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Comparative Evaluation of In-cabinet Amplification Factor for Devices Mounted in Electrical Cabinets

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1. Introduction

Electrical cabinets and control panels in a critical industrial facility like nuclear power plants have safety related electrical instruments such as relays mounted on them. These instruments must continue to operate during an earthquake and are seismically qualified by a shake table test in which the earthquake input is defined in terms of an in-cabinet response spectrum (ICRS). The ICRS should be estimated prior to seismic qualification of devices mounted in electrical cabinets. EPRI report [1] introduces a simple method to estimate seismic demand on relays mounted on or within such cabinets (in-cabinet seismic demand).

If the ICRS generated by amplifying floor response spectra through a constant factor of EPRI report [1] is found to be much higher than the vendor's test data for relay then a more accurate method is used for generating ICRS. The more accurate methods can range from using finite element analysis, in-situ testing and analysis, and shake table testing of similar cabinets.

This study estimated the in-cabinet amplification factors by using various methods. Comparative results are presented in this paper.

2. Methods to Calculate In-Cabinet Amplification Factor

The in-cabinet amplification factor is defined by the ratio of the ICRS at the device location to the controlling base response spectrum (BRS). This is expressed by:

$$\mathrm{AF_g} = \frac{S_{a1}(f_{x1}, 5\%)}{S_{a0}(f_{x0}, 5\%)} \qquad \text{(Eq. 1)}$$

where $S_{a1}(f_{x1}, 5\%)$ is the ICRS at the device location, f_{x1} is the frequency at the maximum of S_{a1} and 5% is the damping ratio, $S_{a0}(f_{x0}, 5\%)$ is the BRS, and f_{x0} is the frequency at the maximum of S_{a0}.

The correction factors are applied to avoid the excessive conservatism in the Eq. 1. The effective amplification factor AF_e is calculated by including a broadband correction factor C_b and a multi-axis correction factor C_m.

$$\mathrm{AF_e} = AF_g \cdot C_b \cdot C_m \qquad \text{(Eq. 2)}$$

2.1 Rigorous calculation method

The rigorous calculation method generates the ICRS by using the relationship between the power spectral density function and the response spectrum in frequency domain. This study applies a method using impact hammer test results which were presented in the previous study [2].

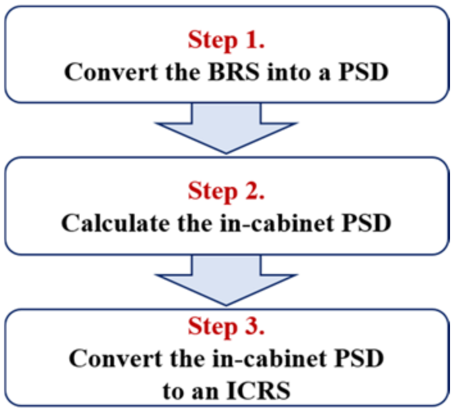

Figure 1. Flow chart of rigorous calculation method

2.2 Simplified method

A simple calculation method defines the amplification factors as a ratio of in-cabinet seismic demand DEM to the BRS.

$$\mathrm{AF_e} = \frac{DEM}{S_{a0}(f_{x0}, 5\%)} \qquad \text{(Eq. 3)}$$

$$\mathrm{DEM} = \max\begin{Bmatrix} DEM1 = DF_e\, S_{ad} \\ DEM2 = S_{a0}(f, 5\%)\ for\ f \geq 4\ Hz \end{Bmatrix} \qquad \text{(Eq. 4)}$$

$$\mathrm{S_{ad}} = \max\{S_{a0}(f, \xi_d)\}\ for\ f \geq f_{dl} \qquad \text{(Eq. 5)}$$

$$\mathrm{DF_e} = C_b C_m R_z M_f \qquad \text{(Eq. 6)}$$

Eq. 4 includes a requirement that the resulting demand must exceed the BRS peak value above 4 Herz. Table Ⅰ shows the effective demand factors and the frequencies, and the damping factors by bin. The factors range from 5.5 to 8.0.

Table Ⅰ: Generic frequencies, dampings and effective demand factors for each fundamental frequency

frequency	f_{di}	ξ_d	DF_e (g/g)
9 ~ 13 Hz	9	4%	8.0
13 ~ 20 Hz	13	3.5%	6.5
Above 20 Hz	20	3%	5.5

3. Comparison between Amplification Factors for In-Cabinet

A typical cabinet was selected to compare the in-cabinet amplification factors estimated by the methods introduced in Section 2.

