Development of PSA Model for Super Typhoon-induced External Hazards

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1. Introduction

In September 2020, a loss of offsite power accident took place at multiple nuclear power plants located in the Kori area due to Typhoon "Maysak." In addition, as climate change is expected to increase the likelihood of super typhoons, interest in safety of nuclear power plant with respect to typhoons has increased.

Accordingly, this study develops a probabilistic safety assessment (PSA) model for the OPR1000 nuclear power plant, which is a representative domestic nuclear power plant, focusing on high wind and external flooding hazards among the external hazards expected to be caused by super typhoons. Using this model, this study aims to identify major accident scenarios that may occur due to typhoons and to examine their resulting impacts on the plant.

2. Methods and Results

2.1 Development of PSA Model for High Wind Hazard

As the intensity of high winds accompanying a typhoon increases, the magnitude of wind loads that structures or equipment within the plant must withstand also increases. Accordingly, damage or overturning of structures or equipment may occur, and the resulting impacts on the plant may differ. As a result of investigating plant impacts by failure of structure and equipment, as shown in Table I, high wind hazards may induce loss of offsite power (LOOP) and loss of main feed-water (LOFW) accidents. Event tree with each failure event as the heading were constructed as shown in Figure 1.

2.2 Development of PSA Model for External Flooding Hazard

External flooding hazards refer to cases in which heavy rainfall accompanying a typhoon accumulates within the plant and causes damage, and plant impacts may differ depending on the flooded structure or equipment. As a result of investigating plant impacts by failure of structure and equipment, as shown in Table II, external flooding hazards may induce loss of essential service water (LOESW), loss of essential power (LEP), LOOP, and LOFW accidents. In the case of LOOP accident, flooding of the emergency diesel generator building and the alternate AC diesel generator building can lead to an extended loss of all AC power (ELAP) accident. Event tree with each failure event as the heading are shown in Figure 2. In the case of external flooding hazards, pre-installed measures such as the installation of flood protection facilities are possible; therefore, failure of these measures were additionally considered.

Table I: Failure effects of structure and equipment caused by high wind hazard

Structure & Equipment	Failure effect
765kV transmission towers and switchyard	Loss of 765kV off-site power
154kV transmission towers and switchyard	Loss of 154kV off-site power
Main transformer (MT)	Loss of 765kV off-site power
Unit auxiliary transformer (UAT)	
Standby auxiliary transformer (SAT)	Loss of 154kV off-site power
Turbine building (TB)	LOFW induced by loss of main feed-water system
	Loss of 765kV off-site power induced by failure of generator circuit breaker

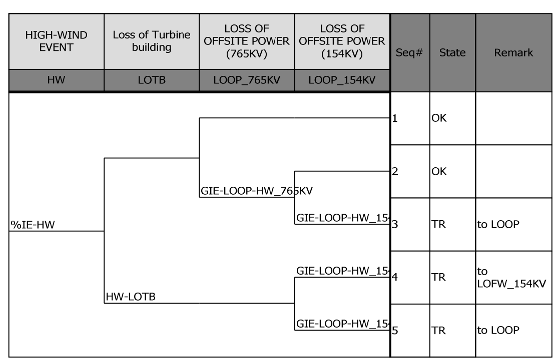

Fig. 1. Primary event tree for high wind hazard.

