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Seismic response evaluation of substation equipment

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Electrical and telecommunication facilities are observed from the past earthquake data, as seismically weak and prone to service failure due to suddenly applied seismic loads. Among them substation equipment are the most vulnerable ones. A need for reliability of electrical equipment against vibrational hazards due to earthquakes has become prime importance. In order to meet the basic requirements regarding seismic qualification of equipment and thereby to ensure reliable power transmission, Earthquake engineering laboratory capable of performing a diverse range of seismic qualification requirements on equipment, sub-assemblies and components as per National and International standards has been established at CPRI, Bangalore. Seismic qualification of few equipment carried out are presented.

Keywords: *seismic qualification, natural frequency, 36 kV circuit breaker, substation equipments.*

1.0 INTRODUCTION

Many earthquakes have caused massive damage to the high voltage installations and electrical equipment around the world. However not much attention is given in our country in preventing such damages to electrical installations caused by earthquakes to prevent disruption in power supply for many days during the critical phase of rescue operation. The reliability and safety of electrical transmission and distribution systems after an earthquake depend on the seismic response of individual substation components such as transformer bushings, switchgears etc,. Hence Equipment and supporting structures for power generating stations, transmission installations and substations located in seismically sensitive regions / zones have to be designed to withstand possible earthquakes. Procedure used to verify the seismic design of equipment includes simulations based on the finite element method combined with either response spectrum or time history analysis and shake table testing.

CPRI is equipped with the state-of-the-art facilities for model or real size testing of structures, components and electrical equipment using a seismic shaker table. The state-of-the-art facilities available at CPRI and shake table tests carried out recently in connection with seismic qualification of electrical equipment are presented in this paper.

2.0 IMPORTANCE OF SEISMIC QUALIFICATION

Engineering design of electrical equipments and their supporting structures due to earthquake is a unique and complex problem. The loading caused due to an intense earthquake is abnormal to which most engineering structures might possibly be subjected. However statistically speaking, the probability that any given structure will be affected by the major earthquake is very low. Therefore, only the critical equipments and structures are designed to resist major earthquake and others to the intensity of moderate earthquake.

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Satisfying this demand is a challenging job to the project engineer.

The assessment of the seismic vulnerability of electrical power equipments is a very complex issue due to the non-deterministic characteristics of the seismic action and the need for an accurate prediction of their seismic responses. The major developments in earthquake engineering have occurred in last four decades. This has been possible as a result of combination of factors such as installation of strong motion instruments world over in active seismic areas, as a result sizeable amount of ground motion data is available, development of basic principles of seismic design, developments in mathematical modeling, dynamic analysis, shake table testing, , seismic isolation and energy dissipating devices [1]. The availability of high-speed digital computers has played a vital role in these developments. Besides, study of behaviour of equipments and supporting structures and their performance in past earthquakes have provided a wealth of information on earthquake protection and safety.

3.0 SEISMIC QUALIFICATION APPROACH

The seismic qualification of equipment should demonstrate equipment's ability to perform its safety function during and after the time it is subjected to the forces resulting from earthquakes. The most commonly used methods for seismic qualification are grouped into four general categories that

- Predict the equipment's performance by analysis
- Test the equipment under simulated seismic conditions
- Qualify the equipment by a combination of test and analysis
- Qualify the equipment through the use of experience data

Each of the preceding methods or other justifiable methods may be adequate. The choice of selection of method to verify the ability of the equipment to meet the seismic qualification requirements is generally based on the practicality of the method for the type, size, shape and complexity of the equipment configuration. The analysis method is not generally recommended for complex equipment that cannot be modeled to adequately predict its response. Analysis is acceptable only if it is not possible to conduct shake table testing due to limitation of the test system.

