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A Study on the Adverse Effect of AOVs in AFWS Recirculation Paths on Plant Safety

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1. Introduction

Auxiliary feedwater system (AFWS) provides water to steam generators in accident condition. In the plants with old Westinghouse design, AFWS recirculation flow paths adopted air operated valves (AOVs) which could fail close on loss of instrument air (LOIA) event. So the AOVs and recirculation paths are closed on LOIA event, which could result in Auxiliary feedwater (AFW) pump(s) damage, which contributes greatly to core damage frequency (CDF).

On February 2002, the USNRC issued an inspection finding related to potential common cause failure of AOVs in AFWS recirculation flow paths on loss of instrument air system in Point Beach nuclear power plant (Pt. Beach). They also evaluated the significance of this failure event with significance determination process (SDP) and the △CDF is estimated around 2E-03/yr, which resulted in RED finding with "high safety significance" (△CDF≥1E-04) [1-3].

The AOVs have been removed from AFWS recirculation paths in the design of Korea standard nuclear power plant (KSNP). So, there is no possibility of abovementioned failure event in KSNP. However, in Korea, there are a couple of old nuclear power plants having AOVs in AFWS recirculation paths, which are Kori unit 1&2. Although they changed operation mode of this AOVs from "fail close" to "fail open" on LOIA event to prevent AFW pumps from deadheading, there is still some possibilities to block the recirculation paths by failure of AOV to open. Therefore, it would be beneficial to evaluate the significance of adverse effect of AOVs in AFWS recirculation paths to realize the importance of maintaining AFWS recirculation paths always open.

In this study, the AFWS modeling of Ulchin unit 3&4 was modified to model the AOVs in AFW recirculation flow paths to evaluate the change in CDF, which is caused by the adverse effect of AOV with operation mode of "fails close" on LOIA event.

2. Methods

In the AFWS design configuration of Ulchin unit 3&4, there are two motor driven pumps (MDPs), two turbine driven pumps (TDPs), and recirculation flow paths for each pump train to recirculate water to condensate storage tanks (CSTs) in order to prevent AFWS MDPs from deadheading, as shown in Fig.1. Even though there is no AOV in recirculation flow paths, it is assumed that AOV is used instead of flow orifice in each MDP trains, as discussed.

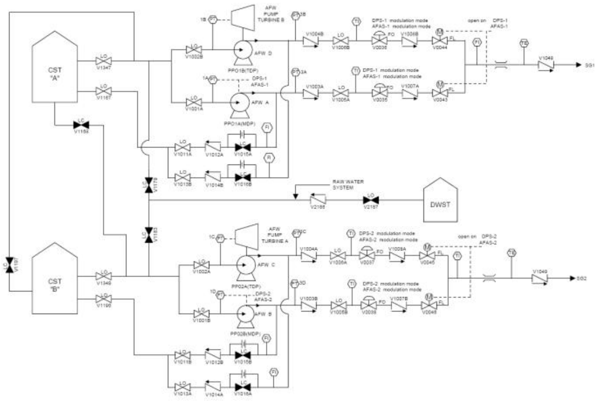

Fig.1. Auxiliary Feedwater System in Ulchin 3&4

When necessary, AFWS starts on auxiliary feedwater actuation signal (AFAS) and provides water from CSTs to both steam generators (SGs). In most cases, depending on how much the secondary side heat removal capacity is needed, it is programmed the flow is throttled back by AFWS flow control valves in pump discharge paths to maintain SG water level and the water is recirculated via its recirculation flow paths. Therefore, during the throttled back operation, it is very important to secure recirculation flow paths to protect pump from damage caused by deadheading. However, as discussed, there is AOV in each recirculation path of two MDPs and its closure during the throttled back operation will block the recirculation path, which results in pump damage and subsequent failure of AFWS.

