UGC Approved Journal
IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 9, September 2017

A Novel Three-Phase to Nine-Phase Transformation using a Special Transformer Connection

Mohd Rizwan Khalid

Research Scholar, Electrical Engineering Dept, Zakir Husain College of Engineering and Technology, Aligarh, India

Abstract: Multiphase i.e. more than three phase electric power supply for electric drive system is the main focus of research in the last decade. Since the three-phase supply is available from the grid, there is a need to develop a static phase transformation system to obtain a multiphase supply. As, the variable speed multiphase drive system considered in the literature are mostly of five, seven, nine, eleven, twelve, and fifteen phases and such multiphase drive systems are invariably supplied from power electronic converters, thus overall system constitutes of complex control circuit and moreover the line current drawn from three phase supply have appreciable amount of harmonics due to power electronics elements in the circuit. In contrast, this paper proposes technique to obtain nine-phase output from three-phase supply system using special transformer connections. Thus, with the proposed technique, a pure nine-phase sine-wave voltage/current is obtained, which can be used in multiphase drive systems.

Keywords: Multiphase, nine phase, transformer, turn ratio.

I. INTRODUCTION

Multiphase system is the main focus of research due to its inherent advantages compared to their three-phase counterparts. The applicability of multiphase systems is explored in electric power generation [2]–[4], transmission [5]–[7], and utilization [9]–[11]. The research on six-phase transmission system was initiated due to the rising cost of transmission corridors, environmental issues, and various stringent licensing laws. Six phase transmission system can provide the same power capacity with a lower line voltage, also tower structures are more compact compared to 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 [8]. The research on multiphase generators has started recently and only a few references are available [2]–[4].

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 in [11]. 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 [12]–[13]). Little effort is made to develop any static transformation system to change the phase number from three to n-phase, where n>3 and odd. The scenario has now changed with this paper, proposing a phase transformation system which converts an available three-phase supply to an output nine-phase supply.

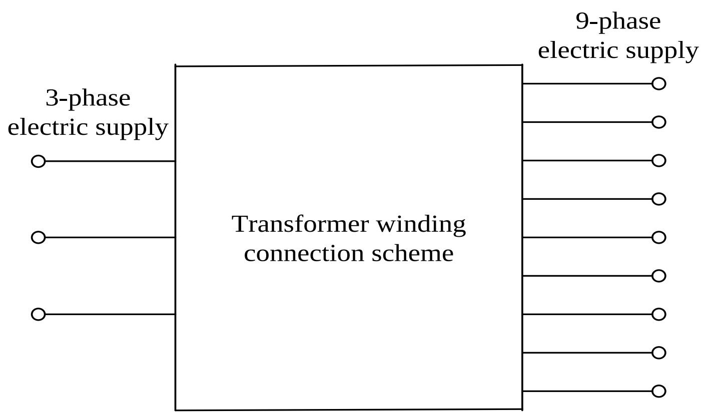

Fig.1 Block representation of proposed system

IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 9, September 2017

Multiphase system, especially 6-phase and 12-phase is found to produce lesser ripples 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 has been proposed for supplying a multipulse rectifier system [14]–[17]. 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 increases the complexity of the system. None of these designs are available for an odd number of phases, such as 5, 7, 9, 11, etc., as far as the authors know.

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 [18]. 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 nine-phase supply obtained from the three phase input supply. The block diagram of the proposed system is shown in Fig.1. The three phase grid supply of fixed voltage and fixed frequency can be transformed to the fixed voltage and fixed frequency nine-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 connections of output side are discussed below.

II. WINDING ARRANGEMENTS FOR NINE-PHASE STAR OUTPUT

Three separate cores are designed with each carrying one primary and four secondary coils. Six terminals of primaries are connected in an appropriate manner thus resulting in star connection and the 24 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.2 and the corresponding phasor diagram is illustrated in Fig.3.

