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Dynamic Short Circuit Withstand Competency of Power Transformer

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Abstract—The most severe mechanical stressing occurs in Transformers when it is subjected to short circuit Since the current occurring through the windings are enormous. The problem does not yield easy solution due to the transient and dynamic nature of phenomena.

It is very important to make the transformer in the way that when the short circuit condition takes place transformer should be able to withstand the electromagnetic forces with less or no effect The MATLAB simulation and FEM model is also shown for the better design of the transformer in this paper

Keywords—short circuit, FEMM model transient, electromagnetic forces, dynamic windings.

I. INTRODUCTION

A short circuit event in the transformer is very common phenomenon in the transformer when two points of the circuit becomes short it is known as the short circuit phenomena.. The current flows in an electrical circuit in the easy route and if any pair of points in a circuit having different potential values are connected with low impedance path. Current in the circuit try to circulate between the two points. Due to this effect normal to very dangerous faults and condition may appear. We can minimize or tolerate this type of condition by analysing the ability of the circuit to carry this high magnitude of current. This type of condition may leads to arc phenomena if the current carrying capacity of the system is in certain limits & protecting devices don´t remove the circuit. short circuit able to generate very high temperature due to the high power dissipation in the circuit. Today in recent time more than before, the electricity organization is developing so fast, the capacity of power plant, the capacity of substation and loads, as well as load density, relatively grow.[3]

As we take china for an example,

Depending on the analysis of the State Grid Corporation of country China, the Short circuit accidents of transformers who's (Size ≥ 110 kV) takes place 125 times. The total Power capacity affected by the Short circuit accidents is 7,996 MVA in year 1995 to 1999. The numbers expresses 37.5% of all short circuit accidents and 44% of the transformer accidents. [1]

A transformer works on the principle of transmitting power from one circuit to another with constant power and frequency. It is use to change the magnitude of voltage level with respect to increase or decrease in current. Mutual inductance is the main principle of transformer. In the transformer two type of coils are used which are primary and secondary One of the coil is connected to source of supply voltage and in the other coil an alternating flux is build up which in turn generates mutually induced emf proposed as faraday's law of electromagnetic induction.[4]

$$E = M*\frac{di}{dt}$$

Where E= induced emf

M= mutual inductance

II. ELECTROMAGNETIC FORCES IN POWER TRANSFORMERS

The common severe mechanical stress occurs in Transformers when there is short circuit condition, since the current implying between the windings are so high. The problem does not possess easy solution because the transient and dynamic nature of this effect.

Due to the short circuit there will be generation of electromagnetic forces and stresses on the transformer which are shown below [5]

(A) NATURE OF FORCES

Due to the short circuit forces takes place in the transformer these are in any direction but to calculate these forces we can take two particular directions radial and axial for ease purpose. [7]

But, it is very easy to speak of the radial forces & axial forces in the transformer, as these two components of the force can be calculated & focused easily. By computing these forces the ability to withstand can be found out. [6]

(B) RADIAL FORCES

One of the forces are known as radial forces , these kind of forces are generally in the radial directions and it is generated due to the interaction of current and axial component of the flux density. This axial flux density is easy to observe so that these forces are also easily and accurately calculable.

But there are problems takes place in the calculation of the stress generated by this type of forces so we have to be very careful while calculating these kinds of forces. [7]

(C) AXIAL FORCES

Second type of forces is known as the axial forces because these act in the axial directions. These types of forces are generated due to the interaction of current and radial component of flux density. The radial component of flux Density is not easily observable so the calculation of these forces is not easy to evaluate accurately. [11]

But the calculation of stresses is easy to observe and analyses so this step is easy in comparison to radial forces. The resultant force on the winding should be none. [2]

In the axial forces the radial lines of flux affects so much to the end of the windings and axial density decreases. Because of that resultant flux density at the end are different to radial component and the axial forces are distributed unevenly between inner and outer part of the winding. They try to squeeze inner winding and burst the outer winding.