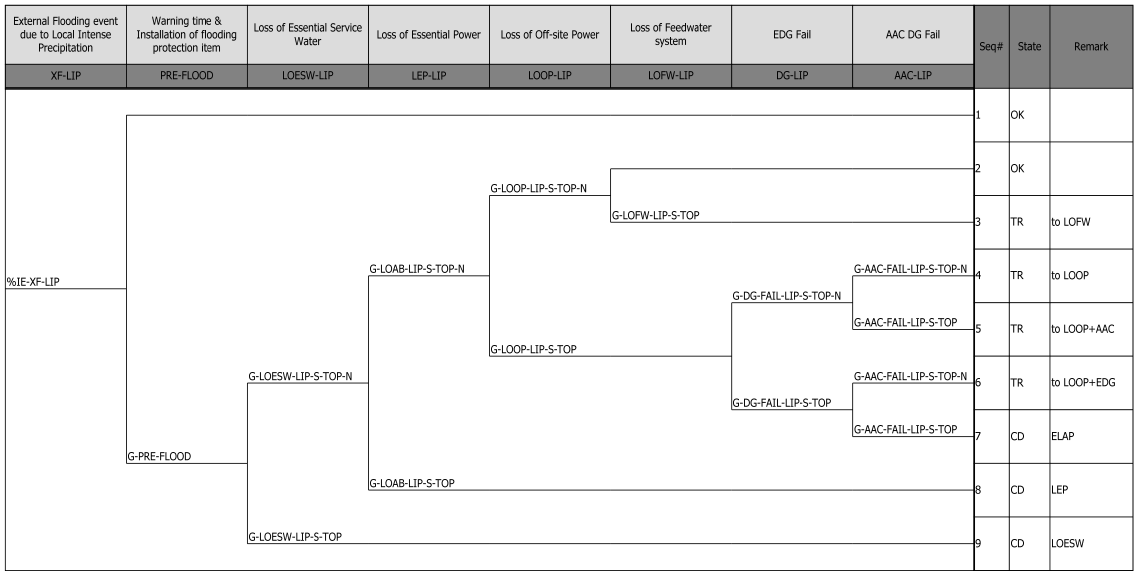

Fig. 2. Primary event tree for external flooding hazard.

Table II: Failure effects of structure and caused by external flooding hazard

Structure & Equipment	Key compartment	Failure effect
Auxiliary building (AB)	Class 1E inverter room	LEP
	Class 1E switchgear room	
Emergency diesel generator (EDG) building	Class 1E EDG room	-
	EDG control room	
Essential service water (ESW) intake structure	HVAC* room	LOESW
Circulating water (CW) intake structure	Electrical room	LOFW
Turbine building	General area	
	Non-class 1E switchgear room	
Alternate AC diesel generator (AAC DG) building	AAC DG room	-
	Switchgear room	
Transformers (MT, UAT, SAT)	-	LOOP

*HVAC: Heating, Ventilation, and Air Conditioning

2.3 Results

To identify major accident scenarios that may occur due to high wind hazards, an analysis was performed by assuming that the probability of occurrence of each failure event due to high wind hazards is 0.1. Here, the frequency of super typhoon occurrence was excluded for the purpose of identifying only the plant impacts caused by a super typhoon.

First, regarding the occurrence probability by accident scenario, accident scenario No. 4, in which only turbine building damage corresponding to LOFW accident occurred, was derived as the highest at 8.10E-02. This was followed by accident scenario No. 3, in which simultaneous loss of the 765 kV and 154 kV offsite power systems, and accident scenario No. 5, in which turbine building damage and loss of the 154 kV offsite power system occurred. These two scenarios may result in LOOP accident.

Subsequently, to examine the plant impacts for each accident scenario, the failure probabilities of accident mitigation measures that can be performed for each accident scenario were analyzed using the internal events PSA model.

First, when LOOP accident occurs, power supply is provided using EDGs or AAC DG. If this operation is successful, cooling operation using this power supply can be performed. In this study, for simplification of the model, only secondary-side heat removal operation through the steam generators was considered as the cooling operation. The event tree expressing this is shown in Figure 3.

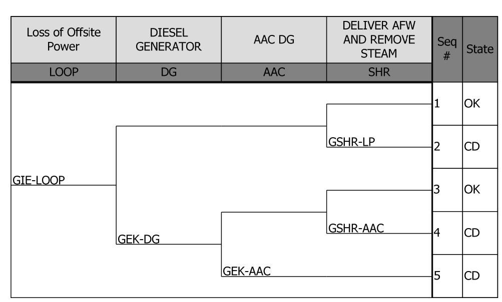

Fig. 3. LOOP event tree for high wind hazard.

In the case of LOFW accident, power supply through the 154 kV offsite power system is available; therefore, secondary-side heat removal operation using this power supply or EDGs can be performed. The event tree expressing this is shown in Figure 4.

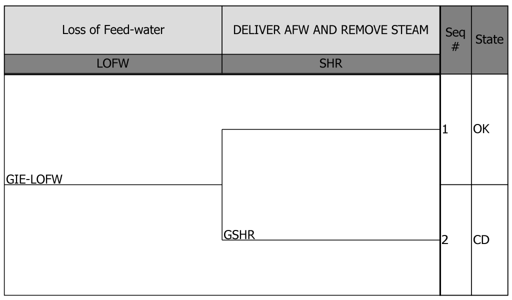

Fig. 4. LOFW event tree for high wind hazard

The failure probability of accident mitigation measures for LOOP accident was derived as 1.73E-04, with failure of both EDGs and AAC DG operation being the dominant contributor. In the case of LOFW accident, evaluation was performed considering conditions in which only the 154 kV offsite power and EDGs was available, and the resulting failure probability of accident mitigation measures was derived as 2.87E-07.

By combining the occurrence probability of each accident scenario derived above with the failure probability of accident mitigation measures after the accident, analysis results showed that, for high wind hazards, LOOP accident had the highest plant impact at 1.13E-05, while LOFW accident was derived to be relatively low at 2.32E-08.

