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Seismic Qualification of Busbar Trunking System

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Earthquake results in multifrequency vibratory ground motion at the earth's surface, having both horizontal and vertical components. Three dimensional random earthquake vibration induces stress in the electricale quipment, components, and structures causing massive damage. Dynamic loading due to earthquake should be taken into consideration while designing electrical system. This will ensure uninterrupted power supply and safety, during and after the event of earthquake. Busbar trunking systems are utilized in high rise buildings, hospitals and industrial applications to distribute power to electrical loads. Sandwich busbartrunking systems are alternative to conventional power cabling. Seismic behaviour of Busbartrunking system depends on support, support structure, anchoring etc. Seismic qualification of Sandwich Busbartrunking system is presented in this paper.

Keywords: *Sandwich busbar, resonance search, time history test*

1.0 INTRODUCTION

Earthquakes are caused by the sudden rupture of a geologic fault. Shock waves radiate from the fault fracture zone and arrive at the earth's surface. Enormous energy is released during breaking of tectonic plates, which travels in the form of waves through the surface of earth causing damage. The amplitude of the shaking caused by an earthquake depends on many factors, such as the magnitude, distance from the epicenter, depth of focus, topography, and the local ground conditions. Earthquakes produce three-dimensional random ground motions that are characterized by simultaneous but statistically independent horizontal and vertical components. Frequency content of earthquake random vibration is usually less than 33 Hz with most of energy distributed at lower frequencies. Level of expected earthquakes in any region can be estimated based on topography and the local ground conditions.

Earthquakes have caused massive damage to the buildings, industrial structures and electrical equipment. Structures and equipment should be designed for expected level of earthquake to avoid failure. Design and testing of electrical equipment and components for seismic loading becomes very important for the substations located at active seismic zone. Functioning of electrical equipment during and after earthquake ensures uninterrupted power supply which is highly essential for timely rescue operation and functioning of critical facilities such as hospital, nuclear power plant etc.

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, Bengaluru. Using this facility seismic qualification of instrument transformer,

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transformer bushing, lightning arrestor, isolator, circuit breaker, tap changer, busbar system etc. are carried out. Seismic qualification of LV sandwich busbar trunking system as per IEEE standard 693-2005 – "IEEE Recommended Practice for Seismic Design of Substations" is presented below.

2.0 SANDWICH BUSBAR TRUNKING

Sandwich busbar trunking system is a prefabricated electrical distribution system consisting of busbars in a protective enclosure. Busbar trunking systemincludes straight lengths, elbow, reducer, T-section, joint, end cover, tap off box, etc.Sandwich busbar trunking systems are utilized in high rise buildings, hospitals and industrial applications to distribute power to electrical loads. Sandwich bus trunking systems are replacement to conventional power cabling. Busducts are safe, compact, flexible and efficient for electrical power distribution. Electrical power distribution by cabling is being replaced by busduct system due to high reported fire cases.

Seismic response evaluation of busbar trunking should be carried out by considering busbar system as a whole with straight length, elbow, T-section etc., along with various types of supports, spring hangers and method of anchoring used. Seismic design of busbar trunking system and validation of design by shake table test will ensure uninterrupted power support to the critical facility during crucial post earthquake time. It is also essential to standardise the method of mounting, supporting arrangement and anchoring system.

3.0 CODAL RECOMMENDATION

Seismic qualification of substation equipment and components can be carried out as per the IEEE standard 693-2005 – "IEEE Recommended Practice for Seismic Design of Substations". Seismic qualification procedures and functional requirements are defined in this standard for different substation equipment. Annexure B of the standard may be used to qualify equipment that are not specifically listed. Generalized frequency response spectrum for two qualification levels, high qualification level (0.5 g) and moderate qualification level (0.25 g) are recommended in this standard.

IEEE standard 344-2013 – "IEEE standard for Seismic qualification of equipment for nuclear power generating stations". Equipment and structures used in nuclear power generating stations which are highly critical in nature are seismically qualified as per IEEE standard 344.

IS 1893, Part 1- 2002 "Criteria for earthquake resistant design of structures" deals with assessment of seismic loads on various structures. Seismic zones of India are defined for assessment of seismic load at different locations.

In addition to this, seismic qualification can also be carried out to the country specific zone levels.

4.0 TRI-AXIAL SHAKER SYSTEM

The seismic qualification is verifying the equipment's ability to perform its specified function during and/or after the specified seismic motions. Seismic qualification of equipment and structure can be carried out by finite element method of analysis, testing under simulated seismic conditions using shake table, combination of testing and analysis and by using experience data [1]. Electrical equipment are complex in nature, hence seismic qualification by testing is recommended.

The equipment to be tested is fixed to a moving platform called shaking table to which a motion history representative of past seismic events or artificial time history is applied.The test on a shaking table has the advantage of being dynamically similar to a real earthquake event. Seismic ground motion occurs simultaneously in all directions in a random fashion. 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 had been established at Central Power Research Institute CPRI, Bengaluru. The seismic qualification tests on various equipment and products are being conducted using the tri-axial earthquake simulation system. Table size is 3mx3m and test specimen weighing upto 10 ton can be seismically qualified. Maximum height of test specimen can be 10m, which makes it possible to test tall slender substation equipment like instrument transformers, breakers etc. Real time earthquake ground motion can also be reproduced using tri-axial shaker system.

