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Study on LOOP and SBO Frequency for Multi-Unit PSA

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1. Introduction

Most of the nuclear power plants in the world have more than two units at a site. Particularly Korea has operated more than two units at all sites due to land availability, suitability and some other reasons. If multiple units are in a site, the units may share certain SSCs (Systems, Structures and Components) because of economics and redundancy. Sharing SSCs have some benefits for safety such as redundancy in terms of single unit events, but it results in dependency between the units in multi-unit events.

In conventional single unit PSA, it was assumed that all accidents or events are independent and the risk of only one unit has been evaluated. In other words, the possibility that simultaneous events occur on multiple units was excluded because it was assumed that the probability of concurrent events were extremely low. After Fukushima accidents, however, it was found that external hazards such as tsunami may impact on multiple units; that means, for the sake of proper mitigation the risk of accidents in shared SSCs should be reevaluated.

New risk metrics to improve conventional CDF (Core Damage frequency) based on reactor-year is needed to perform MUPSA (Multi-Unit Probabilistic Safety Assessment). IAEA suggested SCDF (Site CDF) as a risk metrics for MUPSA [1]. The frequency based on reactor-year was converted to the frequency based on site-year. In addition, shared SSCs were modeled in single unit PSA as if those units have independent shared SSCs. Therefore, the risk of shared SSCs should be reevaluated [2, 3].

In this paper, the frequency of LOOP (Loss of Offsite Power), which is typically a multi-unit event, was evaluated and the frequency of SBO (Station Blackout) depending on LOOP frequency and emergency power systems such as EDG (Emergency Diesel Generator) and AAC (Alternate AC), that can mitigate SBO events, was modeled [2].

2. Methods and Results

Schroer [4] has classified the initiating events for MUPSA into single or multiple unit impact. LOOP and SBO events were defined as multiple unit impact events. Also, it was found that LOOP and SBO considerably contributed to the overall CDF from the existing PSA results and their importance has emerged after Fukushima accidents.

2.1 How to count the number of LOOP events for MUPSA

LOOP occurs when switchyard that is connected to the plant or electric grid fails. EDG and AAC are installed to mitigate LOOP and SBO events. LOOP is converted to SBO scenario just in case all of EDGs and AAC fail. Thus, SBO frequency is calculated by LOOP frequency and all combinations of success or failure probability of EDG and AAC.

U.S.NRC [5] has classified LOOP events into different groups as follows: Plant-centered, Grid-related, Switchyard-centered and Weather-related. Plant-centered LOOP event occurs within the plant and does not impact multiple units. In other words, it is considered as an independent event. Figure 1 shows the description of LOOP event depending on single or multiple unit impact.

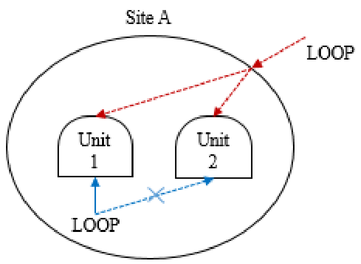

Fig. 1. LOOP event impacting on single and multiple units

For example, there are two cases. One is a LOOP event impacting on both units (red line) and the other is a LOOP event impacting on only one unit (blue line) as shown in figure 1. In conventional PSA, LOOP frequency is calculated by a counting each case independently (3 events in case of figure 1) and dividing by reactor-year as follows:

$$f_{LOOP} = \frac{Total\ number\ of\ LOOP\ events}{reactor-year} \quad (1)$$

f_{LOOP} is the frequency of LOOP used in conventional single unit PSA. However, the frequency of a LOOP event impacting on both units can be considered only one event, not two events, regarding to the site. This approach is more proper, so, it is needed to be calculated separately as follows:

$$f_{LOOP,S} = \frac{No.\ LOOP\ events\ impacting\ on\ only\ single\ unit}{reactor-year} \quad (2)$$

If the LOOP event impacting on multiple units occurs, the number of events should be counted as a one event during Multiple Reactor Year (MRY) of both units as follows:

$$f_{LOOP,M} = \frac{No.\ LOOP\ events\ impacting\ on\ both\ units}{Multiple\ reactor\ year} \quad (3)$$

In order to clearly show how to count the number of LOOP events, below figure 2 shows the detailed example for two units at a site. In figure 2, S (Single) indicates a LOOP event impacting on single unit and M (Multiple) indicates a LOOP event impacting on both units.

