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Design and Implementation of Single Phase to Three Phase Drive System Using Space Vector Modulation

Manikandan Ganesan[1]; K.R. Ishwarya[2]; Demoz Lisanework[3]; Ganesh Babu Loganathan[4]

[1]Department of Electromechanical Engineering, Faculty of Manufacturing, Institute of Technology, Hawassa University, Hawassa, Ethiopia.

[1]mani301090@hu.edu.et

[2]Department of Electromechanical Engineering, Faculty of Manufacturing, Institute of Technology, Hawassa University, Hawassa, Ethiopia.

[2]ishwarya.raghav@gmail.com

[3]Head, Department of Electromechanical Engineering, Faculty of Manufacturing, Institute of Technology, Hawassa University, Hawassa, Ethiopia.

[3]demoz0504@gmail.com

[4]Department of Mechatronics Engineering, Tishk International University, Erbil, KRG, Iraq.

[4]ganesh.babu@tiu.edu.iq

Abstract

This paper discusses about the transformation of 1Φ to 3Φ drive system. Generally, the distribution of electric power is typically three phase, however, when it is distributed to suburban areas, small scale industries and rural areas it is single phase. This proposed system was developed by using MATLAB Simulink Model and Hardware Implementation. It describes various conversion techniques such as AC to DC conversion using single phase rectifier, DC to DC conversion by using boost converter, DC to Three phase AC by using space vector modulation inverter. Besides software, hardware system was also developed to control the 3Φ asynchronous motor and its performance was successfully obtained.

Key-words: Single-phase Grid, Switching Time, Static Power Converter, Total Hormonic Distortion.

1. Introduction

While comparing with 1Φ induction motor, the 3Φ induction motor has high power factor, consumes less energy, high starting torque, torque ripples are less, high efficiency and smaller in size for the same power rating. Generally the single phase wirings are used in our home appliances. Hence a compatible 1Φ to 3Φ converter is essential to use 3Φ motor in single phase grid to conserve energy and to overcome the draw backs of single phase motors. [1] illustrated that effect of power ripple was double the time of grid frequency which is the major problem while converting from 1Φ to 3Φ [2]. Implemented the control approach which has been developed by using fixed-point DSP-based controller ADMC 401 to improve power quality for unbalanced and nonlinear loads. Suggested that the input converter topology can decrease the harmonic distortion and rectifier switching currents [3]. Derived a system model for reducing the circulating current which is used to decrease the total energy loss [4]. Developed voltage to frequency controller using TMS320C31 digital signal processor to eliminate the dc-link voltage ripples for asynchronous motor drives [5]. For various load conditions the bi-directional AC- AC converter was implemented by Yang, Proposed PWM based voltage source inverter and it functions as both active filter and voltage compensator depending upon the PCC drop voltage range [6,7]. To obtain the high power efficiency, cost effective and reliable system, the less numbers of advanced semiconductor devices were used by Developed the control strategies for both transformers less and transformer-based topologies [8,9]. Without transformer designed a 1Φ rectifier which has two parallel 1Φ halfwave converter [10]. Experimented the system to decrease the circulating currents without isolation transformer [11-13]. The present paper describes the space vector modulation (SVM) technique to convert 1Φ to 3Φ system instead of the PWM inverter technique which was widely used [14-17]. To suppress the harmonics, the SVM technique is utilized to produce the required switching pulses in order to achieve various modulation indexes[18-22].

2. Methodology

The 1Φ to 3Φ systems consist of following conversion stages and they are:

AC to DC Conversion (Single Phase Rectifier).

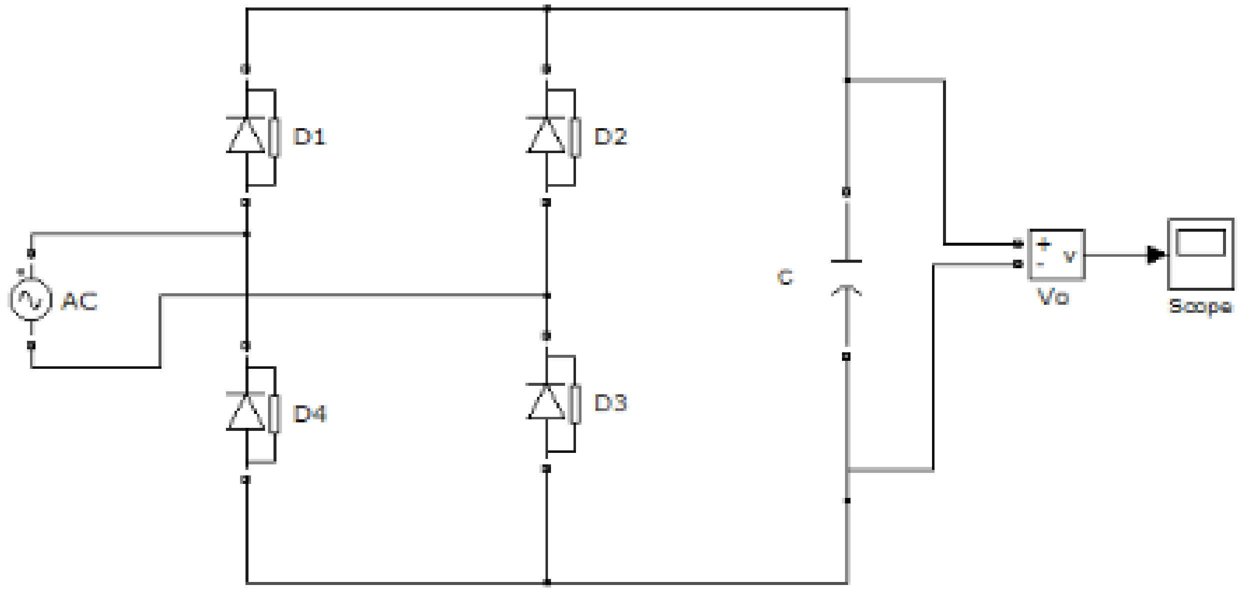
DC to DC Conversion (Boost Converter).

DC to AC Conversion (Voltage Source Inverter using SVM).

AC to DC Conversion (Single Phase Rectifier)

The single-phase sinusoidal voltage is converted into constant DC voltage by using 1Φ bridge rectifier. The circuit diagram of the 1Φ rectifier is shown in Fig. 1.

Fig 1- Simulation Circuit of Single Phase Rectifier



Operation of Rectifier

The single-phase rectifier consists of two operational cycles, in the positive half cycle, the current flows to the load through diodes D1 and D3 shown in Fig. 2. During the negative half cycle the current flows to the load through diode D2 and D4 as shown in Fig.3. The output converter voltage Vo = $V_m \sin \omega t$ for both the half-cycles.

