Reliability Analysis of Diesel Generators of Wolsong Unit 1

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ABSTRACT

As a maintenance optimization project to improve the safety of Wolsong NPP (Nuclear Power Plant), reliability of diesel generators are estimated based on the operating experience, and improvement options are suggested. A reliability measure is suggested for the estimation of reliability for standby safety systems to reflect availability. It is assessed that the reliability of diesel generators can be much improved if the suggested improvement options are implemented.

Introduction

Korean government are going to urge for the utility to set up reliability target and reliability management program to achieve and maintain the high reliability for emergency diesel generators (EDGs) of nuclear power plant. If the reliability trend of emergency diesel generators of each plant has good performance, the utility burden caused by regulatory inspection and monitoring may be reduced. To derive the guide of reliability management program of standby diesel generators (SDGs) of Wolsong Unit 1 as a demonstration plant, reliability analysis is being performed based on 11 years operating data.

Since Wolsong Unit 1 is a Canadian style (CANDU type) NPP, it has additional two small diesel generators (1,000 kW each) in EPS (Emergency Power Supply System) other than SDGs (5,700 kW each). The current technical specification requirement for Wolsong SDG & EPS is to test SDG & EPS DGs every two weeks for 2 hours. SDGs are similar to EDGs of PWR except they are not seismic classes. If SDGs are not operable, EPS which has two seismic class diesel generators (DGs) can supply electricity to EWS (Emergency Water Supply) pumps of ECCS (Emergency Core Cooling System). Thus, reliabilities of EPS DGs as well as SDGs are estimated in the next section.

USA uses the reliability target of 0.975 and 0.95[1] in USA Station Blackout (SBO) Rule[2] of Federal Register. Recently, the importance of unavailability due maintenance has been issued[3]. That is, the unavailability due to maintenance which were estimated as 0.007 previously was recently identified to be increased to 0.04[3]. The unavailability due to maintenance which was negligible when SBO Rule was issued could not be neglected any more. The unavailability due to maintenance is also an important factor in evaluating performance of safety equipments. Therefore, a new reliability measure which can reflect the unavailability due to maintenance is suggested, and the reliabilities of SDGs and EPS DGs are estimated based on this new reliability measure.

This reliability measure is composed of availability, starting reliability, and load-run reliability. In other words, with an opposite concept, it is composed of unavailability due to test & maintenance, start failure probability, and load-run failure probability. To identify the factors which impact these three aspects, respectively, test-failure history and maintenance history are reviewed thoroughly.

Reliability Analysis Method

SDGs and EPS DGs do not run but stand by at normal situation, and start to run during emergency situation. SDG and EPS DG should be available when they are demanded. In other words, they should avoid the time during which they are in the inoperable state due to maintenance. That is, SDG(EPS) should be available as well as reliable to work its intended function. Thus, a new reliability measure is defined reflecting availability as follows;

$$R = (1 - U_m) * R_s * R_r$$

where R_s = Starting Reliability
R_r = Load and Running Reliability
U_m = Unavailability Due to Test and Maintenance
R = Reliability

Also,

U_m = total test and maintenance time / (11 years * 8760 hrs/yr)
$R_s = N_{ss} / N_{sd}$
$R_r = N_{rs} / N_{rd}$
where N_{sd} =Total # of Starting Demands
N_{ss} =Total # of Starting Successes
N_{rd} =Total # of Load/Run Demands
N_{rs} =Total # of Load/Run Successes
N_{rf} =Total # of Load/Run Failures

Thus, reliability of SDG #1,2 can be calculated as follows

$$R = (1 - U_m) * R_s * R_r = (1 - U_m) * (N_{ss} / N_{sd}) * (N_{rs} / N_{rd}) \qquad \text{-------------} \quad (1)$$

To calculate reliability of SDG & EPS using Equation (1), failures were investigated from a review of the quarterly performance reports and work report issued by Wolsong NPP[4] dated from 1985 through 1995. N_{sd}, N_{rf}, U_m of SDGs and EPS DGs and the reliabilities of SDGs and EPS DGs calculated with Equation (1) are shown. For example,

Reliability of SDG #1 = (1- 0.0263) * (364 / 370) * (315 / 324)= 0.9313

Average reliability of SDG #1 & #2 = (1- 0.0330) * (726 / 744) * (674 /691) = 0.9204

Reliability of EPS #1 = (1- 0.0421) * (316 / 328) * (289 / 301) = 0.8861

Average reliability of EPS #1 & #2 = (1- 0.0269) * (727 / 742) * (678 /697) = 0.9025

The characteristics of above calculation is to use plant specific test and operation data. It seems reasonable to use only plant specific data in analysis of SDG and EPS since the operation period is long enough.

Reliability Analysis Result

Reliability of diesel generators of Wolsong Unit 1 is summarized in the following table. In thistable, EPS#2 is the best in reliability, and EPS#1 is the worst.

Table 1. Reliability Calculation

Diesel Generator	Number of Starting Demands	Number of Starting Failures	Number of Load-Run Failures	Unavailability due to Maintenance	Reliability
SDG#1	370	6	9	0.0263	0.9313
SDG#2	374	12	8	0.0396	0.9082
EPS#1	328	12	12	0.0421	0.8861
EPS#2	414	3	7	0.0116	0.9639

Since EPS DG is seismic class while SDG is non-seismic class, generally EPS DGs would be more reliable than SDGs are. Therefore, it turns out that EPS #2 is the most reliable. However, reliability of EPS#1 is the worst. The reason is as follows;

> The Turbo Charger of EPS#1 had exploded in 1985, and new one was installed. However, the performance of EPS#1 is not improved since then because it is not the original one. The other problem is low test load. When EPS DG is tested, EPS is connected to EWS Pump whose load is only 120 kW which is only 12% load of nominal output (1000kW) of EPS DG. Therefore, it is required to raise the test load.

