Three-Phase to Five-Phase Transformation using a Special Transformer Connection

Ambuj Gupta[1], Dr. Krishna Teerth Chaturvedi[2]

[1]M.Tech. Scholar, [2]Guide

Department of Electrical Engineering, UIT RGPV, Bhopal

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 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 - Five Phase Converter, Multiphase Power Conversion, Transformer, Transformer Configuration,Multiphase Drive, Three Phases to Five Phase Converter. bi-directional switch.

I. INTRODUCTION

The power electronic converter is the heart of a variable speed drive system. It is used to process the electrical power of utility grid and supply to the electric motor. This will act as an interface between the utility grids and the electric motor. Huge research effort is put to develop technically feasible and commercially viable power electronic converters. The rapid growth in the semiconductor material and switching devices has led to significant improvement in the power converters and also has helped in developing their several variants. Mainly classified, the power electronic converters used in variable speed drive applications are as presented in reference.

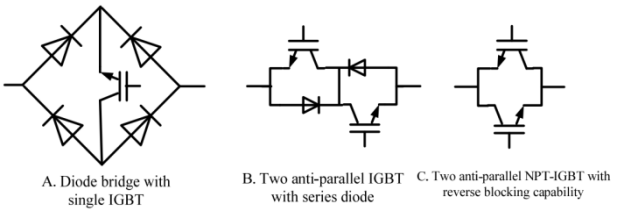

Figure 1.1 Possible discrete implementation of a bi-directional switch.

Direct AC-AC converter system mostly called Matrix Converter consist of arrays of bi- directional power semiconductor switches (bi-directional switches are shown in Fig. 1.1). Three-phase utility grid system is connected to the output through the matrix arrays. Each leg has three bi-directional switches and any output can be connected to any input line through the switching action of bi-directional power switches. The voltage of input side appears at the output side and the current in any phase of the load can be drawn from any phase of the utility grid. A small LC filter is connected at the source side to remove the current ripple (Which appears due to switching action). Matrix Converter has the following major advantages:

- Sinusoidal input and output currents
- Controllable input side power factor
- No bulky DC link capacitor is needed
- Bi-directional power flow.

The major disadvantage with the Matrix Converter is the low output voltage, in case of three- phase configuration the output is 15% less than the input side. In case of five-phase output the output is almost 20% lower than the input side. Higher the output number of phases, lower the output voltage magnitude. To enhance the output voltage, over-modulation is required and also AC chopper can be used in conjunction with the Matrix Converter. Additional shortcoming of a Matrix Converter is its complex control.

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.

Features of Multi-phase System

A multi-phase drives offers compared to their three-phase counterpart. Some of the known advantages of multi-phase motor drives are given in reference.

The frequency of torque pulsation is 2n*fundamental frequency, where n is the number of phases. Thus for instance in a five-phase machine the torque pulsation occurs at 10 times the fundamental frequency while in three-phase case it is 6 times the fundamental.

Higher efficiency compared to the three-phase counterpart. This is attributed to the fact that the stator excitation produces a field with lower space harmonic in case of multi-phase machine when compared to three-phase machines.

For instance in case of a five-phase machine, third harmonic along with the fundamental may be injected to enhance the torque production and similarly in case of a seven- phase machine, 3rd and 5th harmonics may be utilised. Thus in general harmonics lower than the phase number may be utilised effectively to enhance the torque production.

In contrast in case of five-phase machine, the machine will start, accelerated, reject load transient and continue to run normally with minimal de-rating even with a loss of one phase.

Thus multi-phase machine drive is suited ideally for safety critical applications such as ship propulsion, air craft applications &defence and emergency services applications.

II. PROPOSED MODEL

The proposed model has been implemented and Simulated on Matlab Simulink the basic block diagram of proposed work has shown in figure 2.1. The Simulink Implementation of proposed three-phase to five-phase transformation using a special transformer connection has been shown in figure 2.2.

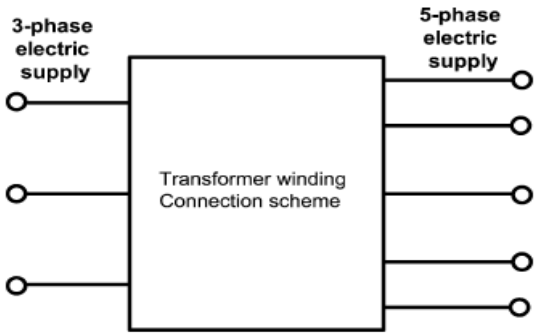

Figure 2.1 Block diagram of proposed system.