Fig. 2- Conduction of Positive Half Cycle in Rectifier

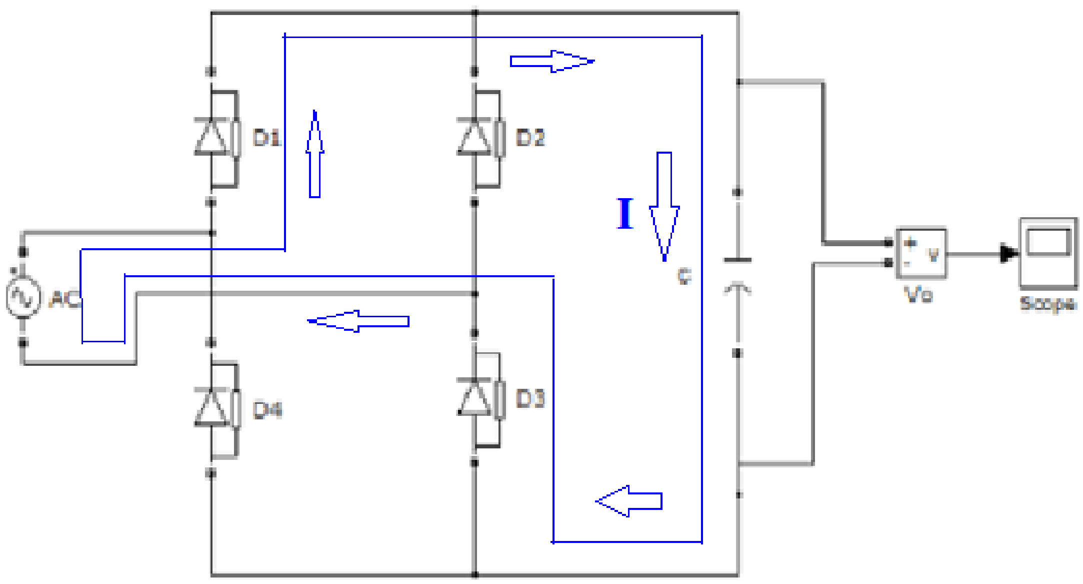


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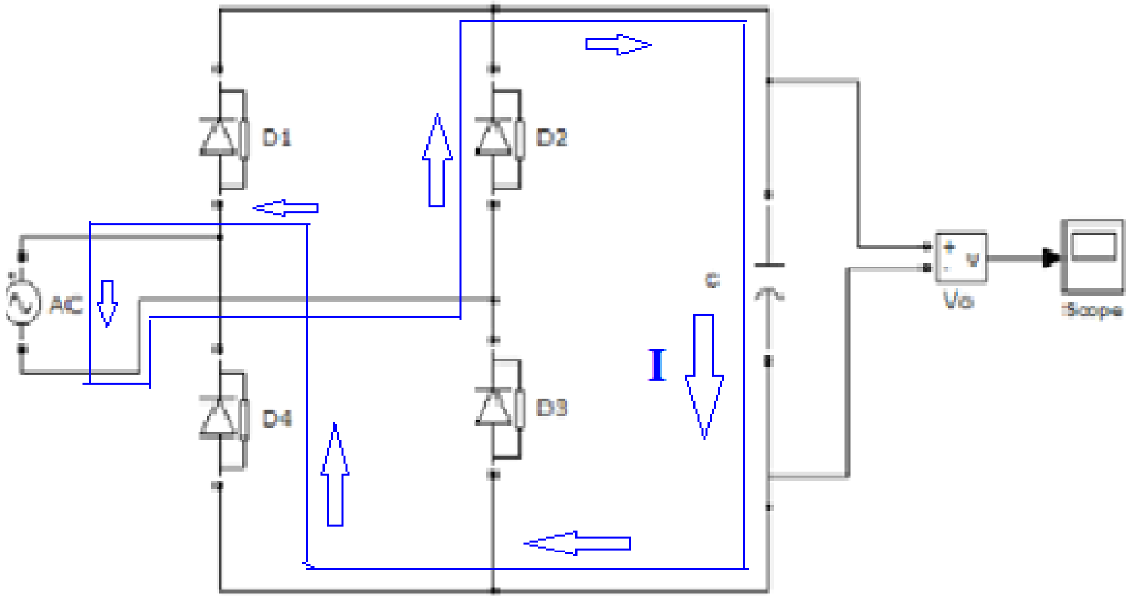
Fig. 3- Conduction of Negative Half Cycle in Conduction of Rectifier



The average output value of positive half cycle is:

For$0 < \omega t < \pi$

$$V_0 = \sqrt{2}V_i \sin \omega t \quad (1)$$

The average output value of negative half cycle is given by

For$\pi < \omega t < 2\pi$

$$V_0 = \sqrt{2}V_i \sin \omega t \quad (2)$$

The total average output value is given as

$$V_{0AV} = \frac{1}{\pi}\int_0^{\pi} \sqrt{2}\, V_i^2 \sin \omega t\ t\ \omega t = \frac{2\sqrt{2}}{\pi} V_i \quad (3)$$

The RMS value of output is:

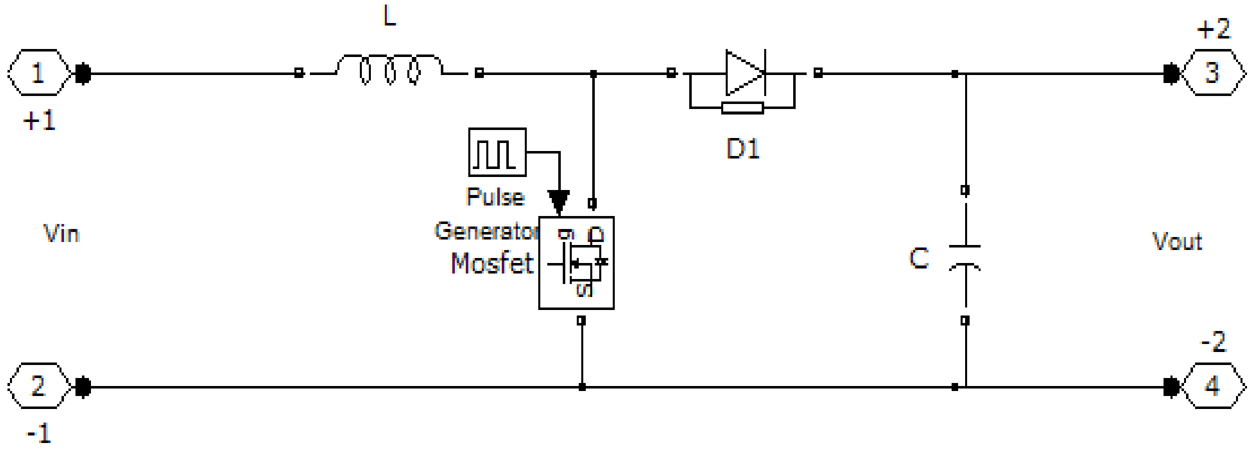
$$V_{0RMS} = \sqrt{\frac{1}{\pi}\int_0^{\pi} 2V_i^2\ sin^2\omega t\ d\ \omega} \quad (4)$$

The output of single phase full wave rectifier is not a pure DC voltage. In order to obtain the ripple free DC voltage the capacitive filter is added across load.

DC to DC Conversion (Boost Converter)

The boost converter is used to step up the DC 230 volts into high level DC volts in the range of 1000 volts. The simulation circuit diagram is shown in Fig. 4.

Fig. 4- Simulation Circuit of Boost Converter



The DC- DC boost converter has two different operational modes which relies switching period length and energy storage capacity. The former and latter modes depend on the Pulse width of switch gate signal and Value of Inductance respectively [23-27]. The inductance and capacitance values are calculated based on following equations.

$$L_c = \frac{RD(1-D)^2}{2F} \quad (5)$$

$$C_b = \frac{V_0 D}{F \Delta V_0 R} \quad (6)$$

Where,

Vo- Output Voltage

F- Switching frequency

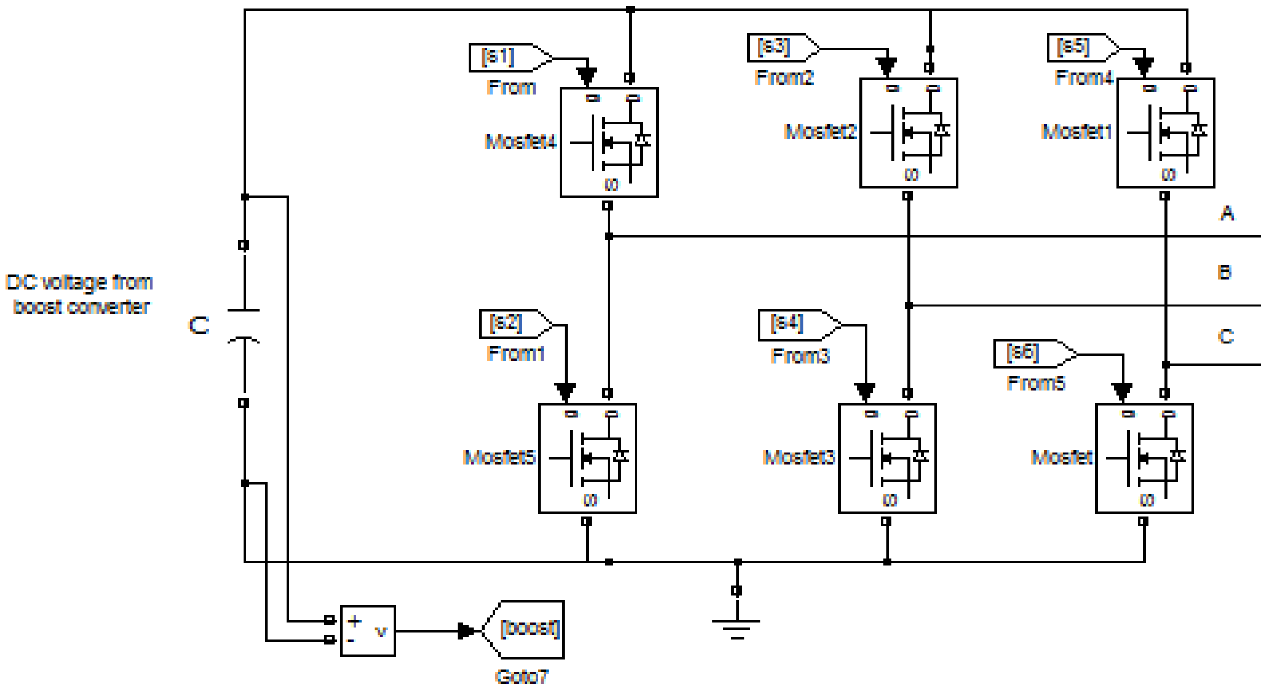
D- Duty Cyle

R- Load Resistance

DC to AC Conversion (Voltage Source Inverter Using SVM)

