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Methods for Reduction of Stray Loss in Flange-Bolt Regions of Large Power Transformers using Ansys

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***Abstract*—In large power transformers, more than 20% of the total load loss is the stray loss in structural components. The biggest part of stray loss takes place in the transformer tank. As the ratings of transformer increase, the stray loss problem also increases significantly resulting in higher temperatures and local hot spots that reduce the transformer life. Due to the heavy current flow in Low Voltage (LV) windings, the strong magnetic flux linking the transformer tank causes over heating of the tank walls and particularly, if there is loose contact between the wall and tank cover it may leads to hot spot in flange bolts which are near the high current bushings of transformer. So in order to ensure a good contact between cover and tank body we use copper links thus significantly reducing the overheating of flange bolt region. This work presents a 3-D Finite Element Analysis of the geometry of interest to verify the copper link solution for the overheating of flange bolts. The overheating results are analyzed and discussed for the case of a 315MVA, 400/220/33KV Autotransformer.**

***Index Terms*— Stray loss, local hot spots, high current bushings, copper link, Autotransformer**

I. INTRODUCTION

All Power and distribution transformers are expensive and vital components in electric power transmission and distribution systems. The statistics of failures in power transformers are as follows: : 41% of faults are related to the tap changer, 19% with the windings, 3% with the core, 12% with the terminals, 13% with the tank and fluids, and 12% with the accessories. Hot spot failures in the tank are included in this 13%. Consequently, it is important to analyze the causes and consequences of tank hot spots as well as to present solutions to the problem of bolt heating. In case of distribution-transformer overheating of flange–bolt regions is not important whereas in the case of large power transformers of ratings 100 MVA and above, this overheating can lead to transformer failure. In order to alleviate the problem of heating of transformer tanks three main methods are utilized they are: 1) Use of magnetic shunts. 2) Use of electromagnetic shields. 3) Varying the distance of the LV leads to the tank wall. For this it is essential to evaluate stray losses first. Evaluation of stray losses has been done using different methods and the methods are: 1) Two-Dimensional Methods 2) Three-Dimensional Formulations 3) Three-Dimensional Finite Element Method (FEM) Analysis. After the evaluation of stray losses, the different methods to reduce the heating of transformer tanks are incorporated to avoid the heating of transformer tanks. The biggest part of stray loss takes place in the transformer tank. As the ratings of transformer increase, the stray loss problem also increases largely resulting in higher temperatures and local hot spots that reduce the transformer life. Stray losses in

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transformer covers depend on the distribution of leakage flux produced by strong induced fields. These induced stray currents are circulated forcefully through the flange-bolt region. Due to this, the region is overheated if there is no good contact between the tank and cover. This effect can damage the properties of the insulating oil and tank's sealing system, the painting, and the insulation of the high current conductors. Figure 1 shows the after effect of flange bolt overheating.

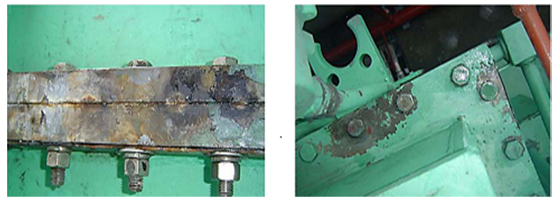

Figure 1. Aftereffect of flange bolt overheating

II. CASES UNDER CONSIDERATION

A. Case A

This case simulates the situation of a loose bolt. It resembles to the situation where there is bad contact between the bolt and the tank surface that is the nitrile gasket has a height of 2 mm in excess, simulating an inadequate tightening. High stray currents are induced in the tank and circulate through the flange that produce high stray losses and overheating in the flange–bolt region. In this case, the tank and cover are at different electrical potential. Figure 2.shows the loose bolt condition.

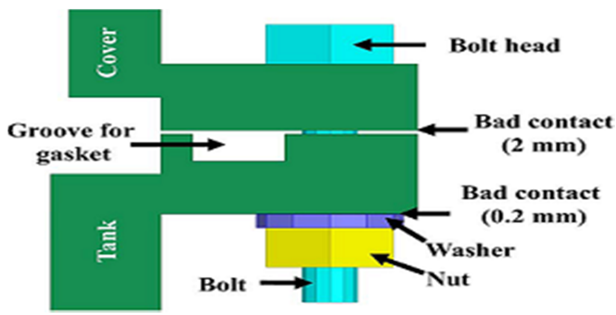

Figure 2. Loose bolt condition

B. Case B

Case B simulates the same situation where there is bad contact between the bolt and the tank surface. Here by means of a copper link the bolt top side was connected to the bolt bottom side to ensure good contact between the tank and its cover. The insufficient contact between the tank and the cover is taken into consideration by using an excess of 2-mm height in the nitrile gasket. A copper link is placed in between the bolt as shown in Figure 3. to avoid heating problems.

