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Sensitivity Study of Three Design Improvement Action Items for OPR1000 Reactor Type In Respect of Core Damage Frequency Reduction

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1. Introduction

Since the Fukushima Daiichi accident, many considerations have been made to intensify the safety of nuclear power plants in Korea. Thus, many ideas in a form of post-Fukushima action items for the accident have been created. SAREX [4], a quantification program was used for the analysis. Applying a few of the action items that seem to be most likely effective on improving the Core Damage Frequency (CDF) for the plant (OPR1000 type), the sensitivity analysis is conducted herein. Three action items such as DC battery, the mobile Diesel Generators (MDG), and external feed to the primary and secondary sides were selected for the assessment. The comparison of the CDFs before and after the sensitivity study is shown and compared in such a way that whether the alterations are effective or not based on this analysis is presented.

2. Analysis and Results

In this section some of the post-Fukushima action items are applied to the plant and the sensitivity analysis is conducted to get the results of the CDFs. The items include increasing the depletion time of DC battery, the adoption of mobile DGs, and external feed to the primary and secondary sides of the plant.

2.1 Increasing Depletion Time of DC battery (Case 1)

The assumption for this item is that the depletion time of DC battery is increased to 8 hours up from the original time, 4 hours.

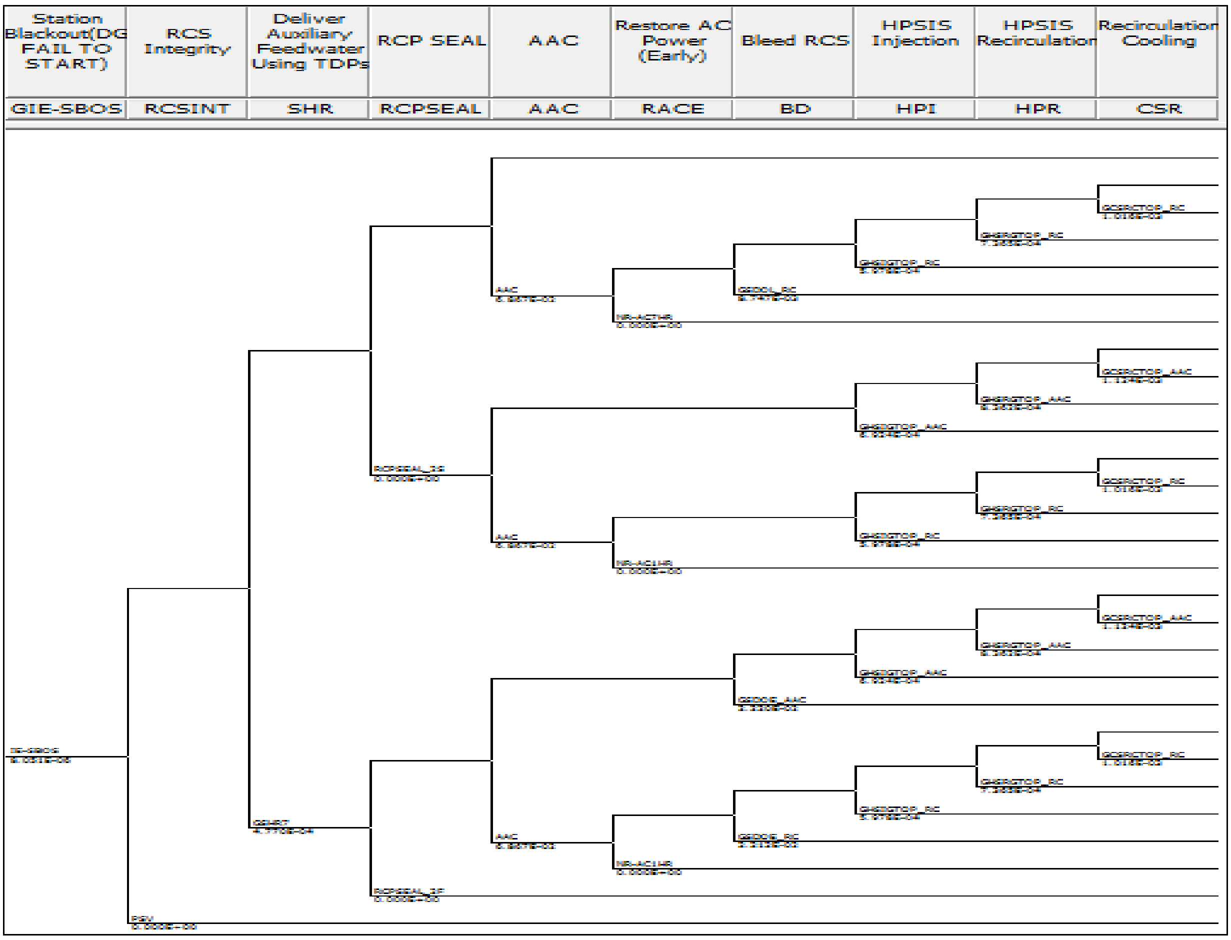

Fig. 1. Event tree of SBO-S (DG fail to start)

