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Analysis of Multiphase Transformer for Static Load

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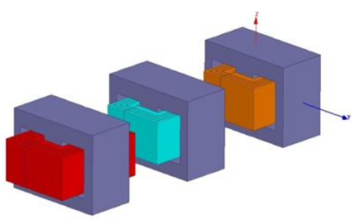
Graphical abstract



Abstract

In the year of 1970 saw the starting invention of the five phase motor as the milestone in advanced electrical motor. Through the years, there are many researchers who passionately worked towards developing for multiphase drive system. They had developed a static transformation system to obtain a multiphase supply from the available three phase supply. This idea gives an influence for further development in electric machines as an example; an efficient solution for bulk power transfer. This paper presents the ability of Finite Element Method to proof the theory and concept in design multiphase transformer before proceeds to the fabrication stages. Identifying of specification on a real transformer had been done before applied in software modelling. The final part of this paper deals with the hardware construction of multiphase system with the static load to see the effect of phase current on variation of load.

Keywords: Five Phase, multi-winding transformer, Finite Element Method (FEM), hardware fabrication

Abstrak

Dalam tahun 1970-an menyaksikan bermulanya ciptaan daripada motor lima fasa sebagai tanda aras dalam pembangunan motor elektrik yang canggih. Dari tahun ke tahun, terdapat banyak penyelidik yang ghairah bekerja ke arah membangunkan sistem pemacu berbilang fasa. Mereka telah membangunkan sistem transformasi statik untuk mendapatkan bekalan berbilang fasa dari bekalan tiga fasa yang ada. Idea ini memberikan pengaruh untuk pembangunan selanjutnya dalam mesin elektrik sebagai contoh; efisien bagi pemindahan kuasa pukal. Karya ini membentangkan keupayaan Kaedah Unsur Terhingga untuk membuktikan teori dan konsep dalam reka bentuk rekaan alatubah berbilang fasa sebelum meneruskan ke peringat fabrikasi. Ini dilakukan dengan cara mengenal pasti spesifikasi sebuah alatubah sebenar sebelum dibangunkan menggunakan pemodelan perisian.Pada bahagian akhir karya ini memperkatakan pemodelan perkakasan sistem berbilang fasa dengan beban statik dilaksanakan untuk melihat kesan arus fasa pada perubahan beban perintang.

Kata kunci: Lima fasa, alat ubah berbilang lilitan, kaedah unsur terhingga, fabrikasi perkakasan

1.0 INTRODUCTION

There are multiple phases in electrical system those considering generate more than three alternating voltage of the same frequency but different phase angle. The multiphase output signal is leading towards the advance development of power system application over three-phase system.

Hence, the history development of multiphase had begun in 1969 century by Harrer Way Back and Ward who were the pioneer to the first proposal of multiphase (five-phase) induction motor. These advantages are inherent to the own structure of the machine, for example by providing the smoother operation and it is more efficient due to the higher frequency of torque pulsation besides the lower total harmonic distortion (THD).

Therefore, due to the higher number of phase, multiphase is widely used into several applications in niche application; electric aircraft, electrical/hybrid vehicles and locomotive.

Thus, this investigation project proposes to a three-to-five-phase by static transformation system using transformer corresponding to the constant voltage supply and frequency. Indeed, the transformer is designed to adapt with the specializing connection scheme with the ideology of changing from three to *n* phase through an arrangement of transformation execution. The idea of this research is depicted in Figure 1. At the end of this paper is providing the analysis performance by using static load.

