UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Investigation of Short circuit forces on individual turn of transformer winding- FEM simulation

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Engineering Technology (Industrial Power) (Hons.)

by

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I hereby, declared this report entitled "Investigation of short-circuit forces on individual turn of transformer winding- FEM simulation" is the results of my own research except as cited in references

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Engineering Technology (Industrial Power) (Hons.). The member of the supervisory is as follow:

……………………………….

(Project Supervisor)

ABSTRACT

In the rapid development of power industry, the need of power transformer capacity is increasing and higher voltage level is used in the system. In this situation short circuit fault easily occurs on transformer winding. When short-circuits occur the currents in transformer turn induce excessive forces in the transformer. These electromagnetic forces are important considerations in the design of transformer as the design of the windings and bracing must consider the magnitude of these forces and provide adequate strength to withstand them without significant mechanical deformation which could result failure. The study tested the short-circuit forces on individual turn of transformer winding is focus and the electromagnetic force due a short circuit current are solved by Finite Element Method (FEM). These electromagnetic forces on transformer winding are modelled by ANSYS and then simulated by FEM.

ABSTRAK

Dalam perkembangan pesat industri tenaga, kapasiti kuasa pengubah semakin meningkat dan voltan tahap tinggi digunakan, dalam keadaan ini litar pintas mudah berlaku pada pengubah penggulungan. Apabila litar pintas berlaku arus akan menjana kuasa yang berlebihan di dalam pengubah. Kuasa elektromagnet ini merupakan pertimbangan penting yg perlu diambil kira dalam reka bentuk pengubah belitan dan perembatan. Nilai kuasa ini akan memberikan kekuatan yang mencukupi untuk menahan ia tanpa pengubahan bentuk mekanikal yang ketara. Dalam laporan ini daya litar pintas pada individu penggulungan pengubah akan dikaji. Selain itu daya elektromagnet akan diselesaikan menggunakan Kaedah Unsur Terhingga (FEM). Kuasa elektromagnet pada pengubah penggulungan dimodelkan oleh ANSYS dan seterusnya simulasi menggunakan FEM.

DEDICATIONS

To my beloved parents

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CHAPTER 1

INTRODUCTION

1.0 Introduction

Transformers are electrical devices that transform or change the voltage levels between two circuits. It plays an important role in the power system, as it help convert power to appropriate levels so that other components can be safely used. These transformers are often in operation for a long time and only stop working during power interruptions or maintenance.

Nowadays at this fast developing country, the demand of electric power is rising sharply and it adding more and more generating capacity and interconnection to the system. Hence, it will cause major losses when service failure and increase of undelivered energy cost. In order to achieve trouble-free power transmission, the failure caused by short-circuits in the transformer had to be considered.

1.1 Problem statement

In short-circuit condition, the forces occurred in winding of transformers have to be determined. This is because electromagnetic forces occurring on the transformer winding during short circuit condition depend on the material selection and careful structural design. Therefore by accurately predict these forces, it aids in choosing structural design or arrangement at the winding to mitigate the impact of this forces in order to avoid in-service failures and reduce the undelivered energy cost and replacement cost.

This report is concentrated on the use of Finite Element Methods (FEM) to model transformer and demonstrate the behaviour of an individual turn during short circuit such as magnitude of force and force direction. It is found that this method provides a significant degree of accuracy which is very useful to analyse electromagnetic forces.

1.2 Objectives

The goal that to be achieving in this research are:

1. To demonstrate the behaviour of an individual turn during short circuit by the use of Finite Element Method (FEM)
2. To compare the analytical and numerical (FEM) calculation in normal and short circuit conditions
3. To determine the effect of this forces on transformer

1.3 Scope

This research has the following scope:

1. To simulate the short circuit on transformer winding.
2. Plot the magnetic forces on transformer winding.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

There are many literature about short-circuits on transformer winding. For better understanding of short-circuit, many research articles of other work and also primary and secondary source had been read and study. This chapter was going to describe the theory and concept of the relevance information about my research topic.

2.1 Core construction

Basically, power transformer had two designs which are core-type and shell-type. In the core type transformer the core is surrounded by the coils are normally with circular concentric windings, while in the shell type transformer the cores surround the coil with sandwich windings and "pan-cake" coils. Their field pattern depends on the overall geometry of the transformer, especially of the core and windings and on the relative permeability of materials. Power transformer manufacturer in North America was well-known for his use of shell-type designs while core-type designs predominate in the UK and is the commonly used designs. In this research or simulation the core-type design will be used to simulate short-circuit on transformer winding.

