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Conversion of Three Phase Supply to Multi Phase Supply by Using a Special Transformer Connection

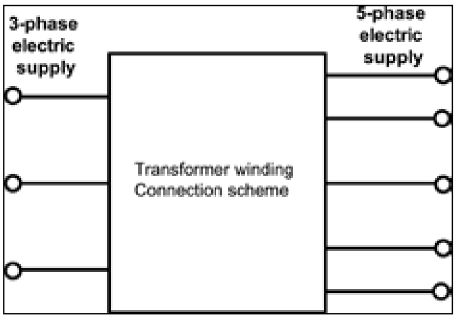
V V Vijetha Inti	Assistant Professor, Vishnu Institute of Technology
M. Saisesha	Assistant Professor, Vishnu Institute of Technology
Balaji Mukkapati	Assistant Professor, Vishnu Institute of Technology

ABSTRACT

In late 1970's the first five-phase induction motor drive system was proposed for adjustable speed drive applications. Since then, a considerable research effort has been made to develop a commercially feasible multiphase drive systems. Thus, this paper proposes a transformer connection scheme to convert the three- phase grid supply to a multi phase i.e., five phase fixed voltage and fixed frequency supply. The proposed transformer connection outputs five phases and can be used in applications equiring a five-phase supply. The five-phase transmission system can be investigated further as an efficient solution for bulk power transfer. The connection scheme is elaborated by using the simulation to prove the viability of the implementation.

INTRODUCTION

Multi phase systems are the main focus of research due to their inherent advantages compared to their three-phase counterparts. The applicability of multiphase systems is explored in electric power generation , transmission , and utilization . 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. Six-phase transmission lines can provide the same power capacity with a lower phase-to-phase voltage and smaller, more compact towers compared to a standard double-circuit three-phase line. The geometry of the six-phase compact towers may also aid in the reduction of magnetic fields as well . The research on multiphase generators has started recently and only a few references are available . The present work on multiphase generation has investigated asymmetrical six-phase (two sets of stator windings with 30 phase displacement) induction generator configuration as the solution for use in renewable energy generation. As far as multiphase motor drives are concerned, the first proposal was given by Ward and Harrer way back in 1969 and since then, the research was slow and steady until the end of the last century.



The research on multiphase drive systems has gained momentum by the start of this century due to availability of cheap reliable semiconductor devices and digital signal processors. It is to be emphasized here that the multiphase motors are invariably supplied by ac/dc/ac converters. Thus, the focus of the research on the multiphase electric drive is limited to the modeling and control of the supply systems (i.e., the inverters . Little effort is made to develop any static transformation system to change the phase number from three to five.The scenario has now changed with this paper, proposing a novel phase transformation system which converts an available three-phase supply to an output five-phase supply.

Multiphase, especially a 6-phase and 12-phase system is found to produce less ripple with a higher frequency of ripple in an ac–dc rectifier system. Thus, 6 and 12-phase trans- formers are designed to feed a multipulse rectifier system and the technology has matured. Recently, a 24-phase and36-phase transformer system have been proposed for supplying a multipulse rectifier system . The reason for 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. However, increasing the number of phases certainly enhances the complexity of the system. None of these designs are available for an odd number of phases, such as 5, 7,11, etc.

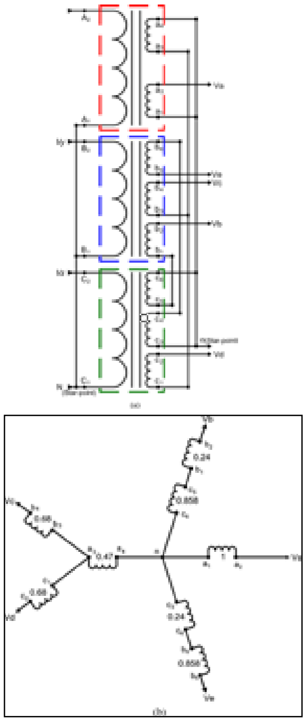


Fig. 2. (a) Proposed transformer winding arrangements (star-star). (b) Pro- posed transformer winding connection (star).

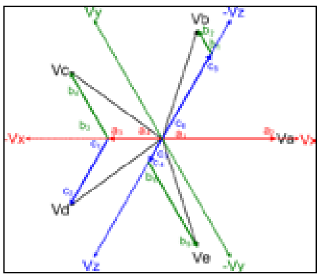


Fig. 3. Phasor diagram of the proposed transformer connection (star-star).

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The usual practice is to test the designed motor for a number of operating conditions with a pure sinusoidal supply to ascertain the desired performance of the motor . Normally, a no-load test, blocked rotor, and load tests are performed on a motor to determine its parameters. Although the supply used for a multiphase motor drive obtained from a multiphase inverter could have more current ripple, there are control methods available to lower the current distortion even below 1%, based on application and requirement. 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. This paper proposes a special transformer connection scheme to obtain a balanced five-phase supply with the input as balanced three phase. The block diagram of the proposed system is shown in Fig. 1. The fixed voltage and fixed frequency avail- able grid supply can be transformed to the fixed voltage and fixed frequency five-phase output supply. The output, however, may be made variable by inserting the autotransformer at the input side.

