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

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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, and (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.

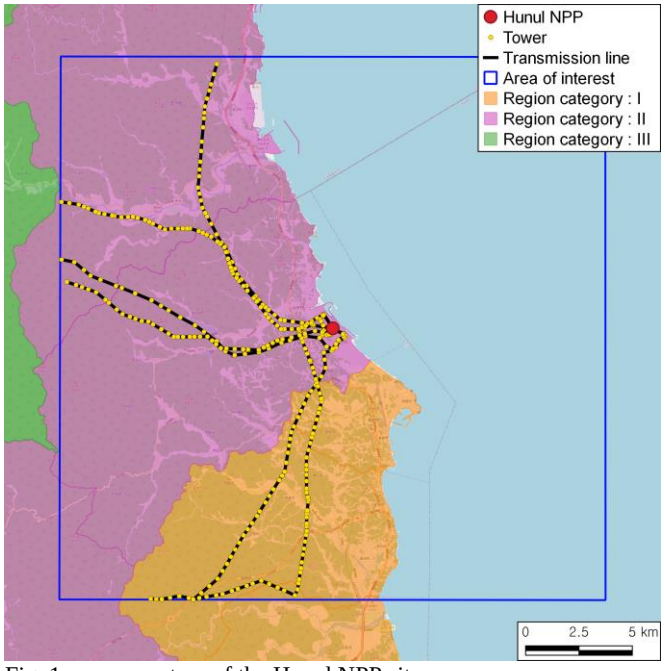

Fig. 1. power system of the Hanul NPP site

Table I: Fragility of transmission towers in the PSA of the power system

Region category	V_m Estimation (m/s) 10-min average	β_c Estimation
I	48	0.136
II	43.92	
III	38.04	

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.

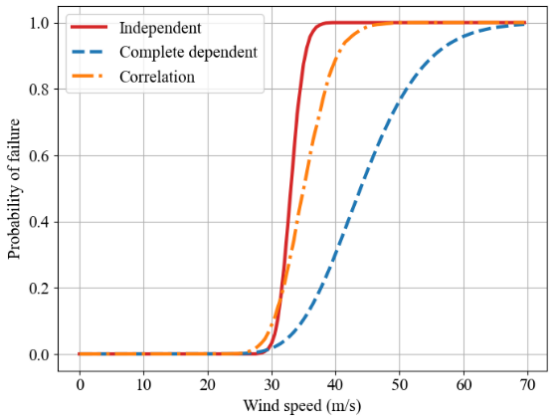

Fig. 2. Fragility curve of the power system considering the failure correlation

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

Corr. Case	HCLPF (m/s)	Risk (Yr^{-1})
Independent	29.1	7.90E-03
Dependent	28.9	1.51E-03
correlation	26.7	6.80E-03

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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REFERENCES

[1] Kim, N. W., Lee, J. W., Joo, G. H., and Kim, S. H.. (2020). “Korean Climate Change Assessment Report 2020(The scientific basis for climate change).” Korea Meteorological Administration. (in Korean)
[2] Korea Meteorological Agency., (2024), “Typhoon movement path.”Available at: https://www.weather.go.kr/w/typhoon/typ-history.do, (Accessed: Feb. 20, 2024), (in Korean).
[3] Korea Institute of Nuclear Safety. (2023)., Available at: https://nsic.nssc.go.kr/information/reguDataActive.do?nsicDtaTyCode=nppAccient, (Accessed: Ang 20, 2023). (in Korean)
[4] An, L., Wu, J., Zhang, Z., and Zhang, R. (2018). “Failure analysis of a lattice transmission tower collapse due to the super typhoon Rammasun in July 2014 in Hainan Province, China.”Journal of Wind Engineering and Industrial Aerodynamics, Elsevier, Vol. 182, pp.295-307.

[5] Smith PD, Dong RG, Bernreuter DL, Bohn MP, Chuang TY, Cummings GE, Johnson JJ, Mensing RW, Wells JE. Seismic safety margins research program. phase I final report-overview. . 1981.
[6] Kim G, Kwag S, Eem S, Jin S. (2024) Probabilistic Safety Assessment of Offsite Power System Under Typhoon-induced High Wind. KSCE Journal of Civil and Environmental Engineering Research Vol.44, No.2 (in Korean)
[7] Kim G, Kwag S, Eem S. "Correlation Analysis of Wind Speeds for the Wind Safety Assessment in Off-site Power System" Transactions of the Korean Nuclear Society Autumn Meeting, Korea Nuclear Society, Gyeongju, Korea.
[8] Eem, S. H., Kwag, S. Y. and Hahm, D. G. (2023). "Development of network safety assessment methodology for loss of off-site power system." Proceedings of Transactions of the Korean Nuclear Society Spring Meeting, Korea Nuclear Society, Jeju, Korea.
[9] Kim G, Kwasg S, Choun Y, Eem S. (2023) Typhoon Hazard and Sensitivity Analysis for Hanul Nuclear Power Plant Site Using Logic Treeg. Korean Society of Civil Engineers 2023 Convention. 2023 Oct. (in Korean)