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Simplification of the Plant Models in PSA

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Abstract

Current Probabilistic Safety Assessment (PSA) techniques are not usually utilized for day-to-day applications in nuclear power plants. The major reason for this anomaly is the complexity of plant models developed for PSA studies and the multitude of resulting fault trees. This impediment can be overcome by the use of simplified plant models. However, oversimplified models usually result in loss of valuable information and therefore, simplification approaches have to be used judiciously in order to achieve accurate and meaningful results. For this reason, development of an appropriate simplification approach must be performed using extreme caution followed with results verification in sequence as well as system levels. If there are no significant differences between the simplified and the original models, the simplified model can be efficiently used in the application of the PSA. This paper presents a methodology for how to develop a suitable simplification technique and the results of its verification for sample systems and sequences. The results show that the utilization of simplified plant models will significantly reduce the number of fault trees with no significant loss of accuracy.

1. Introduction

Typically, plant models developed for PSA studies are too complex, especially fault trees which lead to time consuming efforts in tracing the models and understanding the results even for personnel who are trained in PSA techniques. As a result, PSA techniques are not commonly used in day-to-day applications despite their usefulness in predicting plant behaviors under different accident and event scenarios.

PSA techniques can be made cost-effective for day-to-day use if existing plant models are simplified while providing the desired level of information accuracy. For YGN 3&4 Nuclear Power Plant, this approach has been widely applied in the external events PSA (References 1&2). During the fire/flood analysis, the simplified plant model, which was developed from the internal events plant model, has been used for the quantification of the impacts of the event. The model used in fire/flood analysis is based on the train concept and do not include detailed information about the components. Although the simplification process is able to make the plant model very simple and easy to understand, the resulting is too simplified to yield valuable information. However, this is not a major concern in fire/flood analyses since in these analyses the random failures of components are not significant contributors to the results. The level of simplification is dependent on its propose.

The major thrust of the simplification approach is to reduce the complexity of the plant model while maintaining the desired degree of results' accuracy. The model simplification concern, e.g., loss of significant information, can be alleviated by developing simplified models and verifying their usefulness. This can be accomplished by comparing simplified models' Minimal Cut Set (MCS) with those of the detailed models. This simplification approach is based on the unavailability of components rather than the failure modes of the component in the detailed model or train level.

2. Simplification Process

As discussed previously, the purpose of developing a simplification process is two fold: 1) to reduce the amount of model complexity, and 2) to maintain the pertinent information contained in the detailed model. The simplification process begins with the detailed plant models, which are made from the internal events PSA, however, it requires full understanding of the detailed plant model. Thus, the simplification approach requires some guidelines to prevent the loss of pertinent information. The basic guidelines of the simplification approach are:

1. Failure modes of component are reduced to one, e.g., random failure of the components.
2. Only the highest level of common cause failures (CCFs) are considered, and the CCF appears only once in the fault tree at the appropriate highest level. The simplification will be verified by comparing MCSs of the detailed and simplified models.
3. All of test and maintenance events in the line (or train) are applied to one event, e.g., unavailability of AFW train A MDP line due to test or maintenance.
4. The failure events with very low failure rate can be combined with adjacent failures having similar failure rate.
5. All operator errors considered in the detailed model remain unchanged in the simplified model.
6. The effects of the local instrumentation failure can be included in the failure of the components affected.

3. Simplified Model Verification

The simplification approach was applied to YGN 3&4 Nuclear Power Plant model. All safety systems' fault trees were simplified. Using the guidelines described above, the amount of fault trees were reduced to approximately 12% of the original fault trees. As a result, the total number of the simplified fault trees can be described using approximately 60 pages compared several hundred pages for the original plant models. Using the simplified model, the unavailability of the system and some of the representative core damage sequences were quantified. The results of quantification for major system's unavailability were compared with their counterparts from the original (detailed) model, and are summarized in Table 1. As shown in the Table 1, the calculated unavailability of major systems from the detailed and simplified models are very close. Comparisons for the auxiliary feedwater system's unavailability is shown in Table 2.

For a more complete verification of the simplified model, the accident sequences were quantified using the same event tree. The results of the quantification for general transient and loss of feedwater events are shown in Table 3 with the comparison of core damage frequency (CDF) resulting from original model. Other sequences not showed in Table 3 have a CDF value less than the cutoff value (1.0E-10). Also, Table 3 shows that the CDFs from each sequence are not in close correlation with each other.

