Sindh Univ. Res. Jour. (Sci. Ser.) Vol.47 (1): 137-140 (2015)

SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)

Seismic Qualification of High Voltage Electric Supply Substation Equipment

N. ULLAH[++], S. M. ALI, G. AHMAD, F. ALI, S.R. HASSNAIN

Department of Electrical Engineering, University of Engineering and Technology, Peshawar

Received 8th June 2014 and Revised 3rd January 2015

Abstract: Earthquakes are one of the deadliest forces of nature that can shake structures to their limits. No comprehensive study has been done in Pakistan on seismic performance of electric supply substations and requires immediate attention as Pakistan is one of the highly seismic area in the world with potential of large earthquakes. Electric supply substations in Pakistan have their own typical geometry, design and construction practices.

Seismic qualification of electric supply substation equipment by time history shake-table testing is presented in this paper. Electrical equipment (surge arrester), already installed in Peshawar (Khyber Pakhtunkhwa, Pakistan) region was selected for seismic qualification. This equipment was tested under "Seismic Qualification Level Moderate" that is according to earthquake input requirements of this region. Seismic qualification of electric supply substation equipment is totally a new dimension in Pakistan's electrical power system.

Keywords: Seismic qualification levels (SQL), electric supply substation (ESS), surge arrester (SA), required response spectrum (RRS).

1. INTRODUCTION

Safety of employees and general public from electrocution and allied hazards, and safety of utility assets shall be top priority of all utility companies (transmission and distribution) in Pak. (PETSAC, 2014).

The term used to define the potential of earthquakes is "Seismic Hazard". Different areas would have different seismic hazard based on the studies of past earthquakes by means of geological and seismological studies done by researchers dealing with earth sciences and seismology.

Seismic design has started in most of the developed countries not very long ago. In USA the first seismic provisions were added in (1961).

2. MATERIALS AND METHODS

2.1 Technical Background

Building Code of Pakistan – Seismic Provisions 2007 (BCP-SP, 2007) explains that Pakistan is in one of the highly seismic areas in the world with potential of large earthquakes, for the purpose of seismic design; Pakistan has been divided into five zones. These zones are based on the peak ground acceleration ranges and are summarized in **(Table 1).**

Table 1: Seismic zones of Pakistan.

Seismic Zone	Peak Horizontal Ground Acceleration
1	0.05g to 0.08g
2A	0.08g to 0.16g
2B	0.16g to 0.24g
3	0.24g to 0.32g
4	> 0.32g

Where "g" is the acceleration due to gravity.

Earthquakes damaged electrical power system all over the world. According to Shiro Takada *et al.*, (Takada, *et al*, 2004) the most vulnerable elements in electric supply substation are bushing made by porcelain used for circuit breaker, disconnect switch, circuit switcher and lightning arrester. October 08, 2005 earthquake was one of devastating earthquake in the history of Pakistan. A preliminary damage report (Pakistan 2005 Earthquake, Preliminary Damage and Needs Assessment, 2005) explains that damages occurred due to this earthquake are estimated at about Rs. 641.8 million. Alexis Kwasinski *et al.*, (Kwasinski, *et al*, 2014) discussed a series of three events, first Darfield event of M 7.0 occurred on 4 September 15 2010, second M 6.1 occurred on 22 February 2011 and third M 6.0 occurred on 13 June 2011. A lot of damage was recorded during these events.

2.2 Related Work

Shanfa Ruan *et al*, (Shanfa, *et al*, 2009) investigated the seismic capacity of high-voltage electric switch cabinet under 8 degree earthquake by shake-table test.

Maria Koliou *et al*, (Koliou, *et al*, 2011) discussed seismic response of transformer bushing system in both mounted on rigid base and "as installed" situation.

Giuseppe *et al*, (Parise, *et al*, 2013) explains different seismic qualification categories of electrical equipment and also defined equipment seismic levels.

2.3 Proposed Model

The objective of the present study is to strengthen the power system to remain operational during and after earthquakes.

In order to design structures and seismically qualify electrical equipment, three qualification levels are defined as "low", "moderate" and "high" (IEEE-693, 2005). Correlation of these seismic qualification

[++]Corresponding Author Noman Ullah email: engrnomankundi@gmail.com

levels to Building Code of Pakistan-Seismic Provisions (BCP-SP, 2007) is defined by Pakistan Electrical and Telecom Safety Code (PETSAC, 2014) and are illustrated in **(Table 2).**

Table 2: Seismic zoning and corresponding qualification levels.

