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Revisiting the Treatment of Real Nonsense Minimal Cutsets Generated from the Quantification of the Single-Top Fire Events PSA Model of Nuclear Power Plant

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1. Introduction

The quantification of an internal fire event probabilistic safety assessment (PSA) model is typically done by modifying a pre-existing internal events PSA model [1]. KAERI has developed a technique [2, 3] for constructing and quantifying single-top fire events PSA models using a single-top internal events PSA model. A single-top fault tree is a single fault tree that represents the PSA logic, including all the event trees and fault trees for core damage frequency (CDF) and large early release frequency (LERF) quantifications. The use of a single-top PSA model is widespread because it reduces the effort required for PSA model tasks and speeds up quantification time [4, 5].

A fire can cause damage to equipment or cables, resulting in multiple initiating events (IEs) for internal events PSA due to a single fire event [1, 2]. Therefore, quantifying the fire PSA model may result in inappropriate minimal cut sets (MCSs) [6]. Inappropriate MCSs [6] can be duplicated, subsumed into other MCSs, nonsense, or over-counted in fire frequency. A previous study [6] demonstrated a resolution process for the issues of each type of inappropriate MCSs using a single quantification of a hypothetical single-top fire PSA model.

When nonsense MCSs are generated from the quantification of the fire PSA model, the previous study [6] recommended modifying mitigating system fault trees (FTs) to resolve the issue of the nonsense MCSs. Some nonsense MCSs for particular accident scenarios were generated during the quantification of the real single-top fire PSA model of a domestic reference nuclear power plant (NPP). In a previous study [7], initiating event (IE) FTs were modified to prevent the generation of nonsense MCSs. However, this approach can be optimistic because it does not consider specific accident scenarios in terms of the quantification of conditional core damage probability (CCDP). This study demonstrates that modifying the FTs of mitigation systems for the realistic single-top fire PSA model of a domestic reference NPP can resolve the issue of nonsense MCSs.

2. Methods and Results

2.1 Nonsense MCSs and their treatment approach

Fig. 1 shows the MCSs for fire initiators, emergency diesel generator (EDG) A and B failure events, and loss of main feed water (LOMF) accident sequence designators. However, these MCSs are considered nonsense because they do not include the event of alternate alternating current (AAC) EDG, which is installed in the domestic reference NPP.

No	BE#1	BE#2	BE#3	BE#4	BE#5
1	%F-100T01_073T14_AL	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!
2	%F-100T01_073T07_AL	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!
3	%F-100T01_135T01_AL	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!
4	%F-100T01	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!
5	%F-073T07_100T01_AL	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!
6	%F-073T07	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!
7	%F-073T07_056T01_AL	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!

Fig. 1. Top seven nonsense MCSs generated from the quantification before modification.

It is judged that the MCSs of Fig. 1 subsume any failure scenario of AAC EDG with failures of EDGs A and B. For instance, consider the following MCSs:

%fire x EDG-A x EDG-B x #GIE-LOFW (1)

%fire x EDG-A x EDG-B x EDG-E x #GIE-SBO (2)

Here, %fire represents the fire initiator, EDG-A and EDG-B are the failures of EDGs A and B, respectively, EDG-E is the failure of EDG E, and #GIE-LOFW and #GIE-SBO are accident sequence designators representing LOFW and station blackout (SBO) initiating events (IEs), respectively.

If we assume that #GIE-LOFW and #GIE-SBO are flag events, MCS (2) is subsumed by MCS (1). Therefore, both MCSs (1) and (2) can be reduced to a single MCS (1). In Fig. 1, the IEs related to the MCSs are determined to be loss of offsite power (LOOP) and LOFW IEs. Each MCS includes the failures of EDGs and accident sequence designators representing LOFW IE. In the single-top fire PSA model of the domestic reference NPP, LOFW IE is not modeled for the mitigation system FTs, it is modeled for the IE FT. However, LOOP IE is modeled for the mitigating system and IE FTs. Therefore, additional mitigating system FTs without LOOP IE were constructed. In a previous study [7], an ad-hoc approach was used to exclude the MCSs from the IE FT models. However, this approach may not be suitable for the quantification of CCDP because MCSs representing specific accident sequences (LOOP or LOFW) may not be generated.

2. 2 Modification of mitigating system FTs

In a previous study [6], it was suggested that in order to avoid generating nonsensical MCSs, mitigation system FTs should be constructed that exclude relevant IEs modeled in them. However, in the single-top PSA model of the domestic reference NPP, there is no separate mitigation system FT model for the LOOP IE. To address this, we constructed FT models that exclude the LOOP IE from the mitigation system FT models. These mitigating system FTs include the electrical power system (EPS), component cooling water system (CCWS), essential service water system (ESWS), heating ventilation and air conditioning (HVAC) system, and the engineered safety feature actuation system (ESFAS). We also modified the primary system FTs used for the LOOP ET and SBO ET, including the auxiliary system (AFWS), main steam system (MSS), high pressure safety injection system (HPSIS), containment spray system (CSS), and safety depressurization system (SDS).