Table 1. Comparison of Quantification Results for Major System Unavailability

System	Success Criteria	Original Model	Simplified Model
Aux Feedwater System	1/4 Pump to 1/2 SG	3.6E-6	3.5E-6
	Long Term Cooling	2.4E-2	2.4E-2
Main Feedwater System	1/1 Pump to 1/2 SG	2.5E-2	2.5E-2
HPSI System	1/2 Pump to 1/4 Injection	5.4E-4	5.4E-4
	Recirculation	1.0E-3	9.8E-4
Shutdown Cooling System	1/2 Pump	3.5E-3	3.6E-3
Safe Depressurization System	Early	2.8E-1	2.8E-1
	Late	1.1E-2	1.0E-2
Containment Spray System	1/2 Pump	2.4E-3	2.4E-3
Containment Fan Cooler System	2/4 Fan Cooler	3.7E-4	3.7E-4

Table 2. Comparison of MCS Resulting from Auxfeedwater System Unavailability

Original Model			Simplified Model		
No	MCS	Freq.	No	MCS	Freq.
1	AFPTKPPSUC	6.5E-7	1	AFPTKPPSUC	6.5E-7
2	AFDPW12 * AFMPW12	3.8E-7	2	AFMP01A1BW * AFDP02A2BW	4.4E-7
3	AFCQ1A2BSW * AFDPW12	1.2E-7	3	AFCQ01A2BW * AFDP02A2BW	1.9E-7
4	AFDP0002SA * AFMPW12 * AFDP0002BS	9.6E-8	4	AFDP02A-RF * AFMP01A1BW * AFDP02B-RF	1.5E-7
5	AFDPW12 * AFMP0001AU * AFMP0001BU	6.3E-8	5	AFMP01A-RF * AFMP01B-RF * AFDP02A2BW	1.3E-7
6	AFCVMINIFW	6.2E-8	6	AFMP0001AU * AFMP01B-RF * AFDP02A2BW	9.4E-8
7	AFCV04849W	6.2E-8	7	AFMP0001BU * AFMP01A-RF * AFDP02A2BW	9.4E-8
8	AFCV034ABW	6.2E-8	8	AFMP0001AU * AFMP0001BU * AFDP02A2BW	6.8E-8
9	AFMV0435OW * AFMV0495OW	5.6E-8	9	AFDP02A-RF * AFCQ01A2BW * AFDP02B-RF	6.3E-8
10	AFMV03538W * AFMV0495OW	5.6E-8	10	AFCVMINIFW	6.2E-8
11	AFCQ1A2BRW * AFDPW12	5.0E-8	11	AFCV034ABW	6.2E-8
12	AFCV1048OA * AFCV1049OB	4.0E-8	12	AFCV04849W	6.2E-8
13	CDCV1178OA * CDCV1181OB	4.0E-8	13	CDCV07881W	6.2E-8
14	AFDPW12 * AFMP0001AR * AFMP0002BU	3.6E-8	14	AFDP02A2BW * AFCV1003BO * AFMP01A-RF	6.0E-8
15	AFDPW12 * AFMP0001AU * AFMP0002BR	3.6E-8	15	AFMV0435OW * AFMV0495OW	5.8E-8
16	AFCQ1A2BSW * AFDP0002AS * AFDP0002BS	3.1E-8	16	AFMV03538W * AFMV04950W	5.8E-8
17	AFMPW12 * AFDP0002AU * AFDP0002BS	3.0E-8	17	AFTK01A-RF * AFTK01B-RF	5.3E-8
18	AFMPW12 * AFDP0002AS * AFDP0002BU	3.0E-8	18	AFMP01A-RF * AFDP02A-RF * AFTK01B-RF	4.9E-8
19	AFDPW12 * AFMP0001AU * AFMP0001BS	3.0E-8	19	AFTK01A-RF * AFMP01B-RF * AFDP02B-RF	4.9E-8
20	AFDPW12 * AFMP0001AS * AFMP0001BU	3.0E-8	20	AFMP01A-RF * AFDP02A-RF * AFMP01B-RF * AFDP02B-RF	4.5E-8