The three phase inverter is designed by connecting three single phase inverters in parallel. In this, the input pulse to the gate signals of each phase have difference of 120°. These inverters drawn Input DC supply from a Booster converter. Fig. 2.5 shows the simulation circuit diagram of 3Φ inverter using six MOSFET's [28-33]. To achieve constant DC input voltage the high value of capacitor was connected across the input terminals and it putdowns the harmonics of the source.

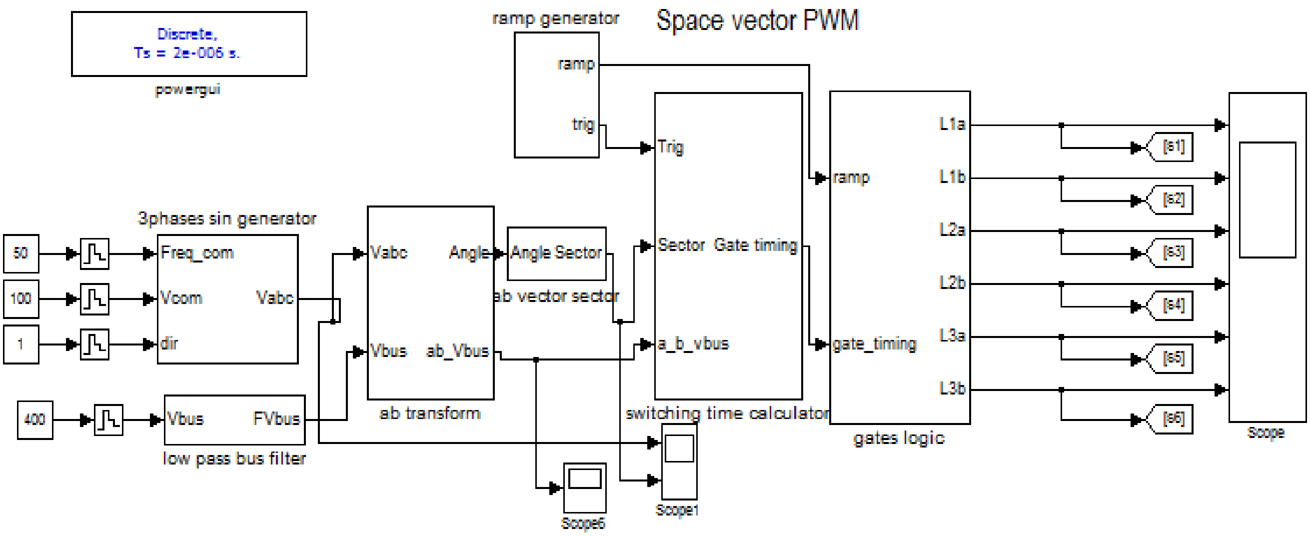
Fig. 5- Simulation Circuit Diagram of 3Φ Inverter



Implementation of SVM in Matlab Simulink

The simulation circuit diagram of space vector modulation is shown in Fig 6. Here the inverter is considered as a single unit and it is uniquely driven by 8 states [34-38]. The output voltage of inverter is regulated by the space vector modulation system.

Fig. 6- Simulation Diagram of Space Vector Modulation



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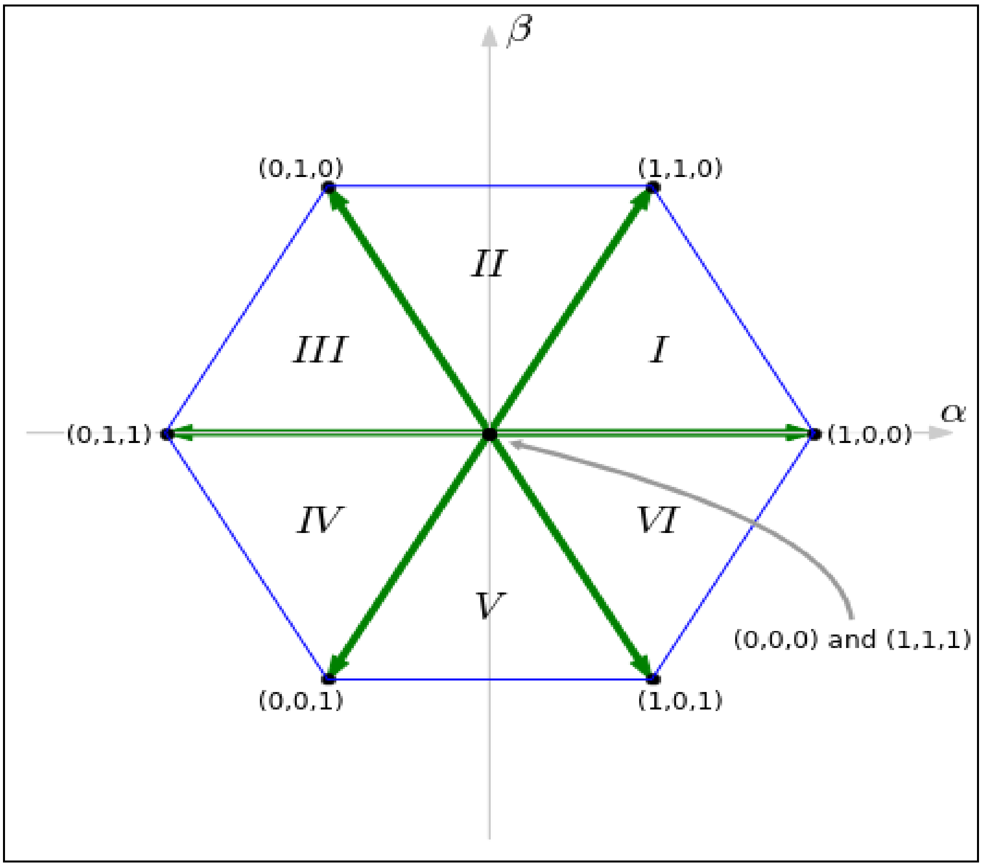
Sampling depends on the proper selection of states for each switch and its respective time duration [39,40]. Hence there are eight possible switching vector combinations are available in the orthogonal plane, only six non-zero switching vectors are used, it forms a hexagon which is shown in Fig.7 cited in [13].

Fig. 7- Vector Representation of Space Vector Modulation [13]



Modulation Scheme

The following procedures are required to develop space vector modulation:

- Initially, the reference vector V_{ref} obtained by mapping the orthogonal d-q coordinates from the reference signals of phase A, B and C.
- Secondly, in order to get one switching cycle the zero and non zero switching vectors are combined for V_{ref}

- Next, by implementing a simple trigonometric algorithm, selected switching vectors time durations are calculated.
- Finally, the switching network receives sequenced switching pulses.

Conversion Algorithm

Step 1: Consider the respective 3Φ reference voltages (V_a,V_b, V_c)

Step 2: Two-phase transformation is mapped from three-phase vectors

Step 3: Determine absolute value of V_d,V_q and arctangent (V_d/V_q)

Step 4: The sector must be identified where the source vector voltage is available.

Step 5: The switching vectors are selected from the respective identified sector.

Step 6: The calculation of switching times relies on the vector magnitude value of output voltage

Step 7: According to the sequencing scheme the switching vectors are obtained

Step 8: The Control signals are delivered to the switching network of each phase.

