International Journal of Advance Engineering and Research Development
Scientific Journal of Impact Factor (SJIF): 4.72
Special Issue SIEICON-2017,April -2017
e-ISSN : 2348-4470 p-ISSN : 2348-6406

Seismic Evaluation of Oil Filled Transformer

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Abstract: *The application of the transformer covers large spectrum of industries. Hence thelocation of the erection of transformer assemblies varies from sea level to the very highon the mountain. Almost all regions experience the earthquake with varying severity.This seismic activity will affect the functionality of a transformer. It may fail underaction of earthquake. So, step by step procedure for calculating required foundation bolt size under the effect of seismic and wind loading should be developed. Hence this research is about the developing methodology to determine the foundation bolt size fortransformer. For the performance of transformer assembly under the event of earthquake, therequired foundation bolt size has been evaluated for particular model of the transformerusing static equivalent method.*

Keywords: *Seismic Evaluation, Oil Filled Transformer, Transformer Foundation, Transformer, Foundation Design*

I. INTRODUCTION

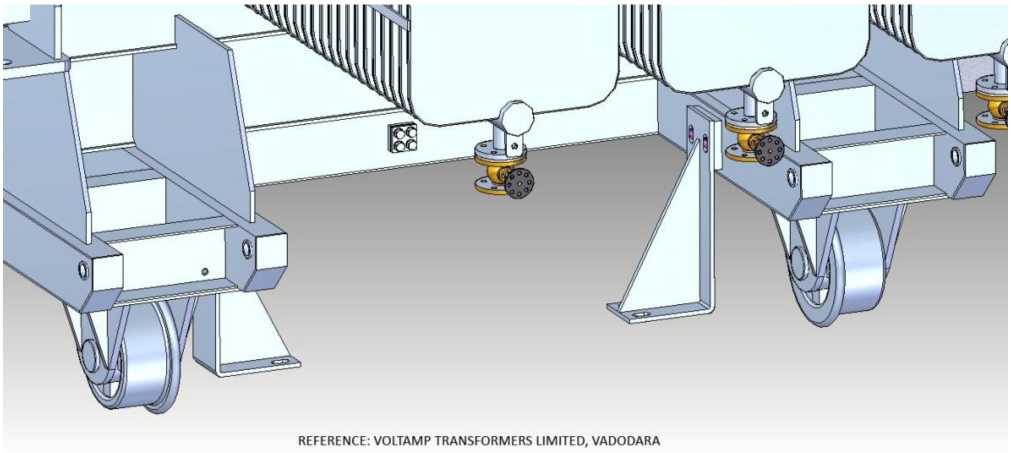

Figure 1. Present Earthquake Resisting Arrangement

The industry is presently designing the transformer foundation arrangement providing the L-shaped plate support and grounding them on concrete floor by means ofM20x190long bolts. As the transformer assembly is mounted in various regions withdifferent geological properties, it is required to obtain proper methodology to calculate the proper foundation bolt which will resist the effect of seismic loadings on thetransformer assemblies at the event of the earthquake.
The methodology for calculating the foundation bolt sizes is to be developed underseismic loading condition.

II. LITERATURE REVIEW

"Seismic qualification of transformer high voltage bushing"[1] as the name of the article indicates itself that a complete understanding about the effect of earthquake on transformer bushing is explained briefly. This article shows the FEA of transformer high voltage bushing. As it is very necessary that the transformer maintains its functionality under the effect of earthquake also. So seismic evaluation of transformer is necessary. This article shows the seismic analysis of transformer bushing with the help of FEA.

"Manual on Transformers"[2] contains complete criteria to design the transformer according to various Indian Standards. This book is very useful for transformer design in transformer industry. One can get idea about complete procedure of erection, commissioning and maintenance of transformer.

Similarly the "Transformers"[3] published by BHEL, Bhopal is another good book on transformer. In this book one can get practical knowledge as well as theoretical knowledge about the transformer. In this book one learns about principles of transformer, material used in transformer, electrical accessories used in transformer, cooling arrangement, design procedure, testing, standards used, erection commissioning and maintenance of a transformer.