NOTE
.AFDP02A2BW (CCF of DDP 02A & 02B to start and run) = AFDPW12 + AFDPK12
.AFMP01A1BW (CCF 0f MDP 01A & 01B to start and run) = AFMPW12 + AFMPK12
.AFCQ01A2BW (CCF of cubicle cooler to start and run) = AFCQ1A2BSW + AFCQ1A2BRW
.AFDP02A-RF (Random Failure of DDP 02A) = AFDP0002SA + AFDP0002RA
.AFMP01A-RF (Random Failure of MDP 01A) = AFMP0001SA + AFMP0001RA

To find out the causes of the differences, the MCSs were compared for the sequence level. The comparison results for sequences GTS08 and LOFS07 are presented in tables 4, and 5, respectively. In the case of GTS08, the CDF estimated using the simplified model is 3 times higher than that from the original model, while in the case of LOFS07, the CDF estimated from the simplified model is approximately two-thirds of that from the original model.

As presented in Table 4, the first MCS in original model showed up as the 5th in simplified model, and the first three and 8th MCSs in the simplified model are associated with the station blackout events. In the original model, the events associated with the station blackout showed as the 6th and the 11th MCSs. The major cause for the different failure rates is the fact that the basic events are combined and thus the failure rate is increased in the simplified model. The detailed comparison of the MCSs also showed that differences in the resulting CDFs stem mainly from the treatment of recovery of the station blackout event. In the original model, the station blackout events are divided into two cases, loss of offsite power (LOOP) followed by the failure of starting the emergency diesel generator (EDG), and LOOP followed by the failure of running EDG. In the former case, the available time for recovery of offsite power is assumed to be 11 hours, and in the latter case, the available time is assumed to be 24 hours. However, in the simplified model the available time is assumed to be the 11 hours for both cases.

Thus, it can be concluded that the differences in the order of the MCSs and the CDFs are not important and can be justified. Moreover, the MCSs from the simplified model are more useful to the plant operator than those from the original model, since the simplified model's MCSs present the order of component, while the original model's MCSs present the order of component's failure modes.

Table 3. Comparison of Quantification Results for General Transient Sequences

Sequence Number	Description	Original Model	Simplified Model	Remarks
GTS06	General Transient, followed by failure of shutdown cooling, failure to maintain secondary heat removal and failure of HPSI recirculation.	5.0E-10	ε	In original model, there found no MCS greater than 1.0E-10.
GTS07	General transient, followed by failure of shutdown cooling, failure to maintain secondary cooling and failure of HPSI injection.	1.2E-9	ε	In original model, there found no MCS greater than 1.0E-10.
GTS08	General transient, followed by failure of shutdown cooling, failure to maintain secondary heat removal, and failure to bleed RCS in late phase.	1.4E-7	4.6E-7	
GTS15	General transient, followed by the failure to deliver feedwater, failure to bleed RCS in early phase.	5.2E-8	5.2E-8	
LOFS06	Loss of Feedwater, followed by failure of shutdown cooling, failure to maintain secondary heat removal and failure of HPSI recirculation.	7.8E-9	5.4E-9	
LOFS07	Loss of Feedwater, followed by failure of shutdown cooling, failure to maintain secondary cooling and failure of HPSI injection.	1.2E-8	7.5E-9	
LOFS08	Loss of Feedwater, followed by failure of shutdown cooling, failure to maintain secondary heat removal, and failure to bleed RCS in late phase.	8.9E-7	1.0E-6	
LOFS15	Loss of Feedwater, followed by the failure to deliver feedwater, failure to bleed RCS in early phase.	3.2E-7	4.7E-7	

In addition, Table 5 shows that all MCSs from the original model are included in the simplified model's MCSs. The differences in the CDFs stem mainly from the fact that the cutoff value is different in both models. In the original model, the cutoff value is 1.0E-12, while in simplified model the cutoff value is 1.0E-10. Therefore, it can be concluded with a high degree of certainty that the simplified model provide the same results of the original model.

4. Conclusions

Cost-effective applications of PSA can be performed using the simplified model instead of the original detailed models. This is a result of developing the simplified model based on component level while maintaining all significant information in the original model. The use of our suggested simplification approach enhances the ability of plant operators for understanding the PSA model, since the simplified models are based on the component level. In addition, the simplified model can be easily adapted for risk monitor, configuration control, and above all to be the base model for living PSA studies.

