EXAMINE THE IMPACT OF PARALLELING TWO 132/22KV TRANSFORMERS THAT HAVE A DIVERSE TOPOLOGY CONSIDERING POTENTIAL FAULT EVENT FOR UTM HIGH VOLTAGE NETWORK

MARDIHA BT ABDUL HAMID

A project report submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical Power)

School of Electrical Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JULY 2021

DEDICATION

This research specially dedicated to both my beloved mother, father, husband, sons and daughter for their support and encouragement, and also to my supervisor Dr Syed Norazizul bin Syed Nasir and all my friends.

ACKNOWLEDGEMENT

First of all, I would like to thank and praise be to Allah S.W.T, the Most Merciful and the Most Compassionate. Peace is upon him, Muhammad S.A.W., the messenger of God.

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my supervisor, Dr Syed Norazizul bin Syed Nasir, for encouragement, guidance, critics and friendship. Without his continued support and interest, this thesis would not have been the same as presented here.

My fellow postgraduate student should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family member.

ABSTRACT

Transformer is a magnetically coupled circuit, whose operation is governed by Faraday's Law of electromagnetic induction. Transformers are also used in AC voltage transfer from one level to another. A step-up transformer raises the voltage from primary to secondary level, while a step-down transformer decreases the secondary to lower voltage. Transformers play a significant role in the power utility as it is the core of the high voltage transmission system. Transformer must always operate without fail and if one transformer fails due to fault, another transformer must take action to supply uninterrupted power (n-1 source) to consumer. To ensure n-1 criteria is met, transformers at transmission level are connected in parallel. To connect transformers in parallel, certain conditions need to be met and the conditions will be discussed in Chapter 1. This study will focus on one of the parallel criteria which is transformer's topology or as known as vector group. Currently, Universiti Teknologi Malaysia (UTM) high voltage network are installed with two 30MVA 132/22kV transformers of same vector group which is YNd1. It should be no restriction to parallel these two transformers since they have same vector group. To examine the effect of paralleling two transformers of diverse topology, two transformers of different vector will be paralleled using MATLAB Simulink software. This network will then be simulated with potential fault event which in this case, will restrict to only short-circuit fault. This study will extend to analysing the network with the absence of earthing transformer that is connected at secondary side of 132/22kV transformer. Literature studies have also been conducted on the previous parallel transformer scenarios. The results of the simulation will be analysed in order to find out the effect of paralleling transformers with diverse topology. If the result is satisfactory and within limit, it can be applied in electricity industry.

ABSTRAK

Alatubah merupakan litar berpasangan magnet, yang operasinya adalah berpandukan kepada aruhan elektromagnetik *'Faraday's Law'*. Alatubah biasanya digunakan untuk menukar voltan AC dari satu tahap ke tahap yang lain. Alatubah menaik meningkatkan voltan dari sisi primer ke tahap voltan yang lebih tinggi di sisi sekunder, sementara alatubah menurun mengurangkan sekunder ke tahap voltan yang lebih rendah. Alatubah memainkan peranan penting dalam sistem kuasa. Ia adalah komponen tulang belakang sistem penghantaran kuasa voltan tinggi. Alatubah mestilah beroperasi tanpa gagal dan jika salah satu alatubah mengalami kerosakan, alatubah lain mestilah mengambil alih untuk membekalkan kuasa elektrik tanpa gangguan (sumber n-1) kepada pengguna. Alatubah penghantaran biasanya disambungkan secara selari untuk memastikan kriteria n-1 dipenuhi. Keadaan penyambungan transformer secara selari akan dibincangkan dalam Bab 1. Kajian ini akan melihat dengan lebih mendalam kepada salah satu kriteria selari iaitu topologi alatubah atau lebih dikenali sebagai kumpulan vektor. Pada ketika ini, Voltan Tinggi Universiti Teknologi Malaysia (UTM) dilengkapi dengan dua alatubah 30MVA 132/22kV kumpulan vektor yang sama iaitu YNd1. Seharusnya tidak ada batasan untuk kedua-dua alatubah ini disambung secara selari kerana mereka mempunyai kumpulan vektor yang sama. Untuk mengkaji kesan sambungan secara selari bagi dua alatubah dari topologi yang pelbagai, dua alatubah dari kumpulan vektor yang berbeza akan disambung secara selari dengan menggunakan perisian '*MATLAB Simulink'*. Litar ini kemudiannya akan disimulasikan dengan arus kerosakan yang mana dalam kes ini, hanya akan terhad kepada kerosakan litar pintas. Kajian ini juga akan menganalisa litar dengan ketiadaan alatubah pembumian yang disambungkan di sisi sekunder alatubah 132/22kV. Kajian literatur juga telah dibuat ke atas pelbagai kajian sebelum ini yang pernah dibuat penyambungan alatubah dalam keadaan selari. Hasil simulasi akan dianalisis untuk mengetahui kesan penyambungan alatubah dalam kedaan selari dengan topologi yang pelbagai. Sekiranya hasil memuaskan dan masih dalam limit yang dibenarkan, ia kemungkinan dapat diterapkan dalam industri elektrik.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

