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EVALUATION FOR IN-CABINET RESPONSE OF BATTERY CHARGER FOR LOW/HIGH FREQUENCY MOTIONS IN NPP

Dong-Uk Park[1], Sung-Jin Chang[1], and Young-Soo Jeong[1]

[1] Seismic Research and Test Center, Republic of Korea (kwenry@pusan.ac.kr)

ABSTRACT

In this study, the seismic performance and dynamic characteristics of a battery charger(BC) in the electrical subsystem were examined to quantifiably investigate and identify the operation of NPPs in South Korea. To examine the change of in-cabinet response spectrum(ICRS) by seismic retrofit such as component anchorage conditions, the seismic tests of battery charger were conducted using the shanking table under combined low frequency (design spectrum, R.G 1.60), high frequency (uniform hazard spectrum, UHS). It was chosen and examined because of their different dynamic characteristics and their effects on the electrical equipment. The contact chatter of relays was measured and evaluated at increasing the PGA level of CRS input motion. From the tests, the transformer anchorage failure from the welding connections and functional failure were observed at PGA 0.75 g level. However, the transformer anchorage failure was not observed at PGA 1.05 g by seismic retrofit. Thus, the peak acceleration and contact chatter at the in-cabinet (electrical component) were compared depending before and after seismic retrofit of transformer anchorage.

INTRODUCTION

The structure members of NPPs were designed to withstand earthquake motions; however, the attached equipment on the structure members is generally sensitive to earthquakes including low- and high-frequency motions. Equipment importance for safety under operating NPPs and the type of failure modes have been reported for sensitive equipment or components such as the contact chatter, change in output signal, and electrical connection discontinuity [EPRI (2007)]. The qualification of sensitive components was conducted for in-cabinet motions consistent with the safe shutdown earthquake (SSE) defined for each plant. In addition, the qualification of electrical system was required to be evaluated to consider low- and high-frequency motions because of the design spectrum and high-frequency effect.

The failure of the battery charger(BC) should not directly affect the operation and safety of the NPPs; however, the five events for the malfunction of BC were reported and the failure mode was defined as a loss of function [KAERI (2004)]. However, the contact chatter of sensitive components in NPPs was not evaluated under some of seismic research tests [Schmidt and Kassawara (1988); Merz et al. (1990); Iijima et al. (2008); Richards et al. (2015); Tseng et al. (2015). The critical characteristics of a relay such as configuration, pick-up/drop-out voltage, voltage rating, current rating, chatter, and response time shall be monitored. In the fragility test for equipment, a non-conformance report should be generated even though the function failure of the equipment was not observed when the contact chatter of the relay component has occurred. However, the contact chatter of the relay under the fragility test of a component was a significant judgment of the performance requirement for electric components in NPPs.

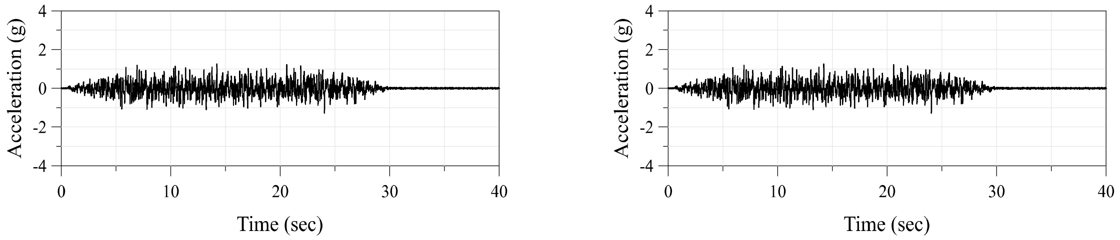
The B/C was installed to supply the charging current to the inverter and the battery that supplies safety and non-safety loads at the NPP. The failure of the BC should not directly affect the operation and safety of the NPPs; however, the five events for the malfunction of BC were reported and the failure mode was defined as a loss of function [KAERI (2004)].

