Asian Journal of Electrical Sciences
ISSN: 2249-6297 (P) Vol.1 No.1, 2012, pp.53-57
© The Research Publication, www.trp.org.in
DOI: https://doi.org/10.51983/ajes-2012.1.1.1648

Optimisation of End Insulation Design in Power Transformer

R. Beema Thangarajan[1], S. Usa[1], Syed Arif Ahammad[2], R. Muthuraj[2] and M. Govindaraj[2]
[1]*Division of High Voltage Engineering, Department of Electrical and Electronics Engineering, Anna University, Chennai - 600 025, Tamil Nadu, India*
[2]*Crompton Greaves Global R&D, Mumbai 400 042, India*
E-mail : beemaoct@yahoo.co.in

(Received on 15 December 2011 and accepted on 05 March 2012)

***Abstract* - The power transformer is an important component in power system that must be highly efficient and reliable in operation. Insulation design in power transformer is one of the important factors for determining reliability and size. It is essential to find a compact optimal design for insulation that satisfies the technical specifications with minimum manufacturing cost. In the transformer insulation design, the top end and bottom end insulation between winding and yoke of a power transformer is one of the important factor determining the total window height of the power transformer; hence optimization in the end will result in reduction in total cost and size of the transformer. In this paper electrostatic finite element analysis of power transformer end insulation is carried out, the cumulative stress distribution for each oil gap is determined and safety margin is evaluated by comparing it with industrial withstand curve. The value of top end and bottom end clearance of winding to yoke is optimised so that the value of window height is minimum and the end insulation design is reliable.**

***Keywords:* Cumulative Stress, End Insulation, Safety Margin, Creep Stress**

I. INTRODUCTION

The transformer insulation system can be categorized into major insulation and minor insulation. The major insulation consists of insulation between windings, between windings and limb/yoke and between high voltage leads and ground. The minor insulation consists of basically internal insulation within the windings that is inter-turn and inter-disk insulation. The materials commonly used in transformer insulation system are: (i) insulating fluid: mineral oil, (ii) conductor insulation: oil impregnated paper (iii) solid insulation, i.e. barriers, blocks, spacers: pressboard, permawood.

Insulation of the winding ends from each other and winding to yoke is called end insulation. The end insulation design of transformer is composite oil-solid insulation system consisting of angle rings/caps, transformer oil and clamping ring. The strength of the end insulation arrangement is predominantly determined by the strength of oil gaps. The maximum occurring oil stress value will not be the only important factor for strength of oil gaps. The cumulative stress calculated for each oil gap should have a permissible safety margin compared to withstand curves. A typical end insulation arrangement in a power transformer is shown in figure 1.

The end insulation design of a transformer is one of the factors deciding the window height of a transformer, so optimisation of end insulation will permit reducing the clearances to core and thus reducing the amount of steel and transformer oil. During optimisation the insulation design rules must be true under all circumstances for reliable design.

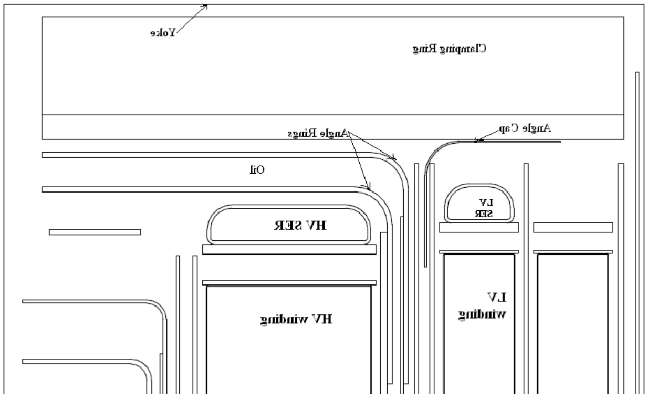

Fig. 1 End Insulation Design of Power Transformer (132kV/33kV)

II. OPTIMISATION PROCEDURE

The electrostatic analysis of the insulation design is done using finite element method (FEM), using the software package 'Elecnet'. The areas of study selected for optimisation are 1) Thickness of clamping ring. 2) Size of oil gaps.

The thickness for clamping ring must be selected in such a way that the clamping ring withstands the clamping force and the end insulation design is electrostatically correct and the formula for maximum bending stress in the clamping ring is given by

$$\sigma_{\max} = \frac{6F \prod D}{8Wt^2 n^2} \tag{1}$$

F = Total axial force, n = No. of clamping point, t = Thickness of ring, W = Width of ring, D = Mean diameter. The thickness of clamping can be reduced by using better material and the cost saving must be higher than earlier design. The value of $\sigma_{\max}$= 120 MPa for permawood®, 400 MPa for Transring.

