Modelling and Analysing Double Helical Windings Using Finite Element Method

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ABSTRACT

Power transformers are the most expensive and critical component of our power system. Its failure would be a costly event. Winding deformation is caused mainly due to short circuit events, other reasons may be ageing of insulation, and mechanical stresses developed due to transportation. Although, deformation may not result in immediate failure, however the dielectric strength of the winding is greatly reduced. And a further untoward short circuit faults may result in complete rupture of insulation which will result in complete damage of the winding.. Short circuit electromagnetic forces are considered as important factor from design point of view of transformer and should be taken care of while designing a transformer as it has very serious damaging effect to the transformer. Short circuit forces are more dominant in case of large power transformers.The work has been carried out on a power distribution transformer.The simulation results show that the forces which apply to transformer windings are negligible. Also the stresses on conductor cross section area are negligible.

Keywords:Power Transformer, Distribution Transformer, Electromagnetic forces, Winding

INTRODUCTION

One of the main reasons of adopting a.c. system instead of d.c. system for generation, transmission and distribution of electric power is that alternating voltage can be increased or decreased conveniently by means of a transformer. In fact, for economical reasons, electric power is required to be transmitted at high voltages whereas it has to be utilised at low voltages from safety point of view. This increase in voltage for transmission and decrease in voltage for utilization can only be achieved by using a transformer.

Transformer is a static device for transferring electrical energy from one alternation current circuit to another without change in frequency. A transformer may receive energy at low voltage and deliver it at a higher voltage, in which case it is called a step up transformer. When the energy is received at a higher voltage and delivered at a lower voltage, it is called a step up transformer. Actually the transformer is an electromagnetic energy conversion device, since the energy received by the primary is first converted to magnetic energy and it is then reconverted to useful electrical energy in the other circuit. Thus primary and secondary winding of transformer are not electrically but coupled magnetically .In a transformer, the electrical transfer from one circuit to another circuit takes place without the use of moving parts therefore it has highest possible efficiency and requires almost negligible maintenance and supervision

Another possible method for extending the electric range of a HEV is to enable continuous battery charging while the vehicle is in motion [1]'. The emergence of solar-powered HEVs (PVHEVs) results in the continuous charging of batteries via solar energy, which reduces the use of gasoline and, consequently, the amount of air pollution [2].

There are various types of transformer used in electrical power system for different purposes such as generation, distribution and transmission and utilization of electrical power. The different types of transformer are step up and step down transformer, power transformer, distribution transformer, instrument transformer comprising current and potential transformer, single phase and three phase transformer, auto transformer ,dry type transformer, phase shifting transformer etc.

Step up and Step down transformer: This type of transformer is categorized on the basis of number of turns in the primary and secondary winding and the induced e.m.f. Step up transformer transforms a low voltage, high current a.c. into high voltage, low current a.c. system. In this type of transformer, the number of turns in the secondary winding is greater than the number of turns in the primary winding. If (V2 > V1) the voltage is raised on the output side and is known as Step up transformer. Step down transformer converts a high primary voltage associated with the low current into low voltage, high current. With this type of transformer, the number of turns in primary is greater than the number of turns in secondary winding .If (V2 < V1) the voltage level is lowered on the output side and is known as Step down transformer.

Power Transformer: The power transformers are used in the transmission networks of higher voltages. The ratings of power transformers are as follows 400 KV, 300KV, 110KV, 66KV, 33 KV.They are mainly rated above 200 MVA.Mainly installed at the generating stations and transmission substation. They are designed for maximum efficiency of 100%.They are larger in size as compared to distribution transformer. At a very high voltage, the power cannot be distributed to the customer directly, so the power is stepped down to the desired level with the help of step down power transformer. The transformer is not loaded fully hence the core loss takes place for the whole day, but the copper loss is based on the load cycle of the distribution network. If the power transformer is connected in the transmission network, the load fluctuation will be very less as they are not connected at theconsumer end directly, but if connected to the distribution network there will be fluctuations in the load.

Distribution Transformer: This type of transformer has lower ratings like 11KV, 6.6KV, 3.3KV, 440V and 230V.They are rated less than 200MVA and used in the distribution network to provide voltage transformation in the power system by stepping down the voltage level where electrical energy is distributed and utilized at the consumer end. The primary coil of the distribution transformer is wound by enamel coated copper or aluminium wire. A thick ribbon of aluminium and copper is used to make secondary of transformer which is high current, low voltage winding. Resin impregnated paper and oil is used for the insulation purpose. The distribution transformers are used in pumping stations where voltage level is below 33KV, in power supply for the overhead wires railways electrified with a.c., multiple distribution transformers are used for industrial and commercial areas.

