Faculty of Electrical and Electronic Engineering Technology

SHORT CIRCUIT FORCE ANALYSIS ON TRANSFORMER WINDING BY DIFFERENT COPPER STRAND SIZE USING FINITE ELEMENT SOFTWARE

KHAIRUL SHAHFIQ BIN ISMAIL

Bachelor of Electronics Engineering Technology with Honours

2021

SHORT CIRCUIT FORCE ANALYSIS ON TRANSFORMER WINDING BY DIFFERENT COPPER STRAND SIZE USING FINITE ELEMENT SOFTWARE

KHAIRUL SHAHFIQ BIN ISMAIL

A project report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Electronics Engineering Technology with Honours

Faculty of Electrical and Electronic Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI TEKNOLOGI KEJUTERAAN ELEKTRIK DAN ELEKTRONIK

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek: SHORT CIRCUIT FORCE ANALYSIS ON TRANSFORMER WINDING BY DIFFERENT COPPER STRAND SIZE USING FINITE ELEMENT SOFTWARE

Sesi Pengajian: 2021/2022

Saya KHAIRUL SHAHFIQ BIN ISMAIL mengaku membenarkan laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (✓):

☐ **SULIT*** (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ **TERHAD*** (Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☐ **TIDAK TERHAD**

Disahkan oleh:

(TANDATANGAN PENULIS)

Alamat Tetap:

Zulkifli Bin Ibrahim
Pensyarah
Jabatan Teknologi Kejuruteraan Elektrik
Fakulti Teknologi Kejuruteraan Elektrik dan Elektronik
Universiti Teknikal Malaysia Melaka

(COP DAN TANDATANGAN PENYELIA)

Tarikh:

Tarikh:

*CATATAN: Jika laporan ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh laporan ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I declare that this project report entitled “Short Circuit Force Analysis On Transformer Winding By Different Copper Strand Size Using Finite Element Software” is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Student Name : KHAIRUL SHAHFIQ BIN ISMAIL

Date : 10/1/2022

APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electronics Engineering Technology with Honours.

Signature :

Supervisor Name : TS. DR. ZULKIFLI IBRAHIM

Date : 1/1/2022

Ts. Dr. Zulkifli Bin Ibrahim
Pensyarah/Penyelaras BEEI
Jabatan Teknologi Kejuruteraan Elektrik
Fakulti Teknologi Kejuruteraan Elektrik dan Elektronik
Universiti Teknikal Malaysia Melaka

Signature :

Co-Supervisor Name (if any) :

Date :

DEDICATION

My dissertation is dedicated to my family and many friends. I am very grateful to my loving parents, En. Ismail and Pn. Norliah, whose words of support and push for persistence continue to ring in my ears. My precious brothers and sisters who have never left my side. I also dedicate this dissertation to my numerous friends and family members who have been there for me throughout the process. I will be eternally grateful for everything they have done for me, especially my fellow friends who have assisted me in developing my technological abilities, as well as the many hours of proofreading and technical competence.

ABSTRACT

Transformer is a passive component that transfer electrical energy from one circuit to another circuit or multiple circuit. A different current in any transformer spin produces a different magnetic flow in the core of the transformer that induces a differing power in any other spinning spinal cord around the very core. Without metallic (conductive) link between the two circuits, electrical energy can be transmitted among independent coils. In 1831 Faraday's laws of induction describe the induced voltage effect in any spindle caused by a change in magnetic flux surrounded by the spindle. Transformers are most typically utilised in power applications for increased low AC voltages (a step-up transformer) or for lowering high AC voltages, or for coupling signal processing cycles (a step-down transformer). The purpose of this research is to study the short-circuit force on transformer winding by different copper strand size and tensile strength using Ansoft Maxwell. Short circuit occurrences in transformer windings cause high current circumstances. In turn, these currents cause excessive pressures in a transformer. In the design, manufacture and operation of transformers, electromagnetic forces are key factors. The forces can be separated into axial and radial forces with individual concerns and mitigations. Therefore, the study will be done to know the ability of a power transformer to withstand the short circuit force. In this study there will be few simulations on design and arrangement of transformer winding by using Ansoft Maxwell software. Besides that, the calculation of different size and axial spacer of copper strands also will be done to get the specific number copper strand needed. From this, the expected result is to get the model of the transformer winding and short circuit force based on the simulation and the number of copper strands of different size and axial spacer from the calculation.