Table 4. Comparison of MCS Resulting from Sequence GTS08

Original Model			Simplified Model		
No	MCS	Freq.	No	MCS	Freq.
1	LSIR65354W * MFMP00001U * AFTKATN-HR	2.1E-8	1	EGDG1A2BSW * EOXH0304NW* NR-AC11HR	1.7E-7
2	LSIR65354W * MFMP00001R * AFTKATN-HR	1.2E-8	2	EGDG01B-RF * EGDG0003SU * EGDG01A-RF * EOXH0304NW * NR-AC11HR	3.4E-8
3	LSIR65354W * MFMP00001S * AFTKATN-HR	1.0E-8	3	EGDG01B-RF * EGDG03S-RF * EGDG01A-RF * EOXH0304NW * NR-AC11HR	3.0E-8
4	LSIR65354W * MFMPRST-HR * AFTKATN-HR	9.0E-9	4	LSIR65354W * AFTKATN-HR * MFMP001-RF	2.7E-8
5	LSIR65354W * MFSPORTCLG * AFTKATN-HR	4.6E-9	5	LSIR65354W * AFTKATN-HR * MFMP00001U	2.1E-8
6	EOSYFTRIP * EGDG1A2BSW * NR-AC11HR	4.2E-9	6	LSIR65354W * AFTKATN-HR * MFSPORT-HR	1.7E-8
7	ELXM11A2BW * MFMP00001U * HHOPENROOM	3.7E-9	7	LSIR65354W * AFTKATN-HR * MFMPRST-HR	9.2E-9
8	LSIR65354W * MFMP00001U * AFOPERT-HR	3.4E-9	8	EGDG01B-RF * EGDG03S-HR * EGDG01A-RF * EOXH0304NW * NR-AC11HR	8.5E-9
9	LSIR65354W * MFCV095-RF * AFTKATN-HR	3.4E-9	9	ELXM11A2BW * MFMP001-RF * HHOPENROOM	4.7E-9
10	LSIR65354W * EOXN0004NU * AFTKATN-HR	2.9E-9	10	LSIR65354W * MFMP001-RF * AFOPERT-HR	4.4E-9
11	EOSYYGRID * EGDG1A2BSW * NR-AC11HR	2.5E-9	11	LSIR65354W * MFCV095-RF * AFTKATN-HR	4.1E-9
12	ELXM11A2BW * MFMP00001R * HHOPENROOM	2.1E-9	12	ELXM11A2BW * MFMP00001U * HHOPENROOM	3.7E-9
13	LSIR65354W * MFMP00001R * AFOPERT-HR	2.0E-9	13	LSIR65354W * MFMP00001U * AFOPERT-HR	3.5E-9
14	LSIR65354W * MFMV095-RF * AFTKATN-HR * NR-HDV	1.9E-9	14	LSIR65354W * AFTKATN-HR * MF416NON1E	3.4E-9
15	ELXM11A2BW * MFMP00001S * HHOPENROOM	1.7E-9	15	LSIR65354W * AFTKATN-HR * MF480NON1E	3.4E-9
16	LSIR65354W * MFMP00001S * AFOPERT-HR	1.6E-9	16	LSIR65354W * AFTKATN-HR * MF138NON1E	3.4E-9
17	ELXM11A2BW * MFMPRST-HR * HHOPENROOM	1.6E-9	17	LSIR56354W * AFTKATN-HR * MF125NON1E	3.4E-9
18	LSIR65354W * MFMPRST-HR * AFOPERT-HR	1.5E-9	18	ELXM11A2BW * MFCV095-RF * HHOPENROOM	3.1E-9
19	LSSDC01-HR * AFTKATN-HR * MFMP00001U * SDMVOPL-HR	1.4E-9	19	ELXM11A2BW * MFSPORT-RF * HHOPENROOM	3.0E-9
20	LSMV65354W * SDMVOPL-HR * MFMP00001U* AFTKATN-HR	1.1E-9	20	LSIR65354W * EOXN0004NU * AFTKATN-HR	3.0E-9

NOTE
.EGDG1A2BSW (CCF of Emergency DG and AAC to start and run) : EGDG01A2BSW + EGDG01A2BSK
.EOXH0304NW (CCF of Startup Transformer 03XN and 04XN) : EOSYFTRIP + EOSYYGRID + EOXH0304NW
.EGDG01A-RF (Random Failure of Emergency DG A) : EGDG0001AS + EGDG0001AR
.MFMP001-RF (Random Failure of Startup Feedwater Pump) : MFMP00001S + MFMP00001R
.MFSPORT-RF (Failure of Startup Feedwater Pump Support System) : MFSPORTCLG + MFSPORTCON + MFSPORTMKP

