Structural Modeling of a Three Phase Core type Transformer using ANSYS Maxwell 3D

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Abstract: Transformers are of great interest ever since its invention because of its robustness and application in power systems. Hence there is a lot of research going on to increase its performance characteristics and compatibility in the higher power system rating due to ever increase in power demand. This is achievable by effective strategic modeling in a high performance simulation environment such as ANSYS Maxwell where in, the transformer is designed for the required characteristic, modeled, analyzed and performance evaluation is done. In this paper design and modeling of a three-phase core type transformer with coil and terminals is described in detail employing magnetostatic analysis in ANSYS Maxwell simulation platform.

Index Terms: Core type transformer, Modeling, Coil design, Terminal design, Magnetostatic analysis.

I. INTRODUCTION

Transformer is predominantly one of the important devices in an power system for its wide range application in, stepping up voltage for power transmission and stepping down voltage for power distribution and also because of it's high power efficiency. Hence an effective design and structural modeling is necessary before real life implementation. In this paper Structural Modeling of a three-phase core type Transformer is described in detail using ANSYS Maxwell 3D simulation tool, which is a high performance industry standard simulation tool, which employs Finite Element Analysis, for its structural evaluation and validation.

II. STRUCTURE OF THREE PHASE CORE TYPE TRANSFORMER

It has a core usually of 3 limbs. The HV winding is wound over the LV winding and this combination on to the limb and insulation is provided between LV and HV windings [1]-[2]. Transformer uses a concentric type of winding, after the winding is laid out the terminals have to be derived from the windings for it to be connected in Y or Δ format depending upon the type of application required. This article discusses the design of generic type of winding of transformer, which is also applicable for design of LV and HV windings. The schematic diagram of three-phase core type transformer with windings is shown in Fig. 1.
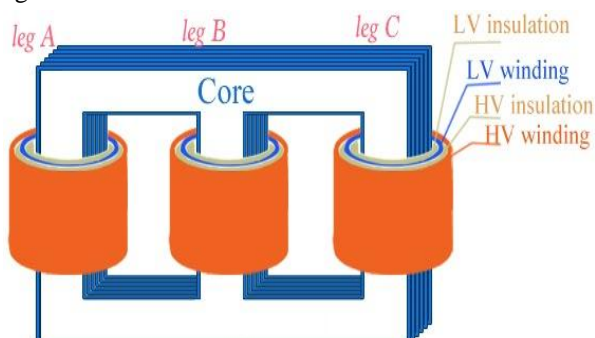

Fig 1. Structure of a three-phase core type transformer

III. STRUCTURAL MODELING OF A THREE PHASE CORE TYPE TRANSFORMER USING ANSYS MAXWELL

Magnetostatic analysis is used as a solution type under ANSYS Maxwell 3D [3]. The units for this model are in inches, but it can be changed to any units by using the Modeler toolbar of Maxwell [4]-[5].

Design parameters:
1. Core: Iron core, non-linear ferromagnetic material.

2. Coil for windings: Copper.

3. For *leg A*:

    Coils: CoilA_1, CoilA_2, CoilA_3

    Terminals: terminalA_1, terminalA_2, terminalA_3

4. For *leg B*:

    Coils: CoilB_1, CoilB_2, CoilB_3

    Terminals: terminalB_1, terminalB_2, terminalB_3

5. For *leg C*:

    Coils: CoilC_1, CoilC_2, CoilC_3

    Terminals: terminalC_1, terminalC_2, terminalC_3

Reference position, P(-1, -6, 0)		
x-size: 2inch	y-size: 12inch	z-size: 10inch

A suitable standard dimensions are used for the modeling of the entire transformer which includes the core, windings, terminals and air gap specification.

A. Designing core for a three-phase core type transformer

Iron is used as a ferromagnetic material for core, since has higher permeability and enhanced mechanical strength [6]. Draw box option is used from the toolbar to draft the core on the Maxwell 3D software with the following specifications on the cartesian co-ordinate system:

Hence, we get the following model as generated form Maxwell as shown in Fig 2., and is named as Core.
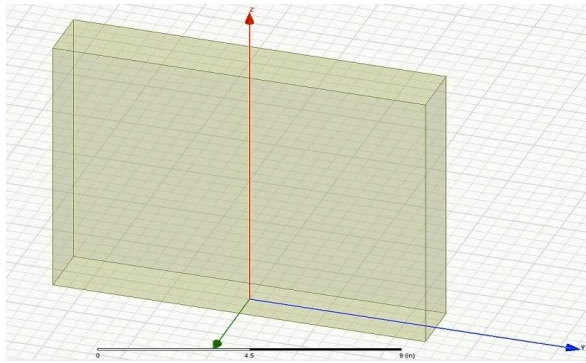
Fig 2. Structure of core drafted without limbs.

