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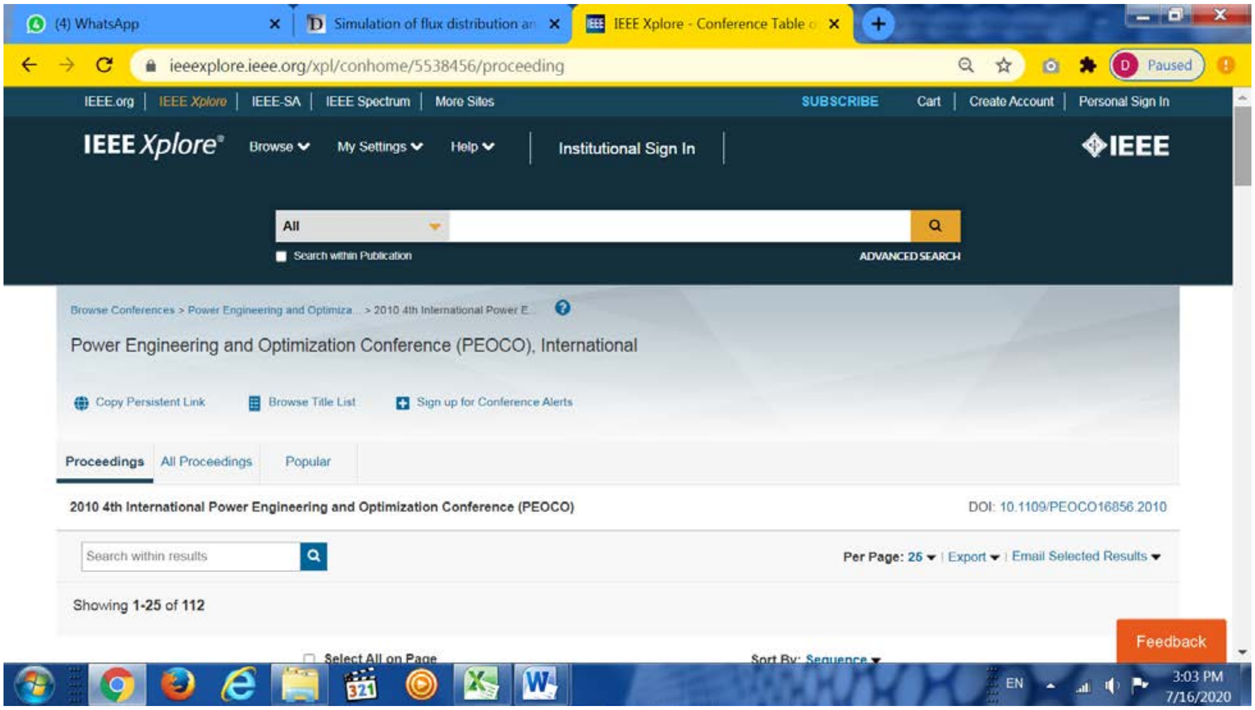

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Influence of the Mix 60° - 23° in different layers of T-joint of 3Phase Transformer Core on Longitudinal Direction of Flux Distribution

Dina. M.M. Ahmad, and F.Fauzi

Abstract--**This paper describes the result of investigation of longitudinal direction of flux distribution in 100kVA 3phase distribution transformer assembled with the mix 60° - 23° in different layers of T-joint. The measurement involves the fundamental and third harmonic of the easy and hard direction of flux density at each location measurement. The flux distributions have been measured using no load test by arrays of search coil in M5 (CGO) grades material of transformer core laminations. The localised flux density at the outer the mix 60° - 23° in different layers of T-joint is 1.4T and rises to be 1.7T at the inner edges of the mix60° - 23° in different layers of T-joint when the transformer core energized 1.5 T 50Hz. Harmonic occurs mostly in the T-joint where local regions are saturated and the flux deviates from the rolling direction.A small amount of flux deviation from the rolling direction occurs at the overlap, but no rotational flux is present in the joint.**

Index Terms—**The in-plane flux distribution, search coil, transformer core, third harmonic.**

I. Introduction

Transformer iron loss can be reduced either by improving the quality of the steel or by using better building and design techniques. The efficiency of a transformer core is also largely dependent upon the design of the joints at the junctions of the yoke and limbs. In these regions the flux may deviate from the rolling direction of the steel or become distorted so that local areas of the high loss are produced. [1] The use of grain-oriented silicon iron has been the main beneficial factor in increasing transformer efficiency. [2]

The behaviour of this investigation is to understand the longitudinal direction of flux distribution of the transformer core built from electrical steel (M5) with 3% silicon iron assembled with the mix 60° - 23° in different layers of T-joint by using arrays of search coil.

This work was supported in part by the School of Electrical Engineering UniMAP under Grant FRGS.