Table 5. Comparison of MCS Resulting from Sequence LOFS07

Original Model			Simplified Model		
No	MCS	Freq.	No	MCS	Freq.
1	AFTKATN-HR * LSSDC01-HR * HSMVWIGHDR	7.9E-10	1	AFTKATN-HR * LSSDC01-HR * HSMVWIGHDR	7.9E-10
2	AFTKATN-HR * HSCVWG40123	7.3E-10	2	AFTKATN-HR * LSSDC01-HR * HSMP00102W	7.1E-10
3	AFTKATN-HR * HSCVWG12347	7.3E-10	3	AFTKATN-HR * LSMV65354W * HSMVWIGHDR	6.0E-10
4	AFTKATN-HR * LSMV65354W * HSMVWIGHDR	6.0E-10	4	AFTKATN-HR * LSMV65152W * HSMVWIGHDR	6.0E-10
5	AFTKATN-HR * LSMV65152W * HSMVWIGHDR	6.0E-10	5	AFTKATN-HR * LSMV65354W * HSMP00102W	5.3E-10
6	AFTKATN-HR * LSSDC01-HR * HSMPW00102	3.6E-10	6	AFTKATN-HR * LSMV65152W * HSMP00102W	5.3E-10
7	AFTKATN-HR * LSSDC01-HR * HSMPK00102	3.3E-10	7	AFTKATN-HR * LSSDC01-HR * HSCQ04A4BW	4.3E-10
8	AFTKATN-HR * LSSDC01-HR * HCCQWHPPS	3.0E-10	8	AFTKATN-HR * LSMV65354W * HSCQO4A4BW	3.3E-10
9	AFTKATN-HR * LSMV65354W * HSMPW00102	2.7E-10	9	AFTKATN-HR * LSMV65152W * HSCQ04A4BW	3.3E-10
10	AFTKATN-HR * LSMV65152W * HSMPW00102	2.7E-10	10	AFTKATN-HR * CWCU2A2BSW * CWCU1A1BRW	2.3E-10
11	AFTKATN-HR * LSMV65354W * HSMPK00102	2.5E-10	11	CCCQ17ABSW * CCCQ16ABRW * HHOPENROOM	2.0E-10
12	AFTKATN-HR * LSMV65152W * HSMPK00102	2.5E-10	12	SWAB2A2BSW * SWAB1A1BRW * HHOPENROOM	2.0E-10
13	AFTKATN-HR * LSMV65354W * HCCQWHPPS	2.3E-10	13	ELLC11A-RF * ELLC12B-RF * HHOPENROOM	1.4E-10
14	AFTKATN-HR * LSMV65152W * HCCQWHPPS	2.3E-10	14	ELLC12A-RF * ELLC11B-RF * HHOPENROOM	1.4E-10
15	CWCU1A1BRW * CWCU2A2BSW * AFTKATN-HR * NR-DDPCLG	1.3E-10	15	ELLC12A-RF * ELLC12B-RF * HHOPENROOM	1.4E-10
16	AFTKATN-HR * LSSDC01-HR * HCCQKHPPS	1.2E-10	16	AFOPERT-HR * LSSDC01-HR * HSMVWIGHDR	1.3E-10
17	AFTKATN-HR * LSMV65354W * HCCQKHPPS	9.1E-11	17	CWCU1A1BRW * CWCU2A2BSW * AFTKATN-HR * NR-DDPCLG	1.3E-10
18	AFTKATN-HR * LSMV65152W * HCCQKHPPS	9.1E-11	18	AFOPERT-HR * LSSDC01-HR * HSMP001W02	1.2E-10
19	AFTKATN-HR * LSMV65758W * HSMVWIGHDR * NR-SCSV	8.4E-11	19	AFTKATN-HR * LSMV65758W * HSMVWIGHDR * NR-SCSV	8.4E-11
20	AFTKATN-HR * LSMV68696W * HSMVWIGHDR * NR-SCSV	8.4E-11	20	AFTKATN-HR * LSMV68696W * HSMVWIGHDR * NR-SCSV	8.4E-11
NOTE	. HSMP00102W (CCF of HPSI pumps to start and run) : HSMPW00102 + HSMPK00102 . HSCQ04A4BW (CCF of HPSI pump room cubicle coolers to start and run) : HCCQWHPPS + HCCQKHPPS				

References

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