A Seismic Fragility Evaluation for Electrical Cabinet in NPP through a Shaking Table Test

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1. Introduction

For the evaluation of a failure mode for Motor Control Centers (MCCs), a shaking table test already performed by Kim et al.[1] In this study, the seismic fragility was evaluated by using previous shaking table test results. At first, amplification results according to the shaking table test about 480V MCCs analyzed according to a method of NUREG/CR-5203[2]. Secondly, the seismic fragility of 480V MCC was evaluated according to the methodology that was introduced in the report EPRI TR-103959[3]. Through this study, it can be concluded that the seismic fragility results of the PSA report in Korea were underestimated.

2. Overview of Shaking Table Test

A 480V MCC Cabinet is one of the major equipment systems in the Nuclear Power Plant. For the shaking table test, a real MCC cabinet was rented from a manufacturing company. A figure and drawing are shown in Figure 1. The descriptions of the MCC are summarized in Table 1.

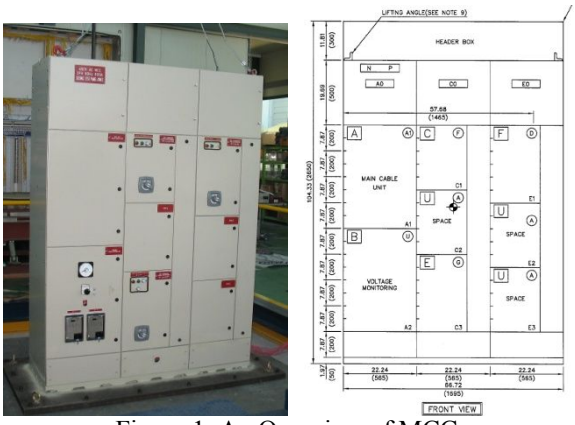
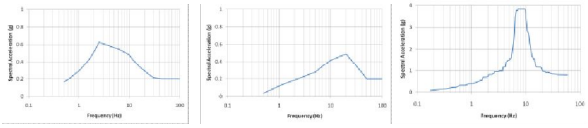


Figure 1. An Overview of MCC

Table 1. Description of MCC Cabinet

Dimension(mm)	Width	1,695
	Depth	550
	Height	2,650
Weight (kg)	Transportation	1,350

For the shaking table test, three kinds of seismic input motions were used. One is an artificial seismic input motion based on the NRC Reg. guide 1.60 design spectrum and the second is also an artificial seismic motion based on the Korean Nuclear Power Plant site specific Uniform Hazard Spectrum (UHS). The UHS motion was selected for an evaluation of a High frequency effect on the electric equipment in a NPP. The last one is a floor response spectrum of PAB 165'. The target input spectrums are shown in Figure 2.



(a) (b) (c)

Figure 2. Seismic Motion for Shaking Table Test; (a) US NRC Design Spectrum (b) Uniform Hazard Spectrum (c) Floor Response Spectrum of PAB 165'

3. Evaluation of Amplification Ratio

Bandyopadhyay et al. [2] presented the dynamic amplification factors about the MCC and Switchgear cabinet system at NUREG/CR-5203 report. This report finally presented amplification results about MCC and Switchgear according to the frequency range as shown in Table 2.

Table 2. Summary of Amplification Results (NUREG/ CR-5203)

Amplification	Motor Control Center		
	Max.	Median	High Confidence
Peak			
4-16 Hz	7.7	4.8	8.2
16-40 Hz	8.3	5.3	9.9
40-100 Hz	13.0	5.7	15.8
Average			
4-16 Hz	4.0	3.0	4.7
16-40 Hz	6.6	3.7	7.7
40-100 Hz	9.3	5.0	11.2
Zero Period	4.8	3.3	5.4

The amplification results of structural and incabinet responses according to the NRC design spectrum are summarized in Table 3 and Figure 3. As shown in Table 3 and Figure 3, the structural amplification results in the case of NRC design earthquake motion is satisfied as the presentation of NUREG reports as shown in Table 2. It is hardly distinguishable from that of the acceleration amplification ratio increasing effect in the case of average value of spectral acceleration. In the case of incabinet acceleration response, it exceeds from that of the value we present in the NUREG report. Particularly, the amplification ratio shows up as the value in which an incabinet is close to 15. Moreover, in a high-frequency region, the amplification ratio shows up more.

