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Analysis of particle movement and partial discharge in the winding of power transformer using CFD

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Power transformer is an important apparatus in electrical substation. It is therefore required that it should be protected against all types of undesirable events. It has been experienced that one of the reasons of failure of transformer is due to the presence of metal particles in the annular space between the windings. The particles during movement cause Partial Discharges (PD) due to the high voltage on the discs. The magnitude of PD depends on the particle nearness to the disk of transformer and stress developed on the metal particle. In order to determine the movement and stress on disc of transformer winding due to the presence of the particle, Computational Fluid Dynamics (CFD) analysis using FLUENT™ software is carried out. The winding considered for calculation is the high voltage part of the 200 kV transformer. Since the transformer is a two group winding only one half is taken for analysis due to symmetry. A particle of length, L = 0.5 mm and hemispherical radius of 0.25 mm is allowed to move in oil with flow velocity of 0.5 m/sec. the stress is calculated at various discs during upward movement of particle. A typical electrical stress obtained on the particle close to HV winding is 0.556 kV / mm. The particle considered for analysis is of spherical nature. Stress on the spherical particle is presented in this paper.

Keywords: *Power transformer, partial discharge, CFD, ANSYS, FEM*

1.0 INTRODUCTION

Electric field analysis is the most important design consideration for any high voltage equipment. Partial discharge is a key factor leading to the failure of a high voltage transformer. High electric stress causing PD is the area of interest for investigation. Many numerical methods can be used for electric field analysis in a transformer. CFD and Finite Element Method (FEM) are the powerful method used at present for the analysis of HV equipment. For a given voltage the dielectric field pattern of transformer oil is determined using ANSYS software [1]. In another work, numerical investigation of electric field distribution and electro-hydrodynamic flow of air for wire - cylinder electrode configuration has been carried out [2]. In this work FEM analysis is used as a part to predict electric field distribution in HVAC test unit. Carlos [3] work suggests that CFD is suitable tool of analysis and it can play a major role on the optimization and design of new geometries by giving detailed information of flow. Statements about the electrical strength of the insulation are drawn and evaluated by Giese, K [4].

A 100 MVA, 220 kV/132 kV/11 kV auto-transformers is considered in the present analysis. The transformer has an interleaved winding structure as shown in Figure 1.

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The work mentioned in the paper deals with the analysis of movement of conducting particle available in the transformer oil, which is sensitive to high voltages. It may lead to PD in the transformer coil.

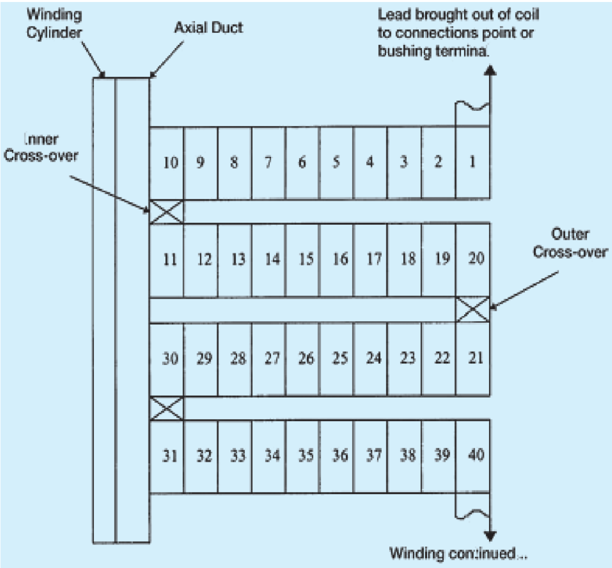

FIG. 1 INTERLEAVED WINDING STRUCTURE OF A TRANSFORMER

Hence the analysis is restricted to 220 kV. The other winding being of lower voltage is less sensitive to PD. Figure 2. Shows the structure of HV winding.

