ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

ANALYSIS OF MULTIPHASE TRANSFORMER SUPPLYING A STATIC AND DYNAMIC LOAD

Nor Azizah Mohd Yusoff, Kasrul Abdul Karim, Sharin Ab Ghani, Fazlli Patkar, Siti Azura Ahmad Tarusan and Auzani Jidin
Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Melaka, Malaysia
E-mail: kasrul@utem.edu.my

ABSTRACT

Transformers are able to step up or step down an output voltage from their input. It also can be used to directly supply an electrical motor when a constant frequency operation is required. Here, the research is focusing on designing a three-to-five phase transformer that acts as static phase converters for supplying a balance five-phase load. The designing process of the transformer is described based on the graphical phasor diagram that is flexible and easy to be implemented. At the end, the performances of the designed transformer are evaluated using a static and dynamic load. The designed three-to-five phase transformer is able to maintain a balance five phase voltage for several type and level of load as shown in experimental result.

Keywords: three-to-five phase transformer, no-load, static load, series R-L, dynamic load.

INTRODUCTION

A three-phase system is commonly used in the electrical grid in order to transfer electrical power. The three-phase system is also a type of poly-phase system which is used to directly supply motors and many other loads for industrial applications. On the other hand, there has been an increasing interest in multiphase system; a system with a number of phases more than three. There has been a number of research that highlight the benefits of multiphase systems over three-phase system for electric power transmission and motor drives (Sunil, 2013). In terms 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, per phase capacity of the motor could also be reduced since the total power could be divided into a number of phases.

Most of the research related to the multiphase drive system are based on utilizing multiphase Voltage Source Inverter (VSI) as a power converter especially for applications 2013). However, for an application of single speed operation, the utilization of VSI can be avoided and static transformation system such as transformer bank can be used to generate the multiphase supply (Abdel, 2013). Supplies generated by using transformer are more stable and in purely sinusoidal form, therefore its total harmonic distortion (THD) is lower than the THD generated by VSI.
This paper presents a development of multiphase transformer for supplying a multiphase load operated at constant frequency. In general, the selection regarding of the number of phases also gives an effect to the motor performance. For example, the uses of even phase number reduce the motor performance since the phases coincide with each other (Prasad, 2011) . Therefore, this research focuses on developing a three-to-five phase transformer. The development of the transformer based on the phasor diagram is explained first, followed by the analysis of transformer performance. Besides supplying a dynamic load (five-phase induction motor), the workability of the transformer is also experimentally tested using static R-L load.

Phasor diagram

This section presents the development of three-to-five phase transformer based on the illustration of phasor diagram shown in Figure-1. The phasor diagram is drawn manually using AutoCAD and an exact dimension of phasors is used in order to produce a concise drawing.

The three-phase transformer is constructed using three single-phase transformers (Srinivas, 2013). The voltage of three-phase inputs is all equal in magnitude but has 120 ^{o} phase difference between each of them, which is required for a balanced three-phase system. The phases of input voltages are represented using a standard color code of three-phase system; red, yellow and blue while the letter “X”, “Y”, and “Z” are used to denote the voltage produced by the three single-phase transformers.

The phasor of five-phase output voltages are represented using “A”, “B”, “C”, “D” and “E” letters and drawn using a green color. The phasors of output voltages are drawn at the same origin as the three-phase input and have the same magnitude as its counterpart. For a balance five-phase system, the phase angle of the output voltages must be phase shifted by 72^0 between each of them (Monika, 2013). To achieve this, the angle between phasor’s spoke and the length of each vector must be precise with the aid of AutoCAD tools. The phasor of five-phase output voltages are obtained based on vector summation (vector triangle) such as illustrated in Figure-1. Two input voltage phasors (with calculated secondary turn ratio) are added in order to generate each output voltage phasor. Table-1 lists the input voltage phasors that are used to generate the five-phase output voltage phasors. The calculated turn ratio of the secondary side of the three single-phase transformer that is used to generate the individual output voltage phasor is also depicted in Figure-1.