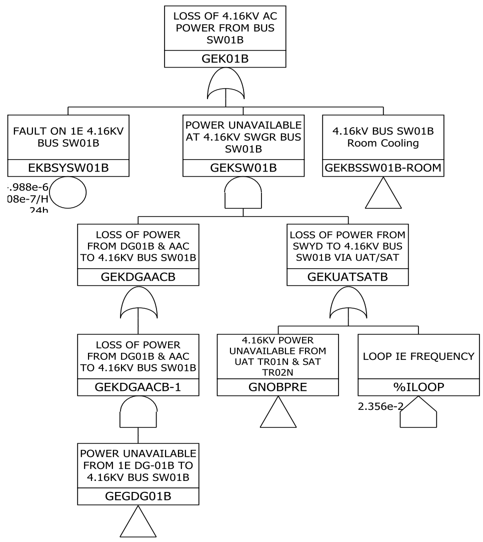

Fig. 2. FT for the loss of 4.16KV B bus before the modification.

Fig. 2 and Fig. 3 show the FTs for the loss of the 4.16KV B bus before and after the modifications, respectively. In Fig. 3, the gate event GEKUATSATB has been excluded. Fig. 4 shows the top seven MCSs with the highest CDF obtained by quantifying the fire PSA model after the FT modifications. All MCSs in Fig. 4 represent SBO accident sequences, including fire initiators, failure events of three EDGs, success event of PSV, and success event of RCP seal LOCA. On the other hand, all MCSs in Fig. 1 represent LOFW accident sequences, including fire initiators, failure events of two EDGs, and success event of PSV. The MCSs in Fig. 1 do not include the failure event of AAC, as shown in Fig. 4, nor do they include the success event of RCP seal LOCA. Fig. 5 shows the corrected MCSs of Fig. 1, including the failure event of AAC and the success event of RCP seal LOCA.

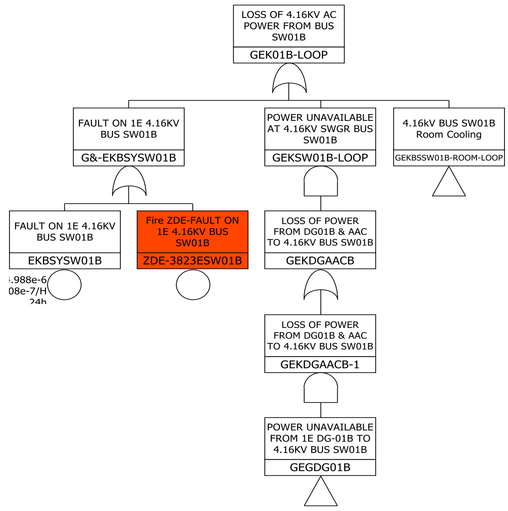

Fig. 3. FT for the loss of 4.16KV B bus after the modification.

No	BE#1	BE#2	BE#3	BE#4	BE#5
1	%F-100T01_073T07_AL	EGDGK3T-1A1B1E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
2	%F-100T01_135T01_AL	EGDGK3T-1A1B1E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
3	%F-100T01	EGDGK3T-1A1B1E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
4	%F-100T01_073T14_AL	EGDGK3T-1A1B1E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
5	%F-073T07_100T01_AL	EGDGK3T-1A1B1E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
6	%F-073T07	EGDGK3T-1A1B1E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
7	%F-073T07_056T01_AL	EGDGK3T-1A1B1E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!

Fig. 4. Top seven MCSs generated from the quantification after modification.

No	BE#1	BE#2	BE#3	BE#4	BE#5	BE#6	BE#7
76	%F-073T07	EGDGM01E	EGDGR01A	EGDGR01B	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
77	%F-073T07_056T01_AL	EGDGM01E	EGDGR01A	EGDGR01B	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
78	%F-100T01	EGDGR01B	EGDGS01A	EGOPHDG01E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
79	%F-100T01_073T14_AL	EGDGR01A	EGDGS01B	EGOPHDG01E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
80	%F-100T01_073T07_AL	EGDGR01A	EGDGS01B	EGOPHDG01E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
81	%F-100T01_073T07_AL	EGDGR01B	EGDGS01A	EGOPHDG01E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
82	%F-100T01	EGDGR01A	EGDGS01B	EGOPHDG01E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
83	%F-100T01_073T14_AL	EGDGR01B	EGDGS01A	EGOPHDG01E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
84	%F-100T01_135T01_AL	EGDGR01A	EGDGS01B	EGOPHDG01E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!
85	%F-100T01_135T01_AL	EGDGR01B	EGDGS01A	EGOPHDG01E	/PSV	/RCPSEAL_2S	#GIE-SBOR-07!

Fig. 5. Corrected MCSs corresponding to MCSs of Fig.1.

3. Conclusions

During the quantification process of fire event PSA models, a single fire event can cause multiple internal events PSA IEs, which can lead to inappropriate MCSs. By modifying the mitigating system FTs for real fire PSA models of the domestic reference NPP, we were able to address the issue of nonsense MCSs. The results of this study will help in resolving the issues of nonsense MCSs that may arise in the quantification of single-top fire event PSA models. Nonetheless, more efforts for the quantification of one top fire PSA model are needed to reasonably estimate fire risk.

Acknowledgments

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