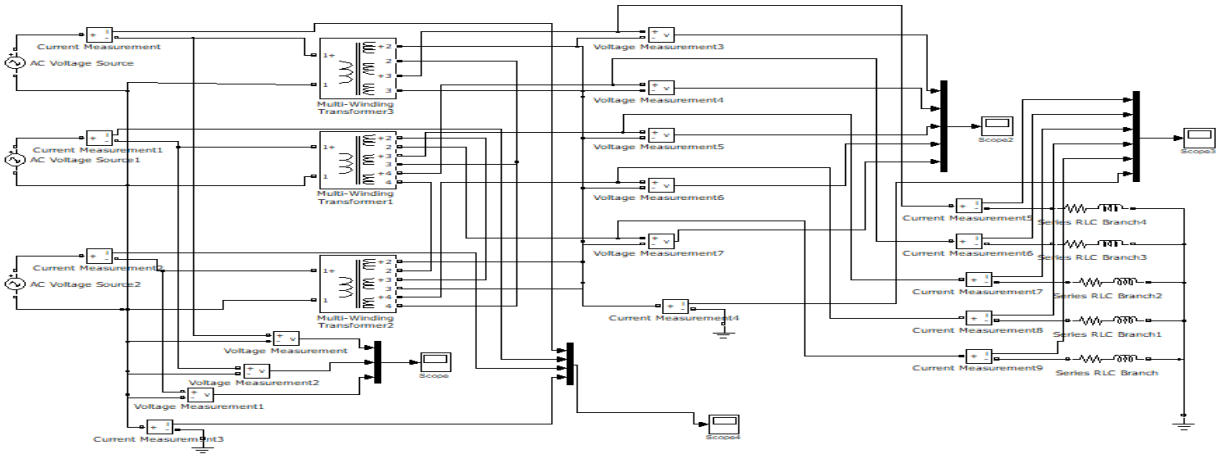

Figure 2.2Simulink Model.

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.

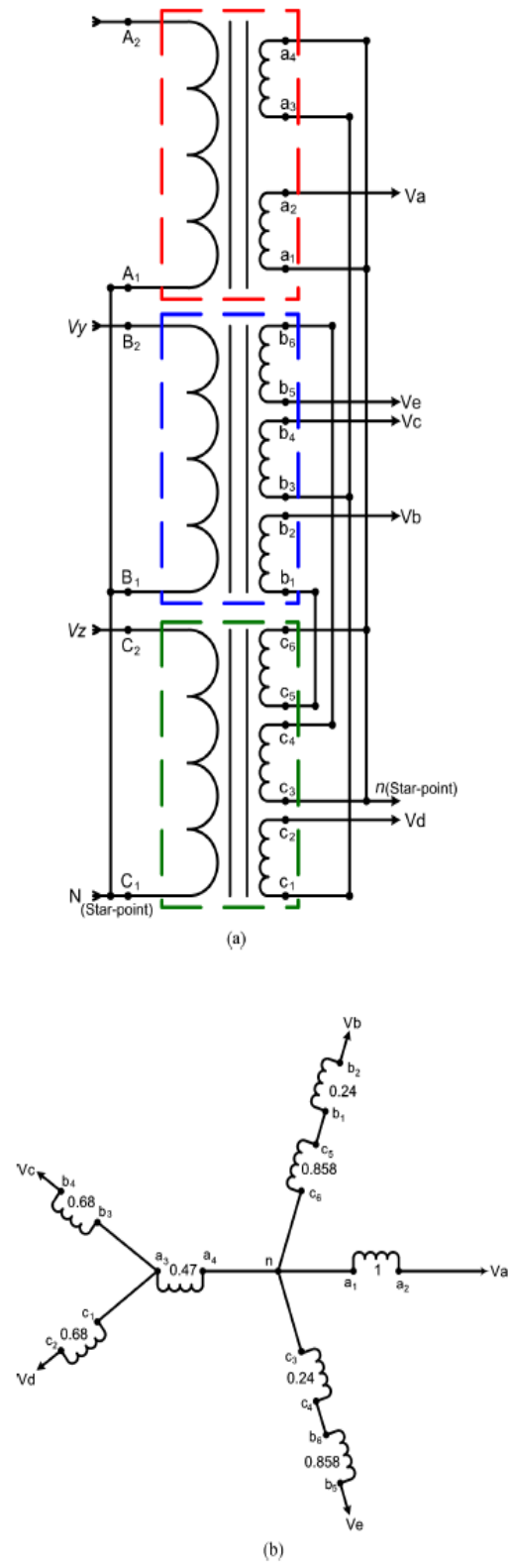

Figure 2.2 Proposed transformer winding arrangement (Star-Star). (b) Proposed transformer winding connection (Star).