ARPN Journal of Engineering and Applied Sciences

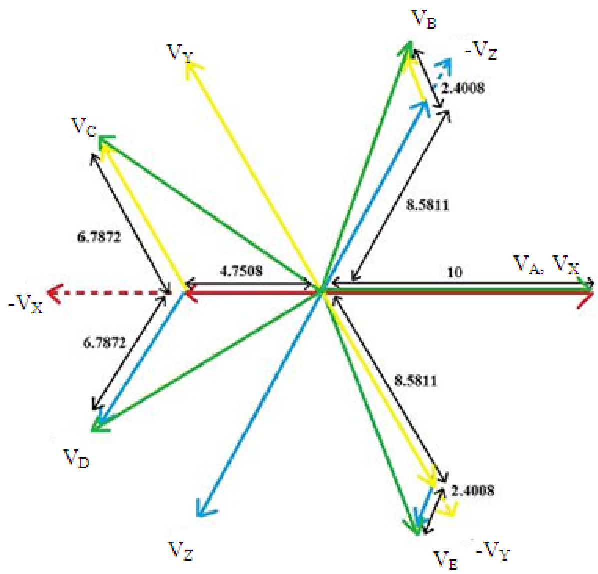

Figure-1. Phasor diagram illustration of three-to-five phase transformer.

Table-1. Generation of output voltage phasor.

Phase voltage	Vector summation
A	$\mathbf{V_A = V_X}$
B	$V_B = -8.5811V_Z + 2.4008V_Y$
C	$V_C = -4.7508V_X + 6.7872V_Y$
D	$V_D = -4.7508V_X + 6.7872V_Z$
E	$V_E = -8.5811V_Y + 2.4008V_Z$

The magnitude of phase B will become the summation of 8.5811 times V_Z in opposite polarity plus with the 2.4008 times V_Y. Magnitude of V_Z and V_Y can be determined by manipulating the number of turns on both winding.

EXPERIMENTAL TEST

The performances of the developed three-to-five phase transformer were analyzed experimentally using no load test and also using two types of load; static and the dynamic load. For the static load test, each phase of the transformer was connected to an R-L load that were connected in series. The test with dynamic load was conducted by using a five-phase squirrel cage induction motor (Atif, 2010). The motor was coupled with electromagnetic brake which powered by the variable DC voltage supply. This experiment has been carried out on the basic application of the eddy-current brake.

No-load test

The no-load test was performed without any load connected at the output of the transformer. The test is conducted to verify the calculated turn ratio of the transformer with 1:1, thus producing an amplitude of the output voltage equals with the input voltage (Iqbal, 2010).

The hardware setup for the no load test is depicted in Figure-2. The output voltages of transformer captured by using an oscilloscope are shown in Figure-3. Only four phases of output voltage waveforms can be observed since the number of channel of the oscilloscope is four. The reconstruction of five-phase output voltage waveforms was done by importing the oscilloscope data and tabulated them into Microsoft Excel. Thus the regenerated waveforms are ~~as~~ shown in Figure-4. It can be seen that the waveforms are not purely sinusoidal as illustrated in Figure-7 and Figure-11 because during the experiment, the secondary winding is open and no current flows through it. The current flows in the primary winding to maintain the flux in the core. Since the core impedance is dominant, it will distort the waveform.

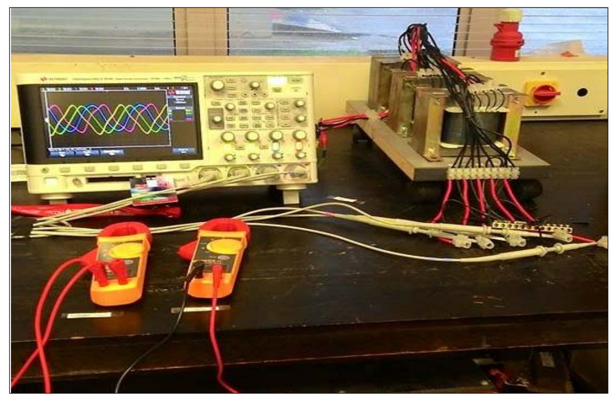

Figure-2. Hardware setup for no-load test.

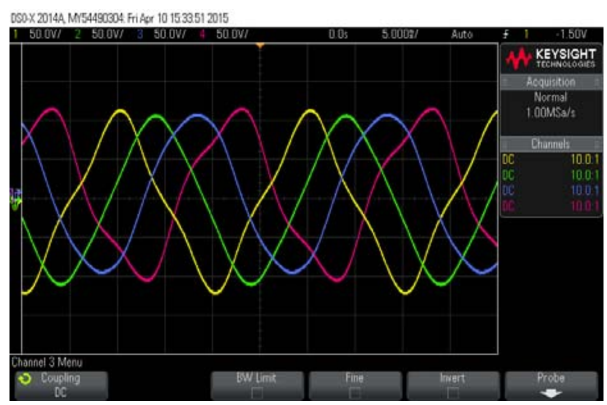

Figure-3. Output voltage waveforms of no-load test obtained using oscilloscope.

