**INTERNATIONAL JOURNAL OF PURE AND APPLIED RESEARCH IN ENGINEERING AND TECHNOLOGY**

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# DESIGN OF MULTIWINDING TRANSFORMER CONNECTION SCHEME FOR THREE PHASE TO FIVE PHASE TRANSFORMATION

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**Accepted Date: 15/03/2016; Published Date: 01/05/2016**

**Abstract**- Multiphase motor drives were first proposed by Ward and Harrer back in 1969. Research in Multiphase systems has grown recently due to multiple advantages of the same over conventional three phase systems. The Supply available from the grid is three phase and hence a static transformation system is needed to convert it to multiphase system. Carrier Based PWM Technique and Special Transformer connection Technique are used to convert Three-phase supply to Five-phase supply. In this paper the transformation using special multi-winding transformer connection scheme is presented. Three single phase Multiwinding transformers are designed, two transformers have one primary and three secondary windings and the third transformer has one primary and two secondary windings. The proposed transformer connection has three phase input and outputs five phases. The special transformer connection scheme is simulated by using 'SIMPOWERSYSTEMS' block sets of MATLAB/SIMULINK software.

**Keywords**:- Five Phase, Multiphase, Three Phase, Transformer, Turn Ratio, HPO.

*PAPER-QR CODE*

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**How to Cite This Article:**

Rekha S. Kandolkar, IJPRET, 2016; Volume 4 (9): 498-507

**INTRODUCTION**

Power system with more than three phases is called Multiphase power system. The applicability of multiphase systems is explored in electric power generation, transmission, and utilization due to their inherent advantages compared to three phase systems. The existing 3-phase concepts can be extended to construct and analyze various performance curves on power flow and voltage stability of the multi-phase line [1].

The research on six-phase transmission system was initiated due to the rising cost of right of way for transmission corridors, environmental issues, and various stringent licensing laws. The 6-phase and 12-phase lines show progressively increased power handling capacity, reduced reactive power losses, increased power at the receiving end, reduced reactive power requirement for maintaining stable load voltage, reduced rating of compensating devices, better voltage stability in case of voltage dependent load and increased line load ability in uncompensated as well as compensated condition and also found to produce less ripple with a higher frequency of ripple in an ac–dc rectifier system [1]. Thus, 6- and 12-phase transformers are designed to feed a multipulse rectifier system and the technology has matured. The reason of choice for a 6-, 12-, or 24-phase system is that these numbers are multiples of three and designing this type of system is simple and straightforward.

The roots of multiphase variable speed drives can be traced back to the late 1960s, the time when inverter-fed ac drives were in the initial development stage. Due to the six step mode of three-phase inverter operation, one particular problem at the time was the low frequency torque ripple. Since the lowest frequency torque ripple harmonic in an *n*-phase machine is caused by the time harmonics of the supply of the order $2n \pm 1$ (its frequency is 2*n* times higher than the supply frequency), an increase in the number of phases of the machine appeared as the best solution to the problem which will also improve the reliability as the drive can start and run even after the failure of one of the phases. Hence, significant efforts have been put into developing 5 and 6 phase variable-speed drives supplied from voltageand current source inverters [4]–[5].

Although the concept of variable-speed drives, based on utilization of multiphase ($n > 3$) machines, dates back to the late 1960s, it was not until the mid- to late 1990s that multiphase drives became serious contenders for various applications. These include electric ship propulsion, locomotive traction, electric and hybrid electric vehicles, “more-electric” aircraft, and high-power industrial applications.

High Phase Order (HPO) drive systems possess several advantages over conventional 3-phase Drive. Higher number of phases reduce the amplitude and increase the frequency of torque pulsations in the drive ensuring satisfactory performance of the inverter-fed motor even at lower speeds. Also the electrical efficiency of the HPO motors are better compared to that of a 3-phase motor **[3].** This has increased interest for such drive systems worldwide [2]. Howeverobtaining suitable power supplies is difficult. The advent of thyristors and other power semiconductor devices has made HPO power supplies feasible.The 5 phase Induction motors are being supplied from voltage/current source inverters [5][7].

