리스크정보를 활용한 비상디젤발전기 허용정지시간 연장시 안전성평가

임혁순† · 김두현*

원자력발전기술원 · *충북대학교 안전공학과

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Safety Assessment for Emergency Diesel Generator(EDG) Allowed Outage Time(AOT) Extension using Risk-informed

Hyuk-Soon Lim† · Doo-Hyun Kim*

Reliability Engineering Team, Nuclear Engineering & Technology Institute

*Department of Safety Engineering, Chungbuk National University

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Abstract : In order to provide the necessary operation flexibility during the Nuclear power operation, the extension of existing allowed outage time(AOT) is needed. The extension of AOT affects the Nuclear power plant safety. The validity of changed technical specification requirements should be proved by the safety assessments. In this paper, we evaluated the extension of emergency diesel generator AOT for a single inoperable emergency diesel generator(EDG) from 3days to 7days, 10days and 14days. Finally, the AOT extension contributes the NPP performances through decreasing the unexpected plant trips, reinforcing maintenance and avoiding risks due to unnecessary operation mode changes when the NPP is under the surveillance tests or maintenance.

초 록 : 원자력발전소의 운전 유연성 증대, 안전성 및 경제성 향상, 정비 부담을 완화하기 위해 비상디젤발전기의 허용정지시간 연장이 요구된다. 확률론적안전성평가(probabilistic safety assessment) 기법으로 현재의 비상디젤발전기의 허용정지 시간을 3일에서 7일, 10일, 14일로 연장시 안전성 영향을 평가하였다. 종합적으로 평가결과, 비상디젤발전기의 허용정지시간 연장시 EDG 점검 또는 정비기간 중 인적실수으로 인한 발전소 불시정지 예방 및 안전성을 향상 시키는 것으로 분석되었다.

Key Words : risk-informed, diesel generator, allowed outage time, safety assessment

1. Introduction

Allowed outage time(AOT) was defined as the time for which a safety component can remain inoperable before a plant state is changed. AOT was determined based on deterministic analysis or engineering judgments. Recently, the result of probabilistic safety assessment(PSA) and the operating experiences of nuclear power plants(NPP) show that the AOT can be optimized. From the point of NPP utilities, AOT extension is desired for the avoiding unnecessary shutdown of NPPs and the flexibility of the NPP operation. In order to provide the necessary operation flexibility during the power operation, the extension of existing AOT is needed. The extension of AOT affects the plant safety. So, overall analysis and evaluation due to the risk changes should be performed. The validity of changed technical specification(TS) requirements should be proved by the assessments. In this paper, we examined the State of the Risk-informed and Emergency diesel generator(EDG) AOT extension, present established AOT methodology, also evaluated the extension of emergency diesel generator AOT for a single inoperable EDG from 3days to 7 days, 10days and 14days.

2. State of the safety and risk informed in KNPP

† To whom correspondence should be addressed.
lhs6169@khnp.co.kr

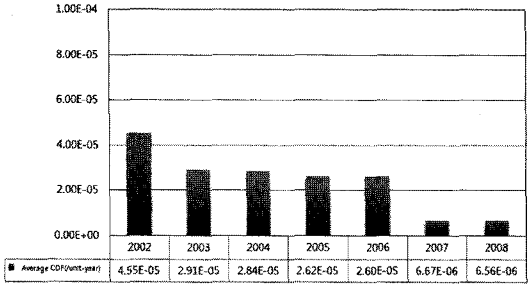

Fig. 1. KNPP average CDF trend from 2002 to 2008.

2.1. Safety and Performance Trends in KNPP

The primary risk metrics used today are core damage frequency(CDF) and large early release frequency (LERF). Fig. 1 illustrates the steady decline in average CDF at Korea Nuclear Power Plants(KNPP). This improvement has been driven by plant equipment reliability, performance improvements and PSA model improvements.

A nuclear power plant's capacity factor represents its health and operational confidence. The highest capacity factor at Korea Nuclear Power Plants(KNPP) was recorded as 95.5% in 2005. KNPP has endeavored to improve plant performance by minimizing refueling outages, optimizing maintenance, extending fuel cycles and enhancing safety. The average capacity factor at KNPP nuclear power plants increased from roughly 90% to about 93% between 1998 and 2008. Fig. 2 illustrates the capacity factor performance at KNPP.

2.2. State of the EDG AOT extension

Since the mid-80', utilities in the United States have been applying the risk-informed operation & maintenance based on PSA technology to the NPPs.