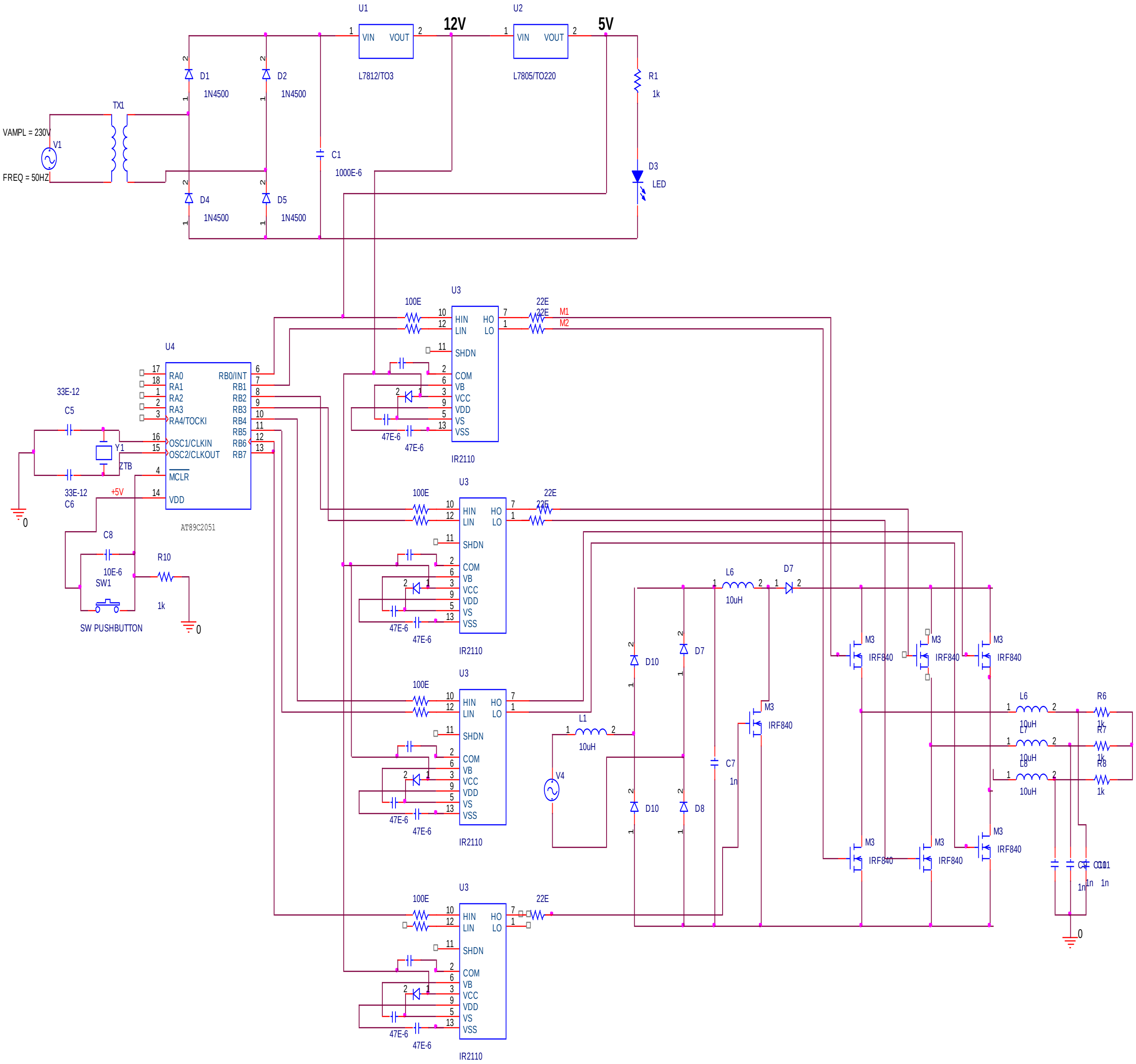
Step 9: Thus, the load terminals of voltage source inverter provide the required output.

3. Hardware Implementation of 1Φ to 3Φ Conversion

The source voltage of 220V AC is supplied to input of the transformer. The transformer is used to step-down the voltage from an AC voltage of 220V to 24V and 24V is given to the bridge rectifiers. Thus, the AC voltage rectified to rippled DC voltage. The capacitor is connected across the rectifier as a filter in order to minimize the ripples. The three-phase inverter is driven by the driver circuit with an angle of 120° mode. In this microcontroller 89C51 controls the gate signals.

The constant DC voltage as the input supply of micro controller (5V dc) is obtained by a circuit which consists of rectifier (40W, 300V, 1A), capacitors (1000 μF, 25PF). The drive circuit consists of Opto-coupler which is used to isolate the circuits of micro controller. The step-down transformer (230/12) V providing input supply to the drive circuits. The each MOSFET receives 12V gate single from the driver circuit to control the ON and OFF time duration of each MOSFET. The power and control circuit of the hardware system is shown in Fig 8.

Fig. 8- Power and Control Circuit of the Hardware System



Hardware Descriptions

The component details used in each control circuit, isolation circuit, microcontroller circuit, power supply circuit and load are given below.

N channel Mosfet -IRF 840

Gate voltage -10 V

Current rating -8A

Voltage -0-300 V

Diode	-1n4007
Micro Controller	-AT89C2051
Transformer	-230/0-15V 50Hz
Voltage Regulators	-LM7812 &LM 7805
Crystal Oscillator	-12MHz
Driver	-IR2110
Resistors	-220 ohms
Capacitors	-10 mf, 1000 μF, 25PF

Hardware Module of SVPWM

Fig. 9 represents the hardware module of 1Φ to 3Φ drive system. The power circuit of hardware which converts voltage of 230 V AC to 18V DC by using transformer with diode rectifier. The capacitor is used here to charge and discharge of voltage. The output voltage of diode rectifier 18 V is fed to the voltage regulator 7812 which regulate only 12 V. This 12 V is given to the driver circuit and the output of 7812 regulator is fed towards the LM 7805 which regulate 5 V. This 5V is fed to the microcontroller. The power and control module shown in Fig 10.

Fig. 9- Hardware Setup of 1Φ to 3Φ Drive System

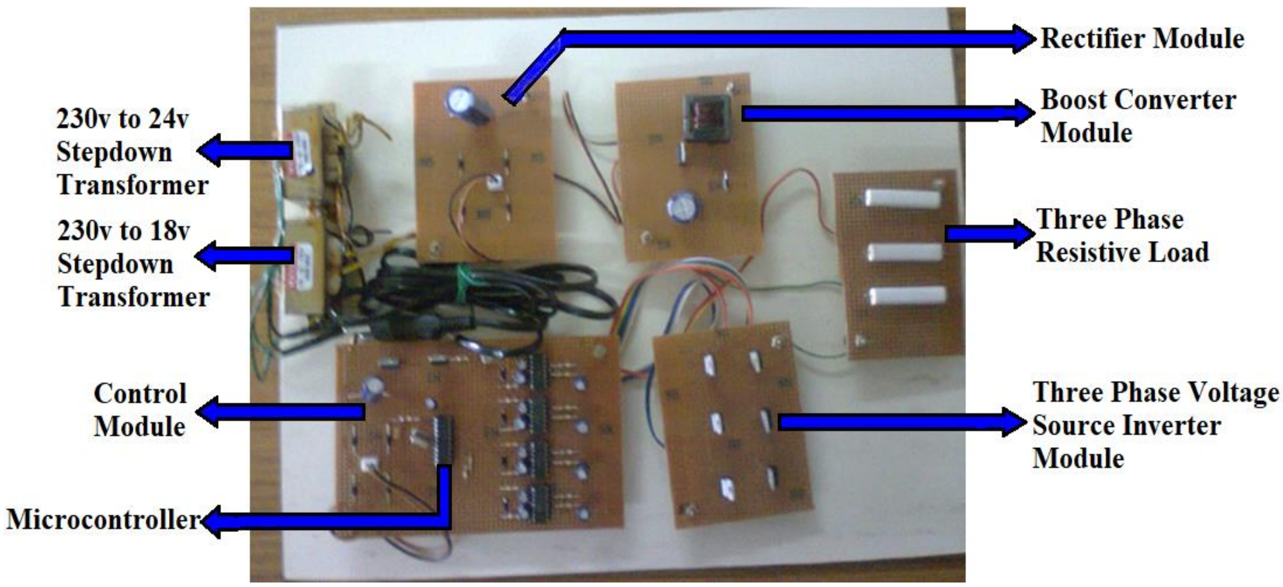
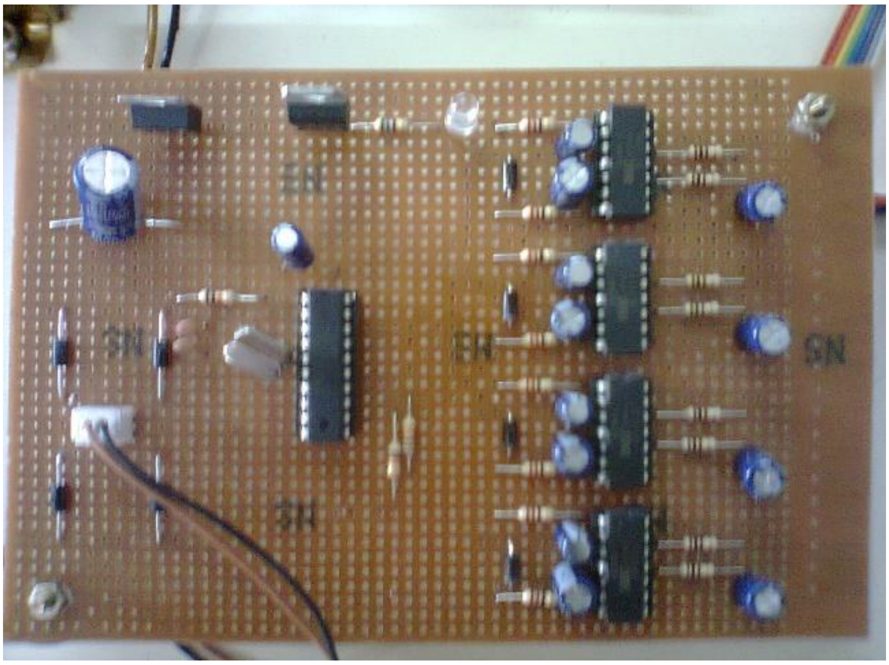