3-phase supply can be transformed into 5- phase supply by a Multiphase Inverter or by using Multiwinding transformers with special connection scheme.The inverter output contains time harmonic components injecting harmonic currents into the machine stator windings. The 5-phase connection eliminates the $5^{th}$ and other quintuple-order harmonics. However, the other harmonics will be present with varying amplitudes and phase sequences.

The designed motor is to be tested for a number of operating conditions with a pure sinusoidal supply to ascertain the desired performance [6]. Normally, a no-load test, blocked rotor, and load tests are performed on a motor to determine its parameters. Hence, the machine parameters obtained by using the pulse width-modulated (PWM) supply may not provide the precise true value. Thus, a pure sinusoidal supply system available from the utility grid is required to feed the motor. The same can be obtained by using Multi-winding Transformers with Special Connection scheme presented in this paper. Block diagram of the proposed scheme is shown in Figure-1.

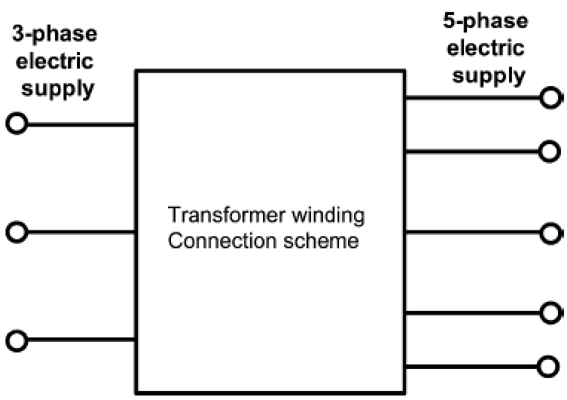


**Figure 1-Block diagram of the proposed system**

The fixed voltage-fixed frequency available grid supply can be transformed to the fixed voltage and fixed frequency 5-phase supply. The output, may be made variable by inserting the autotransformer at the input side.

## II.WINDING CONNECTION FOR THREE PHASE TO FIVE PHASE TRANSFORMATION

Three single phase Multiwinding transformer cores are designed with each carrying one primary and three secondary coils, except in one core there are only two secondary coils. Fig. 2 shows transformer winding arrangement for 3-phase to 5-phase transformation. Primary windings of the three transformers may be connected in Star or Delta across 3-phase grid supply. The 16 terminals of eight secondary windings are connected in a different fashion resulting in star or polygon five phase output. The output phases with requisite phase angles of $^{360}/_{5} = 72^{\circ}$ between each phase is obtained using appropriate turn ratios and the governing phasor equations are illustrated in (1)–(10). The turn ratios are different in each phase and are calculated from voltage equations. The choice of turn ratio is the key in creating the requisite phase displacement in the output phases. Table1 shows Turns ratio to obtain 5-phase Star output.

The input phases are designated with letters "X" "Y", and "Z" and the output are designated with letters "a", "b", "c", "d", and "e". The primary windings of the three transformers are connected in star as shown in Fig.2. The 5-phase star output is obtained by connecting the secondary windings as shown in Fig. 3.As illustrated in Fig.4, the output phase "a" is along the input phase "X". The output phase "b" results from the phasor sum of winding voltage "$c_6c_5$" and "$b_1b_2$", the output phase "C" is obtained by the phasor sum of winding voltages "$a_4a_3$" and "$b_3b_4$". The output phase "d" is obtained by the phasor addition of winding voltages "$a_4a_3$" and "$c_1c_2$" and similarly output phase "e" results from the phasor sum of the winding voltages "$c_3c_4$" and "$b_6b_5$". In this way, five phases are obtained. The Input 3-phases are displaced by 120 degrees and output 5-phases are displaced by 72 degrees.