TNB	-	Tenaga Nasional Berhad
T1	-	Transformer 1
T2	-	Transformer 2
PMU	-	Pencawang Masuk Utama
PPU	-	Pencawang Pembahagian Utama
HV	-	High Voltage
LV	-	Low Voltage
NER	-	Neutral Earth Resistance
SLG	-	Single Line to Ground
THD	-	Total Harmonic Distortion
MRT2	-	Mass Rapid Transit 2
DL	-	Double Line
DLG	-	Double Line to Ground
TL	-	Three Line
OLTC	-	On-Load Tap Changer

LIST OF SYMBOLS

MVA	-	Mega Volt-Ampere
kV	-	kilo-Volt
kA	-	Transformer 2
V	-	Volt
A	-	Ampere
Ω	-	Ohm
%	-	Percentage

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Transformer is one of the main equipment in TNB distribution system which can be categorised into power transformer and distribution transformer. Power transformer (7.5 MVA and above) is mainly used in PMU and PPU whilst distribution transformer (1000 kVA and below) is usually utilised in substation [1]. In the field of power utilities, the n-1 contingency power supply system is planned so that during fault event, the other transformer can automatically supply to the affected loads. According to IEEE Standard C57.152TM-2015, two or more transformers connected to common load buses should be taken into account in parallel. These common buses can be connected to all kinds of loads, as well as to capacitor banks, shunt reactors and power sources. The transformer primary windings can be linked to common buses or buses with electricity from different lines [2]. The operating of power transformers in parallel is a common occurrence. The objective is to minimize reactive current circulation between transformers caused by mismatches in their electrical characteristics. Numerous control systems have been developed over the years to optimize the functioning of paralleled transformers equipped with on-load tap changer (OLTC) [3]. The operation of parallel transformers contributes to improved system reliability and performance; hence it increases transformers' short circuit current.

Transformer operates in parallel when load is increased and capability exceeds. In order to provide increased load, an additional transformer may be connected to the existing transformer in parallel. When bigger capacity of transformer is not available, two or more smaller transformers are put in parallel to replace bigger capacity of transformer to meet load requirement. Parallel transformer can also secure the security of supply especially when a fault occurs in one transformer, the other transformer can supply and backup to the affected loads while the faulty transformer can be taken out for service [4]. The connections of transformer when connected in parallel is shown in Figure 1.1:

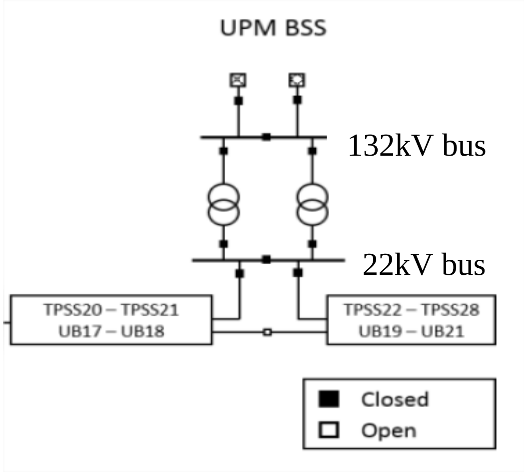

Figure 1.1 Example of parallel connection of transformers

Both transformers are interconnected in bus tie configuration. Low voltage side transformer's busbar is connected between each other by bus tie. To parallel two transformers, bus tie circuit breaker is in close position. While to non-parallel transformers, bus tie circuit breaker is switched to open position. These two transformers (T1 and T2) are isolated from each other during non-parallel operation. In case of any breakdown or planned outage one of the transformers, bus section circuit breaker at LV side is closed in order to supply uninterrupted power supply to consumer. The breakdown transformer can be taken out for maintenance without interrupting supply. The IEEE Standard describes general needs for the parallel transformers. Transformers can be made parallel when transformer ratios of the reactance to the equivalent resistance of the secondary windings, relative impedances of transformers, phase sequence and phase shift are the same [2].

