Preliminary Quantification of a Fire PSA Model Using Initiating Event Fault Trees

Yong Hun Jung [a*], and Dae Il Kang [a]
[a] *KAERI, 111 Daedeok-daero 989beon-gil, Yuseong-Gu, Daejeon, Korea, 34057*
[*] *Corresponding author: juingyh@kaeri.re.kr*

1. Introduction

An internal fire event probabilistic safety assessment (PSA) model has been generally developed by modifying a pre-developed internal event PSA model. Some fire-induced accident scenarios have their own unique accident sequence logics that not covered in the internal event PSA model, and therefore, these have been separately developed and incorporated into the fire PSA model. One more thing to note about the fire PSA model is that a single fire event within a fire compartment or fire scenario can cause multiple initiating events. For instance, a fire in a turbine building area can cause both the loss of the main feed-water and loss of off-site power initiating events. With reference to the recent studies [1,2], fire-induced initiating events are modeled using fault tree analysis technique by modifying the mitigating system fault trees of the pre-developed internal event PSA model, and applied to the fire PSA model to resolve multiple initiating event issues of a fire PSA model. In this study, we compared the quantification results of fire PSA models for a reference nuclear power plant with or without initiating event fault trees to get an insight into whether and how initiating event fault trees affect the quantification results.

2. Methods and results

2.1 CDF equation and modification rules

A level-1 PSA provides an estimate of the core damage frequency (CDF) as a quantification result, and also, information on the major components, systems, and accident sequences that significantly contribute to it. The CDF of a nuclear power plant for the fire-initiated accident scenarios can be represented by Eq. (1).

$$CDF = \Sigma CDF_k \quad (1)$$

In Eq. (1), CDF_k represents the CDF of each zone (or each fire-induced accident scenario) k. The CDF_k can be further expanded as [3]

$$CDF_k = \%R_k * S\%R_k * N\%R_k * CCDP_k \quad (2)$$

where,
$\%R_k$ = fire frequency of zone *k*,
$S\%R_k$ = severity factor of zone *k*,
$N\%R_k$ = non-suppression probability of zone *k*,
$CCDP_k$ = conditional core damage probability (CCDP) of zone *k*.

The modification algorithm for transforming an internal event PSA model to a fire event PSA model is as follows [3]:

- Initiating event:

$$\%I => \Sigma\%R_k * S\%R_k * N\%R_k \quad (3)$$

- Basic event:

$$a => a + \Sigma\%R_k * S\%R_k * N\%R_k * P\%R_k\text{-}a \quad (4)$$

where,
%I: internal initiating event
a: basic event due to the random failure of component
$P\%R_k$-*a*: fire damage event for the component (and cables) related to the basic event *a*.

Eq. (3) can be applied to internal initiating events not modeled using the fault trees but represented simply as single events. Eq. (4) converts an internal basic event into an 'OR' logic combination of the internal basic event itself and a 'AND' logic combination that consists of the fire damage event for the component (and cables), and of the specific zone fire occurrence events, including the fire frequency, severity factor and non-suppression event. Eq. (4) can also be used for modeling fire-induced initiating event fault trees based on the pre-developed internal initiating event fault trees.

2.2 Fire-induced initiating fault trees

In the internal event PSA model, the initiating event gates are represented as a set of single events with frequency data. The same structures for the initiating event gates also apply to the original fire PSA model. These structures are changed by adding fire-induced initiating event fault trees under the initiating event gates. Fig. 1 and 2 show fire-induced initiating event fault trees for the loss of one (train A) 125V DC bus (LODCA) and loss of one (train A) component cooling water system (PLOCCW), respectively.

2.3 Quantification results of fire PSA models with or without initiating event fault trees

Table I summarizes CDF variations by fault tree modeling of three representative fire-induced initiating events: LODCA, LODCB, and PLOCCW. The results indicate that the modeling of fire-induced initiating event fault tree generally reduces CDF values to a greater or lesser extent depending on the initiating event. For the LODCA and LODCB, the CDF decreases by 66% and 45%, respectively. On the other hand, the CDF decreases by only 16% for the PLOCCW. Fault tree for the PLOCCW contains far more basic events than that of LODCA or LODCB, which makes more intersection probabilities ignored in the quantification process through so-called rare event approximation.