Seismic Zoning①	Ground Acceleration	Qualification Level	
		Low and Medium Voltage	High and Extra High Voltage
Zone-1	0.05 to 0.08g	Low	Low
Zone-2A and Zone-2B	0.08 to 0.24g	Low/Moderate②	Moderate
Zone-3 and Zone-4	0.24 to > 0.32g Or > 0.24	Low/Moderate②	High

The electrical equipment selected for seismic qualification is "132kV Metal-Oxide Gapless Surge Arrester", Type: Y10W-120/295, manufactured by "Wenzhou Yikun Electric Company, Ltd, China".

The surge arrester unit is supported by a steel frame, composed of angle sections. Base steel plate of supporting structure is bolted at twelve points on the shake table. **(Fig.1,2)** shows surge arrester mounted on the steel structure and locations for instrumentation. Approximate weight of steel structure is about 200 kg (440 lbs.) and approximate weight of surge arrester unit is about 350 kg (770 lbs.). The surge arrester assembly is fitted with accelerometers and displacement transducers at two points, namely Point A and Point B. Point A is located at the top of the surge arrester and point B is located at the bottommost part of the steel structure as shown in **(Fig.1).**

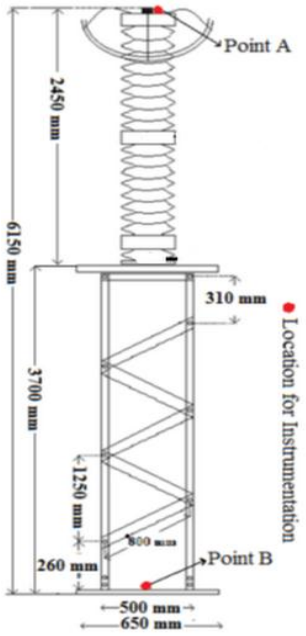


Fig.1: Sketch of surge arrester mounted on steel structure.

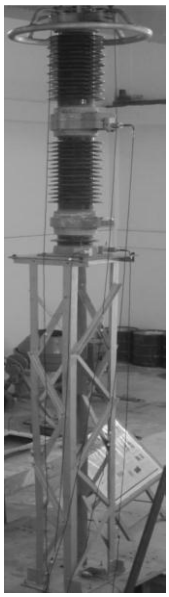


Fig.2: Surge arrester assembly mounted on shake-table for seismic qualification.

2.4 Analysis and Equations

Three types of tests are performed on the whole surge arrester assembly. Free vibration test is conducted to find damping ratio and natural frequency of the structure (Chopra, 2001). Natural frequency of assembly indicates the stiffness of structure. As explained by Equation 1.

$$f = \frac{1}{2\pi} * \sqrt{\frac{k}{m}} \qquad \text{Equation 1}$$

Where
f *is Frequency of the structure*
k *is Stiffness of the structure*
m *is Mass of the structure*
Equation 1 can be written as,

$$f \propto \sqrt{k} \qquad \text{Equation 2}$$

Equation 2 illustrates that frequency is directly proportional to the stiffness of the structure. If stiffness decreases frequency will decrease and vice versa. This type of test is conducted to examine the stiffness of the structure and ultimately examine the mechanical strength. Any mechanical damage or loss of stiffness can be evaluated by this test.

Time history shake-table tests with 50% intensity are conducted to demonstrate the effect of mechanical aging.

Time history shake-table tests with 100% intensity will actually explains the strength of whole surge arrester assembly and the important conclusion that whether the surge arrester assembly is able to withstand strong ground motions and can perform correct operational state during and after seismic event or its design should be updated.

For this purpose to find natural frequency and damping ratio whole assembly is subjected to free vibration test and data of accelerometers was recorded. Natural frequency and damping ratio were calculated by using Equation 3, 4 and 5.

$T = \frac{X_{i+N} - X_i}{N}$ Equation 3

Where

T is Time Period

X_{i+N} *is final value of X-Axis (time in Sec)*

X_i *is initial value of X-Axis (time in Sec)*

N is the total number of peaks

By utilizing this formula and data of accelerometers, time period is calculated, we get

$T = 0.4005\ Sec$

Now frequency is the reciprocal of time period, so

$f = 1/T$ Equation 4

$f = 1/0.4005$

$f = 2.5\ Hz$

Equation 5 given below is used to calculate damping ratio of the structure.