VOL. 11, NO. 14, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

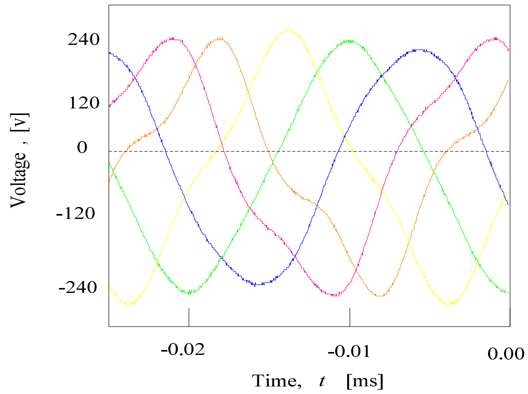

Figure-4. Five-phase output voltage waveforms of no-load test reconstructed using Microsoft Excel.

Static R-L load test

The experiment for static RL load was conducted for a fixed value of inductance and varying values of the resistance. There were two different values of reactants used; 0.796kΩ and 0.15kΩ. The range of the resistance was from 0.05kΩ to 0.27kΩ selected based on ~~to~~ the rated current for the selected size of wire. The experimental setup for the static RL load test is depicted in Figure-5. The test results observed from oscilloscope are presented in Figure-6. The reconstruction of five-phase output voltage waveform using Microsoft Excel is shown in Figure-7.

Figure-5. Experimental setup for series R-L load test.

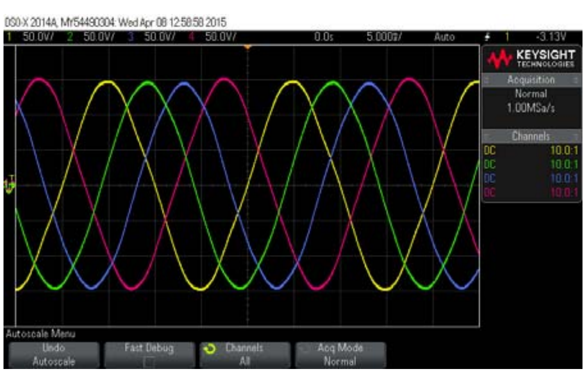

Figure-6. Output voltage waveforms of series R-L load test from oscilloscope.

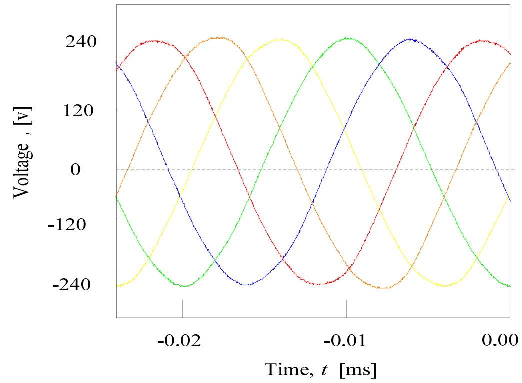

Figure-7. Five-phase output voltage waveform for series R-L load test.

Table-2 and Table-3 list the experimental data of the changes in phase current for primary (**$I_{P(\Theta)}$**) and secondary (**$I_{s(\Theta)}$**) windings of the transformer with the different values of R. It is clear from Table-2 that there is no changes on phase current due to the different value of R. When the reactance was larger than the resistance, there was no significant different for the value of phase current in both windings that was detected. The results from Table-2 indicate that once the value of reactance becomes dominant or close, the back emf opposes the rise and fall of the current flowing through the coil. Table-3 shows the experimental data that is implemented using a lower value of reactance. Here, the value of phase current increases (or decreases) based on the value of resistance since the total impedance are now dominated by the resistance value.

The value of current that flows in a conductor is affected by the total impedance of the circuit. The total impedance is the sum of the component R and X_L. In this test, the lower value of reactance has led to decreasing the amount of total impedance, hence allowing more current flows in the whole circuit connection. Therefore, the impedance load occurs in the power transformer will be reflected to the input. Each of this has a role on establishing the transformer efficiency. This impedance helps the performance of transformer, depending on the implementation.

Table-2. Phase current values with X_L= 0.796kΩ.