Obviously, it is virtually impossible to meet the requirements described under actual operation conditions because of potential difference in transformer characteristics and electrical network configuration. It is nearly impossible to fulfil the described requirements in actual operating conditions as a result of possible differences in electrical network transformer characteristics and configuration. The problem of transformers running parallel is of particular practical concern especially when power supply of transformer primary windings from different power lines and difference of relative impedances of parallel transformers under change of transformer ratios [2].

In this case, parallel transformers should meet the voltage control requirements of the load buses as a result of inappropriate transformer ratios. The circulating current should be minimized. These conditions should also be provided irrespective of changes in the power system configuration [5]. Many studies focus on the problem and control of paralleled power transformers. However, not any evidence on the impact on the parallel transformers of the power supply system configuration and the load connection layout [5-9].

1.2 Problem Statement

Normally in any utilities practice, transformers will only be paralleled when they met the requirements for paralleling. The requirements are MVA rating, tap changer and vector group should be the same. Also, to parallel transformers, make sure that loading for each transformer is less than 50% of full capacity.

Utility companies would not permit transformers to be paralleled when these requirements are not met. This is because if the transformers do not meet the conditions of paralleling transformers, then large circulating currents would flow between two transformers which are dangerous and unnecessary. This circulating current will keep circulating between transformers and does not contribute to load current. This circulating current can overheat the transformer and reduces the lifespan of the transformers [10]. In this study, we will examine the effect when transformers with diverse topology are paralleled together. This study can be implemented to real situation if the result comes out satisfactory.

1.3 Objectives

The main objectives of this study are:

(a) To evaluate utility's current practice in paralleling transformers.

(b) To analyse the output voltage and current using MATLAB Simulink by paralleling transformers of different topologies with earthing transformer and without earthing transformer during fault event by considering 4 types of short circuit fault (single line to ground fault, double line fault, double line to ground fault and three-line fault).

(c) To validate the advantage and disadvantage of paralleling transformers with same and different topology.

1.4 Scope

The scopes of work considered in this research are summarized as follows:

(a) This research will only focus on Universiti Teknologi Malaysia (UTM) High Voltage Network that comprises of two 30MVA 132/22kV transformers of vector group YNd1.

(b) There are 3 topologies to be focused in this study which are:

   i. Two (2) 30MVA 132/22kV transformers of vector group YNd1. The primary winding of the transformer is connected in Wye/Star while secondary winding is connected in Delta connection.

   ii. Two (2) 30MVA 132/22kV transformers of vector group Dd1. The primary winding of the transformer is connected in Delta while secondary winding is also connected in Delta connection.

iii. Two (2) 30MVA 132/22kV transformers of vector group YNd1 and Dd1.

(c) The fault event that will be simulated for this study is only on short-circuit fault comprises of single phase to ground, phase to phase, phase to phase to ground and three phase faults.

(d) 22/0.415kV Zig-zag earthing transformer at low voltage side. This transformer is installed at the low voltage (secondary) side of power transformer.

1.5 Thesis Outline

Chapter 1 explains the general background of transformer, parallel operation of transformers and types of fault. Other than that, project objectives and project scopes are also being emphasized in this chapter.

Chapter 2 focuses on the literature review related to the paralleling transformers with diverse topology. It will cover on the past studies on the paralleling method together with the benefits and drawbacks. Other than that, these studies will be highlighted in detail and being compared with other studies.

Chapter 3 discusses the methodology of the project and the proposed framework using MATLAB Simulink.

Chapter 4 highlights on the results of simulation by using MATLAB Simulink software for all topologies as mentioned in scope. The simulation will focus on paralleling transformers with same topologies and different topologies

Chapter 5 reviews the conclusion of paralleling transformers using MATLAB Simulink. This chapter will also discuss recommend for future works.

REFERENCES

[1] TNB Asset Management Department (2014) ‘TNB Distribution Engineering Fundamentals’, *Distribution Division Tenaga Nasional Berhad, First Edition.*

[2] Y. Varetsky, V. Konoval (2020), Parallel Operation of Transformers Within the Power Supply System of a Mine, *Electric Power and Electromechanical Systems*, pp. 27-35.

[3] Trebolle, David, Valecillos Baudilio (2008), ‘Optimal Operation of Paralleled Power Transformers’, *Renewable Energy and Power Quality Journal.*

[4] Beckwith Electric Co., Inc (1998) ‘Introduction to Paralleling of LTC Transformers by the Circulating Current Method’, *Tapchanger Control Application*.

[5] Ed Zientek (2011), Loading Considerations when Paralleling Transformers., *PE. Schneider Electric USA*, pp. 17.

[6] Harlow J. H. (2000), ‘LTC Control and Transformer Paralleling’, The Electric Power Engineering Handbook, *CRC Press LLC*, pp.135–148.

