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Analysis of loss of off-site power events for Korean nuclear power plants

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ABSTRACT : This paper presents the analysis results of Loss of Off-Site Power (LOSP) events in Korean Nuclear Power Plants. Three complete LOSP events occurred during 64.5 reactor years in Korea, which were caused by Typhoons. The event frequency is estimated as 0.047/Rx-yr. It also describes the insights that come from the analysis and the suggestions for reducing the frequency of LOSP event.

1 INTRODUCTION

According to the results of several Probabilistic Safety Assessments (PSAs) in Korea and other countries, LOSP event is known as one of the dominant contributors to the plant risk. The most severe event, station blackout also starts from the LOSP initiating event, which is no AC power source in the site. In case of Kori units 3&4 PSA, almost 70% of core damage frequency caused by internal events is initiated by LOSP. Therefore the estimation of LOSP event frequency is very important to the quality of the final plant risk estimation. Since the LOSP event completely depends on the switchyard configuration and plant site, plant specific data is essential to estimate the plant risk.

The LOSP event is defined as loss of power supply to safety buses from off-site power grid. If all off-site power supply paths are lost, it is called a total LOSP that is of the greatest interest. If all emergency diesel generators are unavailable in the total LOSP situation, it is called a station blackout that has a most considerable potential hazard to the plant safety.

This paper describes the development of a database and the analysis results for LOSP events in Korea(Kim 1993). All LOSP events occurred in Korea are classified into 5 different event types and corresponding frequencies are estimated. It also summarizes the insights which come from the analysis and the suggestions for design modification.

2 POWER DISTRIBUTION SYSTEM

This section describes generally how the power supplies for plant loads are configured. This is useful to understand the events that are described later. Power distribution system of Korean Nuclear Power Plants (NPPs) can be widely categorized into two groups. One type is a plant that has one 345KV switchyard such as Kori units 3&4, Yonggwang units 1&2,

and Ulchin units 1&2. The other type of plants like Kori units 1&2 and Wolsong unit 1 can be supplied power from either 345KV or 154KV switchyard. However, there are some variations in configuration within a same type power distribution.

When plant is operating, most plant loads are fed from Unit Auxiliary Transformers (UATs) which are supplied power from the unit generator. Whenever the main generator is tripped, those plant loads are automatically transferred to the Unit Startup Transformers (USTs) which are powered from off-site grid. Some unit has a Generator Load Breaker System (GLBS), so that whenever there is an internal problem of the unit all plant loads can be fed from 345KV switchyard through main transformer and USTs by breaking the unit generator.

For safety related buses that is designed to be isolate physically and separate electrically, two types of design are used in Korea. First one such as Kori units 1&2 and Wolsong unit 1, all safety related loads are connected to main generator during normal operation. Whenever the plant trips, safety buses are automatically transferred to the off-site gird via USTs. The other type has a configuration of which all safety buses always connect to the off-site grid directly through one 345KV switchyard. All safety related loads are fed from 345KV switchyard through two USTs in every operation phase.

Under any circumstance, if all off-site power is lost and the safety related buses become deenergized, the Emergency Diesel Generators (EDGs) automatically start and power them.

3 CATEGORY CRITERIA OF THE EVENT

To get the event data, all event reports and operational documentation of every NPP were surveyed from 1978 initial operation of Kori unit 1 to the end of 1993. Events are classified into five categories that were defined in NSAC-182(Wyckoff 1992). The categories are;

- Ia. No off-site power available for 30 minutes or longer and the unit trips off or is off-line
- Ib. No off-site power available for less than 30 minutes and the unit trips off or is off-line
- II. Loss of startup(or shutdown or backup) off-site power but if on-line, the main generator generator connected to the normal off-site system and the plant received power from the UATs, or even if the main generator trips off, the GLBS operate successfully and plant loads are fed from the normal off-site system via main transformer and UATs.
- III. Loss of normal off-site power (and loss of feed through the unit auxiliary transformer) but backup off-site power is available via a startup, shutdown or reserve source by automatic switching or manual switching from the control room. A loss of unit auxiliary power that is caused by a unit trip is not a category III event. To be a category III event the loss of power must be the initiating event.
- IV. No off-site power available during cold shutdown because of special maintenance conditions that do not occur during or immediately following operation.

Category Ia and Ib represent a true total loss of off-site power event. Events in category Ia, losses that last 30 minutes or longer, are of the greatest interest and have a considerable potential hazard to the plant safety. While category Ib in most instances have lesser safety significance. If power is available via switching from the control room but requires a short time interval for operator action, the event is usually classified to a category II or III event, even though there are complete loss of off-site power. Where for the short interval, power is unavailable to the operator, it should be considered a Ib event.