To apply the seismic retrofit of electric cabinet in NPP, the seismic restraints by strut bolt or external angled brackets, seismic isolation system and a vibration control device were installed [Huang et al. (2013); Kumar et al. (2017), Lee and Constantinou (2018)]. Extensive research and technical development have been carried out to retrofit the seismic performance of structures, but the experimental study on seismic retrofit of electrical equipment cabinets is relatively insufficient. In order to evaluate the seismic performance of the cabinet structure, the reduction of the In-Cabinet Response Spectra(ICRS) is evaluated to the parametric analysis of the seismic retrofit method.

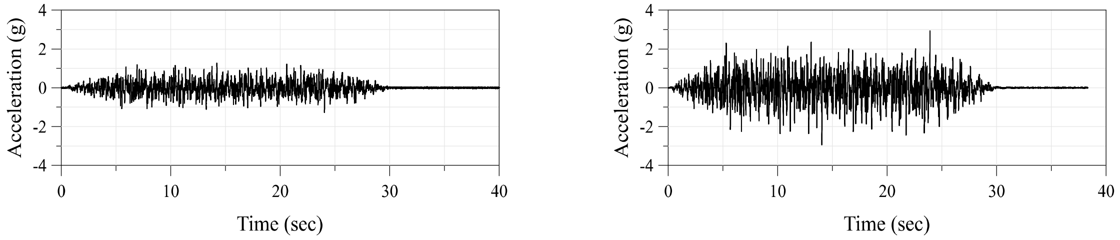
In this study, to examine the component response and contact chatter of relay at in-cabinet, the seismic tests were conducted. The seismic tests were to consider the input motions such as design spectrum, R.G 1.60(low frequency dominant), uniform hazard spectrum, UHS (high frequency dominant) and combined response spectrum, CRS. It was compared the seismic capacity of battery charger depending input motion based on designed peak acceleration level. The contact chatter of relays was measured and evaluated at increasing the PGA level of CRS input motion. Therefore, the peak acceleration at the in-cabinet response (electrical component) was compared before and after seismic retrofit. The functional tests were conducted to measure the rated voltage of relay during seismic test. An acceptance criteria of relay contact chatter was evaluated in accordance with the IEEE standard.

SEISMIC TEST CONDITION

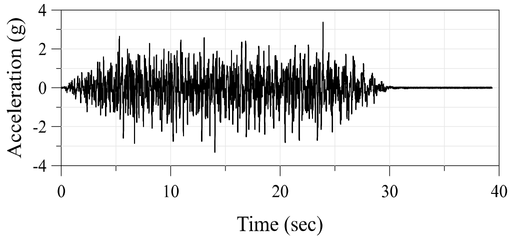
The BC was manufactured to evaluate the structural response and electrical function. To consider the effect of design response spectrum and uniform hazard spectrum, the CRS spectrum shape was defined based on the average of each floor's response spectra for an auxiliary building. The acceleration time histories and acceleration response spectra for different input seismic motions are summarized Fig. 1 and Fig. 2.



(a) SSE (PGA 0.2g)
(b) HCLPF (PGA 0.47g)



(c) Fragility 10% (PGA 0.75g),
(d) Fragility 20% (PGA 0.91g)

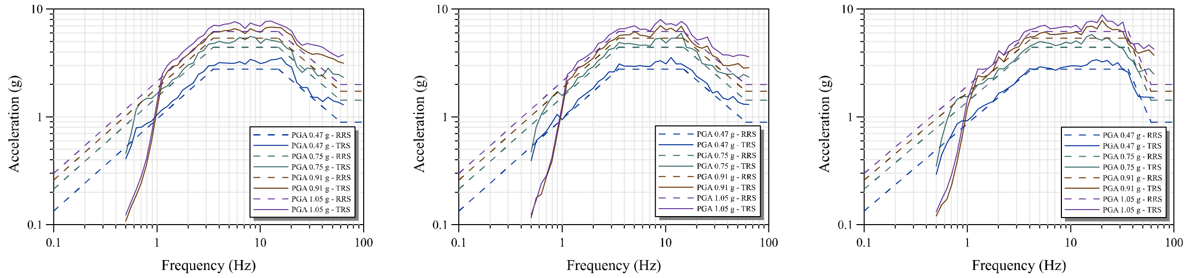


(e) Fragility 30% (PGA 1.05g)

Figure. 1. Acceleration time history of front to back depending on input motions

The seismic tests were conducted in a three-dimensional shaking table using three seismic input motions as shown Table 1. Figure 3 shows the evaluation for the in-cabinet response of the BC at major components such as the transformer, air breaker, relay and fuse.