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II. Experiment Apparatus and Measuring Technique

THE main apparatus consist of a model cores three-phase 100kVA transformer assembled with three limbs core with the mix 60° - 23° in different layers of T-joint assembled from CRGO (M5 grades) 3% Si-Fe material. The core has 550 mm x 580 mm with the limbs and yokes 100 mm wide as shown in Figure 1. The experimental cores assembled with the mix 60° - 23° in different layers of T-joint as shown in Figure 2 and assembled from 0.3 mm thick laminations of M5 grain-oriented silicon iron (CRGO). Associated instruments are used to measurement fundamental and third harmonic content of the localized flux density distribution.

The localized flux density distribution in individual laminations is measured using search coils. The samples are drilled with an aid of drilling machine. It is constructed from 0.15 mm diameter wire treaded through 0.8 mm diameter holes 10 mm a part as shown in Figure 3. Each measuring position suitable coils are wound to measure the easy and hard direction flux density. The search coil induced voltages are analyzed to find the magnitude and plane coil induced voltage of flux density by using power analyzer [PM6000] as shown in Figure 4.

The magnitude and direction with reference to the x axis of the in-plane instantaneous flux density can be written in the form [3]:

$$|b| = \frac{1}{4fNAn}[\bar{e}_x^{\,2} + \bar{e}_y^{\,2}]^{1/2} \qquad (1)$$

And

$$\alpha = \tan^{-1}\left(\frac{e_y}{e_x}\right) \qquad (2)$$

Where

f = frequency supply

N = Number of transformer winding

A = Cross section area of transformer core lamination that measured

n = number of layer of transformer core lamination

e_x = maximum value of the component of induced emf in the easy direction

e_y = maximum value of the component of induced emf in the hard direction

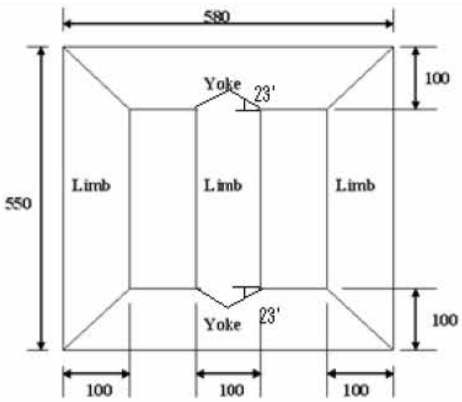

Fig. 1: Dimension (mm) of 100kVA transformer model

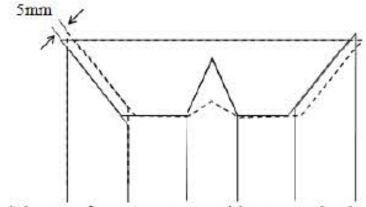

Fig. 2: Corner-joint transformer core type with staggered yoke and limb 5mm

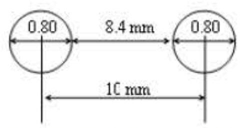

Fig. 3: Dimensions [mm] of the holes drilled in the specimen

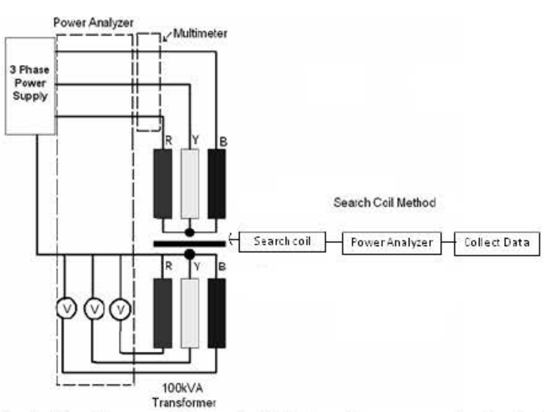

Fig. 4: The diagram of the methods that used to measure the localised flux density.

Sample calculation as follow:

From transformer frame are obtain number of turn is 254 turns, area of lamination is $0.000003m^2$ with number of layer is 15 layers and frequency supply is 50 Hz. When the supply adjusted to transformer at 1.5T so at the search coil will find the induced emf by oscilloscope measurements at easy direction is 3.55V and hard direction is 3.55V. By using the equation (1) will find the flux density at this point is 1.4 T.

The primary induced emf in the windings of the three phase transformers core were monitored by three identical voltmeters and voltages displayed during the measurement were only allowed to vary well within $\pm 0.4\%$ of the induced voltage corresponding to the required flux density.

Flux distribution in the Cold Rolled Grain Oriented (CRGO) is measured by using an array of search coils to get the satisfactory result. In this investigation an array of single turn search coil is employed to measure in-plane (longitudinal and transverse) of flux density in the lamination within the transformer core as indicated in figure 5.Because the flux tends to deviate out of the longitudinal direction in some region, small 10mm search coils are used to measure localized longitudinal and transverse flux component. The locations are chosen to cover the areas where the flux is more likely to vary direction so as to find distribution of the flux behavior as shown in Figure 5.

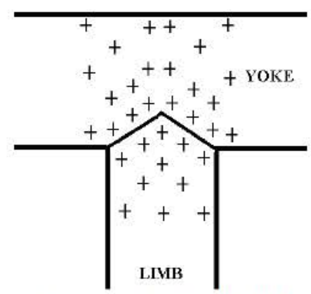

Fig. 5: Location of orthogonal search coils in the three phase core.