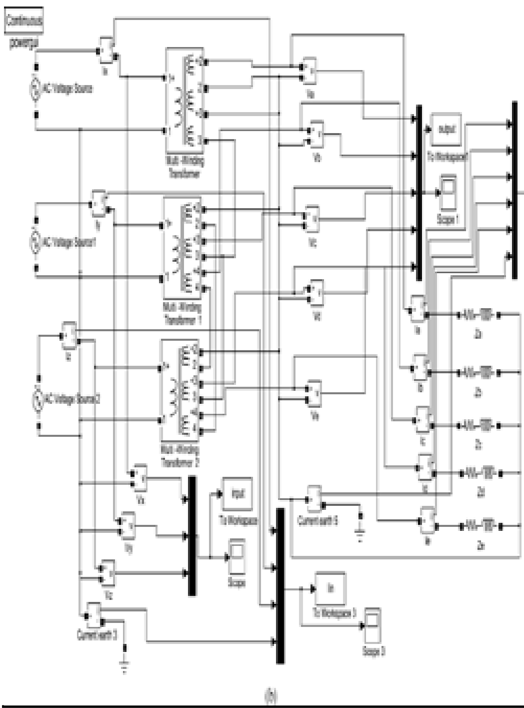
The input and output supply can be arranged in the following manner:

1) input star, output star;
2) input star, output polygon;
3) input delta, output star;
4) input delta, output polygon.

Since input is a three-phase system, the windings are connected in an usual fashion. The output/secondary side connection is discussed in the following subsections.

II. WINDING ARRANGEMENT FOR FIVE-PHASE STAR OUTPUT

Three separate cores are designed with each carrying one primary and three secondary coils, except in one core where only two secondary coils are used. Six terminals of primaries are connected in an appropriate manner resulting in star and/or delta connections and the 16 terminals of secondary's are connected in a different fashion resulting in star or polygon output. The connection scheme of secondary windings to obtain a star output is illustrated in Fig. 2 and the corresponding phasor diagram is illustrated in Fig. 3. The construction of output phases with requisite phase angles of 72 between each phase is obtained using appropriate turn ratios, and the governing phasor equations are illustrated in (1) to (10) . The turn ratios are different in each phase. The choice of turn ratio is the key in creating the requisite phase displacement in the output phases.

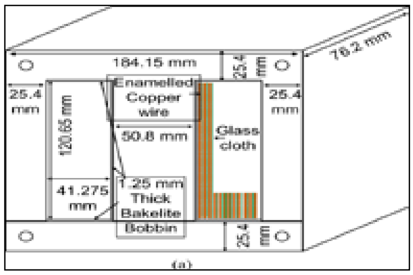


The input phases are designated with letters "X" "Y", and

"Z" and the output are designated with letters "A", "B",

"C" D", and "E". As illustrated in Fig. 3, the output phase

"A" is along the input phase "X".



The output phase "B" results from the Phasor sum of winding voltage "c6c1" and "b1b2", the output phase "C" is obtained by the Phasor sum of winding voltages "a4a1" and "b3b4".The output phase "D" is obtained by the Phasor addition of winding voltages "a4a1" and "c1c2" and similarly output phase "E" results from the Phasor sum of the winding voltages:c3c4" and "b3b5".In the way five phase are obtained. The transformation from three to five and vice-versa is further obtained by using the relation given in(1) toS (10)

$$\begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \\ V_e \end{bmatrix} = \frac{1}{\sin\pi/3} \begin{bmatrix} \sin\pi/3 & 0 & 0 \\ 0 & \sin\pi/15 & \sin4\pi/15 \\ -\sin2\pi/15 & \sin\pi/3 & 0 \\ -\sin2\pi/15 & 0 & \sin\pi/15 \\ 0 & -\sin4\pi/15 & \sin\pi/15 \end{bmatrix} \begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} \quad (1)$$

Va = Vmax sin (2)
Vb = Vmax sin (3)
Vc = Vmax sin) (4)
Vd = Vmax sin) (5)
Ve = Vmax sin) (6)
Vx = Vmax sin (7)
Vy = Vmax sin) (8)
Vz = Vmax sin) (9)

Fig. 4. (a) Geometry of the transformer (b) Matlab/Simulink model of the three- to five-phase transformation