The transformer anchorage failure from the welding connections and functional failure were observed at PGA 0.75 g level as shown in Fig. 4. The retrofit method of transformer anchorage was increased welding length.

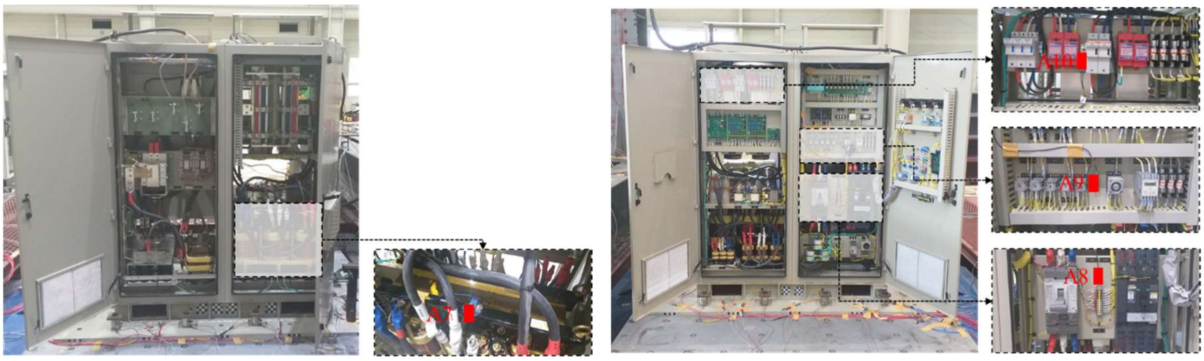


(a) side to side(S-S) (b) front to back(F-B) (c) vertical

Fig. 2. Acceleration response spectrum of seismic test

Table 1: Seismic test sequence

Test No.	Earthquake motion (PGA)	Remarks
1	Modal test	Resonant frequency verification (S-S, F-B, vertical)
2	SSE level 0.2 g	Combined Response Spectrum (3D input)
3	Modal test	Resonant frequency verification (S-S, F-B, vertical)
4	HCLPF level 0.47g	Combined Response Spectrum (3D input)
5	Modal test	Resonant frequency verification (S-S, F-B, vertical)
6	Fragility 10% level 0.75g	Combined Response Spectrum (3D input)
7	Retrofit of transformer anchorage	
8	Modal test	Resonant frequency verification (S-S, F-B, vertical)
9	SSE level 0.2 g	Combined Response Spectrum (3D input)
10	Modal test	Resonant frequency verification (S-S, F-B, vertical)
11	CRS (0.47 g)-HCLPF level	Combined Response Spectrum (3D input)
12	Modal test	Resonant frequency verification (S-S, F-B, vertical)
13	CRS (0.75 g)-Fragility 10% level	Combined Response Spectrum (3D input)
14	Modal test	Resonant frequency verification (S-S, F-B, vertical)
15	CRS (0.91 g)-Fragility 20% level	Combined Response Spectrum (3D input)
16	Modal test	Resonant frequency verification (S-S, F-B, vertical)
17	CRS (1.05 g)-Fragility 30% level	Combined Response Spectrum (3D input)
18	Modal test	Resonant frequency verification (S-S, F-B, vertical)



(a) transformer (A7), (b) air breaker (A8), relay (A9) and fuse (A10)

