Pertanika J. Sci. & Technol. 25 (S): 21 - 28 (2017)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

The Response of a High Voltage Transformer with Various Geometries of Core Joint Design

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ABSTRACT

The core losses in a three phase transformer can be significantly reduced by improving the core joint geometry. The researchers were applied numerous types of T-joint designs in order to reach the optimum design that can be used in three phase transformer to reduction the losses. Two types of T-joint design are presented in this paper; T-joint with 90° butt-lap design and T-joint with 45° mitered design. A 3-phase distribution transformer was simulated in 3D using Ansys Maxwell software. The core loss for a three-leg three phase transformer rated 1000 KVA and the flux density distribution are investigated. The simulation results show the core losses were increased up to 3% and the flux density was increased to reach more than 22% flux density become higher when using T-joint with 90° butt-lap design as compared with T-joint with 45° mitered design.

Keywords: Core loss, power transformer, joints design, flux distribution

INTRODUCTION

No-load losses are also called iron or core losses. The three main components of no-load losses are eddy currents, hysteresis and stray losses. Hysteresis describes the memory of a magnetic material. More force is necessary to demagnetise a magnetic material since the magnetic domains in the material resist realignment. Eddy current losses are small circulating currents in the core material. The steel core is a conductor that carries an alternating magnetic field, which induces circulating currents in the core. Many papers, books, reports and standards have been published on new models of transformers which ensure low losses (Amoiralis, Tsili,

ARTICLE INFO

Article history:
Received: 24 August 2016
Accepted: 03 Jun 2017

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ISSN: 0128-7680

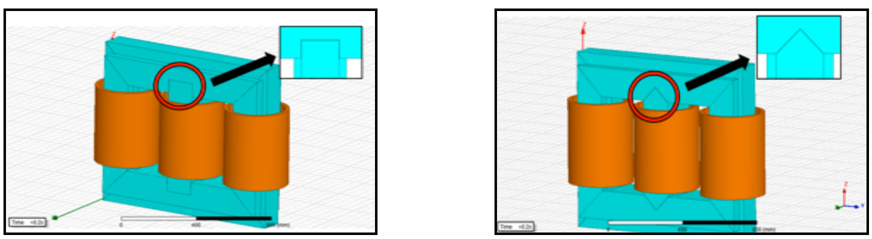
& Kladas, 2009). The most recognised contributors of core loss performance in power and distribution transformers are firstly the iron losses of the core material (Valkovic, 1982) and secondly the additional losses caused by the global redistribution of the core flux in the different regions of the core (Mechler & Girgis, 1998; A. J Moses & Thomas, 1973). It is therefore important to obtain a better understanding of the magnetic flux behaviour in stacked transformer cores (Mechler & Girgis, 1998). Other studies have looked at the effect of the T-joint design on the flux distribution in the core and the additional losses caused by this joint in 3-phase 3-limb cores (Moses & Thomas, 1973; Moses, Thomas, & Thompson, 1972; Valkovic, 1982). Increasingly important in the transformer industry to reduce the core losses and improve the estimation techniques right from the design stage(Daut & Moses, 1990; Loffler, Booth, Pfützner, Bengtsson, & Gramm, 1995; Nakata, Takahashi, & Kawase, 1982). Several studies in this area in the literature have been reported over the past few decades(Du et al., 2010; Elleuch & Poloujadoff, 1998; Girgis, Te Nijenhuis, Gramm, & Wrethag, 1998; Moses, 1998; TeNyenhuis, Girgis, & Mechler, 2000).

The flux path in the T-joint area is very complex. A sinusoidal supply is provided to the core transformer by the windings. The change in direction of the supply can overcome the air gap distance, and the two processes cause the flux to pass through from the joint area. Circulation and rotation flux appears in this area with every change in the flux direction because the flux has the same properties as the supply. The middle limb is connected to the top and bottom yoke, and this joint is called a T-joint. The T-joint is considered to be the spine of the transformer core because it provides mechanical support for the core and most of the flux flows through the T-joint connection. Cores are typically made from cold-rolled, grain-orientated silicon steel laminations. The effects of materials on the behaviour of a three-phase three-core leg in a power transformer has been investigated under different operating conditions in(Alyozbaky, Kadir, Izadi, Gomes, & Azis, 2016). A third component of core loss is the eddy current or hysteresis phenomena, or stray, extra or anomalous loss. The finite element method (FEM) has been extensively employed in the prediction of no-load losses prediction problem. It has been previously shown that harmonics circulate in individual laminations in the limbs and yokes. Other studies (A.J. Moses & Thomas, 1974) have explored the local flux distribution in transformer cores as a function of joint design and its relevance for power loss and noise. FEM has been used extensively to study transformer joint air gaps, although this information does not appear to be applied in circuit models. In earlier research (Thomas, 1975) experiments to determine the flux paths and flux transfer mechanisms in the T-joints of three phase transformer cores had been performed. Third harmonic flux circulation similar to that observed previously (Basak & Higgs, 1982) in three limb cores has been observed in both core geometries.

