Development of Preliminary Multi-unit PSA Models for Seismic Event

Jeong-Seon Park [a], Hojun Jeon [a*], Kyemin Oh [a]
[a]Central Research Institute of Korea Hydro & Nuclear Power Co. Ltd., Daejeon, Republic of Korea
[*]*Corresponding author: jeonhojun@khnp.co.kr*

1. Introduction

About 90% of the nuclear sites in the world have two or more reactor units. Especially, the concerns about multi-unit safety have been raised in the world after the Fukushima Daiichi accident in 2011. During the licensing process of new build units in the site containing more than existing six units in Korea in 2016, the multi-unit issues were arisen as one of the most important challenges in nuclear industries. As a countermeasure for the issues, Korea Hydro & Nuclear Power (KHNP) has started the project on developing methodology of multi-unit Probabilistic Safety Assessment (PSA) and applying it to a reference site by 2020.

We have reviewed the previous researches and projects including the project of "Development of the Integrated Risk Assessment Technology for Multiple Units" performed by Korea Atomic Energy Research Institute (KAERI) from 2015 to 2017 [1]. Based on these backgrounds at the current status, we have performed the pilot study on development and quantification of preliminary multi-unit PSA for seismic event with some assumptions with focusing on integrating single unit PSA models and quantifying the integrated models.

2. Limitations and Assumption

2.1 Estimating Seismic Induced Initiating Event

Although multi units are operating in the same site, ground response or equipment response in a unit against an earthquake would be different. The effects from these differences, however, were ignored. As for the fragility analysis, we used the results from the single unit seismic PSA, and applied the latest seismic hazard analysis for a new build unit to all units in a site.

2.2 Modeling Mitigating Systems

Based on Fussell-Vesely importance measures, we selected the components, which are related to CCF basic events over 0.005 of FV measures, for modelling inter unit CCF. We considered one basic event of inter unit CCF between twin units, among four units of OPR1000, and among all units in the site. As for estimating CCF multiplier factors, we applied Impact Vector Mapping-Up method in Appendix D of NUREG/CR-4780 [2], and considered the similarity factor as 1.0 between twin units, as 0.5 among four units of OPR1000, and as 0.1 among all units.

2.3 Seismic Correlation

Seismic correlation is one of the typical controversial issues in seismic PSA. There is no mature method except for using fully correlated or fully independent for dealing with seismic correlation, which has technical adequacy with international consensus. EPRI report "Seismic PRA Implementation Guide" [3], although there could be some correlation approaches, seismic correlation model may be treated as binary of fully correlated or fully independent. Therefore, we conservatively assumed 1.0 for the identical components between twin units, for example, all Component Cooling Water (CCW) pumps in twin units were fully correlated against concurrent seismic hazard in a site. Otherwise, we assumed 0.0.

3. Methods and Results

3.1 Analysis of Seismic Induced Initiating Event

Basic concept of analyzing seismic induced initiating events for multi-unit PSA is the same as that of single unit seismic PSA. First, we identify and select seismic induced initiating events by using primary event tree method. The frequencies of initiating events were estimated by using S/W of PRASSE [4], for which seismic hazard information, fragility information on the components and the failure logic causing initiating events were used as input. Although we have considered seismic hazard curve as one group, we divided seismic hazard curve into five groups based on the magnitude of seismic hazard in order to derive risk insights from different seismic levels for multi-unit PSA.

After estimating the frequencies of initiating events for each hazard group, the logic trees for seismic induced initiating events should be developed by using a fault tree method in order to consider seismic correlation coefficient. As for the conditional failure probability, we composed two basic events with 'or' gate, one is for concurrent failure between twin units and the other is for independent failure of a single unit to reflect seismic correlation coefficient on the models. For two basic events, we estimated the conditional failure probability by using the multiplier of seismic correlation.

3.2 Modeling Approach on Multi-unit PSA

To make quantification process simple and speed up, we developed multi-unit seismic PSA models as a form of a single top fault tree. After making a single top fault tree for one unit, we tried to integrate each single top fault tree of a unit into the single top logic for multi units with 'or' gate or combination gates such as 2 out of 4 or 4 out of 6. Fig. 1 shows our modelling structure.