Figure 3. Location of installed accelerometers

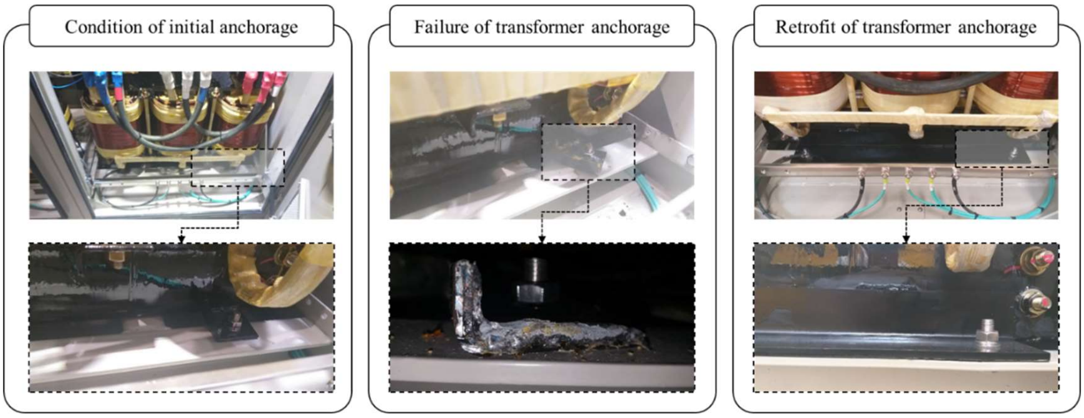


Figure 4. Seismic retrofit of transformer anchorage

SEISMIC TEST RESULTS

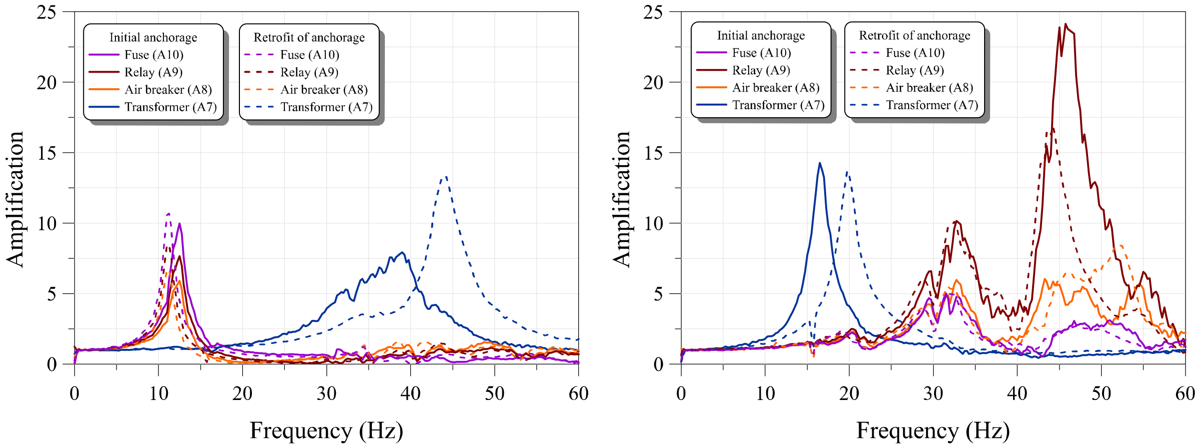
Resonant-Frequency Test

The resonant frequency tests were conducted before and after the seismic test. The resonant frequency is shown in value of transfer function over two is summarized Tables 2. The resonant frequency of the in-cabinet component was different according to the installed location, weight, and fixed method, as shown in Fig. 5.

Table 2 : Summary of resonant frequency test with side to side

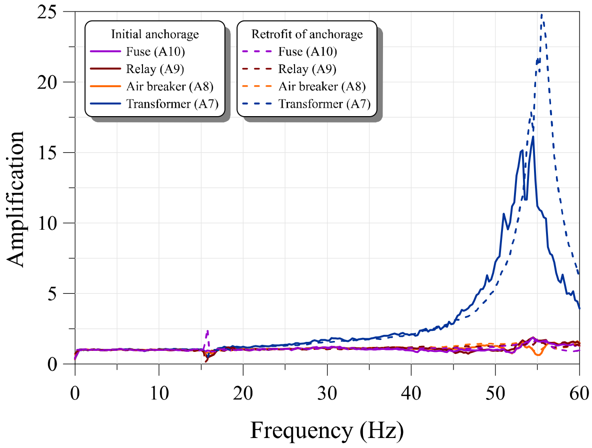
Test	side to side				front to back				vertical	
No.	A7	A8	A9	A10	A7	A8	A9	A10	A7	A8/A9/A10
1	39.00	12.50	12.50	12.50	16.50	20.25	20.25	20.25	53.00	N/A
5	24.25	11.25	11.25	11.25	12.50	19.75	19.75	19.75	33.25	N/A
6	43.75	11.25	11.25	11.25	19.75	28.75	28.75	28.75	55.50	N/A
12	34.00	10.75	10.75	10.75	17.75	28.50	28.50	28.50	50.00	N/A
14	31.00	10.25	10.25	10.25	15.25	28.25	28.25	28.25	43.00	N/A

In the cases of side-to-side and front-to-back directions, the resonant frequency of the panel of the in-cabinet was similar to those of the in-structure, but the resonant frequency of A7 (transformer) was different because it was directly fixed on the bottom of BC and a heavy mass. Particularly, the resonant frequency of A7 was changed after the PGA 0.47-g seismic test. The release of bolt connection was shown by the bracket of the transformer and the cracked welded joint.