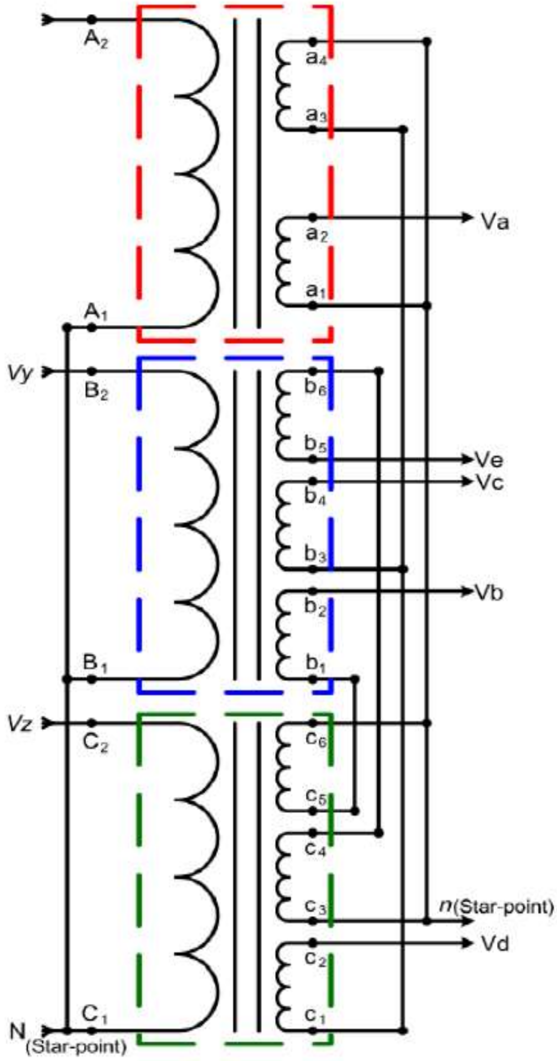


**Figure 2-Transformer Winding arrangement**

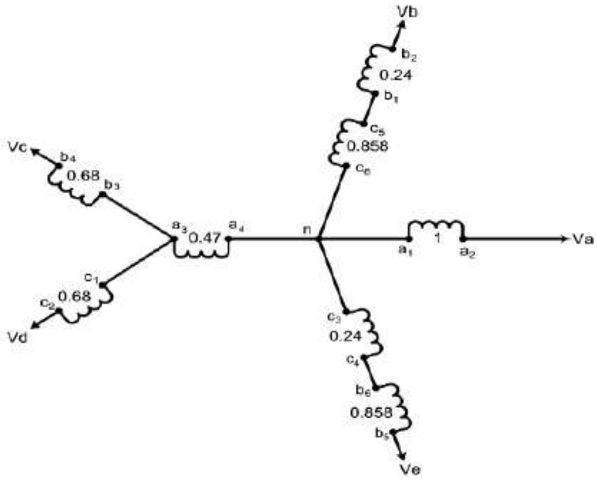


**Figure 3-Transformer secondary winding connection**

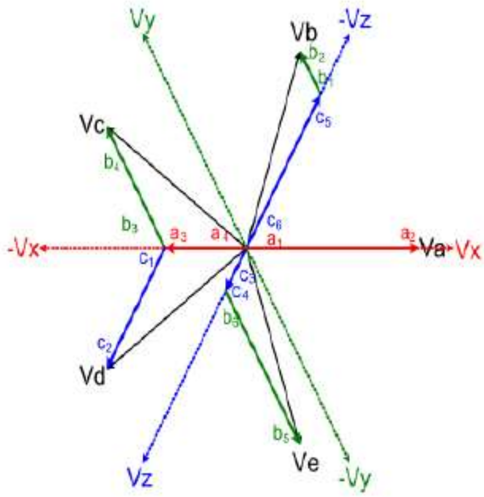


**Figure 4-Phasor Diagram for Input Star-Output Star Connection**

From the phasor diagram the output phase voltage equations in terms of input phase voltages are given as follows:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \\ V_e \end{bmatrix} = \frac{1}{\sin(\frac{\pi}{3})} \begin{bmatrix} Sin(\frac{\pi}{3}) & 0 & 0 \\ 0 & Sin(\frac{\pi}{15}) & -Sin(\frac{4\pi}{15}) \\ -Sin(\frac{2\pi}{15}) & Sin(\frac{\pi}{5}) & 0 \\ -Sin(\frac{2\pi}{15}) & 0 & Sin(\frac{\pi}{5}) \\ 0 & -Sin(\frac{4\pi}{15}) & Sin(\frac{\pi}{15}) \end{bmatrix} \begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} \quad (1)$$

If $V_a = V_{max} Sin\ \omega t$ is reference voltage then instantaneous voltages of other five phases with respect to the reference voltage are given by equations (2) to (9) given below.

$$V_a = V_{max} Sin\ \omega t \quad (2)$$

$$V_b = V_{max} Sin\left(\omega t + \frac{2\pi}{5}\right) \quad (3)$$

$$V_c = V_{max} Sin\left(\omega t + \frac{4\pi}{5}\right) \quad (4)$$

$$V_d = V_{max} Sin\left(\omega t - \frac{4\pi}{5}\right) \quad (5)$$

$$V_e = V_{max} Sin\left(\omega t - \frac{2\pi}{5}\right) \quad (6)$$

$$V_x = V_{max} Sin\ \omega t \quad (7)$$

$$V_y = V_{max} Sin\left(\omega t + \frac{2\pi}{3}\right) \quad (8)$$