Thus, changing the design of the T-joint of a core transformer is still an important factor, especially when this issue is reflected in its impact on the core losses and potential improvement of the core performance. In this paper a three-leg three-phase distribution transformer rated 1000KVA is simulated in 3D using Ansys Maxwell Software. The main objective is to present the relationship between the geometry of the T-joint with 90° butt-lap design, T-joint with 45° mitered design, the core loss issue and the correlation between the flux density and core loss of different T-joint designs.

METHOD

In this work the transformer core was built from grain orientated silicon steel (CRGO) 3% silicon, 97% iron which has saturation point around 2 Tesla. Two models of a T-joint design for the core transformer were compared and modelled in the Ansys Maxwell software, namely T-joint with 90° butt-lap design and T-joint with 45° mitered design. The simulation for the 3-D design using the Ansys Maxwell software was based on the common geometry model of a three phase transformer. The relevant data of the transformer was rated power 1MVA, 11/0.433KV, 50Hz. The height of the core is 900mm, width 1030mm and depth 243mm. The operation flux density for this core is 1.56T, the primary winding 16 turns and simulated as cylindrical shapes to reduce the running time for simulation. Figure 1 shows the sketch of the transformer for T-joint with 90° butt-lap design and T-joint with 45° mitered design.



(a) (b)

Figure 1. The core design (a) T-joints with 90° butt-lap, (b) T-joints with 45° mitered

RESULTS AND DISCUSSION

The flux density and core losses consider the main concern of this study. To compare the different types of T-joint geometries of the transformer core, primary windings has been set to provide a flux density of around 1.56 T in the limbs. However, to achieve the main goal of comparing the different geometries of the T-joints, it is necessary to compare the flux density, and the core loss should be on the same level of voltage. The region between the core and winding is filled with transformer oil. Each winding is connected to a voltage terminal that has been excited by a sinusoidal supply.

As a results the geometrical design of the T-joint of the core improves the core losses. Figure 2 shows the core losses for the T-joint with 90° butt-lap design and T-joint with 45° mitered design. It appears the core loss was reduced as average and maximum values when compare between the design of the T-joint with 90° butt-lap design and the T-joint with 45° mitered design.

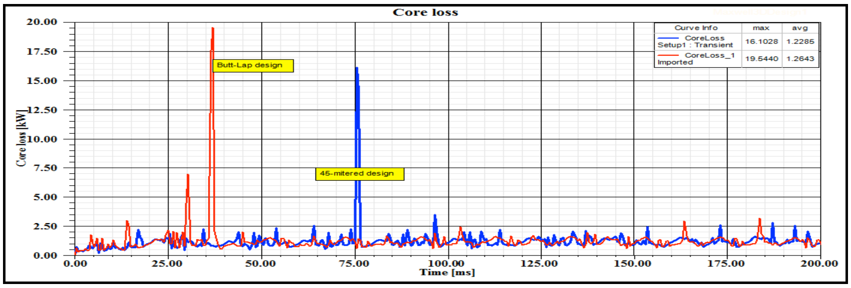
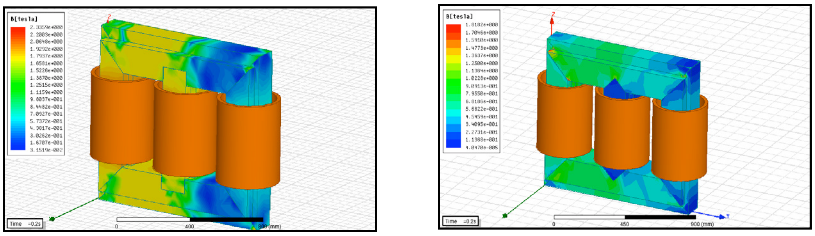


Figure 2. Core losses for different designs of T-joint

Furthermore, the main flux density which distributed on the transformer core with T-joint with 90° butt-lap design and T-joint with 45° mitered design is shown in Figure 3. By comparing the distribution of the flux density in the core geometry, although all the cores were excited using the same voltage level, in the case of butt-lap design, the flux density reached to 2.335 Tesla while decrease to 1.81T when the T-joint design was used T-joints with 45° mitred. The reason of that, the behaviour of movement for flux density was dissimilar because the shape of these joints was different. An efficient core can be built if manufactured using a T-joint with 45°mitered. In addition, from the results show that the saturation phenomena in the core transformer can be overcome.