After selecting the thickness of clamping ring electrostatic analysis is performed for electrostatic feasibility.

After fixing the thickness of clamping ring further modification is carried out in the size of oil gap in the end insulation, and then three main criteria must be satisfied. [1]

(i) Maximum local stresses at the surface on an electrode must be less than 11-12 kV/mm.

(ii) In an oil gap having maximum stress is at one of the extremes, the cumulative stress at any point with a distance of d from the point of maximum stress is given by the equation. [2]

$$E(d) = \frac{1}{d}\int_0^d E(x)dx \tag{2}$$

The cumulative stress calculated must have a safety margin of 15% with respect to the industrial withstand curve.

(iii) The creep stresses along the solid insulation to oil boundary should not exceed the design limit of 2kV/mm.

III. FINITE ELEMENT PROBLEM DEFENITION

A. Problem Formulation

A 33/132 kV power transformer design is taken for design optimisation. End insulation design of a 132 kV power transformer under power frequency condition is expressed as an electrostatic problem. The governing equation for electrostatic finite element analysis is the given below

$$\nabla^2 V = 0 \tag{3}$$

The end insulation of a transformer is modelled as an axis symmetric and FEM is used calculate voltage distribution curves and electric field intensity in the end insulation.

B. Material Details

The three main dielectrics which are used in the transformer insulation are 1) Transformer oil 2) Pressboard barrier 3) Oil impregnated paper, whose relative permittivity are shown in table I.

TABLE I MATERIAL PERMITTIVITY

Transformer oil	**2.2**
Oil impregnated Paper	**3.5**
Pressboard	**4.4**

C. Excitation, Boundary Condition and Assumptions

The assumptions made during analysis are LV, HV and TAP windings are considered as a single cylinder with uniform voltage axially symmetrical. The conductors are rounded at the corners are rounded to a radius of 0.5mm and a paper covering of 0.5 mm is given.

The boundary condition taken for this finite element problem is Dirichlet boundary condition. The limb, yoke and winding next phase is considered as the boundaries and are grounded. V (AB, BC, CD) = 0.

The transformer is subjected to four main high voltage test i) lightning impulse test, ii) short duration power frequency test and iii) long duration power frequency test, it is important to convert all these values to equivalent one minute power frequency test. Highest of these values is used as excitation for HV winding during simulation. For the conversion the following design insulation factor are taken.

TABLE II DESIGN INSULATION FACTORS (DIL) IN REFERENCE TO THE AC POWER FREQUENCY 1 MINUTE TEST

Condition	DIL factor
Lightning impulse (FW)	**2.3**
AC one-minute test level	**1.0**
AC one-hour test	**0.8**

After calculation of DIL for 132kV transformer the one minute power frequency voltage 275kV is taken as excitation for calculating top end clearance and the one minute power frequency voltage of 133kV is taken for calculating bottom end clearance.

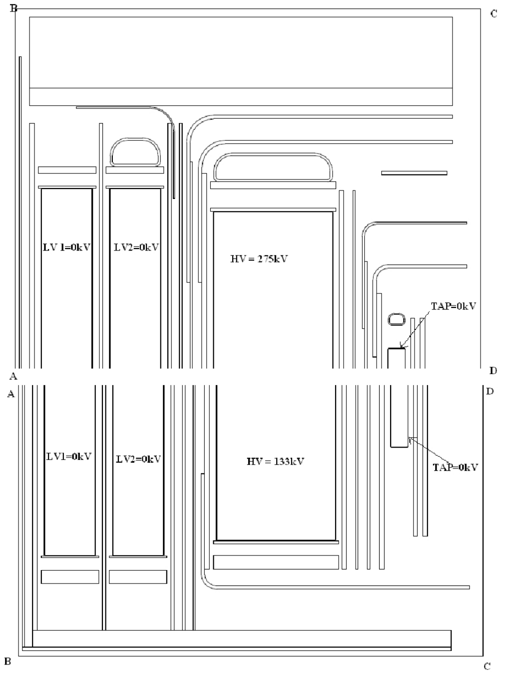

Fig. 2 Boundary condition and excitations for top and Bottom end insulation.

