

Three-Phase To Five-Phase Transformation With A Special Transformer Connection

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Abstract:

The first five-phase induction motor drive system was proposed in the late 1970s for adjustable speed drive applications. Since then, a considerable research effort has been in place to develop commercially feasible multiphase drive systems. Multiphase (more than three phase) systems are the focus of research recently due to their inherent advantages compared to their three-phase counterparts. The multiphase motors are invariably supplied by ac/dc/ac converters. This is a special transformer connection scheme to obtain a balanced five-phase supply with the input as balanced three phases. The fixed voltage and fixed frequency available grid supply can be transformed to the fixed voltage and fixed frequency five-phase output supply. Since input is a three-phase system, the windings are connected in a usual fashion. 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 secondaries are connected in a different fashion resulting in star or polygon output. The connection scheme of secondary windings to obtain a star output. 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 construction of output phases with requisite phase angles of 72 between each phase is obtained using appropriate turn ratios. The designed transformation turns ratio can be achieved by simply multiplying the gain factor in the turn ratios. A five-phase induction motor under a loaded condition is used to prove the viability of the transformation system. It is expected that the proposed connection scheme can be used in drives applications and may also be further explored to be utilized in multiphase power transmission systems.

Key Words: Threephase, Fivephase, Starconnection, Delta connection, Multiphase, Transformer, Induction motor

I Introduction:

Multiphase (more than three phase) systems are the focus of research recently 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 300 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. Detailed reviews on the state of the art in multiphase drive research are available.

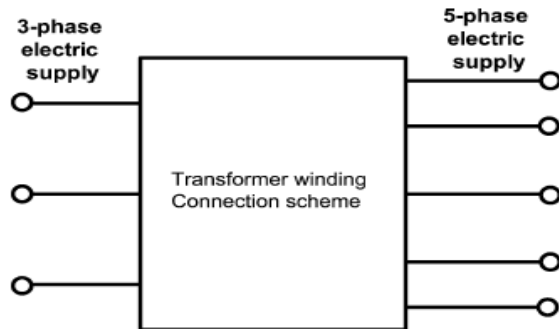


Fig. 1.1 Block representation of the proposed system

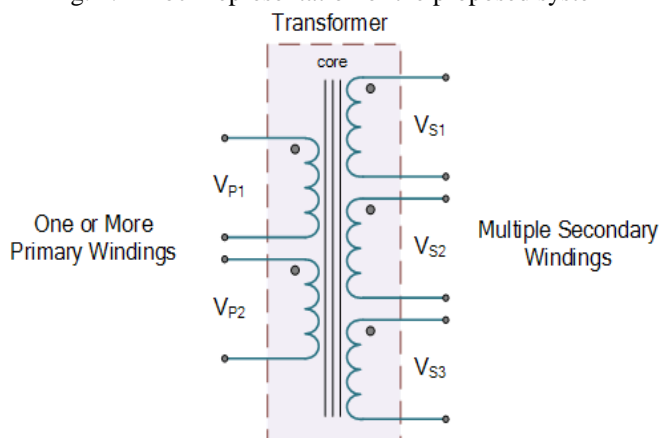


Fig. 1.2 Proposed transformer winding arrangement

Above shows an example of a typical “multiple winding transformer” which has a number of different secondary windings supplying various voltage levels. The primary windings can be used individually or connected together to operate the transformer from a higher supply voltages.

The secondary windings can be connected together in various configurations producing a higher voltage or current supply. It must be noted that connecting together transformer windings is only possible if the two windings are electrically identical. That is their current and voltage ratings are the same.

The rest of this paper is organized as follows. The active filter topology is briefly described in Section II. The control algorithm of the active filter is discussed in Section III. Simulation results are presented in Section IV to evaluate the proposed configuration and control. In addition, the system is implemented on RTDS hardware to further validate the proposed active filter, and the results are also presented in Section V. Finally, the conclusions are given in Section VI.

II Induction Motor:

Conversion of Electric power into Mechanical power takes place in the rotating part of an electric motor. In DC motor, the electric power is conducted directly to the armature (rotating part) through

brushes and commutator. Hence in this sense, a DC motor can be called Conduction motor. However in AC motors, the rotor does not receive electric power by conduction but by induction in exactly the same way as the secondary of a two binding transformer receives its power from primary that is why such motor are known as induction motors. In fact, an induction motor can be treated as a rotating transformer i.e. one in which primary winding is stationary but the secondary is free to rotate of all the AC motors, the poly phase induction motor is the one which is extensively use for various kinds of industrial drives.