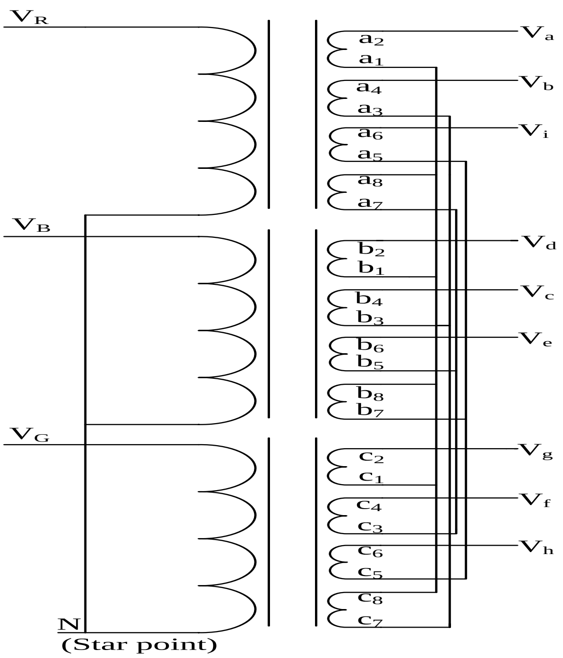

Fig.2 Winding connections of proposed transformer

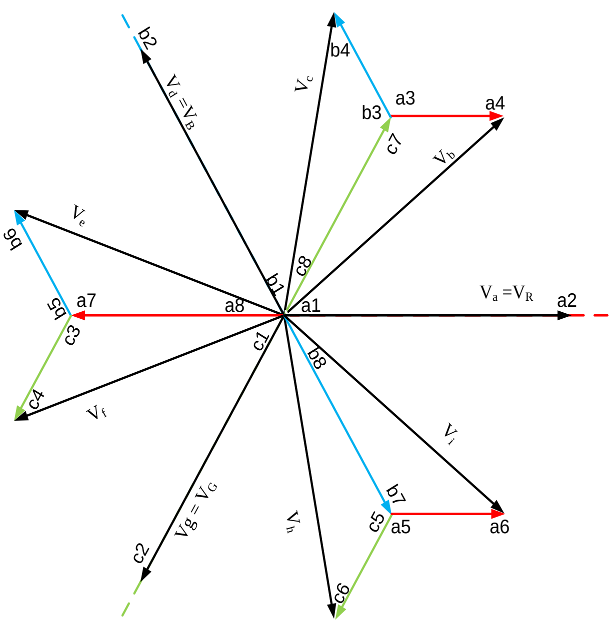

Fig.3 Phasor diagram of output and input voltages

DOI 10.17148/IJIREEICE.2017.5927

IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 9, September 2017

The construction of output phases with phase difference of 40 degrees between each phase is obtained using appropriate turn ratios, and the governing phasor equations are illustrated in (1)–(9). The choice of turn ratio is the key in creating the requisite phase displacement in the output phases, values of turn ratios are given in table 1, turns ratios are selected in such a manner that the magnitude of input phase voltage and output phase voltage are same.

- $V_a = V_{max}*Sin(\omega t) = V_R$ (1)
- $V_b = V_{max}*Sin(\omega t+\frac{2\pi}{9})$ (2)
- $V_c = V_{max}*Sin(\omega t+\frac{4\pi}{9})$ (3)
- $V_d = V_{max}*Sin(\omega t+\frac{2\pi}{3}) = V_B$ (4)
- $V_e = V_{max}*Sin(\omega t+\frac{8\pi}{9})$ (5)
- $V_f = V_{max}*Sin(\omega t-\frac{8\pi}{9})$ (6)
- $V_g = V_{max}*Sin(\omega t-\frac{2\pi}{3}) = V_G$ (7)
- $V_h = V_{max}*Sin(\omega t-\frac{4\pi}{9})$ (8)
- $V_i = V_{max}*Sin(\omega t-\frac{2\pi}{9})$ (9)

The input phasors are designated by V_R, V_B, V_G, and output phasors are designated by V_a, V_b, V_c, V_d, V_e, V_f, V_g, V_h, V_i. As illustrated in Fig.3, the output phase V_a is along the input phase V_R. The output phasor V_b results from the phasor sum of winding voltage "c_8c_7" and " a_3a_4", the output phase V_c is obtained by the phasor sum of winding voltages "c_8c_7" and "b_3b_4". The output phase "V_d" is along the input phase $V_{B,}$ the output phase V_e is obtained by phasor sum of winding volages "a_8a_7" and "b_5b_6", the output phase V_f is obtained by the phasor addition of winding voltages "a_8a_7" and "c_3c_4" and output phase V_g is along the input phase V_G. The output phase V_h is obtained by phasor addition of wining voltages "b_8b_7" and "c_5c_6" and the output phase V_i is obtained by phasor addition of winding voltages "b_8b_7" and "a_5a_6". In this way, nine phases are obtained.