Fig. 10- Power and Control Module



4. Results and Discussion

Simulation Results

The waveform of the single-phase AC input to the drive system appears in Fig.11. and the 1Φ rectified output shown in Fig.12. From this image it is seen that the AC sinusoidal voltage waveform was converted into DC voltage with filter capacitor used to suppress the ripple in converted DC Voltage. The boost converter modifies the output voltage from 1Φ to 3Φ which is represented in Fig 13 and it is in the range of 1000 volts. The three phase sine wave for SVM and the DC bus voltage waveforms are shown in Fig. 14.This input waveforms is useful to generate the pulses to control the switching timing of each MOSFET in the VSI. The switching time of all six switches is generated, which will control the ON and OFF time of each MOSFET. The generated pulses from the space vector modulation Using MATLAB Simulink software for six switches are shown in Fig 15. The stepped inverter output of the inverter Phase voltages and Line Voltages are shown Fig 16 and 17 It clearly shows the generated three phase voltages with ripples. The novelty of the proposed system uses the Low Pass 2nd order filter with cut off frequency 200Hz and its damping factor is 0.707, which removes unwanted ripples and finally three phase sinusoidal output waveform was generated as shown in Fig 18.

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Fig. 11- 1Φ AC Input to the Drive System

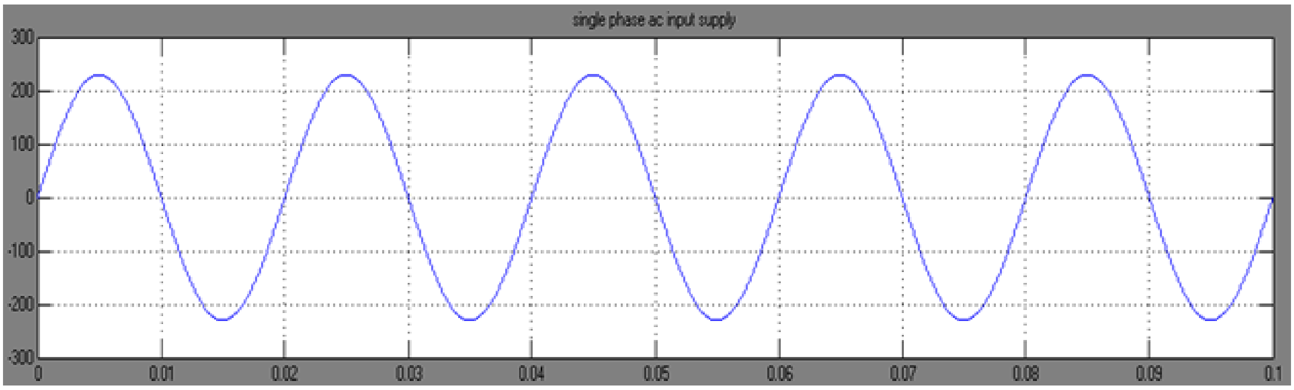

Fig. 12- Single Phase Rectifier Output Waveform

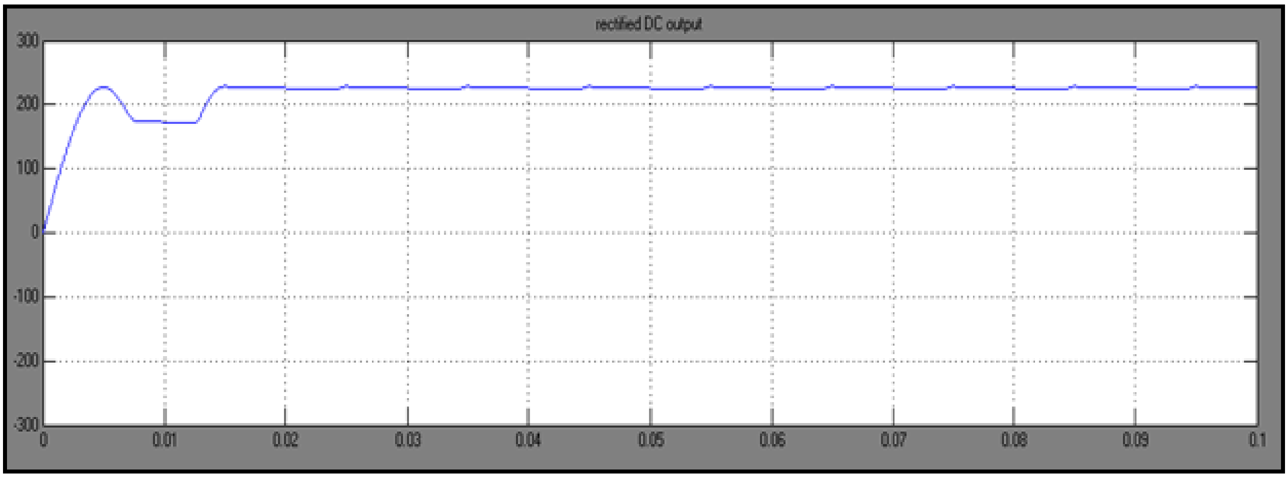

Fig. 13- Boost Converter Output Voltage

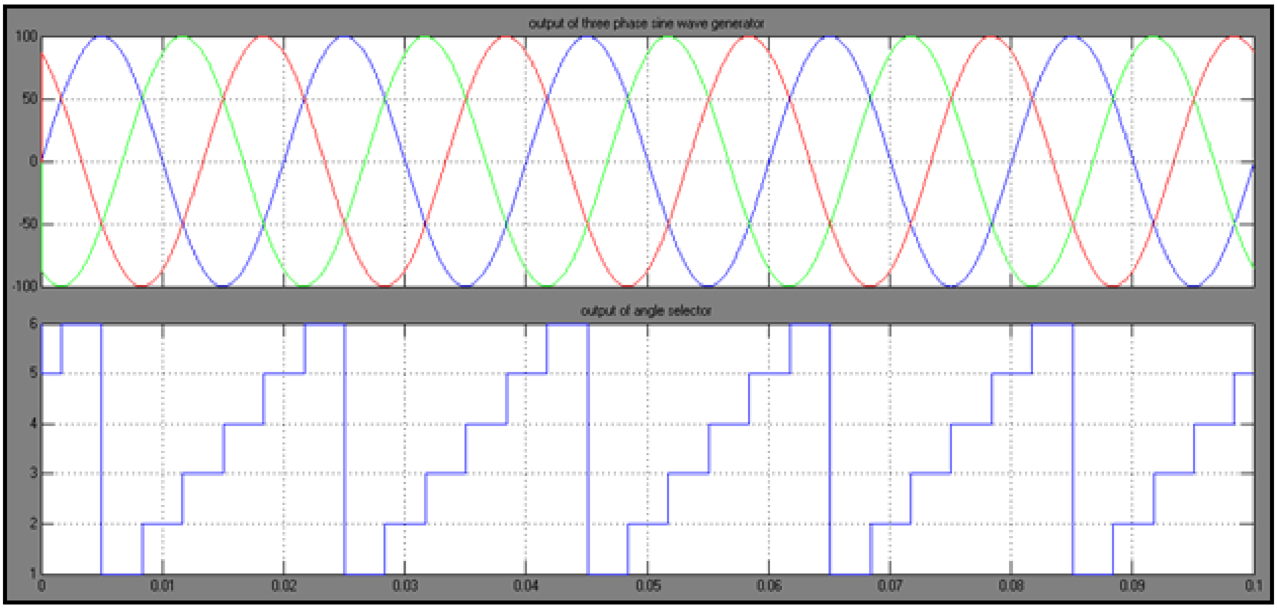

Fig. 14- Sine Wave Generator Output Signal and dc Bus Reference Voltage Wave Form