In this Chapter, advantages of a induction motor is presented in Section 2.2, disadvantages of a induction motor is presented in Section 2.3, stator of an induction motor is presented in Section 2.4, rotor of an induction motor is stated in Section 2.5 and summary of this Chapter is described in Section 2.6.

2.2 ADVANTAGES

- It is very simple and unbreakable construction.
- Its cost is low and it is very reliable.
- It requires less maintenance.

2.3 DISADVANTAGES

- Its speed cannot be varied without sacrificing some of its efficiency
- Just like DC shunt motor, its speed decrease with increase in load.
- Its starting torque is somewhat inferior to that of a DC shunt motor



Fig. 2.1 Induction motor

2.4 STATOR

The stator of an induction motor is, in principle, the same as that of a synchronous motor or generator. It is made up of a no of stampings which are slotted receive the windings. The stator carries a three- phase winding and is fed from a three-phase supply. It is wound for a definite no of poles, the exact number of

poles being determined by the requirements of speed. Greater the number of poles, lesser the speed and vice-versa. The stator windings, when supplied with three-phase current, produce a magnetic flux, which is of constant magnitude but which revolves (rotates) at synchronous speed (given by $NS=120f/p$). This revolving magnetic flux induces an EMF in the rotor mutual induction.

2.5 ROTOR

There are two types of rotors, they are given below

- (1).Squirrel cage-rotor; motors employing this type of rotor are known as squirrel cage induction motor.
- (2).Phase-wound or wound rotor; motors employing this type of rotor are variously known as 'Phase-wound' motors or 'wound motors' or as 'slip-ring' motors.

2.5.1 Squirrel cage rotor

Almost 90% of induction motors are squirrel-cage type, because this type of rotor has the simplest and most rugged construction imaginable and is almost and in almost indestructible. Rotor consists of a cylindrical laminated core with parallel slots for carrying for rotor conductors which, it should be noted clearly, are not wires but consist of heavy bars of copper, aluminium or alloys. One bar is placed in each slot; rather the bars are inserted from the end when semi-closed slots are used. The rotor bars are brazed or electrically welded or bolted to two heavy and stout short-circuiting end-rings, thus giving us, what is so picturesquely called, a squirrel-cage construction

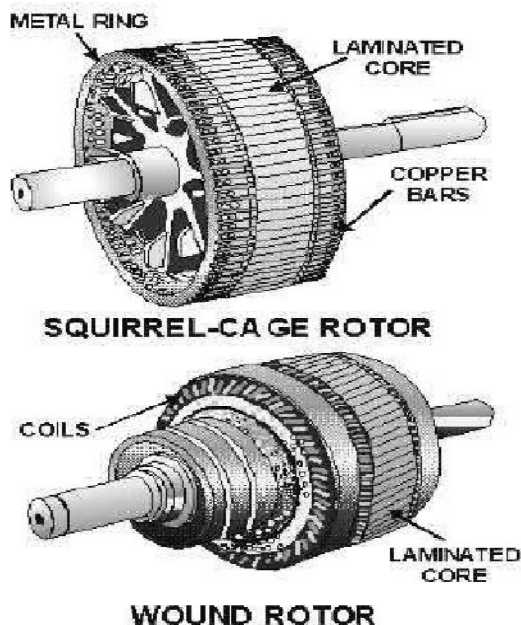


Fig. 2.2 Squirrel cage rotor & phase wound rotor

2.5.2 Phase wound rotor:

This type of rotor is provided with 3-phase, double-layer, distributed winding consisting of coils as used in alternators. The rotor is wound for as many poles as the number of stator poles and is always wound 3-phase even when the stator is wound two phase. The three phases are starred internally. The other three winding terminals are brought out and connected to three insulated to three slip-rings mounted on the shaft with brushes resting on them. These make possible the introduction of additional resistance in the rotor circuit during the starting period for increasing the starting torque of the motor.