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 phases (where 3 and odd). The scenario has now changed with this work, proposing a novel phase transformation system which converts an available three-phase supply to an output five-phase supply. Multiphase, especially a multi-phase system is found to produce less ripple with a higher frequency of ripple in an ac–dc rectifier system. Thus, multiphase transformers are designed to feed a multipulse rectifier system and the technology has matured. Recently, five-phase transformer systems have been proposed for supplying a multipulse rectifier system. The reason of choice for a 5-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.

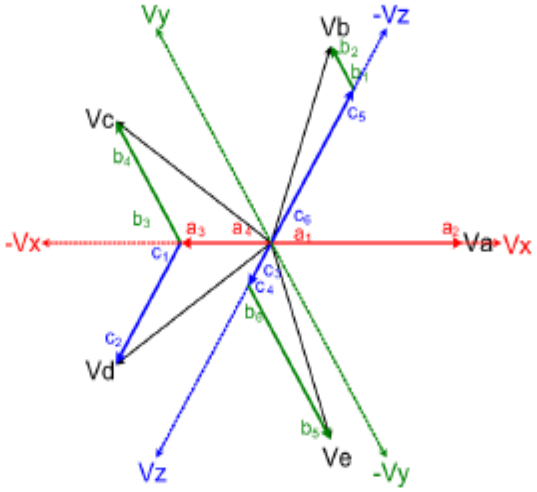

Figure 2.3 Pharos diagram of proposed winding connection (Star-Star).

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 exploration presents a special transformer connection scheme to obtain a balanced five-

phase supply with the input as balanced three phases. The block diagram of the proposed system is shown in Fig. 2.2. 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.

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.

Figure 2.3 shows the Pharos diagram of proposed winding connection (Star-Star).

III. SIMULATION OUTCOMES

The simulation of proposed work has done on Matlab Simulink Simulation environment the simulation waveform of proposed work has Taken from Matlab Scope are given in figure 3.1 to figure 3.4.Three Phase Input Voltage Waveforms has shown in figure 3.1 and Three Phase Input Current Waveforms has shown in figure 3.2.five phase output voltage waveforms shown in figure 3.3 andfive phase output current waveforms has shown in figure 3.4.

