Design of 25 KA Current Injection Transformer Core with Finite Element Method

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Abstract—Since Current Injection Transformers (CIT) are within the major group of the standard type test equipments in electrical industry, their performances are very crucial. CIT is widely used for standard tests in electrical industry for a variety of purposes, such as relay protection systems consisting of insolated HV conductor, fuses, SF6 switches, low voltage switches (ACB, and MCCB), sectionalizing switches, and so on. With the help of Finite Element Method (FEM), some of the prominent problems can be solved. This paper attempts to fill this void by making direct comparison of the localized flux in 25KA CIT with three-limb single phase transformer cores. Flux distribution is solved by Ansys5.4 software. Then we compare results of the three-limb single phase transformer cores together and we obtain effect of overlap size of the core laminations on its hot-spot temperature.

Key-Words: Current Injection Transformer (CIT), Finite Element Method (FEM), Local Flux density.

1-INTRODUCTION
As an electrical utility you have the right to demand that every piece of power equipment installed on your system meets your exact specifications. The reliability and safety of your system depends on all of the components performing as intended. As a manufacturer, the performance and conformance to industry standards of your product are of prime importance. Testing can assure that your product meets or exceeds performance standards. Current Injection Transformers (CIT) is within the major group of the standard type test equipments in electrical industry and its performance is very critical. Secondary voltage of this transformer are very low, is less than 10 volts, and its output current varied from 1 to 100KA.

The final objective of this paper is to establish a FEM method which leads to localized fluxes of the CIT [1, 2]. Case study in this paper is dry-type transformer that its output current, is 25KA, its secondary voltage is 5 volts and short-circuit time duration is about 3 seconds for 25KA test.

2-CURRENT INJECTION TRANSFORMER EQUATIONS
2.1- The Voltage Equation
Faraday’s Law relates the impressed voltage on a winding to the rate of change of flux density
\[ v = -N A_m \frac{dB}{dt} \]  

Where N is the number of turns and A\textsubscript{m} is the effective cross sectional area of the magnetic core. In the case of laminated and tape-wound cores, this is less than the physical area A\textsubscript{c} due to interlamination space and insulation. The layout of the transformer is shown in Fig (1) and the physical parameters are illustrated.

Fig.1. Typical layout of Current Injection Transformer

The two areas are related by the core stacking factor K\textsubscript{f} (A\textsubscript{m} = k\textsubscript{f} A\textsubscript{c}). Typically, K\textsubscript{f} is 0.9 for laminated cores.
\[ V = \frac{1}{T} \int_0^T vdt = \frac{1}{T} NB_m A_m \quad (2) \]

Where \( V \) is the average value of the impressed voltage in the time period. The form factor \( K \) is defined as the ratio of the rms value of the applied voltage waveform to \( V \)

\[ k = \frac{V_{rms}}{V} \quad (3) \]

Combining (2) and (3) yields

\[ V_{rms} = KfNB_m A_m \quad (4) \]

Where \( f \) is the frequency of \( v \) and \( T \) is the period of \( v \).

Equation (4) is the classic equation for voltage in a transformer.

Winding with \( K \), the waveform factor, defined by \( k \), and \( T \). Evidently, for a sinusoidal waveform \( K=4.44 \), and for a square waveform \( K=4.0 \).

The core manufacturer normally supplies the core data: cross section \( A_m \), window area \( A_w \), the mean length of a turn \( MLT = \omega A_m \) , and the core mass \( (m = \rho_c V_c) \) [2, 3].

### 3-Design of the CIT and results of 2-D finite element analysis

With the help of above equations we design this transformer as below:

Secondary voltage of the CIT, \( V_2 = 5[v] \) and output current is,

\[ I_2 = 25[KA] \rightarrow Q_2 = V_2 I_2 = 125[KVA] \]

If the voltage per turns be as:

\[ E_t = 5[v/turns] \]

Maximum flux density obtains as:

\[ \phi_m = \frac{E_t}{4.44 f} = \frac{5}{4.44 \times 50} = 22.5[mT] \]

For flux density \( B_{max} = 1.6[T] \) we have

\[ A_m = \frac{22.5 \times 10^{-3}}{1.6} = 0.014[mm^2], K_f = 0.9 \rightarrow \]

\[ A_c = \frac{0.014}{0/9} = 156.2[mm^2] \]

\[ A_r = 12.5 \times 12.5[cm^2] \]

