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Variability Estimation of Natural Frequency of Electrical Equipment Based on the Shaking Table Tests

In-Kil Choi[a*], Sung-Jin Chang[b], Dong-Uk Park[b]
[a]*Korea Atomic Energy Research Institute, Daejeon, Korea*
[b] *Korea Construction and Transport Engineering Development Collaboratory Management Institute, Yangsan, Korea*
[*]*Corresponding author: cik@kaeri.re.kr*

1. Introduction

Safety related electrical system of a nuclear power plant has a significant role on the safety of the plant. During and after a strong earthquake, damage to the electrical equipment will greatly affect the safety of the nuclear power plants. In order to evaluate the seismic performance of electrical equipment that affects the safety of nuclear power plants during earthquakes, it is important to understand the dynamic characteristics of electrical equipment.

In this study, the variability of the natural frequency of electrical equipment used in a nuclear power plant was evaluated using the results of the resonance search test performed during the shaking table tests of electrical equipment.

2. Shaking table test of electrical components

2.1. Equipment for the shaking table tests

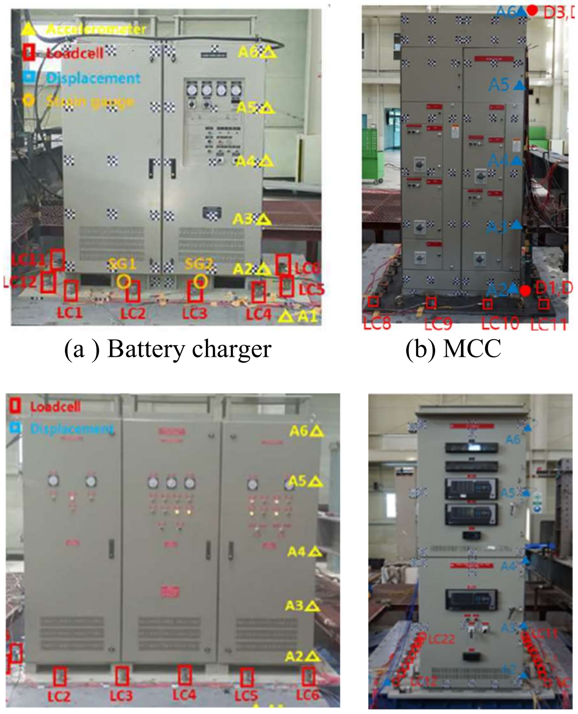
In this study, we evaluated the variability of natural frequency of electrical equipment using the results of existing shaking table tests. The shaking table test results were obtained from past tests performed by seismic Research and Test Center in Pusan National University (PNU).

Figure 1 shows the test setup of past shaking table test performed by PNU, and shows the locations of installed accelerometer to measure the acceleration responses of the equipment.

In the seismic fragility analysis of nuclear power plant equipment, the variability of the natural frequency of numerically verified electrical equipment is evaluated to be in the range of 0.1 ~ 0.3, and the variability of experimentally verified equipment is evaluated to be relatively smaller than this value [1]. A more reasonable value can be obtained by using the results of the shaking table tests to evaluate the variability of the dynamic characteristics of an electrical equipment.

2.2. Resonant search Test

The resonant frequency search tests were performed before, during and after the shaking tests. Total number of the resonant search tests for each equipment is shown in Table 1.



(a) Battery charger (b) MCC

(c) Inverter (d) Switchgear

Fig. 1. Test setup of electrical equipment for shaking table tests

Table 1: Total number of resonant frequency search test for each equipment

Equipment	No. of Specimen	No. of Tests
Battery Charger	2	20
Inverter	3	37
Switchgear	3	27
Motor Control Center	3	37

Three acceleration time histories for two horizonal and one vertical direction were used for the resonant frequency search tests. Figure 2 shows the input acceleration time histories for 3 directions. The peak acceleration for the resonant test was 0.05g.

2.3. Analysis of resonant search test results

The resonant frequency of the equipment was determined by calculating the transfer function ($T_{xy}(f)$) for the acceleration input and response from the following equation.

$$T_{xy}(f) = \frac{P_{yx}(f)}{P_{xx}(f)} \qquad (1)$$

Where, $P_{yx}(f)$ and $P_{xx}(f)$ are cross power spectral density and power spectral density, respectively.

