Improvement Measures for Power System Reliability through the Analysis of Loss of Offsite Power Events

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1. Introduction

A stable and reliable power supply is essential for the safe operation of nuclear power plants (NPPs). In particular, off-site power to Class 1E electrical systems must be secured not only during normal operation but also under accident conditions.

A loss of offsite power (LOOP) event refers to the complete interruption of the external power supply to a plant. If the emergency diesel generator (EDG) fails during a LOOP, the situation may escalate into a station blackout (SBO), potentially leading to severe accidents. [1] Both domestic and international experience confirm that LOOP events can be caused by a wide range of factors, including equipment failures, weather-related events, grid disturbances, and human errors. The 2011 Fukushima accident, initiated by an SBO, underscores the critical importance of managing power supply systems in NPPs.

This study analyzes LOOP events in domestic NPPs and proposes improvement measures to enhance the reliability of electrical power systems.

2. LOOP Analysis

In this study, both quantitative and qualitative analyses were conducted on LOOP events that have occurred in domestic NPPs. The analysis covers the entire operating history from the commencement of commercial operation through December 2024.

The LOOP events were classified and analyzed by plant type, causal category, and plant operational status. For this purpose, operational data and failure reports from the Operational Performance Information System (OPiS) of the Korea Institute of Nuclear Safety were utilized. [2]

2.1 LOOP Events by Plant Type

Domestic nuclear power plants (NPPs) can be broadly classified into standardized and non-standardized types. Standardized NPPs are built on domestic standard designs such as the OPR-1000, whereas non-standardized NPPs are based on early imported foreign reactor designs.

Plants with relatively high LOOP frequencies are highlighted in [Table I, II]. Most of these were non-standardized NPPs, among which certain units (e.g. K1, W2, Y2) exhibited particularly high frequencies. In contrast, all plants with no recorded LOOP events were standardized NPPs.

Table I: LOOP Frequency in Standardized NPPs
* rcy: reactor calendar year

Plant	Years (rcy*)	LOOP Events	Frequency (/rcy)
K5	13.85	1	7.22.E-02
K6	12.46	1	8.03.E-02
K7	8.04	-	-
K8	5.35	-	-
W5	12.43	-	-
W6	9.45	-	-
Y3	29.78	1	3.36.E-02
Y4	29.02	2	6.89.E-02
Y5	22.63	1	4.42.E-02
Y6	22.04	-	-
U3	26.41	-	-
U4	25.02	1	4.00.E-02
U5	20.44	1	4.89.E-02
U6	19.71	1	5.07.E-02
U7	2.07	-	-
U8	0.74	-	-
Total	**259.40**	**9**	**3.47.E-02**

Table II. LOOP Frequency in Non-standardized NPPs
* Permanently Shutdown

Plant	Years (rcy)	LOOP Events	Frequency (/rcy)
K1*	39.16	9	2.30.E-01
K2	41.47	3	7.23.E-02
K3	39.28	3	7.64.E-02
K4	38.70	2	5.17.E-02
W1*	36.02	2	5.55.E-02
W2	27.52	3	1.09.E-01
W3	26.52	2	7.54.E-02
W4	25.27	1	3.96.E-02
Y1	38.38	2	5.21.E-02
Y2	37.59	5	1.33.E-01

U1	36.33	1	2.75.E-02
U2	35.28	3	8.50.E-02
Total	**421.52**	**36**	**8.54.E-02**

Table III. LOOP Frequency by Plant Type

Plant Type	Years (rcy)	LOOP Events	Frequency (/rcy)
Standard	259.40	9	3.47.E-02
Non-standard	421.52	36	8.54.E-02
Total	**680.92**	**45**	**6.61.E-02**

The results indicate that the LOOP frequency in non-standardized NPPs is approximately 2.5 times higher than that in standardized NPPs. This finding demonstrates the reliability advantage of standardized NPPs in terms of power supply systems.

2.2 LOOP Events by Category

According to NUREG/CR-6890, LOOP events are categorized into four groups: plant-centered, switchyard-centered, grid-related, and weather-related. [3] However, the analysis of domestic LOOP events in revealed that a significant portion was attributable to human error. Accordingly, this study treated human error as a separate category, independent of the four classifications suggested in NUREG/CR-6890.

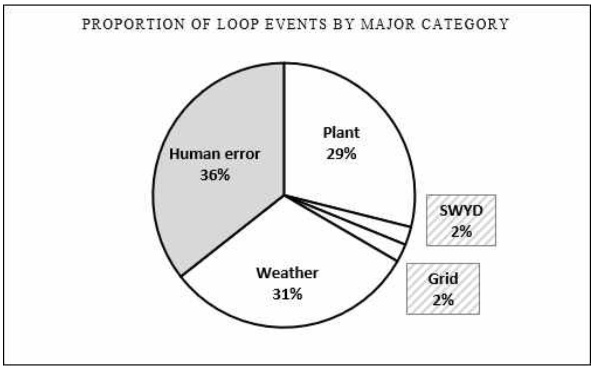

Fig. 1. Proportion of LOOP events

As shown in [Fig. 1], LOOP events in domestic NPPs were classified into five categories. The results indicate that human error accounted for approximately 36% of the events. In contrast, LOOP events caused by failures in the switchyard or the grid were extremely rare, which demonstrates that the reliability of the domestic off-site power system is at a relatively high level.

