Chapter 5

Conclusion and Future Scope

5.1 General

In this thesis, an effort has been made to use finite element method for designing a dry type transformer. The problems associated with the oil cooled transformers especially in distribution segment draw an attention of researchers to find out an efficient, reliable and economical alternative. Although the capital investment in a dry type transformer is high as compared to the similar rating of oil cooled transformer, negligible maintenance, higher overloading capacity, capability to sustain higher temperature rise, etc. have made dry type transformers suitable for the use in distribuiton segment. Also for lighting load applications, control circuit applications and use as instrument transformers, dry type technology is more versatile as compared to oil cooled one. Reduction in cost of a dry type transformer is a prime aspect of a designer. This creates a need for developing a firm design without the development of a prototype coil especially which is required for assessment of impedance value and hot spot temperature in a winding. Use of finite element method and finite element analysis helps in overcoming these problems. This thesis has addressed certain aspects of finite element method for designing low and medium voltage dry type transformers. The objective of this chapter is to highlight the main findings of the work carried out in this thesis and provide suggestions for the further research work. The important findings of this thesis are summarized below.

5.2 Salient Features of Research Work and Summary of Important Finding

5.2.1 Salient Features

In this research work an approach has been suggested for calculating stresses generated in a winding during short circuit conditions using FEA.

3D variational approaches of Finite Element Method has been successfully implemented for estimating the temperature rise in a complete transformer geometry - core coil assembly (CCA) i.e. for core and coil both.

Suggested a 3D approach to estimate an electric field in a transformer / reactor for determining the inrush current and the air clearances. Minimum value of air clearances have been suggested based on FEA results for a system voltage up to 12 kV.

Optimization has been carried out for a transformer whose basic design parameters were estimated using FEA. A reverse design has been worked out and finally optimized solution has been achieved. The results were validated by developing a practical transformer.

5.2.2 Important Findings

In chapter 2, it has been discussed about the use of finite element method as an efficient tool for designing the transformer. Whereas the determination of impedance, winding hot spots temperature, insulation class and insulation level etc. are the major challenges while designing a transformer, the FEA can serve a vital role and may provide a cost effective and efficient solution to the problem. The preliminary results obtained from finite element model may be useful to develop cost effective and efficient design. It was observed during the study that a three dimensional finite element model is predominant over a two dimensional model. While initiating the analysis a two dimensional model may be adopted but for the betterment of results the analysis must be completed by developing a three dimensional model only.

The findings of chapter 3 are related to the core design parameters that is impedance, hot spot temperature, magnetizing inrush current and air clearances. They are summarized as under.

The short circuit stresses have been evaluated in terms of mechanical deformation using finite element method for a dry type reactor. Based on the analysis, the factor of safety was improved and desired results have been obtained. The results have been verified through a type test conducted at third party inspection laboratory. The physical deformation observed in the coil after test was well within 2 % limit as per relevant standards. Same approach can be adopted for designing a short circuit proof transformer for a specified short circuit level. This approach is accurate, less time consuming and helps in identifying the factor of safety without developing any prototype model for verification of impedance value and thereby short circuit current and forces. A reverse calculation can be done to finally estimate the impedance value.

The other important design requirement is the prediction of hot spot temperature. The thermal behavior of dry type transformers has been estimated quite accurately with the help of 3D finite element method using Variational approach in this chapter. This helped in adopting proper designing approach (safety factor) whereby the required level of temperature rise (thermal class) has been achieved. The results were well within the required accuracy limits and were just differing by 2.5 $^{\circ}C$ from the actual test results obtained after heat run test as per simulation load method of IS11171, 1985 at third party inspection laboratory. This has saved the time and helped in developing an actual transformer with adequate safety margins without any physical development of prototype model for the winding.

The magnetizing inrush currents and air clearance have been approximated to a quite close approximation using 3 dimensional Finite Element Method in the last phase of chapter 3. A small transformer has been analyzed using FEA for finding out the values of inrush currents. The transformer is then subjected for the actual measurements and results found are quite close to the estimated ones using FEA. Also the air clearances have been estimated for different system voltage levels in this chapter after doing the FEA. This will help designer in optimizing the design without an actual built up of a prototype model of entire transformer. The approach is extendable for the estimation of electric field when the equipments are subjected for the operations at higher altitude also.

In chapter 4 design optimization has been carried out for finding out the cost effective and technically suitable design as per customer's requirement.

The results of this chapter prove that the optimization of an objective function leads to a more realistic assumption during the design stage. Based on the obtained values of design variables and their feasibility of selection during the practical realization of the actual transformer, the need for prototype development can be avoided. An optimization of a design of 100 kVA transformer has been carried out in this chapter. With reverse design approach, a practical transformer was developed and the designed parameters obtained are well within the requirement of the specifications conveyed by the customer.

5.3 Scope for Further Research

The findings of this research work are very well describing approaches those are adopted in designing the transformer and related products by the use of FEM and results obtained are quite close to the actual requirements, still there exists scope for the improvement. Certain areas were kept untouched during the design analysis. They are as listed below and provide the scope for further research.

- While carrying out the FEA, a 3 D tetrahedron element has been used. This is a basic 3 dimensional element. For higher accuracy, one may use eight node break elements with each of the nodes having three translational degrees of freedom in the nodal x, y and z directions or with elements having even higher than eight nodes especially for the analysis of large power and distribution transformers or other equipments with high voltage or extra high voltage.
- Apart from non linear loads, the effect of eddy currents in transformer windings is quite predominant especially in large power transformers.

FEA can be used to predict the eddy currents in the winding by estimating the electric field across the low voltage windings. This will help in identifying the hot spot temperature in a winding.

- The effect of mutual inductance between the windings of different phases may be accounted for during the estimation of short circuit forces using FEA.
- The effect of temperature rise of the winding of middle phase on the other two phases can be modeled using FEA for better prediction of the actual temperature rise of a transformer.
- A model of large power transformer can be developed and analyzed using finite element method for predicting the magnetizing inrush currents. A pre-fluxing model can be suggested based on FEA for reducing the inrush currents.