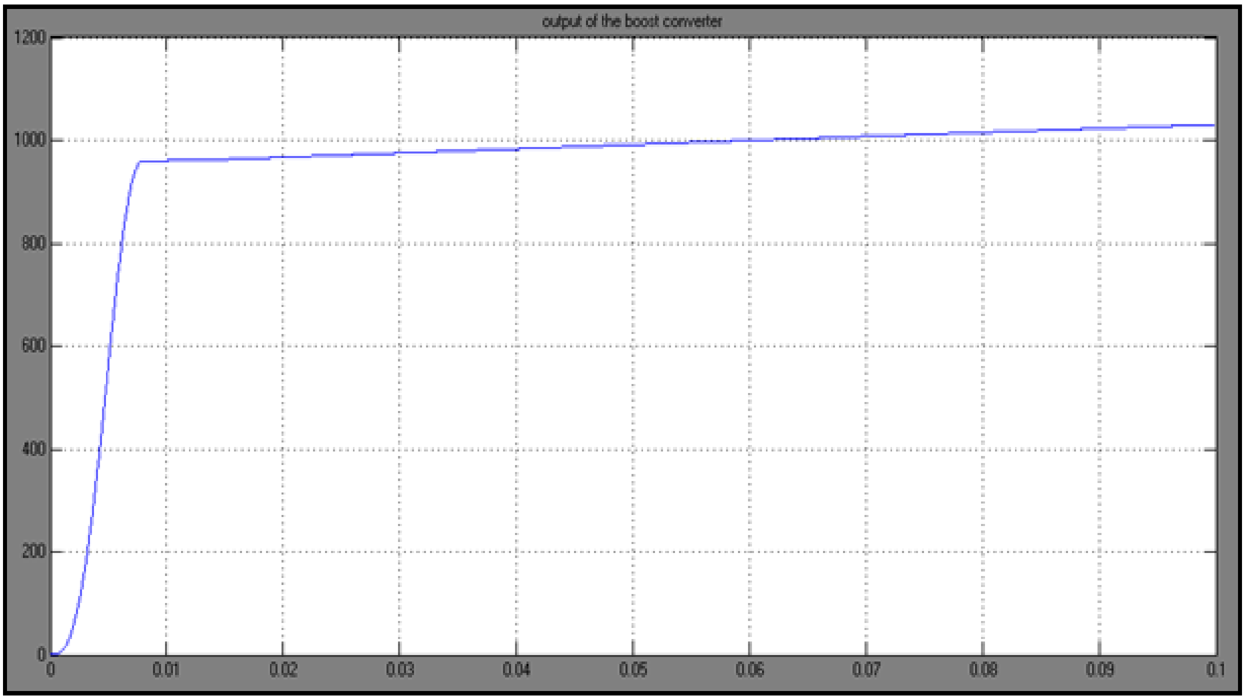

Fig. 15- Space Vector Modulation Output Pulses

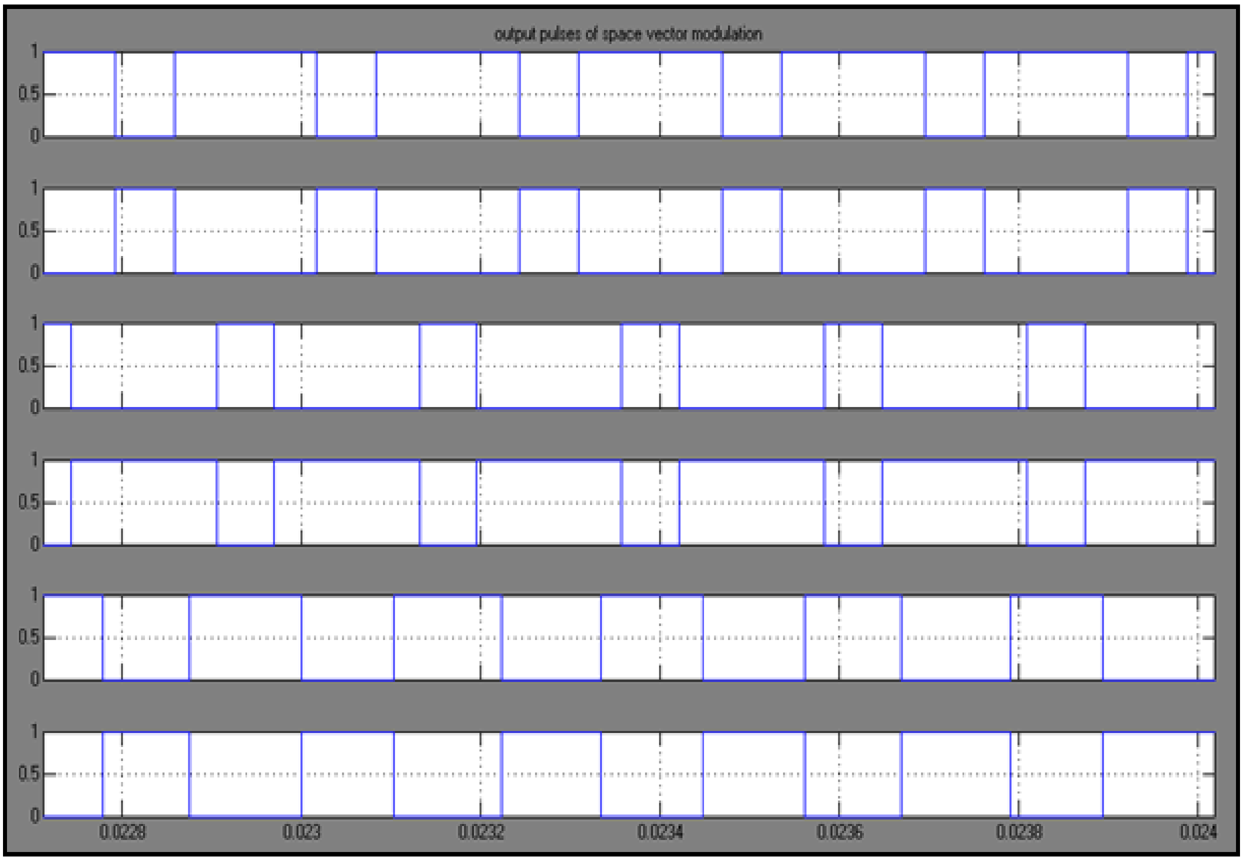

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Fig. 16- Inverters Stepped Output Phase Voltage