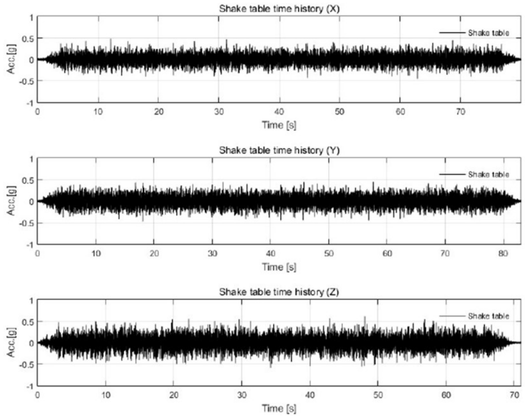


Fig. 2 Input motions for resonant frequency search tests

3. Variation of Measured Resonant Frequency

In this study, the median frequency and logarithmic standard deviation were calculated from the result of the resonant frequency search test results. For a variate a which follows a log-normal distribution, the median frequency S_m and the log-normal standard deviation of the frequencies β_a can be expressed by its mean μ_a and the coefficient of variation δ_a [2].

$$S_m = \frac{\mu_a}{\sqrt{1+\delta_a^2}} \quad (2)$$

$$\beta_a^2 = ln(1 + \delta_a^2) \quad (3)$$

Table 2 shows the median and log-normal standard deviation of the natural frequencies of a battery charger calculated from the test results. In the table, location represents the location where the accelerometer is installed shown in Fig. 1.

Table 2: Median and standard deviation of measured natural frequencies

Location	Median	Log. Std. Dev.
A3	11.52	0.05
A4	11.60	0.06
A5	11.59	0.06
A6	11.61	0.06
A7	11.59	0.06
A8	11.60	0.06
A9	11.61	0.06
A10	37.37	0.15

As shown in Table 2, the logarithmic standard deviations are generally below 0.06, with only the results from A10 being above 0.15. in the case of A10. This is based on the measured acceleration responses of an accelerometer attached to the relay inside the cabinet rather than outside, and corresponds to the localized vibration at the location where the relay is installed rather than the natural frequency of the cabinet.

To evaluate the variability of the dynamic characteristics of the cabinet, the variability of the natural frequencies was evaluated using the measured data from the accelerometers attached to the outside of the cabinet.

Table 3 shows the average standard deviation of the measured natural frequencies using the acceleration data measured outside of the cabinet.

Table 3: Average standard deviation of the measured natural frequencies

Equipment	Direction	Average Std. Dev.
Battery Charger	x	0.06
	y	0.01
	z	-
Inverter	x	0.04
	y	0.09
	z	-
Switchgear	x	0.04
	y	0.02
	z	0.04
Motor Control Center	x	0.10
	y	0.07
	z	0.00

The seismic safety of an electric cabinet is generally governed by its horizontal response. It is reasonable to evaluate the natural frequency of a cabinet based on the measured data from the top of the cabinet.

Table 4 shows the average standard deviation of the measured natural frequencies using the acceleration data measured at the top of the cabinet.

Table 4: Average standard deviation of the measured natural frequencies at the top of the cabinet

Equipment	Directio n	Average Std. Dev.
Battery Charger	x	0.06
	y	0.02
Inverter	x	0.05
	y	0.09
Switchgear	x	0.04
	y	0.02
Moto Control Center	x	0.10
	y	0.08

4. Summary and Conclusion

The dynamic characteristics of electrical equipment and their variability are important parameters in the seismic fragility analysis of electrical equipment. In this study, the variability of natural frequency of electrical equipment were evaluated using the shaking table tests performed in the past.

The logarithmic standard deviation of the natural frequency obtained by performing seismic qualification using shaking table test is less than 0.1. In case of switchgear and battery charger, the values are even smaller.

The variability of the natural frequency of electrical equipment estimated by this study can be used to seismic fragility analysis of electrical equipment of nuclear power plants.

Acknowledgment

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[2] Ang ZH-s, Tang W. H. 1975. Probability Concepts in Engineering Planning and Design, Basic Principles, Vol. 1, Wiley, New York.