The testing process is done by using the No-Load Test Frame. The No-Load Test Frame consisting of three windings for each three phase core are designed in order not only to avoid introducing stress to the laminations but also to keep the magnetism exactly constant in all limbs of the cores. Each winding only extends along 85% on each limb in order to enable the stagger length of the three phase core to be varied. An extra softwood base 200mm high is used to raise the overall height of the core, in order to minimize the effect of the stray flux on the localized measurements.

Installation search coil takes quite a long time in completing this step which every hole needs to be inserted with search coil. Search coil is the enamel copper coated 0.1mm diameter wire. Each set of test point (4 holes) consist of easy and hard direction where the holes of easy and hard direction will be inserted search coil and the leads are twisted together. All the holes at testing point need to be repeated the same method of inserting and twisting the leads.

After the search coils are wound and the leads twisted together, the holes are filled with polyurethane varnish to give added insulation protection. The search coil leads, which are twisted to prevent any spurious pick up, are stuck to the lamination by a polyurethane varnish. The leads from all the search coils are taken to a junction box placed in the core to prevent any interference from the core or magnetising windings.

III. Result and Discussion

The instantaneous magnitude and direction of flux at this instant is shown in Figure 6 on a larger scale. At this instant the total flux in the centre limb reaches its maximum and outer limb carry half their maximum flux. A small amount of flux deviation from the rolling direction occurs at the overlap.

The rotational flux produced in the T-joint region of the three-phase three limbs transformer core are due to a combined effect of alternating and rotating fields. This rotational flux illustrates the locus of the variation of the variation of the localized flux distribution throughout the magnetizing cycle. The rotational flux of the fundamental component (50Hz) of flux density on the mix 60° - 23° in different layers of T-joint at a core flux density of 1.5T is shown in Figure 7. A large rotational flux is present in the yoke area which near with centre limb. Rotational flux in this region is more circular. Some large rotational flux is also observed in or near the T-joint region.

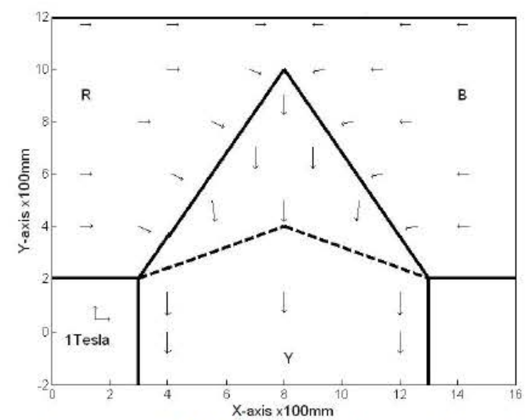

Fig. 6: Distribution of localized flux density on the mix 60°-23° in different layers of T-joint of three phase core at different instant in time when ωt=60°

Figure 8 shows the rotational flux of the third harmonic component of flux density in the T-joint of the core assembled with the mix 60° - 23° in different layers of T-joint at core flux density of 1.5T. The extent of rotating flux at this frequency is more widespread. As with the 50Hz component, a large amount of rotating flux is present in the T-joint region between the right yoke and centre limb in all four cores. A small rotating flux occurs also observed in the middle of centre limb region in the core. There is more rotational flux present in this region.

The major axes of the locus do not always follow those of the fundamental component but tend to be parallel to butt joints over much of the core where the fundamental components also deviate from the longitudinal direction of the strip in the yoke.

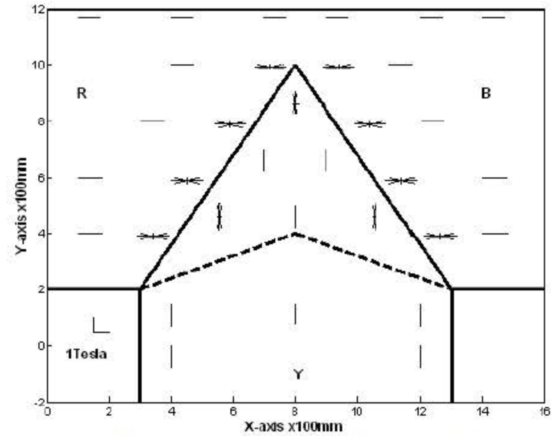

Fig. 7: Locus of the fundamental component of localised flux density on the mix 60° - 23° in different layers of T-joint core at 1.5T, 50Hz

A large amount of rotating flux is present in the T-joint region between the right yoke and centre limb in the core. Rotating flux in this region is elliptical with showing the highest value. A small rotating flux occurs also observed in the middle of centre limb region in the core.

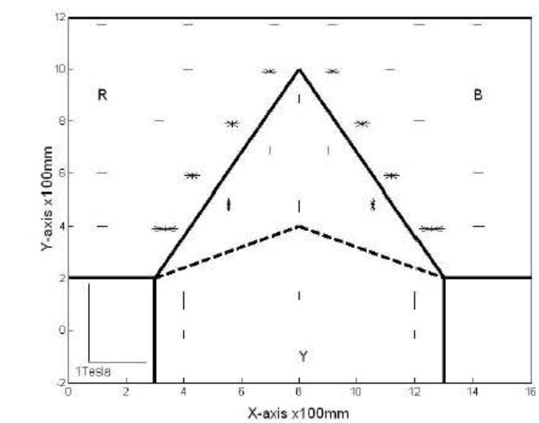

Fig. 8: Locus of the third harmonic component of localised flux density on the mix 60° - 23° in different layers of T-joint core at 1.5T, 50Hz.