III Windig Arrangement:

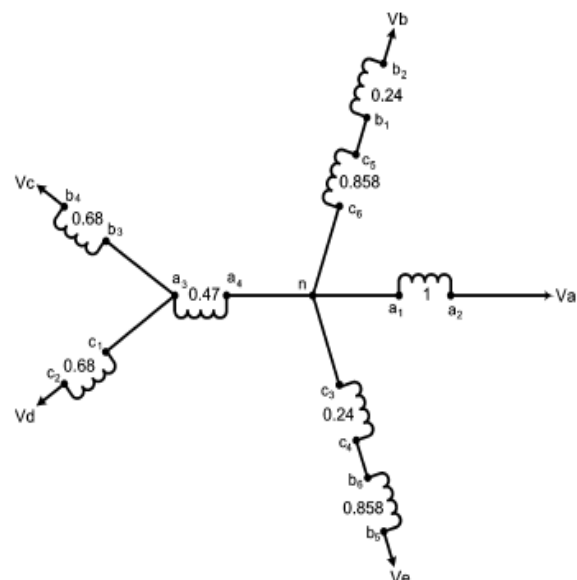


Fig. 3.1. Proposed transformer winding connection

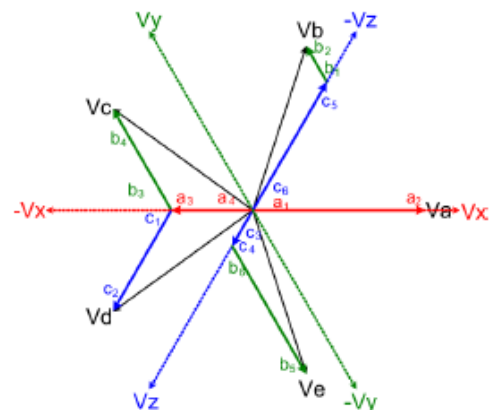


Fig. 3.2. Phasor diagram of the proposed transformer connection (star-star)

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. 5.1, the output phase “A” is along the input phase “X”. The output phase “B” results from the phasor sum of winding voltage “c6c5” and “b1b2”, the output phase “C” is obtained by the phasor sum of winding voltages “a1a3” and “b3b4”. The output phase “D” is obtained by the phasor addition of winding voltages “a1a3” and “c1c2” and similarly output phase “E” results from the pharos sum of the winding voltages “c3c4” and “b6b5 ”. In this way, five phases are obtained. The transformation from three to five and vice-versa is further obtained by using the relation given in Eqns. (3.1) to (3.10).

$$\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} = \frac{1}{\sin(\frac{2\pi}{5})} * \begin{bmatrix} \sin(\frac{4\pi}{5}) & 0 & 0 & 0 & 0 \\ 0 & \sin(\frac{2\pi}{15}) & \sin(\frac{4\pi}{15}) & 0 & 0 \\ 0 & 0 & 0 & \sin(\frac{4\pi}{15}) & \sin(\frac{2\pi}{15}) \end{bmatrix} \dots (3.10)$$

Table 1 : Design of the proposed Transformer

Primary	Secondary	Turn Ratio (N _p /N _s)	SWG
Phase – X	a ₁ a ₂	1	17
	a ₄ a ₃	0.47	15
Phase – Y	b ₁ b ₂	0.68	17
	b ₄ b ₃	0.858	17
	b ₅ b ₆	0.24	17
Phase – Z	c ₁ c ₂	0.68	17
	c ₄ c ₃	0.858	17
	c ₅ c ₆	0.24	17

Necessary equations:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \\ V_e \end{bmatrix} = \frac{1}{\sin(\frac{\pi}{5})} * \begin{bmatrix} \sin(\frac{\pi}{3}) & 0 & 0 \\ 0 & \sin(\frac{\pi}{15}) & -\sin(\frac{4\pi}{15}) \\ -\sin(\frac{2\pi}{15}) & \sin(\frac{\pi}{5}) & 0 \\ -\sin(\frac{2\pi}{15}) & 0 & \sin(\frac{\pi}{5}) \\ 0 & -\sin(\frac{4\pi}{15}) & \sin(\frac{\pi}{15}) \end{bmatrix} \begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} \dots (3.1)$$

$$V_a = V_{\max} \sin(\omega t) \dots (3.2)$$

$$V_b = V_{\max} \sin\left(\omega t + \frac{2\pi}{5}\right) \dots (3.3)$$

$$V_c = V_{\max} \sin\left(\omega t + \frac{4\pi}{5}\right) \dots (3.4)$$

$$V_d = V_{\max} \sin\left(\omega t - \frac{4\pi}{5}\right) \dots (3.5)$$

$$V_e = V_{\max} \sin\left(\omega t - \frac{2\pi}{5}\right) \dots (3.6)$$

$$V_x = V_{\max} \sin \omega t \dots (3.7)$$

$$V_y = V_{\max} \sin\left(\omega t + \frac{2\pi}{3}\right) \dots (3.8)$$

$$V_z = V_{\max} \sin\left(\omega t - \frac{2\pi}{3}\right) \dots (3.9)$$

IV Simulation Results:

Numerical simulations have been conducted in the Advanced Continuous Simulation Language (ACSL) to validate the proposed topology.