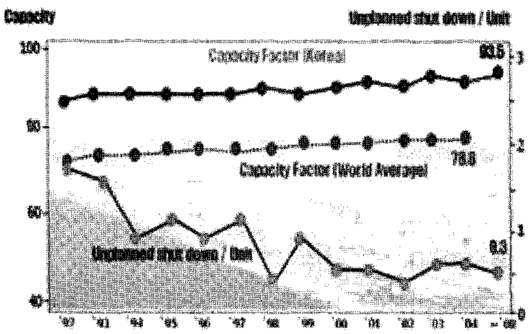

Fig. 2. Capacity Factor Performance at KNPP.

They successfully operated the NPPs through extensions of AOTs and surveillance test intervals(STI) for safety systems. The nuclear regulatory commission recommended utilities in the U.S. to reasonably improve T.S. requirements based on the plant risk by NUREG-1366 "Improvements to Technical Specifications Surveillance Requirements" issued in December 1992.

In 1998, the staff published the guidance of TS in RG 1.174 "an approach for using probabilistic risk assessment in risk-informed decisions on plant-specific changes to the licensing basis" and 1.177 "an approach for plant-specific, risk informed decision making : technical specification". According to this guidance, westinghouse owner's group(WOG) and CE owner's group(CEOG) have performed several studies of AOTs and STIs optimization.

Many NPPs have extended AOTs of safety injection tank(SIT), low pressure safety injection(LPSI), containment spray system(CSS) and EDG. Lately, risk-managed T.S. studies for high pressure safety injection(HPSI) system to extend the AOT until 30days are been lead by utilities. Table 1 illustrates the EDGs AOT extension in U.S. NPPs[1].

2.3. New Concept of Risk Managed Technical Specification(RMTS) Application

The established methodology of AOT extension evaluates risk changes due to technical specification(TS) changes by a deterministic and by a probabilistic method. The results should satisfy the defense in depth (DID) concepts, safety margin and the quantitative criteria. Then, evaluate the validity of changed risk due to the extension of AOT should be evaluated.

Table 1. EDGs AOT extension state of the U.S. NPPs

Description	D.C Cook		Beaver Valley		Calvert Cliffs		Millstone Unit 2
	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2	
Owner	I&M		FENOC		CCNPP		DNC
NSSS Provider	WH	WH	WH	WH	CE	CE	CE
Application date	SEP. 21, 2004		May 26, 2004		MAY 12, 2003		MAY 31, 2001
Issuance date	SEP. 30, 2005		SEP. 29, 2005		APR. 13, 2004		JAN. 04, 2002
Extension of AOT(days)	3→ 14	3→ 14	3→ 14	3→ 14	3→ 14	3→ 14	3→ 14

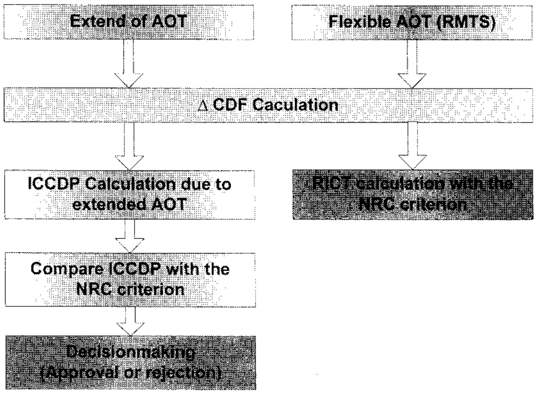

Fig. 3. Application process of AOT & RMTS extension.

The methodology of RMTS, which is making and managing the permissive Out-of-Service time, decides the completion time(CT is same as AOT) of TS as a risk criterion. Risk managed action Time(RMAT) means the time to perform the AOT extension action when the calculated risk(ICCDP) meets 1.0E-6. Risk informed completion time(RICT) means finishing the corrective maintenance when the ICCDP meets 1.0E-5 or maximum 30 days of maintenance(Table 2, Fig. 4).

Table 2. Risk managed technical specification thresholds

Criterion		RMTS Risk Management Guidance
CDF	**LERF**	
≥1.0E-3 events/yr	≥1.0E-4 events/yr	- Voluntary entrance into configuration prohibited-if in configuration due to emergency event, implementation appropriate risk management actions
ICCDP	**ICLERP**	
≥1.0E-5	≥1.0E-6	- Follow the tech. spec. requirements for required action not met
≥ 1.0E-6	≥1.0E-7	- RMAT and RICT requirements apply - Asses non-quantifiable factors - Implement compensatory risk management actions
< 1E-6	< 1.0E-7	- Normal work controls-no additional controls required