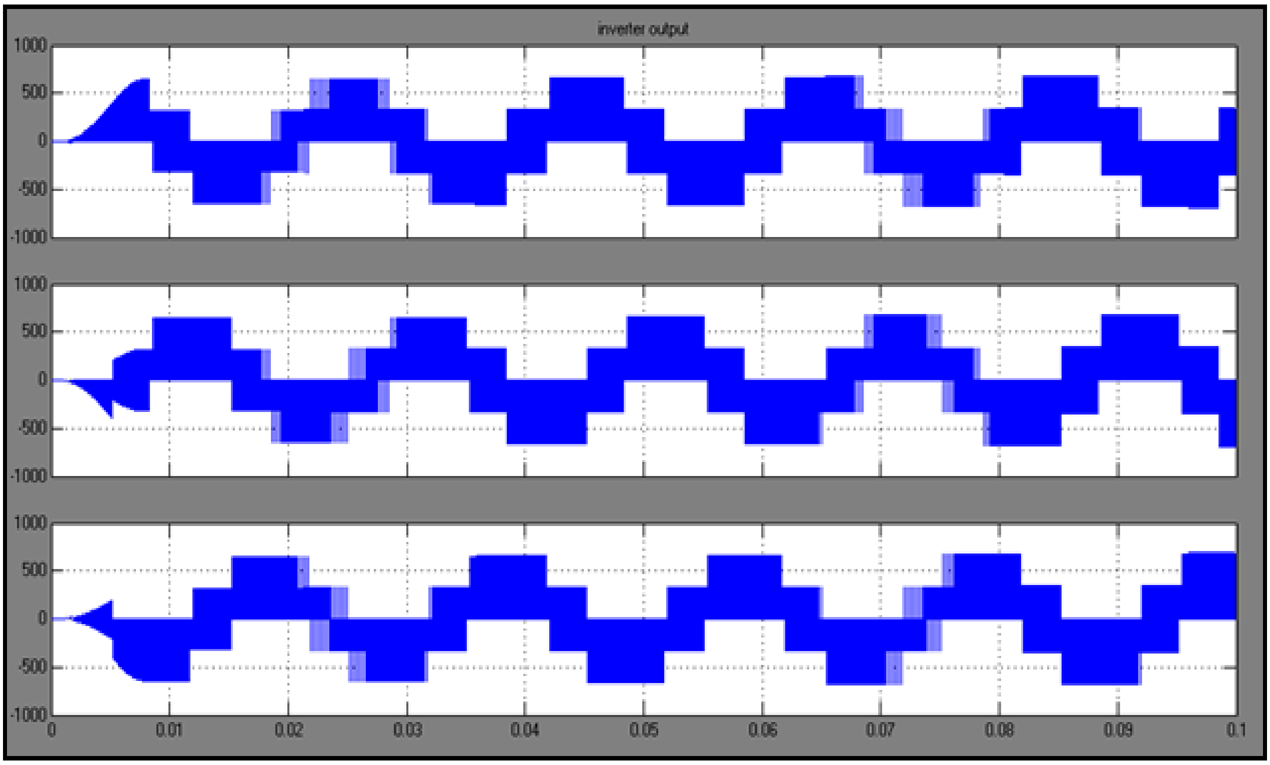


Fig. 17- Line Voltages of Inverter Output

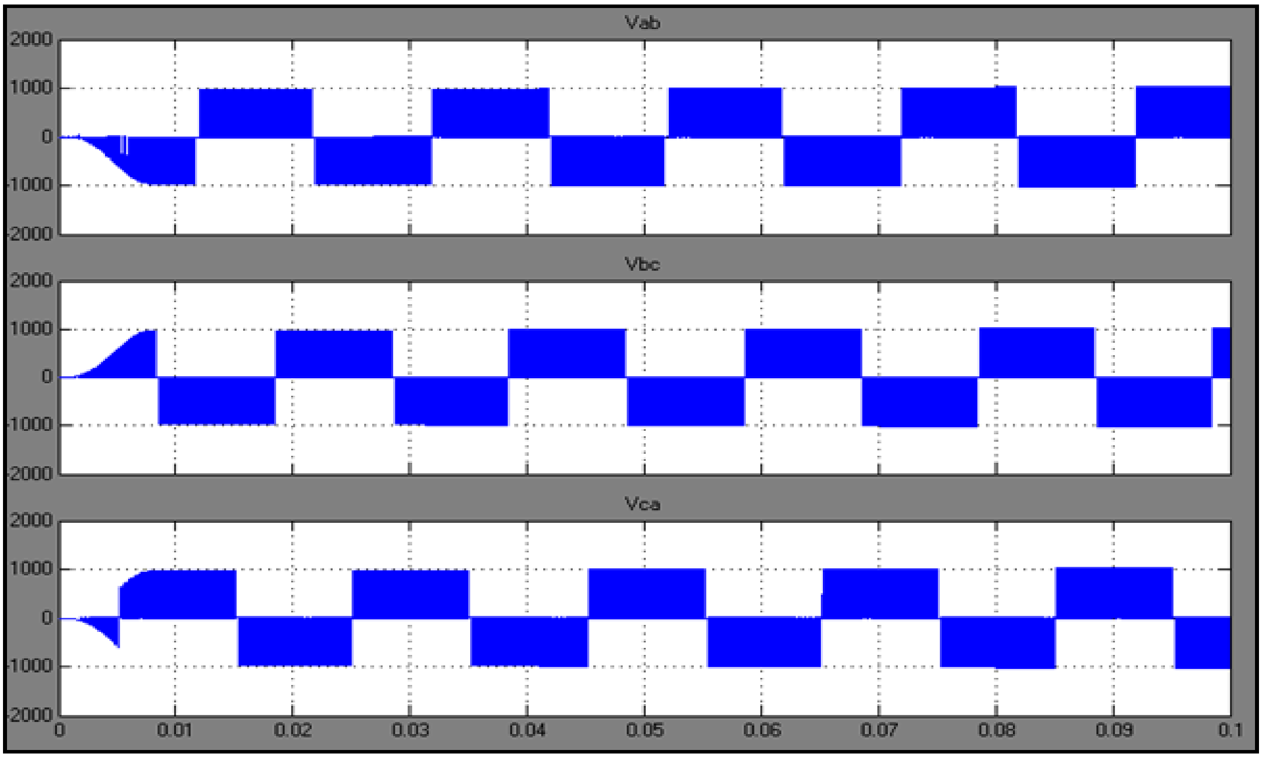
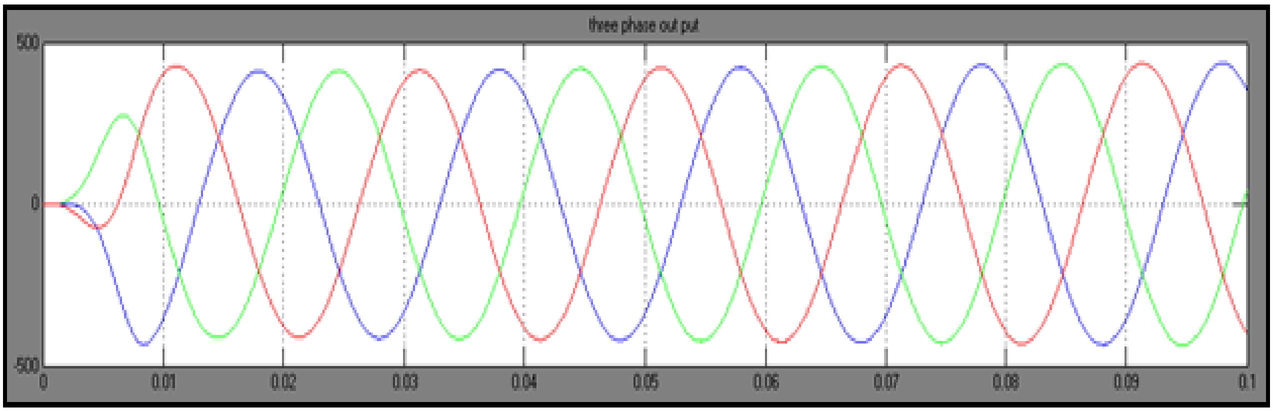


Fig. 18- Three Phase Sinusoidal Output



Hardware Design Result

Hardware with help of proposed system circuit and description shows the 1Φ input AC voltage converted into 3Φ AC voltage by using Space vector PWM technique. The Designed hardware clearly shows that conversion of AC Voltage to DC voltage was done and pure DC voltage was observed from the rectifier as shown in Fig. 19. The booster circuit increases the DC voltage for the required level of inverter voltage as shown in Fig. 20. The timing of the pulses was generated by SVPWM method, and the time duration was achieved by using Microcontroller AT89C2051. The generated pulses for the MOSFET are shown in Fig. 21. Finally the three phase AC Voltage generated from the Designed hardware has been supplied to the three phase induction motor. The performance of the induction motor was found to be smooth due to reduced total harmonic distortion. The converted three phase line volage shown in fig. 22.