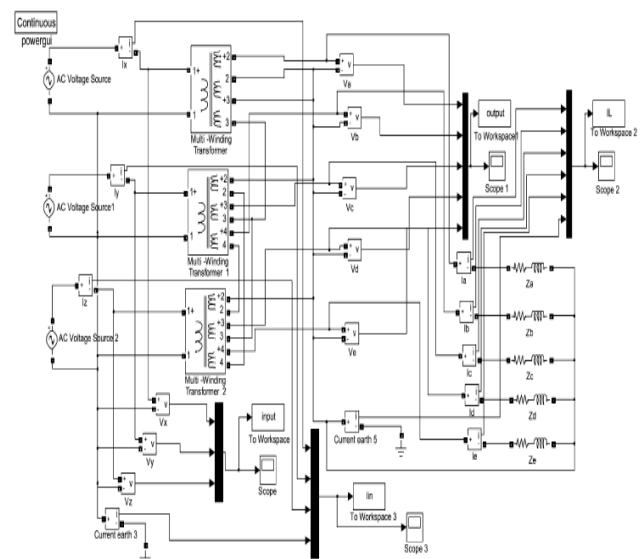


Fig: 4.1. MATLAB/SIMULINK Model Of The Three- To Five-Phase Transformation

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. 4.1, the output phase “A” is along the input phase “X”. The output phase “B” results from the phasor sum of winding voltage “c6c5” and “b1b2”, the output phase “C” is obtained by the phasor sum of winding voltages “a1a3” and “b3b4”. The output phase “D” is obtained by the phasor addition of winding voltages “a1a3” and “c1c2” and similarly output phase “E” results from the pharos sum of the winding voltages “c3c4” and “b6b5 ”. In this way, five phases are obtained.

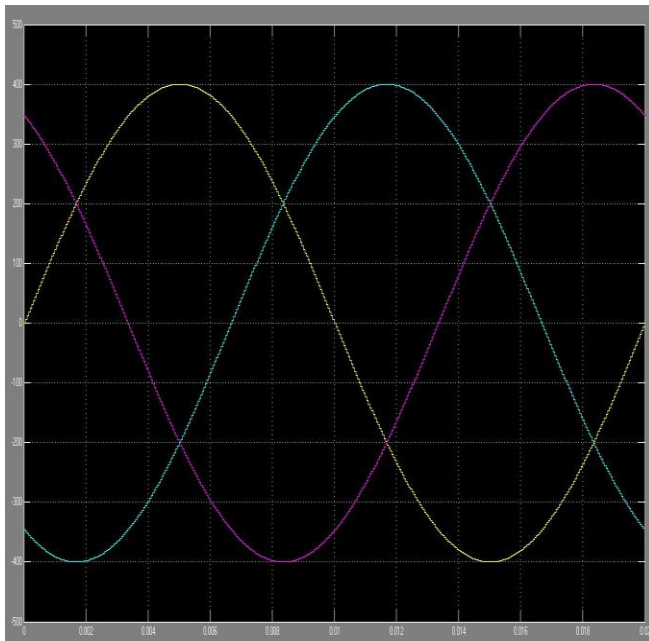


Fig4.2 Three phase input Voltage

Fig. 4.2 represents the three phase input supply voltage taken from the balanced grid system. The supply voltage is 400 volts. In the above figure, the input phase voltage VX is represented with yellow colour, the input phase voltage VY is represented with magenta colour and the input phase voltage VZ is represented with cyan colour. The above waveforms are plotted between the parameters of Voltage and Time. Time is taken as reference on X-axis in seconds and Voltage is taken as reference on Y-axis in Volts.

