3-D Comparative Analysis of 3-phase Transformer core Using CRGO Silicon Steel, Amorphous and FINEMET for Low Losses using ANSYS

Sarpreet Kaur and Damanjeet Kaur

University Institute of Engineering and Technology, Panjab University, Chandigarh, India

E-Mail : sarpreetdua@yahoo.co.in

Abstract: A transformer correspond electric power among various circuits without change in frequency. It comprises essentially two types of windings i.e. primary and secondary. Design and selection of material to construct a transformer is a very crucial process. To select a suitable material for transformer design there are various limitations in terms of usage of the materials like impedance, effectiveness, flux solidity, current & voltage losses needs to be taken care which is totally influenced on the construction process and material selection. This paper deals with the 3-D analysis and usages of the effective materials to design transformer so that losses in the real time can be reduced. The materials studied in this paper are CRGO silicon steel, Amorphous, Finemet and their comparative analysis is done. The comparison is made between the proposed work and configured design and losses of the three phase transformer installed at PGIMER Chandigarh (Post Graduate Institute of the medical education and research).

Keywords: 3-Phase Transformer, Losses, ANSYS, Transformer design, Materials Selection, Electromagnetism

1. INTRODUCTION

A transformer which is also well known by reflexive electrical method benefits to transfers electrical power among various electrical circuits. A fluctuating current in one coil in the transmission process yields a fluctuating magnetic flux, which prompts a fluctuating electromotive energy through any other coils looped nearby the equivalent core. Electrical power can be transferred among various coils, without a copper linking among the two different circuits as shown in figure 1. The induced current can influence several coils due to varying magnetic flux bordered by the transformer coil. Transformers are recycled for up & down alternating energies in electric power presentations, and for connections through which the signal is transmitted [1].

As per daily usage of electricity in the real time scenario after considering high costing and complex structures of the electrical circuits, transformers is now become an important part for the communication, circulation, and operation of discontinuous current to generate the efficient power for the population [2]. A wide collection of designs of the transformers exists in automated and power applications. Designing and selection of the material in the transformer is a very crucial part. There are variety of materials used for the transformer construction which produces efficient power but they are causing high losses which should be minimized for the efficient usages [2][3].

There are various linear aspects of transformer and in this paper some of the linear aspects in the designing and construction of the transformers are discussed as:
a) Losses in the cores in terms of magnetizing current losses deals with the Hysteresis damage due to nonlinear effects of the magnetic field rise in the core of the transformers must be taken care for high power generations.

b) There is a lot of problems occurred in terms of leakages of the flux which results in the high reactive impedances and the resistance of the current increases which reduces the current flow in the windings and current losses increases which must be minimized for the proper functioning of the transformers.

c) Comparable to an inductor, dependent capacitance and phenomenon of the resonance due to the distribution of the electric field, there are mainly two dependent capacitance which are generally reflected are given below

![Diagram](image)

**Figure 1.** Transformer using Induction law

1. Capacitance among end-to-end turns in transformer’s layers.
2. Capacitance among the adjacent layer to the core and the actual core of the transformer [4].

Addition of capacitance is complex in the transformer model and does not contain dependent capacitance. Still, effect of the capacitance can be restrained by linking open-circuit inductance which signifies the inductance of a key winding at the time when the secondary winding is vulnerable which may result in the short circuit of inductance which also give rise to the losses in the transformer windings.

To design the core, the first step needs is the flux density selection and grade of the material to be considered for transformer. There are diverse materials available in market like CRGO, Amorphous and nano-crystalline material for the transformer core. CRGO consists of numerous grades such as M4, M5, and M6 etc. It should be taken care while selection of the core material, the amount of silicon steel should be in the series of 4 to 5 %, to diminish the total losses in the core of transformers [12] [13].

There are different materials used for the designing and development of transformers. They are given below:

**Solid iron:** These types of materials serve as a brilliant pathway to offer magnetic flux and maintain high magnetic fields. But, these are not suggested in terms of the cores for the transformers that work in AC solicitations since its magnetic field yields huge eddy currents, which produces heat at great occurrences.