$\xi = \frac{1}{2\pi N} \ln(\frac{Y_i}{Y_{i+N}})$ Equation 5

Where

ξ *is Damping ratio*

Y_i *is initial value of Y-Axis (Acceleration in g)*

Y_{i+N} *is final value of Y-Axis (Acceleration in g)*

N is the total number of peaks

By utilizing this formula and data of accelerometers, damping ratio is calculated, we get

$\xi = 1\%$

The electrical equipment is to be qualified for the Peshawar (Khyber Pakhtunkhwa, Pak.) region and according to study about seismic qualification, electrical equipment of this voltage ratings shall be subjected to "Qualification Level Moderate". According to Pak. Electrical and Telecom Safety Code (PETSAC, 2014), Required Response Spectrum for damping ratio of 1% is calculated and plotted. After many attempts and iterations a time history was finalized that has time span of thirty seconds (30 Sec) and follows the requirements of Required Response Spectrum.

3. RESULTS AND DISCUSSION

Multiple time history shake-table tests are conducted on surge arrester assembly, free vibration test is conducted before, in middle and after time history shake-table tests. Five free vibration tests, five time history shake-table tests with 50% intensity (Test No. 1 to Test No. 5) and one time history shake-table test with 100% intensity (Test No. 6) are conducted on surge arrester assembly.

Values recorded from Point A accelerometer (Accelerometer No. 1) during all above mentioned time history shake-table tests are tabulated in **(Table 3),** absolute maximum displacements (from displacement transducer No. 1) at Point A are tabulated in **(Table 4)**.

Table 3: Point A acceleration values.

	Maximum Acceleration (g)	Time of Maximum Acceleration (Sec)	Sustained Maximum Acceleration (g)
Test No. 1 – Accelerometer No. 1	0.52	14.40	0.50
Test No. 2 – Accelerometer No. 1	0.47	18.95	0.45
Test No. 3 – Accelerometer No. 1	0.50	26.22	0.46
Test No. 4 – Accelerometer No. 1	0.50	26.25	0.42
Test No. 5 – Accelerometer No. 1	0.50	26.32	0.44
Test No. 6 – Accelerometer No. 1	0.80	20.15	0.66

Table 4: Absolute maximum displacements of Point A.

Test Number	Displacement Transducer Number	Absolute Maximum Displacement (mm)
1	1	54.05
2	1	60.13
3	1	58.97
4	1	63.72
5	1	60.84
6	1	140.34

Values recorded from Point B accelerometer (Accelerometer No. 2) during all above mentioned time history shake-table tests are tabulated in **(Table 5)** absolute maximum displacements (from displacement transducer No. 2) at Point B are tabulated in **(Table 6).**

Table 5: Point B acceleration values.

	Maximum Acceleration (g)	Time of Maximum Acceleration (Sec)	Sustained Maximum Acceleration (g)
Test No. 1 - Accelerometer No. 2	0.24	25.61	0.22
Test No. 2 - Accelerometer No. 2	0.24	14.99	0.20
Test No. 3 - Accelerometer No. 2	0.24	15.04	0.21
Test No. 4 - Accelerometer No. 2	0.23	25.92	0.21
Test No. 5 - Accelerometer No. 2	0.24	26.00	0.21
Test No. 6 - Accelerometer No. 2	0.36	25.64	0.30

Table 6: Absolute maximum displacements of Point B.

Test Number	Displacement Transducer Number	Absolute Maximum Displacement (mm)
1	2	39.66
2	2	44.45
3	2	46.19
4	2	47.64
5	2	48.06
6	2	96.92

Comparison of Required Response Spectrum, accelerometer No. 2 Response Spectrum and artificial earthquake Response Spectrum of 50% intensity tests (test No. 1 to test No. 5) illustrates that values of

acceleration for 50% Intensity tests are lower than Required Response Spectrum and artificial earthquake Response Spectrum for almost all the frequency range. This type of response is desired from 50% intensity tests because these tests are conducted to include the factor of mechanical aging.

Comparison of Required Response Spectrum, accelerometer No. 2 Response Spectrum and artificial earthquake Response Spectrum of test No. 6 (100% intensity) is shown in **(Fig.3)** and illustrates that values of acceleration of test No. 6 (100% intensity) is higher than Required Response Spectrum for almost all the frequency range. Moreover, as calculated by free vibration tests the whole surge arrester assembly's frequency is 2.5 Hz, the value of acceleration for 2.5 Hz of recorded accelerometer No. 2 data is greater than Required Response Spectrum acceleration value for the same 2.5 Hz frequency. So it is concluded that whole surge arrester assembly is excited fulfilling the requirements of Required Response Spectrum.