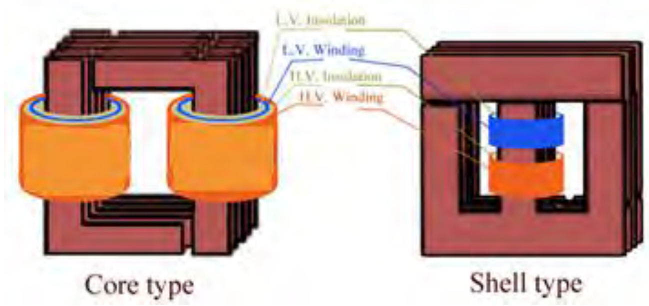


Figure 2.1 : Type of transformer

Source: http://www.electricaleasy.com/2014/03/electrical-transformer-basic.html (1/3/2014)

2.2 Short-circuits current effects the transformer winding

Jurcik, J., Gutten, M., & Korenciak, D. (2011) states that short circuit and overvoltage (transient actions) affect the power transformer and it need to be specialise analyzed. This is because they had serious importance in design and operation on transformer. Short-circuit in operation are mainly produced by different line faults such as the mechanical damage of insulation, electric insulation, electric insulation breakdown on over voltage, wrong operation and so on.

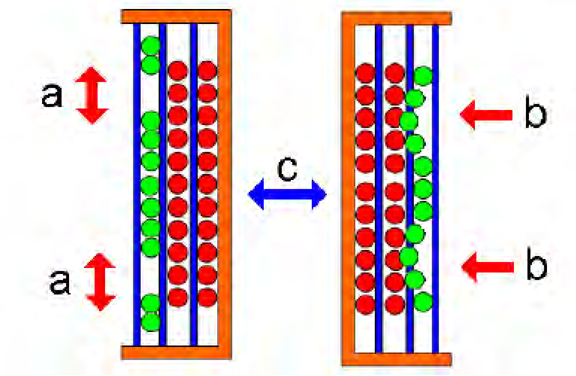
Short-circuit can be identified as serious poor condition of transformer due to neglect because the high current produced will cause badly rising temperature that can damage transformer insulation. The high electro-magnetic forces is the most dangerous one as it may occur due to great destruction of transformer so the transformer winding and its coils must be structural and stable in order to tolerate high mechanical forces without damage .

The state of the percentage changes in short circuits voltage or impedance depending up frequency is the geometrical winding movement refluxing and their construction in transformer. The change of state depend on thermal and mechanical effects of short circuits currents. For better comprehension of the relation between transformer damage and short circuits the effect of mechanical forces on transformer winding had to be considered.

2.3 Mechanical forces effect on transformer winding during short-circuit

The main cause of the pattern of forces that affect the winding is the magnetic field that influence on current flowing conductors. In transformer, it is the field of stray flux. When in the state of normal operation, the currents in transformer do not exceed rating value so the forces affecting on winding was usually in low level. But when in short-circuits conditions, the currents rating values will be double and this forces is dangerous to the windings.

Forces that affecting the winding usually divided into two groups which is radial forces (cross) and axial forces (longitude). These two components was considered independently in calculating strength, as they usually produce stresses of different kinds and can trigger different and independent modes of collapse.



a – axial forces affect,

b – Radial forces affect,

c – Normal winding (without force affect).

Figure 2.2 : Mechanical forces on transformer winding. (Jurcik, J., Gutten, M., & Korenciak, D. 2011)

2.4 Radial forces in windings

Radial forces are produced by the axial component of leakage flux by Rosentino Jr. A.J.P et al (2011). This force creates different effect in the outer and the inner winding of the transformer. In core type transformer, the tendency of the mechanical stresses is to compress (compression stress) the inner winding and expand (tensile stress) the outer winding. The occurrence of radial deformation in the inner winding is more frequent than in the outer winding and it may occur due to two different ways.

One of the occurrences radial deformations is the forced buckling, it occurs when the inner winding is supported by spacers located in the axial direction to the conductors. These occur when the stress value exceeds the material elastic limit. While the other is known by free buckling. For this, the conductor is deformed in one or more radial points of the coil winding.