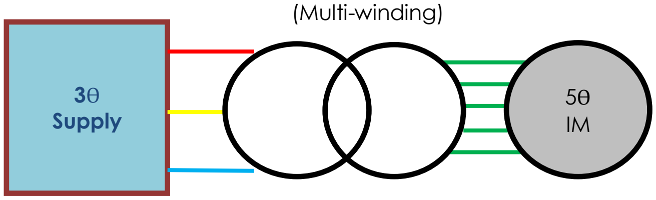


Figure 1 Block representation of the Multiphase system

2.0 MULTIPHASE DESIGN

This section present the technique of three-to-five phase as illustrated in Figure 3, Table 1, and Table 2. Figure 2 below summarizes all necessary steps for creating a Multiphase by power Transformer:

Drawn a phasor
↓
Scaling
↓
Turn ratio
↓
Winding

Figure 2 Modeling process of multiphase transformer

2.1 Phasor Diagram

The phase voltages are all equal in magnitude but only differ in their output phase angle, which required for phase angle 72° between each phase. The construction for output phase is figured out using the appropriate number of turns from the principal of phasor diagram. In the transformer modelling the input phases are indicated with letters "X", "Y", and "Z" while the output phases are indicated with letters "A", "B", "C", "D" and "E" as illustrated in Figure 3.

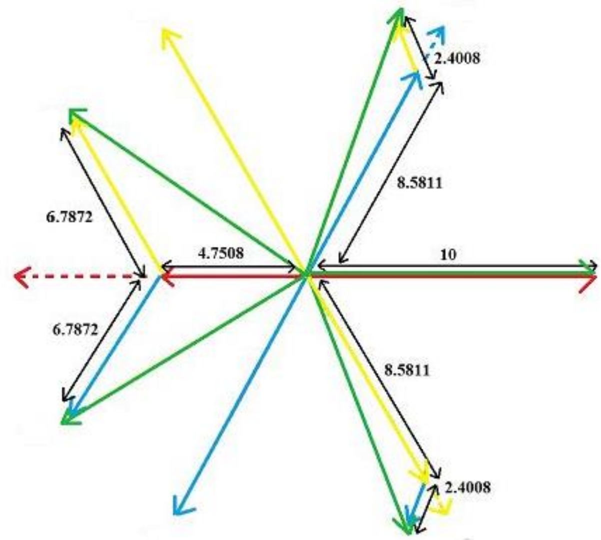


Figure 3 Phasor representation of the Multiphase transformer connection

2.2 Turn Ratio

The number of turns for primary windings can be calculated by applying the Faraday's Law as yields in Equation (1).

$$\text{Np} = \frac{V}{4.44 f \Phi_{max} A_{Bobbin}} \tag{1}$$

where:

V = RMS value
f = frequency of the flux
N_P = Number of turns on the primary winding
Φ_{max}= Peak value of the flux
A = area of bobbin
4.44 = a constant [exact value $=2\pi/\sqrt{2}$]

Further, the turn ratio of secondary side is determined through phasor scaling. This process can be done mathematically by ruling the magnitude or the length of the arrow from zero point. For example the output phase "A" (V_A) is aligned with the input phase "X" (V_X). Next, the output phase for "B" (V_B) will be determined through the vector addition of two voltages which involves by forming a triangle. So, the components for output phase "B" can be formed by adding two vectors ($-V_Z + V_Y$). Similarly, "C" (V_C) is obtained from vector ($-V_X + V_Y$). The output of phase "D" (V_D) is obtained by the vector addition of voltage in ($-V_X + V_Z$) and last but not least the output phase "E" (V_E) is from the vector sum of voltage ($-V_Y + V_Z$). Table 1 and 2 shows the turn ratio for primary and secondary windings using in modelling by following the equation below.

$$\frac{Length\ of\ the\ line\ (magnitude)}{10} \times Np\ = Turn \qquad (2)$$

Table 1 Turn ratio for Primary turns

Primary	***Magnitude (Voltage, V)***	***Turns, N***
X	10	310
Y	10	310
Z	10	310

Table 2 Turn ratio for Secondary turns

Secondary	***Length(Voltage Magnitude, V)***	***Turns, N***
X	10	310
	4.7508	147
Y	2.4008	210
	6.7872	74
	8.5811	266
Z	2.4008	210
	6.7872	74
	8.5811	266

2.3 Winding Arrangement

As can be seen in the first column of Table 1 and Table 2 for Multiphase system, three single phase transformers are needed (X, Y, and Z). Each core is carrying one primary and three secondary coils, except for the core 'X', only two secondary coils are used. Thus, this entire transformer consists of six terminals of primary (V_X, V_Y and V_Z) and 10 terminals of secondary (V_A, V_B, V_C, V_D and V_E).