"Engineering Mechanics of Solids"[4] is very advanced book of mechanics of solids. Author Popov has described all the aspects very good. One can get idea about solution of various problem related to strength of material.

Many formulas related to designing of various mechanical components used in any industry are given in "Design data hand-book (for mechanical engineers)"[5].

"Westermann tables"[6], this handbook gives us formulas and basic concepts of physics and mechanical engineering, which are very useful for basic understanding for mechanical engineers.

Very good fundamental aspects of machine design are given in "Design of Machine Elements"[7] by author V.B.Bhandari. One can get very useful information about various loadings arrangements and their calculations in this book.

In IS 2062,2006[8] complete specification of hot rolled low, medium and high tensile structural steel is given. From this various mechanical and chemical properties of steel of various grades used in industry can be referred.

"Standard terminology for power and distribution transformers"[9], standard terminology for power and distribution transformers are given in this standard. This is known as IEEE C57.12.80 - 2010.

"IS 1893 part-2"[10], this standard explains complete design of earthquake resisting structure for liquid retaining tanks. As transformer falls under this category, the earthquake resisting arrangement for transformer can be obtained with the help of this standard.

Different values of coefficients and factors used in design of building and structures are available in "IS 1893 part-1"[11]. Values of zone factor and response reduction factor for different severity of earthquake are given in this standard.

A complete Seismic calculations on ABB bushing mounted on a transformer tank cover[12]is given in this literature. This is a product information catalogue published by ABB, Sweden. Step by step procedure is given in very easy manner.

As transformer also falls under category of liquid retaining tank, IIT Kanpur and Gujarat state disaster management authority published a useful literature "Guidelines for seismic design of liquid storage tanks"[13]. One can get value of response reduction factor for different type and configuration of liquid retaining tanks.

III. TRANSFORMER FOUNDATION SEISMIC EVALUATION

The stable supply of electricity is an increasing social need in industrialised countries.If facilities are damaged by an earthquake, the supply of power is stopped for a considerable period of time, and it will have a disastrous influence over the social activitiesin the area. Therefore, seismic resistance of electrical equipment is of major concernwith respect to ensure operation of electric power systems during and after even a verysevere earthquake.

It has been recognised that earthquakes are not evenly distributed over the earth.The earth's surface plates move relatively eachother and stresses are built up in therocks. Rock is elastic and can, up to a point, accumulate strain where adjacent areas ofrock are subjected to forces pushing and pulling them. Sometimes, for reasons that arenot understood, seismic energy is released slowly and the rocks slide past each other.At other times, the seismic energy is released violently over a period of seconds as therocks ruptures, producing an earthquake.

For design purposes the best information has been obtained from strong motionrecords of acceleration relatively near epicentre of the earthquake. For a major earthquake the peak acceleration (ZPA = Zero Period Acceleration) is 0.3-0.5g (3-5 m/s^2)and for moderate one about 0.2g (2 m/s^2). Other well known measure of an earthquakemagnitude like Richter magnitude and Intensity scales are not well suited for designpurposes and there is no connection capable of being used between the Richter scaleor the Intensity scale and the peak acceleration of an earthquake.

IV. SEISMIC COEFFICIENT ANSLYSIS

This method normally adopted for rigid equipment, but it may also be used for flexible equipment, as a method of which allows a simpler technique in return for addedconservatism (According to IEC 61463).

A useful analytical procedure for assessment of the seismic load is the ResponseSpectrum Method. The response reduction factor R, is taken from can be taken fromTable 7 - IS 1893 Part I.

This response is then multiplied by a static coefficient s_c which has been establishedfrom experience to take into account of both multifrequency excitation and multimoderesponse. The value of s_c depends on natural frequency of transformer. But if thenatural frequency is not known, the conservative value of the static coefficient, s_c= 1.5shall be used.

V. PROBLEM FORMULATION AND SOLUTION

For better understanding of use of this method, a particular model is selected.
For that consider a transformer tank having following dimensions.
Lengh of tank : 4000 mm
Width of tank : 2000 mm
Height of tank : 3000 mm
All plates of transformer tank are 10 mm thick.

