PSA Effect Analysis of a Design Modification of the Auxiliary Feedwater System for a Westinghouse Type Plant

Yeon Kyoung Bae [a*], Eun Chan Lee [a]
[a] *Korea Hydro & Nuclear Power Co., Ltd., 1312 Yusungdaero Yusung-Gu, Daejeon, Korea*
[*] *Corresponding author: ykbae@khnp.co.kr*

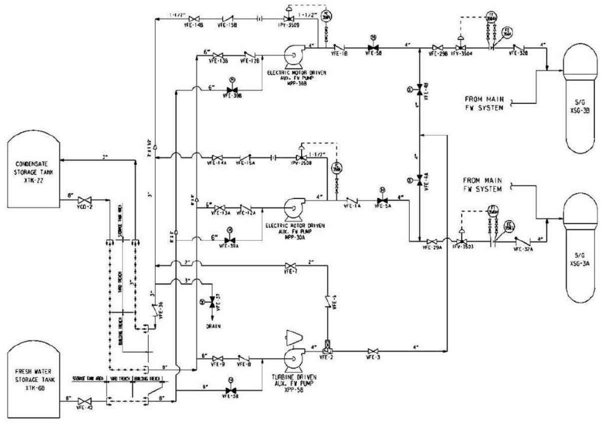
1. Introduction

The auxiliary feedwater system is an important system used to mitigate most accidents considered in probabilistic safety assessment (PSA) [1]. The reference plant has produced electric power for about thirty years. Due to age related deterioration and lack of parts, a turbine-driven auxiliary feedwater pump (TD-AFWP), some valves, and piping of the auxiliary feedwater system should be replaced. This change includes relocation of some valves, installation of valves for maintenance of the steam generator, and a new cross-tie line [2]. According to the design change, the Final Safety Analysis Report (FSAR) has been revised [3]. Therefore, this design modification affects the PSA. It is thus necessary to assess the improvement of plant safety. In this paper, the impact of the design change of the auxiliary feedwater system on the PSA is assessed. The results demonstrate that this modification considering the plant safety decreased the total CDF.

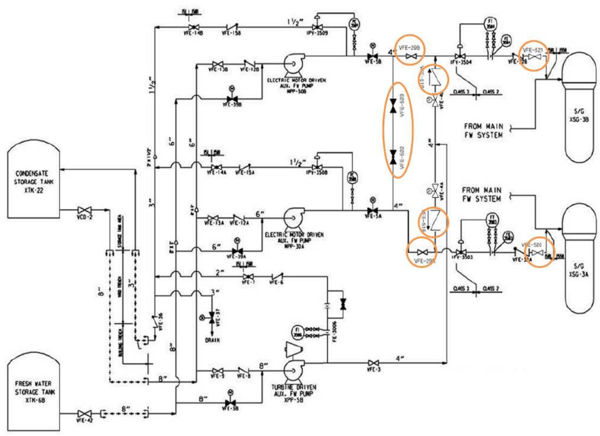
2. Analysis and Results

2.1 Design modification of auxiliary feedwater system

As the auxiliary feedwater system of a reference plant ages due to long-term operation, TD-AFWP, piping, and some valves were recently changed. The simplified schematic diagrams of before and after the design change of an auxiliary feedwater system are shown in Fig. 1.



(a) Before a design change



(b) After a design change

Fig.1. Simplified schematic diagram of auxiliary feedwater system before and after a design change

Design changes of the auxiliary feedwater system are summarized as follows:

- Manual block valves (VFE-29A, VFE-29B) for the auxiliary feedwater flowrate test are moved from the discharge flow path of the tie line to the inlet flow path of it.
- Manual valves (VFE-522, VFE-523) in a new cross-tie line are newly installed to deliver the auxiliary feedwater by a motor-driven auxiliary feedwater pump (MD-AFWP) when the TD-AFWP fails to start.
- Check valves (VFE-518, VFE-519) are set up to prevent a reverse flow.
- Manual valves (VFE-520, VFE-521) are added for maintenance of check valves (VFE-32A, VFE-32B) to prevent leakage.
- Operation status of motor operated valves (VFE-4A, VFE-4B) is changed from normal close into normal open.

2.2 Modeling of the fault tree

The following assumptions are used to modify and model the fault tree.

- Operator' action failure event of manual block valves (VFE-29A, VFE-29B) is relocated at the discharge segment of the MD-AFWP (XPP-30A, 30B).
- Failure mode of manual valves (VFE-522, VFE-523) is the failure to open and the operator's action is modeled.

