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Simulation and Modeling of New Transformer Connection Scheme for Multiphase Power Transformation

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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 phase. 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 an 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.

KEYWORDS: *transformation, multiphase, PMSM drive, fixed voltage and fixed frequency*

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.

Three Phase:

A single phase system has only one AC waveform. A 3 phase system has three AC wave forms, separated by an angle of 120 degrees each. Three-phase electric power is a common method of alternating-current electric power generation, transmission, and distribution. It is a type of polyphase system and is the most common method used by electrical grids worldwide to transfer power.

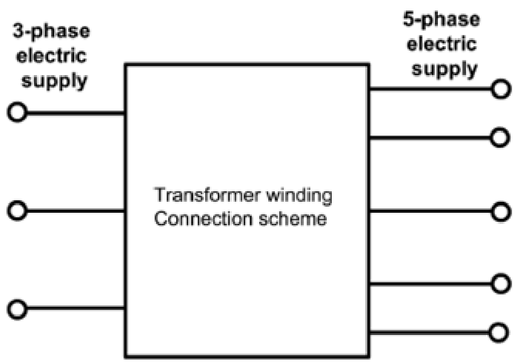


Figure 1 Block representation of the proposed system

It is also used to power large motors and other heavy loads. A three-phase system is usually more economical than an equivalent single-phase at the same line to ground voltage because it uses less conductor material to transmit a given amount of electrical power.[2] The three-phase system was independently invented by Galileo Ferraris, Mikhail Dolivo-Dobrovolsky, Jonas Wenström and Nikola Tesla in the late 1880s.

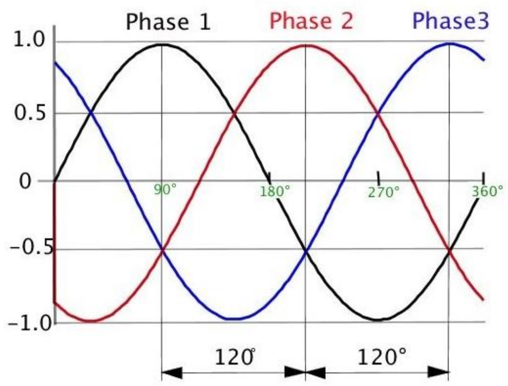


Figure 2 Three Phase waveform

Five phase:

A 5 phase system has Five AC wave forms, separated by an angle of 72 degrees each. Variable speed electric drives predominately utilize three-phase machines. However, since the variable speed ac drives require a power electronic converter for their supply (in vast majority of cases an inverter with a dc link), the number of machine phases is essentially not limited. This has led to an increase in the interest in multi-phase ac drive applications, since multi-phase machines offer some inherent advantages over their three-phase counterpart. Interesting research results have been published over the years on multi-phase drives. The 5 Phase was introduced in the year 1970's by Ward and Harrer way back.

Advantages of 3-phase to 5-phase Transformation:

- Multiphase system is found to produce less ripple with a higher frequency.
- More power can be transmitted for same conductor parameters.
- Multi-phase machine has
- Higher Torque density
- Greater efficiency
- Reduced torque pulsations
- Greater fault tolerance

Applications of 3-phase to 5-phase transformation:

- 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.

II. THREE PHASE TO FIVE PHASE TRANSFORMATION

A. Constructional details

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 and experimental approach to prove the viability of the implementation.

Special Transformer

This entire paper depends upon the special transformer only. It is actually as like 3-phase transformer but only difference in its secondary winding arrangement. Little effort is made to develop any static transformation system to change the phase number from three to-phases (where3 and odd). 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. Five phase, 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 and 36-phase transformer system have been proposed for supplying a multipulse rectifier system. The reason of choice for a 6, 12, or 24-phase system is that these numbers 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

Figure 3 Basic Special Transformer

Winding Arrangement:

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 connect 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 is illustrated in Fig. 3.2 .The construction of output phases with requisite phase angles of 72 between each phase is obtained using appropriate turns ratios.

