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A Preliminary Study on a Fire PSA Reflecting the New High Energy Arcing Faults Methodology in a Domestic NPP

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1. Introduction

'High Energy Arcing Faults' (HEAF) is defined as 'a fault that results in the rapid release of electrical energy in the form of heat, vaporized metal, and mechanical force' [1]. Recently, new research results for HEAF have been published, and a LIC-504 [2] process has been carried out to determine if there is a significant increase in risk due to the new HEAF results. The results of the LIC-504 assessment are [1]; 1) the increased core damage frequency (△CDF) of a U.S PWR reference nuclear power plant (NPP) is 3.4E-5 /yr, 2) the △CDF of a U.S BWR reference NPP is -1.1E-5 /yr.

Since the increased risk depends on the design of the NPP, a new quantification of the fire PSA, reflecting the new HEAF methodology, is required and performed for a domestic NPP.

In this paper, it is described how the new HEAF methodology can be applied to and the preliminary result of the fire PSA for the domestic reference NPP is presented.

2. Methods and Results

2.1 The HEAF Frequency of NUREG-2262 [2]

The HEAF ignition source bins of NUREG-2262 [2] are derived according to the different zones established on the electrical distribution system (EDS) of NPPs, as shown in Fig. 1.

The HEAF source bins and their corresponding zones are shown in Table I.

The HEAF frequencies also changed as shown in Table II. The total HEAF frequency increased up to 1.77 times.

Another important change is the HEAF source counting method. In NUREG/CR-6850 [4], the number of ignition sources was counted by the vertical section of the cabinet. However, in the new HEAF methodology, only the number of supply circuit breakers is counted for the load centers. And for the medium-voltage switchgear, the entire bank is counted as one and not by individual vertical section.

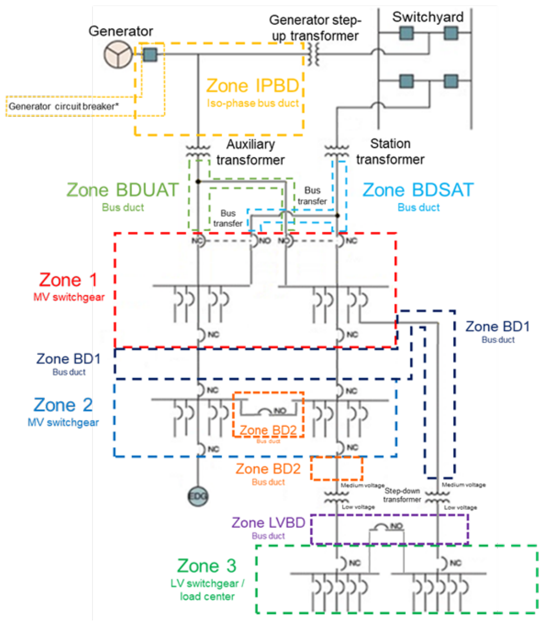

Fig. 1. HEAF zones for a NPP electrical distribution system

Table I: HEAF Zones and Ignition Source Bins

HEAF Zones	Bin	Portion of EDS
IPBD	16.2	Iso-phase bus duct
BDUAT	16.1-1	Bus duct between UAT and Zone 1
BDSAT	16.1-1	Bus duct between SAT and Zone 1
Zone 1	16.b	Medium voltage (MV) switchgear
Zone 2		
Zone 3	16.a	Load center
BD1	16.1-2	MV bus duct between Zone 1 and Zone 2 and Zone 1 and Zone 3
BD2	16.1-2	MV bus duct between Zone 2 and Zone 3, and Zone 2 to Zone 2
LVBD	16.1-2	LV bus duct between Zone 1, Zone 2 and Zone 3 to Zone 3

Table II: The Change of HEAF Ignition Frequency

NUREG-2169 [3] (1968~2009)		NUREG-2262 (1981~2021)	
Bin	Freq.	Bin	Freq.
16.a	1.52E-4	16.a	5.32E-4
16.b	2.13E-3	16.b	1.98E-3
16.1	1.1E-3	16.1-1	2.61E-3
16.2	5.91E-4	16.2	1.01E-3
		16.1-2	8.98E-4
Sum	3.97E-3		7.03E-3