[7] Harlow J. H. (2007), ‘Load-Tap Change Control and Transformer Paralleling’, *Electric Power Transformer Engineering*, 2nd ed.

[8] Ed Zientek (2011), ‘Loading Considerations when Paralleling Transformers., *PE. Schneider Electric USA*, pp.17.

[9] Jauch E. T. (2006), ‘Factors in Choosing Transformer Paralleling Methods’, *IEEE/PES Transmission and Distribution Conference and Exhibition Note, Beckwith Electric Co., Inc*., pp. 1–6.

[10] Neutral Earthing Resistor, Fact Sheet, Captech Power Quality Solutions, pp. 1-3.

[11] IEEE Guides for Paralleling (2015), The Institute of Electrical and Electronics Engineers, Inc.

[12] Dr. Pituk Bunnoon (2013), 'Fault Detection Approaches to Power System: State-of-the-Art Article Reviews for Searching a New Approach in the Future', *International Journal of Electrical and Computer Engineering (IJECE)*, pp. 553-560.

[13] Zhi Hao Tan, Kein Huat Chua, Yun Seng Lim, and Li Wang (2019), 'Short-Circuit Analyses of Parallel and Non-Parallel Transformer Operations for Railway Power Supply: A Case Study for Third Rail System', *International Conference on Smart Grid and Clean Energy Technologies*, pp.155-160.

[14] Ebrahim Barghamadi, Tauraj Tavassoli (2019), 'The advantages of Yzn transformers over Dyn for small distribution networks (below 250kVA)', *Linkedin.*

[15] Jiazhu Xu, Xiutian Gu, Chonggan Liang, Ziyi Bai, Andreas Kubis, 'Harmonic suppression analysis of a harmonic filtering distribution transformer with integrated inductors based on field–circuit coupling simulation', *The Institution of Engineering and Technology*, pp. 615 – 623.

[16] Electrical Engineering Portal, Principals of Transformers in Parallel Connection (Part 2), Retrieved July 14, 2021, from https://electrical-engineering-portal.com.

[17] A. Papalexopoulos (2013), 'Transmission Grid Fundamentals', *Climate Vulnerability Academic Press*, pp. 217-230.

[18] Saif Aldeen, Saad Obayes Al-Kadhim (2020), 'Three phase Transformer: Connection and Configuration', *Technical Report*, pp 1-20.

[19] Zin Wah Aung (2019), 'Analysis of Three Phase Transformer Parallel Operation and Circulating Current ', *International Journal of Trend in Scientific Research and Development (IJTSRD)*, pp. 1147-1150.

[20] Ahmad Shahsiah (2017), ‘Evolution of the Traditional Power System’, *The Power Grid Academic Press*, pp. 1-36.

[21] Electrical Notes and Articles, Parallel Operation of Transformers, Retrieved July 14, 2021, from https://electricalnotes.wordpress.com.

[22] Circuit Globe, (n.d), Types of Faults in Power System, Retrieved January 24, 2021, from https://circuitglobe.com.

[23] Bill Whitlock (2016), ‘Understanding, Finding, & Eliminating Ground Loops’, *CEDIA Class*, pp3-42.

[24] ‘What is Earthing Transformer or Grounding Transformer’, Retrieved July 14, 2021, from https://www.electrical4u.com.

[25] Circuit Globe, (n.d), Zig-Zag Transformer, Retrieved January 24, 2021, from https://circuitglobe.com

[26] Mike Dickinson (2011), ‘Grounding Transformers’, *Pacific Crest Transformers*.

[27] Sunny Katyara, Sunny Kumar Gemnani (2016) " Simulink Analysis of Vector Groups of Transformers Installed at 132kV Grid Station Qasimabad, Hyderabad and their Effects on System Operation ", *International Journal of Science and Research (IJSR), Wroclaw University of Technology Poland*, pp. 1697-1701.

[28] M.Sc. Eng. G.Calzolari, M.Sc. Eng. C.Saldaña (2005), ‘Power transformers in parallel which share a neutral resistance: how to manage the circulating current between the secondary windings’, *The International Conference on Power Systems Transients (IPST’05) in Montreal, Canada*.

[29] A. J. Duque, N. M. Galeano, J. R. Castrillon, J. M. Lezama and R. A. Sanchez (2018), ‘Power Loss Minimization for Transformers Connected in Parallel with Tap Based on Power Changeability Balance’, *Energies*, pp. 439.

[30] SCHNEIDER Electric Industries (2011), ‘Loading Considerations When Paralleling Transformers’, Schneider Electric USA, Inc.