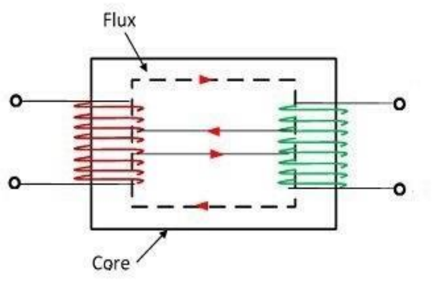

Figure 1. Core type transformer

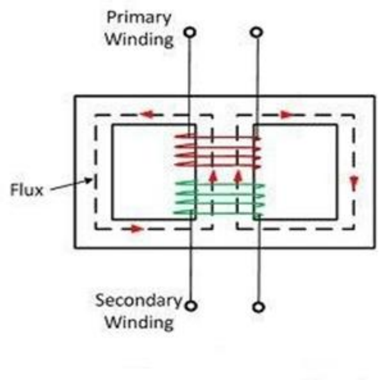

Figure 2. Shell type transformer

METHODOLOGY

There are mainly two methods for analysis of electromagnetic forces: analytical and numerical method. These are discussed as follows:

Analytical Method: Analytical solutions are in terms of an infinite series that converges to the exact one. The n-th partial sum of this series is considered to be an approximate. Analytical solutions of mathematical problems are solutions that are exact and in closed or quadrature form. Sometimes, these solutions may not be usable as they are for practical purposes and approximating these values to a predetermined degree or error of precision/approximation is used to the sought solution and works fine. There are many analytical method such as conformal mapping, method of images, separation of variable. But these are difficult to apply in case of complex structure.

Numerical Method: First of all, it should be emphasised that the "numerical approach" is not automatically equivalent to the "approach with use of computer", although we usually use numerical approach to find the solution with use of computers. That is because of the high computer performance incomparable to abilities of human brain. Numerical approach enables solution of a complex problem with a great number (but) of very simple operations, we can find situations when numerical methods are used instead of analytical methods: When analytical solution of the mathematically defined problem is possible but it is time-consuming and the error of approximation we obtain with numerical solution is acceptable. In this case the calculations are mostly made with use of computer because otherwise it's highly doubtful if any time is saved. When analytical solution is impossible, this means that we have to apply numerical methods in order to find the solution. This does not define that we must do calculations with computer although it usually happens so because of the number of required.operations. Limitations: Analytical methods are limited to highly simplified problems in simple geometries. Better modelling: An approximate solution is usually more accurate than exact solution of crude mathematical model. Flexibility: Engineering problems often require extensive parameter studies. Complications: Even when the analytic solutions are available, they might be quite intimidating. Human nature: Diminishing use of human brain power with expectations for powerful results. Impressive presentation style colourful output in graphical and tabular form Analytical solutions denote exact solutions that can be used to study the behaviour of the system with varying properties. Unfortunately very few practical systems lead to analytical solutions, and analytical solutions are of limited use. That's why we use numerical approach to make close answer to practical result .Numerical analysis has a rich store of methods to find the answer by purely arithmetical operations. So Numerical analysis can solve problems where analytical solutions are not available (using mathematical approach) or very hard mathematical process. Numerical methods are capable of handling large systems of equations, different degrees of nonlinearities which are common in engineering practice. Numerical methods can handle any complicated physical geometries which are often impossible to solve analytically.

Finite Element Method Magnetics (FEMM) is a finite element package for solving 2D planar and axisymmetric problems of magneto statics and electrostatics in low frequency magnetic and electrostatics. The current version of the program runs under runs under Windows 2000, XP, Windows 7 and Windows 8. The program has also been tested running in Wine on Linux machines. Users commonly perform simulations with as many as a million elements, though simulations with tens of thousands of elements are typical. The program currently addresses linear/non linear magnetostatic problems, linear/non linear time harmonic magnetic problems, linear electrostatics problems, and steady state heat flow problems.

RESULTS & DISCUSSIONS

The continuous increase in demand of electrical power has resulted in the addition of more generating capacity and interconnections in power systems. Both these factors have contributed to an increase in short circuit capacity of networks, making the short circuit duty of transformers more severe. Failure of transformers due to short circuits is a major concern of transformer users. The success rate during actual short circuit tests is far from satisfactory. The test data from high power test laboratories around the world indicates that on an average practically one transformer out of four has failed during the short circuit test, and the failurerate is above 40% for transformers above 100 MVA rating [3]. There are continuous efforts by manufacturers and users to improve the short circuit withstand performance of transformers. A number of suggestions have been made in the literature for improving technical specifications, verification methods and manufacturing processes to enhance reliability of transformers under short circuit.