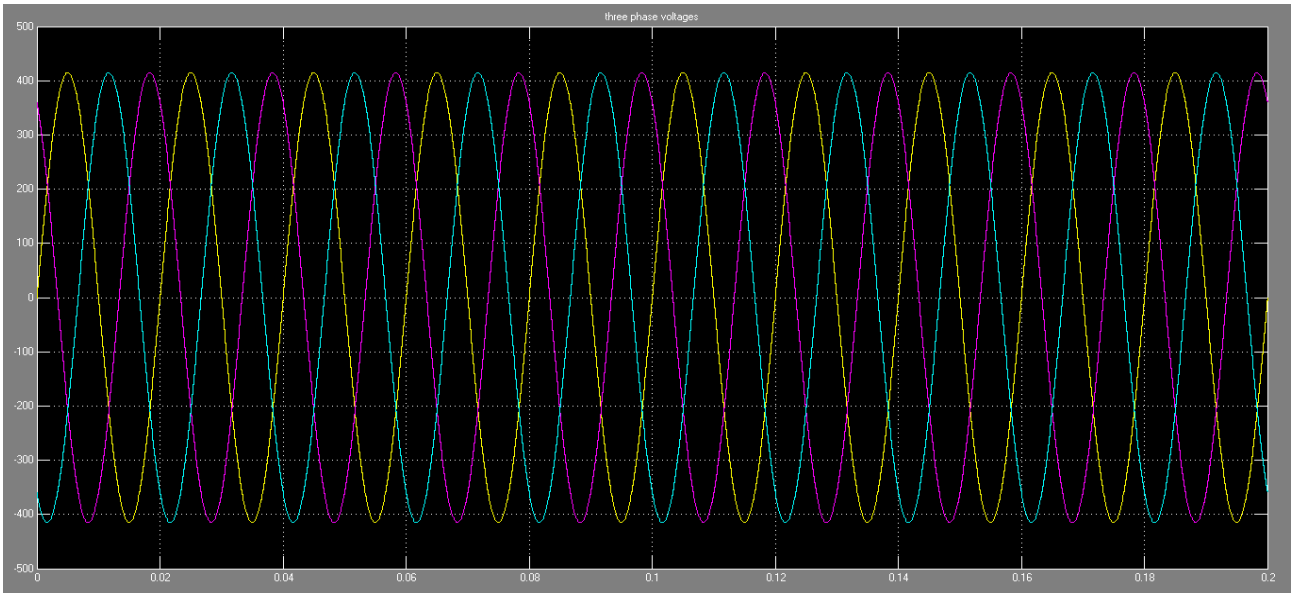

Figure 3.1Three Phase Input Voltage Waveforms.

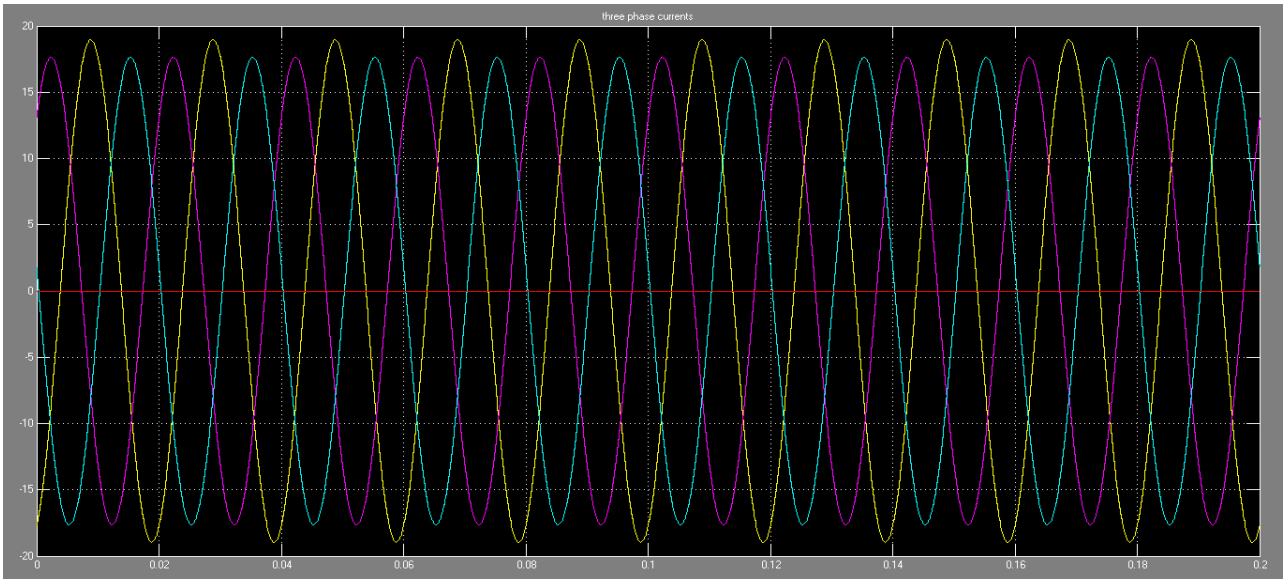

Figure 3.2Three Phase Input Current Waveforms.