5.0 SEISMIC QUALIFICATION SANDWICH BUSBAR TRUNKING

Seismic qualification by shake table test is carried out by mounting the equipment on tri-axial shake table and simulating three dimensional random vibration. Resonance frequency search test is to determine the dynamic characteristics of the equipment and it is a part of seismic qualification. Seismic test is a simultaneous three directional time history test. Spectrum compatible time histories are generated for simulating earthquake vibration. Functional test are performed before, during and after seismic test to evaluate performance of equipment.

5.1 Description of Sandwich Busbar System

Seismic qualification was carried out for three phase, 4 wire, 1000 V, 2500 A, sandwich insulated copper busbar system having horizontal orientation,vertical orientation, elbow and 250 A MCCB tap off box. Length of horizontal busbaris 1000 mm and vertical busbaris 1500 mm. Busbars are provided with supports and in case of vertical oriented busbar, spring hanger are provided in addition to supports.

5.2 Mounting

Sandwich busbar system is mounted on tri-axial shaker system as shown in in Fig.1. 'L' shape support structure is used for mounting the busbar on shaker system. Seismic qualification should be carried out with equipment mounted in the identical manner as it would be in field condition. Equipment mounted on support structure will experience acceleration several times more than ground acceleration during earthquake. When equipment is mounted on support or variety of supports and parameters of the supports are not known, seismic qualification can be carried out without support. Under this condition seismic qualification is carried out at 2.5 times the requirements specified in the standard. Sandwich busbar system is supported by variety of supports, support height is unknown and dynamic parameters of the support are also unknown, hence seismic qualification is carried out with super elevation factor of 2.5. Accelerometers and strain gauges were mounted on busbar during seismic qualification. Accelerometers were mounted at ends of horizontal and vertical busbar and on tap off box to measure response acceleration during time history test and also to determine resonance frequency. Strain gauges were mounted to measure strain at the critical location.

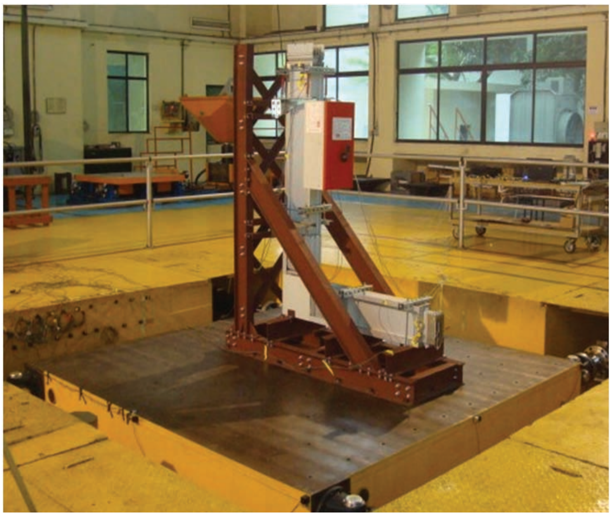

FIG.1 SANDWICH BUSBARSYSTEM MOUNTED ON SHAKE TABLE

5.3 Functional check

Circuit resistance measurement, Power frequency withstand voltage test and Insulation resistance measurement were carried out for sandwich busbar before and after seismic qualification. Circuit resistance value before and after test are shown in Table 1. During seismic test busbar was under energized condition. Three phase power supply was connected to horizontal busbar and voltage at plugin box was monitored. No interruption in voltage was noticed.

TABLE 1		
CIRCUIT RESISTANCE, MΩ		
POINT	BEFORE SEISMICTEST AT 30 ^{O}C	AFTER SEISMIC TEST AT 29 ^{O}C
R-phase	45.72	43.00
Y-phase	45.03	42.94
B-phase	45.14	43.44
Neutral	46.55	43.04

5.4 Resonance search test

Resonance search test is carried out before seismic test to find natural frequency and damping. Resonance search test is also carried out after seismic test to check change in natural frequency. Change in resonance frequency indicates structural changes and it is one of the parameters to determine structural changes.

Resonance search is carried out by base excitation method. Low level sinusoidal excitation with constant acceleration (typically 0.1 g), frequency sweep from 1 to 33 Hz at 1 Oct/minute sweep rate is used for resonance search test [2]. During sinusoidal sweep, table acceleration and response acceleration on the busbar were recorded and resonance frequencies were computed. Resonance frequencies found before and after test are shown in Table 2 and 3. Typical resonance search test graph is shown in Fig.2. Marginal change in natural frequency is noticed.