TABLE I DESIGN OF PROPOSED TRANSFORMER

Primary	Secondary	Turn ratio (Secondary/Primary)
Phase R	a_1a_2	1.00
	a_3a_4	0.39
	a_5a_6	0.39
	a_7a_8	0.74
Phase B	b_1b_2	1.00
	b_3b_4	0.39
	b_5b_6	0.39
	b_7b_8	0.78
Phase G	c_1c_2	1.00
	c_3c_4	0.39
	c_5c_6	0.39
	c_7c_8	0.78

III. SIMULATION RESULTS

The designed transformer is at first simulated by using "SimPowerSystem" block sets of the Matlab/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. The simulation model is depicted in Fig. 4. Fig.5

UGC Approved Journal
IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 9, September 2017

shows the input supply voltage and Fig.6 shows the input three phase current when some RL load is connected at the load side, correspondingly the output voltage at load side and the current flowing through nine phase load is shown in Fig.7 and Fig.8 respectively. It is clearly seen that the output is a balanced nine-phase supply for a balanced three-phase input. It can be seen that the output nine phase current lags output nine phase voltage due to inductive nature of the load.

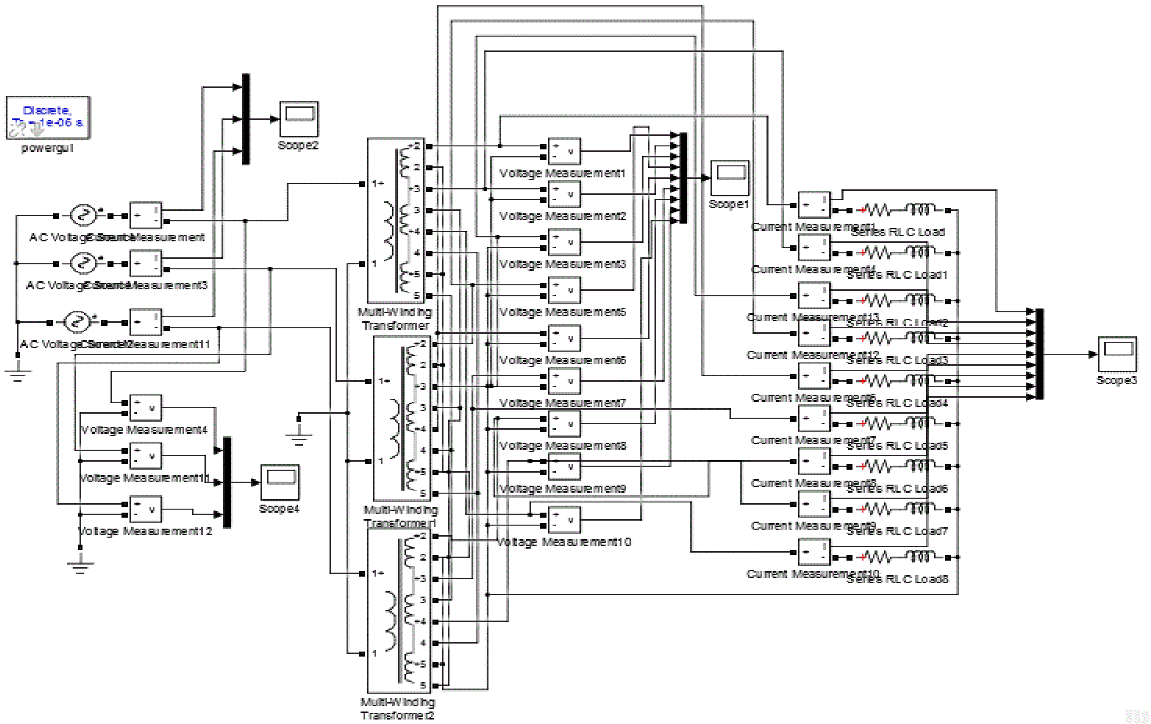

Fig. 4 Simulink/Matlab model of proposed three to nine phase transformer connections