The other important change is that the new HEAF methodology takes into account the circuit protection relays, such as instantaneous, time delayed or generator circuit breaker (GCB), in the HEAF ignition frequency and zone of influence (ZOI). For example, even if a generator-fed fault occurs that could damage the IPBD, BDUAT and medium voltage switchgears (MV SWGR), the GCB can protect the IPBD, BDUAT and MV SWGR with an unreliability of 3.5E-5. Therefore, the fault clearing time of the protection relay, determined for the coordination of the overcurrent relay, is indispensable for the estimation of the arc energy.

2.2 *HEAF Frequency of a Domestic Reference NPP*

The HEAF ignition frequency of the domestic reference NPP was calculated according to the new HEAF methodology. An example of the results is shown in Fig. 2. In Fig. 2, when the "old" and "new" ignition frequencies are calculated from the data of NUREG-2169 and NUREG-2262, respectively, the change in Bin 16.a of each fire room is shown. Since the frequency of Bin 16.a was increased from 1.52E-4 to 5.32E-4 (see Table II), the new Bin 16.a value of each fire room is greater than the old Bin 16.a value.

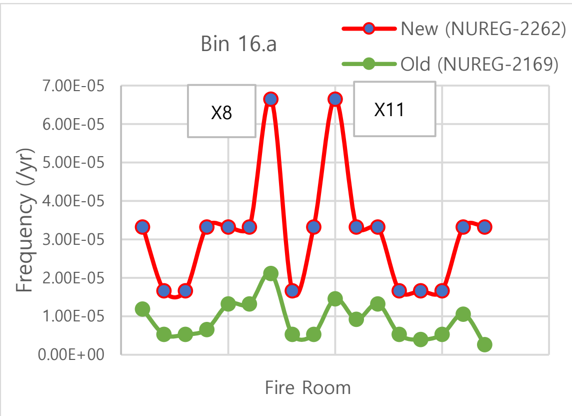

Fig. 2. Ignition Frequency Change in Bin 16.a

The change in total HEAF frequency of each fire room is shown in Fig. 3. In Fig. 3, since the ignition frequency of each HEAF bin was generally increased in the new HEAF method, the total HEAF frequency of each fire room increased. The average new HEAF ignition frequency increased up to 1.77 times the average old frequency.

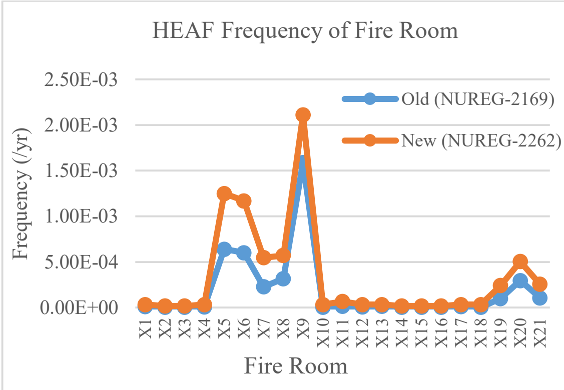

Fig. 3. The change of total HEAF frequency of each fire room

2.3 *Fire PSA Result of a Domestic Reference NPP*

With the new HEAF frequency and methodology, the fire PSA of the domestic reference NPP was quantified.

Let's call the "old" fire PSA the fire PSA using the NUREG-2169 methodology, including the full burn-up model, which means that all equipment and cables are burned up in the event of a fire in the room. Again, let's assume this;

Old: a fire PSA with NUREG-2169, by full burnup model
New 1: a fire PSA with NUREG-2262, by full burnup model
New 2: a fire PSA with NUREG-2262, by using;
1) GCB to prevent IPBD (Bin 16.2) and BDUAT (Bin 16.1), and MV SWGR (Bin 16.b) HEAF, and
2) a 'free ZOI of 480V Load Center (LC)'

The 'free ZOI of 480V LC' can be explained with Fig. 4. In Fig. 4, if a supply circuit breaker is located in the inner section such as 'A2', the HEAF cannot damage the other neighboring equipment except the LC itself and the transformer (XFMR) because its outward ZOI has been blocked. In the domestic reference NPP, all 480V LCs are the free ZOI ones except two 480V LCs.