There are two possibilities of inadvertent AOV closure in this situation. One is loss of instrument air (LOIA) if the AOV is designed as "fail close" (as in Point Beach case) and the other is the potential for "fail to open" if the AOV is programmed to be closed for certain purpose (as in Kori 1&2 units). In this study, the CDF is calculated to evaluate the effect of AOVs with "fail close" design in AFWS recirculation paths. The AOV is assumed to be closed on LOIA event and LOIA event may be caused by random failure of equipment, certain transients such as loss of off-site power (LOOP), loss of service water (LOSW) and seismic event.

Starting with the Ulchin 3&4 AIMS-PSR model developed by Korea atomic energy research institute (KAERI), the AFWS fault tree is modified as follows. AOV with "fail close" design is modelled for each MDP recirculation path in place of flow orifice. And the AOV may be closed by either random failure or LOIA, which results in MDP failure caused by recirculation path blockage.

3. Results and discussion

The CDF with modified AFWS design is calculated as 1.717E-05/yr, which is approximately 131% increase from the CDF of 7.447E-06/yr with original AFWS design. As summarized in Table 1, LOOP initiating event is still the most dominant contributor to CDF but the contribution is increased greatly from 29% to from 68.8%. Probably it can be interpreted as the increase in CDF comes from the increase in LOOP contribution

Table 1: Contribution of Initiating Event to Total CDF

Initiating event	**Original value**		**Adding AOVs in AFWS recirculation flow paths**	
	Point estimate (/yr)	% to CDF	Point estimate (/yr)	% to CDF
Loss of off-site power	**2.210E-06**	**29.7%**	**1.182E-05**	**68.8%**
Steam generator tube rupture	1.143E-06	15.3%	1.147E-06	6.7%
Small LOCA	1.106E-06	14.9%	1.107E-06	6.4%
Large LOCA	6.777E-07	9.1%	6.777E-07	3.9%
Medium LOCA	5.930E-07	8.0%	5.931E-07	3.5%
Loss of CCW train	5.571E-07	7.5%	5.881E-07	3.4%
Loss of main feedwater	3.905E-07	5.2%	4.021E-07	2.3%
Loss of a 125V DC bus	2.937E-07	3.9%	2.966E-07	1.7%
General transients	1.591E-07	2.1%	**2.144E-07**	1.2%
Large secondary side break	1.715E-07	2.3%	1.725E-07	1.0%
Anticipated transient without scram	1.265E-07	1.7%	1.265E-07	0.7%
Loss of condenser vacuum	1.803E-08	0.2%	**2.439E-08**	0.1%
Loss of a 4.16 KV AC bus	4.066E-10	0.0%	4.350E-10	0.0%
Total	**7.447E-06**	**100.0%**	**1.717E-05**	**100.0%**

The increase in CDF ($\triangle$CDF $\approx$ 1E-05) is estimated relatively small compared to that of Point Beach case. The reason for that can be explained as follows. Ulchin 3&4 AFWS still has two TDPs in operation even though two MDPs fail by AOV closure in recirculation path, while the plants with old Westinghouse design, such as Point Beach and Kori 1&2, and has only 1 TDP (or DDP).

4. Conclusion and recommendation

It is concluded that the existence of AOV with "fail close" design in AFWS MDP recirculation paths results in CDF increase of 131%, which is significant adverse effect on plant safety. In this regard, the improved Westinghouse design and KSNP design had removed the AOVs from AFWS MDP recirculation paths. However, a couple of units with old Westinghouse design, Kori 1&2, still have AOVs in AFWS MDP recirculation paths and throttle back operation of AFWS is in effect. Although those AOVs adopt "fail open" design to prevent abovementioned inadvertent closure, considering the big increase in CDF, there still exists considerable risk from the possibility of "failure to open" during this throttle back operation. Therefore, it is strongly recommended that any possibility of AOV closure in any situation should be removed to prevent undue risk increase. It can be achieved by either "physical removal of AOV" from MDP recirculation paths or "removal of AOV closure procedure during the throttle back operation the throttle back operation" of AFWS.

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