UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Engineering

DESIGN AND ANALYSIS OF THREE-TO-FIVE-PHASE TRANSFORMER FOR MULTIPHASE LOAD

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DESIGN AND ANALYSIS OF THREE-TO-FIVE-PHASE TRANSFORMER FOR MULTIPHASE LOAD

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
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DECLARATION

I declared that this thesis entitle "Design and Analysis of Three-to-five-phase Transformer for Multiphase Load" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

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APPROVAL

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Date : 23/07/2016

DEDICATION

To my beloved mak, abah and husband

ABSTRACT

This research is focusing on a development of a multiphase transformer, or more specifically a three-to-five-phase transformer. The development of this transformer is based on the manipulation of the phasor diagram. The two input voltage phasors are added together in order to generate the output voltage on the secondary side of the three-to-five-phase transformer. The connection is modelled and validated in finite elements methods (FEM) software prior to the fabrication process. The performance of the developed three-to-five phase transformer is analysed experimentally using No-load test and then followed by using two types of load; static resistance (R) and inductive (L) load and finally with the dynamic load. The No-load test is performed to verify the calculated phase to phase turn ratio, which in this case is 1:1. Thus, the amplitude of the output voltage is equal to the input voltage. For the static load test, each phase of the transformer is connected to the R load and the RL load that connected in series. Then, the analysis of the three-to-five phase transformer with dynamic load is conducted by using a five-phase squirrel cage induction motor. The developed transformer is supplying the motor that has been coupled with electromagnetic brake. The braking power of the electromagnetic brake can be increased or decreased by varying the variable DC voltage supply. This experiment has been carried out to represent the actual load as in the industrial machineries or equipment. Therefore, the successful of static transformation design is elaborated by using the simulation and experimentation method. The simulations result is capable to generate five-phase output and the five-phase induction motor under loaded condition is used to prove the viability of the transformation system. Finally, it is expected that the development of three-to-five-phase transformer can be used for drives application and may also be further explored to be utilized in power transmission system.

ABSTRAK

Kajian ini memfokuskan mengenai pembangunan alat ubah berbilang fasa, atau lebih dikenali sebagai alat ubah tiga-hingga-lima-fasa. Pembangunan alat ubah ini adalah berpandukan kepada gambar rajah fasa. Dua voltan masukan fasa telah di tambah bagi menghasilkan voltan keluaran di bahagian kedua alat ubah tiga-hingga-lima-fasa.Sambungan telah di modelkan dan di sahkan di dalam kaedah tidak terhingga sebelum diteruskan dengan proses fabrikasi. Keupayan alat ubah ini dianalisis secara eksperimen yang menggunakan ujian bebas beban dan ujian beban dimana menggunakan dua jenis beban; statik RL dan beban dinamik.. Ujian bebas beban dilakukan bagi membuktikan pengiraan nisbah alat ubah adalah 1:1, seterusnya menghasilkan amplitud voltan keluaran sama dengan amplitud voltan masukan. Untuk ujian beban statik pula, keluaran setiap fasa alat ubah akan disambungkan pada beban R dan RL secara sesiri. Bagi ujian beban dinamik pula, sebuah motor sangkar tupai lima-fasa telah digunakan. Kuasa bagi brek electromagnet boleh dinaikkan atau diturunnkan oleh voltan DC boleh ubah. Eksperimen ini digunakan sebagai mewakili beban sebenar dalam peralatan dan mesin dalam industri. Oleh itu, keberkesanan reka bentuk pengubahsuaian statik telah diterangkan dengan menggunakan kaedah simulasi dan eksperimen. Keputusan daripada simulasi berupaya menghasilkan keluaran signal lima-fasa dan bebanan pada motor sangkar tupai lima-fasa pula untuk membuktikan keupayaan pengubahsuaian tersebut. Akhir sekali, dijangkakan pembinaan alat ubah tiga-hingga-lima fasa boleh digunakan dalam aplikasi penggerak dan seterusnya ujiikaji yang lebih mendalam untuk digunakan di dalam sistem kuasa pengantar.