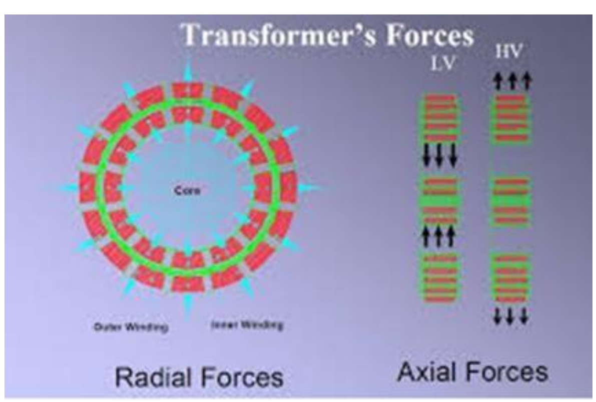

Fig.1 *Direction of radial an axial forces*

These types of forces which acts on top and end part of winding are having the opposite direction of the current and the current in the middle section has the same current flow directions so that in the calculation purpose there is not more difficulty to observe. The actual force acting on both the winding is equal to zero. Any displacement occurs vertically between the magnetic flux centers of HV and LV windings can be known as net axial resultant forces.

In practice a total balance of all components of windings cannot be perused totally for many reasons like protection to tappings , HV line get away from center of winding , Accuracy of dimensions and windings stability.[8]

(D) BASIC FORMULA AND METHODS FOR FORCE CALCULATIONS

(E) BASIC FORMULA FOR FORCE CALCULATIONS –

Basic equation F = I x B x l ....(1)

Where B = flux density because of leakage flux at mean depth of winding [8]

I = short circuit current

L = length of the conductor

Since F is the product of i and B ,a radial flux will generated to a axial force which then the axial flux will try to generate radial force. In the eq. the flux density is because of leakage flux, so as the conductors stays in field of leakage flux. The calculation of both radial and axial force is a very difficult task. [11]

METHODS FOR FLUX CALCULATIONS –

Attempts to solve these forces are done by designers. The main thrust was towards obtaining a closed form solution so that designer would directly apply a set of formula and graphs to his particular design to his particular design for calculating the forces. With the advent of digital computers field plotting techniques were developed and today numerical methods of force calculation using digital computer is common. [9]

A calculation of radial forces requires evaluation of the axial leakage flux density and the formulas are ready. Hence radial forces are easy to calculate with good accuracy.

So, evolution of the radial leakage flux density, required for axial flux calculations which is complex. Various investigators have given different formulas and constants based on their experiments , for it. Such formulas to be used with care as to their applicability to case in hand. [12]

(F) ANALYSIS METHOD

Billing has given the formula and curves for calculation for radial and axial short circuit forces. His formula is derived considering the windings are current sheet. These are fairly accurate for close wound coils.

Waters has given formula and constants for calculations for radial and axial forces. He used to residual ampere turn method to get the unbalanced ampere turns by that axial forces are calculated easily using empirical constants. This method is applicable to two coil transformers. [10]

(G) NUMERICAL METHODS

The most known methods for force calculation in the category are mainly corresponding to Roth's method which is basically an analytic method. He has used this method of images to get the magnetic flux density since a double Fourier series. In rectangular type coordinates, the best solution is in difficult form of algebraic equations but in cylindrical type coordinates the solution surrounds Bessel and Struve functions. The method is so most suitable for programming easily on a digital computer.

Rabin's developed A simple form of field solution using single type of Fourier series for the opposition to double Fourier series of Roth. Rebin developed this for reactance calculations but the problem is expressions obtained, when differentiated takes to the flux density and so the electromagnetic forces. This method is very much suitable for digital computers with some problems the basic formulation takes away to an analytic expression.