The terminal from entire transformer is connected in star-star connection that is the easiest way to set up the configuration regarding to the multiple winding in secondary side which has more than one secondary. Despite, the proposed connection scheme is choose due to less total harmonic distortion when compared to the other fashion.

In consequence, Table 3 provides an overview of turn ratio and vector represented. The winding configuration was then being organized as in Figure 4 accordingly to the direction of vector in phasor diagram. Recently, this configuration has been practice into software development and hardware construction.

Table 3 Transformer vector

Transformer	Phase Output	Turn and Vector
X	A	310 (V_X)
Y	B	74 (V_Y) + 266 ($-V_Z$)
	C	210 (V_Y) + 147 ($-V_X$)
Z	D	210 (V_Z) + 147 ($-V_X$)
	E	74 (V_Z) + 266 ($-V_Y$)

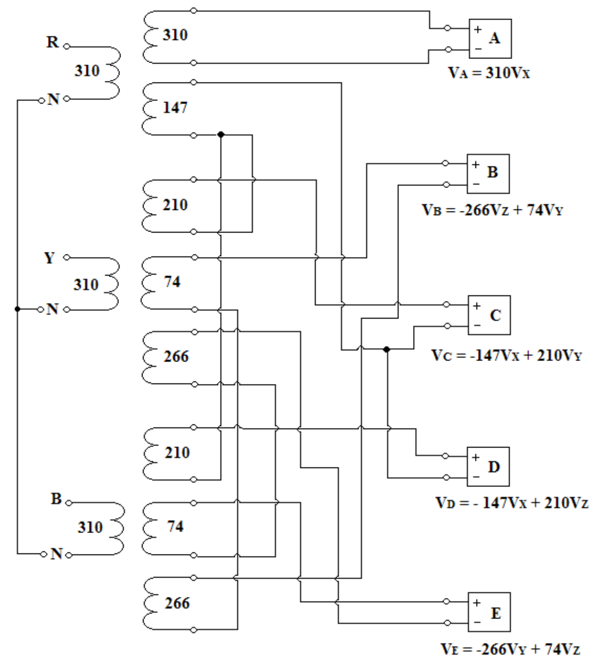


Figure 4 Winding arrangement of Multiphase Transformer

3.0 SOFTWARE DEVELOPMENT

Finite element method (FEM) techniques are useful to sketch the model of transformer in geometrically and solve compositionally complex problem [6]. In fact, it is capable to take into account the non-linearity and inhomogeneous characteristic of the model [7]. Multiphase systems of transformer in FEM working under transient analysis have two main parts: Geometrically model 3-D and Maxwell Circuit Editor.

3.1 FEM Model

Hence, by using Finite Element tools, three single-phase transformers model have been developed according to the actual specification. The first stage of the simulation is started with sketch the geometry model for three single phase transformer by Finite Element Method (FEM). Figure 5 shows the three single phase transformer model is created in 3D. The description of power transformer model details is shown in Table 4.

Table 4 Details of transformer model specification

Classification	*Specification*
Voltage [V]	240
Frequency [Hz]	50
Core Material	Steel 1008
Winding Material	Copper

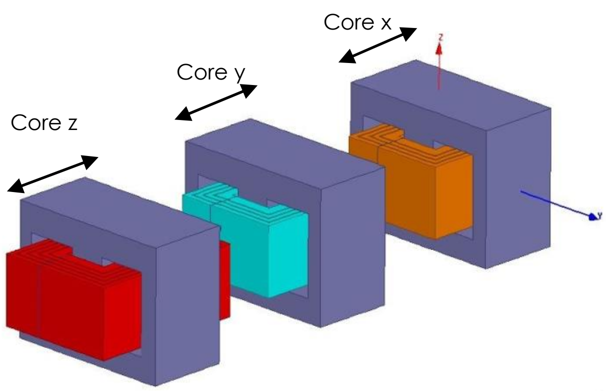


Figure 5 Modeling process of Multiphase Transformer

3.2 Maxwell Circuit Editor

The model has typically been coupled to circuit simulation using ANSYS Circuit Editor. It means that, for each rectangular sketch in transformer model has been represented to the coil terminal in Maxwell Circuit Editor as clearly seen in Figure 8.