Figure 9 shows the measuring point of location and localized flux densities at the mix 60° - 23° T-joint that are measured by using the search coil on transformer core. This result is produced by calculating localized flux density after the search coil measures the vector of the voltage in the easy and hard direction at the lamination.

The flux density in the yoke then drops rapidly as the flux distributes itself equally between the laminations. The flux density reaches a peak at the inner of the mix 60° - 23° T-joint; this is caused by the saturated material. The minimum flux density occurs at the outer of the mix 60° - 23° T-joint of transformer core lamination. The localised flux density will increase from the outer to the inner edge of the mix 60° - 23° T-joint. The localised flux density at the outer of the mix 60° - 23° T-joint is 1.4T and rises to be 1.7 T at the inner edges of yoke at the mix 60° - 23° T-joint when the transformer core energized 1.5 T 50Hz.

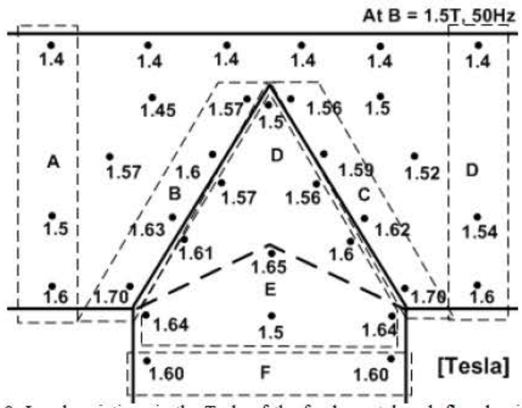

Fig. 9: Local variations in the Tesla of the fundamental peak flux density of the lamination on the mix 60° - 23° in different layers of T-joint core at 1.5T, 50Hz.

The local variation in magnitude of the third harmonic component of peak in-plane flux density in the mix 60° - 23° T-joint at a core flux density of 1.5T is shown in Figure 10. Most of the high third harmonic flux occurs in the T-joint region. The high third harmonic of peak in-plane flux occurs at the inner edge of right yoke passes over to the Butt-joint of centre limb is 14%. Harmonic occurs mostly in the T-joint where local regions are saturated and the flux deviates from the rolling direction. However, it has been confirmed experimentally that harmonics circulated in individual laminations in the limbs and yokes.

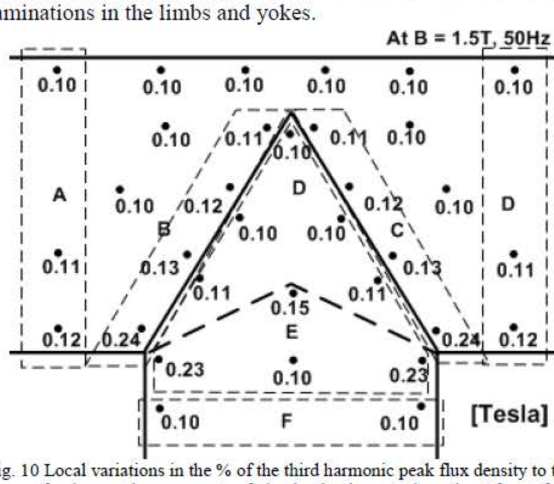

Fig. 10 Local variations in the % of the third harmonic peak flux density to the fundamental component of the lamination on the mix 60° - 23° in different layers of T-joint core at 1.5T, 50Hz.

IV. Conclussion

The flux distribution in cores assembled with M5 material was found varies along overlap area of the stagger at the T-joint. The localised flux density in longitudinal direction will increase from the outer to the inner of the mix 60° - 23° T-joint. The localised flux density at the outer edges of the mix 60° - 23° T-joint is 1.4T and rises to be 1.7T at the inner edges of the mix 60° - 23° T-joint when the transformer core energized 1.5 T 50Hz. A large rotational flux is present in the yoke area which near with centre limb. Rotational flux in this region is more circular.

The high third harmonic of peak flux occurs at the inner edge of right yoke passes over to the Butt-joint of centre limb is 14%.Harmonic occurs mostly in the T-joint where local regions are saturated and the flux deviates from the rolling direction.

A small amount of flux deviation from the rolling direction occurs at the overlap, but no rotational flux is present in the joint.

V. Acknowledgment

The authors would like to express their gratitude to the Malaysian Transformer Manufacturing (MTM) for the supply of transformer core material.

VI. References

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VII. Biographies

Dina M.M. Ahmad received her Eng. from University of North Sumatera, Indonesia in 1991 and MSc in Electrical Conversion from Institute of Bandung Technology, Indonesia in 1995 and now PhD student in Electrical System at University of Malaysia Perlis.