- Failure mode of check valves (VFE-518, VFE-519) is the failure to open and common cause failure of them is modeled.
- Failure mode of manual valves (VFE-520, VFE-521) locked open is considered as transfer closed by mechanical cause.
- The failure mode of motor operated valves (VFE-4A, VFE-4B) is the failure to remain open. Component failure datum of the motor operated valve (MOV) is 1.40E-7/hr. The supporting system of the MOV is not considered, because the MOV opens at a normal condition.

2.3 Analysis Results

Table I shows that the frequency of the top 15 sequences contributes to the total CDF are compared to those before and after the improvement of the auxiliary feedwater system. In the LOOP event, the rank of the frequency of sequence no. 5 falls from 8 to 15 due to the design modification of the auxiliary feedwater system.

Table I: Comparison of results for frequencies of important sequences contributed to total CDF in internal events

Sequences	Frequency		Importance	
	Before	After	Before	After
IE-LOP006	7.75E-06	7.70E-06	1	1
SL-MRI-LOP	1.30E-06	1.30E-06	2	2
IE-SBO006	9.01E-07	9.01E-07	3	3
IE-GTN006	6.81E-07	5.93E-07	4	4
IE-SLOCA003	5.97E-07	5.97E-07	5	5
IE-LKB006	5.33E-07	5.02E-07	6	7
SL-MRI-GTN	5.09E-07	5.09E-07	7	6
IE-LOP005	3.25E-07	1.74E-07	8	15
IE-MLOCA003	3.08E-07	3.08E-07	9	8
SL-MRI-LKA	3.03E-07	3.03E-07	10	9
IE-SGTR006	2.54E-07	2.53E-07	11	10
IE-SBO011	2.32E-07	2.32E-07	12	11
IE-LKA006	2.13E-07	1.87E-07	13	13
IE-SUBU002	2.04E-07	2.05E-07	14	12
IE-SBO016	1.75E-07	1.75E-07	15	14

Table II shows the unavailability of the top events for the auxiliary feedwater system according to the related initial events. By modifying the design, the unavailability of the auxiliary feedwater is decreased by a maximum of 16.9% at power operation and by 12.0% under the LOOP condition. The unavailability of the auxiliary feedwater system is meanwhile reduced by a minimum of 0.4% in a SBO event.

Table II: Unavailability of the top events for the auxiliary feedwater system

Top Event	Unavailability		Change Ratio
	Before	After	
GAF-TOP	1.60E-4	1.33E-4	-16.9%
GAF-TOP-LOP	2.33E-4	2.05E-4	-12.0%
GAF-TOP-SBO	2.38E-2	2.37E-2	-0.4%

The number of minimal cutsets is decreased from 16,183 to 14,445. As the failure mode of MOVs (VFE-4A, VFE-4B) in the previous tie line is changed, the common cause failure (CCF) event related to those is removed in the minimal cut set (MCS) [4]. The reduced cutsets causes a reduction in the CDF of the reference plant. The total CDF is reduced by 3.7%. The implementation of the auxiliary feedwater results in improvement of plant safety.

Table III: Cutset and CDF analysis of before and after the design modification of the auxiliary feedwater system

CDF	Total Number of MCS	Change ratio (%)
Before	16,183	0.0
After	14,445	-3.7

3. Conclusions

This study assessed the effects of a design modification of the auxiliary feedwater system on the PSA. The results show that the design change provides considerably reduced unavailability of the system under a normal condition and LOOP. This decreased unavailability results in the reduction of the total CDF by 3.7%. The main reason why CDF is declined is change of the failure mode of the MOV from failure to open to failure to remain open at a normal condition. Due to change of the failure mode of the MOV, CCF event is cleared in MCS which affects CDF. This causes a reduction in the CDF. Also, this change can provide the delivery of the auxiliary feedwater from the TD-AFWP in the event of an accident during the test of the MD-AFWP.

REFERENCES

[1] KHNP, “Probabilistic Safety Assessment for Kori unit 1, May, 2007.
[2] KHNP, K01-Equipment-FE-968D, “Improvement of an Auxiliary Feedwater System for Kori unit 1”, February, 2012.
[3] KHNP, “Final Safety Analysis Report Chapters 9 and 10”, Rev. 27, 2012.
[4] F.M. Marshall, D.M. Rasmuson, A. Mosleh, NUREG/CR-5497, “Common-Cause Failure Parameter Estimations”, 1998