3.3 Result and Discussion

Figure 6 has represented the results of three phase input supply of voltage waveforms from Finite Element Method (FEM). The amplitude voltage of input (240 V) is similar to the output (240 V) amplitude regarding to the 1:1 ratio of magnitude phasor diagram.

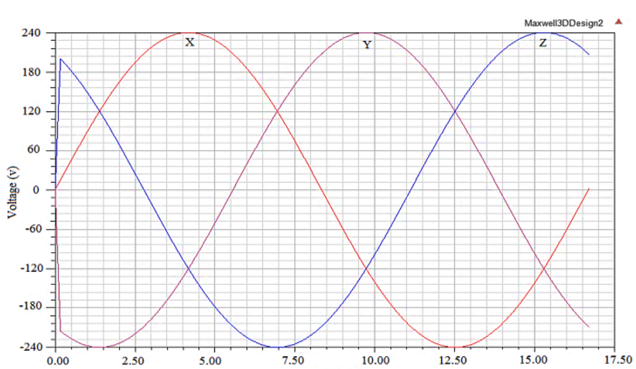


Figure 6 Three phase input by ANSYS Maxwell

Then as shown in Figure 7, it is clearly seen that the output is a balanced five-phase output signal. Individual output phases are shown along with their respective output voltages.

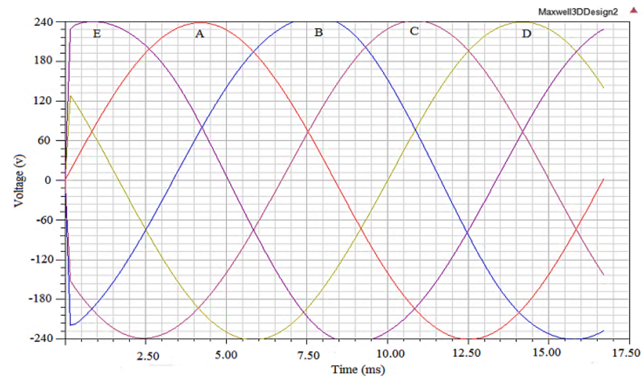


Figure 7 Five phase output by ANSYS Maxwell

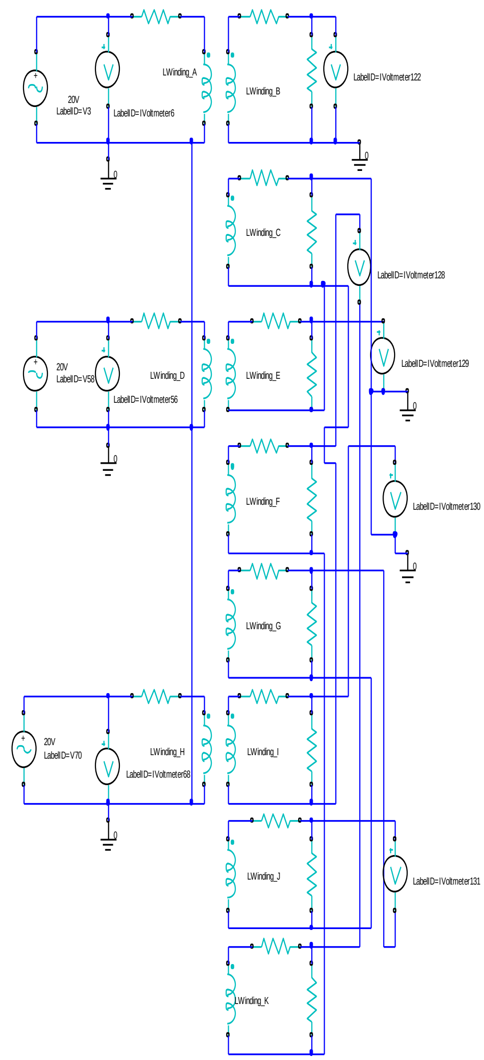


Figure 8 Winding arrangement of multiphase transformer

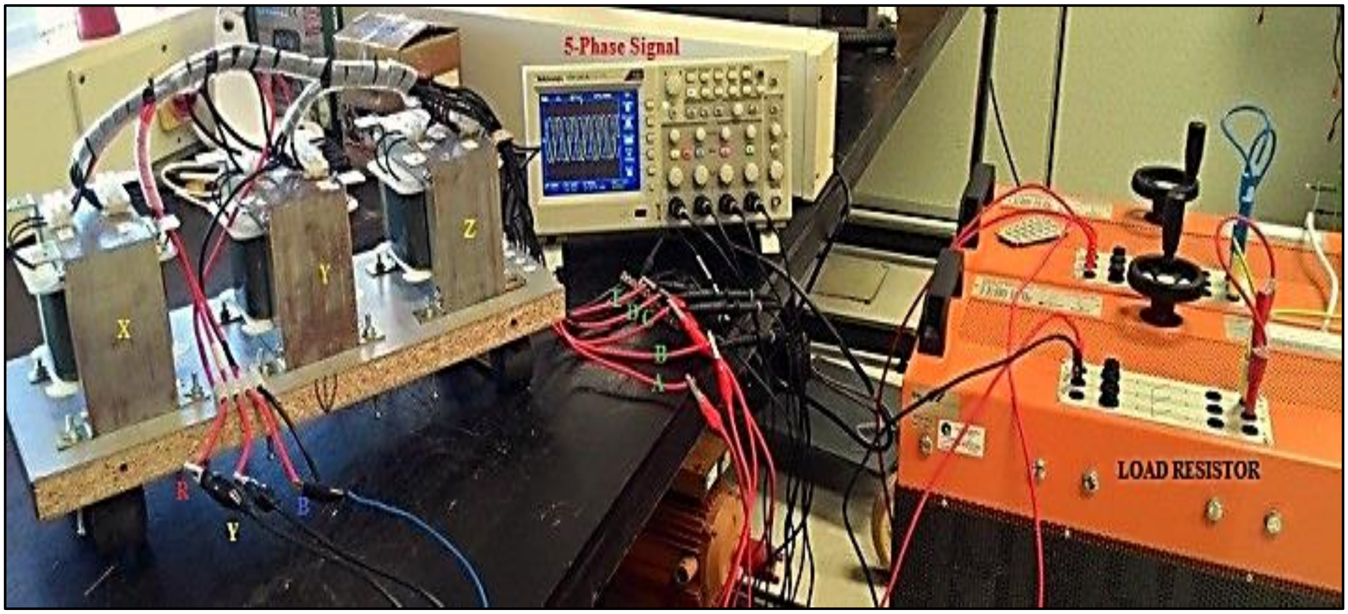


Figure 9 Picture of the test system

4.0 HARDWARE DEVELOPMENT

The final section of this paper is turning to the experimental evidence on five-phase transformer development. This test is to examine the behaviour of transformer on static load, resistor.

Therefore, design transformation system has being loaded through the variation of resistive load by load resistor as shown in Figure 9. Means, the load resistor is connected to the secondary terminals. The selection for the range of resistance is about 0.05 kΩ until 0.27 kΩ regarding to the rated current for the size of wire.

This load current solely depends upon the characteristic of the load and also upon to the secondary voltage of transformer. The effectiveness of load is observed by taking the measurement of phase voltage and current

4.1 Result and Discussion

The five-phase signal is displayed in oscilloscope as shown in Figure 10. However, there is only four output phases being able to display due to the limited capability of oscilloscope itself. Therefore, in Figure 11, there is a clear view of five phase signals when the data for each phase from oscilloscope are combined by using Microsoft Visio.