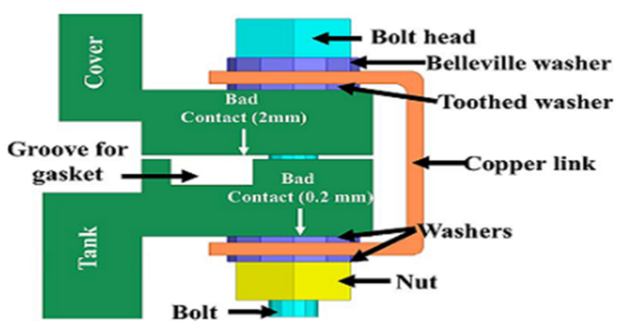

Figure 3. Loose bolt with copper-link

C. Copper-link method

In transformer manufacturing, three methods have been engaged to reduce and avoid the heating of transformer tanks they are use of magnetic shunts, use of electromagnetic shields and varying the distance of the LV leads to the tank wall.

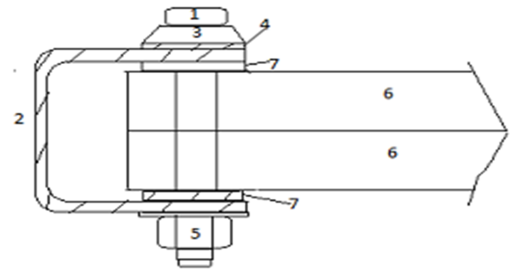

Figure 4. Geometry of the proposed solution. 1. stainless steel bolt IS 1367. 2.copper link. 3. belleville washers, nonmagnetic material AISI-304. 4. flat washers, non-magnetic material IS 2016. 5. stainless steel nut, nonmagnetic material IS 1367. 6. flange for connection of tank and cover IS 2062:2006. 7. toothed washer, nonmagnetic material.

Here in this work, for the hot spot removal, installation of bridges of copper links in junction of the cover and tank is implemented. The configuration adopted is shown in Figure 4. The use of copper was selected because of its high conductivity. Nonmagnetic stainless steel nuts and bolts were used to reduce corrosion, which will ensure good contact with the walls of the tank. The link can provide a low impedance path for stray currents and keeps both parts at the same electrical potential. The reluctance of the flange–bolts is more than twice that of a solid wall when bolts have a good contact.

III. Introduction To FEA And Ansys Workbench

A. FEA

The study of behavior of components in real time conditions in computer aided engineering is achieved through Finite Element Analysis (FEA). The Finite Element Analysis is a computing technique that is used to obtain approximate solutions of Boundary Value Problems. It uses a numerical method called as Finite Element Method (FEM). FEA involves a computer model of a design that is loaded and analyzed for specific results. The main advantages of FEA are:

- It reduces the amount of prototype testing, thereby saving the cost and time.
- It helps to optimize a design and it helps to create more reliable, high quality and competitive designs.

B. ANSYS Workbench

ANSYS Workbench is a Computer Aided Finite Element Modeling (FEM) and Finite Element Analysis (FEA) tool. In the graphical user interface of ANSYS Workbench, the user can generate 3-D and FEA models, perform analysis and generate results of analysis. Different steps included are 1) build geometry 2) define material property 3) generate mesh 4) apply loads 5) obtain solutions 6) present the results. Among different analysis included in ANSYS, here thermal analysis is used.

C. Thermal Analysis

The thermal analysis is used to determine the temperature distribution and related thermal quantities such as: thermal distribution, amount of heat loss or gain, thermal gradients and thermal fluxes. All primary heat transfer modes such as conduction, convection and radiation can be simulated. There are two types of thermal analysis:

- **Steady State Thermal Analysis:** In this analysis, the system is studied under steady thermal loads with respect to time.
- **Transient Thermal Analysis:** In this analysis, the system is studied under varying thermal loads with respect to time.

IV. Results And Discussions

A. Steady State Thermal Analysis on The Flange Bolt Region Using ANSYS:

In the steady state thermal analysis, the thermal load does not vary with time and remains constant throughout the period of application. This analysis considers only steady loads and does not consider any thermal load that varies with time. In this steady-state thermal analysis, the system is studied under steady thermal loads with respect to time. These thermal loads include convection, radiation, heat fluxes, heat generation rates, and constant temperature boundaries. The steady state thermal analysis may be either linear or non-linear, with respect to material properties that depend on temperature. The thermal properties of most of the materials do vary with temperature; therefore the analysis usually is non-linear. Including radiation effects or temperature-dependent convection in a model also makes the analysis non-linear.
Here steady state thermal analysis is done with an ambient temperature of 22^{o} C(see table 1) for case A on the inner surface (6 faces) of the tank walls and a convection boundary of 6 faces are selected and the medium is selected as stagnant air – horizontal cylindrical. Figure 5. shows the steady state thermal analysis of flange bolt region without copper link. For case B also the ambient temperature is selected as 22^{o}C (see table 2) and convection boundary is selected including the two faces of copper link. Figure 6. shows the steady state thermal analysis of flange bolt region with copper link. From table 1 it is clear that the temperature near the flange without copper link is about 394.23^{o}C. Due to this temperature there is a big possibility for hot spots in the flange bolt. And from table 2 it is clear that the temperature with copper link is about 83.285^{o}C. Hence there is a great reduction of temperature that is about 310.945^{o}C when copper link was inserted on the bolts. This reduced hot spots near the bolt region.