Her research interest is Transformer design. She has authored and co-authored more than 67 technical papers in the national, international journal and conferences.

F.Fauzi received her B.Eng. (Electrical) and M.Eng from Universiti Teknologi Malaysia (UTM), in 2003 and 2006 respectively. He is a lecturer in School of Electrical Systems Engineering at University of Malaysia Perlis.

His research interest is in renewable energy. He has authored and co-authored several technical papers in the national and international conferences.

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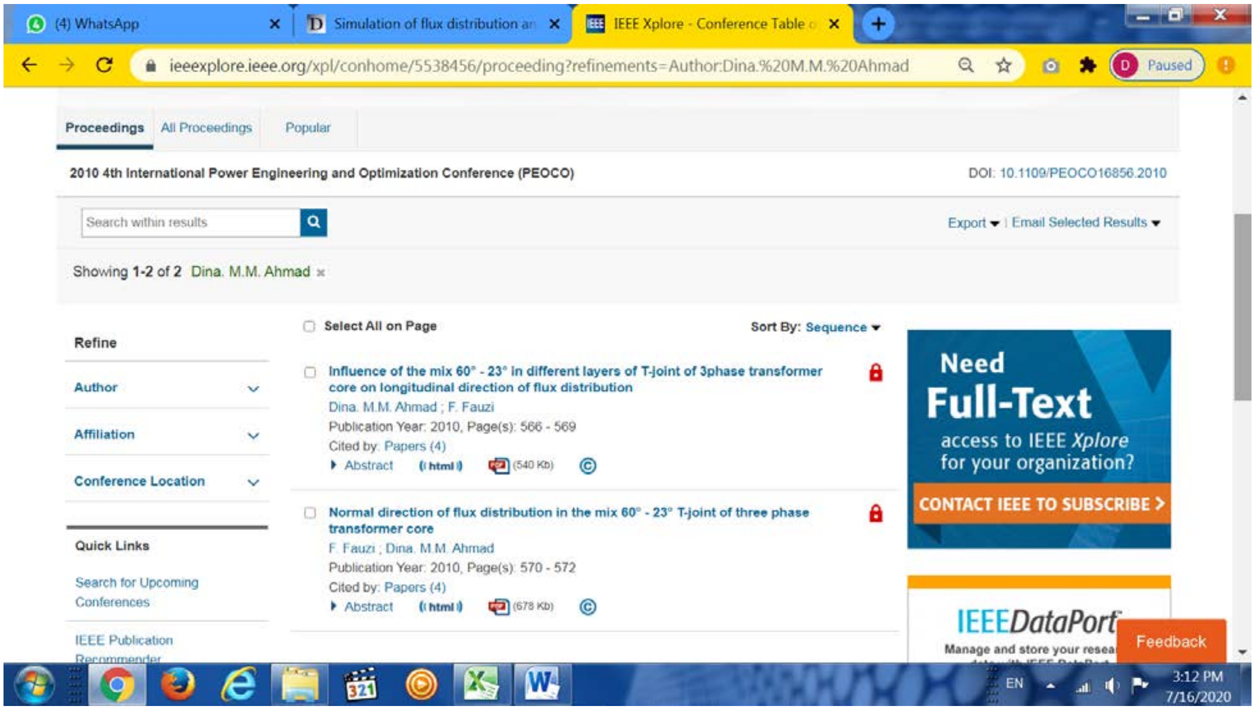

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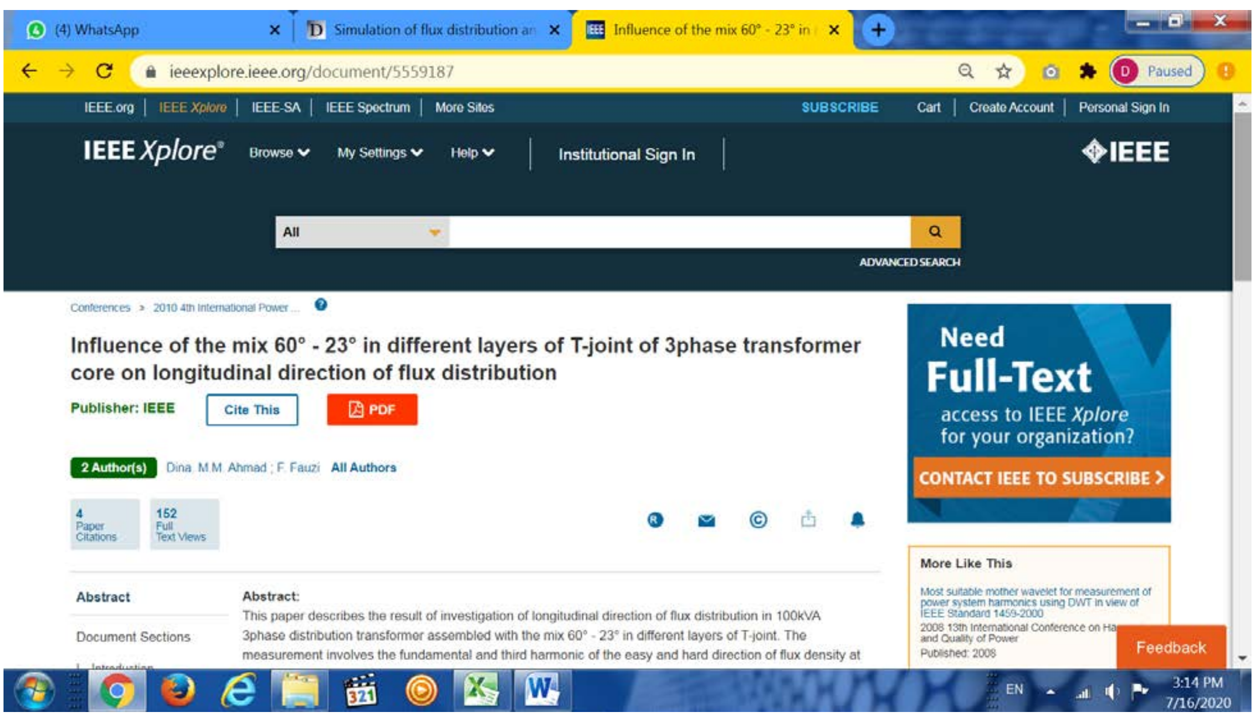