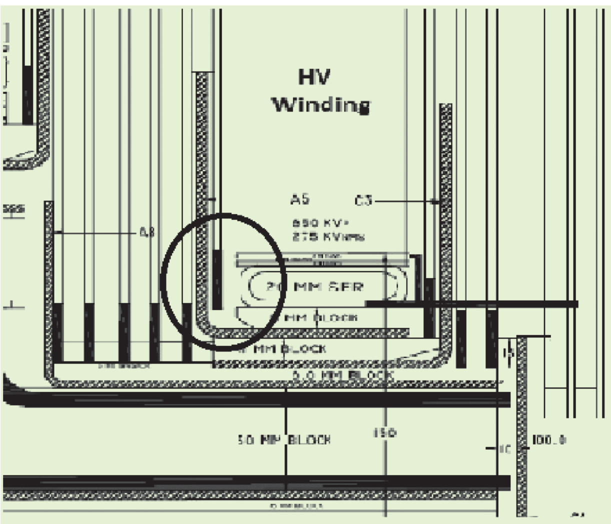

FIG. 2 HV WINDING OF A 100 MVA, 220 KV/132KV/11KV TRANSFORMER

2.0 SPECIFICATIONS FOR CFD ANALYSIS

High voltage winding of transformer is having 58 discs in the upper and 58 disc in the lower section. For the purpose of analysis only lower section is considered due to symmetry. The distance between the press board cylinder and inner radius measures 8 mm. A configuration of a disc pair of the transformer is shown in Figure 3.

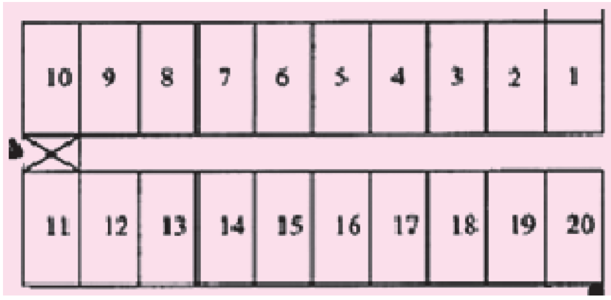

FIG. 3 DISC PAIR OF A 100 MVA, 220KV / 132KV/11KV TRANSFORMER WINDING

Parts of transformer, participating in PD phenomenon are transformer oil, transformer winding, conducting particle and insulating paper. Winding material has a relative permeability of 1.0 and relative permittivity of 10^5. Resistivity of a copper is 1.6×10^{-6} Ω-cm. Insulating paper has got relative permeability of 4.2 and relative permittivity of 4.2. Resistivity of an insulating paper of this transformer is considered to be 10^{12} Ω-m.

A copper particle of spherical shape of 0.5 mm radius is considered to be available in the transformer oil, at the bottom of transformer. The transformer oil is hydro carbon mineral oil. The transformer is assumed to work at room temperature. At this temperature, the density of the transformer oil is 0.89 gm/cc, viscosity of above oil is 27 centi-strokes and velocity of transformer oil is 0.5 m/sec.

The spherical particle available in the oil is of copper, which has the density of 8.96 gm/cc and resistively of 16.78 nano-ohm – meter. Transformer winding is also made up of copper.

3.0 CFD ANALYSIS OF OIL FLOW IN TRANSFORMER

Two dimensional model of a HV winding of the considered transformer is obtained by ANSYS™ software. ANSYS FLUENT™ is used to model a flow pattern of transformer oil. Oil flow is considered in correlation with the outside flow, as the design part includes the inlet and exit way of an oil flow.

To obtain the oil flow pattern, the HV winding part is divided into 1651 time slots. A copper particle of spherical shape with 0.5 mm is also allowed to move along with the transformer with the oil velocity of 0.5 m/sec.

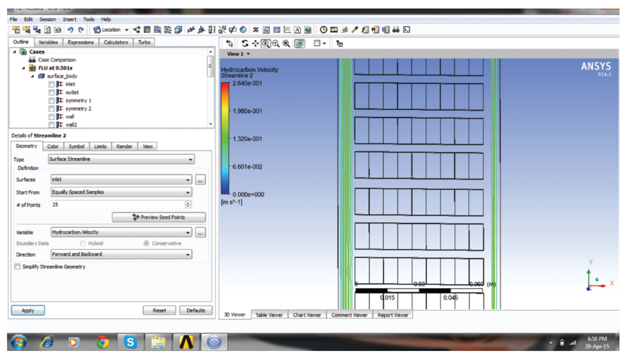

FIG. 4 SIMULATED OIL FLOW STREAMLINES AT HV WINDING SIDE OF A TRANSFORMER

To follow the oil along with the particle, numbers of iterations are carried out. After each iteration, ANSYS produces current status of oil flow. As the particle is also moving along with the oil it also takes a flow path of transformer oil. This status is updated in terms of the time strip of the structure.