B. Steady State Thermal Analysis of Flange Bolt Region Without Copper Link

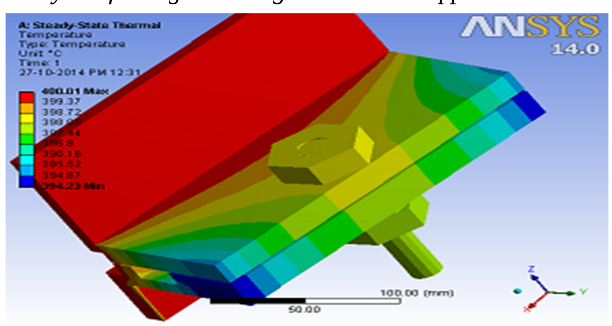

Figure 5. Result showing Steady state thermal analysis of transformer tank's flange bolt region without copper link

TABLE I. MODEL-STEADY STATE-THERMAL ANALYSIS OF FLANGE BOLT WITHOUT COPPER LINK SETTINGS

Definition		
Initial Temperature	Uniform Temperature	
Initial Temeperature Value	$22.^{o}$C	
Step Controls		
Number Of Steps	1.	
Current Step Number	1.	
Step End Time	1. s	
Radiosity Controls		
Flux Convergence	1.e-004	
Maximum Iteration	1000.	
Solver Tolerance	0.1	
Over Relaxation	0.1	
Hemicube Resolution	10.	
Results		
Minimum	394.23°C	9.039e-010 W/mm²
Maximum	400.01^{o}C	8.2506e-003 W/mm²
Minimum	Part 4	Part 1
Maximum	Part 3	

C. Steady State Thermal Analysis of Flange Bolt Region Without Copper Link

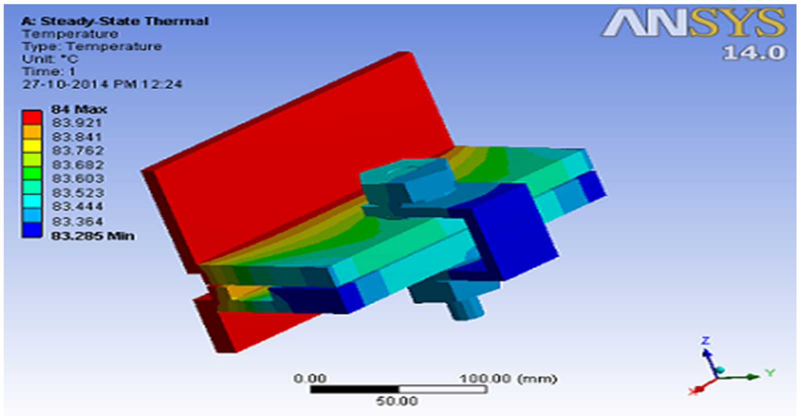

Figure 6. Steady state thermal analysis of flange bolt region without copper link

TABLE II. STEADY STATE THERMAL SOLUTION OF FLANGE BOLT WITH COPPER LINK

<table>
<tr><td colspan="3">Definition</td></tr>
<tr><td>Object Name</td><td colspan="2">Solution Information</td></tr>
<tr><td>Initial Temperature Value</td><td colspan="2">22. °C</td></tr>
<tr><td colspan="3">Solution Information</td></tr>
<tr><td>Solution Output</td><td colspan="2">Solver Output</td></tr>
<tr><td>Update Interval</td><td colspan="2">2.5 s</td></tr>
<tr><td>Display Points</td><td colspan="2">All</td></tr>
<tr><td colspan="3">Results</td></tr>
<tr><td>Minimum</td><td>83.285 °C</td><td>3.0452e-009 W/mm²</td></tr>
<tr><td>Maximum</td><td>84. °C</td><td>9.8544e-004 W/mm²</td></tr>
<tr><td>Minimum Occurs</td><td>Part 3</td><td>Part 2</td></tr>
<tr><td>Maximum Occurs</td><td>Part 2</td><td>Part 4</td></tr>
</table>

V. CONCLUSION

This work has shown the unfavourable effect of bad physical contact between the cover and walls of Auto-transformer tanks. The results indicate that due to the loose bolts there is an increase in stray currents as the bolts serve as current paths which leads to the overheating of the region and could result in life-threatening fire explosions. To avoid such hot spots, it is important that the bolts are always kept tight, by an arrangement used in this work (Belleville washers, antiseize paste). Furthermore, when copper links are installed between bolts, connecting the tank and cover, they help to remove potential differences that produce the stray currents, as well as, a greater surface for heat dissipation. As the cost of each copper link is extremely low ($0.5) compared to the very high cost of the transformer ($2 000 000), so installation of copper link is a good remedy for hot spot removal in flange bolt region of power transformers.

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