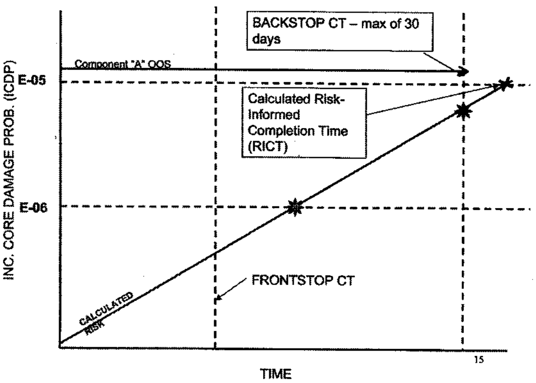

Fig. 4. New concept of risk managed technical specification extension.

Where

Completion time(CT) : Same as tech. spec. allowed outage time

Risk Management Action(RMA) : action taken to manage or mitigate further risk increase - must be implemented when risk reaches 1.0E-6, but can be implemented earlier

Risk Management Action Time(RMAT) : time at which RMAs are required to be implemented when calculated risk 1.0E-6 RMTS threshold

Risk Informed Completion Time(RICT) : when calculated risk reaches 1.0E-5 RMTS threshold-not allowed to exceed 30 days.

RMTS risk management thresholds are established quantitatively by considering the magnitude of the risk indicators for the plant configuration.

2.4. State of Risk-Informed Application in KNPP

2.4.1. Regulatory Body Requirements for RIA

Korean nuclear regulatory body specifies particular requirements during the review of PSAs and risk-informed applications.

- General scope : Level 1 and Level 2 PSAs.
- PSA technical adequacy : ASME Category 2.
- The quantitative targets of KINS GT/N-24 must be met.

2.4.2. KNPP Risk-Informed Application Status

KNPP try to focus on option 1 areas such as risk-informed integrated leakage rate test(RI-ILRT), risk-informed allowed outage time(RI-AOT), and risk-informed in-service inspection(RI-ISI). KNPP PSA models are adequately maintained for RIA and PSA above ASME Category 1.

· Containment integrated leakage rate test interval relaxation

The containment integrated leakage rate test(ILRT) interval can be relaxed to 10 years(it is currently 5 years)[2]. 11 plants have extended ILRT intervals. RI-

Table 3. State of risk-informed applications at Korea

Item	Status	Description
RI-ILRT	- 11 units extended out of 20 operating units (Kori 2~4, Yonggwang 1~4, Ulchin 1~4)	Test interval (5yr→10yr)
RI-AOT/STI	- K3,4/Y1,2 RPS/ESFAS STI extended in '99 - U3,4 RPS/ESFAS STI extended in '08 - U3,4 Class 1E Inverter AOT extended in '07 - U5,6 Battery STI extended in '08	
	Not submitted to regulatory agency - Y3~6/ U3,4 AOT study performed in '04 - K3,4/Y1,2 AOT study performed in '07	(Study only)
RI-ISI	- RI-ISI methodology established in '04 - RI-ISI methodology endorsed in '08	
PSA adequacy	- K3,4 peer review performed in '05 - K3,4 PSA model quality update('04~'06)	NEI00-02

ILRT benefits include fewer tests, lower personnel exposures, and increased plant availability and capacity factor due to shorter outages. Most plants will be able to reduce outage durations by one day and thus save millions of dollars. We are preparing to extend ILRT intervals for 5 plants: Kori unit 1, Yonggwang units 5&6, and Ulchin units 5&6.

· Technical specification optimization

Kori units 3 and 4 were evaluated for allowed outage time(AOT) based on their plant specific PSA results[3]. The extension of AOT met the criteria specified in R.G. 1.174 and 1.177.

· Risk-informed in-service inspection

RI-ISI is the alternative to the present ISI method(ASME Sec XI). This method requires tests for class 1 and class 2 welding points for 1 period(10 years). The RI-ISI method test was performed on risk significant piping and reduced test points while maintaining safety level. The RI-ISI method was endorsed by Korean nuclear regulatory body for use with OPR1000 plants in 2008[3]. The nuclear power plants in KNPP are partially engaged in a variety of risk-informed applications, as indicated in Table 1.

3. Methodology of the Risk Assessments

The evaluation of the "at power" risk increment result from the extended EDG AOT was evaluated in a plant specific basis using the most current individual plant PSAs for their respective baselines. Plant specific evaluations were performed by each participating utility. Results of these evaluations were them compared using the following risk measures.

· Average core damage frequency(CDF)

The average CDF represents the frequency of core-damage occurring. In a PSA, the CDF is obtained using mean unavailabilities for all standby-system components.