The total weight of cabinet is 200kg. It is assumed that the weight is distributed on the cabinet. The fundamental frequencies are 9.48Hz in X-direction and 25.98Hz in Y-direction. The BRSs are the design response spectrum (EW direction) at EL.95.43 in Wolsung site and the horizontal response spectrum in US Reg. Guide 1.60. Fig. 2 shows the shaped of the cabinet and Fig. 3 & 4 show the BRS. Table Ⅱ shows the dynamic properties of the cabinet identified by dynamic test.

Figure 2. The geometry of cabinet specimen

Table Ⅱ: The cabinet properties

Size	$2100\ (\mathrm{h}) \times 800\ (d) \times 800\ (w)$ mm	
Weight	200.0 kg	
Natural frequency	x-dir.	9.48 Hz
	y-dir.	25.89 Hz
Damping ratio	x-dir.	1.45 %
	y-dir.	1.13 %

The in-cabinet amplification factors which were estimated by two methods are summarized in Table Ⅲ. The ICRS are compared in Fig. 5 & 6. The simple method yields larger amplification factors by 3~4 times than the rigorous method. The amplitudes of the factors depend on the types of BRS.

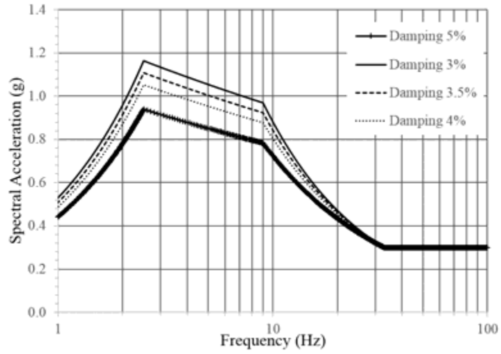

Figure 3. Base response spectrum of R.G. 1.60 (0.3g)

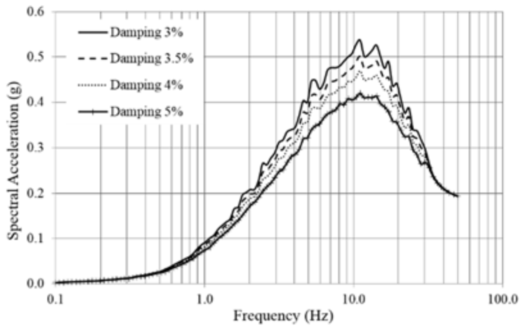

Figure 4. Base response spectrum at Wolsung site

Table Ⅲ: Estimated amplification factors

	Rigorous Calculation	Simplified Method
Wolsung	2.81	8.48
R.G 1.60	1.73	7.46

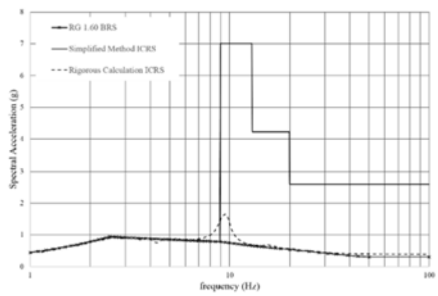

Figure 5. ICRS for R.G. 1.60

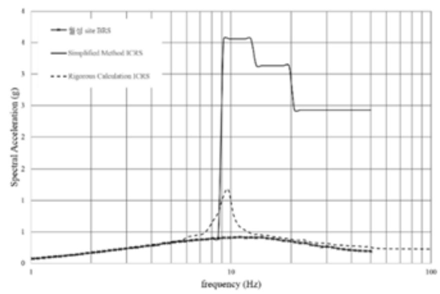

Figure 6. ICRS for WolSung site BRS

3. Conclusions

This study compares the differences of the in-cabinet response spectra estimated by a simple method and a rigorous method. A simple method of EPRI yields larger amplification factors by 4 times than the rigorous method for the same cabinet.

If the ICRS generated by amplifying floor response spectra through a constant factor is found to be much higher than the vendor's test data for relay then a more accurate method is used for generating ICRS. The more accurate methods can range from using finite element analysis, in-situ testing and analysis, and shake table testing of similar cabinets.

REFERENCES

[1] O'sullivan, J. J. and Djordjevic, W., Guidelines for Development of In-Cabinet Amplified Response Spectra for Electrical Benchboards and Panels, EPRI NP-7146-M, Electric Power Research Institute, Palo alto, CA, 1990.

[2] Cho, S.G., Cui, J.T., and Kim, D.K., "A Procedure for Generating In-cabinet Response Spectra Based on State-Space Model Identification by Impact Testing", J. Nuclear Engineering and Technology, Vol. 43, No. 6, 573-582, 2011.