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Case Study of Multi-Unit Risk: Multi-Unit Station Black-Out

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1. Introduction

After Fukushima Daiichi Accident, importance and public concern for Multi-Unit Risk (MUR) or Probabilistic Safety Assessment (PSA) have been increased. Most of nuclear power plant sites in the world have more than two units. These sites have been facing the problems of MUR or accident such as Fukushima. In case of South Korea, there are generally more than four units on the same site and even more than ten units are also expected. In other words, sites in South Korea also have been facing same problems. Considering number of units on the same site, potential of these problems may be larger than other countries.

The purpose of this paper is to perform case study based on another paper submitted in the conference [1]. MUR is depended on various site features such as design, shared systems/structures, layout, environmental condition, and so on. Considering various dependencies, we assessed Multi-Unit Station Black-out (MSBO) accident based on Hanul Unit 3&4 model.

2. Case Study of Multi-unit SBO

In this chapter, case study for MUR was summarized. According to following four step procedures [2] for estimating MUR, case study based on modified method, which was suggested by another paper [1], had been performed. This method is to modify single unit PSA model through considering various dependencies (shared systems/structures, layout, organizational factor, and so on) between units on same site.

- Initiating event identification
- Estimation of initiating event frequency
- Determination of accident sequence
- Risk quantification

2.1 Initiating Event Identification

Identification of Multi-Unit Event (MUE) is first step to assess multi-unit risk. MUE could be defined as internal and external hazards that affect more than two units concurrently. To sort into single-unit and multi-unit events, it had been considered using experience data of domestic nuclear power plants in this paper. Most of MUE in Korea had been occurred by external hazards such as typhoon, heavy snowstorm, and massive influx of marine life.

In accordance with failure data, we identified and assessed MSBO caused by Multi-unit Loss of Off-site Power (MLOOP). Backgrounds for identification of MSBO as a MUE were followed:

- MSBO caused by MLOOP is major scenario of Fukushima Daiichi accident, which is representative accident of multi-unit accident internationally.
- Important consideration of identification MUE is various dependencies between units such as shared systems, structures, layout, and so on. Therefore, MSBO is one of the strong candidates of MUE because one of major dependency is switchyard in Hanul site.

2.2 Estimation of Initiating Event Frequency

MSBO was one of the sequences of MLOOP. So, assessment of MLOOP had to be preceded to estimate MSBO frequency. The method for estimation of frequency was basically same with single-unit PSA. The only difference was selection of operation period. While calculation of operation period was based on unit considering operation mode (operation & shutdown) in single-unit PSA, multi-unit PSA was based on site operation period regardless of number of unit on same site.

To estimate frequency of MLOOP, information for numbers of occurrence and operation period was required above mentioned. Table.1 shows site operation period during reference duration (1993.01.01~2012.12.31).

Table.1 Operation period

Site	Commercial operation Start	Operation period during reference duration [site-yr][a)]
Kori	1978.04.29	20.0
Hanul	1988.09.10	20.0
Hanbit	1986.08.25	20.0
Wolsong	1983.04.22	20.0
Sin Kori[b)]	2011.02.28	1.84
Sin Wolsong[b)]	2012.07.31	0.42
Total		82.26

a) Operation modes (operate/shutdown) for each unit on same site were not considered.
b) Sin Kori and Sin Wolsong were near with Kori and Wolsong site, but we considered different site.

Site operation period of six sites was 82.26/site-yr during twenty years, occurrence of MLOOP was one. Therefore, calculation of MLOOP frequency using GAMMA distribution was followed.

$$f_{MLOOP} = (1 + 0.5) / 82.26 = 1.82E\text{-}2/\text{site-year}$$

2.3 Determination of Accident Sequence

Basic rules of multi-unit risk used in this paper were based on existing PSA model. So, we used single-unit LOOP model to determine MSBO frequency. Assumptions used in sequence model were followed.