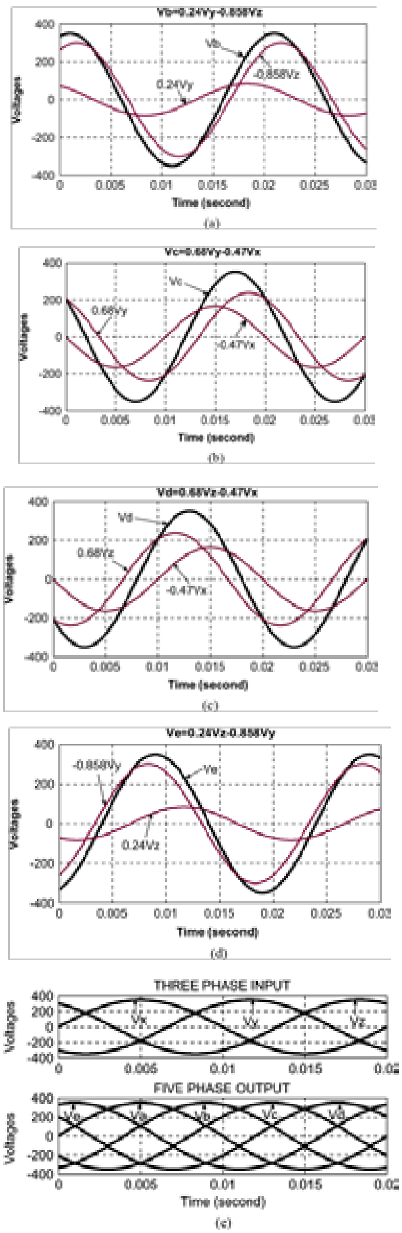
TABLE-1
DESIGN OF PROPOSED TRANSFORMER

Primary	Secondary	Turn Ratio	swg
Phase x	a1 a2	1	17
	a4 a3	0.47	15
Phase y	b1 b2	0.68	17
	b4 b3	0.858	17
	b5 b6	0.24	17
Phase z	c1 c2	0.68	17
	c4 c3	0.858	17
	c5 c6	0.24	17

3.SIMULATION RESULTS

The designed transformer is at first simulated by using "sim-power system" block sets of the Mat lab/Simulink software. The inbuilt transformer blocks are used to simulate the conceptual design. The appropriate turn ratios are set in the dialog box and the simulation is run. Turn ratios are shown in Table I. Standard wire gauge SWG) is shown in Table I. A brief design description for the turn ratio, wire gauge, and the geometry of the transformers [Fig. 4(a)] are shown in the Appendix.

The simulation model is depicted in Fig. 4(b) and the resulting input and output voltage waveforms are illustrated in Fig. 5. It is seen clearly that the output is a balanced five phase supply for a balanced three phase input. The input and output currents with earth current waveforms are also shown in Fig. 5. From this, we can say that the transformer, connected to the X input line, carries 16.77% (19.5/16.7) more current than that of the other two transformers (or two phases).Due to this efficiency the overall transformer set is slightly lower than the conventional three phase transformer.



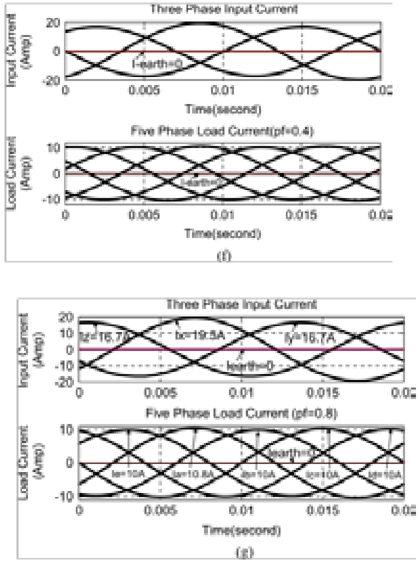


Fig. 5
(a)–(g). (a) Input Vy and Vz phases and output Vb phase voltage wave- forms. (b) Input Vy and Vx phases and output Vc phase voltage waveforms. (c) Input Vz and Vx phases and output Vd phase voltage waveform (d) Input Vz and Vy phases and output Ve phase voltage wave- forms. (e) Input three-phase and output five-phase voltage waveforms. (f) Input three-phase and output five-phase load current waveforms at 0.4. (g) Input three-phase and output five-phase load current waveforms at 0.8.

4. CONCLUSION
This paper proposes a new transformer connection To transform the three phase grid power to a five Phase supply. The successful implementation of The proposed connection scheme is elaborated by using simulation. It is expected that the Proposed connection can be used in drives Applications and may also be further explored to be utilized in multiphase power transmission System.

Appendix
Design of the Transformer

1) The volt per turn (Et) =
   Et = K = 0.7 = 0.984949 v/turn
   Where K = 0.7 (assumed) Q= 2KVA

   ∴ Core area = (E_t × 10000)/(4.44 ×f ×B_m) cm2 = (0.7√2× 10000)/(4.44 ×50 ×1.25)
   = 35.67385563 cm2
2) Standard core size of No. 8 of E and I was used whose cetral limb width is 2×2.54=5.08 cm=50.8 mm.

3) Standard size of Bakelite bobbin for 8 no. core of 3*2.54=7.62cm=76.2mm was taken which will give core area of 38.7096 cm.
4) Turns of primary windings of all three single-phase Transformers are equal and the enameled wire gauge is 15 SWG. The VA rating of each transformer is 2000. Wire gauge was chosen at a current density of 4 A/mm because enameled wire was of the grade which can withstand the temperature up to 180 . The winding has 15 SWG wire because it carries the sum of two cur rents (i.e., $I_{\_c}+I_{\_d} = \sqrt{(2(1+\cos(2\pi/5))}$= 1.618 times the 5-phase rated current).

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