According to [Table IV], plant-centered events accounted for 13 cases (29%) of the total LOOP events. Among these, circuit breaker failures in the electrical field represented the predominant cause, most of which occurred in non-standardized plants. In contrast, in the instrumentation field, all four cases were attributable to plant control card malfunctions, which were observed exclusively in standardized plants.

Weather-related events accounted for 14 cases (31%) of the total, and these showed distinct regional characteristics. Most wind-related events occurred in the Kori region in southeastern Korea. This finding suggests that the area is particularly vulnerable to typhoons. In contrast, all wildfire-induced events were reported in the Ulchin region in northeast. This can be attributed to the fact that the forest density in the Ulchin area reaches approximately 85%, far exceeding the national average of 62%. [4]

Table IV. Detailed breakdown of LOOP events

Major	LOOP	Sub	LOOP	Detailed	LOOP
Plant	13	Elec.	9	C.B.	5
				Relay	2
				Cable	2
		I & C	4	Card	4
SWYD	1	-	-	Lightning	1
Grid	1	-	-	Sub station	1
Weather	14	Typhoon	11	-	-
		Wildfire	3	-	-
Human error	16	Main-tenance	12	Ry. test	4
				Ground fault	4
				Ect.	4
		Oper-ation	4	C.B. mis operation	4
Total	45	-			

Human error events accounted for 16 cases (36%) of the total. Among the maintenance-related cases, protective relay testing was the single most frequent activity, while all four operation-related cases resulted from circuit breaker misoperations.

2.3 LOOP Events by Plant Status

LOOP events were further analyzed according to plant operational status. Events that occurred during shutdown were denoted as LOOP-SD, those during operation accompanied by a reactor trip as LOOP-IE, and those during operation without a reactor trip as LOOP-NT. [3] Based on this classification, domestic nuclear power plants experienced 15 LOOP-SD cases, 20 LOOP-IE cases, and 10 LOOP-NT cases.

Table V. LOOP events by plant status

LOOP Events	LOOP-SD	LOOP-IE	LOOP-NT	Total
	15	20	10	45

Among the total of 45 LOOP events, 30 occurred during operation and 15 during shutdown. Notably, during shutdown, human error accounted for approximately 60% of the events.

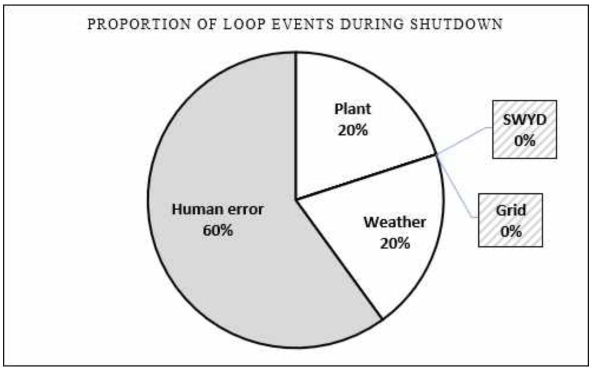

Fig. 2. Proportion of LOOP events during shutdown

Most LOOP events caused by human error during shutdown were attributable to maintenance activities. This is likely because the majority of tasks during planned outages involve equipment inspection and maintenance. In particular, a considerable proportion of maintenance-related human errors occurred during protective relay testing, highlighting this as a critical risk factor requiring focused management during shutdown periods.

3. Reliability Improvement Measures

Based on the analysis of LOOP events in nuclear power plants, this section proposes measures to enhance the reliability of electrical power systems.

First, for plant-centered causes, the reliability of circuit breakers and plant control cards should be improved through equipment upgrades and strengthened inspection procedures.

Second, regarding weather-related factors, the Kori region requires countermeasures such as replacing overhead transmission lines with gas-insulated bus (GIB) systems and reinforcing and securing structures against typhoons. In contrast, the Ulchin region requires forestry management around transmission lines to mitigate wildfire risk.

Third, for human error prevention, in the maintenance field, strict compliance with protective relay testing procedures and improved understanding of system protection zones are necessary. In the operations field, adherence to human error prevention techniques such as concurrent and independent verification, as well as enhanced training and education, should be emphasized.

4. Conclusions

This study aimed to derive improvement measures for enhancing the reliability of electrical power systems in NPPs through an analysis of domestic LOOP events. Based on the findings, three key strategies were proposed in Chapter 3.

The results are expected to contribute not only to improving the reliability of electrical power systems in domestic NPPs, but also to reducing the Core Damage Frequency (CDF).

Future research should quantitatively evaluate the effectiveness of the proposed measures and conduct comparative analyses with international cases to establish more universal strategies for strengthening power system reliability.

REFERENCES

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