- All units on same site are identical plant
- Single-unit LOOP frequency → Multi-unit LOOP frequency
- Assume that Station Black-Out (SBO) will be occurred by Common Cause Failure (CCF) of Emergency Diesel Generator (EDG) (Fig. 1, 2)

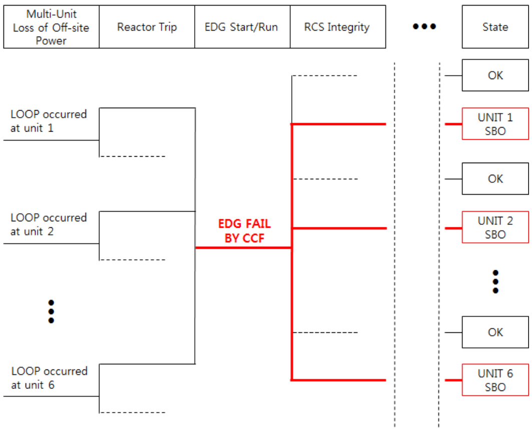

Fig. 1 Event tree for multi-unit LOOP

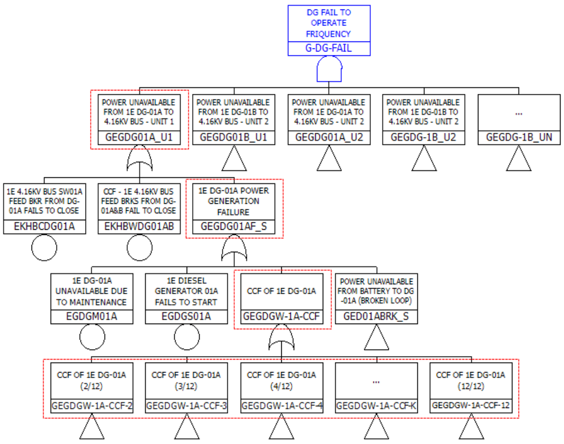

Fig. 2 EDG fault tree

- AAC diesel generator is only one on a site, and it can supply one of 1E 4.16kV bus of only one unit on a site. For this reason, we excluded AAC DG from sequence model conservatively.

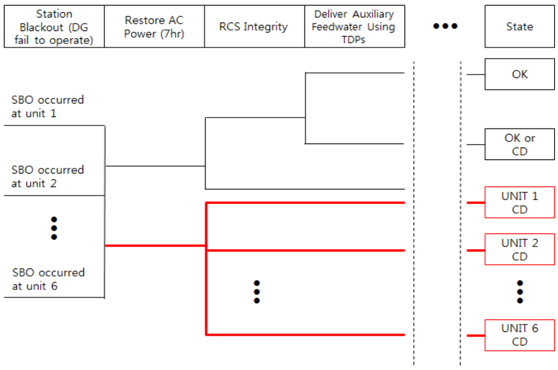

Fig. 3 Event tree for multi-unit SBO

- In case of failure of off-site power recovery, all units, which SBO was occurred, will progress to multi-unit core damage (Fig. 3)

2.3.1 EDG

One of the important issues to assess MUR was increase of combination by number of units. Failure mode of EDG was one of above problems. To solve it, the following assumptions were required:

- Considered failure of EDG itself excluding supporting system
- Considered single failure mode (fail to operate) using data pooling

EDG Fail to Operate = Fail to Start
+ Fail to Run * Mission Time (24hr)

Hanul site have six operating units and total twelve EDG (two per unit) excluding AAC DG. So, we performed CCF assessment for twelve EDG. CCF alpha factor used values suggested in NRC database [3]. The value of Common Cause Component Group (CCCG) of size 12 was estimated using mapping up.

Table.2 CCF data for CCCG=12

Size	CCCG=4	CCCG=5	CCCG=6	CCCG=7	…	CCCG=12
α_1	1.47E-02	9.84E-01	9.84E-01	9.84E-01	-	9.89E-01
α_2	7.38E-03	8.36E-03	7.05E-03	5.32E-03	-	7.39E-04
α_3	4.44E-03	4.54E-03	5.12E-03	5.08E-03	-	1.62E-03
α_4	1.74E-03	2.30E-03	2.70E-03	3.18E-03	-	2.36E-03
⋮	-	-	-	-	-	⋮
α_{12}	-	-	-	-	-	1.85E-04

Prior to CDF assessment, it is noted that number of core damage units may be different under same number of EDF failure because SBO was occurred by failure of two EDG at same unit. For example, if seven EDG failed by CCF, SBO can be occurred at one or two or three units.