ABSTRAK

Transformer adalah komponen pasif yang memindahkan tenaga elektrik dari satu litar ke litar lain atau litar berganda. Arus yang berbeza dalam putaran pengubah menghasilkan aliran magnet yang berbeza di inti pengubah yang mendorong daya yang berbeza dalam saraf tunjang berputar lain di sekitar teras. Tanpa hubungan logam (konduktif) antara dua litar, tenaga elektrik dapat dihantar di antara gegelung bebas. Pada tahun 1831 undang-undang induksi Faraday menerangkan kesan voltan teraruh pada gelendong yang disebabkan oleh perubahan fluks magnet yang dikelilingi oleh gelendong. Transformer biasanya digunakan dalam aplikasi kuasa untuk meningkatkan voltan AC rendah (transformer step-up) atau untuk menurunkan voltan AC tinggi, atau untuk kitaran pemprosesan isyarat gandingan (transformer step-down). Tujuan penyelidikan ini adalah untuk mengkaji daya litar pintas pada belitan transformer dengan ukuran helai kuprum yang berbeza dan kekuatan tegangan menggunakan Ansoft Maxwell. Kejadian litar pintas dalam belitan pengubah menyebabkan keadaan arus tinggi. Sebaliknya, arus ini menyebabkan tekanan yang berlebihan pada pengubah. Dalam reka bentuk, pembuatan dan pengoperasian transformer, daya elektromagnetik adalah faktor utama. Daya boleh dipisahkan menjadi daya paksi dan radial dengan kebimbangan dan mitigasi individu. Oleh itu, kajian akan dilakukan untuk mengetahui kemampuan pengubah daya menahan daya litar pintas. Dalam kajian ini akan ada sedikit simulasi mengenai reka bentuk dan susunan penggulungan transformer dengan menggunakan perisian Ansoft Maxwell. Selain itu, pengiraan ukuran dan jarak paksi bagi helai tembaga juga akan dilakukan untuk mendapatkan bilangan helai tembaga tertentu yang diperlukan. Dari hasil ini, hasil yang diharapkan adalah mendapatkan model daya lilitan dan litar pintas transformer berdasarkan simulasi dan bilangan helai kuprum dengan ukuran dan jarak jarak paksi yang berbeza dari pengiraan.

ACKNOWLEDGEMENTS

First and foremost, I'd want to offer my heartfelt thanks to the many people and organisations that helped me throughout my graduate studies. First and foremost, I would like to express my heartfelt gratitude to my supervisor, TS. DR. Zulkifli Ibrahim, for his enthusiasm, patience, insightful comments, helpful information, practical advice, and never-ending ideas, which have greatly aided me throughout my research and writing of this thesis. His vast knowledge, extensive experience, and professional skills in Electrical Engineering helped me to effectively accomplish my research. This endeavour would not have been feasible without his help and supervision. I could not have asked for a better supervisor during my studies.

My heartfelt gratitude goes to my parents and family members for their love and prayers during my studies.

I'd also want to thank Universiti Teknikal Malaysia Melaka (UTeM) for allowing me to complete my bachelor's degree program. I am also grateful to the following FTKEE university personnel, co-workers, and classmates, as well as those persons who are not included, for their assistance.

Finally, but not least, thank you to everyone in my course for a wonderful four years of sharing premises with you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE	TITLE	PAGE

LIST OF SYMBOLS

F	-	Lorentz Force
J	-	Current winding
B	-	Leakage flux density vector product in the area
I	-	Current
l	-	Length
B	-	Magnetic field
μ_0	-	Permeability
N	-	Number of turns
I	-	Current in the winding
h_R	-	Rogowski height
D	-	Diameter of transformer windings
W	-	Width
W_G	-	Magnetic field
i	-	Current at LV/HV
l	-	Length between LV and HV winding 25mm
$\emptyset$	-	Magnetic flux
A	-	Area of winding
N	-	Number of turn in winding
I	-	Induced current in HV

LIST OF ABBREVIATIONS

AC	-	Alternating current
LV	-	Low voltage
HV	-	High voltage
CTC	-	Continuously transposed conductors
SV	-	Stabilisation of the voltage
TV	-	Tapped winding
B	-	Magnetic field
F	-	Force

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Power transformers are the most expensive components in power generation, transmission, and distribution substations. The importance of the transformer is not only because of its capital cost, but the cost of energy that cannot be delivered if a failure occurs this makes economic losses unbearable. The rapid growth of the power system had improved the level of failure, the transformer should be able to handle the fault current to ensure the reliability of the power system.

Transformers consist in general of primary and secondary windings, through which constant power is induced by a current and voltage transformation. The transformer is supplied primarily with rated voltage and current during normal operation. The primary winding current flow will induce a magnetic field which connects the winding of the secondary, which induces current flow. Current in secondary winding flow will be inversely commensurate with the turn ratio between the primary and the secondary winding. Consequently, electromagnetics within the transformer generates the electromagnetic field. However, this electromagnetic field will produce forces within magnetism laws in the transformer windings.

