The Effectiveness of EDG cross-tie in Single-unit SBO for Risk Reduction in Low Power and Shutdown Operation

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1. Introduction

It was believed that the risk of low power and shutdown (LPSD) was not significant because the core decay heat level is very low. But it was found that the risk of LPSD would not be ignorable comparing to that of full power according to the USNRC investigation. On the following, USNRC GL 88-17 [1] and NUMARC 91-06 [2] were issued by USNRC and the industry to implement programmed enhancements for LPSD.

The Korean Advanced PWR (e.g. APR1400) has various advanced safety features and the risk for full power is low. But the risk for LPSD presented NUREG/CR-6144 [3] is relatively high comparing to that of full power despite the much lower level of the decay heat. The reasons are that the most channels of Engineered Safety Features Actuation Signal (ESFAS) are bypassed during MODE 5 and the supporting systems are considered to be in maintenance with the related major systems. So, this paper discusses the appropriate method to reduce the overall risk associated with all MODES to deal with the LPSD risk.

The process performs the conceptual level design for the alternative and the sensitivity analyses associated with the design alternative are performed.

2. Characterization of LPSD operation

2.1 Identification of Plant Operational State (POS)

According to the plant configuration in planned refueling outage, plant operational states (POSs) are defined and characterized.

The six operating MODES are defined in technical specification. The six operating MODES are not enough to define the characteristic of each POS. The six operating MODES are divided into 15 POSs according to the Reactor Coolant System (RCS) water level, RCS opening (pressurizer manway, SG manway), and maintenance schedule of major systems. On the following, POSs will cover the LPSD evolution from full power operation to refueling conditions.

2.2 Significant Initiating Event for LPSD operation

NUREG/CR-6144 [3] provides a shutdown PRA for Surry Unit 1 in 1994. It provided the results of accident progression analysis and Plant Damage States (PDS) analysis for LPSD Level 2 PRA. In the Level 2 PRA, risk metric is Large Release Frequency (LRF) that is included containment bypass, early/late containment failure, containment failure before reactor vessel breach, and containment isolation failure. The Human Error grouped by PDS is the most significant risk contributors as initiators in LPSD operation modes. And next significant risk contributor is station blackout (SBO). These initiators contribute to containment isolation failure and early containment failure. The accidents that bypass the containment (such as SGTRs or interfacing systems LOCAs) were not included because the configuration of the plant precludes such events.

2.3 The Analysis Results in Base Case

According to the Table I and II, the result of LPSD Level 2 PRA for Advanced PWR shows that the most risk metrics are concentrated on the associated drain and Mid-loop operation such as POS4B ~ 6, POS10 and the Multi/Single-unit SBO. In terms of the LPSD initiating events, Multi and Single-unit SBO are the most significant because some of AC sources (e.g. EDG or UET/SAT) might not be available since the component maintenance activities.

Table I: LRF for each POSs (Base Case)

POS No.	LRF Contribution (%)
POS03A	4.1
POS03B	20.4
POS04A	0.4
POS04B	9.0
POS05	14.3
POS06	36.5
POS10	13.6
POS11	0.2
POS12A	0.0
POS13	1.5
Sum	100.0

Table II: LRF for each I.E. (Base Case)

Initiating Event	LRF Contribution (%)
Multi-unit Station Blackout	45.3
Single-unit Station Blackout	35.8
Unrecoverable LOCA	7.0
Over-Drainage During Reduced Inventory Operation	3.6
Loss of Offsite Power	2.8
Loss of 4.16 kV AC Bus	2.2
Recoverable Loss of SCS	1.5
Others	1.9
Sum	100.0

3. Design Alternatives

The design alternatives provide additional safety functions to mitigate accidents during LPSD operation modes. The design effectiveness is evaluated by the sensitivity analyses with the related risk parameters.

3.1 Design alternatives

In the domestic NPPs, Emergency Diesel Generator (EDG) cross-tie is not considered with any plant operation mode based on Technical Specification 3.8.2. But in this study, the modeling of EDG cross-tie is considered assuming that there is no limitation of plant status for a donor unit which means that any operating modes for a donor unit are allowed for EDG cross-tie. As a result, it is considered in POS 3A to 13 for single-unit SBO event. In case of multi-unit SBO condition, EDG unit cross-tie is not credited because donor unit has not enough AC sources to provide target unit.

This design alternative is modelled to include failure of operator action to align EDG cross-tie and EDG failure in other unit. It prevents the electric power loss during SBO scenarios with AAC DG failure.

3.2 Sensitivity analyses results for design alternatives

Sensitivity analyses are used to evaluate the effectiveness of the proposed design alternatives. The effectiveness of the design alternative is interpreted based on the results of the sensitivity analyses.

The alternative for sensitivity is mainly effective for SBO because EDG of a donor unit performed when AAC DG failed.

The sensitivity 1 has assumed EDG cross-tie may be possible in POSs 3A, 3B, 4A and 13. It is considered that available time for operator is enough to perform EDG cross-tie during above POSs only. The sensitivity 2 has assumed that EDG cross-tie may be possible in POSs 3A through 13 (no limitation for available time).

As a results, the total LPSD LRF (Large Release Frequency) in case of sensitivity 1 is reduced to 4.7% whereas that of sensitivity 2 is reduced to 21.5% from its Base Case value. The LRF reduction due to design alternative for each POS and I.E (Initiating Event, i.e. SBO) are summarized in Table III and IV, respectively.

Table Ⅲ: LRF reduction due to design alternatives for each POS

POS No.	LRF (%) comparing to Base Case	
	Sensitivity 1	Sensitivity 2
POS03A	0.0	0.0
POS03B	-24.2	-24.2
POS04A	-19.2	-19.2
POS04B	0.0	-26.4
POS05	0.0	-18.1
POS06	0.0	-25.7
POS10	0.0	-18.3
POS11	0.0	-19.3
POS12A	0.0	-21.3
POS13	0.0	0.0
Sum	-4.7	-21.5

Table IV: LRF reduction due to design alternatives for each I.E.

Initiating Event	LRF (%) comparing to Base	
	Sensitivity 1	Sensitivity 2
Multi-unit Station Blackout	0.0	0.0
Single-unit Station Blackout	-13.0	-60.1
Unrecoverable LOCA	0.0	0.0
Over-Drainage During Reduced Inventory Operation	0.0	0.0
Loss of Offsite Power	0.0	0.0
Loss of 4.16 kV AC Bus	0.0	0.0
Recoverable Loss of SCS	0.0	0.0
Others	0.0	0.0
Sum	-4.7	-21.5

4. Conclusion

This paper proposes design alternative to reduce LPSD risk for Advanced PWR design. The sensitivity analyses have been performed to measure the effectiveness of the proposed alternative. According to the results, if EDG cross-tie is available during all POSs, it is very effective to reduce LPSD risk. So, EDG cross-tie needs to be designed to reduce the risk during electric power loss such as SBO scenarios. And plant specific procedure and design change need to be prepared to perform the accident mitigating operation, such as EDG cross-tie within available time. In terms of sites, when one site has at least two units, crediting EDG cross-tie might be effective to reduce the site risk as well as unit risk.

REFERENCES

[1] USNRC generic letter No. 88-17, Loss of Decay Heat Removal, October 17, 1988.
[2] NUMARC 91-06, “Guideline for Industry Actions to Assess Shutdown Management,” December 1991.
[3] USNRC NUREG/CR-6144, “Evaluation of Potential Severe Accidents during Low Power and Shutdown Operations at Surry, Unit 1,” October, 1995.