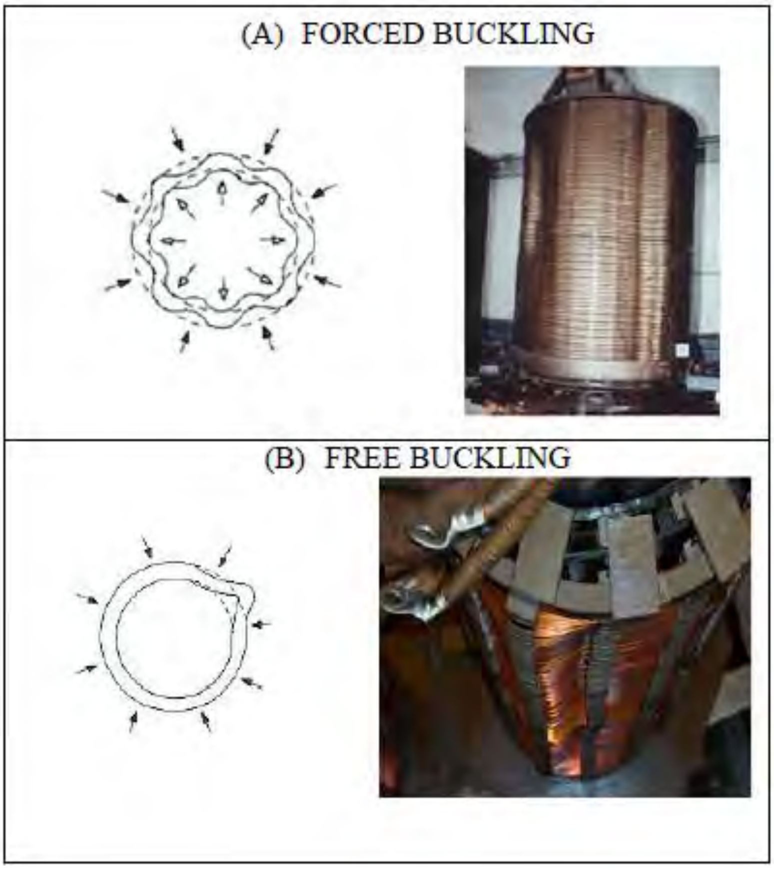


Figure 2.3: Typical effects of electromechanical stress on the transformer windings caused by radial forces. (Rosentino Jr, A. J. P et al, 2011).

2.5 Axial forces in windings

The axial forces are produced by the radial component of the leakage flux and it is in control by the compressing of the windings. Under this situation, the windings conductor can bend between the insulating spacers located radialy or leaning each other. The occurrence of this latter situation is typically for the disc type windings and generally this arrangement was used in large transformers.