IV. ANALYSIS OF EXISTING AND MODIFIED END INSULATION DESIGN

A. Existing End Insulation Design

The existing end insulation of the 132kV power transformer design is shown in figure 3. The two angle rings placed are placed over the high voltage winding to divide the oil between high voltage winding and yoke of the transformer. There is a total of four oil gap on the top and 3 oil gaps on the bottom between the HV winding and the yoke of the transformer. The safety margin of this oil gaps have to be analysed for end insulation design.

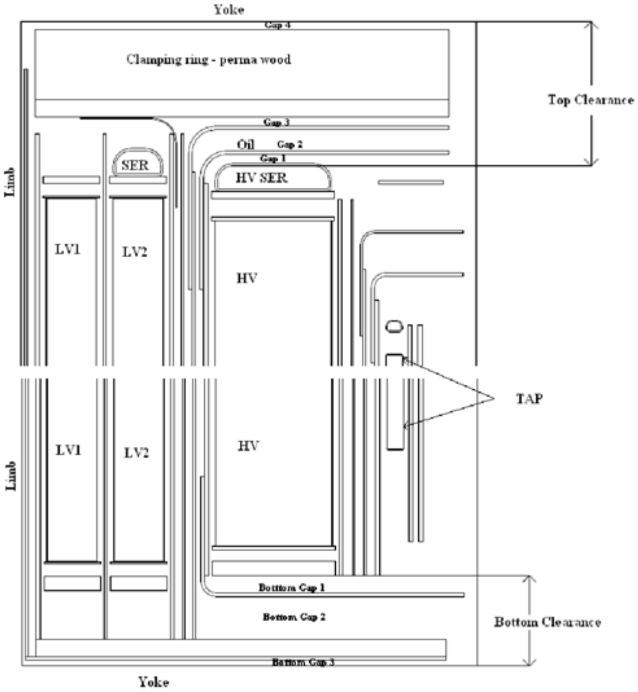

Fig. 3. Existing insulation design structure.

The finite element electric field analysis is carried out using the above said boundary conditions on the top and bottom end insulations for existing design and the field plot is shown in figure 4.

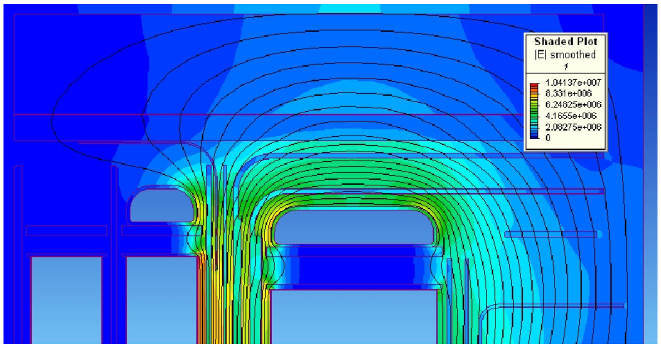

Fig. 4 a). E Field and equipotential lines of existing top end insulation design

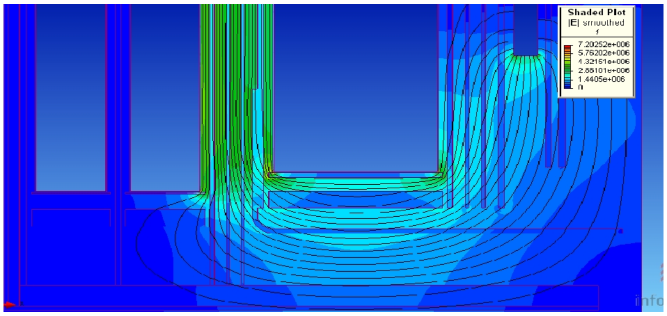

Fig. 4 b). E Field and equipotential lines of existing bottom insulation design.

The value of local stress on the surface of the electrodes is less than 11kV/mm in both cases. The cumulative stress is calculated along a line in critical stressed region and the safety margin is calculated. The calculation of safety margin of one such gaps is shown in figure 5.