For external flooding hazards, analysis was performed by assuming that the probability of occurrence of each failure event is 0.1 and that the failure probability of pre-installed protective measures is 0.5. In addition, for safety-related structures, watertight doors are installed, making them less likely to be flooded compared to other structures. Therefore, for such structures, the probability that the watertight doors fail to function properly was considered as 0.01, while a probability of 0.1 was considered for structures with non-watertight doors.

First, regarding the occurrence probability by accident scenario, accident scenario No. 4 corresponding to LOOP accident was derived as the highest at 4.94E-02. This was followed by LOFW, LEP, and LOESW accidents, as well as accident scenario No. 5 and No. 6, in which flooding of EDG building or AAC DG building occurred simultaneously with LOOP accident.

Regarding the failure probabilities of accident mitigation measures that can be performed for each accident scenario, continuous accident mitigation measures are not possible for LOESW and LEP accidents. Therefore, according to conservative assumptions, these were classified as direct core damage accidents and a probability of 1.0 was assumed for the failure of accident mitigation measures. Although power supply can be provided for ELAP accident through mobile diesel generator, these were excluded in this study and ELAP accident classified as direct core damage accident.

For LOOP accident, the same failure probability of accident mitigation measures as in the high wind hazard analysis, 1.73E-04, was considered. When EDG building was flooded, a failure probability of 5.81E-02 was considered, and when AAC DG building was flooded, a failure probability of 2.52E-03 was considered.

For LOFW accident, unlike in the high wind hazard case, all offsite power sources are available; therefore, a failure probability of accident mitigation measures of 2.33E-07 was considered.

By combining the occurrence probability of each accident scenario derived above with the failure probability of accident mitigation measures after the accident, analysis results showed that, for external flooding hazards, LEP accident had the highest plant impact at 5.00E-03. This was followed by the LOESW accident at 5.00E-04 and LOOP accident at 8.54E-06. The case in which EDG building was flooded together with LOOP accident was evaluated as 2.87E-06, and the case in which AAC DG building was flooded with LOOP accident was evaluated as a lower value of 1.24E-07. Finally, ELAP and LOFW accidents were evaluated as 4.95E-08 and 2.06E-09, respectively.

3. Conclusions

In this study, a PSA model for the OPR1000 nuclear power plant was developed for high wind and external flooding hazards among external hazards expected to be caused by super typhoons. Using this model, major accident scenarios that may occur due to typhoons and their resulting impacts on the plant were identified.

First, as a result of investigating accidents that may occur due to high wind hazards targeting structures and equipment within the plant, it was confirmed that LOOP accident due to loss of transformers or offsite power grids and LOFW accident due to loss of the turbine building may occur. In the case of external flooding hazards, it was confirmed that LOESW accident due to flooding of ESW intake structure, LEP accident due to flooding of auxiliary building, LOFW accident due to flooding of turbine building or CW intake structure, and LOOP accident due to flooding of offsite power-related facilities such as transformers may occur.

Reflecting these results, event trees with the identified failure events as headings and related fault trees were constructed for high wind and external flooding hazards.

To identify major accident scenarios and their resulting impacts, the occurrence probability of each failure event was assumed to be 0.1 to evaluate the occurrence probability of each accident scenario. These probabilities were combined with the failure probabilities of accident mitigation measures after accidents derived using the internal events PSA model to evaluate plant impacts.

As a result of the analysis, for high wind hazards, although the occurrence probability of LOFW accident due to turbine building damage was derived to be the highest, their impact was confirmed to be low due to the existence of many available systems. Conversely, LOOP accident, which have relatively low occurrence probability, were evaluated as having the highest plant impact due to high failure probabilities of accident mitigation measures.

In the case of external flooding hazards, excluding LEP and LOESW accidents for which the failure probability of accident mitigation measures was assumed to be 1.0, LOOP accident were confirmed to have the greatest impact on the plant. ELAP and LOFW accidents were evaluated as having relatively low impacts.

In summary, among accident scenarios that may occur due to high wind and external flooding hazards, LOOP accident are expected to have the greatest impact on the plant. Therefore, if protective measures or prior inspections are performed for equipment that may cause loss of offsite power during a super typhoon to maintain their integrity, plant safety against super typhoons can be improved. In addition, although this study conservatively assumed failure probabilities for each external hazard, resulting in a tendency to derive relatively high plant impacts, it can be utilized as base model for performing safety assessments for super typhoons. Furthermore, if actual equipment-specific failure probabilities and hazard-specific occurrence frequencies are evaluated and reflected in the future, it is expected that more realistic results can be presented.

ACKNOWLEDGEMENT

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