(H) RADIAL FORCES CALCULATION

A formula to find the average radial force can be obtained by evaluating the component of the leakage flux density in the axial direction & applied between top and bottom yoke in machine's straight lines. This assumption is taken in consideration made in evaluation of leakage reactance & will able to become slightly bigger value of radial force. [2]

$B = ½\mu_0$ x NI/L NI/L x I x πD_m N

$= 19.739 \times 10^{-7} (NI)^2/L \times \pi D_m$ N …. (2)

If there is uneven current distribution in axial direction takes place then that cause the force integral to reach a final value higher than zero. In example

F_r *is acting toward bottom yoke* & integral has crossed zero line once and become negative. [2]

The average radial force is

$$F_r = B \times i \times l$$
$$= ½\mu_0 \times \text{………} \quad (3)$$

Due to this assumption that all flux is axial in nature this eq. will become larger than that because of any other formula. It can be used in all stress calculations and also design purpose of windings. The maximum force per turn will apply at the inner turn of most inner layer of outer winding and force is given by

$$F_m = 2F_r/N \quad \text{… (4)}$$

(I) AXIAL FORCES CALCULATIONS

The electromagnetic forces generated because of the short circuit fault are oscillatory in nature and implies on the electrical system. Such forces dynamically transmitted to different components same as conductors, end supports , press plating and clampers may be different.[2]

The design for the force calculations are performed on both sides for symmetrical configuration of windings

In case when symmetrical winding arrangement in axial directions obtained uniform current distributions then there will be no resultant force against the yoke & winding also becomes compressed in axial direction but not radial.

III SIMULATION MODEL IN MATLAB & RESULTS

The simulation is shown for the transformer operating under normal condition and short circuit condition both and the results are also shown.

In the first circuit fig 3.1 fault blocks is not applied to the transformer so transformer is working under normal condition. The three phase source of value 440 V is applied to the step down transformer of rating 11000/400 voltage and the connected load is the inductive load because most of the loads in the industries are inductive and then fault is applied for some time and result are achieved.

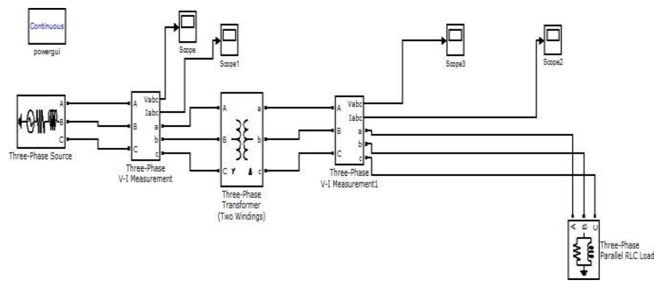

Fig.3.1 *Transformer without fault*

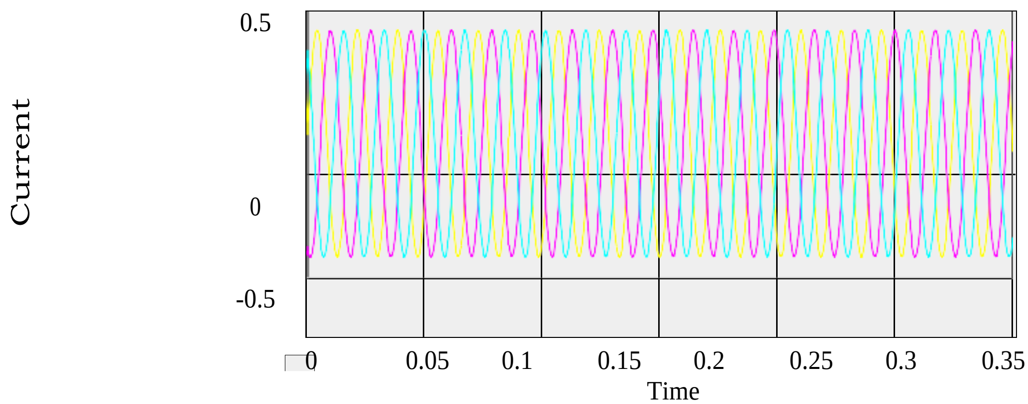

Fig 3.2 *Current under normal condition*

Here in this figure 3.2 the results for the simulation of the transformer before the fault applied and this result shows the normal HV side current which is approximately 0.4 ampere value.