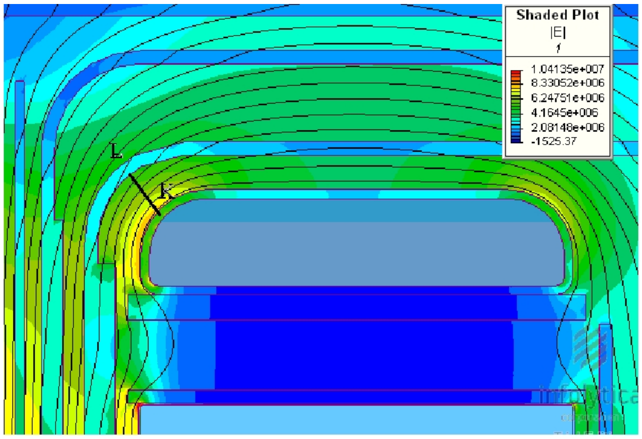

Fig. 5. a) Determination of cumulative stress along line KL

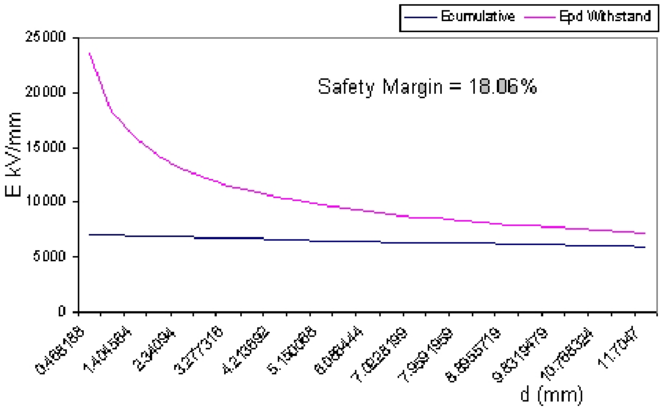

Fig. 5. b) Safety margin calculation for Gap 1 along KL

The creep stress criterion is checked along the pressboard oil surface for the transformer to be partial discharge free. The example of one such analysis is shown in fig. 6.

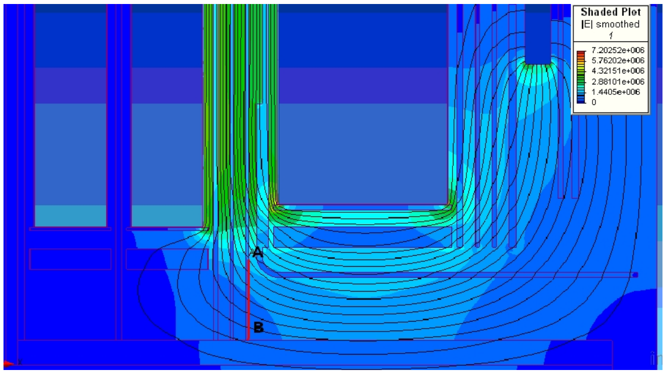

Fig. 6 a) Creep stress analysis for existing design along AB

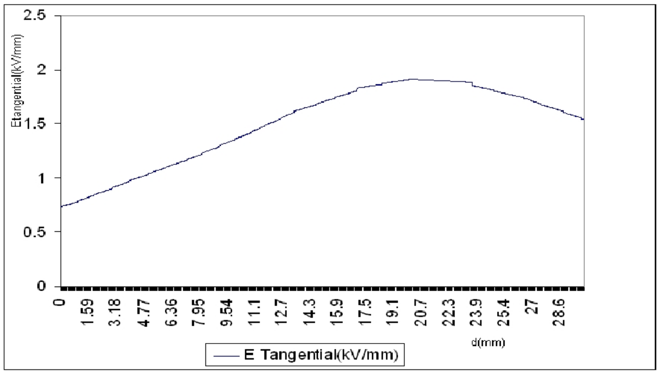

Fig. 6. b) Values of Creep stress along AB< 2kV/mm

From the analysis of the existing design the modification of the design is done by reducing the size of oil gaps, thickness of clamping and further electrostatic analysis is done to check the reliability of the design.

B. End Insulation Design after Modification

The first modification has been done in the solid insulation clamping ring, in the existing design permawood clamping ring. The maximum clamping force applied on clamping ring is 102.8 Ton, after calculation based on (1) the thickness of permawood® clamping ring having bending strength of 120MPa has been replaced by Transring material of lesser thickness having bending strength of 400 MPa. The second modification is done by rearrangement of pressboard and the size of the oil gaps has been reduced by 10mm on the top end and the bottom end clearance has been reduced by 12mm. The modified insulation structure is shown in figure 7.

The boundary condition and excitation is applied for top and bottom end insulation and finite element analysis is carried out, the field plots are as follows.

The cumulative stress analysis for oil gaps in the modified design is done and the safety margins in all gaps are above the permissible limit of 15%. The safety margin calculation for one of the gap is shown below.