There are different types of faults which result into high over currents, viz. single line- to-ground fault, line-to-line fault with or without simultaneous ground fault and three-phase fault with or without simultaneous ground fault. When the ratio of zero-sequence impedance to positive-sequence impedance is less than one, a single-line-to-ground fault results in higher fault current than a three-phase fault .It is shown in [4] that for a particular case of YNd connected transformer with a delta connected inner winding, the single-line-to-ground fault is more severe. Except for such specific cases, usually the three-phase fault (which is asymmetrical fault)[5] is the most severe one. Hence, it is usual practice to design a transformer to withstand a three-phase short circuit at its terminals, the other windings being assumed to be connected to infinite systems/sources (of constant voltage).

The basic equation for the calculation of electromagnetic forces is

$$F=L\ I\times B$$

where B is leakage flux density vector, I is current vector and L is winding length If the analysis of forces is done in two dimensions with the current density in the z direction, the leakage flux density at any point can be resolved into two components, viz. one in the radial direction (Bx) and other in the axial direction(By).[6] Therefore, there is radial force in the x direction due to the axial leakage flu density and axial force in the y direction due to the radial leakage flux density, as shown in figure 3. and 4

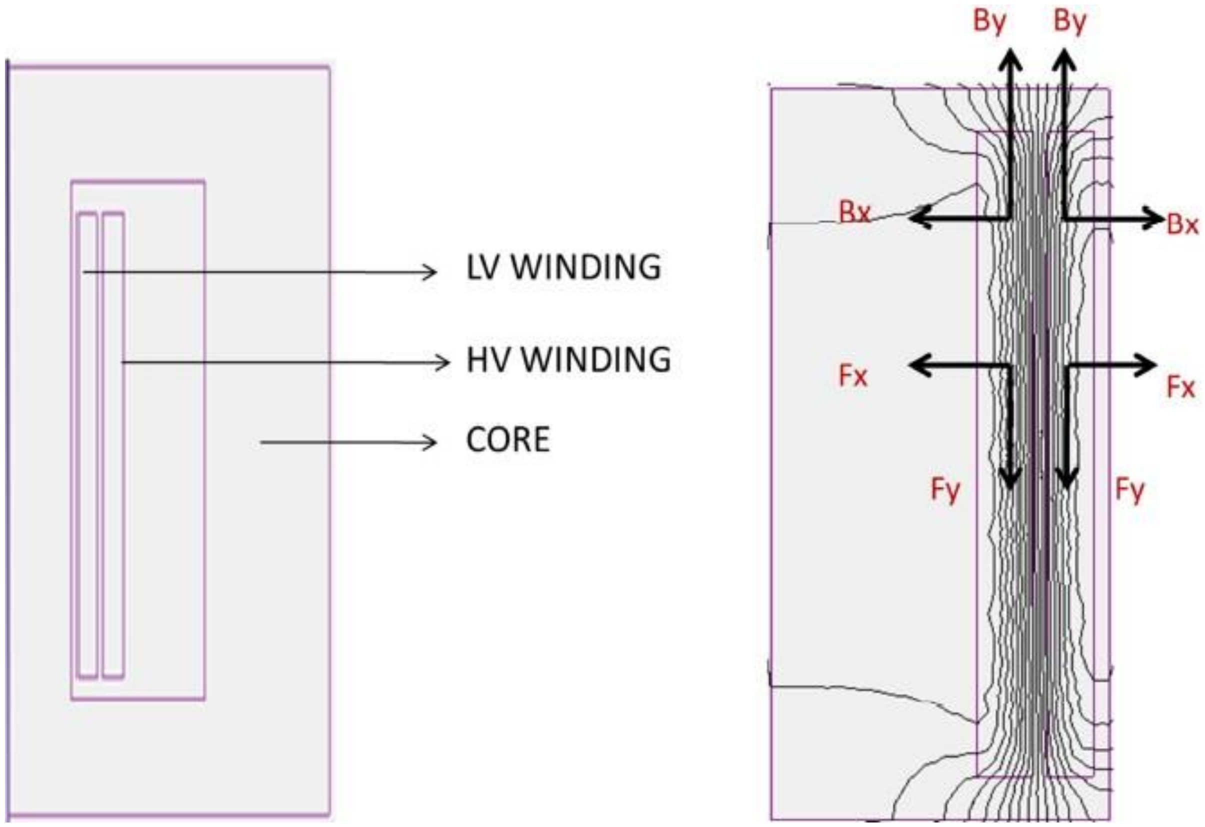

Figure 3: Radial flux in x direction and axial in y direction

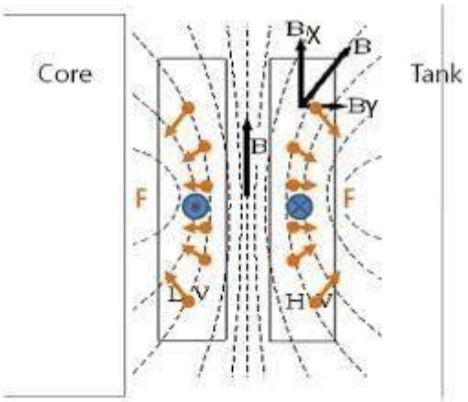

Figure 4: Direction of flux

As described earlier, the short circuit forces are resolved into the radial and axial components simplifying the calculations. The approach of resolving them into the two components is valid since the radial and axial forces lead to the different kinds of stresses and modes of failures.