Other than that, short circuit occurrences in transformer windings can cause high current circumstances. In consequence, these trends lead the transformer to have excessive forces. In the design, production and operation of transformers, electromagnetic force is a significant factor. These forces may be separated into axial and radial force, with individual concerns and prevention measures for each factor. The forces are generally modest during normal operations, and the design of the transformer in this state is mainly focused on dielectric and thermal loss reduction and isolation integrity concerns. The current excitation increases dramatically with a short circuit malfunction.

A single-line to earth fault in which one phase is short to the ground is the most common short- circuit occurrence. The consequences of lightning strikes, waste, pollution, animal, and vegetation may lead to this sort of defect. Other forms of defects, including a three-phase earth defect, are also included in short circuit calculations. Using symmetrical components, the short-circuit current is usually estimated for different scenarios.

1.2 Problem Statement

Transformer coils are subject to tremendous forces under short circuit conditions because currents may be of the order of hundreds or thousands of amperes. Therefore, since the short circuit current destroys the core flux passing through the secondary winding, the flux generated by the primary current appears as leakage flux passing between the primary and secondary coils. In concentric windings, this causes radial forces to act outwards on the outer coil, putting tensile stress on the conductors. As the primary and secondary conductors carry currents in opposite directions, they repel each other. Another force that happens is axial, in which the inner and outer windings are subjected to axial forces if they are magnetically unbalanced, causing them to be axially separated. Lastly, to know how the size of copper strand and axial spacer can give effect to short circuit transformer.

1.3 Project Objective

The main aim of this project is to propose a simulation on the short circuit force on the transformer winding.

Specifically, the objectives are as follows:

a) To investigate the transformer ability to withstand short circuit.

b) To analyse the transformer capability to handle the force when short circuit force event occur.

c) To investigate the effect of the different size of copper strand and axial spacer based on calculation.

1.4 Scope of Project

The scope of this project is more to research and simulation for the result because it is difficult to get the real transformer to do the research. For the research, it is more to read the journal or article from the previous project that related to short circuit force om transformer winding. From this previous project it gives more information about on how to do this project. The previous research journal can be found from IEEE Xplore at Laman Hikmah UTEM portal. Beside previous research, the information also can be got from another platform like Google and YouTube. As for the simulation the Ansoft Maxwell application will be used to construct the circuit for short circuit transformer. In Ansoft Maxwell also show the wave form for the short circuit also can be got to be put in the result.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

One of the main reasons we utilize alternating AC voltages and currents at house and at work is because we can easily manufacture AC power supplies at a favorable voltage, turn it into a much greater voltage and distribute them throughout the country using a national grid consisting of pylons and cables. In fact, a transformer is an electro-magnetic passive electrical device that functions by transforming electrical energy from one value to another according to the Faraday Law of Induction concept. In this literature review it will be stated about short circuit force, Lorentz force, radial force, axial force, and transformer winding.

2.2 Short Circuit Force on Transformer

In the first study the electrical forces in a transformer are applied to the windings when a transformer is short-circuited. Throughout these transitory stresses the transformer might distort or expose a large amount of mechanical damage. As a result, a power transformer's important characteristic is known to withstand short-circuit current. For safe service, electromagnetic forces should be foreseen during the design phase owing to short circuit currents before a power transformer is built. Moreover, the utilisation of specialised testing equipment, instruments and professionals is necessary for a short-circuit test. When transformer capacity grows, the quantity of transformer test equipment or tools available is reduced. It is apparent from this research that the electromagnetic force in the winding of power transformer may be calculated given leakage flux and transient current. [1].

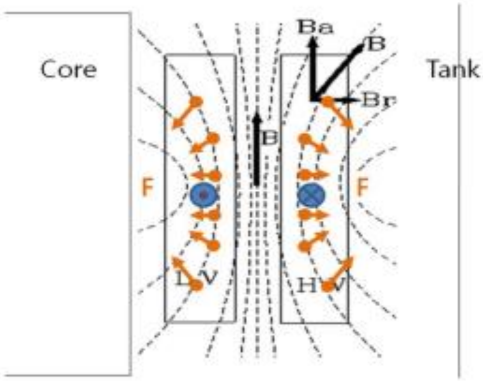

Figure 2.1 **electromagnetic force and leakage flux distribution density in concentric winding of power transformer**

Otherwise, the transformer winding might be bent as the consequence of electromagnetic stress in the short circuit, creating a power infrastructure disruption and disrupting regular power grid operation if the real short circuit failure happens. Electromagnetic short circuit force winding cause deformation of transformer problems currently account for almost 30 percent of all problems in the transformer. The very dynamic transformer winding arrangement effects electromagnetic strength of the short circuit. [2].