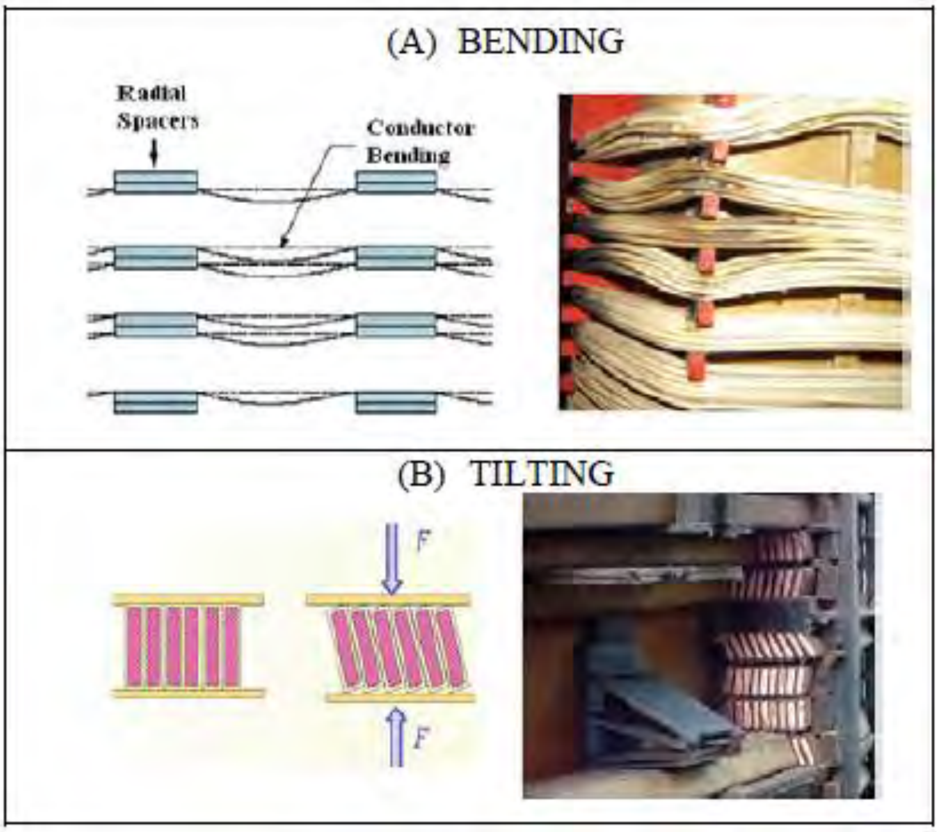
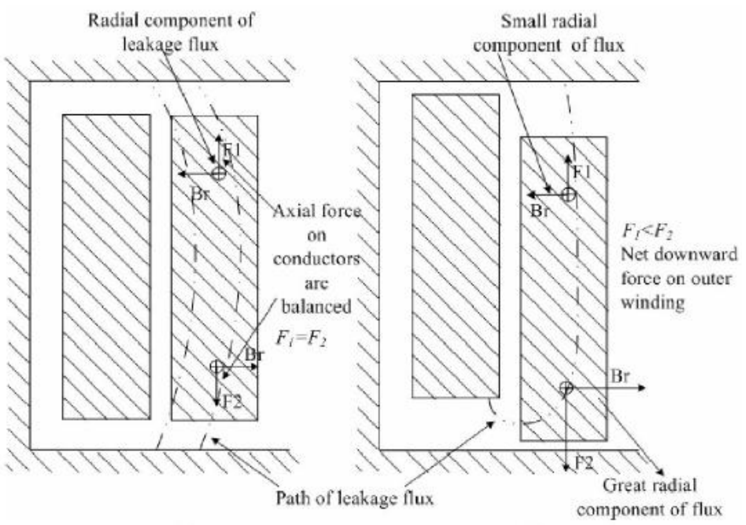


Figure 2.4 : Typical effects of electromechanical stress on the transformer windings caused by axial forces. (Rosentino Jr, A. J. P et al, 2011).

2.6 Displacement between winding

Any asymmetry between windings can produce large axial forces and produce serious hazard for the transformer solidarity by Ana C.de Azevedo et al (2006). In the situation where the inner and outer windings are symmetrical and balanced built up, the leakage flux is symmetrically distributed and generating opposite axial forces at the ends of the winding, thus generate zero resultant force.

While in high physical displacement between the inner and outer windings, it will cause varying values for the axial forces in each half winding. This will make the full balancing of the winding troublesome and produces a hazard resultant force on the winding.



a)Windings magnetically balanced   b) windings displaced axially

Figure 2.5 : Axial forces on the winding (Ana C. De Azevedoet al ,2006)

2.7 Calculation of the electromagnetic forces

Under short circuit conditions, the leakage flux will greatly increased cause forces occurring on the windings. The resultant force is proportional to the squared current, independently of the type of arrangement of the transformer windings.

The maximum electromagnetic forces are produced by three-phase short circuits, so it is common to design transformers to withstand the maximum peak of this short circuit current. This condition takes into account the transformer connected to an infinite busbar. The equation to determine the worst condition of short circuit current (I_{cc}) for a three phase transformer is

$$Icc = \frac{k\sqrt{2} \times MVA \times 10^6}{\sqrt{3} \times V \times Z} \text{ [A]}$$

Where: $k\sqrt{2}$ is the factor of asymmetry;

MVA is the transformer rating power [MVA];

V is the transformer rated voltage [V];

Z is the per unit impedance of the transformer.

2.7.1 Calculation of radial electromagnetic forces for concentric windings

The analytical calculation of radial force components in the transformer with concentric windings can be calculated easily and accurately. The axial field density (Ba) has its maximum in the region between the windings (leakage flux) and it is zero in the internal and external surfaces of the inner and outer windings respectively. Thus the force in per unit of length throughout the length of the coils remains almost constant and can be precise calculated. Below was the cross section for the transformer with two concentric windings.