(a) (b)

Figure 3. Flux distribution in the core (a) T-joints with 90° Butt-lap, (b) T-joints with 45° mitred

The behaviour of the flux density in the joint areas such as rotating and circulating flux and the effects of angles in T-joint with 90° butt-lap design led to magnetic flux tend to deviation in this area. The distortion and deviation of the flux density and localised losses in the T-joints is due to the core gaps across the core stack. The over stacking, limited area, gaps and corners in the T-joint with 90° butt-lap design are considered major reasons for increase in core losses and push the core to reach to the saturated condition. An improvement in the core loss is due to its effect on the flux path in the core. The flux density distribution in the T-joint area for different designs appears in Figure 4. It is noted there is an increase in the flux density along the path of flux, especially in the gaps and in the angles.

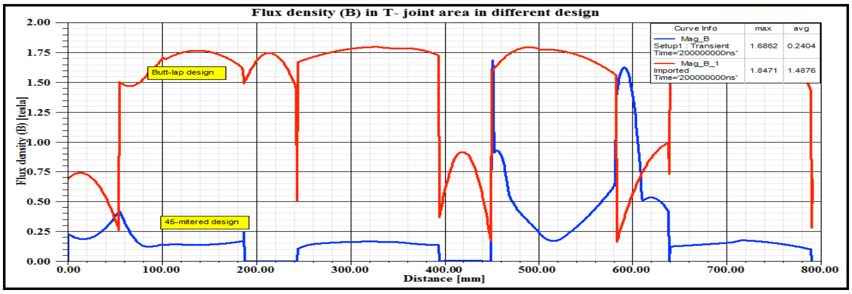


Figure 4. Flux distribution in the T-joint area for both designs

This deviation of the magnetic flux lines with respect to the rolling direction generates localised losses areas with higher flux density and therefore increased losses. At the maximum values of the flux density about 1.84 T and 1.68 T on joints with 90° butt-lap and T-joints with 45° mitered respectively. There is more than a 9.5 % increase in the flux density in the T-joint area when using T-joints with 90° butt-lap, while it is clear from Figure 4 that the average value of the flux density is better more value when using the T-joints with 45° mitred design. The T-joint section is very important as a case study because it is the main joint between the yoke and the limb. The flux path from the top yoke to the middle limb for different T-joint designs is presented in Figure 5. It is noticeable that the behaviour of the flux density is more complicated in the gaps which appear between the laminations when assembling the core during manufacture. It is about 1.9 T in the gap area while it is 1.07 T when using T-joints with 90° butt-lap and T-joints with 45° mitered respectively.

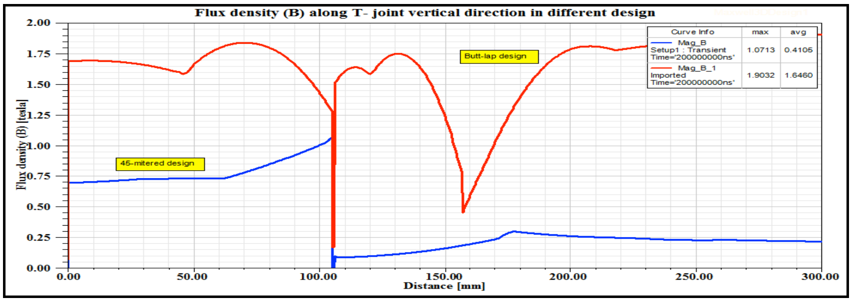


Figure 5. Flux density path from the top yoke to the middle limb for both designs

Figure 6 illustrates the behaviour of the flux density in the gap. The decrease in the amount of flux density in the gap area it is good sign especially in the edges for designers and researchers because that means the losses in this area have been reduced.