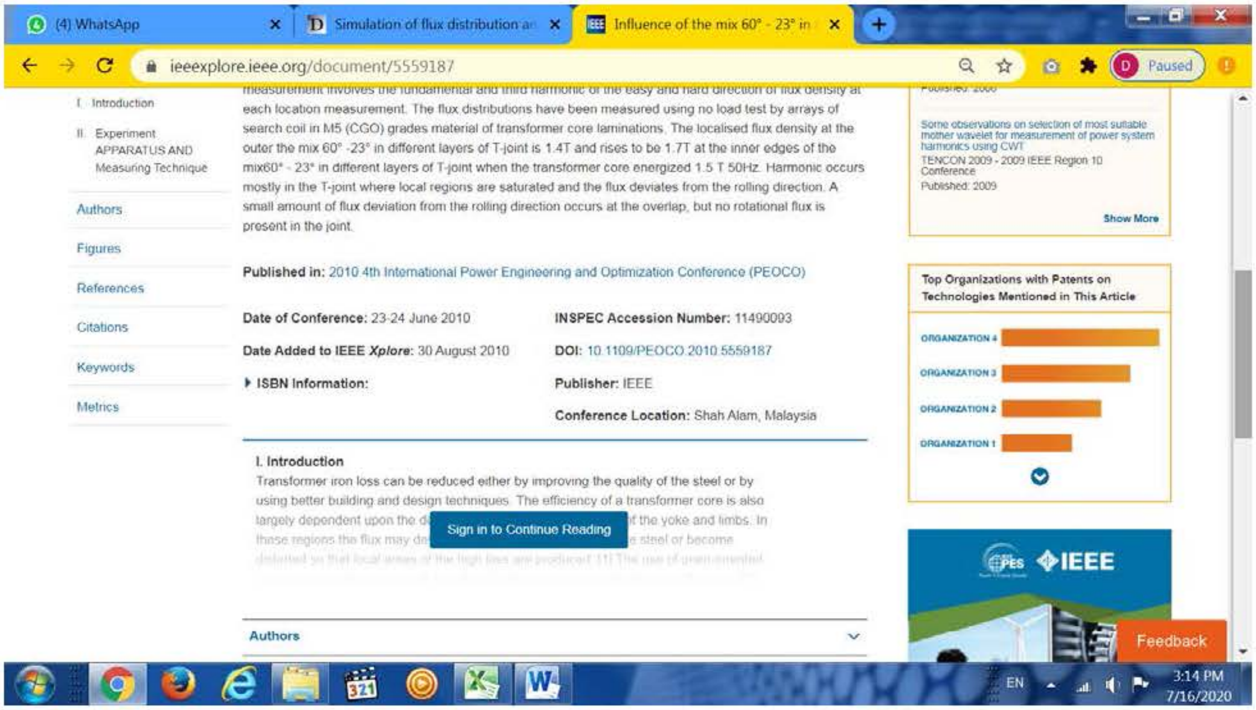
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I. Introduction

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Normal Direction of Flux Distribution in the Mix 60^o - 23^o T-joint of Three Phase Transformer Core

F.Fauzi, and Dina. M.M. Ahmad

Abstract--**This paper describes the result of measurement of normal flux distribution 3-phase 100kVA transformer core assembled with the mix 60^o - 23^o in different layers of T-joint. The investigation involves the variation of normal flux distribution in the core lamination. The normal flux distribution has been measured using no load test by arrays of search coil. The highest normal flux distribution occurs at the corner edge of the centre limb that is 0.17T and lowest at upper edge of yoke that is 0.09T. The average value of normal flux distribution is high at flux transfer region of the lamination. The flux transfer mechanism shows that two separate path flowing horizontally in the yoke before leaving the lamination to vertically adjacent layer and combine with the flux in that layer. Then, it will transfer back to origin region and extend through the centre limb.**

Index Terms—**Grain oriented silicon iron, transformer core, normal flux distribution, fundamental flux.**

I. Introduction

Power transformers are usually employed in electric power stations, high voltage transmission lines and large utilities. On the other hand, distribution transformers can be found in small and midsize industries, hotels, hospitals, schools, entertainment centers, residential areas and etc [1].