2.3.2 Multi-Unit CDF evaluation

Core Damage Frequency (CDF) was representative result of existing PSA. However, it is not sufficient for characterizing MUR. In case of multi-unit PSA, site or multi-unit CDF may be adequate. Its definition was a frequency that can cause core damage including two or more units on a site concurrently.

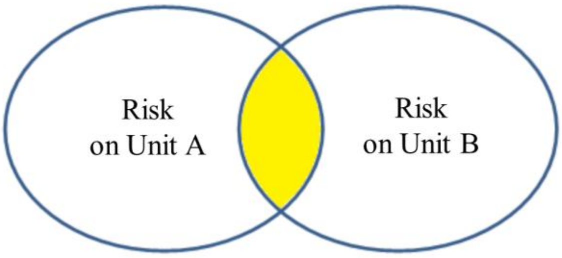

Fig. 4 Simplified structure of multi-unit risk

Intersection portion represented in Fig.4 was multi-unit Core Damage Frequency (CDF) or Site CDF (SCDF) caused by various dependencies. It means that CDF used in existing PSA involve multi-unit CDF. Therefore, CDF of single-unit PSA was required to divide with single-unit CDF and multi-unit CDF.

There are various sequences of SBO. While most of event tree heading of SBO were independent causes, failure of AC recovery was common cause under condition of MLOOP. For this reason, we identified and assessed the sequence including failure of AC recovery that can cause multi-unit core damage. In accordance with various dependencies and assumptions, minimal cutset and equation of our sequence model were followed:

- Minima cutset
  Occurrence of MLOOP → Failure of EDG by CCF → Failure of off-site power recovery → Core Damage → …*
- Equation
  Multi-Unit $CDF_k^{(n)} = IE^{(n)} * Q_{EDG} * CCF_k * Q_{AC\_recovery}$

Table.3 shows results of multi-unit CDF.

Table.3 Operation period for each site

CCF	···	9	10	11	12	$CDF_k^{(n)}$
N of unit	Multi-Unit $CDF_k^{(n)} = IE^{(n)} * Q_{EDG} * CCF_k * Q_{AC\_recovery}$					
⋮	-	-	-	-	-	⋮
3	-	7.78E-11	-	-	-	1.95E-10
4	-	2.92E-11	7.34E-11	-	-	1.07E-10
5	-	-	7.34E-12	6.37E-11	-	7.11E-11
6	-	-	-	-	5.21E-11	5.21E-11

2.4 Risk Quantification

Risk quantification step also had combination issue considered in previous steps. For this reason, estimation of multi-unit risk has been simplified through following conservative assumptions and processes.

i. Use and modify base input of single unit
ii. Amount of source term release increase as number of unit proportionally (ex. source term of three units is three times of single unit)
iii. Radioactive materials were released concurrently
iv. Not consider various combination between initial event, Plant Damage State, and Source Term Category
v. Define typical STC of SBO, and frequency of typical SBO scenario was assigned to STC
vi. Release time is one hour after accident

Simulation code for off-site impact assessment was MACCS2 code [4] that is used in existing PSA. In accordance with above assumptions and processes, we defined and calculated typical SBO scenario and amount of release. The result of risk quantification had been summarized as follows: 1) fatalities based on total population within 30 km radius for six units increased by 0.6% approximately in comparison with single-unit result, 2) risk for six units decreased by two orders approximately in comparison with single-unit risk.

3. Conclusions

In this paper, case study for multi-unit risk or PSA had been performed. Our result was incomplete to assess total multi-unit risk because of two challenging issues. First, economic impact had not been evaluated to estimate multi-unit risk. Second, large uncertainties were included in our result because of various assumptions. These issues must be resolved in the future.

Acknowledgments

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* Assume that Plant Damage State (PDS), Containment Event Tree (CET), and so on are independent sequence