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LIST OF ABBREVIATIONS

a	-	Turn ratio
A_C	-	Area of core cross-sectional area
B_{max}	-	Peak flux density
d	-	Diameter wire
E_g	-	Supply voltage
E_f	-	Induced voltage
I_m	-	Magnetizing current
M'	-	Mutual inductance
N	-	Number of turn
R_m	-	Winding resistance
X_m	-	Magnetizing reactance
Z	-	Impedance
Φ_f	-	Flux leakage
Φ_m	-	Mutual flux
Φ_{max}	-	Peak flux
$e.m.f$	-	Electromotive force
$m.m.f$	-	Magneto motive force
FEM	-	Finite Element Method
THD	-	Total Harmonic Distortion

LIST OF PUBLICATIONS

Nor Azizah Mohd Yusoff, Kasrul Abdul Karim, Sharin Ab Ghani, Tole sutikno, and Auzani Jidin, 2015. Multiphase Transformer Modelling Using Finite Element Method. *International Journal of Power Electronics and Drive System (IJPEDS)*, 6, pp. 56-64.

Nor Azizah Mohd Yusoff, Kasrul Abdul Karim, Sharin Ab Ghani and Siti Azura Ahmad Tarusan, 2015. Analysis of Multiphase Transformer for Static Load. *Jurnal Teknologi (Science and Engineering), 75*, pp. 13-18.

K. Abdul Karim, L. Geok Yin, N. A. Mohd Yusoff, M. N. Othman, A. Jidin, 2015. Design of Five-Phase Transformer through Finite Element Simulation, *Applied Mechanics and Materials, Vol. 761*, pp. 12-16.

CHAPTER 1

INTRODUCTION

1.1 Research Background

The multiphase system can be considered to has more than three alternating voltages of the same frequency but differ in phase angle ($n > 3$) (Emil, 2008). The utilization of multiphase system has allow the development of advanced application which have better performance than conventional three-phase machines (Parsa, 2005). Some of the advantages are inherent to the characteristic of multiphase system, for example by providing smoother operation and more efficient due to the higher frequency of torque pulsation (Ayman, 2012). Therefore, due to a larger number of phases, multiphase is widely used in several applications such as electric aircraft, electrical/hybrid vehicles and locomotive (Palak, 2013).

Thus, this research project proposes to utilize a multiphase system through three-to-five-phase static transformation which concerning a linear speed characteristic of multiphase machine. Indeed the transformer is becoming an important component in static transformation system in converting the available three phase grid supply to a higher number of phases. The transformers are designed to adapt with special connection scheme with the idea to change from three to n phase through an arrangement of phase transformation execution. Previous research related to (Atiff, 2010) on five-phase transformation has pointed out those methods used in power transformer includes the phasor diagram construction, and the winding arrangement with special connection. The phasor diagram is used to governing the turn ratio by creating the appropriate phase displacement of 72^0 between each phase with different selection of turn ratio for secondary winding.

While the formation of winding arrangement is employed to layout the input and the 16 terminals of output configuration. The configuration can be in several ways: star (input) and star (output); star (input) and delta (output); star (input) and polygon (output); and finally delta (input) to polygon (output). In this project the primary and secondary of the transformer is connected in a star (wye) form. The idea of this research is depicted as in Figure 1.1 where three-to-five-phase transformer is designed to convert from three-phase supply to five-phase output.

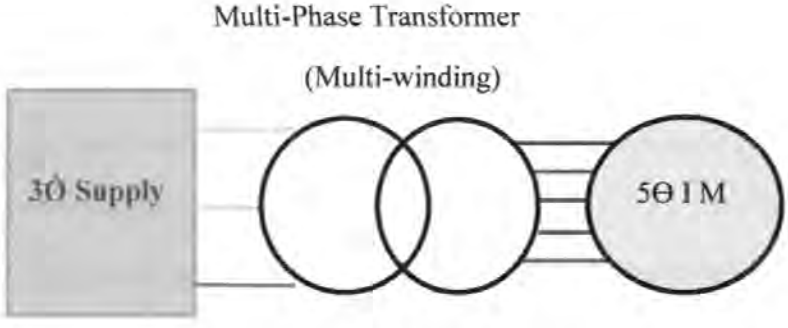

Figure 1.1: Three-to-five-phase transformer basic diagram

1.2 Motivation of Research

Nowadays, the attention in multiphase motor drive system has been increased due to the several advantages over than of a three-phase variable speed motor drive. The utilization of more than three phases enables splitting of the power across a large number of inverter legs, thus enabling use of semiconductor switches of lower rating. Otherwise, multiphase machines are characterized with much better fault tolerance than the three-phase machines. Independent flux and torque control requires means for independent control of two currents (Emil, 2008).