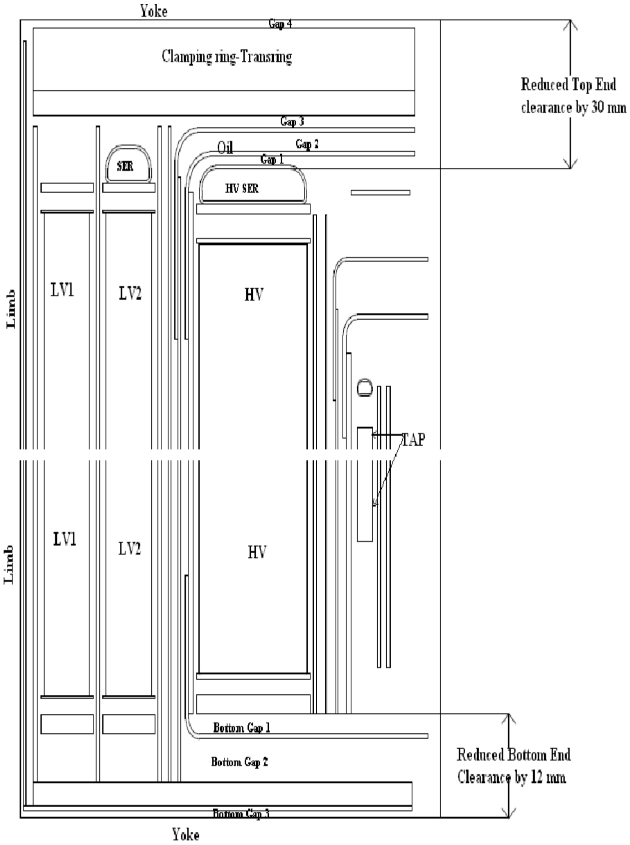

Fig. 7. Modified insulation design structure.

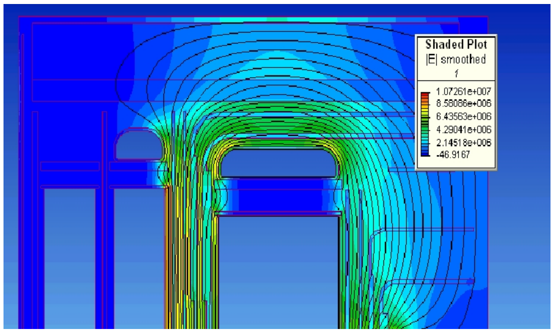

Fig. 8 a). E Field and equipotential lines for modified top end insulation design.

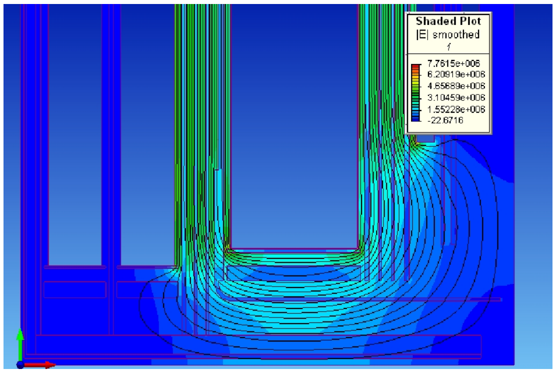

Fig. 8 b). E Field and equipotential lines for modified bottom insulation design.

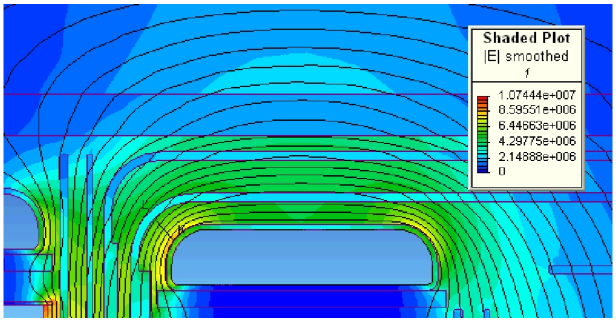

Fig. 9. a) Cumulative stress determination along KL for modified design.