For the purpose of analysis through Figure 12 it can be seen that the phase current for primary and secondary is gradually decreased along with the increasing of resistor value. Besides, the secondary phase current is lower than primary with the same of power delivery capacity.

Then, table 5 illustrates the results obtained from the analysis of five-phase transformer on static load at 0.27 kΩ.

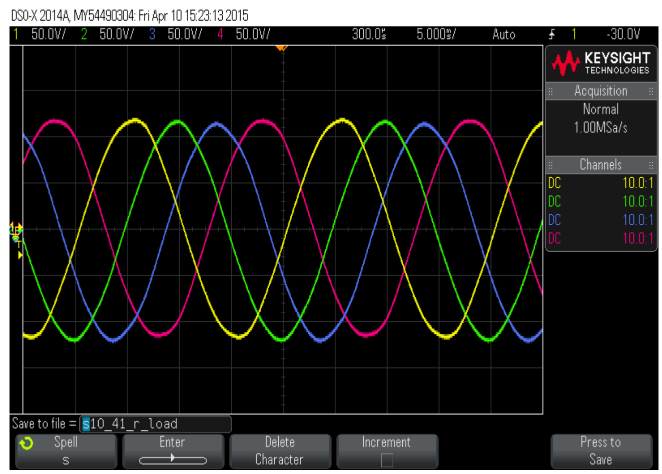


Figure 10 Output signal from oscilloscope

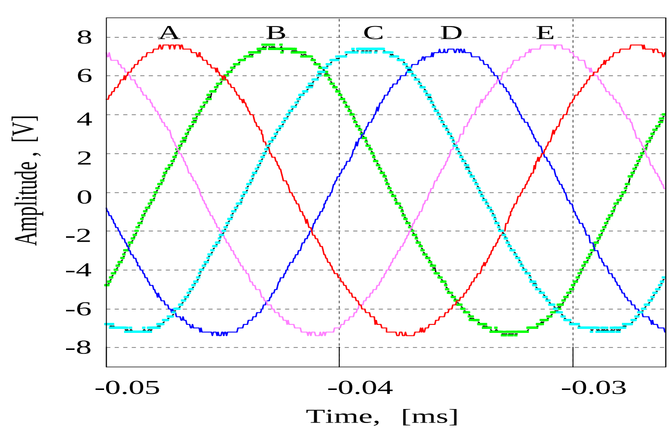


Figure 11 Five-phase of output signal

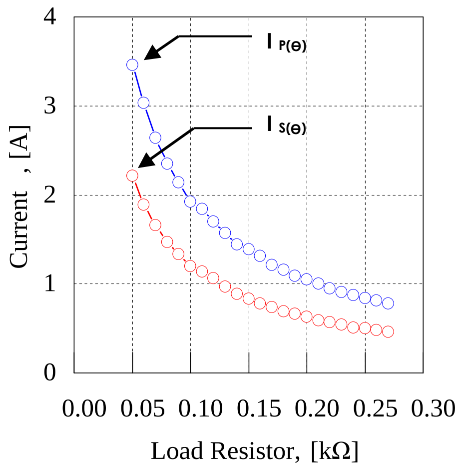


Figure 12 Phase current for primary and secondary

Table 5 Experimental data of load resistor 0.27 kΩ

Primary voltage	240 (V_{L-L})	Secondary voltage	167.7 (V_θ)
Primary current	0.78 (A)	secondary current	0.46 (A)
Rating Frequency	50 (Hz)	Load Resistor	0.27 (kΩ)

5.0 CONCLUSION

This paper deals with the contribution to develop a five phase output supply using static transformation system through a vector in phasor diagram. Then, the relevance of multiphase development is clearly supported through the simulation by combined the software from ANSYS Maxwell and Maxwell Circuit Editor. Further, the second major finding was the result from hardware construction. The five-phase output signal is successful to produce as it was similar in software. Finally, this paper is able to identify the performance in terms of phase current once the output of secondary is being coupled with the static load resistor.

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