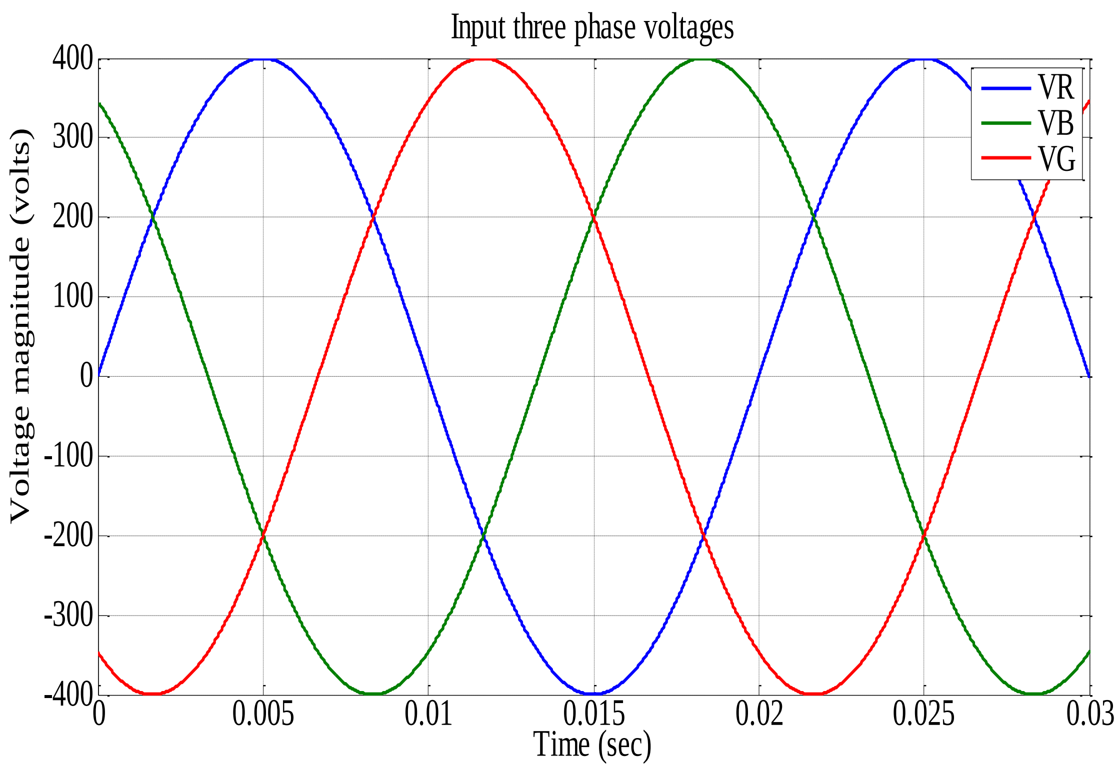

Fig.5 Three phase input voltage

UGC Approved Journal
IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 9, September 2017