<table>
<tr><td>C1</td><td>B1</td><td rowspan="2">A1</td><td rowspan="4">XFMR</td></tr>
<tr><td>C2</td><td>B2</td></tr>
<tr><td>C3</td><td>B3</td><td>A2</td></tr>
<tr><td>C4</td><td>B4</td><td>A3</td></tr>
</table>

Fig. 4. An example of 'free ZOI 480V LC'

The fire PSA result of the domestic reference NPP can be explained with Fig. 5. In Fig. 5, the increased HEAF frequency ratio, which is the ratio of the new HEAF frequency to the old HEAF frequency of Fig. 3, is represented by the blue line, although it is not well seen by the other green line.

In Fig. 5, since the quantification result of New1 and Old is based on the assumption of full burnup, the quantification ratio 'New1/Old', represented by the green line, is almost equal to the HEAF frequency ratio 'New/Old'. This is because the quantification result (= New 1) of the fire PSA would increase as much as the HEAF frequency increase under the full burnup assumption. Thus, two lines (green and blue) overlapped.

However, if we consider that the GCB can protect the HEAF on IPBD, BDUAT and MV SWGR and the 'free ZOI of 480V LC', the quantification result (= New 2) of the fire PSA would be significantly reduced. Therefore, the reduced quantification ratio is represented by the red line in Fig. 5. The average value of the quantification result (= New 2) is 11% lower than the old result although the average new HEAF ignition frequency increased 1.77 times the average old frequency.

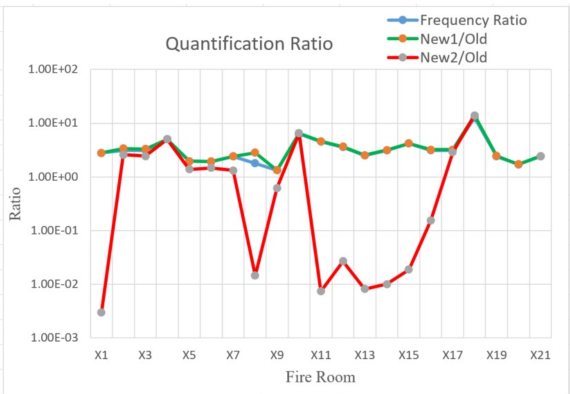

Fig. 5. Quantification ratio of each fire room in fire PSA

However, in the New 2 quantification, only the GCB related BDUAT, IPBD and MV SWGR as well as the 'free ZOI of 480V LC' were considered. If we consider the risk of the other bus ducts, the risk could be increased by the ZOIs. Another possible increase in risk is the post-HEAF ensuing fire. In Fig. 4, it is assumed that the ZOI of 480V LC could be blocked with a XFMR. However, as this assumption was not mentioned in NUREG-2262, the other adverse effect should be further investigated.

3. Conclusions

Since the new HEAF methodology was introduced, and the increased CDF of a US reference PWR quantified with the new HEAF methodology was a large value, the new HEAF methodology was applied to a domestic reference NPP fire PSA. The following are the results of the fire PSA using the new HEAF methodology.

First, a simplified method (New 2 method) with GCB and 'free ZOI 480 V LC' is applied, and then, the increased risk of the domestic reference NPP is negligible. However, the risk of the other bus ducts with appropriate ZOIs should be considered in the further study. Five (5) fire areas with a value greater than 1.0E-08/yr were selected for further detailed analysis. Without GCB in the domestic NPP, the risk would be greatly increased. Although the new HEAF methodology is complicated, the New 2 method is simple and useful, which gives an insight into the fire risk of the domestic reference NPP.

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