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# Re-evaluation of Station Blackout in Nuclear Power Plants

Eun-Chan Lee*, Tae-Young Shin
*Korea Hydro & Nuclear Power Co., Ltd., 1312 Yuseongdaero, Yuseong-Gu, Daejeon, Korea*
**Corresponding author: eclee@khnp.co.kr*

## 1. Introduction

The probabilistic safety assessment (PSA) [1] of new Korea Hydro & Nuclear Power Co. (KHNP) plants found that the portion of station blackout (SBO), which is an event where both emergency diesel generators (EDGs) and an alternate alternating current diesel generator (AAC DG) fail during the loss of offsite power (LOOP), is 60.8% of the total of core damage frequency (CDF). Therefore, the risk profile with a large SBO effect needs to be improved because there have been few LOOP experiences, except in the early operating stages in the 1980s, due to the countermeasures enacted in order to prevent recurring events. This paper proposes a reduction of the uncertainty due to the small number of LOOP events and an estimation of the non-recovery probability after a LOOP event where the operators fail to energize a safety bus using the offsite power recovery during an SBO with recent operating experience. In addition, in this analysis, the CDF is re-evaluated through reflecting the enhancement of the Class-1E battery capacity.

## 2. Analysis

For new KHNP plants, the unbalanced risk profile, which primarily focuses on SBOs, is determined using uncertainty due to the small data set of available LOOP events and the non-recovery probability after a LOOP in the old reference without recent experiences. In order to resolve this issue, KHNP re-evaluated the SBO effects on the PSA considering the improvements in the LOOP frequency, non-recovery probability after a LOOP, and enhancement of battery capacity.

Regarding the non-recovery probability, the existing PSA used values from the operator's power recovery failure curve and its table data from the EPRI document [2] based on past experiences from 1975 to 1990. In order to reflect Korean domestic experiences, a data update that included recent operating experiences was undertaken because there have been switchyard relocations and improvements, as well as reinforced maintenance, since the 1980s. Therefore, KHNP used NUREG/CR-6890 [3] as the foundation for a Bayesian update in which the NRC analyzed a number of events in the USA and provided a LOOP frequency and non-recovery probability after a LOOP event for the nuclear industry.

In addition, KHNP intends to lengthen the Class-1E battery duty time from 8 hours to 16 hours as a result of the Fukushima accident. However, because 8 hours of battery capacity was used as the operator available time for recovery of offsite power during SBOs in the previous PSA, the modular accident analysis program (MAAP) analyses were conducted considering a battery installation with 16 hours of capacity.

### 2.1 LOOP Frequency

The LOOP frequency in the PSA reports for newly constructed plants was evaluated using the LOOP experiences (refer to Table I) [4] that have occurred since the 1980s, while the NUREG/CR-6890 created a new LOOP frequency using recent experiences from 1997 to 2004 from the USA in order to consider the technical developments and to decrease the data uncertainty. This was undertaken in order that the utilities could use the results to calculate their specific LOOP frequency. The offsite power supply system for domestic nuclear power plants has two designs: one design has the start-up transformers providing offsite power from the switchyard during normal operation and outages, and the other design has unit auxiliary transformers (during power operation) and a main transformer (during outage) energizing the safety buses from the switchyard. These system structures are generally the same as those used in the American nuclear industry. In addition, the same design concept is used for the power grid system, which should have redundancy in order to manage a single failure. Therefore, the application of the Bayesian-updated LOOP frequency, which was created through updating KHNP's experiences with the NUREG/CR-6890 data, to the PSA can be an effective method of reducing uncertainty due to the small size of the data set. Figure 1 presents a specific LOOP frequency that was created through the Bayesian update based on the NUREG/CR-6890 using BURD [5]. The previous LOOP frequency was 3.19E-2 per year and the new LOOP frequency using the NUREG/CR-6890 is 2.98E-2 per year. The affected CDF was reduced from 1.09E-6 per year to 1.05E-6 per year (4.1%) after this result was applied to the PSA model.

Table I. Loss of offsite power experiences at critical power.

| NO | Date | Description | Cause | Duration |
|---|---|---|---|---|
| 1 | Aug. 28, 1986 | SUT 'A'/'B', MOT trip | Typhoon | 7.67 |
| 2 | July 15, 1987 | T/L failure | Severe wind | 0.03 |
| 3 | July 15, 1987 | T/L failure | Severe wind | 0.03 |
| 4 | July 16, 1987 | T/L failure | Typhoon | 0.65 |
| 5 | July 17, 1987 | SUT flashover | Typhoon | 9.22 |
| 6 | July 17, 1987 | SUT flashover | Typhoon | 9.22 |
| 7 | Jan. 01, 1997 | 345 kV T/L failure | Heavy snow | 0.47 |
| 8 | Jan. 01, 1997 | 345 kV T/L failure | Heavy snow | 0.47 |
| 9 | Apr. 19, 2011 | SUT failure during maintenance | Human error | 0.83 |