Figure 1 depicts the event tree of Station Blackout – Start (SBO-S; DG fail to start). It consists of ten types of headings at the top. Increasing the depletion time of DC battery, the SBO is the only scenario that is affected by the modification. SBO is comprised of SBO-S and Station Blackout–Running (SBO-R; DG fail to run). The SBO in total takes up 26.3% in CDF, which is the greatest percentage amongst all types of initiating events. We suppose that the Emergency Diesel Generator (EDG) fails to run after 8 hours of running in the SBO-R. The heading of ‘RACE’ in Figure 1 which means ‘restore AC power’ is closely related to the extension of DC battery lifetime.

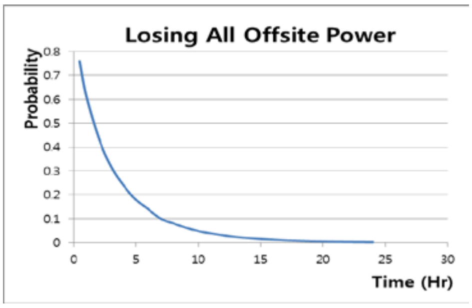

Fig. 2. Fraction of failure probability as a function of time.

In the above graph (Fig.2), the y-axis represents the probability that an operator fails to recover offsite AC power in time and the x-axis describes how much margin of time an operator has in order to solve the problem with losing all AC power. Based on the graph, the corresponding probabilities for the improved times (plus 4hours to the previous times) are simply put in the basic event namely ‘NR-AC#HR’ in the fault tree (Fig.3) that is connected to the branches at the heading of ‘RACE’ in the event tree (Fig.1).

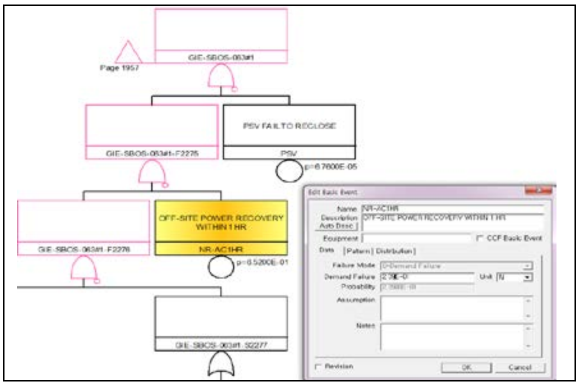

Fig. 3. Part of the fault tree connected to the heading of Recover AC Power.

If secondary heat removal (called ‘SHR’ as a heading) or RCP seals (RCPSEAL) fail at an early stage, the battery is no longer available for ensuring the time needed for recovering offsite power regardless of its extended lifetime. Therefore, the branches stemmed from the headings of ‘SHR’ and ‘RCPSEAL’ in the event tree of SBO as failures never benefit from the battery capacity improvement.

Seeing Figure 1, when all of the RCS integrity, secondary heat removal, and RCP seal succeed in sequence (that is, the sequence succeeds the headings of ‘RCSINT’, ‘SHR’, and ‘RCP SEAL’) and then the Alternate AC Diesel Generator (AAC DG) fails to function (the sequence fails the heading of ‘AAC’), the failure probability at the heading of ‘RACE’ is improved because the DC battery capacity is increased by four hours so that Turbine Driven auxiliary feedwater Pump (TDP) can function four more hours accordingly, which gives more time for the operator to recover offsite power.

The actual corresponding failure probability in case of SBO-S is improved to 1.06E-01 (when the battery capacity is 11 hours) down from 1.74E-01 (7 hours) as seen in Fig. 2. That in case of SBO-R is improved to 5.24E-02 (19 hours) down from 7.21E-02 (15 hours). Consequently, these two branches contribute to improving the CDF of the plant.

Table I : CDF Change of Case 1

	Reference CDF	Improved CDF	Variation(ΔCDF)
Total CDF	2.59E-06	2.40E-06	-7.3%
SBO-S	2.47E-07	1.56E-07	-36.8%
SBO-R	4.34E-07	3.36E-07	-22.6%

After extending the battery lifetime the total CDF is 7.3% down from the reference CDF that is 2.59E-06. The CDFs of SBO-S and SBO-R are reduced by 36.8% and 22.6% down from the reference CDF respectively.

2.2 Adoption of Mobile Diesel Generator (Case 2)

It is supposed that Mobile DGs (MDG) per unit of the plant are available for supplying AC power to the relevant systems in case where the AAC DG fails. Also, it is estimated that it takes two hours to successfully set up cable connections and the MDG in place and so on before using it.