(a) side to side(S-S)

(b) front to back(F-B)

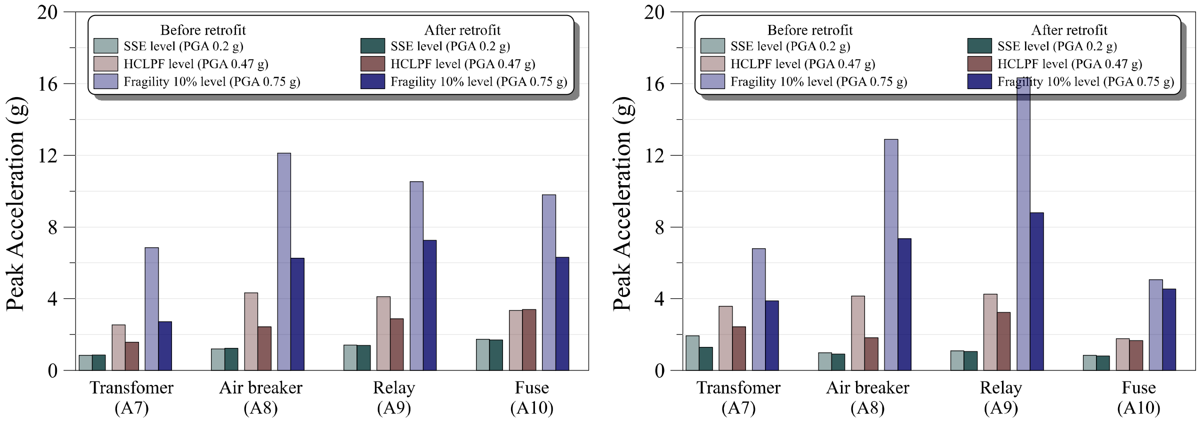


(c) vertical

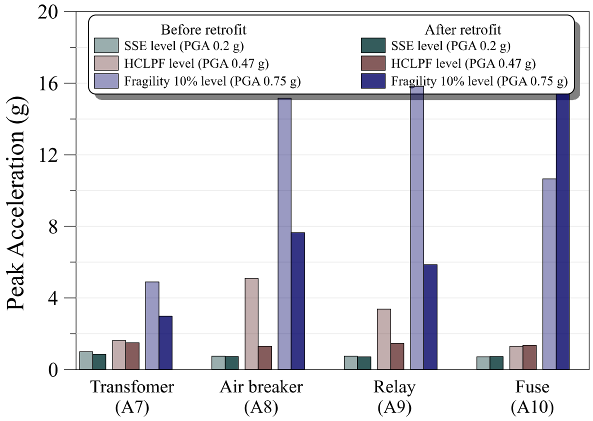
Figure 5. Resonant frequency test results for in-cabinet

Peak acceleration

The peak accelerations of each component for the in-cabinet were compared before and after seismic retrofit, as shown in Fig. 6. Comparing the peak acceleration of each component with the same input motion based on the 0.2-g PGA level, that of relay (A9) was larger than air breaker (A8) and fuse (A10). The peak acceleration was increased rapidly with the PGA level; particularly, the peak acceleration of CRS (PGA 0.75 g) was 3.83 times larger than that of CRS (PGA 0.47 g), and 14.9 times than that of CRS (PGA 0.2 g) at relay (A9). The vertical direction shows the similar tendency for the front to back. To increase the input motion level, the reduction rate of peak acceleration at in cabinet was increased by retrofit. It is important to consider the high and low frequencies for the safe operation of NPPs.