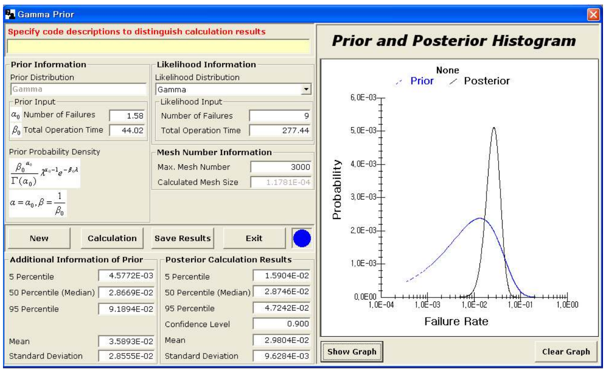


Fig. 1. Bayesian update of the LOOP frequency using BURD.

2.2 Non-recovery Probability after a LOOP

The EPRI document [2] reviewed 11 power recovery histories after LOOP events from 1975 to 1990 and fitted them to the Weibull distribution in order to extract the non-recovery probability based on time. NUREG/CR-6890 fitted a number of recent operating experiences during critical operations from 1986 to 2004 to the lognormal distribution. However, nine domestic LOOP experiences during critical operations were not sufficient in order to fit the data to a certain distribution. Furthermore, although few recurring events occurred because KHNP reduced the switchyard vulnerabilities after experiencing two concurrent LOOP events for 9 hours due to a typhoon in 1987, these two long-term events primarily affected the determination for KHNP-specific non-recovery probability after a LOOP. Therefore, 63 LOOP events in the USA and 9 LOOP events in Korea were integrated in order to create a new non-recovery probability after a LOOP (Fig. 2). The new non-recovery probability could reduce the uncertainty of the small size of the domestic data and to include effects due to other types of switchyard equipment failures and human errors. Therefore, the non-recovery probability within 9.5 hours was reduced from 5.60E-2 to 4.67E-2 (16.6%) through this approach using a wider data set containing historical data in both countries. This new non-recovery probability during the SBO lowered the previous CDF from 1.09E-6 per year to 9.86E-7 per year (9.6%).

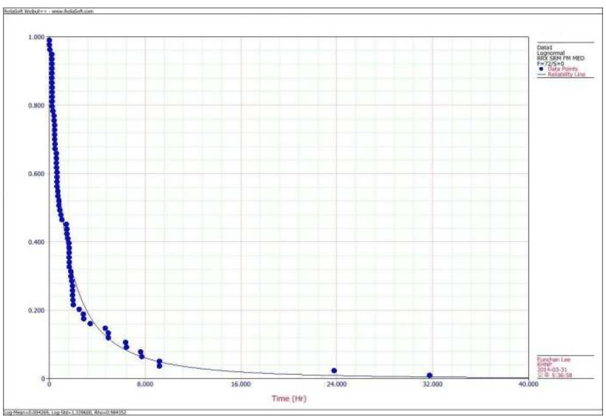


Fig. 2. Offsite power recovery failure probability curve using NUREG-6890 data and domestic experiences.

2.3 Battery Capacity

The battery capacity for new plants will support 16 or more hours of duty time, which is double the previous capacity. The MAAP analysis demonstrates that a steam generator (S/G) dries in 65,708 seconds (18.25 hours) after an SBO occurs without actions. This indicates that a new case with the improved battery approximately doubles the available time for operator countermeasures compared with the base case with an 8-hour battery capacity in which the S/G dries in 35,733 seconds (9.9 hours) after an SBO. This study analyzed a new case in which the operators recovered offsite power within 18 hours considering the improved battery. The resultant CDF decreased from 1.09E-6 per year to 5.57E-7 per year (48.9%). This indicates that the effect of the SBO initiating event can be reduced in the current unbalanced CDF profile of new plants.

## 3. Conclusions

For newly constructed KHNP plants, the LOOP frequency and non-recovery probability after a LOOP during an SBO were re-evaluated through integrating the KHNP events into generic data containing broader experiences for PSA. For an initiating event frequency, a new LOOP frequency was calculated through a Bayesian update of the KHNP LOOP frequency using NUREG/CR-6890, which reflects the recent trends and has a large data size. For the non-recovery probability estimation, domestic data were added to the American experiences in the NUREG/CR-6890; these data were fitted to a lognormal distribution in order to reduce the uncertainty due to the small size of the KHNP data. Regarding the battery capacity enhancement, the success criteria during an SBO were re-evaluated considering the longer battery duty time. The CDF was recalculated using the resultant available time for operator action. The changed CDF was reduced by approximately 50% compared with the value before battery improvement.

In conclusion, it was quantitatively proven that enlarging the battery capacity to manage SBOs positively affected plant safety. In addition, methods to improve data uncertainty due to the small number of experiences were selected in order to evaluate the LOOP frequency and non-recovery probability after a LOOP for future plants. These efforts contribute to obtaining a realistic risk profile and to prioritizing countermeasures and improvements of vulnerabilities for safety.

## REFERENCES

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