$$V_z = V_{max} Sin\left(\omega t - \frac{2\pi}{3}\right) \quad (9)$$

Equation (1) gives three phase to five phase transformation. Five phase to three phase transformation can be obtained by inverting (1). The same is given by equation (10).

$$\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} = \frac{1}{Sin(\frac{\pi}{3})} \begin{bmatrix} Sin(\frac{2\pi}{5}) & 0 & 0 & 0 & 0 \\ 0 & Sin(\frac{2\pi}{15}) & Sin(\frac{4\pi}{15}) & 0 & 0 \\ 0 & 0 & 0 & Sin(\frac{4\pi}{15}) & Sin(\frac{2\pi}{15}) \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \\ V_e \end{bmatrix} \quad (10)$$

**Table I-Turn Ratio to obtain Five phase Star output**

| Phase | Secondary winding | Secondary to primary Turns ratio |
|---|---|---|
| X | $a_1 a_2$ | 1 |
| | $a_4 a_3$ | 0.47 |
| Y | $b_1 b_2$ | 0.680 |
| | $b_4 b_3$ | 0.858 |
| | $b_5 b_6$ | 0.24 |
| Z | $c_1 c_2$ | 0.68 |
| | $c_4 c_3$ | 0.24 |
| | $c_5 c_6$ | 0.858 |

**III.SIMULATION RESULTS**

The designed transformer connection scheme is simulated by using “simpowersystem” block sets of the Matlab/Simulink software. The inbuilt transformer blocks are used to simulate the conceptual design. Appropriate turn ratios are set in the dialog box and the simulation is run. The simulation model for star-star connection is depicted in Fig. 5.The Input and output waveforms in Figure 6 and 7 clearly show that the output is a balanced 5-phase supply for a balanced 3-phase input.