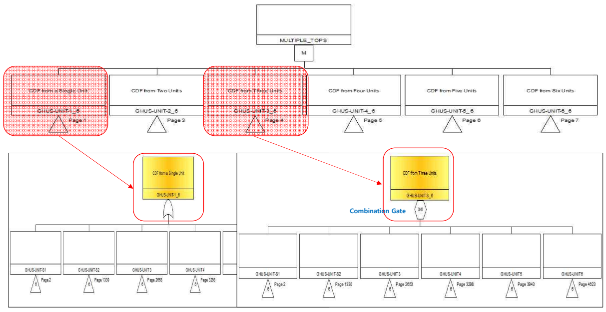

Fig. 1. Modeling Structure of Multi-unit PSA (Single Top Fault Tress)

2.3 Results from Preliminary Seismic Multi-unit PSA

Based on the quantification results from the above modelling structure, we estimated the CDF of any single unit or two units, etc. by the following concept;

CDF of any single unit = [CDF from 1 out of n units] – [CDF from 2 out of n units]
CDF of any two units = [CDF from 2 out of n units] – [CDF from 3 out of n units]
⋮
CDF of n units (all the units in a site) = [CDF from n out of n units]

To get some insights with respect to multi-unit risk caused by adding new build units in the reference site, we developed two kinds of multi-unit PSA models. One is the case for four units of OPR1000, and the other is the case for six units of OPR1000 and APR1400. Fig. 2 shows the results of preliminary multi-unit PSA for seismic events. In the first case, CDF of any two units takes up around 70% based on CDF of multi-units, and CDF of four units takes up about 30%. On the other hand, CDF of any three units could be ignored. In the second case, CDFs of any two, four & six units take up around 60%, 23% and 6% each, and CDFs of any three & five units could be ignored. We considered that the assumption of 'fully correlated' between twin units caused these results, and the results were reasonable. According to adding new build units in the reference site, CDF increasing ratios of any n units are shown in Table 1.

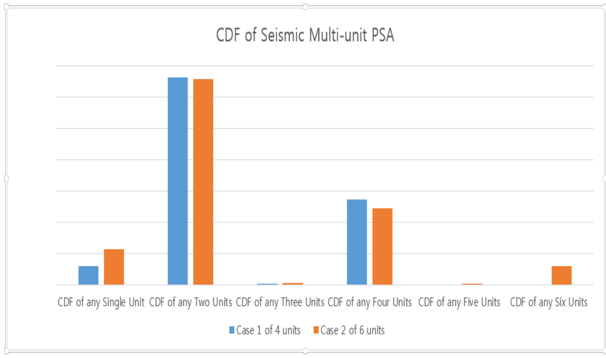

Fig. 2. Results of Multi-unit PSA for Seismic Events

Table 1: CDF Increasing Ratios Caused by New Build Units

	Increasing Ratios	CDF Portion of 'All Cases'
CDF of any Single Unit	5.36 %	10.48%
CDF of any Two Units	- 0.62%	60.49%
CDF of any Three Units	0.47%	0.64%
CDF of any Four Units	- 2.78%	22.60%
CDF of any Five Units	-	0.26%
CDF of any Six Units	-	5.53%
CDF of All Cases	8.73%	100%

4. Conclusion

This paper describes the plot study with some assumptions in the early stage of our project, which is for preliminary multi-unit PSA for seismic events, with focusing on integrating single unit PSA models and quantifying the integrated models. Although some limitations and assumptions were taken as for technical issues, this paper suggested the method of inter unit CCF and the modelling structure as a form of single top fault tree, integrating single unit PSA models. Also, we introduced multi-unit risk metrics as CDF of any n units, and the concept of quantification by using the single top fault tree. Through the pilot study, we derived the results of preliminary multi-unit PSA for seismic events as the form of CDF, and provided the information on the increased risk caused by adding new build two units.

Reference

[1] KAERI/RR-4225/2016, "*Development of the Integrated Risk Assessment Technology for Multiple Units*", KAERI, 2017, Daejeon.
[2] NUREG/CR-4780, "Procedures for Treating Common Cause Failures in Safety and Reliability Studies", US NRC, 1989, Washington.
[3] EPRI TR-3002000709, "Seismic PRA Implementation Guide", EPRI, 2013, Palo Alto.
[4] KAERI/TR-4649/2012, "*Development and Validation of the Seismic Probabilistic Safety Assessment Software PRASSE*", KAERI, 2012, Daejeon.