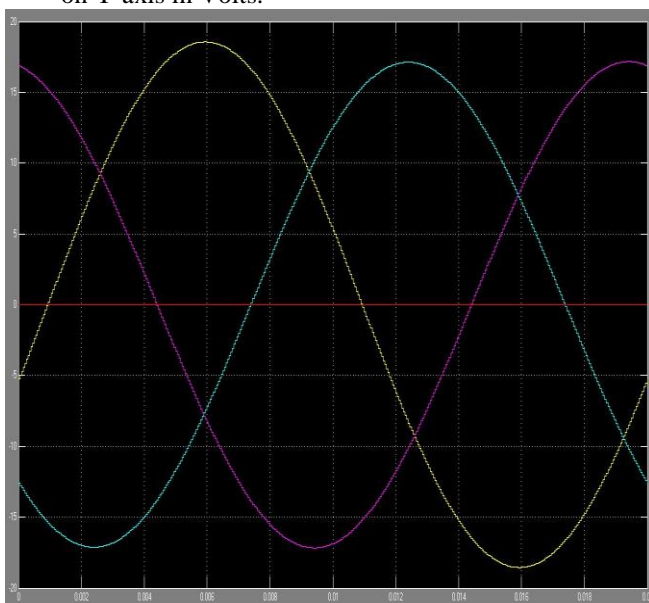


Fig4.3 Source Current

Fig. 4.3 represents the three phase input supply current taken from the balanced grid system. In the above figure, the input phase current IX is represented with yellow colour, the input phase current IY is represented with magenta colour and the input phase current IZ is represented with cyan colour. The above waveforms are plotted between the parameters of source current and time. Time is taken as reference on X-axis in seconds and input Current is taken as reference on Y-axis in Amperes.

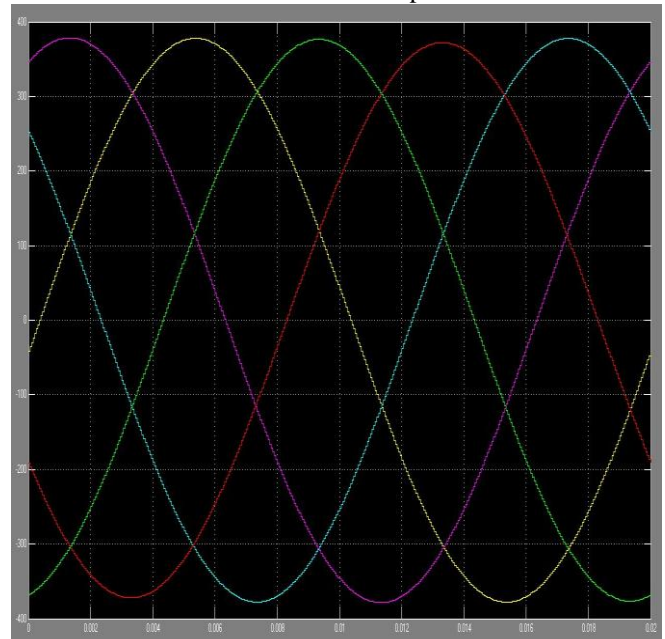


Fig4.4 Output five phase load Voltage

Fig. 4.4 represents the five phase output voltage. The proposed transformer is designed in order to obtain five phase voltage, for driving a five phase induction motor. In the above figure, Va is represented with yellow colour, the output phase voltage Vb is represented with magenta colour, the output phase voltage Vc is represented with cyan colour, the output phase voltage Vd is represented with red colour and the output phase voltage Ve is represented with green colour. The above waveforms are plotted between the parameters of voltage and time. Time is taken as reference on X-axis in seconds and Voltage is taken as reference on Y-axis in Volts.