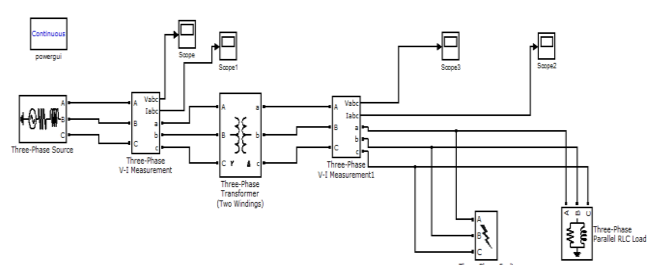

Fig.3.3 *Transformer under faulty condition*

In the fig 3.3 it shows that the fault block is applied to the transformer for 0.1to 0.2 sec time period and the fault type can also be changed by us as per requirement and the result of the fault is shown in fig 3.4.

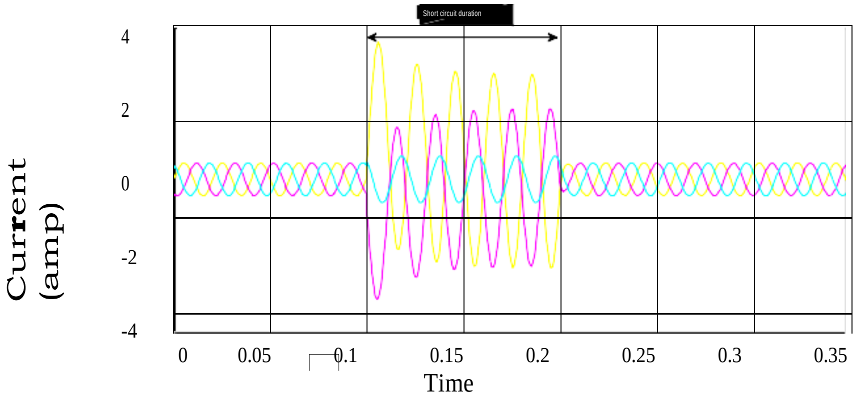

Fig.3.4 *Current under fault condition*

In fig 3.4 there is a spike of current we can see in the result is short circuit spike which generate due to the fault given during 0.1 to 0.2 sec. the electromagnetic forces in the winding and that bursts the windings of the transformer.

IV FEM MODEL AND RESULTS OF THE TRANSFORMER

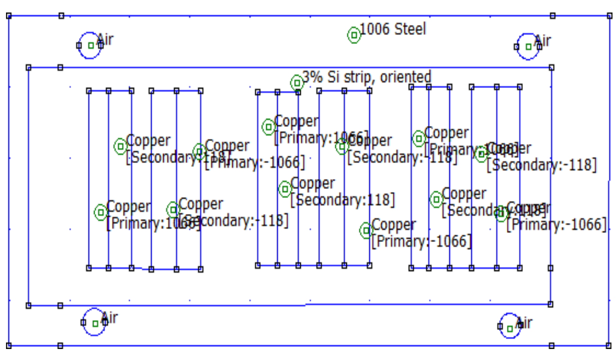

Fig. 4.1 FEM model with defined blocks

In the fig 4.1 transformer is designed in the FEM software further in this transformer the short circuit fault will be applied and the flux distribution and forces generated will be observed.