Setup		Measured		
V_{INPUT}	R (kΩ)	$V_{S(\Theta)}$ (v)	$I_{P(\Theta)}$ (A)	$I_{S(\Theta)}$ (A)
240	0.05	138.5	0.18	0.08
240	0.08	138.5	0.18	0.08
240	0.12	138.5	0.18	0.08
240	0.16	138.5	0.18	0.08
240	0.19	138.5	0.18	0.08
240	0.23	138.5	0.18	0.08
240	0.27	138.4	0.18	0.08

VOL. 11, NO. 14, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-3. Phase current values with X_L= 0.15kΩ.

Setup		Measured		
V_{INPUT}	R (kΩ)	$V_{S(Θ)}$ (v)	$I_{P(Θ)}$ (A)	$I_{S(Θ)}$ (A)
240	0.05	138.5	1.01	0.58
240	0.08	138.5	0.96	0.54
240	0.12	138.5	0.89	0.50
240	0.16	138.5	0.81	0.45
240	0.19	138.5	0.76	0.42
240	0.23	138.5	0.69	0.39
240	0.27	138.4	0.63	0.35

Dynamic load test

The second experimental load test was to drive a 1.5HP five-phase induction motor with a rated speed of 3000rpm which fed by the designed transformer of 240 AC input voltage supply. During this test, the five-phase induction motor was coupled with the electromagnetic brake which powered by DC voltage supply. The variation of DC voltages from zero to 220 volts with an increment of 20 volts was applied on the electromagnetic brake once the induction motor had reached its steady-state speed.

The eddy current brake which was capable to stop the rotation of the motor was used to mimic the actual load as in industrial machineries. The eddy current brake provided an option to slow the things down with the force of electromagnetism instead of friction. The eddy currents produced a braking effect toward the induction motor. This test sought to examine the performance of the transformer to handle the increases of load power. The schematic diagram for conducting the test is depicted in Figure-8. The experimental setup for the dynamic load test is shown in Figure-9.

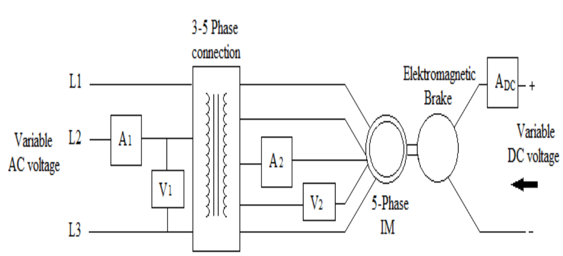

Figure-8. Schematic diagram for dynamic load coupled with electromagnetic brake.

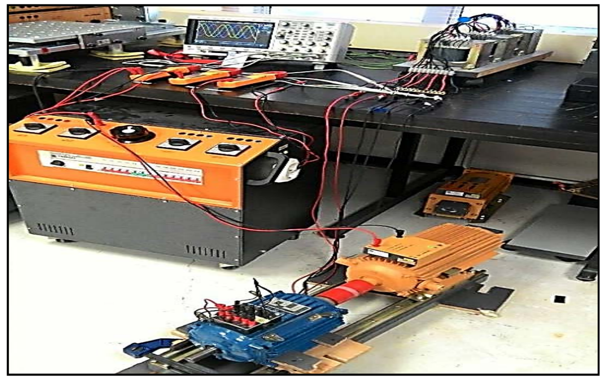

Figure-9. Experimental setup for dynamic load test.

The output voltage waveforms captured by using oscilloscope for the conducted test are shown in Figure-10 while the regeneration of five-phase output voltage waveforms by using Microsoft Excel are presented in Figure-11. The change of motor speed based on the applied DC voltage is shown in Figure-12. From the graph, it can be seen that the speed of the motor decreases from its synchronous speed value by increasing the applied DC voltage. The high the DC voltage is applied, the braking effect becomes stronger hence reducing the speed of the five-phase induction motor. The maximum result to emerge from the data was at V_{DC} = 220 volts where a smoke was started emanating from the transformer along with a burnt smell with phase current $I_{P(Ø)}$ = 5.33 Amp for the rated current for the wire size of 0.06mm.

Nevertheless, based on the conducted test, it can be concluded that the designed three-to-five phase transformer are capable to generate a constant and almost sinusoidal output voltages to supply a balance five-phase load.

Figure-10. Output voltage waveforms of dynamic load test from oscilloscope.

