Assessment of the Seismic Safety Improvement of Nuclear Power Plants by Equipment Isolation

Jae-Wook Jung [a*], Gyeonghee An [a], Minkyu Kim [a]
[a]*Advanced Structural and Seismic Safety Research Division, Korea Atomic Energy Research Institute, 111, Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, 34057, Republic of Korea*
[*]*Corresponding author: jaewook1987@kaeri.re.kr*

1. Introduction

Numerous types of electrical equipment are installed in nuclear power plants. The failure of such electrical equipment does not stop at the failure of the electrical equipment itself, but can greatly affect the safety of the entire power plant [1]. The safety system of a nuclear power plant consists of numerous devices and structures, and in an accident such as an earthquake, many devices can be damaged at the same time, leading to core damage. Seismic probabilistic safety assessment (SPSA) can quantitatively evaluate the core damage frequency of nuclear power plants due to potential earthquakes [2]. In this study, we investigate the effect of seismic performance enhancement of each piece of equipment due to equipment isolation on the seismic safety of nuclear power plants. Seismic isolation is one of the alternatives that can dramatically improve the seismic performance of important infrastructure structures such as nuclear power plants [3]. We re-evaluated the seismic fragility of cabinetry devices assuming a scenario where seismic isolators were applied to the devices. In addition, the core damage frequency is evaluated using the re-evaluated equipment fragility, and the risk change due to the device earthquake is derived.

2. Methods and Results

This section describes the results of the re-evaluation of fragility applied with seismic isolators and evaluates the Fussell-Vesely (FV) importance for each device. In addition, the seismic safety of nuclear power plants, which is improved due to equipment isolation, is quantitatively evaluated.

2.1 Equipment Fragility Re-evaluation by the Equipment Isolation

The procedure for evaluating the fragility of internal devices for seismic probabilistic safety assessment is described in detail in the technical report of the Electric Power Research Institute (EPRI) [4,5]. However, no general procedure has been established for the equipment to which seismic isolators are applied. The fragility of the seismic isolated devices is re-evaluated by referring to the fragility assessment procedure presented by EPRI. Assuming the limit displacement of the seismic isolator as the failure criterion and setting the capacity factor of the device as a displacement term, the seismic fragilities of cabinetry devices are re-evaluated, and the results are summarized in Table 1 and 2. Am is the median capacity of equipment, β_r and β_u are aleatoric and epistemic uncertainties, respectively

Table I: Fragility parameters for internal devices

	A_m	β_r	β_u
Off-site power	0.30	0.22	0.20
Diesel generator	0.92	0.30	0.20
4.16kV SWGR	1.33	0.33	0.29
Battery charger	1.35	0.29	0.31
Inverter	1.43	0.29	0.30
480V Motor Control Center	1.48	0.34	0.30
125V DC Control Center	0.75	0.29	0.27
Instrumentation Tube	1.50	0.30	0.30
Safety Injection Tank	1.09	0.36	0.35
CCW Pump	1.30	0.21	0.21

Table 2: Fragility parameters for cabinetry devices by equipment isolation

	A_m	β_r	β_u
4.16kV SWGR	4.19	0.28	0.38
Battery charger	5.33	0.28	0.36
Inverter	4.04	0.28	0.38
480V Motor Control Center	4.70	0.28	0.38

2.2 FV Importance of Internal Devices

FV importance is a measure of the contribution of the cut sets with the specific basic event to the total risk and is used as an indicator to classify Structures, Systems, Components (SSCs) that are important to the safety of nuclear power plants. The contribution of the equipment to the core damage frequency can be evaluated through the evaluation of the FV importance of each piece of equipment. Fig. 1 shows the FV importance distribution of the internal devices. The FV importance of the diesel generator shows the largest value close to 50%. However, in the case of cabinet devices, only the battery charger has a value of about 10%, and the rest has a value of less than 1%. Therefore, it is expected that there will be no significant change in the frequency of core damage if equipment isolation is applied only to cabinet devices.

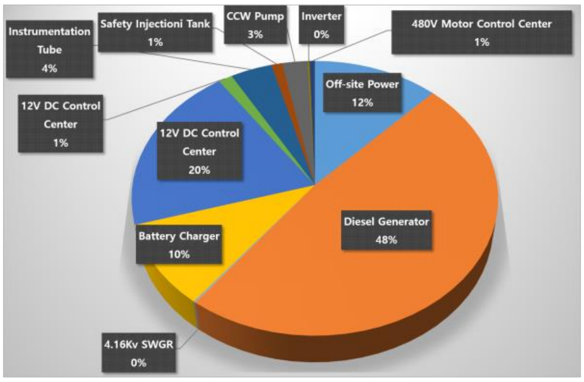

Fig. 1. FV importance of the internal devices

2.3 Core damage frequency by the equipment isolation

Fig. 2 shows the evaluation of the core damage frequency according to the application of equipment isolation. It can be confirmed that the core damage frequency is reduced by about 9.7% if the equipment isolation is applied to cabinet devices. The reason why there is no significant improvement in seismic performance due to the application of the seismic isolator to cabinet equipment can be confirmed by the FV importance distribution. This is because the FV importance of cabinet devices is relatively low, so there is a limit to the effect on the core damage frequency. If it is additionally assumed that the median capacity of the diesel generator with the greatest FV importance is improved by 50%, it can be seen that the core damage frequency is significantly reduced by 40.7%. Therefore, it can be concluded that it is important to secure seismic performance for a device with a high FV importance value rather than many devices with low FV importance.

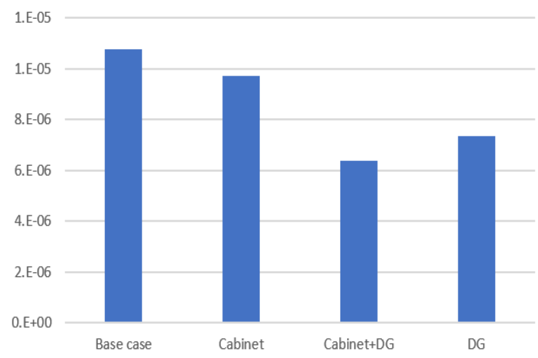

Fig. 2. Core damage frequency by the equipment isolation

3. Conclusions

In this study, seismic fragilities are re-evaluated for internal devices of nuclear power plants to which equipment isolation is applied, and the effect on seismic safety is investigated. Enhancement in the core damage frequency due to equipment isolation and the effect of FV importance are evaluated. It is concluded that it is important to evaluate the contribution of the equipment to the core damage frequency and to secure seismic performance by selecting important equipment.

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