Because magnetic fluxes become half for left and right legs, cross section of each one is half of central leg.

\[ b=2a \rightarrow a = 6.25[cm] \]

If the current density \( \delta = 2 \times 10^6[A/m^2] \) windows area, \( A_w \) obtained as [2, 3]:

\[ Q = 2.22 \times f \times B_m \times K \times \delta \times A \times A_w \]

\[ A_w = 930[cm^2] \rightarrow H_w = 45[cm] \]

\[ D_w = 21[cm] \]

\[ H = H_w + 2H_y = 45 + 12.5 = 57.5[cm] \]

\[ W = 2D_w + 2b = 67[cm] \]

\[ A_1 = \frac{I_1}{\delta} = \frac{313}{2 \times 10^6} = 156.5[mm^2] \]

\[ A_2 = \frac{I_2}{\delta} = \frac{25000}{2 \times 10^6} = 0.0125[mm^2] \]

The transformer modeling in this work has been carried out using electromagnetic FEM analysis software, Ansys 5.4 [4]. The calculation of flux distribution and resulting core losses performed using a 2-D finite element method (FEM). The solution is accounts for the magnetic anisotropy and nonlinearity of the material, all components of the material iron loss, and localized losses in the joint region due to distorted flux distribution. This calculation method is accurate for all core materials, at all operating inductions, for all core geometries and for both 50 and 60 Hz [5].
In all transformers, only half of the core width is modeled and boundary conditions are placed on all nodes on the outer edge of the core half, i.e. the centerline of the core. This is based on the assumption that the centre of the core is placed at zero magnetic potential. In all transformers, full load conditions are established in all the windings in the model, by proper external excitation [1].

This transformer is modeled with 4 areas as the core, the air gaps, and the primary and secondary windings.

Fig (3) shown B-H curve of the core laminations, used in finite element model.

![B-H curve of core laminations](image)

Fig.3, B-H curve of 30M5 core laminations used for Finite Element Model

Boundary conditions are, flux is parallel with external node and we use 5 mm overlap in the core arrangements

Results of 2-D analysis are as below:

![Core joints in T shape single phase transformer core with 5 mm overlap](image)

Fig.4, Core joints in T shape single phase transformer core with 5 mm overlap

![Core joints in left and right of T shape single phase transformer core with 5 mm overlap](image)

Fig.5, Core joints in left and right of T shape single phase transformer core with 5 mm overlap

![Core joints in left and right of T shape single phase transformer core with 5 mm overlap](image)

Fig.6, Single phase transformer core with 45° core joints

![Core flux density distribution of the current injection transformer with T-45° joins with 5 mm overlap](image)

Fig.7, Core flux density distribution of the current injection transformer with T-45° joins with 5 mm overlap

![Core flux density distribution of the current injection transformer with T-45° joins with 5 mm overlap](image)

Fig.8, Single phase transformer core with 90° core joints
Last results shown that increasing of overlap size; decrease the flux density in internal edge of the transformer core and it leads to decrease of hot spot temperature of those point.

For loss calculation we use loss curve of 30M5 core lamination that shown in fig (16)

Mass of the transformer core is about 190 [kg] and losses for this transformer is about 175 [W]. Obtained loss factor \( \frac{W}{kg} \) from above results are as table(1)

<table>
<thead>
<tr>
<th>Degree of joints</th>
<th>Y-45°</th>
<th>90° and Y-45°</th>
<th>Y-90°</th>
</tr>
</thead>
<tbody>
<tr>
<td>losses (W/kg)</td>
<td>0.929</td>
<td>0.932</td>
<td>0.927</td>
</tr>
</tbody>
</table>
4-CONCLUSIONS

Finite element method for solving of main problem of transformers is an effective method. Sizes of overlap in this transformer are a determinant factor for hot spot temperature of core in this particular case. If overlap size be less than 3 mm localized flux increases than $1.95 \frac{wb}{m^2}$ and it create hot spot, out of the safe range.

REFERENCES

[1] Günter F. Meckler and Ramsis S. Girgis, Fellow, IEEE  
"Magnetic Flux Distributions in Transformer Core Joints" IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 15, NO. 1, JANUARY 2000
[4]"ANSYS Simulation Software", ver5.4, 1997