Fig. 19- The Rectifier Output Waveform

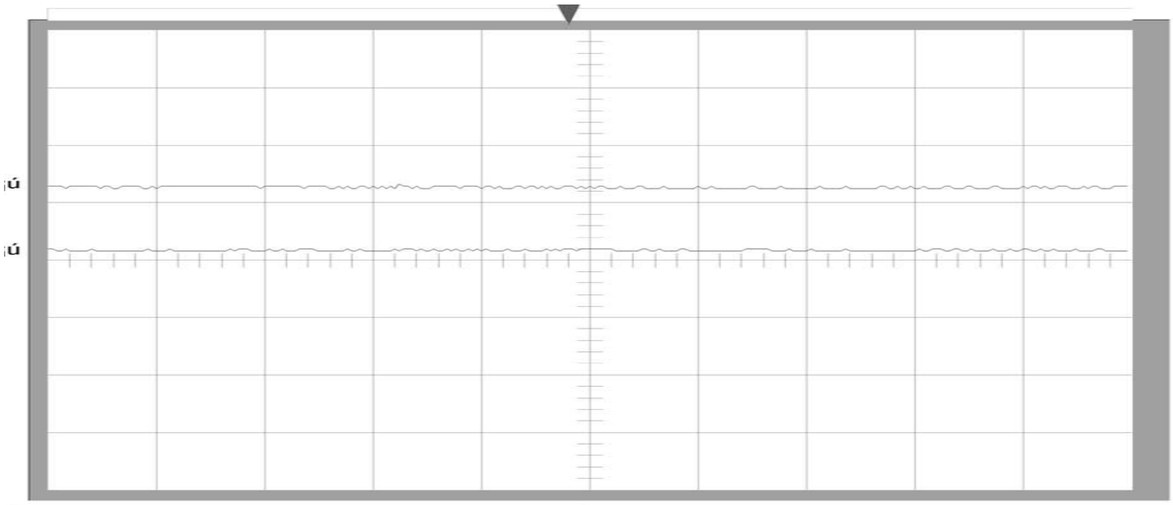


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Fig. 20- The Boost Converter Output Voltage Waveform

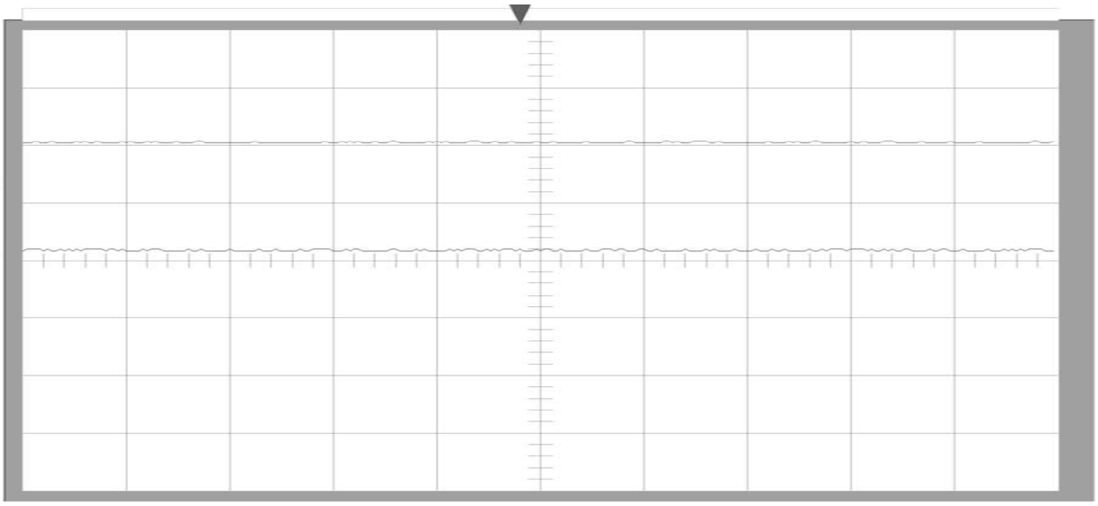


Fig. 21- The PWM Pulses for the 3Φ Voltage Source Inverter

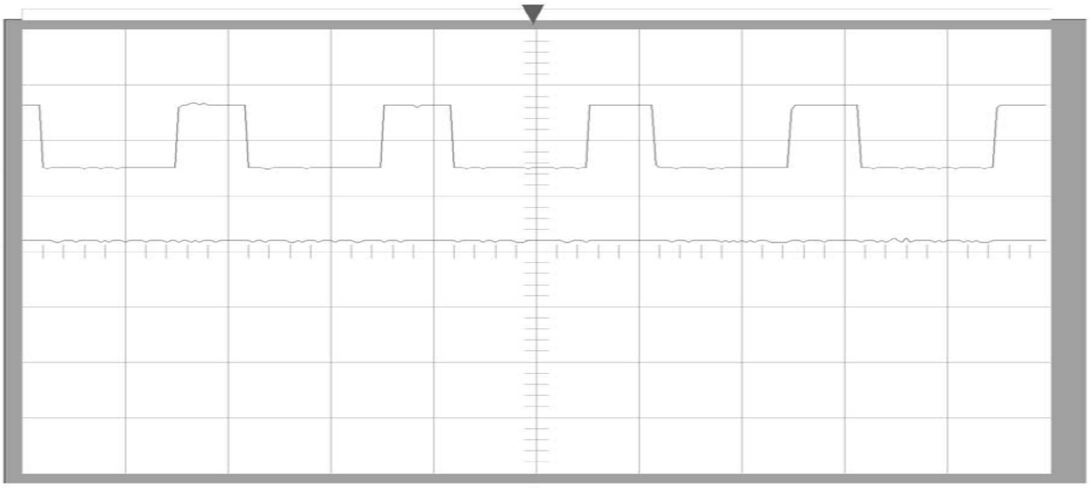
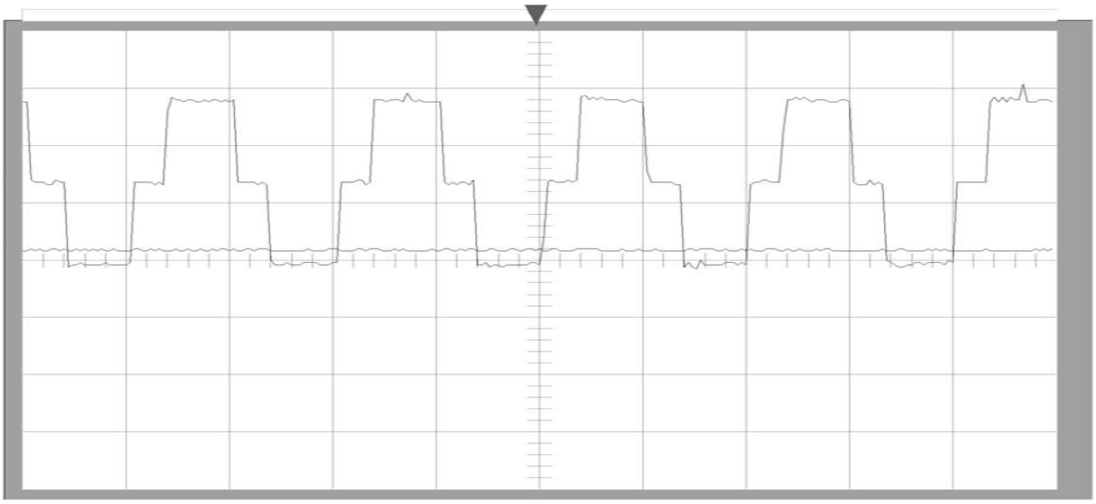


Fig. 22- The Line to Line Voltage of R Load of the Drive System



5. Conclusion

A 1Φ to 3Φ drive system consists of 1Φ bridge rectifier, a 3Φ inverter and an asynchronous motor which shows various control strategies, its system models and also it includes the space vector technique were developed. The correlation of the standard and proposed configurations has been analyzed. In contrast to the typical topology, the developed system allows to minimize the rectifier switch currents. In order to improve the fault tolerance characteristics, the *THD* (Total Harmonics Distortion) plays a vital role. This distortion factor is achieved by maintaining the similar switching frequency and grid current. Furthermore, the system developed in the present study has advantages such as reduced cost and losses due to fewer components over the traditional system. Compared to reviewed systems this proposed system incurs less investment cost and it is highly advantageous. The software and hardware output of the system was controlled precisely, even though the system exhibits the dynamic errors.

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