For designing the limbs for the core, Draw box option on the Maxwell toolbar is used, with the following specifications:

Reference position, P(-1, 1, 2)		
x-size: 2inch	y-size: 3inch	z-size: 6inch

The box drafted is named as Box, and for the formation of three limbs the Box is replicated by using Duplicate around axis tool bar with a phase displacement along z-axis = 180^0 and the new box created is named as Box_1. The modified model of the core is as shown in Fig 2.1.
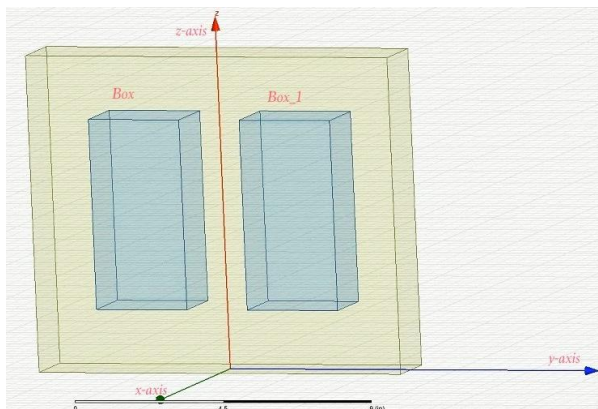

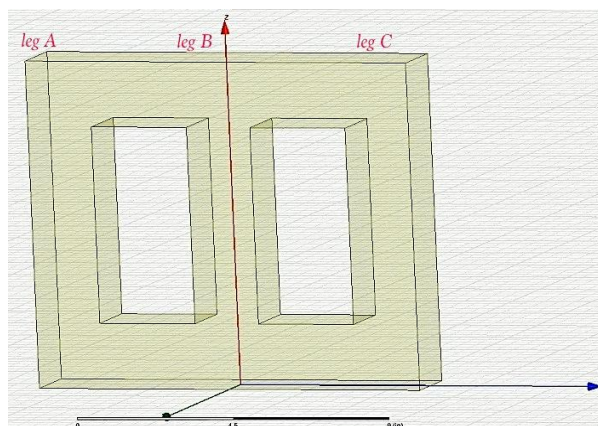Fig 2.1. Structure of core containing boxes from which the core is derived

Fig 2.2. Structure of core consisting of three limbs

Hence the Box and Box_1, have to be eliminated with respect to the core to form the limb structure for a three-phase core type transformer. By selecting Core, Box & Box_1 the Subtract option is selected form the toolbar, thereby leaving out a trace form the core.

Henceforth we obtain the modified structural design for the core with limbs which is as shown in Fig 2.2.

The laminations of the Iron core are laid out in such a way that staggering of butt joint occurs, which avoids continuous air gap and thereby, the reluctance of the magnetic circuit is not increased. The staggering of butt joints is done in even layers (2nd, 4th, 6th….) for the core employed in designing. Hence, there is an air gap formed between the E-segment and the I-segment of the core. The designing methodology for the air gap between the E and I-segments in Maxwell is done with the following specifications:

Reference position, P(-1, -6, 2)		
x-size: 2inch	y-size: 12inch	z-size: 0.05inch

Therefore, the E and I-segments of the core are separated form each other with a distance along z-axis equal to 0.05inch, and to separate them into two different bodies right click on the E and I-segments and select the Split option under the Modeler option of the Maxwell's toolbar. Hence the final design of the core is completed and is as shown in Fig 2.3. Therefore, since the core design is ready the coil windings can be laid on to the core.
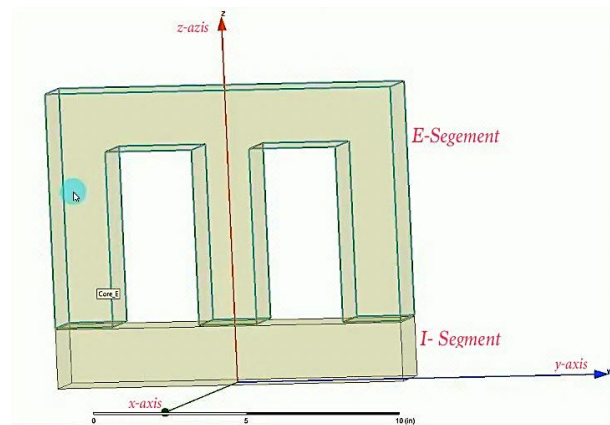

Fig 2.3. Final structural design of the three-phase core type transformer

B. Coil design and winding the coils on to the limbs of the core

Transformers employ concentrated type of winding and hence the winding factor, $k_w = 1$. We know that each limbs of the core will have to carry three coils and therefore three terminals, hence we shall first design the coils and terminals for *leg A* and then for *leg B*, *leg C* respectively.