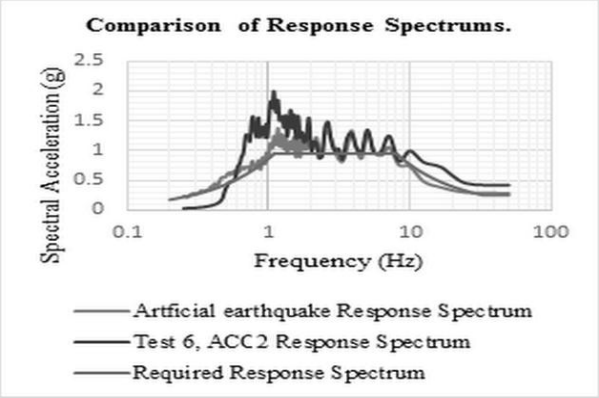


Fig.3: Comparison of Required Response Spectrum, accelerometer No. 2 Response Spectrum and artificial earthquake Response Spectrum (Test 6).

Five free vibration test are conducted. They are conducted before, in middle and after time history shake-table tests. These tests are conducted to find natural frequency of the structure and helps us to evaluate the stiffness of the structure. **(Table 7)** summarizes the natural frequency of the structure calculated from free vibration test's data.

Table 7: Summary of structure frequency through-out free vibration tests.

Test Number	Frequency (Hz)
Free vibration test No. 1	2.52
Free vibration test No. 2	2.54
Free vibration test No. 3	2.53
Free vibration test No. 4	2.53
Free vibration test No. 5	2.50

According to **(Table 7)** slight change in frequency is observed which may be due to noise generated by the instrument or may be due to other electrical interferences. This slight change is in the acceptable limits and is neglected.

4. CONCLUSION

No degradation or mechanical damage observed visually in the whole surge arrester assembly. Moreover, free vibration test shows slight frequency variations that may be due to noise in the electrical circuit or other electrical interferences. This slight change is in the acceptable limits and is neglected. As the natural frequency of the surge arrester assembly is almost constant which means that stiffness of the structure is not changed and is same as it was before shake-table testing. This helps us to conclude that surge arrester assembly was perfectly intact with shake-table before and after time history shake-table testing. It is concluded that surge arrester assembly of this design is "Seismically Qualified" for "Seismic Qualification Level Moderate".

REFERENCES:

Asian Development Bank and World Bank, (2005), "Pakistan 2005 Earthquake, Preliminary Damage and Needs Assessment," Islamabad.

Building Code of Pakistan – Seismic Provisions, (BCP-SP, 2007), Islamabad: Pak. Engineering Council.

Chopra, A. K. (2001), "Dynamics of Structures Theory and Applications to Earthquake Engineering," New Jersy, USA: Prentice-Hall Inc.

Kwasinski, A., J. Eidinger, T.Alex, and T.B. Christophe, (2014), "Performance of Electric Power Systems in the 2010–2011 Christchurch, New Zealand, Earthquake Sequence," Earthquake Spectra, Vol. 30, 1, 205–230.

Koliou, M., A. Filiatrault, and A. M. Reinhorn, (2011), "Seismic Protection of Electrical Transformer-Bushing Systems Incorporating Flexural Stiffeners," 8th International Conference on Structural Dynamics, Leuven, Belgium, 227-233.

Pakistan Electrical and Telecom Safety Code, (PETSAC-2014), Islamabad: Pak. Engineering Council.

Parise, G., L. Martirano, M. De Angelis, and A. Reggio, (2013), "Seismic Qualification Categories (EQC) of Electrical Equipment," Industry Applications Society Annual Meeting, 1-7, Lake Buena Vista, FL: IEEE.

Recommended Practice for Seismic Design of Substations, (IEEE Std 693-2005).

Shanfa, R., W. Meiying, D. Miaolin, and Z. Jiyong, (2009), "The Study on a Seismic Test of High-Voltage Electrical Switch Cabinet," Power and Energy Engineering Conference, Asia-Pacific, Wuhan, 1-6.

Takada, S., M. Bastami, Y. Kuwata, and M. B. Javanbarg, (2004) "Performance of electric power systems during the bam earthquake and its fragility analyses," Memoirs of Construction Engineering Research Institute No.46 161-152.