Table 3. Amplification Results in the case of NRC Design Earthquake Motion

			0.2g		0.4g	
			mid	top	mid	top
Structural Response	Peak	4-16Hz	2.6	4.3	2.3	4.3
		16-50Hz	2.2	4.0	2.1	4.0
	Average	4-16Hz	1.5	2.1	1.5	2.1
		16-50Hz	1.4	2.2	1.3	2.1
	ZPA		1.4	2.3	1.3	1.9
Incabinet Response	Peak	4-16Hz	2.1	10.6	2.0	9.5
		16-50Hz	1.9	14.1	1.8	15.4
	Average	4-16Hz	1.4	4.7	1.4	4.5
		16-50Hz	1.5	10.6	1.3	10.0
	ZPA		1.9	13.8	1.5	13.4

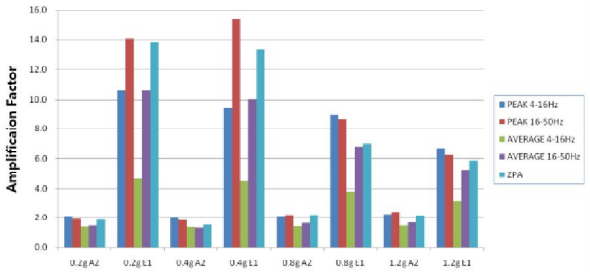


Figure 3. Amplification Results of Incabinet Response in the case of NRC Design Earthquake Motion

Through this study, it can be concluded that the amplification ratio as suggested by NUREG/CR-5203 was conservative as regards the structural response but it is insufficient to the incabinet response

4. Seismic Fragility Evaluation

For the assessment of seismic fragility of 480V MCC in NPP, a methodology presented in EPRI TR-103959 was used. A HCLPF(High Confidential and Low Probability of Failure) value can be evaluated using the equation (1).

$$HCLPF_{50} = A \cdot e^{-1.65(\beta_r + \beta_u)} \quad (1)$$

where, median capacity 'A' can be determined using equation (2).

$$A = \frac{TRS_C}{RRS_C} \cdot F_D \cdot F_{RS} \cdot PGA \quad (2)$$

where, TRS and RRS can be determined using equation (3) and (4).

$$TRS_C = TRS \cdot C_T \cdot C_I \quad (3)$$

$$RRS_C = RRS \cdot C_C \cdot D_R \quad (4)$$

where,
TRS : Equipment Test Response Spectrum Capacity
RRS : Required Response Spectrum Demand
C_T : Clipping Factor for Narrow-banded TRS
C_I : Capacity Increase Factor
C_c : Clipping Factor for Narrow-banded Demand
D_R : Demand Reduction Factor
F_D: Broad Frequency Input Spectrum Device Capacity Factor
F_{RS}: Response Factor for Building (Structure)

The seismic fragility of 480V MCC was evaluated using the above procedure. Three kinds of failure were considered as previous shaking table test results; functional failure according to a fire, functional failure according to relay chattering and structural failure according to the shear failure of a side panel. The HCLPF results are summarized in Table 4. As shown in Table 4, it can be concluded that the 480V MCC in NPP sites have sufficient seismic capacity.

Table 4. The Fragility Results of 480V MCC according to Shaking Table Test

	A_m	β_R	β_U	HCLPF
Ground Level (NRC 1.2g) functional	0.71	0.26	0.27	0.298
Ground Level (UHS 3.0g) functional	1.81	0.26	0.27	0.765
PAB 165′ (FRS 2.5g) Structural	2.16	0.28	0.36	0.746

5. Conclusions

Seismic amplification characteristics and seismic fragility of 480V MCC were evaluated by using results of the shaking table test in this study. From this study, it is found that seismic amplification factors as presented in NUREG reports were underestimated. Moreover, it can be concluded that the 480V MCC have sufficient seismic capacity.

ACKNOWLEDGEMENT

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