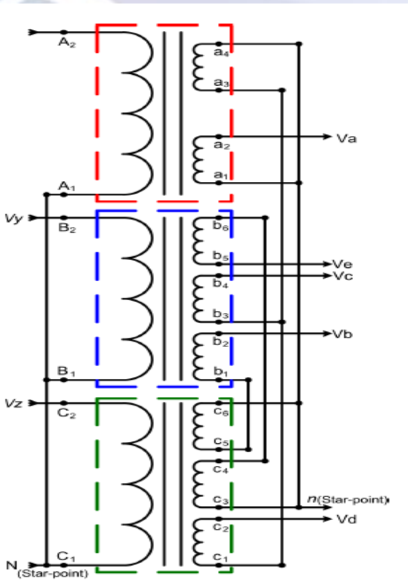


Figure 4 Proposed transforme rwinding arrangement

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. 3.2, 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 "a4a3 " and "b3b4". The output phase "D" is obtained by the phasor addition of winding voltages "a4a3 " and " c1c2" and similarly output phase "E" results from the phasor sum of the winding voltages "c3c4 " and "b6b5 ". In this way, five phases are obtained.

Winding Turns Ratio

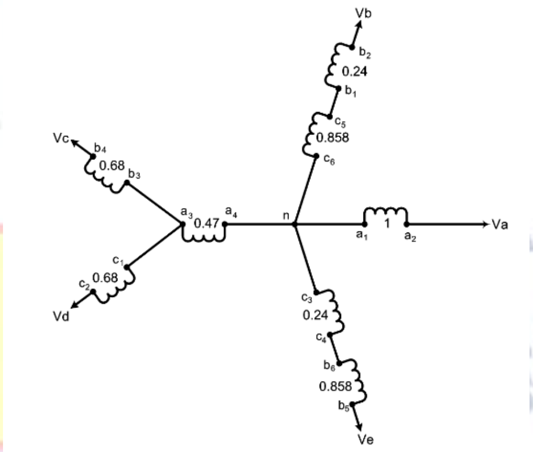


Figure 5 Proposed transformer winding connection

When a transformer is used to "increase" the voltage on its secondary winding with respect to the primary, it is called a Step-up transformer. ... It is necessary to know the ratio of the number of turns of wire on the primary winding compared to the secondary winding. From fig 3.3 Va has two terminals a1,a2. Vb has four terminals b1,b2 one winding and other winding c5,c6. Vc has four terminals b4,b3 one winding and other winding a3,a4. Vd has two terminals c1,c2 and connected with a3,a4. Ve has four terminals c3,c4 one winding and other winding b5,b6. This values are obtained by using the relation given

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

$$V_a = V_{\max} Sin\left(\omega t\right)$$

$$V_b = V_{\max} Sin\left(\omega t + \frac{2\pi}{5}\right)$$
$$V_c = V_{\max} Sin\left(\omega t + \frac{4\pi}{5}\right)$$
$$V_d = V_{\max} Sin\left(\omega t - \frac{4\pi}{5}\right)$$
$$V_e = V_{\max} Sin\left(\omega t - \frac{2\pi}{5}\right)$$
$$V_x = V_{\max} Sin\left(\omega t\right)$$
$$V_y = V_{\max} Sin\left(\omega t + \frac{2\pi}{3}\right)$$
$$V_z = V_{\max} Sin\left(\omega t - \frac{2\pi}{3}\right)$$

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

Primary	Secondary	Turn Ratio (N_p/N_s)	SWG
Phase-X	a_1a_2	1	17
	a_4a_3	0.47	15
Phase-Y	b_1b_2	0.68	17
	b_4b_3	0.858	17
	b_5b_6	0.24	17
Phase-Z	c_1c_2	0.68	17
	c_4c_3	0.858	17
	c_5c_6	0.24	17

Table 1 Transformer windings ratio

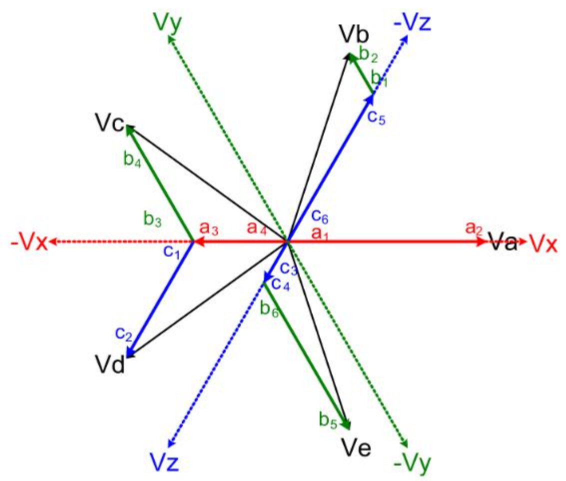


Figure 6 Winding phasor diagram

From the above phasor diagram we can know that Vx, Vy, Vz are three phases are dividing 120 degrees each. The reference voltage Vx is taken as Va. From Va,Vb,Vc,Vd,Ve are five phases are dividing 72degrees each.