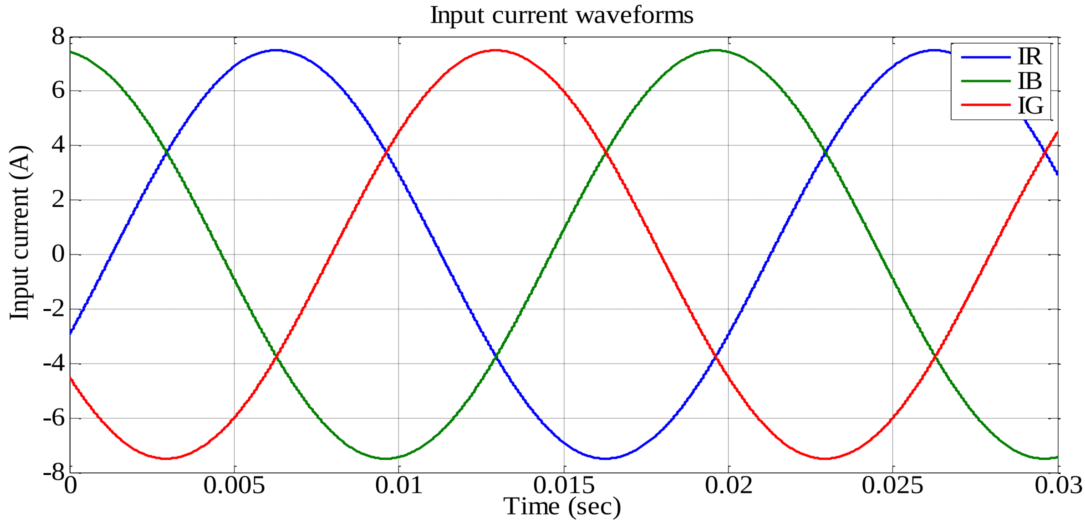

Fig.6 Three phase input current

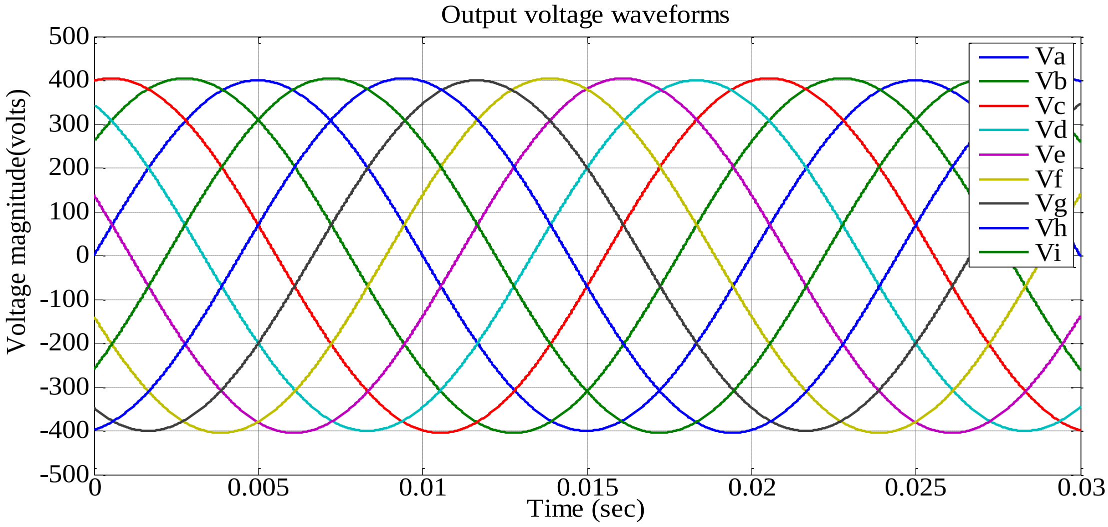

Fig.7 Nine phase output voltage

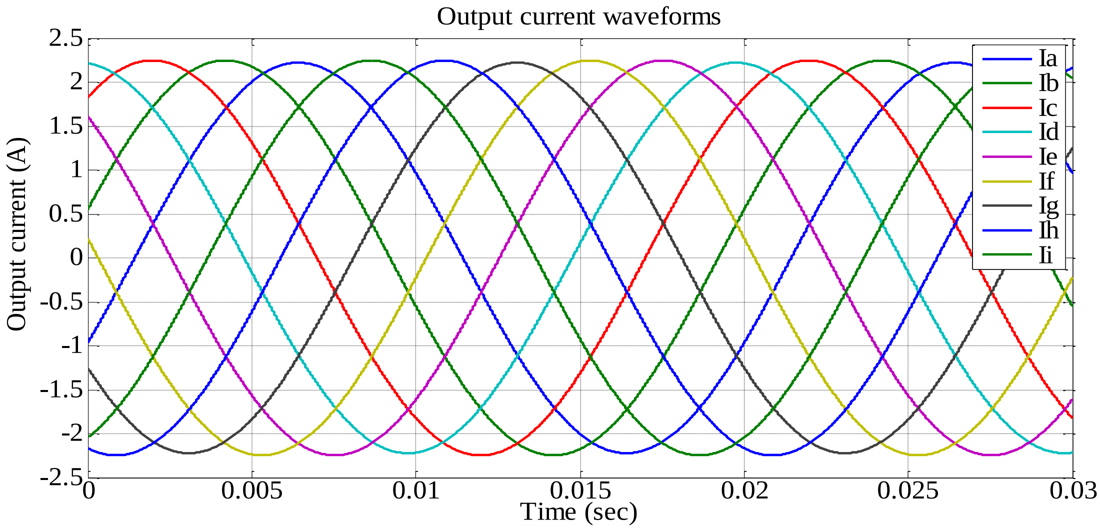

Fig.8 Nine phase output current

UGC Approved Journal
IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 9, September 2017

IV. CONCLUSION

This paper proposes a new transformer connection scheme to transform the three-phase grid power to a nine 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 shown by using simulation. It is expected that the proposed connection scheme can be used in drives and other multiphase applications, e.g., ac–ac and dc–ac power conversion systems.