**Carbonyl iron:** These are highly pure materials that deal with the stability through a wide collection of heats and magnetic flux intensities. The material powder contains micrometer-sized iron domains coated by a thin isolating layer that diminishes the eddy current at extraordinary temperature.
Amorphous steel: These material cores are made of several layers of metallic tapes that are used to reduce the stream of eddy streams. These centers have fewer losses than other cores material, which easily work at high heats as associated to standard lamination heaps.

Nano-Crystalline: This type of material is very demanding these days for preparing high stability in designing and development of the transformer material. The material arrangement is 84% iron with stability of the silicon quantity, boron, copper, molybdenum, and nickel. These types of material are man-made and completed in an amorphous phase. It is re-crystallized in terms of precise amorphous mixture and Nano crystalline segments when strengthened; giving the sensible magnetic belongings.

This physical process has the overall development over an extensive range of occurrences when associated to other available resources. It's moderately high capacity flux density, shared with its inconceivable low loss and great permeability concluded a wide frequency series, makes it convenient in many presentations

CRGO steel: These types of sheet steel is well suited to give easy way to all its crystals. CRGO process is generally used for manufacture of cores of the transformer. The current that deals by the transformers among CRGO material is truncated. If steel was recycled, it needs small amount of force in terms of magnets to form flux in terms of high magnetizing process. The attracting force should be enough to strength the fields which are widely differing from the functional axis of the field, to come into placement with the applied field axis.

This paper is divided into various sections. Section 1 explains the introduction while Section 2 is literature survey. Section 3 is 3-D design and development of transformer core. Section 4 discusses the experimental results and evaluation of losses. Finally the last section is about conclusion and future scope.

2. RELATED WORK

This section covers various valuable researches which are done on the selection of materials for high efficiency of the transformer working. Kana Takenaka et al. [5] the construction of the transformer in their present effort which exhibits a low loss in the core that is comparable to the transformer created by a profitable Fe-based amorphous mixture. Sweta A Jain et al. [6] presents the exhibition and investigation of core and winding damage in power converters. 2-D and 3-D finite elements based materials are cast off for the accurate scheming of flux concentration and total core and winding damage of a 3-phase 15 MVA power convertor. The outcomes of the projected numerical system are compared with the tentative outcomes.

Omar Sh. Alyozbaky et al. [7] examines the performance of 3-phase in power converter and their design of the cores under two forms of the signal i.e. Sinusoidal and non-sinusoidal effective conditions. Three categories of core materials are used in terms of the grades i.e. M4, M5 and M6 which have been selected to link the core damages in steady-state and temporary operation circumstances. Simulation outcomes of behaviour of the core loss on the different ingredients are obtainable and deliberated.

Kamran Dawooda et al. [8] show various kinds of transformer prototypes which are observed for the intention of the no-load damages by analysis of the finite element based materials. 2-D and 3-D finite element investigates models in their research work which are used for the mock-up of the converter. Effects of the finite element system are also linked with the experimental outcomes. The outcomes show that 3-D model offers high exactness as linked to the other dimensional models.

Xiaojing Liu et al. [9] presented efficient analytical process which is presented to estimate the loss of
copper and the outcomes are linked with the controls by finite element methods. Amorphous and nano-crystalline based materials are now generally castoff for the practicalities of high frequency converters.

Yugendra Rao K N et al. [10] have presented the design and modeling of a 3 phase core windings of the transformer with various coil and components and is defined in detail engaging magneto static exploration in ANSYS simulation stage.

Transformers are the hot topic ever since its development because of its strength and presentation in power arrangements. This is reachable by effective deliberate modelling in a high enactment simulation atmosphere like ANSYS Maxwell whereas the converter is planned for the essential characteristic, exhibited, analyzed and outcome evaluation is achieved in their research work.

Magdaleno Adame et al. [11] worked on the 3-phase transformer for a coated steel core with a frequency range of 50 Hz with several voltage ratings with the winding of the limb.