[31] Zhenfei Zhu, Xiaochun Mou, Shouxin Sun, Chao Zhang (2013), ‘Qualitative calculation and simulation analysis of transformer parallel operation’, *2013 2nd International Symposium on Instrumentation and Measurement, Sensor Network and Automation (IMSNA),* pp. 1027-1030.

[32] Igbogidi, O. N., Dahunsi, A. A. (2020), ‘Enhancement of Power Supply with Paralleling of Transformers Using Same Parameters Approach’, *International Research Journal of Engineering and Technology*, pp. 397-404.

[33] A.R.Sultan, M.W.Mustafa, M.Saini, A.Gaffar (2019) ‘Identification of Ground-Fault Current in Various Transformer Connections and Generator Grounding using Symmetrical Components Method’ , *IOP Conference Series: Materials Science and Engineering*, pp. 1-9.

[34] Daware K, (2014), ‘Parallel Operation of Transformers’, Retrieved January 24, 2021, from https://www.electricaleasy.com.

[35] Hana A. Halim, Nur S. Noorpi, Melaty Amirruddin, Nurhakimah M. Mukhtar (2012), ‘Analysis of Cross Blocking Method Implementation for Overcoming Sympathetic Inrush Current Phenomena’, *2012 Fourth International Conference on Computational Intelligence, Modelling and Simulation*, pp. 288-293.

[36] G. B. Kumbhar & S. V. Kulkarni (2007). ‘Analysis of Sympathetic Inrush Phenomena in Transformers using Coupled Field- Circuit Approach’, *Power Engineering Society General Meeting*, pp 1-6.

[37] Amjad Ali Jatoi, Abdul Khalique Junejo, M.Khan Bozdar, Assadullah Khohawar (2017), ‘Harmonic Analysis of Power Transformer Vector Groups’, *Engineering Science and Technology International Research Journal*, pp. 15-22.

[38] D. K. Patel, J. K. Chauhan, A. R. Patel and N. G. Mishra (2012), ‘A User-Friendly Simulation for Transformer Vector Group’ *2012 International Conference on Communication Systems and Network Technologies,* pp.820-824.

[39] Pirjo Heine, M. Lehtonen, (2003), ‘Voltage Sag Distributions Caused by Power System Faults’, IEEE Transactions on Power Systems, pp. 1367-1373.

[40] Xiaoqing Yan, Yunlan Ruan and Fei Cao (2014), 'Discussion based on the condition of transformer parallel operation', *Jiangxi Yuzhou Vocational College of Science & Technology,* pp.983-985.

[41] EE 423 - Power System Analysis: Faults – J R Lucas – October 2005.

[42] Prof.S.U. Kulkarni, Shraddha S. Phale, Sheetal Mahajan, Amit Kumar (2019), 'Vector Group Testing of Three Phase Transformers and Simulation of Results on Simulink', *JETIR.*

[43] Uche C. Ogbuefi, Jude O. Onyishi, Stephen E. Oti (2020), 'Effectiveness of Neutral Grounding on Power System Application', *Asian Journal of Basic Science & Research*.

[44] Theodor Connor, Qing Biao Liu, Hong Bo Xue, Ying Jie Tang, Gao Hong Song (2017), 'Suitable Methods For Neutral Grounding Of Xining's Distribution Networks', *24th International Conference & Exhibition n Electricity Distribution (CIRED),* pp. 12-15

[45] Tao Yeqi (2017), 'Discussion on the Neutral Point of Urban Distribution Network Transformed by Small Resistance Grounding', *Electrical Engineering*. pp.12.

[46] Shengxi Dong, Mengbo Li, Cancan Huang (2019), 'Selection and protection of earthing transformer', pp. 123-125.

[47] Fulczyk. M and Bertsch. J (2002), 'Ground-Fault Currents in Unit-Connected Generators with Different Elements Grounding Neutral', *IEEE Transactions on Energy Conversion.*

[48] Bo Yang (2017), 'Reliability of Parallel Connected Power Transformers with Failure Correlation and its Preventive Maintenance' *2014 17th International Conference on Electrical Machines and Systems (ICEMS),* pp. 1044-1047.

[49] Kosjenka CapuderBikić, MislavGazdović, FranjoKelemen, AleksandarLojpur (2017), 'Transferred Voltages due to Single Phase Earth Fault on Power Transformers', *Procedia Engineering,* pp.305-311.

[50] Dharita K. Patel, J. K. Chauhan, Ashish R. Patel, N. G. Mishra (2012), 'A User-Friendly Simulation for Transformer Vector Group' 2012 International

Conference on Communication Systems and Network Technologies, pp 820-824.