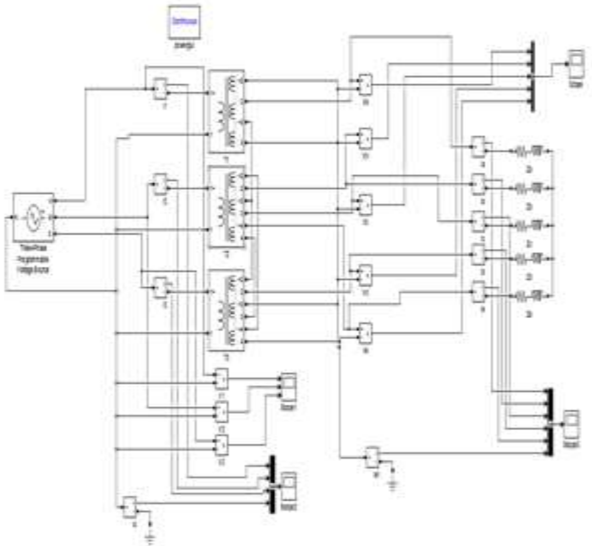

**Figure 5-Simulink model for Input three phase Star and Output five phase Star**

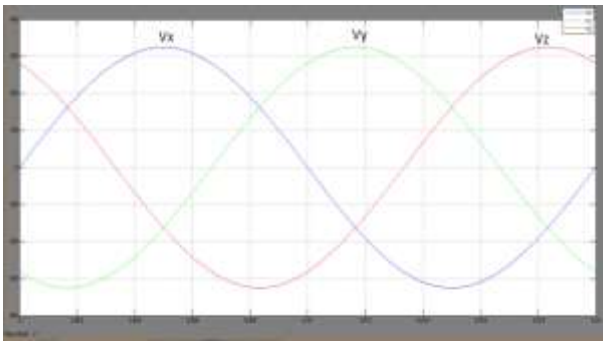


**Figure 6-Input Voltages Vx=Vy=Vz=325V(pk-pk)**

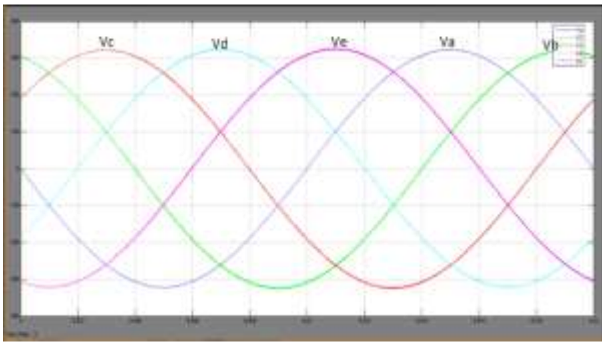


**Figure 7-Output Voltages Va=Vb=Vc=Vd=Ve=325V(pk-pk)**

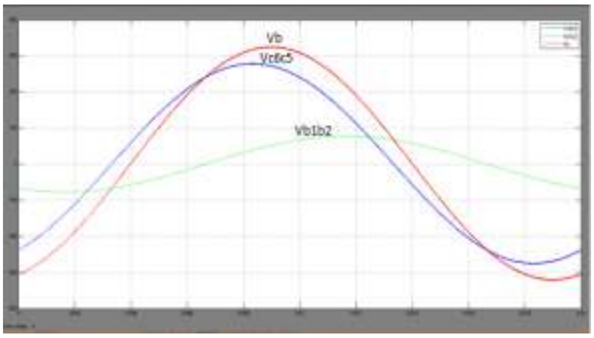


Figure 8-Vb=0.24 Vy (Vb1b2)-0.858 Vz(Vc5c6)

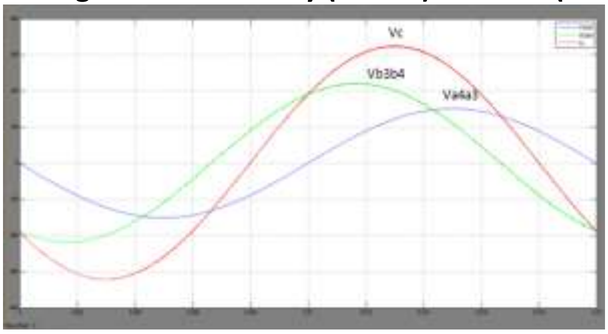


Figure 9-Vc=0.68Vy(Vb3b4)-0.47Vx(Va3a4)