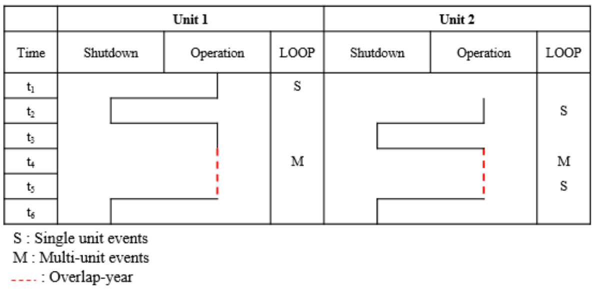

Fig. 2. An example of LOOP events at two-unit site

The conventional LOOP frequency from figure 2 is calculated as follows:

$$f_{LOOP} = \frac{N_{LOOP}}{T_1 + T_2}$$

Where, N_{LOOP} is the total number of LOOP events (5 events in the example) and T_i is reactor-year of each unit ($T_1 = t_1 + t_3 + t_4 + t_5$, $T_2 = t_2 + t_4 + t_5$).

However, the number of LOOP events impacting on only single unit is just 3 and the number of LOOP events impacting on both units is one. Therefore, it is obvious that $f_{LOOP,S} = \frac{3}{T_1+T_2}$ and $f_{LOOP,M} = \frac{1}{MRY}$. Conditional probability in equation 4 is used to verify this approach.

$$P(E1 \cap E2) = P(E1)P(E2/E1) \quad (4)$$

Where, P(E1) indicates the probability of LOOP event at unit 1 and P($E1$ ∩E2) means the probability of LOOP events at both units concurrently. Thus, each probability can be calculated as follows:

$P(E1) = \frac{2}{5}$ and $P(E2/E1) = \frac{1}{2}$ so, $P(E1 \cap E2) = \frac{2}{5} \times \frac{1}{2} = \frac{1}{5}$. Therefore, $N_{LOOP,M}$ which is the number of LOOP events impacting multiple units is calculated as follows:

$$N_{LOOP,M} = N_{LOOP} \times P(A \cap B) = 1$$

$$f_{LOOP,M} = \frac{N_{LOOP,M}}{MRY} = \frac{1}{MRY}$$

This calculation has the same results that the number of LOOP event impacting both units is counted as a one event.

2.2 How to define multiple reactor year

When calculating $f_{LOOP,S}$, there is no concerns for calculating frequency. However, $f_{LOOP,M}$ has significant problem for the multiple reactor year of both units to be determined. Thus, we suggest 2 ways to consider multiple reactor year for multiple events. However, it should be noted that these suggestions should be studied and verified more deeply.

2.2.1 Overlap-year

Two units should be operated at the same time so that a LOOP event impact on both units. Therefore, overlap-year represented in red line in figure 2 can be multiple reactor year for multiple events. In section 2.1 example, $f_{LOOP,M}$ can be calculated as follows:

$$f_{LOOP,M} = \frac{1}{t_4 + t_5}\ (No.\,events\ per\ overlap - year)$$

However, the frequency of multiple events is quite high depending on the number of events and overlap period of both units in this case. Thus, more deeply research is required.

2.2.2 Average-year

The average year between two units can describe both units at the same time to consider suitable period for both units.

$$f_{LOOP,M} = \frac{1}{(T_1 + T_2)/2}\ (No.\,events\ per\ average - year)$$

In case of average-year, $f_{LOOP,S} + f_{LOOP,M}$ becomes f_{LOOP}. Thus, it may give more proper insights from conventional PSA.

2.3 SBO frequency for MUPSA

SBO frequency should also be considered by classifying into single unit events and multi-unit events [1]. Although SBO scenario contains shared AAC, the shared AAC has been modeled in conventional PSA as if there are several independent AAC in unit. However, AAC is typical time sequential shared component that cannot support two units at the same time [4]. Thus, AAC cannot be used for multiple units concurrently when multiple unit events occur.

For example, there are two identical-units at a site that include two EDG respectively and share an AAC as shown in figure 3. The red line indicates conventional PSA scope and the blue line indicates MUPSA scope.