TABLE 2		
RESONANCE FREQUENCIES BEFORE SEISMIC TEST		
LOCATION	DIRECTION	RESONANCE FREQUENCY, HZ
Vertical busbar	North-south	7.75
	East-west	22.00
	Vertical	NR*
Horizontal busbar	North-south	33.75
	East-west	22.00
	Vertical	NR

* NR – No resonance found

5.5 Time history test

Sandwich busbar system was subjected to tri-axial time history test as per IEEE Std 693 for highrequired response spectrum (RRS), 0.5g. Sandwich busbar system is supported by variety of supports, and parameters of the support are also unknown, hence seismic qualification is carried out with super elevation factor of 2.5, that is RRS with zero period acceleration of 1.25g in horizontal direction and 1g in vertical direction (80% of horizontal). Spectrum compatible time histories were generated as per standard procedure and tri-axial time history test simulated. Required Response Spectrum (RRS) and Test Response Spectrum (TRS) for horizontal axis is shown in Fig.3. TRS envelops RRS from 1.5 Hz onwards.

TABLE 3		
RESONANCE FREQUENCIES AFTER SEISMIC TEST		
LOCATION	DIRECTION	RESONANCE FREQUENCY, HZ
Vertical busbar	North-south	7.00
	East-west	21.00
	Vertical	NR
Horizontal busbar	North-south	32.50
	East-west	21.50
	Vertical	NR

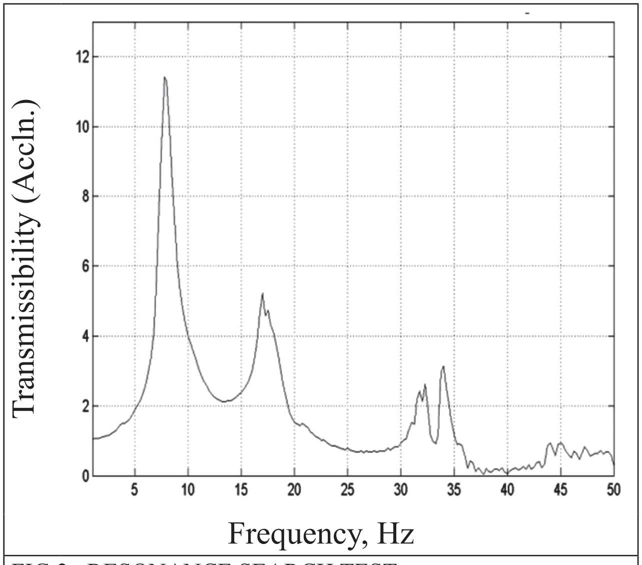

FIG.2 RESONANCE SEARCH TEST

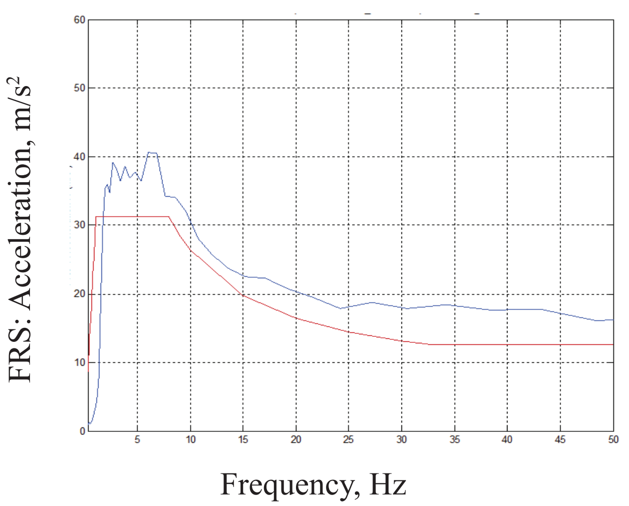

FIG.3 RRS AND TRS

5.6 Acceptance criteria

Functional electrical acceptance criteria: Circuit resistance measurement, Power frequency with stand voltage test and Insulation resistance measurement results before and after seismic qualification are within acceptable limit. During seismic test busbar voltage was monitored using high speed data logger and no interruption in voltage was noticed.

Mechanical acceptance criteria: Change in resonance frequencies are within 20% as per standard requirements. Addition to this no permanent deformation, dislocation, breakage or cracks noticed.

6.0 CONCLUSIONS

Sandwich busbar system is supported by variety of supports and dynamic parameters of the support are unknown. Seismic qualification of busduct is conducted at 2.5 times the requirements of the standard. Supports should be designed such that the maximum amplification of earthquake vibration is less than 2.5 times the ground acceleration to avoid failure. Designing of busduct system for seismic loading and validation of design by testing can prevent the failure of busduct system in the event of an earthquake. This will ensure uninterrupted power supply for critical facilities like hospitals and hence loss of human life can be minimised. Power utilities may utilize the state-of-the-art facilities available at CPRI to ensure reliable power supply to their customers.

ACKNOWLEDGEMENT

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REFERENCES

[1] IEEE standard 344-2013 – "IEEE standard for Seismic qualification of equipment for nuclear power generating stations".

[2] IEEE standard 693-2005 – "IEEE Recommended Practice for Seismic Design of Substations"