Finite element process based 3-D approach has been castoff to evaluate value of full losses in the core. In their research model simulation the flux crowding is included in the settings of the air gap, currents spread in the essential windings which create a magnetic field that improves core magnetic area. So losses in the core from the virtual model are conflicting than the established losses. Salvador Magdaleno-Adame et al. [12] presented finite element based analysis of groupings of electrical toughness in the core steps of the single distribution converter. The magnetic part of this converter has cross section with core steps of the lamination. Two steels are joined in the core steps of convertor which is a convectional grain focused on electrical steel. FE based three dimensional simulations are achieved to analyze the losses in the core without groupings of electrical strength.

3. PROPOSED WORK

In this section the efficient designing of the 3-D transformer process with low core losses in the windings and using nano-crystalline material for core of transformer is discussed. As the selection of the material and optimization is one of the crucial steps in the designing of the transformer. The proposed approach is about the selection and simulation of the losses for the efficient transformer design methodology. In the proposed work, various configurations are used for the simulation i.e. Maxwell equations, type of connection, voltage, frequency, number of turns, FEM procedure etc. for reduction of losses in the designing and development of the transformer. The whole simulation is done in AUTOCAD and ANSYS. The transformer geometry is achieved using ANSYS which further integrated using FEM method in the ANSYS software. This is used to attain losses evaluations and distribution of the flux densities. These types of transformers are cast-off for generation and transmission of electrical power as well as the distribution for industrial practices. Three-phase provisions have several electrical benefits above single-phase control and when dealing with 3-phaseconvertorsmeans three varying voltages and varying currents in divergence with phase-time of 120 degrees. The proposed 3-D analysis is compared with the configured design and losses of the three phase transformer installed at PGIMER (Post Graduate Institute of the medical education and research) complex, comprises of CRGO steel material and is able to achieve high performance in terms of the reduce losses, low cost, reduced sizes. The whole simulation environment is taken place in the ANSYS Maxwell simulation tool.

The general specifications of the three phase transformers are given below in Table 1 and its related design specifications are given in Table 2.
Table 1. Generalized Specifications of 3-phase transformer

| 12.5 MVA Transformer | H.V. Windings | L.V. Windings |
|-----------------------|---------------|---------------|
| Connection type       | YNyn0         |               |
| Power                 | 10/12.5 MVA   | 11kV          |
| Cooling               | ONAN / ONAF   |               |
| Rated Voltage         | 66kV          | 11kV          |
| Rated Frequency       | 50Hz          |               |
| Rated Current         | 109.35A       | 656.09A       |
| Number of Turns       | 828           | 138           |

Table 2. Design Specifications

|                        |               |
|------------------------|---------------|
| Height of Window       | 1340mm        |
| Number of Stacks       | 23            |
| Height of Outer Limb   | 2180mm        |
| Number of Disc of H.V. Winding | 70          |
| Inner/Outer Diameter of L.V. Winding | 458/531mm  |
| Inner/Outer Diameter of H.V. Winding | 656/723mm  |
| Space Factor           | 0.96          |
| Maximum Flux Density   | 1.569 Tesla   |

The proposed work has been prepared to fetch the superlative performance outcomes of a three phase power transformer by changing core material to find the losses of the transformer with same dimensions and supply conditions. The proposed work is done on a three phase power transformer using rated power of 10/12.5MVA. The designing and development has been achieved using recent finite element apparatus. The comparative exploration is showed for different electromagnetic appearances by means of distribution of the flux density, magnetic vector potential, current concentration etc. For the transformer model current density is input in primary and secondary winding in all three phases and problem is analyzed at frequency 50 Hz.

4. RESULTS AND DISCUSSIONS

This section deals with the result and discussion of the designing and development in terms of applied input current (low and high voltage) and input voltage (high voltage) for different materials i.e. CRGO steel, Amorphous, Finemet.
Firstly 3-D modelling of the 3-phase transformer using ANSYS MAXWELL is done as shown in figure 2(a). Figure 2(b) shows the BH curve properties which explains the magnetic properties, and also tells how the selected material will react to the external magnetic field while constructing the transformer. In the same manner the construction is done for other different materials i.e. CRGO steel, Amorphous and Finemet.