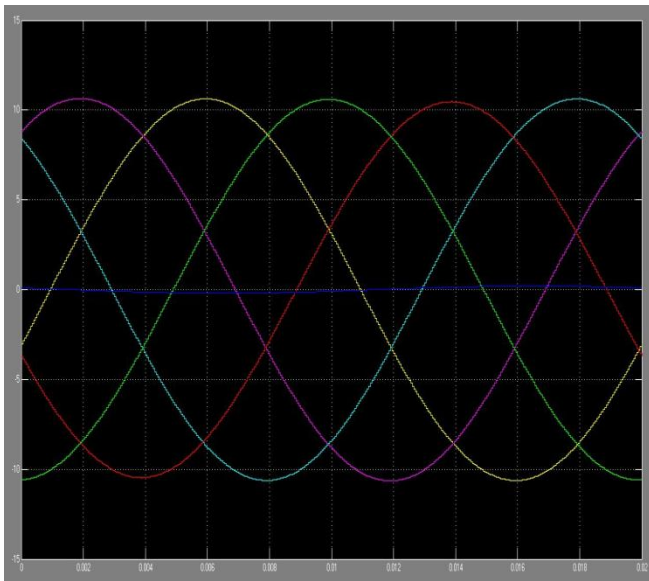


Fig4.5 Output five phase load Current

Fig.4.5 represents the five phase output load current. The proposed transformer is designed in order to obtain five phase output load current, for driving a five phase induction motor. The output of the five phase currents are shown in Fig. 4.5, I_a is represented with yellow colour, the output phase current I_b is represented with magenta colour, the output phase current I_c is represented with cyan colour, the output phase current I_d is represented with red colour and the output phase current I_e is represented with green colour. The above waveforms are plotted between the parameters of Load Current and Time. Time is taken as reference on X-axis in seconds and Load Current is taken as reference on Y-axis in Amperes.

$$V_b = 0.24V_y - 0.858V_z \quad \dots (4.1)$$

Fig. 4.6 represents the output phase voltage V_b . In the above figure yellow colour represents V_b , magenta colour represents $0.24V_y$ and cyan colour represents $-0.858 V_z$. The above waveforms are plotted between the parameters of output phase Voltage and Time. Time is taken as reference on X-axis in seconds and Load Current is taken as reference on Y-axis in Volts.

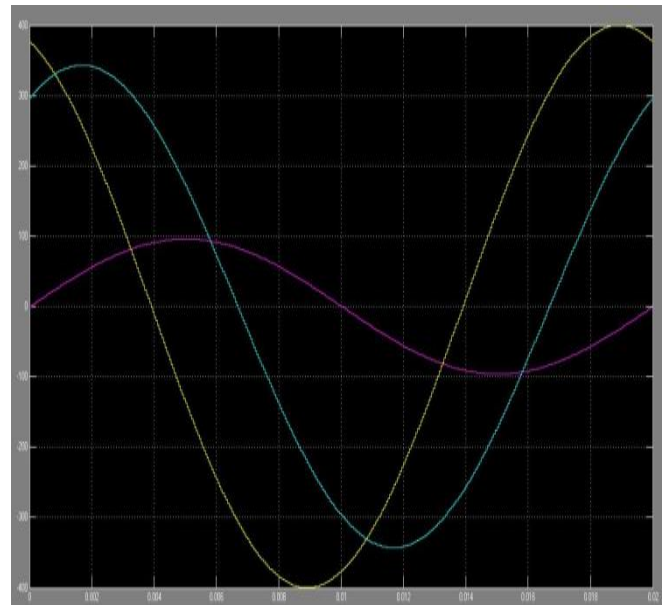


Fig4.6 Output phase Voltage V_b

$$V_c = 0.68V_y - 0.47V_z \quad \dots (4.2)$$

Fig 4.7 represents the output phase voltage V_c . In the above figure yellow colour represents $-0.47V_z$, magenta colour represents $0.68V_y$ and cyan colour represents $-0.858 V_c$. The above waveforms are plotted between the parameters of output phase Voltage and Time. Time is taken as reference on X-axis in seconds and Load Current is taken as reference on Y-axis in Volts.