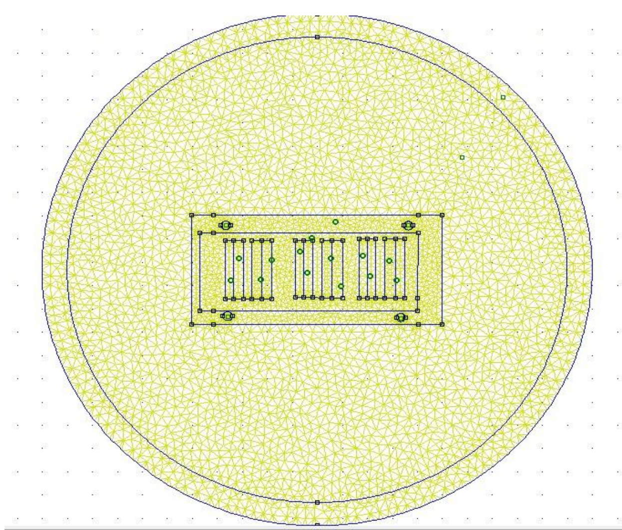

Fig.4.2 *FEM With mesh view*

In the fig 4.2 the mesh view of the transformer which is designed in the FEM software is shown.

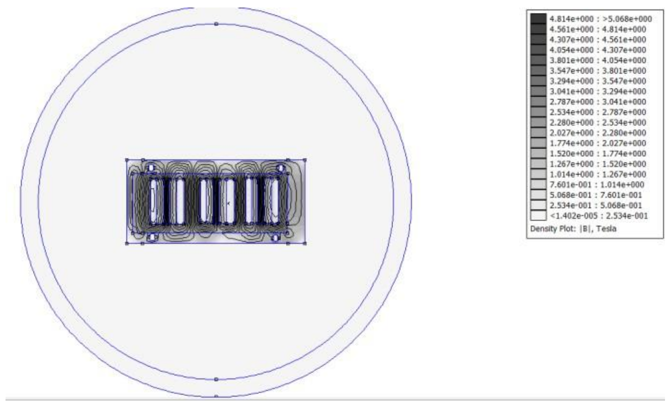

Fig **4.3** *FEM Result*

From fig 4.3 we can see a simple transformer model with flux distributions. Then by applying short circuit fault we can actually recognize the effect of the short circuit fault and able to design the transformer with good ability to withstand.

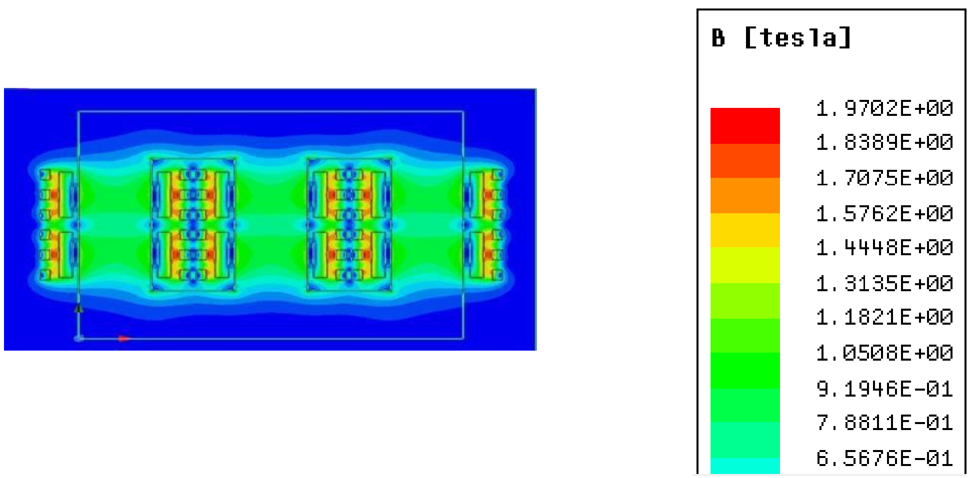

FIG. 4.4 *Magnetic Flux density distribution for SC effect*

In the figure 4.4 we have applied the short circuit fault to the transformer and the flux distribution can be seen in the result.

Also by the result the calculation of radial and axial electromagnetic forces will be much easier.

V. CONCLUSION

By MATLAB simulation we can see the short circuit spike during the fault condition and by FEM model we can see the effect of flux distribution during short circuit condition so by analyzing the results we may able to design the transformer so that it could withstand the short circuit condition effectively.

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