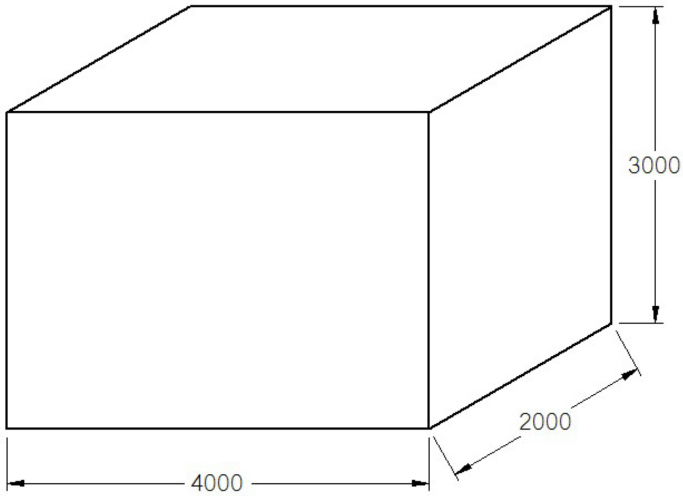

Figure 2. Transformer Tank

In order to find-out total mass of a transformer, mass of steel tank and mass of oil filled in the transformer should be found-out. Following data are derived by analytical calculations.

5.1. Mass of Transformer

Mass of steel tank = 4082kg.
Mass of oil = 20915kg.
Total mass of transformer = Mass of steel tank + Mass of Oil = 24997kg.

5.2. Seismic Loading[12]

5.2.1. Horizontal Loading

$$F_h = m \times K \times A_{hg} \times R \times s_c$$

$$F_h = 24997 \times 1.5 \times 5 \times 2.5 \times 1.5 = 703040N$$

5.2.2. Vertical Loading

$$F_v = (m \times K \times A_{vg} \times R \times s_c) + (m \times g)$$

$$F_v = (24997 \times 1.5 \times 2.5 \times 2.5 \times 1.5) + (24997 \times 9.81) = 596740N$$

5.2.3. Resultant Loading

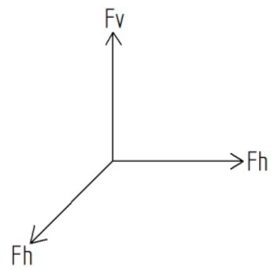

Figure 3. Components of Seismic Loading

For combine effect of horizontal loading, vertical loading and gravity, the resultantforce is to be derived.

$$F_r = \sqrt{F_h^2 + F_h^2 + F_v^2} = 1159581N$$

This load is to be applied at the centre of gravity location of the overhung structure of the tank fitted with the oil. The transformer is supplied with 8 foundation bolts.The schematic diagram is as shown in figure 4.

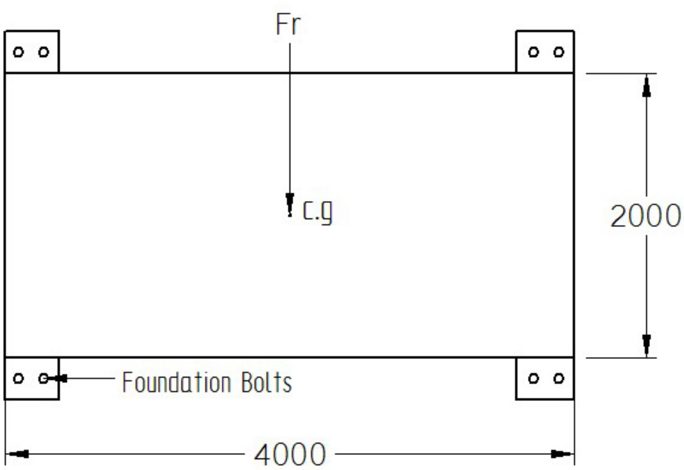

Figure 4. Top view of tank with loading and 8 foundation bolts

Above figure shows the top view of a transformer tank. At every corner the foundation bolts are provided to fix the transformer to the ground. There are total 8 bolts inthis arrangement, 4 on each side of the tank. Now as the resultant force due to seismicactivity acts on the centre of gravity of a tank.