**Figure 2(a)** ANSYS 3-phase transformer 3-D modeling (b) B-H Curve Characteristics
Figure 3 (a) Input Current (Low voltage) (b) Input Current High Voltage (c) Input Voltage (High Voltage) for three phase transformer using CRGO silicon steel material
Figure 4 (a) Input Current (Low voltage) (b) Input Current High Voltage (c) Input Voltage (High Voltage) for three phase transformer using amorphous material
Figure 5 (a) Input Current (Low voltage) (b) Input Current High Voltage (c) Input Voltage (High Voltage) for three phase transformer using Nano crystalline soft FINEMET material
The figure 3, figure 4, figure 5 shows the input current in terms of low voltage and high voltage. The aim for converting the power to a much greater level is that upper distribution energies indicates lower current streams for the identical influence and consequently lower $I^2R$ damages alongside the interacted cables grid. These complex AC communication currents and streams can then be condensed to a considerable lesser, safer and functioning voltages where can be recycled to stream electrical apparatus in our workplaces and homes due to high voltage transformers. If these material properties are not given high and sufficient currents then transformers will not able to broadcast high level energies which will reduce the supplies in the working environments. The Convertors are proficient of either aggregating or reducing the voltage levels and current streams without adjusting its occurrence, or the volume of electrical energy being transmitted among windings by using magnetic circuitry.
Figure 6. Proposed evaluated Losses using different materials

Figure 6 shows the current and voltage losses in the proposed 3-phase transformers using CRGO steel, Nano crystalline FINEMET, Amorphous materials. Losses in the transformer are very significant which is well-defined as the variance among input and output influence. So the typical transformer consists of electrical losses which can be considered as the core losses.

The losses must be low for the proper functioning and efficient power generation. These losses are generated due to losses in the eddy current and hysteresis which depend upon the magnetic material which is used for the construction and development of the core in the transformer. The losses also occur due to the reversal of magnetization in the core of the transformer which also rely on the volume and iron grading, magnetic reversals frequency or occurrences and concentration of the flux. The alternating current reaches to the winding of the transformers which deals with the alternating flux. When this concentration of the flux associates with secondary winding in the converter, it creates induced EMF and some flux part also gets linked with the core of the steel, which will also produce induced EMF and triggering small current circulation in that part which produces some power dissipated in heat form. So these types of losses must be controlled to increase the efficiency of the transformer designing, selection and development. Also it can be noticed from comparative analysis from different materials that the transformer construction using FINEMET material is achieving fewer losses as compared with the CRGO and Amorphous materials.

| Transformer Material | Losses     |
|----------------------|------------|
| CRGO Steel           | 12 (MegW)  |
| Amorphous            | 10 (MegW)  |
| Finemet              | 7 (MegW)   |

The above table shows the loss performance of 3-phase transformer from which it can be seen that the nano-crystalline material is well suited for the performance in terms of low losses in the designing and development of the transformer. It can be noticed from Table 3 that the FINEMET has minimum losses among materials considered for achieving high performance in terms of generating high power in the 3-phase transformers.
5. CONCLUSION

Core losses in the transformer occur due to the unstructured material used for the development and designing which are very sensitive to the magnetization. So these losses should be controlled and diminished. So selection of the material is very important during construction of the transformer. In the proposed work the comparative analysis is done after selection of the different materials. The materials used are CRGO steel, Amorphous and Finemet. From the result and discussion it can be seen that the FINEMET material is most suitable material to reduce losses in transformer and it can increase efficiency of transformer. Amorphous is also having fewer losses and is one of the significant materials that can be used for the core of the transformers. Reduction in core losses also increases the lifespan of the transformers. Also the comparison is made with the one of the top most research organization’s real time readings which is taken from their transformer performance evaluation in terms of the losses and the proposed work is able to achieve high performance in terms of low losses and efficient design materials.

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