4.0 SEISMIC QUALIFICATION OF SUBSTATION EQUIPMENT

Shake table test is more realistic method of earthquake testing than pseudo dynamic method. The shake table test is economic, tangible, and reliable validation test to assess the seismic safety and reliability of structures and equipment. Specimens of interest are mounted on the table and tests are carried out simulating design or postulated earthquakes. The dynamic behavior of the structure or equipment and its damage pattern under earthquake can be reproduced [2]. Extensive shake table tests are conducted to study earthquake resistant design of civil engineering structures and to qualify electrical equipment, control systems, switching relay banks, electrical control panels etc., To prevent failure of substation equipment and thereby ensure reliable power supply after earthquake, the International standards like International Electro technical commission (IEC) TR 62271-300, Standard 61463 and Institute of Electrical & Electronic Engineers (IEEE) Std. 693 recommend testing of substation equipment along with the support structure for the site specific response spectra or peak ground acceleration using Shake table. They define qualification seismic levels, qualification procedures and acceptance criteria of all components of substation. Seismic levels have to be identified before test based on voltage capacity rating, physical properties and the seismic zone. The IEEE Standard recommends that sites with projected ground motions above 0.1g should have their equipment seismically qualified. Thus power utilities with service areas in seismic Zone III, IV and V (as per IS 1893:2002) should have their equipment seismically qualified. One of the most effective ways of reducing earthquake damage for new installations is to use equipment that has been seismically qualified.

4.1 Testing

For engineering purposes, the time variation of ground acceleration is the most useful way of defining the shaking of the ground during an earthquake. The behaviour of the structures depends on the earthquake excitation given to its base during earthquake [3]. Shake tests are performed by subjecting equipment to vibratory motion that conservatively simulates that postulated at the equipment mounting during an earthquake. One practical problem that arises when attempting to establish the tests to be used to qualify equipment is the choice of the earthquake environment. Many factors to be considered are location of the equipment, the nature of the equipment, the nature of expected earthquakes, and others. An additional consideration is whether the equipment is to be used in one application or many. When the equipment is used on only one application the seismic motion can be specified and the qualification test can be chosen to meet the specification (proof-testing). When the equipment is used in many applications, the test should be designed to qualify the equipment for future undefined applications (generic testing). Fragility testing is conducted to determine the limit of the equipments capabilities.

4.1.1 Mounting

The equipment to be tested is mounted on the vibration table in a manner that simulates the intended service mounting. The mounting method is same as that recommended for actual service, and the recommended bolt size, type torque, configuration and weld pattern and type are used.

4.1.2 Preliminary Dynamic Tests:

Though exploratory vibration tests are generally not part of the seismic qualification requirements, but are carried out on equipment to determine the the dynamic characteristics of the equipment. These low input level vibration tests are normally described as resonance searches. This test is performed as a slowly swept sinusoidal vibration test with the input uni-axial. The equipment responses are measured to determine resonances.

4.1.3 Monitoring

Functional and vibrational response parameters are continuously monitored during seismic testing. Accelerometers and strain gauges are mounted at critical locations and their responses are monitored during testing using data acquisition system. In addition sufficient monitoring instrumentation are used to evaluate the functionality of the equipment before, during and following its vibration test exposure.

5.0 TRI-AXIAL SHAKER SYSTEM AT CPRI

Earthquake engineering laboratory housing the tri-axial shaker system with six degrees of freedom,capable of performing a diverse range of seismic qualification test requirements on equipment, sub-assemblies and components as per National / International standards had been established at Central Power Research Institute CPRI, Bangalore in the year 2003. The tri-axial shaker system consisting of a shaking-table is a unique facility only one of its kind in India that can strictly simulate the earthquake ground motion without any distortion. A typical view of the laboratory is shown in Figure 1.

The shaking table can vibrate in one axis to three axes with six degrees of freedom. The advanced control system allows the reproduction of earthquake ground motions with high fidelity and little distortion.. The seismic qualification tests on various electrical equipments are being conducted using the tri-axial earthquake simulation system, which features a 10-ton pay load capacity shake table of all-welded steel construction. An advanced control system allows the reproduction of earthquake ground motions with high fidelity.

6.0 SEISMIC PERFOMANCE OF CIRCUIT BREAKER

A typical 36 kV outdoor Circuit Breaker with support structure has been identified for shake table tests and finite element analysis. Steel support structure of 1.7m height with bracings is fabricated using mild steel sections. The circuit breaker has three porcelain hollow cylinders separated with steel spacers. The Circuit Breaker with support structure was mounted on the Tri-axial Shake table as shown in Figure 1.