Categories II or III is a partial loss of off-site power event occurred during full power operation, while category IV is a total loss of off-site power during cold shutdown.

4 SURVEY AND ANALYSIS OF LOSSES OF OFF-SITE POWER EVENTS

4.1 *Complete loss of off-site power (category Ia and Ib)*

Three complete losses of off-site power events occurred during 64.5 reactor years in Korea. Two events were in Kori unit 2 and one was in Kori unit 4. Two of them lasted longer than 30 minutes and other was less than 30 minutes. All three events occurred because of typhoons that pass frequently through Korean peninsula during summer season. Specially Kori and Wolsong site are located in the southern seashore so that those sites are directly effected by the typhoons. Salt spray or thunderbolt onto switchyard or transformer insulators during the typhoon have directly caused flash over of the power distribution system and resulted in complete loss of off-site power.

Additional one event was in Kori unit 1, which was resulted from the system disturbance caused by flash over on the UST of Kori unit 2. This event does not counted for complete loss of off-site power because the event lasted less than one minute and reactor was shutdown before it.

Two events of Kori unit 2 occurred during one typhoon. After recovering from first loss of off-site power event, second event occurred about 18 hours later. Each event was counted as a separate event based on consideration of its potential safety significance.

The event occurred in Kori unit 4 due to a typhoon was lasted 7 hours and 40 minutes. Two EDGs were the only AC power source to plant safety systems during that period. At that time, loss of off-site power event also occurred in Kori unit 3 that had been in overhaul maintenance stage. Because one EDG was disassembled for maintenance, the other one EDG met all plant loads during 12 hours. This event is classified into category IV event.

Total accumulated reactor years are 64.5 so that the LOSP frequency in Korea is estimated as 3/64.5Rx-yr = 0.047/Rx-yr. As shown in Table 1, the event frequency of US is 0.036/Rx-yr(Wyckoff 1992).

4.2 *Partial loss of off-site power (category II, III and IV)*

Total 19 partial loss of off-site power events occurred during 64.5 reactor-years. These events occurred by not only direct off-site gird lose but also electric system disturbances caused by other unit or substation trips. Table 1 summarizes the event frequencies regarding to each category of partial LOSP event.

There were ten partials LOSP in Kori unit 1, two events in Kori unit 2 and 3 respectively. One was in Kori unit 4, three in Wolsong unit 1 and one in Yonggwang unit 2 respectively. According to the event classification, 19 events can be classified into follows; 3 events for category II, 14 events for III, and 2 events for IV respectively. More than 50% of all partial LOSP events occurred in Kori unit 1. This is caused by the relatively old design, long operational history and unstable of the grid network in the initial operation period.

There were two LOSP events during plant overhaul. The event of Kori unit 3 on Aug. 28 of 1986 lasted over 12 hours under one EDG maintenance condition, so that just one EDG had to meet the unit loads during that time. This event might affected significantly to the plant safety because the EDG was the only one available power source to remove the residual heat of the reactor during 12 hours.

4.3 *Event cause analysis*

The causes of LOSP event can be categorized as plant-centered, grid-related, and weather-related event(Baranowsky 1988). A LOSP event caused by mechanical failure, design deficiency or human error would be categorized as a plant-centered event. And a LOSP event due to the random disturbance of grid network or regional severe weather, such as typhoon, heavy rain or snow, could be classified into grid-related or weather-related event respectively. Table 2 summarizes the all LOSP events according to their causes.

There were three experiences of complete LOSP event in Korea, all of which occurred due to typhoons. Direct causes of the events were proved as a salt spray or a lightning on the electrical equipment rather than strong wind itself. Total 17 partial LOSP occurred during plant operation, 11 of them were caused by grid disturbance and others by severe weather. There was no plant-centered LOSP in that event history. Two LOSP events were during plant overhaul, one was caused by typhoon and the other due to grid disturbance.

In the 9 grid-related events, 3 events occurred by mechanical faults in nearby substations and other 6 events were due to breaking or grounding of a transmission line.

In Korea, weather-related events can be divided into two separate gròups according to a type of weather, a typhoon related or other type of severe weather like squall, heavy rain and snow. As mentioned above, typhoon was a cause of all three complete LOSP and four partials LOSP events. There were also three partials LOSP experiences due to other type of severe weather.

4.4 *Recovery time analysis*

There are many variations in recovery time. While plant-centered LOSP events are usually not of long of duration, LOSP events that are caused by severe weather have a potential for longer duration. According to the LOSP event history in Korea, that was true. All three complete LOSP events were caused by typhoons, and their duration was 8 minutes, 39 minutes, and 7 hours and 40 minutes. The recovery times of partial LOSP events must had been short according to the documents described those events. However, partial LOSP events could not be incorporated in the recovery time analysis because of insufficiency of recovery time data.