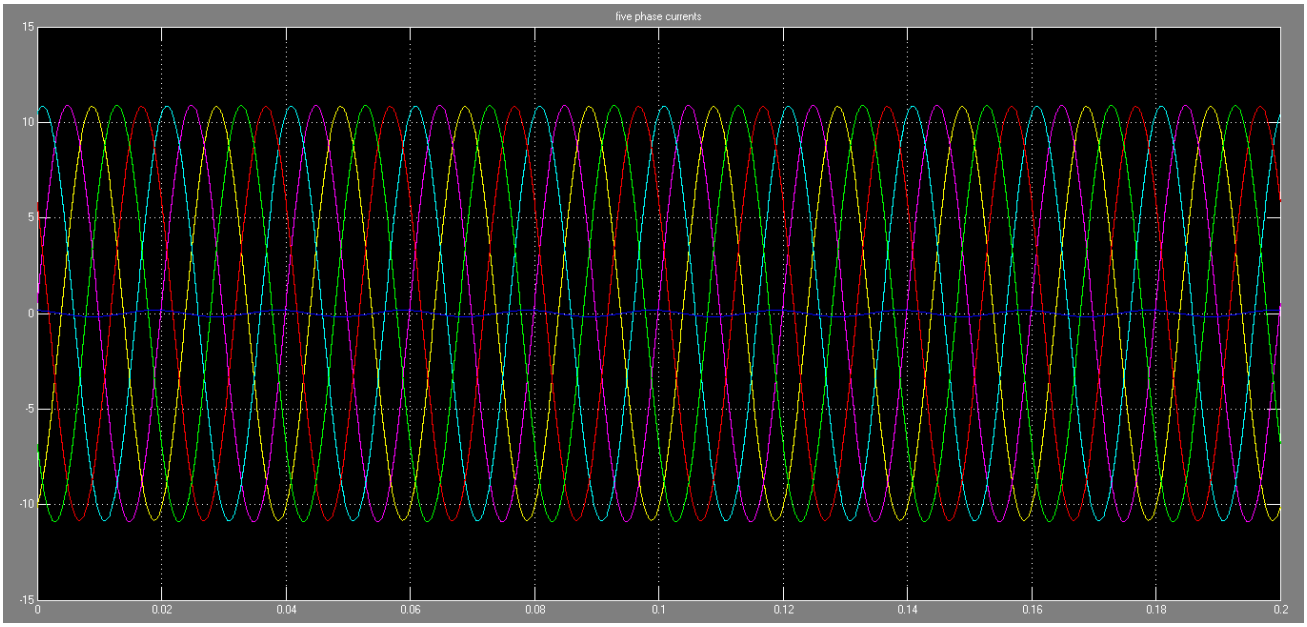

Figure 3.3Five Phase Output Voltage Waveforms.

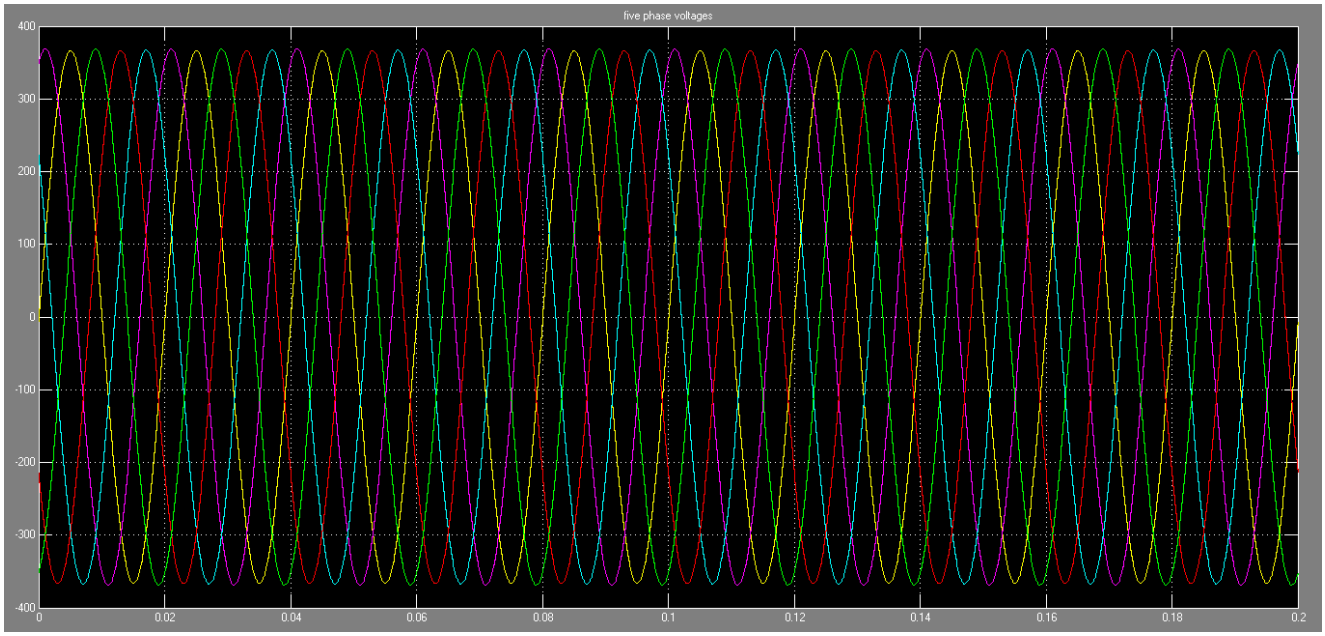

Figure 3.4 Five Phase Output Current Waveforms.