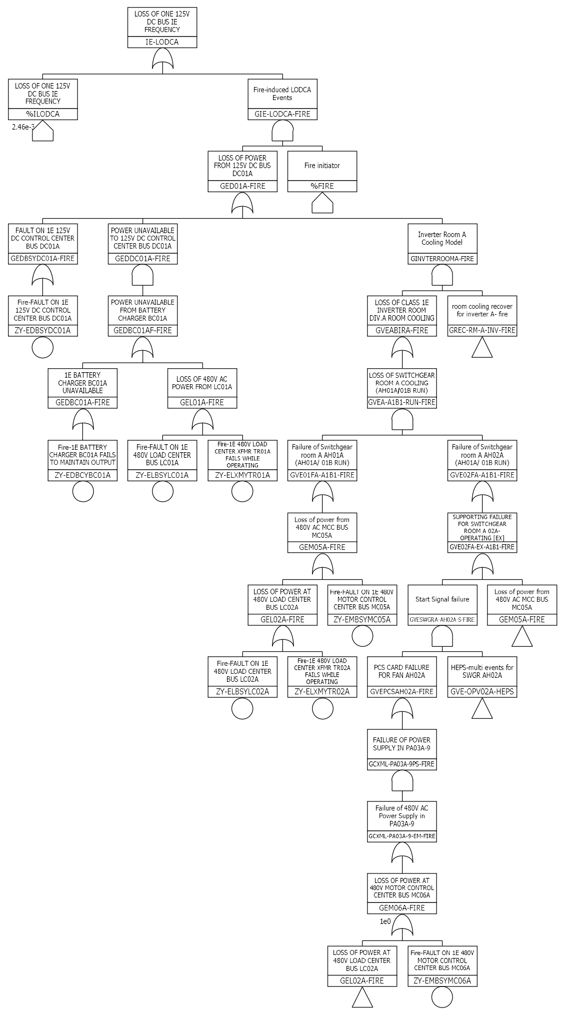

Fig. 1. Fire-induced IE FT for loss of one (train A) 125V DC bus (LODCA).

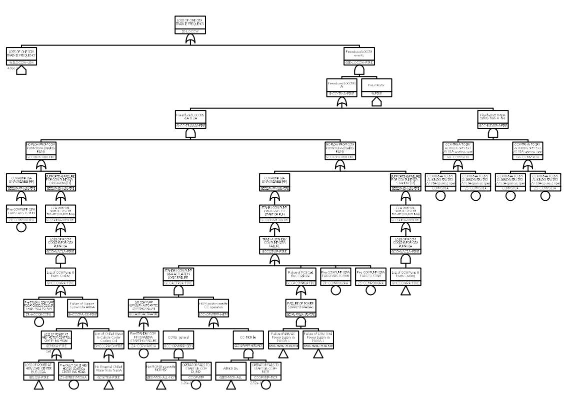

Fig. 2. Fire-induced IE FT for loss of one (train A) component cooling water system (PLOCCW).

Table I: Percentage changes of CDF values by IE FT modeling

IE	Percentage Changes of CDF Values by IE FT
LODCA	-66%
LODCB	-45%
PLOCCW	-16%

3. Conclusions

In this study, we compared the quantification results of fire PSA models for the reference nuclear power plant with or without initiating event fault trees. Through the comparative study, we found that the use of fire-induced initiating event fault trees can entail changes in the CDF results depending on the sizes of initiating event fault trees because of the rare event approximation. Further studies should be conducted to check quantification effects on other initiating events.

Acknowledgements

This work was supported by Nuclear Research & Development Program of the National Research Foundation of Korea grant, funded by the Korean government, Ministry of Science and ICT (Grant number 2017M2A8A4016659).

REFERENCES

[1] Anoba, Richard C., 2011. MAPPING OF FIRE EVENTS TO MULTIPLE INTERNAL EVENTS PRA INITIATING EVENTS. International Topical Meeting on Probabilistic Safety Assessment and Analysis PSA 2011, March 13-17.

[2] Lovelace, N., Johnson, M., and Lloyd, M., 2014. Approach for Integration of Initiating Events into External Event Models. Probabilistic Safety Assessment and Management PSAM 12, June, Honolulu, Hawaii.

[3] Kang, D.I., Han, S.H., Yoo, S.Y., 2013. Development of the IPRO-ZONE for Internal Fire Probabilistic Safety Assessment, Nuclear Engineering and Design 257, 72–78.

[4] Julius, J. and Schroeder, J., 2008, Support System Initiating Events: Identification and Quantification Guidelines, 1016741, Electric Power Research Institute, Palo Alto, CA. and US Nuclear Regulatory Commission, Washington, DC.