FIG. 1 CIRCUIT BREAKER WITH SUPPORT STRUCTURE MOUNTED ON SHAKE TABLE

Accelerometers were mounted on top and bottom part of the porcelain element and at the top of the support structure to monitor and record dynamic response of the Circuit Breaker. Sine sweep test (Resonant frequency search test) was conducted on the equipment varying the frequency at the rate of one octave/minute from 1 Hz to 35 Hz maintaining acceleration at constant magnitude of 0.1g to determine the resonant frequencies and damping of the equipment. The parameters sine sweep test carried out are listed in Table 1. Structural response in terms of acceleration and strain has been monitored from strain gauges and accelerometers at the pre identified locations as per the recommendations of relevant standards. The data obtained from this test are an essential part of an equipment qualification; however, the test does not constitute a seismic test qualification by itself.

TABLE1

PARAMETERS FOR SINE SWEEP TEST

Type of vibration	Sinusoidal sweep
Axis of vibration	X, Y & Z
Frequency (range)	1.0 to 35 Hz
Acceleration (Peak)	1.0 m/s^2
Sweep rate (Log)	1.0 Oct/minute
Number of Sweeps	One
Status of test sample during testing	Non-energized

Sine sweep test was conducted in both vertical and horizontal axes. The resonance frequencies identified are shown in Table 2. The seismic test was conducted on the circuit breaker mounted on support structure as per the recommendations of IEC TR 62271-300 (1992-93) for AF5 (zero peak acceleration) qualification level at damping value of 5%for a duration of 30s [4]. The recommended response spectra of IEC simulated on the shake table is shown in Figure 2 and Figure 3. The seismic response of the equipment and the structure was recorded. After successful testing of the circuit breaker, the specimen was certified as seismically qualified.

TABLE 2

RESONANCE FREQUENCIES

Sl.No.	Axis	Resonance Frequencies (Hz)
1	X-Axis	5 and 13
2	Y-Axis	5 and 13
3	Z-Axis	No resonance below 50 Hz

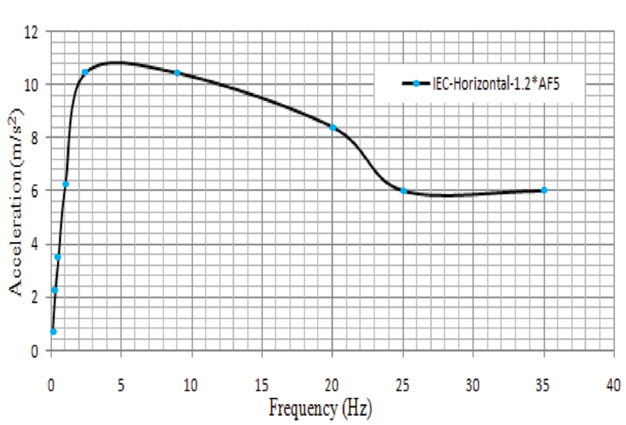

FIG. 2 IEC AF5 AT 5% DAMPING IN X & Y DIRECTIONS APPLIED TO THE TABLE

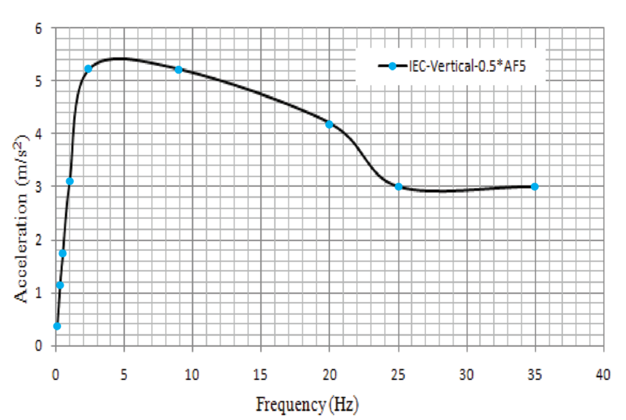

FIG. 3 IEC AF5 AT 5% DAMPING IN Z DIRECTION APPLIED TO THE TABLE

7.0 CONCLUSIONS

A series of tests have been performed using shake table to determine the seismic performance of the equipment. To sum up it may be stated that earthquake is a natural and unpredictable phenomenon which may occur at any time. The havoc caused by earthquake to living being (human and animals) and infrastructures is ineffable. It is only through seismic qualification of equipment (design and testing) and supporting structures, loss to human life and equipments can be minimized. Power utilities may utilize the state-of-the-art facilities available at CPRI to ensure reliable power supply to their customers.

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