Using above three recovery time data, the following distribution parameters are estimated based on the assumption of log-normal distribution.

5 % : 3.4 min., 50 % : 52.0 min., 95 % : 765 min. (12h:35m)
Error Factor : 15

The derived log-normal distribution become clear to be fit to the experience data. However, as would be expected from the error factor 15, there are lots of uncertainty in the estimated parameters due to the scant of data.

Table 1. Frequency of Total and Partial LOSP events in Korea and USA

Event types	Korea (Total Rx years : 64.5)		USA (Total unit years : 1089.6)*	
	# of events	Freq.(Rx-yr)	# of events	Freq.(Rx-yr)
Ia (> 30 min.)	2	3.1E-2	24	2.2E-2
Ib (< 30 min.)	1	1.6E-2	15	1.4E-2
Sub total	3	4.7E-2	39	3.6E-2
II	3	4.7E-2	6	5.5E-3
III	14	2.2E-1	30	2.8E-2
IV	2	3.1E-2	18	1.7E-2
Sub total	19	2.9E-1	54	5.0E-2

* 1980 through 1991

Table 2. Causes of LOSP events

Cause type	Detailed Cause	Partial LOSP		Total LOSP		Total
		Normal operation	Shut-down	Normal operation	Shut-down	
Grid-related	Electric shock	6	1	0	0	11
	Service station	4	0	0	0	
Weather-related	Typhoon	4	0	3	1	11
	Others	3	0	0	0	
Plant- centered		0	0	0	0	0
Total		17	1	3	1	22

5 *Discussion on site and unit basis*

All complete LOSP events were in Kori site, and caused by Typhoons. During summer season, several typhoons used to pass Kori and Wolsong sites that are located in the southeast coast. Four units at Kori site and one unit of Wolsong site were usually affected at the same time by one typhoon. Typhoon 'Vera', on Aug.28 of 1986, affected Kori unit 3 and 4 simultaneously, and one year later, from July 15 to 17 of 1987, typhoon 'Selma' hit the all four units of Kori site at the same time. Wolsong unit 1 had also experienced a partial LOSP due to a typhoon 'Diana' on Aug.31 of 1987.

Kori unit 1, which is the first NPP built in Korea, had experienced 10 partial LOSP events that were over 50% of total partial LOSP events in Korea. Most events occurred by grid disturbances rather than typhoons. In case of Kori unit 1, whenever the main generator trips off, all safety related buses are designed to transfer to 154KV switchyard and could not be fed from 345KV switchyard. Therefore it needs to modify the power distribution system as follows to reduce the LOSP frequency. First one would be to add GLBS after main generator, then 345KV off-site power could be used after cutting off the generator. Second is changing the connection method of 154KV transmission line to 1.5 isolator could be one design improvement(Kang 1994).

Kori unit 3 and 4 lost all off-site power sources at the same time on Aug.28 of 1986 as an influence of typhoon 'Vera'. At that time, Kori unit 3 was under overhaul maintenance. That LOSP event lasted over 7 hours at unit 4 and 12 hours at unit 3 respectively, so that associated EDGs, two EDGs for unit 4 and one EDG for unit 3, had to supplied power to safety buses until the recovery of off-site power. During the typhoon 'Selma' on July 16 of 1987, both units lost startup off-site power source, which is category II, and EDGs powered associated safety buses until the recovery of the off-site power. Several items could be considered as design improvements. First one is to add GLBS after main generator and add connection line between safety buses and UATs, then 345KV off-site power could be used for safety buses after cutting off the generator. Considering that most LOSP event of Kori unit 3 and 4 occurred by typhoon, to set up insulator cleaning system could be one of the most economic design modification to reduce the LOSP frequency.

To add additional AC power sources as another EDG or gas turbine generators would be a fundamental design upgrade for all units of Kori site in a viewpoint of plant safety.

5 CONCLUSIONS

Considering that the risk contribution caused by LOSP event is very high, the event frequency based on plant specific history is very important to the quality of the final plant risk estimation. All kinds of LOSP events for Korean NPPs are surveyed and analyzed for PSAs. Three total LOSP events have occurred during 64.5 reactor years and the event frequency of total LOSP is estimated as 0.047/Rx-yr.

In order to reduce the LOSP events, several suggestions are issued for each plant site. For Kori site, to install an additional EDG and to set up a procedure for typhoons are strongly recommended to keep the plants from the potential hazard caused by LOSP events.

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