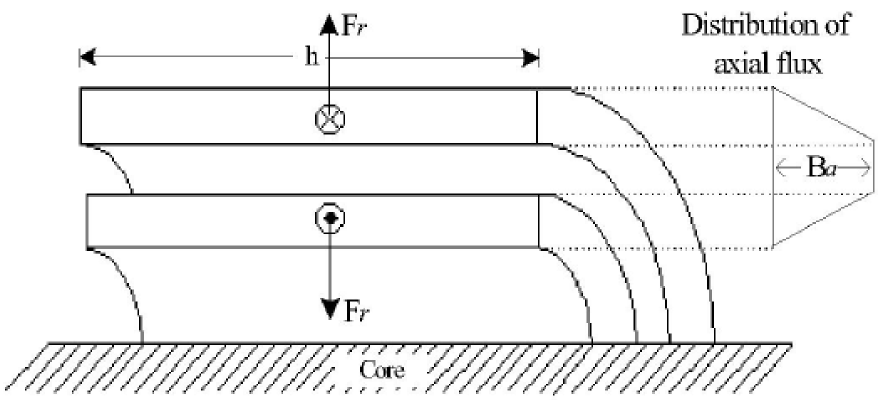


Figure 2.6: Cross section of a transformer concentric windings

(Ana C.de Azevedo et al 2006)

By neglecting the flux spreading out at the end of the windings, the radial force (Fr) due to interaction between the instantaneous-turns in each winding (ni) and the leakage field density can calculated as below.

$$Ba = \frac{4\pi(ni)}{10^4}[T]$$

$$Fr = \frac{2\pi(ni)^2 Dm}{h} \times 10^{-7}[N]$$

Where : i is the currents in transformer winding,

n is the number of turn,

h is the length of the winding and

Dm is the mean diameter of the winding.

2.7.2 Calculation of axial electromagnetic forces for concentric windings

Below was the layout of the radial field and the axial forces in an arrangement with asymmetrical windings. The asymmetry was due to the height of the outer winding is shorter than the inner windings causes a huge density of radial flux in the region where the unbalanced of ampere-turns occurs.

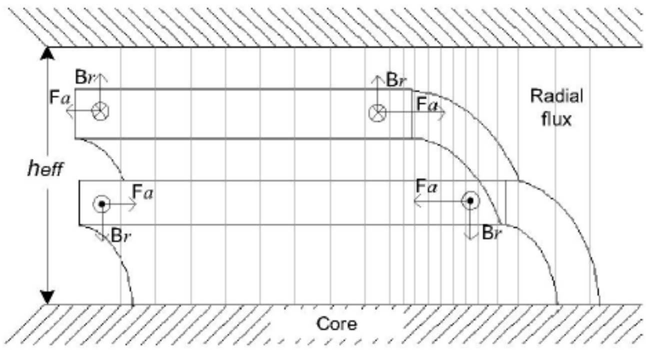


Figure 2.7 : Cross section of a transformer, radial field density and axial force

(Ana C.de Azevedo et al 2006)

The analytical calculation of the radial leakage field and axial force cannot calculate simply as axial field calculation. Residual Ampere turns method was a well-accepted approach used in calculate radial force, it is based on the principle that any arrangement of concentric windings can be split into two groups having balanced ampere turn. One produces the axial field and the other the radial field.

To calculate the axial compression force, the following parameters is necessary to identified.

a. The effective length of path of the radial flux, $h_{eff.}$ This differs for each arrangement of tapings.

b. The average radial flux density (Br) , considering the average diameter of the transformer

c. The average value of ampere turns which is equal to (1/2)a(ni), where a is the length of tap section (or group of short-circuited turns) expressed as a fraction of the total length of the winding.

$$Br = \frac{4\pi}{10^4} \times \frac{a(ni)}{2h_{eff}} [T]$$

The axial force (Fa) for a transformer with tap section in one end of the external winding is determined as:

$$Fa = \frac{2\pi a(ni)^2}{10^7} \times \frac{\pi D_m}{h_{eff}} [N]$$

2.8 Finite Element Method for Designing and Analysis of the transformer

Finite Element Analysis using Finite Element Method (FEM) was used to solve complex elasticity and structural analysis problem in civil and aeronautical engineering by G.H.Chitaliya, S.K.Joshi (2013). This application had been enlarge to simulation in electrical engineering to solve complex design problems and used for