Probabilistic Safety Assessment of the Offsite Power System of Hanul Nuclear Power Plant Considering the Failure Correlation Caused by Typhoon-Induced High Winds

Kim, Gungyu a, Kim, Dongchang a, Kwag, Shinyoung b, Eem, Seunghyun a

a Department of Convergence & Fusion System Engineering, Kyungpook National University, 2559, Gyeongsang-daero, Sangju-si, Gyeongsangbuk-do, Republic of Korea
b Department of Civil & Environmental Engineering, Hanbat National University, 125, Dongseo-daero, Yuseong-gu, Daejeon, Republic of Korea

*Corresponding author: eemsh@knu.ac.kr

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1. Introduction

According to the ‘Korea Climate Change Assessment Report 2020’, the intensity and frequency of typhoons are continuously increasing [1]. According to the typhoon paths from the National Typhoon Center of the Korea Meteorological Administration, the typhoons that have affected Korea over the past 20 years tend to shift from northeastward to northward [2]. Accordingly, typhoons can have a significant impact not only on southeastern Korea but also throughout the country.

In the case of domestic incidents, there was a Loss of Offsite Power (LOOP) event at the Kori Nuclear Power Plant (NPP) due to a typhoon (Vera, 1986), which caused transmission line failures, resulting in a reactor shutdown. Additionally, during the typhoon (Maysak, 2020), although there was no LOOP event, there was an occurrence where the reactor automatically shut down, and emergency diesel generators were automatically activated [3].

There have been incidents of multiple transmission towers being damaged by typhoons [4]. Considering only complete independence or complete dependence when evaluating the probability of damage to the power system due to typhoon-induced high winds is unrealistic. In order to perform a realistic power system safety assessment, it is necessary to apply appropriate correlation factors.

In this study, we conducted PSA due to high winds accompanied by typhoons, considering the correlation of damage probability between the marginalized power systems of the Hanul NPP. A fragility analysis of the offsite power system was conducted to perform a PSA using the Seismic Safety Margins Research Program (SSMRP) formula for the typhoon hazard and the correlation of damage caused by typhoon-induced high winds [5]. Considering typhoon-induced high winds, the PSA determined the probability of being unable to supply power to the NPP.

2. Methodology for PSA Considering Failure Correlation

The safety assessment of the power system considering failure correlation due to typhoon-induced high winds was conducted through the following process:

1. Analysis of typhoon hazard,
2. Fragility analysis of power system components,
3. Analysis of failure correlation between power system components,
4. Analysis of fragility curves for the power system,
5. Convolution of typhoon hazard and power system fragility to derive risk.

2.1 Analysis of the Fragility of Power System Components

The power system components include transmission towers, transmission lines, power plants, substations, and others. In the context of typhoon-induced high winds, transmission towers were considered the most vulnerable component. It was assumed that typhoon-induced high winds would not damage substations and power plants. The fragility of transmission towers was used based on the study by Kim et al. and is presented in Table 1 [6]. A power system within a 16km radius of the area of interest was constructed. It was assumed that the power system components outside the area of interest were not damaged. The power system layout for the Hanul Nuclear Power Plant site is illustrated in Figure 1.
Table I: Fragility of transmission towers in the PSA of the power system

<table>
<thead>
<tr>
<th>Region category</th>
<th>$V_m$ Estimation (m/s) 10-min average</th>
<th>$\beta$ Estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>48</td>
<td>0.136</td>
</tr>
<tr>
<td>II</td>
<td>43.92</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>38.04</td>
<td></td>
</tr>
</tbody>
</table>

2.2 Analyze Failure Correlation Between System Components

The failure correlation between power system components was determined using the failure correlation formula from the SSMRP study. Response and wind performance correlation are needed to derive the failure correlation. The wind performance correlation was set to 0. The response correlation for typhoon-induced high winds was calculated using the correlation fitted to the Abrahamson Equation by Kim et al. [7]. It was applied as a correlation to conduct a PSA of the power system [7].

3. PSA Results for Typhoon-induced High Winds

3.1 Analysis Results of Power System Fragility

The fragility of the offsite power system at the Hanul NPP site was analyzed based on the application of independence, dependence, and correlation. Fragility analysis was conducted using the network risk assessment program developed by Eem et al. [8]. The fragility curve for the offsite power system at the Hanul NPP site obtained from the analysis is shown in Figure 2.

![Fig. 2. Fragility curve of the power system considering the failure correlation](image)

3.2 Result of Risk

The typhoon hazard for the Hanul NPP site utilized the hazard model developed by Kim et al. PSA for the power system was conducted considering failure correlation due to typhoon-induced high winds. The errors in High Confidence Level Probability of Failure (HCLPF) and risk are shown in Table 2.

Table II: HCLPF and risk for each correlation case

<table>
<thead>
<tr>
<th>Corr. Case</th>
<th>HCLPF (m/s)</th>
<th>Risk (Yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent</td>
<td>29.1</td>
<td>7.90E-03</td>
</tr>
<tr>
<td>Dependent</td>
<td>28.9</td>
<td>1.51E-03</td>
</tr>
<tr>
<td>Correlation</td>
<td>26.7</td>
<td>6.80E-03</td>
</tr>
</tbody>
</table>

4. Conclusions

A PSA of the offsite power system at the Hanul NPP site was conducted using the failure correlation induced by typhoon-induced high winds. The safety assessment results indicated that the risk was lowest when considering the correlation as completely dependent, whereas it was highest when considering it as independent. Applying the failure correlation of typhoon-induced high winds between transmission towers using the correlation resulted in an annual occurrence probability of 6.80E-3. Significant differences were observed in the PSA, with 16.22% and 77.75% for independent and dependent, respectively. Therefore, applying the failure correlation induced by typhoon-induced high winds in the PSA of the power system is more realistic.

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