[7] There are number of methods reported in the literature for the calculation of forces in transformers. Once the leakage field is accurately calculated. Overthe years, the short circuit forces have been studied from astatic consideration, that is to say that the forces are produced by a steady current.The methods for the calculation of static forces are well documented in 1979 by a CIGRE working group , The static forces can be calculated by any one of the following established methods, viz. Roth's method, Rabin's method, the method of images and finite element method.. A transformer is a highly asymmetrical 3-D electromagnetic device. Under a three-phase short circuit, there is heavy concentration of field in the core window and most of the failures of core-type transformers occur in the window region.[8] In three-phase transformers, the leakage fields of adjacent limbs affect each other. The windings on the central limb are usually subjected to higher forces. There is a considerable variation of force along the winding circumference. Although, within the window the two-dimensional formulations are sufficiently accurate, the three-dimensional numerical methods may have to be used for accurate estimation of forces in the regions outside the core window**.**

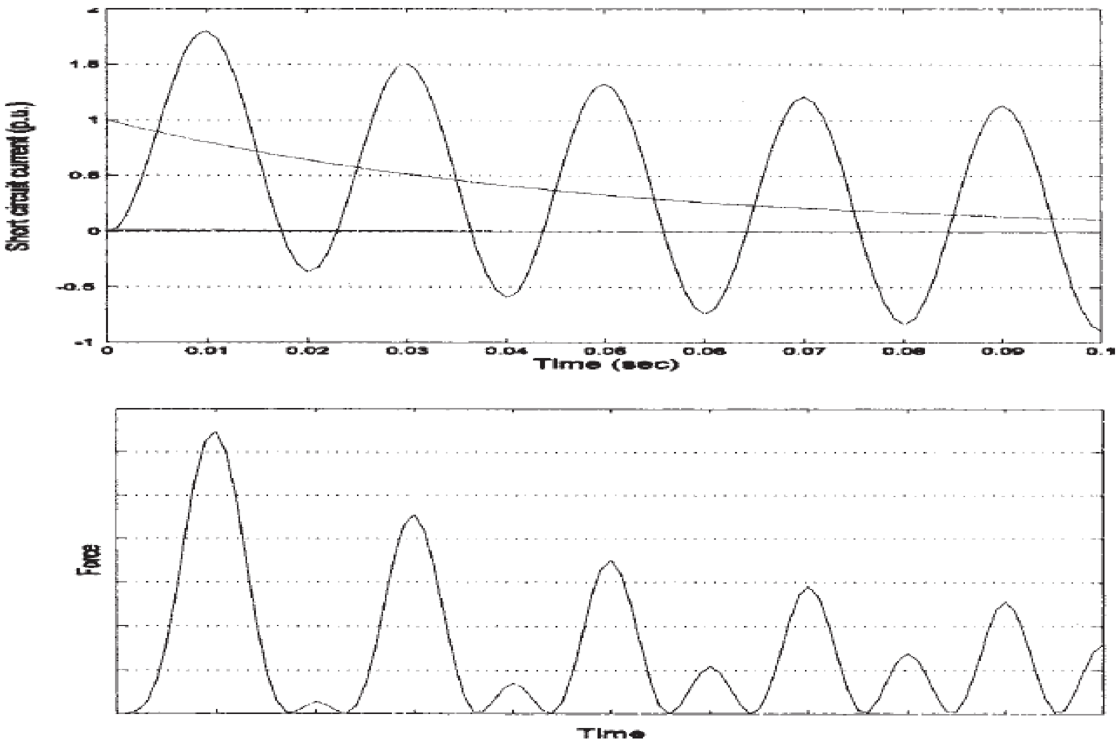

Figure 5: Graph showing characteristics of short circuit forces with time

CONCLUSION

In this study ,two dimensional study is done to find out electromagnetic forces with the help of finite element method. Comparison of forces on single helical and double helical winding is done ,it is find out that forces on double helical windings are less than forces acting on single helical winding. The research analysis suggest that the transformers should be designed by keeping in mind the short circuit forces acting on them during short circuit situation. The technique used and result obtained from research may help in the design of transformer...

FUTURE SCOPE

Further work can also be extended to double helical windings with tappingsIn addition to incorporating uncertainty and parameter variations, the mathematical model can be improved by employing robust control algorithms to solve the optimization problem.

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