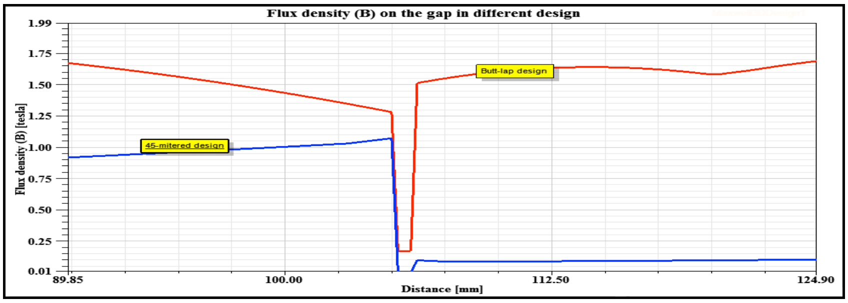


Figure 6. The behaviour of flux density in the gap between Top yoke with middle limb for different T-joint designs

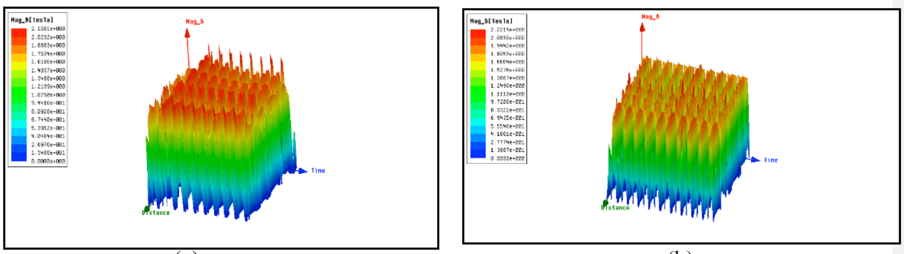
The flux density is increased and caused to localized losses due to the distorted flux distribution in the T-joint regions (due to core gaps) across the core stack. The saturation phenomenon, one of the important point in transformer core performances. This study showed butt-lap joint design core reach to the saturation point of work within no-load. While the 45° mitered it appeared more efficient on this point. For the flux densities in overall the core it is exceeded the allowable limit of flux, the value reached to 2.33 T when used T-joint with butt-lap while in 45° mitered T-joint design it is still acceptable within the boundaries, the value reached to 1.81 T.

Thus the butt lap T-joint design is closest to the undesirable case of the saturation phenomena. The relationship between the core loss and flux density seems clear. As a result, each has an impact on the other. When the flux density increases in the T-joint section, the core loss is shown to increase concurrently. Simulated results of the transformer core in different joint designs are shown in Table 1.

Table 1
Difference between the values of Flux densities in T-joint with 90° butt-lap design and T-joint with 45° mitred design

Type of joint	Area test	Max (B)T	Average (B)T	Core loss
butt-lap design	Vertical distance in T-joint	1.9	1.64	
	Horizontal distance in T-joint	1.946	1.347	
	Around the T-joint area	1.84	1.48	
	All the core	2.33		
45° mitered design	Vertical distance in T-joint	1.07	0.14	
	Horizontal distance in T-joint	0.655	0.365	
	Around the T-joint area	1.68	0.24	
	All the core	1.81		

Generally, to complete the picture and to determine the effect of the geometry of the T-joint design on the flux density distribution in the T-joint area, a 3D simulation of the flux density for different T-joint designs was developed and illustrated in Figure 7. From the figure, it can be observed that the flux density for the T-joint with 90° butt-lap design has a higher value from T-joint with 45° mitered design.



(a) (b)

Figure 7. 3D flux density in the T-joint area for different design (a) T-joints with 90° butt-lap, (b) T-joints with 45° mitered

CONCLUSION

The flux distribution of two types of T-joint designs and the correlation between the geometry of the T-joint design and core loss was presented. . The flexibility of the proposed model for a three-leg three phase transformer core that deals with the distribution of flux density in the core part, especially in the joint area highlighted. The losses of the core using a butt-lap design for the T-joint is 3% higher than the core using a 45°-mitered T-joint design are also shown. The 3D simulation model can be used to study transient operations and steady state operations. The flux density increases by up to 22 % when the T-joint with 90° butt-lap core design was used. Our results show that the overall performances for the T-joint with 45° mitered core design is better than for T-joint with 90° butt-lap core design.

ACKNOWLEDGEMENTS

The authors wish to thank the Centre for Electromagnetic and Lightning Protection Research (CELP), Electrical and Electronic Engineering Department, Universiti Putra Malaysia, Malaysia, for supporting this study. .The main author would also like to thank The Ministry of Higher Education and Scientific Researches and Mosul University, College of Engineering, electric department for the scholarship.

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