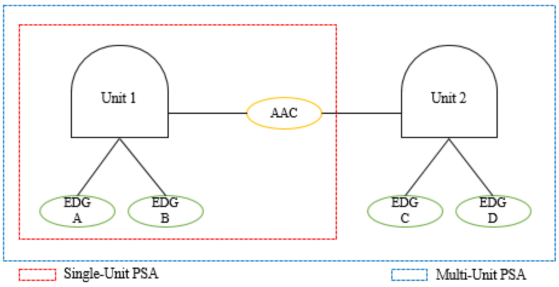

Fig. 3. Configurations of two identical units at a site

In order to understand SBO frequency for MUPSA, figure 4 shows the simplified LOOP ET (Event Tree) which is widely used in PSA. It is assumed that an AAC is aligned to unit 1 when LOOP occurs on both units and all of EDGs fail. It means that an AAC cannot support unit 2 concurrently. Red line in figure 4 is the scope of conventional single unit PSA similar to figure 3.

Thus, SBO frequency is calculated using LOOP frequency in Section 2.1:

$$f_{SBO,S} = f_{LOOP,S} \times P_f(EDG) \times P_f(AAC) \qquad (5)$$

$$f_{SBO,M} = f_{LOOP,M} \times P_f(EDG) \times P_f(AAC) \qquad (6)$$

Where, P_f is the failure probability of EDGs and AAC. As a result, SBO frequency is divided into SBO_1, SBO_2 and $SBO_{1,2}$ which means SBO occurs on only single unit such as $unit_1$ or SBO occurs on both units such as $unit_{1,2}$.

3. Conclusions

This paper describes how to calculate LOOP and SBO frequency from the simple example for two-unit site with shared AAC. The events impacting on multiple units, which were excluded in conventional PSA, should be considered for MUPSA. Furthermore, ET should be simplified because MUPSA considers more cases.

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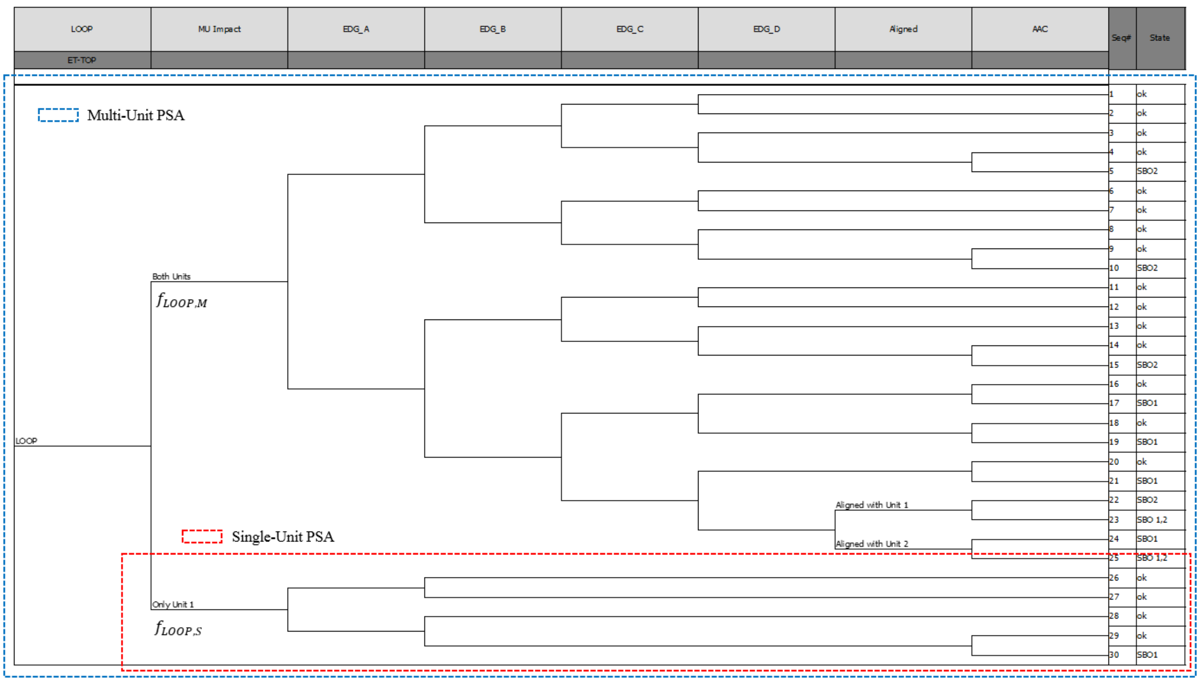

Fig.4 LOOP and SBO Event tree for MUPSA [1, 2]