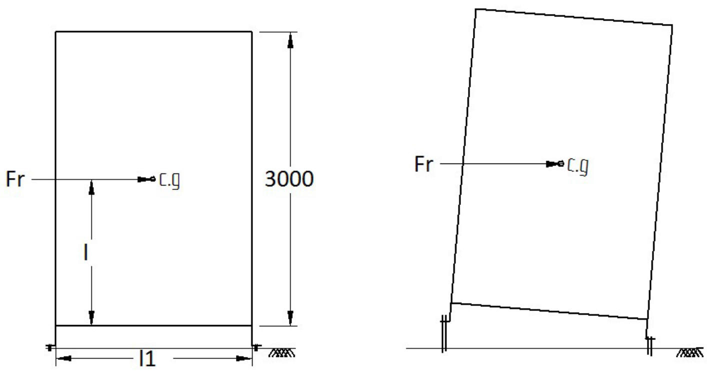

Figure 5. Effect of seismic load on transformer tank

5.3. Stress Calculation

In figure 5, it is clearly seen that as the force acting on centre of gravity of a oil filledtank, it tries to bend. Which creates tensile stresses in the foundation bolts. Each boltis stretched by amount δ, which is proportional to its distance from the tilting age.

In figure 5, let's consider the distance is measured from the right hand side anchored bolt. So the distance l_2 becomes zero and distance l_1 can be taken same as thewidth of the tank. There are 4 bolts on each side (i.e. LHS and RHS).

Here,

l = 1500mm

l_1 = 2000mm

l_2 = 0mm

F_r= 1159581N

By considering bolt size M30 for foundation after many trials, following values of stresses are derived

- Maximum Tensile Stress = 387MPa
- Shear Stress = 258MPa
- Maximum Shear Stress = 376MPa.
- Factor of Safety = 1.55

The value of factor of safety shoul be 2. So, there is requirement of increasingnumber of bolts or the size of bolts.

By increasing 2 nos. of bolts on both sides of a transformer tank, the arrangement is as shown in figure 6 and calculate the stresses again.

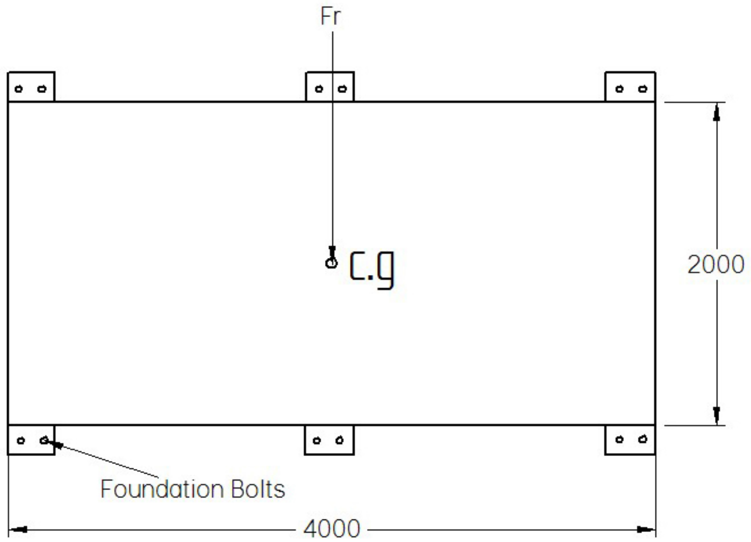

Figure 6. Revised top view of transformer tank with loading and 12 foundation bolts

Now the values of stresses are,

- Maximum Tensile Stress = 258.37MPa
- Shear Stress = 172.24MPa
- Maximum Shear Stress = 251.08MPa.
- Factor of Safety = 2.32

As factor of safety is greater than 2, the foundation is safe.

VI. CONCLUSION

Seismic evaluation of transformer to decide the foundation anchorage requirements isdone and general methodology for determining the size of foundation bolts has beendeveloped.

VII. FUTURE SCOPE

A generalized program can be developed for selection of size and location of the fastening bolts which can be applicable to all the varieties of the transformers availablewith the industry.

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