In addition, if a transformer is produced, some examination must be performed. It is mounted at the substation if the test is successful. It requires a lot of testing, including an oil test, a short circuit test and an overcharging heat test, before a transformer can be utilized. When short circuit tests were done on transformers, it was found that around 30 of every hundred transformers didn't pass the test. This leads to a considerable money and energy shortage. The strength of the transformer should be enough to survive even under harsh situations. If the strength is insufficient, the clamping will damage, or the windings will mechanically deform. Sometimes the tank of the transformer blows. Previously, the effects of a short-circuit current in a transformer have been examined. As a result, the transformer design is being upgraded. In this investigation, the nature of the internal or low voltage (LV) winding transformer was occasionally helical and causes axial asymmetry that is high voltage (HV) to wind when crossed by the transformer. Because of this imbalance, an axial force is applied to the windings. Another explanation for this imbalance is that the transformer is inaccurate, the ampere turns between windings are different, and so on. The presence of tapping might also cause the symmetry winding to move vertically. In this research paper it also stated about the Lorentz force for the easier understanding about the force between two separated components that is radial forces and axial forces. This short circuit electromagnetic force happened when the current flow in it under the condition of short circuit. The schematic showing various components of EM forces under ideal conditions encountered by the winding is presented in Figure 2.2. [3]

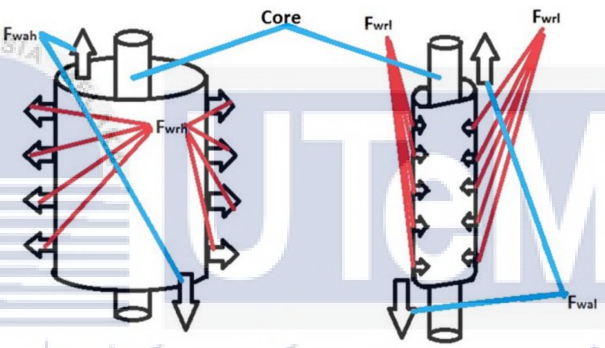

Figure 2.2 different components of short circuit force

A power transformer is an important feature of power systems because it is a vital and expensive component. With the exponential rise in grid power and transformer ranking, the number of malignant incidents triggered by transformer short-circuit has significantly increased. Furthermore, short-circuit faults are a significant source of concern for both power supplies and producers. When a short-circuit condition occurs, the transient short-circuit current can cause short-circuit force, which produces critical mechanical stress on a transformer. It is critical to predict short-circuit current and force for safe operation, which is why short circuit architecture is one of the most crucial aspects of transformer design. [4].

2.3 Lorentz Force

Short circuit electromagnetic force windings are powered by the current flowing in them in a short circuit state. A short circuit current is computed that passes through the windings. The forces are split into two components radial force and axial force. To be simpler to grasp, Lorentz Force, F, is calculated to detect the value of force. It is defined as the current winding, J and leakage flux density vector product in the area, B. The expression of F is

$$F = J \times B$$

The Lorentz force is estimated together with its direction when the windings are vertically. Figure 3 and Figure 4 demonstrate the direction of forces when there is no tapping for high voltage winding and when tapping is performed for high voltage winding. [3]

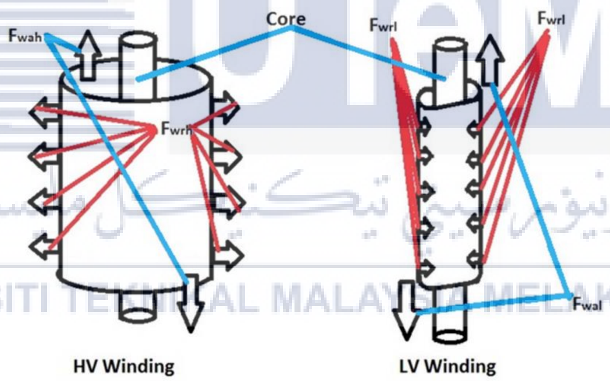

Figure 2.3 **Lorentz force on the winding because of axial asymmetry**

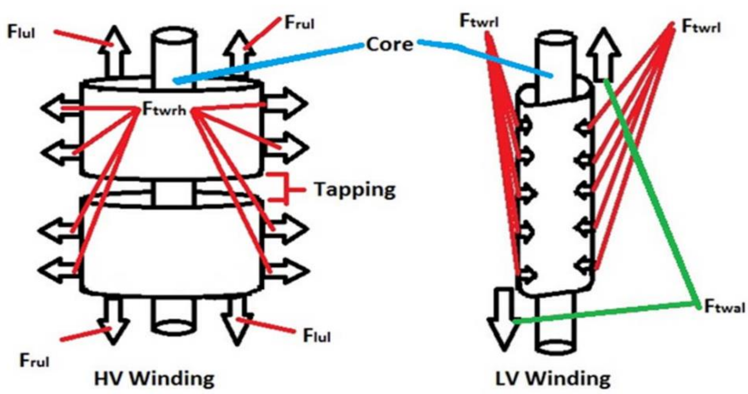

Figure 2.4 **Lorentz force on winding because of axial asymmetry under tapped high voltage winding**