IV. CONCLUSION

The results obtained in the simulations on Matlab Simulink and the previous base results are observed and analyzed based on various parameters like phase voltage and current. The operations of the control strategies during the extreme conditions aretested to analyze the stability of proposed system.From the results it can be concluded that strategies for three phases to five phase conversion system based on different transformer configuration.The research on the multiphase machine is still ongoing, the research work carried out in multiphase motor drives over the span of last four decade has proven that the technical and economic advantages of the multiphase motor are superior than that of the three phase motor drives.The further work consists of adding the DC link torque limiting chain and the speed torque limiting chain in the drive to check the performance under the limiting conditions also the proposed system can be designed for multiple even and odd three phase to multiphase conversion system.

REFERENCES

[1]. N. B. de Freitas, C. B. Jacobina, A. C. N. Maia and A. C. Oliveira, "Six-Leg Single-Phase to Three-Phase Converter," in IEEE Transactions on Industry Applications, vol. 53, no. 6, pp. 5527-5538, Nov.-Dec. 2017.

[2]. N. Rocha, Í. A. C. de Oliveira, E. R. Cabral da Silva and C. B. Jacobina, "Single-phase to three-phase generation system based on doubly-fed induction generator," 2017 IEEE Energy Conversion Congress and Exposition (ECCE), Cincinnati, OH, 2017, pp. 3274-3280.

[3]. N. B. de Freitas, C. B. Jacobina, A. C. N. Maia and A. C. Oliveira, "Six-leg single-phase to three-phase converter," 2016 IEEE Energy Conversion Congress and Exposition (ECCE), Milwaukee, WI, 2016, pp. 1-8.

[4]. M. S. Diab, A. Elserougi, A. S. Abdel-khalik, A. M. Massoud and S. Ahmed, "A reduced switch-count SEPIC-based inverter for asymmetrical dual three-phase induction machines," IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society, Yokohama, 2015, pp. 000990-000995.

[5]. G. Waltrich, J. L. Duarte and M. A. M. Hendrix, "Three-phase bidirectional dc/ac converter using a six-leg inverter connected to a direct ac/ac converter," in IET Power Electronics, vol. 8, no. 11, pp. 2214-2222, 11 2015.

[6]. Euzeli dos Santos; Edison R. da Silva, "Three-Phase to Three-Phase and other Back-to-Back Converters," in Advanced Power Electronics Converters:PWM Converters Processing AC Voltages , 1, Wiley-IEEE Press, 2014, pp.376-

[7]. A. Fatemi, M. Azizi, M. Mohamadian, A. Yazdian Varjani and M. Shahparasti, "Single-Phase Dual-Output Inverters With Three-Switch Legs," in IEEE Transactions on Industrial Electronics, vol. 60, no. 5, pp. 1769-1779, May 2013.

[8]. B. Saint, “Rural distribution system planning using smart grid technolo- gies,” in 2009 IEEE Rural Electric Power Conference, pp. B3–B3–8, April 2009.

[9]. A. R. C. D. L. M. Duarte, U. H. Bezerra, M. E. D. L. Tostes, and G. N.

[10]. D. R. Filho, “Alternative energy sources in the amazon,” IEEE Power and Energy Magazine, vol. 5, pp. 51–57, Jan 2007.

[11]. E. Cipriano, C. Jacobina, E. da Silva, and N. Rocha, “Single-phase to three-phase power converters: State of the art,” Power Electronics, IEEE Transactions on, vol. 27, pp. 2437–2452, May 2012.

[12]. S. Chiang, T.-S. Lee, and J. Chang, “Design and implementation of a single phase three-arms rectifier inverter,” Electric Power Applications, IEE Proceedings -, vol. 147, pp. 379–384, Sep 2000.

[13]. C. Jacobina, T. Oliveira, and E. da Silva, “Control of the single-phase three-leg ac/ac converter,” Industrial Electronics, IEEE Transactions on, vol. 53, pp. 467–476, April 2006.

[14]. J. Chang, W. Chang, and S. Chiang, “Multilevel single-phase recti- fier inverter with cascaded connection of two three-arm converters,” Electric Power Applications, IEE Proceedings, vol. 153, pp. 719–725, September 2006.