Transformers are ubiquitous in all part of the power system, between all voltage levels, and exist in many different sizes, types and connections [2]. Grain-oriented 3% silicon-iron is used for transformer cores where high efficiency and low weight are often paramount [3]. The efficient operations of power transformer cores depend on a large extend on the design of the joints between their limbs and yokes. The most complex joint in three limb cores are the T-joints at the intersection of the centre limb and yokes. Under ideal conditions the total flux in the limbs of a transformer core has a sinusoidal waveform, but in the corners of the core the flux is far from sinusoidal. The additional loss caused by the flux distortion can lead to localized heating within the joints [4].

This work was supported in part by the School of Electrical Engineering UniMAP under Grant FRGS.

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Dina M.M. Ahmad is PhD Student in UniMAP (e-mail: dina@unimap.edu.my).

The objective of this research is to measure normal flux distribution on the lamination of transformer core that built from the electrical steel (M5 grade material) 3% silicon-iron assembled with the mix 60^o - 23^o in different layers of T-joint by using arrays of search coils.

II. Experiment Apparatus and Measuring Technique

THREE phase 100kVA distribution transformers are assembled with the mix 60^o - 23^o in different layers of T-joint, mitred overlap corner joints length of 10mm as indicated in figure 1. Each core is 550 mm x 580 mm with the limbs and yokes 100 mm wide as indicated in figure 2. The main apparatus consisted of three phase cores, two yoke cores and three limbed cores and the cores are assembled from 0.3 mm thick laminations of M5 grain oriented silicon iron (CRGO) [7]. Each core comprises of 15 layers. The system for measuring normal flux density is shown in Figure 3.

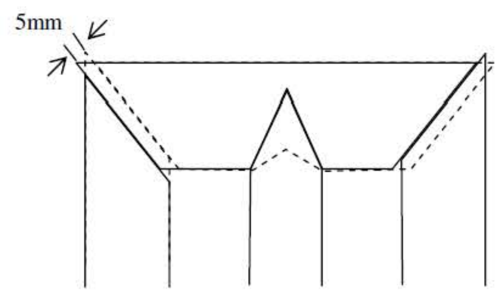

Fig. 1: Corner-joint transformer core type with staggered yoke 5mm

In order to study the normal flux density variation, normal search coil arrays are used to measure normal flux density variation along and across the lamination. The squares of 10mm x 10mm normal search coils are placed on a layer of lamination at the T-joint of the transformer core. The locations chosen must cover the areas where the flux is more likely to vary direction so as to find the mechanism distribution of the flux behavior. The location of the investigation for the transformer core is shown in figure 4.

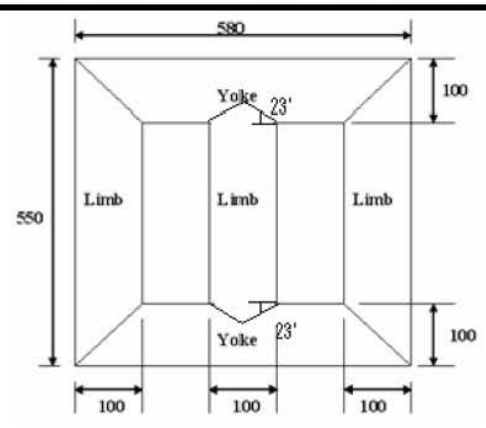

Fig. 2: Dimension (mm) of the mix 60° - 23° in different layers of T-joint of 3-phase 100kVA transformer core model

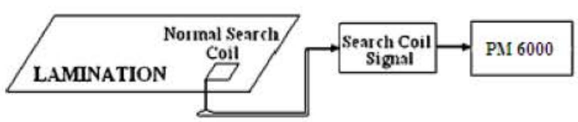

Fig. 3: Associated system for measuring normal flux density.

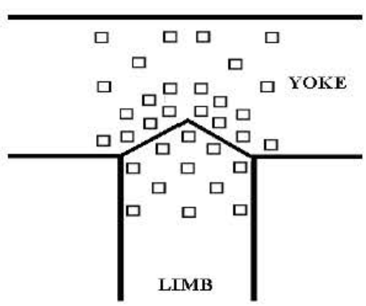

Fig. 4: The normal search coils position in the T-joint of transformer core

III. Result and Discussion

Fundamental normal flux density at T-joint flowing in a direction normal to the plane of the lamination in the mix 60° - 23° in different layers of T-joint at flux density of 1.5T, 50Hz is shown in figure 5.

