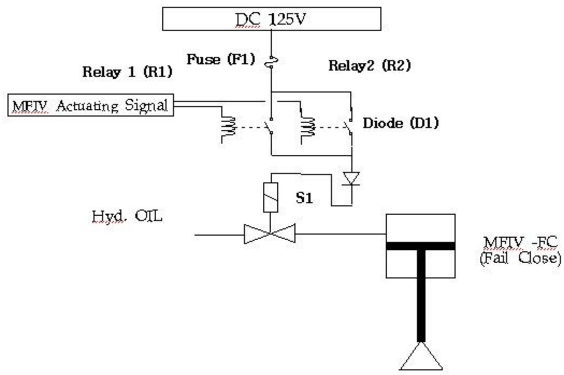

Fig.2 Original MFIV Power Circuit

3. Configuration of Changed Power Circuit to Improve Reliability

3.1 Changed Power Circuit: MSIV

In the changed power circuit, the events resulting in the MSIV fail close are upgraded as Fig. 3. The new fuse and diode are installed to separate the power supplying wires for the SOV.

(1) $F_{I1}*F_{I2}+F_{CCF}$: Fuse1(F1) and Fuse2(F2) are opened.
(2) $R_{I1}*R_{I2}+R_{CCF}$: Relay1(R1) and Relay2(R2) are failed.
(3) $D_{I1}*D_{I2}+D_{CCF}$: Diode1(D1) and Diode2(D2) are failed.
(4) $S_{I1}*S_{I2}+S_{CCF}$: SOV1(S1) and SOV2(S2) are failed.
(5) Total probability of other interrupted current path.

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[1] Multiplication of the independent failure probabilities
R_{I1} (or R_{I2}) = R1(or R2)*(1-β)

[2] Failure probability due to the common cause
R_{CCF} = R1(or R2)* β

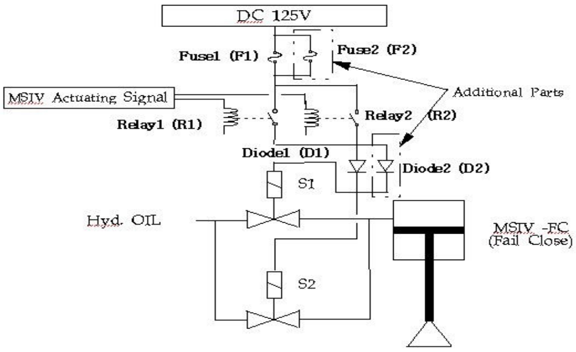

Fig. 3 Changed MSIV Power Circuit

3.2 Changed Power Circuit: MFIV

The changed MFIV power circuit has two routs to supply the power to the SOV. This circuit includes another electric wire with the additional diode, but, unlike the MSIV circuit, it has only one SOV at the cathode junction of diode pairs. In the changed power circuit, the cases resulting in the MFIV fail close are as follows.

(1) $F_{I1}*F_{I2}+F_{CCF}$: Fuse 1(F1) and Fuse 2(F2) are opened.
(2) $R_{I1}*R_{I2}+R_{CCF}$: Relay 1(R1) and Relay 2(R2) are failed.
(3) $D_{I1}*D_{I2}+D_{CCF}$: Diode 1(D1) and Diode 2(D2) are failed.
(4) S1: SOV is failed.
(5) Total probability of other interrupted current path.

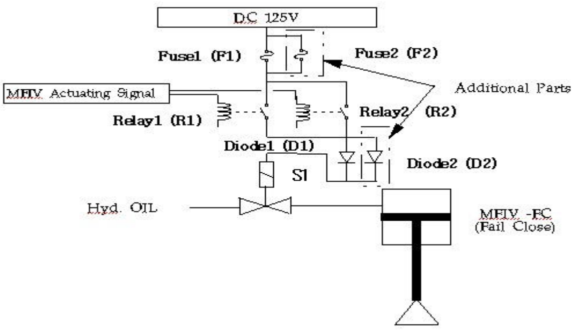

Fig. 4 Changed MFIV Power Circuit

4. Calculation of Power Circuit Reliability

4.1 Investigation of Component Failure Rate

In the application of the component failure rate causing the MFIV & MSIV close, it is supposed that fuses and diodes are failed only to the open state and the failure of the electric wire does not occur (practically this is true). Investigation of affected plants' MFIV and MSIV operating experiences did not show the sufficient number of events that the power circuit fault had become the cause of the reactor trip due to the valve malfunction. Therefore, generic data related with the circuit components are used to calculate the valve failure probability instead of the specific plant's data. Failure rates for the components included in the SOV power circuit are as follows.

Table 1. Component Failure Rates

Parts	Failure Rate (per hour)	Probability (per year)	Sources
Fuse	5.00E-07	4.38E-03	EPRI URD/'95.12
Relay	1.00E-06*	8.76E-03	EPRI URD/'95.12
Diode	3.21E-08	2.81E-04	MIL-HDBK-217F
SOV	2.00E-06	1.75E-02	NUREG/CR-2815

* Contacts operated spuriously to de-energized state

4.2 Calculation of MSIV/MFIV Fail Close Reliability

The MSIV/MFIV fail close probabilities before the design changes due to the power circuit component failure are calculated as follows:

$G_{MSIV} = (1) + (2) + (3) + (4) \approx 6.35E-03$
$G_{MFIV} = (1) + (2) + (3) + (4) \approx 2.26E-02$

After the consideration of above design changes of each case, the reliability(G´) due to the power circuit component failure can be recalculated as follows:

$G'_{MSIV} = (1) + (2) + (3) + (4) + (5) \approx 2.39E-03$
$G'_{MFIV} = (1) + (2) + (3) + (4) + (5) \approx 1.84E-02$

5. Conclusion

The calculation results of the redundant power circuits for the MFIV & MSIV showed that the design change will reduce the probability of the unexpected valve close due to the component failure to decrease the frequency of the unnecessary plant shutdown which could result in a thermal transient of the plant equipment.

Table 2. Calculation Results

Valves	Original Configuration	Changed Configuration
MFIV	2.26E-02 /year	1.84E-02 /year
MSIV	6.35E-03 /year	2.39E-03 /year

The analyses are performed as a part of technical supports for the plant reliability improvement in case of single component failures and the design changes are implemented in site.

This simple PSA technique is verified as an efficient tool for the reliability confirmation of plant design change and operational flexibility.

REFERENCES

[1] "Advanced Light Water Reactor Utility Requirements Documents, Chapter 1, Appendix A, PRA Key Assumptions and Groundrules," EPRI, Revision 7, December, 1995.
[2] NUREG/CR-2815-Vol.1-Rev.1, "Probabilistic Safety Analysis Procedures Guide," August, 1985.
[3] MIL-HDBK-217F, "Military Handbook, Reliability Prediction of Electronic Equipment," December, 1991