(a) side to side (b) front to back



(c) vertical

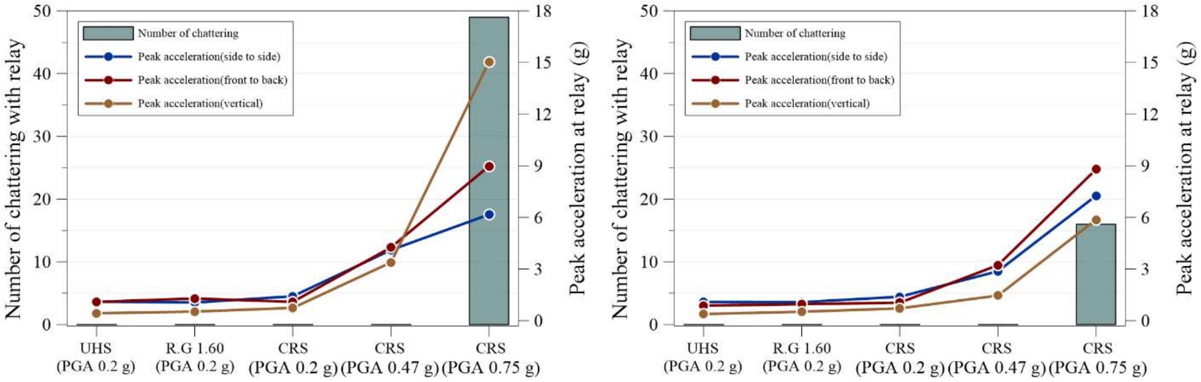
Figure 6. Comparison of peak acceleration depending on before and after seismic retrofit

Contact chatter of relay

The representative components in operating NPPs such as relays, contactors, switches, and other similar devices were tested by high-frequency seismic motions [Richards et al. (2015]]. The safety-related relays for NPPs would be formally qualified by shake-table tests in accordance with the IEEE Std C37.98. However, it was difficult to apply the available seismic qualification test data and actual earthquake experience (high frequency earthquake) data on a wide variety of relay types, because the protective and auxiliary relays were mounted in a specific cabinet or panel arrangement. Therefore, even a small change in chatter with relay might cause a significant damage to the plant.

In this study, to evaluate the relay chatter during an earthquake, the voltage of the relay at the mounted panel of the cabinet were measured by a 19,200 sampling rate and it was evaluated to change during each seismic tests. IEEE C37.98 was defined in relay contact chatter as the unauthorized intermittent closure or opening of contacts. An unauthorized change of state that is equal to or greater than 2 ms constitutes a failure. The 2 ms contact chatter duration is readily established by measuring the time between when the voltage decreased below the reference voltage and when the voltage returned to the reference voltage.

The relay chatter for larger than 2 ms in the dropped below reference voltage of total 46 number of times were evaluated. However, those of total 16 number of times were dropped to decreased by seismic retrofit. BC equipment cannot be unable to the functional failure when contact chatters of the relay component were occurred. If structural failure of BC did not occur, it will be operated during seismic test.



(a) Before seismic retrofit (b) After seismic retrofit

Figure 7. Relationship with contact chatter and acceleration response by seismic retrofit

CONCLUSION

In this study, to ensure the operation of NPPs in South Korea, the effect of seismic retrofit for battery charger component were evaluated by the shaking table test. The seismic tests of BCs were performed at combination spectrum (CRS) to consider the low frequency (R.G 1.60) and high frequency (UHS). From the tests, the dynamic characteristics and effect of seismic retrofit of the in-cabinet depending on input level were evaluated and compared. Comparing the peak acceleration of each component with the same input motion under the 0.2-g PGA level, the peak acceleration from relay (A9) was larger than form air breaker (A8) and form fuse (A10). It was similar tendency to before and after seismic retrofit. However, to increase the input motion level, the peak acceleration response was decreased by retrofit. The acceptance criteria of relay contact chatter were evaluated by the measured output signal during the seismic test. The contact chatter was unobserved under peak acceleration 17.8 g on the panel installed relay; however, the relay chatter for larger than 2 ms in the dropped below reference voltage of total 46 number of times were observed. In case of seismic retrofit, the number of chattering with relay was reduced to 16 times which is approximately 84% of un-retrofit case and the structural failure of battery charger did not occur.

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