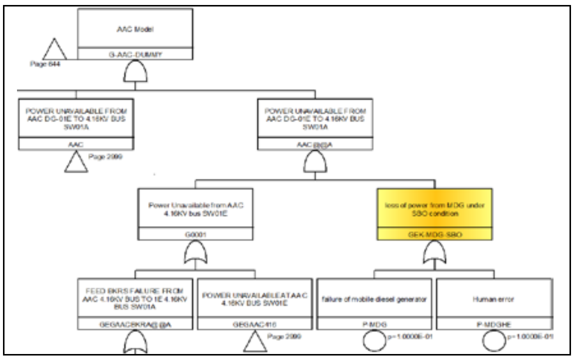

Fig. 4. Part of the fault tree to which the MDG is applied.

The unavailability of the MDG itself is determined as 0.1[3] and the human error probability is simply supposed to 0.1. Regarding that the failure probability of EDG is 0.01, it can be easily noticed that the probability of 0.1 is set very conservatively. Likewise, the human error probability of 0.1 is also a somewhat conservative value.

The MDG setup is built in the fault tree connected to the heading of AAC. Seeing Figure 1, when the sequence succeeds the headings of 'RCSINT', 'SHR', and 'RCPSEAL', the failure probability at the heading of AAC is improved to 1.40E-2 down from 6.87E-2 because the MDG setup helps reduce the failure probability as seen in Figure 4. The failure probabilities in the two other lower branches at the heading of AAC in Figure 1 are not improved since one hour given to an operator is too short for the MDG setup which takes two hours.

As a result, the MDG setup in each of the first top branches at the headings of AAC of both SBOs contributes to reducing the failure probability of the heading of AAC which leads to reducing the total CDF of the plant.

Table Ⅱ: CDF Change of Case 2

	Reference CDF	Improved CDF	Variation(ΔCDF)
Total CDF	2.59E-06	2.05E-06	-20.9%
SBO-S	2.47E-07	5.05E-08	-79.5%
SBO-R	4.34E-07	8.91E-08	-79.4%

The total CDF is reduced to 2.05E-06 down from 2.59E-06 by -20.9%. That of SBO-S is decreased by 79.5% and that of SBO-R is decreased by 79.4%.

2.3 DC Battery Depletion Time Extension and Adoption of Mobile Diesel Generator Simultaneously (Case 3)

To maximize the impact of applying the action items, DC battery deletion time extension and adoption of MDGs simultaneously are considered at a time in case 3.

Table Ⅲ: CDF Change of Case 3

	Reference CDF	Improved CDF	Variation(ΔCDF)
Total CDF	2.59E-06	2.01E-06	-22.4%
SBO-S	2.47E-07	3.24E-08	-86.8%
SBO-R	4.34E-07	6.98E-08	-83.9%

The total CDF of the plant is reduced to 2.01E-06 down from 2.59E-06 by -22.4%. The CDF variation of each SBO is about -85%.

2.4 External Feed to Primary and Secondary Sides of the plant (Case 4)

This section is about external feed to both sides of the plant in the phase of level 1 PSA before core damage. Basically, the external feed on the primary side is to back up the Low Pressure Safety Injection (LPSI) systems for the integrity of the vessel and that on the secondary side is to back up auxiliary feed water pumps (both motor-driven and turbine-driven) for the steam generator. We supposed that it takes four hours for the external feed to be successfully set up for implementation.

For the primary side, there is mainly one initiating event, Large LOCA. In this plant, LPSI is able to last around 103.2 minutes which is even less than half the essential time. For this reason, external feed cannot be used to back up LPSI. Setting aside from this issue, it is almost no use applying primary side external feed for LPSI because of its negligible impact of probability.

Table Ⅳ: Comparison of Unavailability between LPSI and External Feed

	Unavailability	Success Criteria	Comparison
LPSI	0.02	1 out of 2	0.02 * 2 = 0.04
External Feed	0.2	-	0.2

The unavailability of each of the LPSI systems (2 systems per unit) is 0.02 and the success criteria is one out of two. 0.02 * 2 = 0.04. The value 0.04 of the LPSI is already far lower than 0.2 of the external feed, which is the number simply assumed in the same way as mobile DG. Hence, it is not as effective to use the facility of external feed which is 0.2 of unavailability.

For the secondary side, the time where a reactor core can remain intact is up to one hour [5] when the TDP fails. In the same sense, the external feed of the secondary side cannot back up TDP due to time constraints. External feed basically represents the situation where there is no AC power in a plant. Even if the secondary side external feed is operable, sufficient number of backup systems for feed water such as MDP and TDP exist. As a result, it is not reasonable applying external feed to the secondary side.

3. Conclusions

DC battery lifetime extension and mobile DG application have significant impacts on improving the total CDF of the plant. External feed of both primary and secondary sides is not useful to reinforce the safety of the plant with respect to the stage of level 1 PSA. Implementing case 3, the total CDF reduction has finally come to -22.4%. From the perspective of cost-benefit, solely applying mobile DGs to the plant is effective to get a vast result of CDF. However, it is important to apply both DC battery extension and the Mobile DG in order to get a maximal CDF reduction.

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