1) Design of CoilA_1, under leg A of a three-phase transformer:

The coil must be wound on *leg A*, circularly hence the Plane of design is chosen as *yz* and Rectangular box is chosen and the following design parameters is employed:

Reference position, P(0, -3.6, 3.5)		
x-size: 0	y-size: 0.3	z-size: -0.8

A rectangular strip is formed with *y* and *z* dimensions just adjacent to the *leg A*. To create a circular sweep for the coil use *xy* plane and choose Rectangular box form the toolbar of Maxwell with the following specifications:

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Reference position, P(1.5, -6.5, 3)		
x-size: -3	y-size: 3	z-size: 0

And the Rectangular box thus formed is a surface plane but we would want it to be a rectangular path, which is achieved by selecting Delete last operation option from the Modeler tool bar of Maxwell. Hence, we obtain the updated structure of the core type three-phase transformer with coilA_1, which is as shown in Fig 2.4.
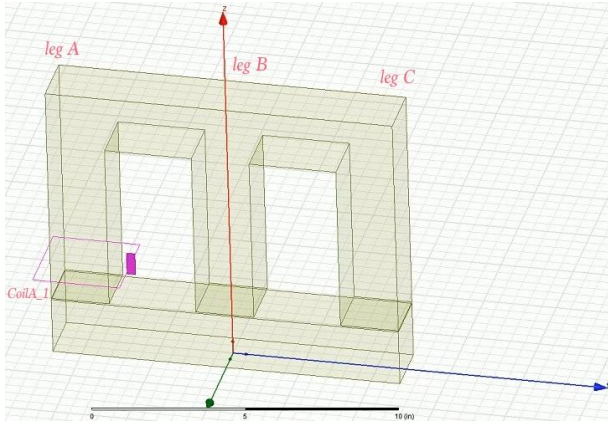

Fig 2.4. Structure of three-phase core transformer showing CoilA_1 wound over leg A

The rectangular strip designed is used as a reference for the length of the coilA_1, and to converter the rectangular path to a real circular coil of certain cross-section select the rectangular strip and the rectangular path and select the Sweep along path form the Draw option on the Maxwell's toolbar. We obtain the modified version of the CoilA_1, which is as seen form Fig 2.5.
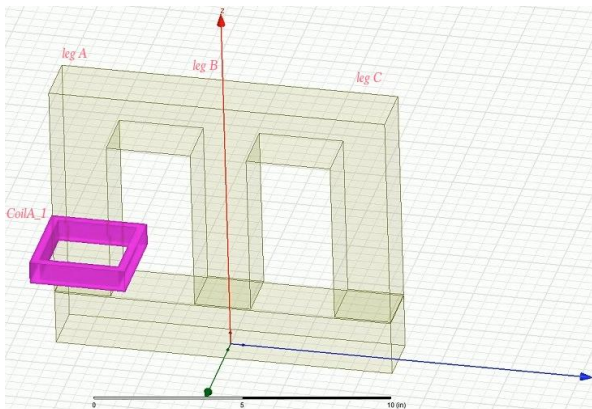

Fig 2.5. Structure of a CoilA_1 in three dimension with certain area of cross-section.

C. Terminal design for the coil of a three-phase core type transformer

Terminals are necessary for the coils to undergo excitation, therefore terminals have been laid out from the CoilA_1, by selecting the Section option form the Surface tab of Modeler toolbar and are laid on the opposite surfaces of CoilA_1, by choosing the section of design as *yz*.

Hence we obtain the following structure with the terminals named as terminalA_1 and terminalA_1[1], which is seen from Fig 3.
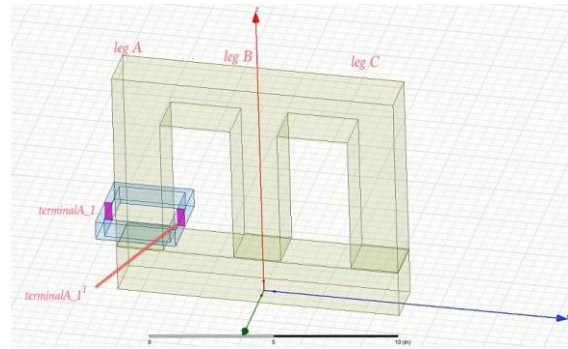

