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Multi-Unit Initiating Event Analysis for a Single-Unit Internal Events Level 1 PSA

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1. Introduction

The Fukushima nuclear accident in 2011 highlighted the importance of considering the risks from multi-unit accidents at a site. The ASME/ANS probabilistic risk assessment (PRA) standard also includes some requirements related to multi-unit aspects, one of which (IE-B5) is as follows:

"For multi-unit sites with shared systems, DO NOT SUBSUME multi-unit initiating events if they impact mitigation capability [1]."

However, the existing single-unit PSA models do not explicitly consider multi-unit initiating events and hence systems shared by multiple units (e.g., alternate AC diesel generator) are fully credited for the single unit and ignores the need for the shared systems by other units at the same site [2].

This paper describes the results of the multi-unit initiating event (IE) analysis performed as a part of the at-power internal events Level 1 probabilistic safety assessment (PSA) for an OPR1000 single unit ("reference unit").

2. Methods and Results

2.1 Multi-Unit IE Analysis for the Reference Unit

A multi-unit IE is an initiating event which leads to reactor trip in multiple units at the same site. For a single-unit PSA, multi-unit IEs should be analyzed because the occurrence of a multi-unit IE can influence the availabilities of the shared systems or components.

The reference unit (OPR1000 type) shares the following systems or components with other units at the same site [3].

- Switchyard
- Intake
- Alternate AC Diesel Generator (AAC D/G)

The switchyard has the capacity of supplying electrical power to two units at the same time, therefore its availability is not influenced by the states of other units. The intake system is equipped independently for each unit and only the sea water is shared by multiple units. Since the sea water can provide water simultaneously to all units at the same site, the availability of the intake system is also not restricted by the states of other units. Even if loss of condenser vacuum or loss of essential service water system occurs due to clogging of the intake in two or more units at the same time, the mitigation capability of each unit is not influenced by the states of other units because there is no shared system or component related to those events.

In case of multi-unit station blackout (SBO), however, an AAC D/G can be connected to only one unit at a time, which impacts the availability of AAC D/G for a single unit. The reference unit shares the AAC D/G with other three units at the same site. Therefore, multi-unit (2~4 units) loss of offsite power (LOOP), which is the starting point of multi-unit SBO, and multi-unit SBO initiating events should not be subsumed by single-unit LOOP or single-unit SBO. In this study, only dual-unit LOOP and dual-unit SBO were considered because the probability of triple- or quadruple-unit SBO is much lower than the probability of dual-unit SBO.

2.2 Adding Dual-Unit LOOP IE to the Single-Unit PSA Model

Using the results of the multi-unit IE analysis described in the previous section, dual-unit LOOP initiating event (IE) was added to the existing PSA model for the reference unit. Single- and dual-unit LOOP IE frequencies were estimated by the proportion of each IE in the Korean industry data from 1978 to 2012. Among 8 LOOP plant level events occurred in critical operations, six were related to dual-unit LOOP (i.e., 3 events involving two units at a site) and the other two events were single-unit LOOP occurrences [3]. Therefore, single-unit LOOP IE frequency and dual-unit LOOP IE frequency were calculated by multiplying the existing LOOP IE frequency by 0.25 (2/8) and 0.75 (6/8), respectively.

Fig. 1 shows the event tree developed for single-unit LOOP initiating event. It has the same logic with the existing event tree for LOOP IE.

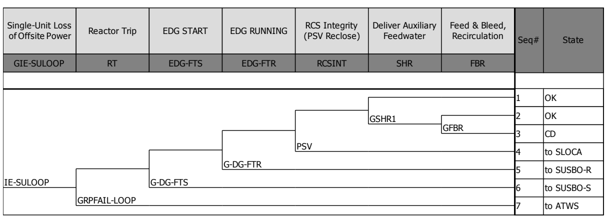

Fig. 1. Event tree for single-unit LOOP initiating event.

Fig. 2 shows the event tree developed for dual-unit LOOP initiating event. In this event tree, unlike the event tree for single-unit LOOP which considers only emergency diesel generators (EDGs) in the reference unit ("Unit 1"), EDGs in the other unit ("Unit 2") should also be taken into account. As shown in Fig. 2, dual-unit LOOP IE progresses to different states according to whether EDGs of each unit succeed or fail to operate. Unlike single-unit LOOP, dual-unit LOOP can be transferred to dual-unit SBO-S (EDG fail to start) and dual-unit SBO-R (EDG fail to run). Since they influence the availability of AAC D/G for "Unit 1", event trees were newly developed for dual-unit SBO-S and dual-unit SBO-R.

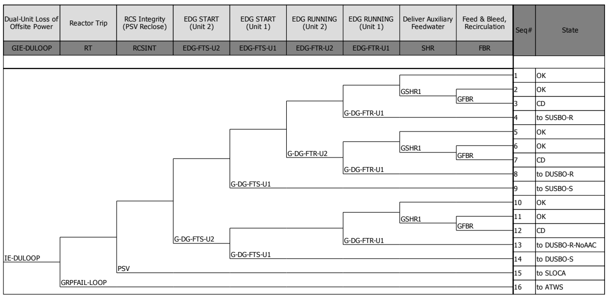

Fig. 2. Event tree for dual-unit LOOP initiating event.

One of the key issues in considering dual-unit LOOP is common-cause failure (CCF) modeling for diesel generators. In the existing single-unit model, 3 diesel generators (i.e., 2 EDGs in the reference unit and AAC D/G) were grouped into a common cause component group (CCCG) and hence 2-out-of-3 and 3-out-of-3 CCF basic events were modeled. In this study, however, 5 diesel generators (2 EDGs in each unit, 1 AAC D/G) were grouped into a CCCG. Therefore, 2-out-of-5, 3-out-of-5, 4-out-of-5, and 5-out-of-5 CCF basic events were modeled.

For the CCF data, alpha factors for EDGs from NUREG/CR-5497 [4] were used. Since NUREG/CR-5497 does not provide alpha factors for 5 EDGs (CCCG size = 5), impact vectors for CCCG=5 were obtained by using the mapping up technique [5]. In addition, a staggered testing scheme was assumed when calculating the probabilities of DG CCF basic events.

2.3 Impact on Core Damage Frequency

When SBO in two units occur simultaneously and they both need the same AAC D/G, the AAC D/G can be connected to only one unit at a time. Since a procedure for this case is not currently available, this study compared two different assumptions: (1) that the probability that the AAC D/G is available to each unit is 0.5; and (2) that the AAC D/G is connected to the other unit ("Unit 2") and is not available to the unit of interest ("Unit 1").

When dual-unit LOOP initiating event was added to the existing single-unit PSA model, the core damage frequency (CDF) due to SBO sequences increased by about 5~9% and hence the total CDF increased by 1~2% depending on the probability that the AAC D/G is available to a specific unit.

3. Conclusions

In this study, a multi-unit initiating event analysis for a single-unit PSA was performed, and using the results, dual-unit LOOP initiating event was added to the existing PSA model for the reference unit (OPR1000 type). Event trees were developed for dual-unit LOOP and dual-unit SBO which can be transferred from dual-unit LOOP. Moreover, CCF basic events for 5 diesel generators were modelled. In case of simultaneous SBO occurrences in both units, this study compared two different assumptions on the availability of the AAC D/G. As a result, when dual-unit LOOP initiating event was added to the existing single-unit PSA model, the total CDF increased by 1~2% depending on the probability that the AAC D/G is available to a specific unit in case of simultaneous SBO in both units.

ACKNOWLEDGEMENT

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