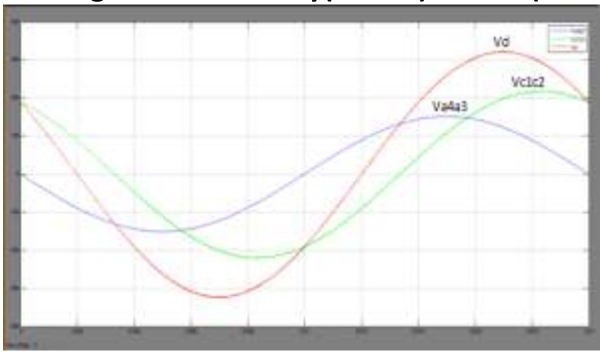


Figure 10-Vd=0.68Vz(Vc1c2)-0.47Vx(a4a3)

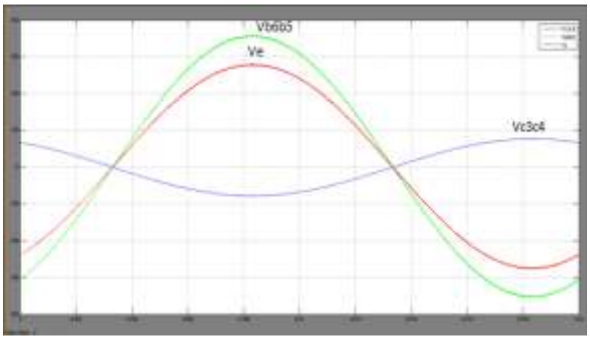


Figure 11-Ve=0.24Vz(Vc3c4)-0.858Vy(Vb5b6)

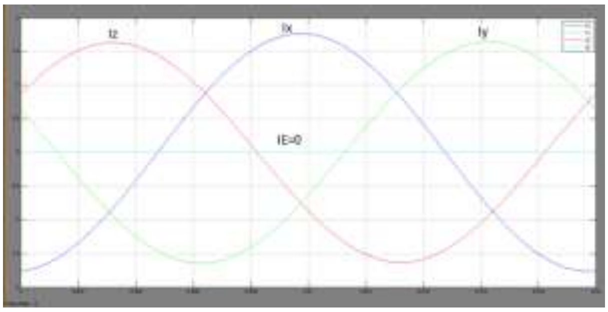


**Figure 12-Three Phase Input currents**

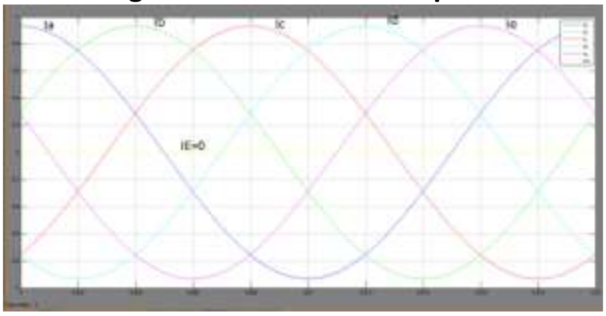


**Figure 13-Five Phase Output Currents**

There was no earth current flowing when both sides neutrals were earthed. The input and output current waveforms with earth current waveform shown in Figure 12 and 13 illustrates that the X input line transformer, carries more current than the other two transformers (or two phases), this lowers the efficiency of the overall transformer set.

**CONCLUSION**

This paper proposes a transformer connection scheme to transform the three-phase grid power to a five-phase output supply. The connection scheme and the phasor diagram along with the turn ratios are illustrated. A five-phase RL-load is used to prove the viability of the transformation system. The proposed connection scheme can be used in drive applications and may also be further explored to be utilized in multiphase power transmission systems.

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