Three phase to five phase transformation

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. 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. Little effort is made to develop any static transformation system to change the phase number from three to phase.

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 transformers are designed to feed a multipulse rectifier system and the technology has matured. Recently, a 24-phase and 36-phase transformer system have been proposed for supplying a multipulse rectifier system.

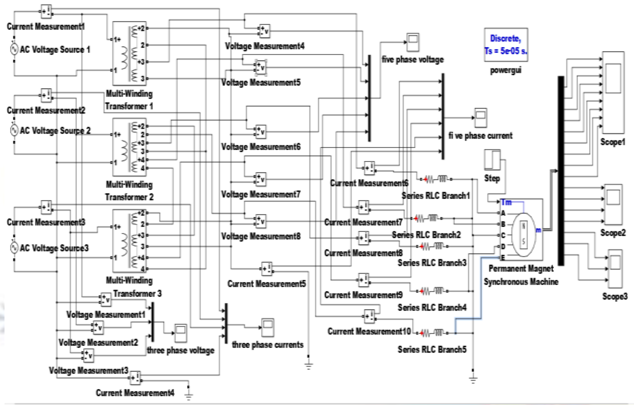
The reason of choice for a 6-, 12-, or 24-phase system is that these numbers are multiples of three and designing this type of system is simple and straightforward. However, increasing the number of phases certainly enhances the complexity of the system. None of these designs are available for an odd number of phases, such as 5, 7,11, etc., as far as the authors know 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 pulsewidth-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 fixed voltage and fixed frequency available 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.

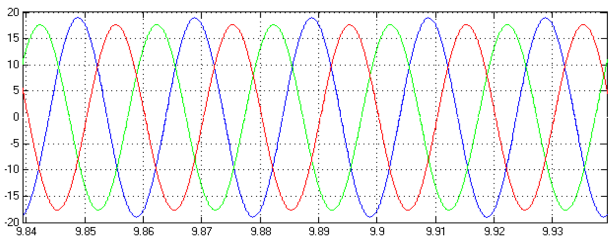
The input and output supply can be arranged in the following manner:

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

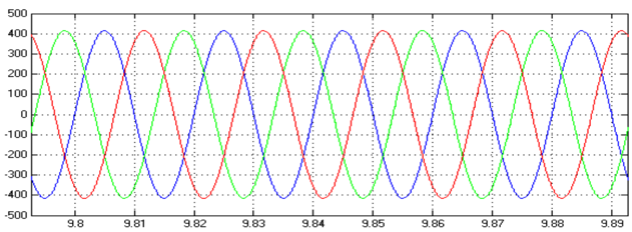
III. SIMULINK DIAGRAM FOR THREE PHASE TO FIVE PHASE CONNNECTED TO PMSM



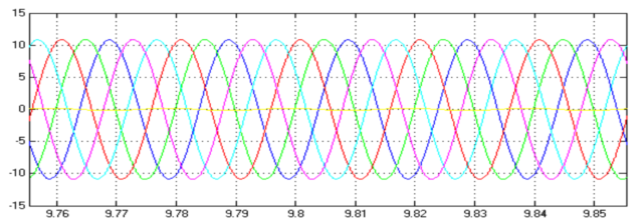
Waveform of Three Phase Input Currrent



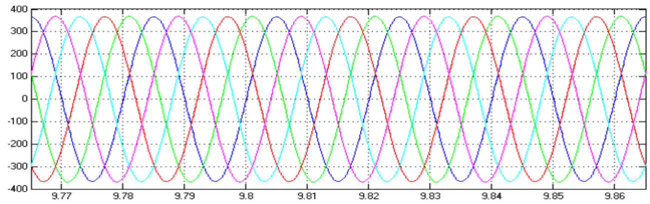
Wave form of Three Phase Input Voltage



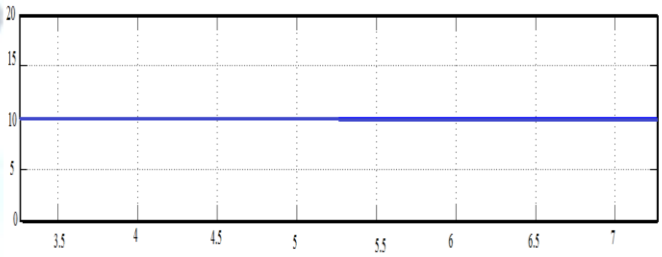
Waveform of Five Phase Output Current



Waveform of Five Phase Output Voltage



Output Wave Form of Torque



IV. CONCLUSION

This paper 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 turn ratios 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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