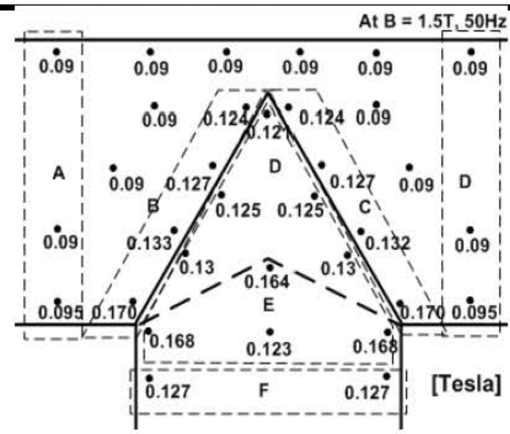

Fig. 5: Distribution of the normal direction of fundamental flux density at the mix 60° - 23° in different layers of T-joint during 1.5 at 50Hz.

The magnitude of the normal flux density is high at and close to an intersection between two adjacent laminations. The highest normal flux occurs at the corner edges of centre limb that is 0.17T at flux density 1.5T, 50Hz. The average magnitude of normal flux density is largest at the overlap region and smallest at the upper edge of the right yoke. The fundamental normal flux density increases as it approaches the T-joint and gradually decrease as it travels further away from the joint. The magnitude of fundamental normal flux density traveling between joints reaches minimum at the mid point of centre limb. This alteration in the fundamental normal flux density is due to increase and decrease of flux density that has been energized.

The instantaneous magnitude and direction of flux at this instant is shown in figure 6 at this instant the total flux in the centre limb reaches its maximum and both right and left yoke carry half their maximum flux.

Since the yokes carry only half the maximum value of the total flux, the majority of the flux from the outer of right and left yoke is carried through the inner half of butt-joint of centre limb and the largest flux concentration is found in the upper edges of centre limb.

Flux path and flux transfer mechanism between laminations at the T-joint has been illustrated as figure 7 for the mix 60° - 23° in different layers of T-joint arrangement. The diagram shows that the flux transfer mechanism between yoke and limb in the T-joint may occur simultaneously at the same instant in time. This can be seen for example at the A and B region where two separate path flowing horizontally before leaving the lamination to vertically adjacent layer of E and F respectively and combines with the flux in that layer. Consequently, the core material in this region approaches saturation. At the same time, this existing flux will transfer back to the C region and extend to the whole length of the middle limb. It has been noticed that the magnitude of normal flux density high at the butt-joint and decrease as the distance away from the joint.

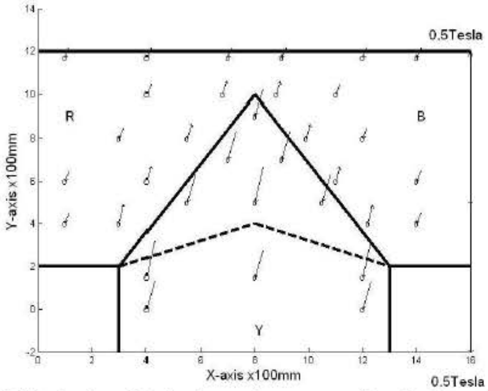

Fig. 6: Distribution of the fundamental component of localised normal flux density in the mix 60° - 23° in different layers of T-joint of three phase core built at different instant in time when $\omega t=60^{\circ}$.

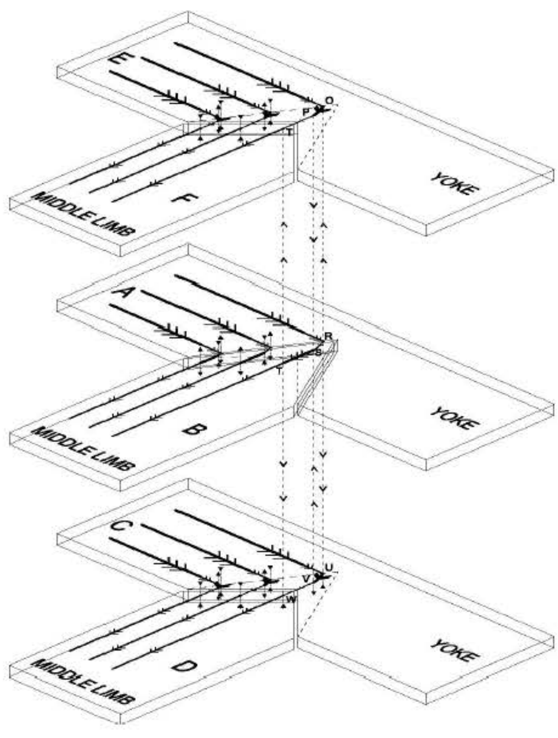

Fig. 7: Flux transfer between laminations of staggered yoke limb arrangement at the T-joint.

IV. Conclusion

From the result of this investigation, the normal flux distribution in the cores assembled with the mix 60° - 23° in different layers of T-joint was found varies along overlap area of the staggered at the T-joint. High normal flux distributions occur in the corner edge of the centre limb that is 0.17T and gradually decrease as it travels far away from the joint area.

The flux transfer mechanism between yoke and limb in the T-joint may occur simultaneously at the same instant in time. The magnitude of normal flux density is high at the butt-joint and decrease as the distance away from the joint.

V. Acknowledgment

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VI. References

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VII. Biographies

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