4.0 COLLISION OF PARTICLE WITH TRANSFORMER WINDING

A simulation comprising the individual insulated conductors inside the disc would require a large computational effort. For this reason, the total disc volume is considered as number of disc bars as shown in Figure 4.

The particle first collides with the disc number 53 and the corresponding disc voltage is 81.466 kV. As the particle touches the winding, electric stress is imposed on the particle shown in Figure 5.

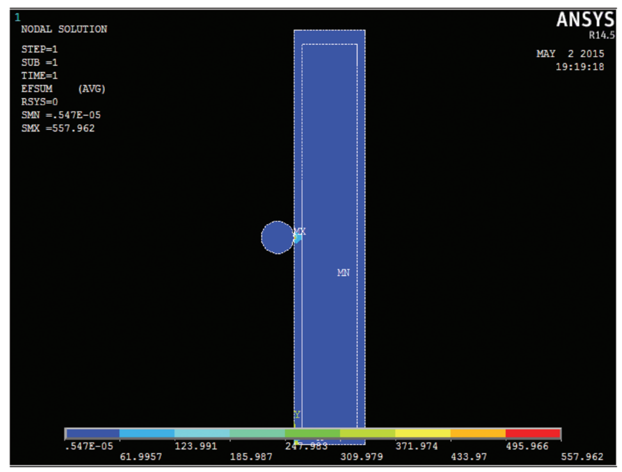

FIG. 5 PARTICLE COLLIDING WITH DISC 53 OF HV WINDING OF A TRANSFORMER

4.1 Electric Field Analysis

ANSYS classic makes use of FEM to obtain a structural analysis. The area of particle under collision with the winding is divided into number of elements by finite element tool. FEM finds the axis of area of contact with the boundary is shown in Figure 6.

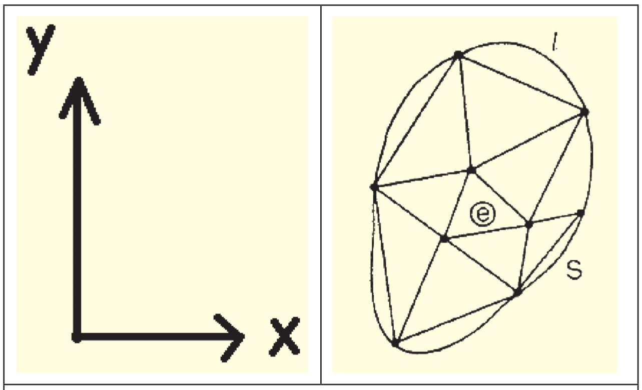

FIG. 6 FINITE ELEMENTS OF COLLIDING AREA OF THE PARTICLE

Electrostatic energy in a bounded volume can be given by

$$2W = \epsilon \int_V E^2 dV \quad ....(1)$$

For a two dimensional analysis along with the axis x and y with m nodes and n number of elements can be written as,

$$2W = \epsilon \int_{s} \left[(dV/dx)^2 + (dV/dy)^2 \right] ds \qquad ....(2)$$

The electric energy inside an element is,

$$2W^e = \epsilon \int_{s^e} (dv^e/dx)^2 + (dv^e/dy)^2 \, ds^e \qquad ....(3)$$

Total energy available in the contact area is given by ,

$$W = W^1 + W^2 + ... + W^n \qquad ....(4)$$

The shape function of a considered 2D geometry is,

$$L_i^{(e)} = \left\{ A_i^{(e)} + A^{(e)} \right\} \qquad i = 1, 2, ...n \qquad ....(5)$$

The total node potential is given by,

$$2W = \sum_{e=1}^{n} \epsilon \int_{s^e} f_e^T f^e ds^{e)} \qquad ....(6)$$

5.0 COLLISION OF PARTICLE WITH OTHER TRANSFORMER WINDING DISCS

With further iterations it is found that apart from disc 53 the spherical particle also collides with discs 52 and 51.