Fig 3. Terminals laid out on both sides of the CoilA_1

Since for a coil two terminals are not necessary one of them have to be eliminated. Before doing so, separate these two sections by selecting Separate bodies from the Boolean tab of Modeler toolbar. Henceforth, leading to elimination of terminalA_1[1], which is shown in Fig 3.1.
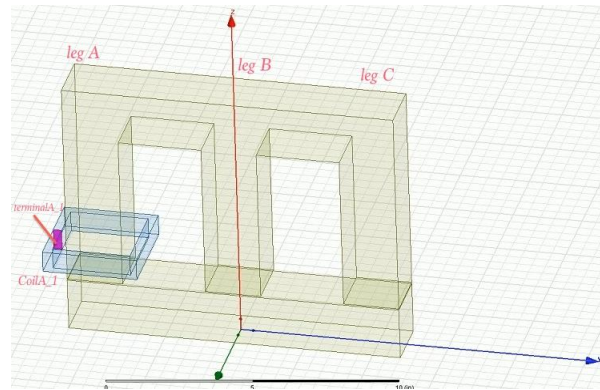

Fig 3.1. The per phase coil winding, per limb *(CoilA_1)* of a three-phase core type transformer.

The above procedure can be generalized for the designing of a coil and terminal for a core type transformer. Hence for completing the windings for the entire three-phase core type transformer we can use the Maxwell's duplication tool, which will ease out the process of creating the coils for every phase and limb.

2) Designing the CoilA_2 , CoilA_3 form the CoilA_1 for the legA: By selecting the CoilA_1 and terminalA_1, choose the Duplicate along line option from the Maxwell's toolbar with, rate of change of z-axis, *dz* = 1.925inch and the no of duplication as 3. Rename the formed coils and terminals as CoilA_2 and terminalA_2 for second coil of *leg A* and name the third coil of *leg A* as CoilA_3 and terminalA_3. The following is evident form the Fig 3.2.
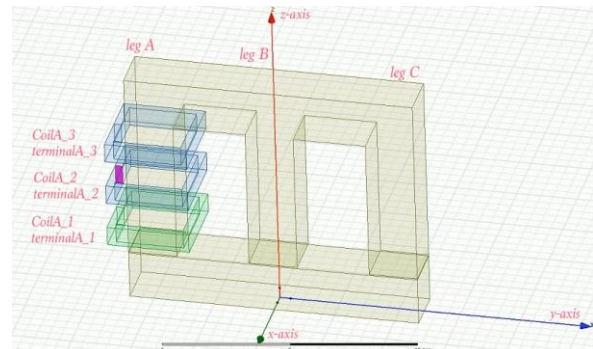

Fig 3.2. Coil and terminals design for the leg A of the three-phase core type transformer

Therefore with the coil design for the *leg A*, being achieved the same design is copied over to the *leg B* and *leg C*, which is accomplished by employing the Duplicate along the line option from the Maxwell's toolbar with *dy* = 5inch. Hence the final structure of a three-phase core type transformer with coil and terminal designing is accomplished and is as shown in the   Fig 3.3.
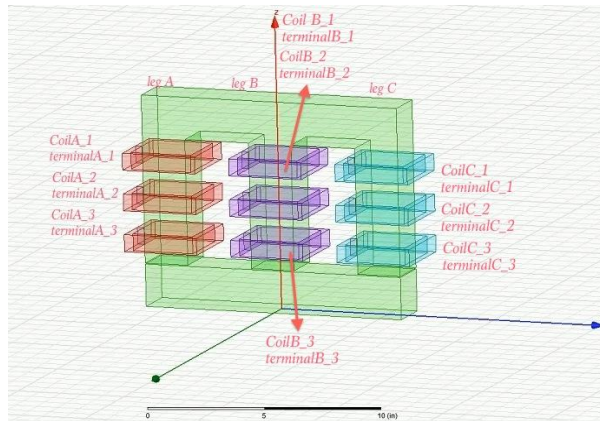

Fig 3.3. Final Structural Model of a three phase core type transformer with coils wound on it.

IV. CONCLUSION

Hence the structural design of the three-phase core type transformer was modeled in ANSYS Maxwell 3D. Maxwell employs Finite Element Analysis in the background for computation purpose thereby ensuring rapid and cost effective analysis before real life implementation. Therefore even more complex systems can be analyzed in Maxwell and the performance characterization and evaluation is possible. Research is going on in obtaining flexible range of output power form transformer by replacing the conventional power transformer units by solid state power transformers which employs high power semiconductor devices, thereby this change will lead to increase in the power system capacity required for the future power demand. Hence before real life implementation the performance characteristics of transformers are analyzed with high power semiconductor devices using ANSYS Maxwell and Simplorer co-simulation.

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