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Fault tree modeling of AAC power source in multi-unit nuclear power plants PSA

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1. Introduction

Dependencies between units are important to estimate a risk of a multi-unit site. One of dependencies is a shared system such as an alternating AC (AAC) power source. Because one AAC can support a single unit, it is necessary to appropriately treat such behavior of the AAC in multi-unit probabilistic safety assessment (PSA).

The behavior of AAC in multi-unit site would show dynamic characteristics. For example, several units require the AAC at the same time. It is hard to decide which unit the AAC is connected to. It can vary depending on timing of station blackout (SBO), with time delay when emergency diesel generators fail while running. It is not easy to handle dynamic behavior using the static fault tree methodology.

Typical way of estimating risk for multi-unit regarding to AAC is to assume that only one unit has AAC and the others does not [1, 2]. KIM [1] calculates the risk for each unit and uses the average value from the results. Jung [3] derives an equation to calculate the SBO frequency by considering all the combination of loss of offsite power and failure of emergency diesel generators in multi-unit site. It is also assumed that the AAC is connected to a pre-decided unit.

We are developing a PSA model for multi-unit site for internal and external events [4]. An extreme external hazard may result in loss of all offsite power in a site, where the appropriate modeling of an AAC becomes important.

The static fault tree methodology is not good for dynamic situation. But, it can turn into a simple problem if an assumption is made:

- The connecting order of AAC is pre-decided. For example, unit 1 has the first priority, unit 2 has the second priority, and so on.

This study provides an idea how to model AAC for each unit in the form of a fault tree, assuming the connecting order of AAC is given.

2. AAC fault tree model for each unit

Assumptions are made to simplify the situation for the AAC modeling:

- If station blackout occurs in more than one unit, the connecting order of AAC is pre-decided in the order of unit 1, 2, 3, and so on.
- Time frame for SBO is divided into 2 cases: one is the early station blackout (SBO-S) for which EDGs fail to start. The other is the late station blackout (SBO-R) for which EDGs fail to run.

Let us define the following:

FS_i : SBO-S for ith unit
FR_i : SBO-R for ith unit
AS_i : AAC unavailable in case of SBO-S for ith unit
AR_i : AAC unavailable in case of SBO-R for ith unit
AAC : AAC itself failure

2.1 AAC Model for EDG's Failure to Start

Let us consider a case of SBO-S at first. If SBO occurs at unit 1, AAC will be connected to unit 1 which has the first priority. Thus, the only failure of AAC itself is modeled for SBO-S case of the unit 1.

$$AS_1 = AAC$$

For unit 2, AAC would not be available if SBO occurs in unit 1 because AAC is connected to unit 1. AAC is available if SBO does not occur in unit 1. This scenario can be modeled using If-Then-Else style in a fault tree: If SBO in unit 1 occurs, the AAC is not available for unit 2 (AAC unavailable = True), else the AAC unavailability becomes the failure of AAC itself. It can be expressed as follows:

$$AS_2 = FS_1 * True + \overline{FS_1} * AAC$$

It can be simplified (note that $A + \overline{A} * B = A + B$):

$$AS_2 = FS_1 + AAC$$

In other word, add the possibility of SBO in unit 1 to the failure of AAC itself to describe the AAC unavailability for unit 2.

In the same way, AAC for unit 3 can be modeled as follows:

$$AS_3 = FS_1 + FS_2 + AAC$$

In general, AAC model for kth unit becomes:

$$AS_k = \sum_{i=1}^{k-1} FS_i + AAC \qquad (1)$$

We can model the fault trees of AAC for SBO-S, when the connecting order of AAC is pre-decided, as follows:

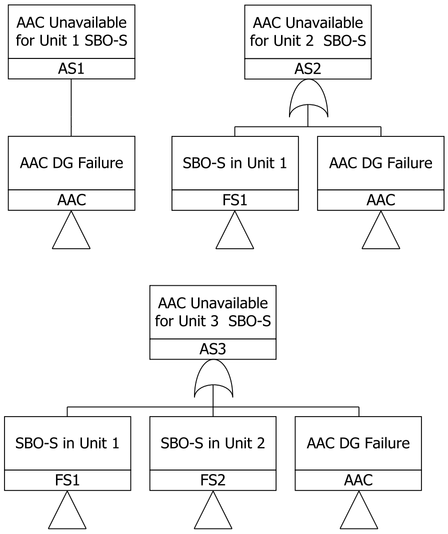

Fig.1. Fault tree model in case of SBO-S

2.2 AAC Model for EDG's Failure to Run

Let us consider a situation for SBO-R case. Suppose unit 1 suffers SBO-R. AAC will be available if SBO-S for other units does not occur. It can be expressed as follows:

$$AR_1 = \sum_{i=1, i \neq 1}^{n} FS_i + AAC$$

For unit 2's SBO-R case, AAC is available if neither SBO-S for other units nor SBO-R for unit 1 occurs.

$$AR_2 = \sum_{i=1, i \neq 2}^{n} FS_i + FR_1 + AAC$$

$$AR_3 = \sum_{i=1, i \neq 3}^{n} FS_i + FR_1 + FR_2 + AAC$$

For SBO-R, AAC model for k^{th} unit is:

$$AR_k = \sum_{i=1, i \neq k}^{n} FS_i + \sum_{i=1}^{k-1} FR_i + AAC \qquad (2)$$

The fault trees for SBO-R are shown in Fig. 2.

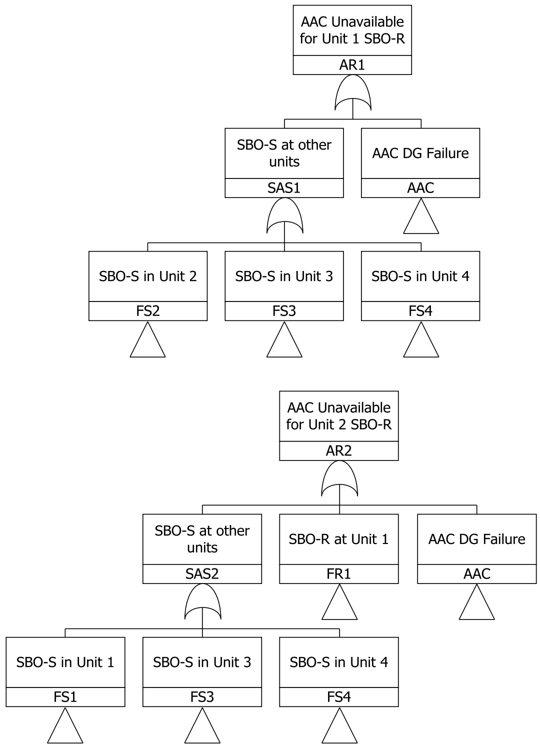

Fig.2. Fault tree model in case of SBO-R

2.3 Multi-unit PSA without connecting order given

If the connecting order is not given for AAC, the approach proposed in this study cannot be applied directly. The multi-unit PSA can be performed as follows:

- Extract the possible series of connecting order
- For each series of connecting order, apply the approach of this study
- Multiply the weighting factor for each series of connecting order and combine models for all series

3. Conclusions

This study illustrates how to model a fault tree for AAC in a multi-unit site. It provides an idea how to handle a shared system in multi-unit PSA, for such a case as loss of all offsite power in a site due to an extreme external hazard.

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References

[1] Myung-Ki Kim, Risk analysis of NPP in multi-unit site for configuration of AAC power source, Proceedings of the 5th International Conference on Probabilistic Safety Assessment and Management, Osaka, Japan, 2000.

[2] Suzanne Schroer and Mohammad Modarres, An event classification schema for evaluating site risk in a multi-unit nuclear power plant probabilistic risk assessment, Reliability Engineering and System Safety 117, pp 40-51, 2013

[3] Woo Sik Jung, Joon-Eon Yang, Jaejoo Ha, A new method to evaluate alternate AC power source effects in multi-unit nuclear power plants, Reliability Engineering and System Safety 82, pp 165–172, 2003

[4] Joon-Eon Yang, Development of an Integrated Risk Assessment Framework for Internal/External Events and All Power Modes, Nuclear Engineering and Technology, Vol.44, No.5, pp 459-470, 2012