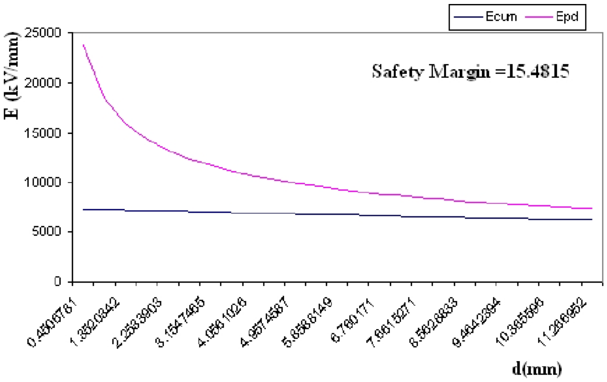

Fig. 9 b) Safety margin calculation for Gap 1 along KL for modified design.

The creep stress analysis is done for the modified design to check whether the value of creep stress lies within design limit.

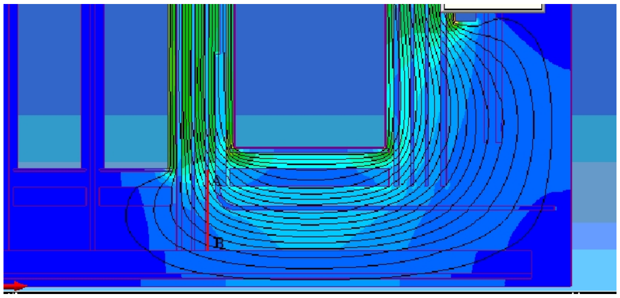

Fig. 10 a) Creep stress analysis for modified design along AB

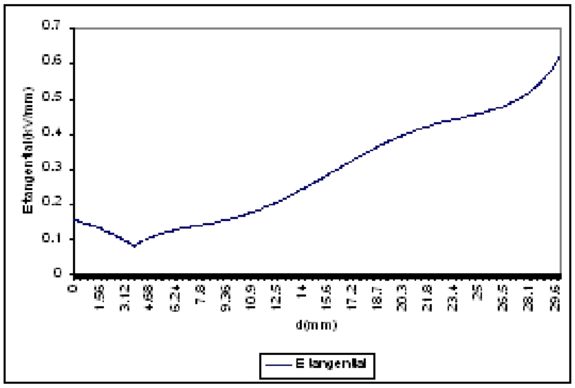

Fig. 10 b) Values of Creep stress along AB< 2kV/mm

V. Discussion

The cost reduction and the reduced weight in material for the modified design are given in the table 3 below consider Rs. 180 per kg for MOH steel and Rs. 72 per litre for transformer mineral oil.

Table III Cost and weight reduction for modified design

Window height reduced	**42mm**
Oil Reduced	**231.872 kg**
Steel Reduced	**374.8717 kg**
Cost savings	**Rs. 2,21,188**

Comparing the existing design and the improved design after performing electrostatic analysis for both, it is estimated that there will be a cost savings of Rs. 2,21,188 per transformer in the end insulation by using the new insulation structure.

IV. Conclusion

The finite element analysis and cumulative stress analysis for existing design has been done and based on the results the modifications has been done in both top and bottom end insulation thus the total window height has been reduced by 42mm. After modification the safety margins calculated for all oil gaps are above 15%, the value of maximum creep stress on press board oil interface is 0.8kV/mm and the value of maximum point stress is 10.7kV/mm, theses values are within permissible limits of the transformer design.

References

[1] W.Ziomek *et al* “High Voltage Power Transformer Insulation Design” *Electrical Insulation Conference* (EIC), June 2011.

[2] Nelson J.K., “Some Steps toward the Automation of the Design of Composite Dielectric Structures”, *IEEE Transactions on Dielectrics and Electrical Insulation,* Vol. 1 No. 4, August 1994.

[3] Okabe, S., Takami, J., “Evaluation of Breakdown Characteristics of Oil immersed Transformers under Non-standard Lightning Impulse Waveforms - Method for Converting Non-standard Lightning Impulse Waveforms into Standard Lightning Impulse Waveforms”, IEEE *Transactions on Dielectrics and Electrical Insulation* Vol. 15, No. 5; Oct.2008

[4] Moser *et al* ”Transformerboard”, 1979

[5] S. V. Kulkarni and S. A. Khaparde, “Transformer Engineering:Design and Practice”. *Newyork: Marcel Dekker,* May 2004.

[6] Khaligh A, *et al* “ Power Transformers Internal Insulation Design Improvements Using Electric Field Analysis Through Finite-Element Methods” TENCON 2004 IEEE Region 10 Conference Nov. 2004

[7] Ch. Krause *et al,* “Economic design of power transformer high voltage lead exit system” *Proceedings of 14th international symposium on high voltage Engineering,* August 2005.