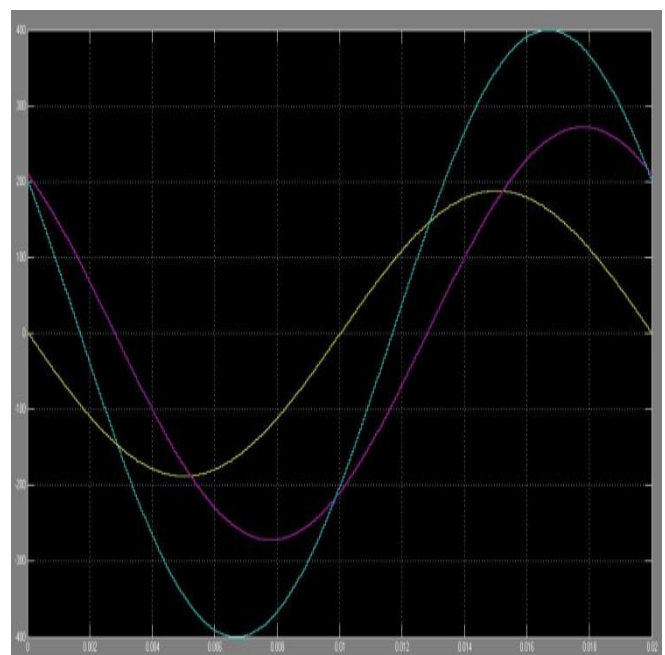


Fig4.7 Output phase voltage V_c

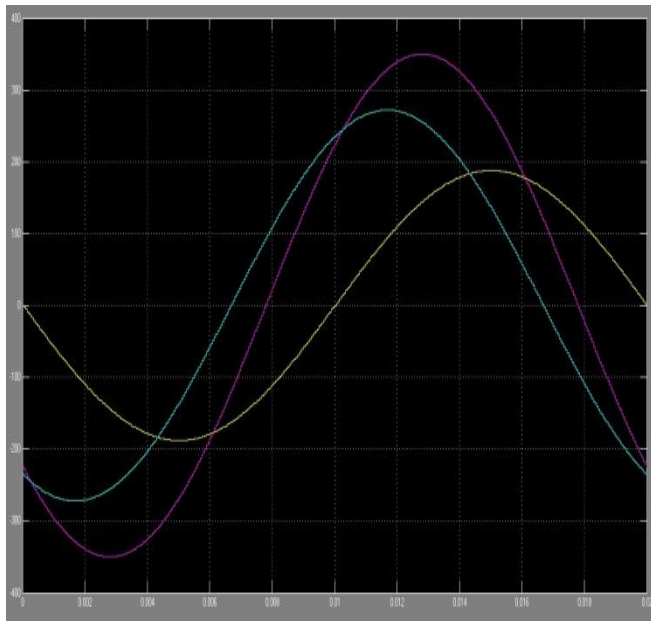


Fig4.8 Output phase voltage V_d

$$V_d = 0.68V_z - 0.47V_x \quad \dots (4.3)$$

Fig. 4.8 represents the output phase voltage V_d . In the above figure yellow colour represents $-0.47V_x$, magenta colour represents V_d and cyan colour represents $0.68V_z$. The above waveforms are plotted between the parameters of output phase Voltage and Time. Time is taken as reference on X-axis in seconds and Load Current is taken as reference on Y-axis in Volts.

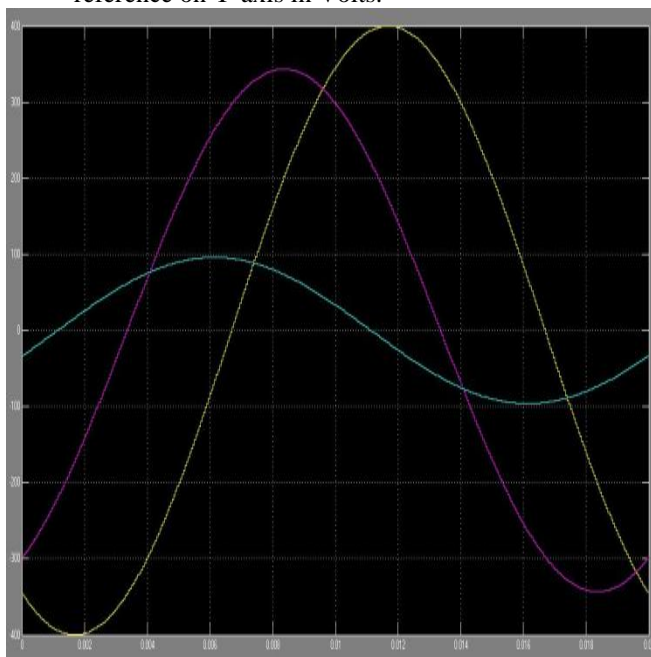


Fig4.9 Output phase voltage V_e

$$V_e = 0.24V_z - 0.858V_y \quad \dots (4.4)$$

Fig. 4.9 represents the output phase voltage V_e . In the above figure yellow colour represents V_e , magenta colour represents $-0.858V_y$ and cyan colour represents $0.24V_z$. The above waveforms are plotted between the parameters of output phase Voltage and Time. Time is taken as reference on X-axis in seconds and Load Current is taken as reference on Y-axis in Volts.

V Conclusion:

This thesis proposes a new 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 turns ratio are illustrated. The successful implementation of the proposed connection scheme is elaborated by using simulation and experimentation. A five-phase induction motor under a loaded condition is used to prove the viability of the transformation system. It is expected that the proposed connection scheme can be used in drives applications and may also be further explored to be utilized in multiphase power transmission systems.

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