Therefore, this becomes impossible in a three-phase machine if one-phase becomes open-circuited, but is not a problem in a multiphase machine. Otherwise, the past three years had seen other researchers from Universiti Teknikal Malaysia Melaka (UTeM) concerned

with induction motor drives fed by five leg inverters (Md, 2013) which also in line with other research around the world (Drazen, 2008), (Ohama, 2009) and (Prasad, 2011). However, more attention has been paid to the complex electronics circuit of the inverter in achieving the multiphase drive. Moreover, repairing sophisticated inverter relatively not easy and requires an expertise of the field and generally requires higher cost to purchase the inverters. Consequently, the objective of this research is to develop and establish a five-phase alternating current (AC) supply that is simple in design and lower in cost. The research project has led to the new knowledge of the development of multi-input to multi-output transformation system.

1.3 Problem Statement

A three-phase system is commonly used in electrical grid in order to transfer electrical power. The three-phase system is also one type of poly-phase system which is used to directly supply motors and many other loads of industrial applications. On the other hand, there has been an increasing interest in multiphase system; which number of phase more than three. There have been number of researches highlight the benefits of multiphase system over three-phase system for electric power generators such as (Arroyo, 2002) and (Singh, 2005) and motor drives (Atiff, 2010) and (Sheriff, 2012).

In term of power transmission, multiphase system is capable to transmit a lower phase current compared to single and three-phase system hence increasing the transmission efficiency. For the multiphase motor, the per-phase capacity of motor could also be reduced since the total power could be divided into more number of phases. Most of the research related to multiphase drives system are based on the utilising of multiphase voltage source inverter (VSI) as a power converter especially for applications where variable speed operation is required. The induction motors fed by five legs pulse width modulation (PWM) inverter

occupies an important place in industrial application such as electric vehicle. Most of the application requires either purely or nearly sinusoidal voltage waveforms.

However, for an application of single speed operation, the utilisation of voltage source inverter (VSI) can be replaced by a static transformation system such as transformer bank that can be used to provide the multiphase supply. The supply provided by using transformers is more stable and in purely sinusoidal form, therefore its total harmonic distortion (THD) is lower than the ones generated by VSI. This indicates the need to develop the alternative type of drive that provide a constant speed towards the electrical motor and the expectation drive in certain application. Table 1.1 shows the comparison between general inverter and transformer.

Basically, an inverter is used to drive an induction motor which output frequencies can be varied to vary the speed while the transformer can provide constant frequency output for constant speed operation. Due to the linearity and stable purely sinusoidal output frequency, transformer can produce lower total harmonic distortion as compared to the inverter. Inverters typically are more complicated to manufacture and their cost are higher than the conventional transformer for a similar capacity. This research attempts to bring the alternative way in terms of variation for electrical motor drive.

Table 1.1: Mode operation of five phase inverter

Characteristic	Inverter	Transformer
Output	Varies	Linear
Frequency	Varies	Linear
Design	Complicated	Simple
Cost	High	Low
Total Harmonic Distortion	High	Low
Application	Wide Range	Limited

1.4 Significance and Rationale of the Research Work

Transformer commonly used to step up or step down output from their input. In another side, it also can be used as a driver for an induction motor if the speed is constant. Hence, the research is focusing on how the three-to-five phase transformer acts as static and linear input for five-phase induction motor. Thus, this study provides an exciting opportunity to advance the knowledge to the designing of three-to-five-phase transformer, the behavior of output, the performance when handling to several static loads and the actual performance while a driving five-phase induction motor.

The study offers some important insights into comparison between three-phases over five-phase system especially in terms of; the phasor diagram, the output phase shift and the formation of the transformer bank. Most interesting, this transformer needs a special connection scheme which led to five-phase sinusoidal output from ideal three-phase supply. Finally, there are several important areas where this study makes a unique and original contribution to the beginning of variation types of drives other than inverters.

1.5 Objective Project

The objectives of the project are stated below:

1) To design special winding connection of three-to-five phase transformer based on phasor diagram concept.
2) To develop the model of three-to-five phase transformer in 3-D geometric by using finite element method software (FEM).
3) To develope a prototype of three-to-five-phase transfomer and for testing and verification purpose.