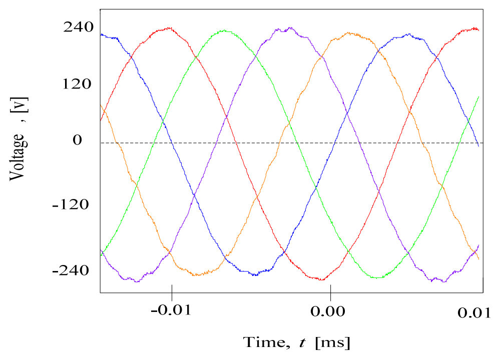

Figure-11. Five-phase output voltage waveforms for dynamic load test.

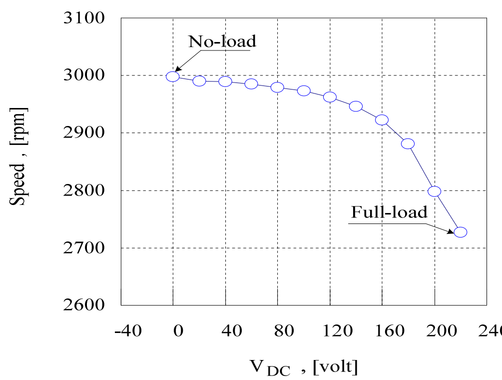

Figure-12. Graph of motor speed versus braking voltage V_{dc}.

CONCLUSIONS

This research has given a credit to the transformation of the three-phase grid power to a five-phase output supply via static transformation system. Here, the design process through graphical phasor diagram is verified by the hardware construction. Then, in analysis of static load which the resistance is on real axis while the reactance is on imaginary axis; both components will be an opposition to the current equals to the sum of their complex number. Further the study has developed several ways towards enhancing the understanding where this paper has demonstrated the application of eddy current brake that represented as a load in the test. Under this condition, the rotor tends to run at nearly synchronous speed at no load and then the speed is reduced as the load increases.

ACKNOWLEDGEMENT

This work is supported by Kementerian Pendidikan Malaysia and Universiti Teknikal Malaysia Melaka through FRGS/2/2013/TK02/FKE/02/2/F00168.

REFERENCES

Abdel Khalik, A.S., Elserougi, A., Shafik, Z., Ahmed, S. and Massoud, A. 2013. A scott conection-based three-phase to five-phase power transformer. IEEE, pp. 2559-2564.

Abdel Khalik, A.S., Shafiq, Z., Elserougi, A., Ahmed, S. and Massoud, A. 2014. A static three-phase to five-phase transformer based on Scott connection. Electric Power System Research, issue 110, pp. 84-93.

Atif Iqbal, Shaikh Moinuddin, Rizwan Khan, M., Moin Ahmed, Sk. and Haithem Abu-Rub. 2010. A novel three-phase to five-phase transformation using a special transformer connection. IEEE Transaction on Power Delivery, July, vol. 25, pp. 1637-1644.

Hairul Nizam Talib, Md., Zulkifilie Ibrahim, Nasrudin Abd. Rahim and Ahmad Shukri Abu Hasim. 2013. Characteristic of induction motor drives fed by three leg and five leg inverters. Journal of Power Electronics, September, vol. 13, pp. 806-812.

Karim, K.A., Yin, L.G. and Yusoff, N.A.M. 2015. Design of five-phase transformer through finite element simulation. Journal of Applied Mechanics and Materials, vol. 761 pp. 12-16.

Koundinya Lanka, Tejaswi Kambhamti, Bhavani Kumar, V.V.S., & Mukkamala Kalyan. 2012. Three-phase to five-phase transformation using a special transformer connection. International Journal of Applied Research & Studies, September, I(II), pp. 1-11.

Monika,.N, Samhita,V., Sindhu, Swetha, P.V. and Somashekar, B. 2013. Modelling and simulation of three-phase to five-phase transformation using a special transformer connection. International Journal of Emerging Technology and Advanced Engineering, May, vol. 3, issue 5, pp. 798-807.

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), June, vol. 75, pp. 13-18.

Prasad Rao, K. P., Jyothi, B. and Naga Surekha, V. 2011. Comparison of specially connected transformer scheme and five leg inverter for five phase supply. IEEE India Conference "Engineering Sustainable Solutions".

Srinivas Goud, L., and Srivani, T. 2013. A simulation of three phase to multi phase transformation using a special transformer. Interntional Journal of Science and Research (IJSR), July, 2(7), pp. 351-357.

Sunil Kumar, Shalini. J, Suresh Kumar, P.G.V. and Fikadu Wakijira. 2013. Development of three phase to five phase transformer using a novel technique. International Journal of Scientific and Engineering Research , March.vol. 4.