· Core Damage Probability(CDP)

The CDP represents the probability of core-damage occurring. Core-damage probability is approximated by multiplying core-damage frequency by a time period.

· Conditional core damage frequency(CCDF)

The conditional CDF is upon some event, such as the outage of equipment. It is calculated by re-quantifying the cutsets after adjusting the unavailabilities of those basic events associated with the inoperable equipment.

· Increase in CDF(△CDF)

The increase in CDF represents the difference between the CCDF evaluated for on train of equipment unavailable minus the CCDF evaluated for one train of equipment always available. For the EDGs :

$$\triangle CDF = \text{Conditional } CDF_{(1\ EDG\ unavailable)} - \text{Conditional } CDF_{(1EDG\ perfect)}$$

Where CDF = Core Damage Frequency(per year).

4. Emergency Diesel Generator AOT Assessment

The assessment of the plant specific PSA was performed to investigate the impact of the emergency diesel generator AOT on the plant risk. The analysis of PSA indicated that initial events frequencies, event/fault tree logics, system success criteria and component failure rates were unaffected. The search of the maximum extension of the EDG AOT was performed by increasing the EDG outage time assumption in the base model from 3 days(base case) to 7, 10, and 14 days, and calculating the incremental changes of the CDF and LERF. As shown in Table 5, the CDF and LERF were increased as the EDG AOT increased. The LERF in Table 5, however, did not exceed 1.0E-6/yr with △LERF less than 1.0E-7/yr, when the AOT was set to be 14 days[3].

Table 4. Base case risk assessment model

Description	Base model(3days)
CDF(/yr)	5.17E-06
LERF(/yr)	9.57E-07

Table 5. △CDF and △LERF sensitivity analysis results due to the changes of the EDG AOT

System	Items	Results(/yr)		
		7days	10days	14days
EDG	EGDGZ001MA	1.92E-02	2.74E-02	3.84E-02
	EGDGZ002MB			
	EGDGZ003MZ			
	Proposed CDF	5.47E-06	5.64E-06	5.87E-06
	Delta CDF	2.99E-07	4.71E-07	7.03E-07
	Proposed LERF	9.69E-07	9.77E-07	9.87E-07
	Delta LERF	1.25E-08	1.99E-08	3.00E-08

Table 6. ICCDP sensitivity analysis results on EDG AOT extension change

Systems	ICCDP		
EDG	7days	10days	14days
	2.53E-07	3.15E-07	3.97E-07

Table 7. ICLERP sensitivity analysis results on EDG AOT extension change

Systems	ICLERP		
EDG	7days	10days	14days
	1.14E-08	1.44E-08	1.83E-08

Table 6, 7 showed the results of incremental conditional core damage probability(ICCDP) and incremental conditional large early release probability (ICLERP). The ICCDP and ICLERP represent the changes of probabilities of the core damage and large early release due to the out-of-service of a particular equipment/system. According to the RG 1.177, the acceptance criteria for the equipment/system out-of-service are to be ICCDP < 5.0E-6, and ICLERP < 5.0E-7. Also, the acceptance domain for the change of CDF and LERF due to the increase of the out-of-service duration is represented in Fig. 5. Through Table 5, it was concluded that the △CDF and △LERF due to the EDG AOT extension up to 14 days were in the acceptance domain(Region III). Also, the ICCDP and ICLERP were found to meet the RG 1.177 acceptance criteria[4,5].

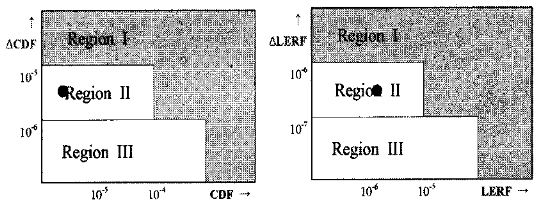

Fig. 5. Acceptance guidelines for △CDF and △LERF.

5. Conclusions

The unavailability of one EDG was found to not significantly impact the three cases events of the EDG outage time increasing from 3days to 7, 10, and 14 days AOT extension in the risk analyses. The possibility of the EDG AOT extension was performed by analyzing the changes of CDF, LERF, ICCDP, and ICLERP. Through the base case, the extension of the EDG AOT was found acceptable, meeting the criteria of RG 1.174 and RG1.177.

Consequently, the AOT extension contributes the NPP performances through decreasing the unexpected plant trips, reinforcing maintenance and avoiding risks due to unnecessary operation mode changes when the NPP is under the surveillance tests or maintenance.

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