The reason why reliability of SDG#1 is better than that of SDG #2 is as follows:

> It is known that SDG#1 was installed with a used one which had been well operated and maintained, while SDG#2 was installed with a new one. Also, test load is only 40 % of nominal power of SDGs, which causes low test load problem. Therefore, SDG#2 is not so good as SDG#1 because SDG#2 which was not yet a well-maintained engine could not endure the low test load problem. To improve the performance, the test load should be increased.

Reliability Improvement Plan

The estimated reliabilities of SDGs and EPS DGs of Wolsong Unit 1 are a little bit unsatisfactory, even being compared with the target values of SBO Rule of USA. Therefore, dominant contributors degrading reliability are identified based on the quarterly performance report and work report of the plant. Based on the analysis, reliability improvement plan including design change and new maintenance method is recommended. Also, new reliabilities of SDGs and EPS DGs are estimated based on the assumption that the recommended plan be implemented.

The reliability of SDG & EPS can be improved with the following actions. The improvement plan are categorized into 3 groups according to three basic factors of which reliability of SDG & EPS DG consists: 1) Reducing starting failure, 2) Decreasing load-run failure, and 3) Reducing unavailability due to test & maintenance. The followings are reliability improvement plan classified with 3 groups. More detailed hardware-oriented improvement plan is described in the interim project report[5,6].

(1) Reducing Starting Failure

Most problems which caused starting failures are lubricating oil low pressure trips and starting air injection system problem according to the test and maintenance history data. In staring air injection system, low quality air which were mixed with dust and debris flowed into from air compressor caused many starting failures. A design change to install a buffer tank is recommended to filter out the debris and dust.

The sensor line of lubricating oil pressure has too many bends which indicates low pressure of lubricating oil flow even if it is normal, and causes several starting failures, especially in winter. Therefore, the starting failure can be reduced by reducing the bends.

(2) Decreasing Load-Run Failure

The root causes of load-run failures were related to the leak of coolant and oil in most cases. Thus, it is recommended that frequent check of leak of coolant and oil with effective manners. In addition, maintenance work should be focused on returning the equipment to normal condition after annual scheduled maintenance.

(3) Reducing Unavailability due to Maintenance

To reduce the unavailability due to maintenance, maintenance work which requires long period should be eliminated. For example, heat exchangers such as jacket water coolers, lubricating oil coolers, intercoolers, etc., are cooled by sea water which causes corrosion by sea water and require much time in cleaning. As a result, several heat exchangers were replaced. In the long run, the cooling by sea water would be replaced with the cooling by component cooling water system.

Sometimes, it took a long time naturally to repair a certain equipment such as engine. Therefore, more predictive maintenance, which uses condition monitoring instead of periodic overhaul, should be adopted for the time-consuming equipment in maintenance.

The Expected Improved Reliability

If the suggested plan of the previous section are implemented, reliability of SDGs & EPS DGs will be increased. In this section, the expected value of improved reliability is estimated.

(1) Improved Effect of Starting Reliability

If the design change recommended in the previous section is implemented, then the frequency of starting failures will be reduced to a third of the previous value. Since 11 starting failures are due to air staring system and 2 starting failures are due to the low pressure of lubricating oil among total 17 starting failures. Therefore, total number of starting success can become 603 from 590.

(2) Improved Effect of Load-Run Reliability

Load-run failures would be reduced to a third. The previous number of failures, 14 can be reduced to 7. load-run successes becomes 596 given 603 times starting successes.

(3) Improved Effect of Unavailability due to Maintenance

The unavailability due to maintenance would be reduced to a third of current value if the number of starting failures and load-run failures are reduced and if cooling is changed from sea water to component cooling water .

Thus, $U_m = 0.0330 * 1/3 = 0.0110$

$$\text{Average reliability of SDG \#1 \& \#2} = (1 - 0.0110) * (721 / 744) * (680 / 686) = 0.9500$$

That is, the average reliability of SDG #1 & #2 can be improved from current 0.9204 to 0.9500 through design change and improvement of maintenance method as mentioned in the previous section. In this calculation, the effect of increased test load was not considered.

CONCLUSIONS

A new reliability measure is suggested and used in the reliability analysis of SDGs and EPS DGs of Wolsong NPP. This new reliability measure seems to simply reflect the unavailability due to maintenance in addition to starting reliability and load-run reliability. Thus, this new reliability measure can be used to estimate the inherent strength and performance of DGs by considering availability and reliability.

The root cause of the starting failure modes is the low quality air in starting air system. The root cause of the unexpected shut down failure mode is too many bends and the temperature loss of lubricating oil tube. The root cause of the frequent noncritical failure mode is the insufficient load during test. The modification of air reservoir, the simplification of lubricating oil tube bends, the load bank installation, and the qualitative instrumentation are recommended as the solution for the root cause of each failure mode.

The average reliability of SDG #1 & #2 is 0.9204 and the average reliability of EPS #1 & #2 is 0.9025. After the above recommendations being implemented, the average reliability of SDG of Wolsong unit 1 could be increased from 0.9204 to 0.9500.

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