REFERENCES

[1] E. E. Ward and H. Harer, "Preliminary investigation of an inverter-fed 5-phase induction motor," Proc. Inst. Elect. Eng., vol. 116, no. 6, 1969.
[2] D. Basic, J. G. Zhu, and G. Boardman, "Transient performance study of brushless doubly fed twin stator generator," IEEE Trans. Energy Convers., vol. 18, no. 3, pp. 400–408, Jul. 2003.
[3] G. K. Singh, "Self excited induction generator research- a survey," Elect. Power Syst. Res., vol. 69, pp. 107–114, 2004.
[4] O. Ojo and I. E. Davidson, "PWM-VSI inverter-assisted stand-alone dual stator winding induction generator," IEEE Trans Ind. Appl., vol. 36, no. 6, pp. 1604–1611, Nov./Dec. 2000.
[5] J. R. Stewart and D. D. Wilson, "High phase order transmission- a feasibility analysis Part-I-Steady state considerations," IEEE Trans. Power App. Syst., vol. PAS-97, no. 6, pp. 2300–2307, Nov. 1978.
[6] J. R. Stewart and D. D. Wilson, "High phase order transmission- a feasibility analysis Part-II-Over voltages and insulation requirements," IEEE Trans. Power App. Syst., vol. PAS-97, no. 6, pp. 2308–2317, Nov. 1978.
[7] J. R. Stewart, E. Kallaur, and J. S. Grant, "Economics of EHV high phase order transmission," IEEE Trans. Power App. Syst., vol. PAS- 103, no. 11, pp. 3386–3392, Nov. 1984.
[8] S. N. Tewari, G. K. Singh, and A. B. Saroor, "Multiphase power transmission research-a survey," Elect. Power Syst. Res., vol. 24, pp. 207–215, 1992.
[9] M. A. Abbas, R. Chirsten, and T. M. Jahns, "Six-phase voltage source inverter driven induction motor," IEEE Trans. Ind. Appl., vol. IA-20, no. 5, pp. 1251–1259, Sep./Oct. 1984.
[10] K. N. Pavithran, R. Parimelalagan, and M. R. Krsihnamurthy, "Studies on inverter fed five-phase induction motor drive," IEEE Trans. Power Electron., vol. 3, no. 2, pp. 224–235, Apr. 1988.
[11] G. K. Singh, "Multi-phase induction machine drive research—a survey," Elect. Power Syst. Res., vol. 61, pp. 139–147, 2002.
[12] A. Iqbal and E. Levi, "Space vector PWM techniques for sinusoidal output voltage generation with a five-phase voltage source inverter," Elect. Power Components Syst., vol. 34, no. 2, 2006.
[13] A. Iqbal and E. Levi, "Space vector modulation schemes for a five phase voltage source inverter," presented at the Eur. Power Electron. Conf. EPE (CD-ROM.pdf), Dresden, Germany, 2005.
[14] S. Choi, B. S. Lee, and P. N. Enjeti, "New 24-pulse diode rectifier systems for utility interface of high power ac motor drives," IEEE Trans. Ind. Appl., vol. 33, no. 2, pp. 531–541, Mar./Apr. 1997.
[15] V. Garg, B. Singh, and G. Bhuvaneswari, "A tapped star connected autotransformer based 24-Pulse AC-DC converter for power quality improvement in induction motor drives," Int. J. Emerging Electric Power Syst. Article 2, vol. 7, no. 4, 2006.
[16] V. Garg, B. Singh, and G. Bhuvaneswari, "A 24 pulse AC-DC converter employing a pulse doubling technique for vector controlled induction motor drives," Inst. Electron. Telecommun. Eng. J. Res., vol. 54, no. 4, pp. 314–322, 2008.
[17] B. Singh and S. Gairola, "An autotransformer based 36 pulse controlled AC-DC converter," Inst. Electron. Telecommun. Eng. J. Res., vol. 54, no. 4, pp. 255–262, 2008.
[18] P. C. Krause, Analysis of. Electric Machinery. New York: McGraw-Hill, 1986.