The voltages corresponding to disc 52 and 51 are 82.342 kV and 83.218 kV respectively. The particle collisions with disc 52 and 51 are shown in Figure 7 and Figure 8 respectively.

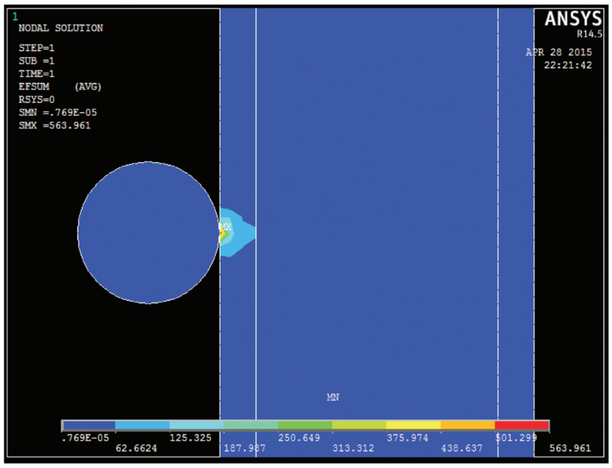

FIG. 7 PARTICLE COLLIDING WITH DISC 52 OF HV WINDING OF A TRANSFORMER

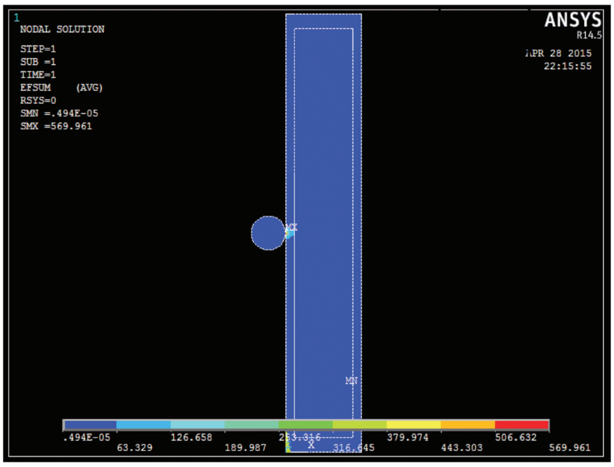

FIG. 8 PARTICLE COLLIDING WITH DISC 51 OF HV WINDING OF A TRANSFORMER

The corresponding stress calculated by FEM are,

Stress near disc 53 = 557.962 v/mm

Stress near disc 52 = 563.961 v/mm

Stress near disc 51 = 575.961 v/mm

The particle is found to have no other collisions apart from above mentioned value. After making these collisions particle leaves the transformer. Since the highest stress obtained in the present simulation is below 7 kV/mm, which is the threshold of onset of PD, it is inferred that no PD could have occurred.

6.0 CONCLUSIONS

Partial discharge occurs only when the stress value is more than that of break down stress of oil. Break down voltage of a considered transformer oil is 7 kV/mm. the maximum stress made by the copper spherical particle of 0.5 mm radius is 0.5759 kV/mm, which is very less when compared to threshold stress for PD initiation. Hence no PD can occur due to the presence of copper particle of above mentioned size.

ACKNOWLEDGEMENT

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REFERENCES

[1] A Arisoy and O Kalenderli, Electric field analysis of HVAC testing unit using finite element method, CiteSeerX Scientific Literature Digital Library and Search Engine, Id. 59971339

[2] K Kantouna, L Ekonomou, G P Fotis and G E Chatzarakis, Finite Element Method Analysis of an Electric Field in Wire-Cylinder Electrode Configuration during Corona Discharge, Latest Advances in Systems Science and Computational Intelligence, ISBN: 978-1-61804-094-7

[3] Carlos M FONTE José Carlos B LOPES Madalena M DIAS *et al,* CFD analysis of core type power transformers, 21st International Conference on Electricity Distribution Frankfurt, 6th-9th June 2011.

[4] K Giese, Evaluation of electrical tests on transformer board IEEE Electrical insulation magazine, Vol. 9, No. 2, pp. 22-25, ISSN 0883-7554, 1993.