

DSP Based Real Time implementation of AC-DC-AC converter Using SPWM Technique

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ABSTRACT - In most of the drives applications, variable speed concept is achieved by using a back-to-back two level frequency converters. Firstly the open loop system model of ac-dc-ac converter is designed, simulated and realized in SIMULINK. TMS 320F28335 is used for pulse generation by SPWM technique. The problem of controlling the induction motors driven through ac-dc-ac converters is considered. The control objective is restricted to forcing the motor speed to track reference signal and is done with D-Q voltage control technique. The simulation is carried out in MATLAB/SIMULINK and results of both simulation and actual model are compared.

Keywords : PWM, induction motor, ac-dc-ac converter, D-Q voltage control, DSP.

1 Introduction

During the recent years in power electronics, many semiconductor switches with high switching frequency and high power handling capability has done great improvement.

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The other factor is the exposure of real-time computer controllers that can implement advanced and complex control algorithms. These factors have resulted in the development of cost-effective and grid-friendly converters. Power electronic converters are now used in many Grid connected applications including STATCOMs, UPFCs and active interfaces for distributed generation systems like PV or wind. Modern power electronics plays major role in development of traction application. In electric traction domain, used power nets are mono-phase. Due to their high capacity to ensure flexible voltage and frequency three phase DC/AC converters are preferred between railway nets and three phase AC motors.

Pulse Width Modulated (PWM) converters are used to overcome the problem of dominant harmonics related with input line current rectifier circuit [1], [2]. Also, the dynamic response of PWM rectifiers is much faster with a cut down in devices bulk and weight [3]. The PWM converters can be operated in variable frequency mode. There is no flexibility to adoption of different control strategies in analog circuitry [4]. Hence, digital circuit is used. Among all PWM techniques most effective and easy to implement method is Sine Pulse Width Modulation (SPWM). The SPWM technique also helps to reduce heat loss in the stator winding [5].

Previous works done on induction machine speed control employs vector control or direct control methods. But instead of going for complex calculation and data handling speed control can achieved with D-Q voltage control explained in this paper. This type of control is mainly confined to motor side converter only and will need current and speed feedback.

The digital control using a digital signal processor (DSP) provides precision and improvement in the system performance. Also, because of high speed central processor designer can process control algorithm in real time. In this paper output of three phase DC/AC converter is realised using digital signal processor. DSP TMS320F28335 can be interfaced with MATLAB 2009b thereby reducing the efforts in pulse generation. It can be programmed as per the requirement of pulses in MATLAB 2009b [14]-[16].

Most of the wind energy conversion systems consist of ac-dc-ac converters after the induction generator so that a symmetric and pure sinusoidal voltage is available at the output end. The WECS is modeled in MATLAB by using an asynchronous motor [8]. This PWM generation can be easily implemented in DSP interfaced with MATLAB. This paper is organized in the following sections. The section II describes block diagram and circuit diagram of the proposed open loop system configuration. The open loop and closed loop simulations with results are explained in section III. IV section explains about performance of controller designed. Hardware circuit description and DSP implementation of proposed system is in section V and VI. Section VII concludes the paper with references.

2 Proposed System Configuration

The basic block diagram of the open loop system is given. Basically it is a back-to-back converter model normally used WECS. It consists of an uncontrolled converter, IGBT based three phase inverter, speed controller and D-Q voltage controllers. Voltage controller can be implemented with the help of MATLAB-DSP interface to provide gate pulses to IGBTs.

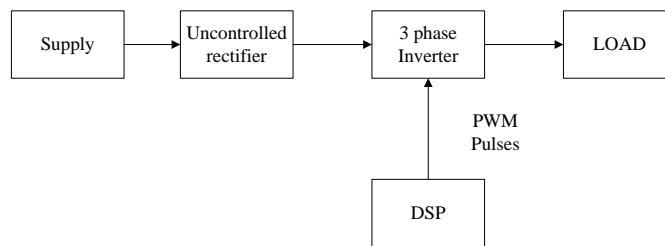


Fig1. Block Diagram of Proposed Model

Figure 2 below shows the circuit diagram for ac-dc-ac converter normally used in drives, tractions and other control applications. In this the main concentration is given on the highlighted DC/AC inverter part. The pulse generation is done with digital signal processor. IGBT switches are used to have a higher current carrying capacity and high switching frequency. The capacitor provided gives the constant DC voltage at the input side of the inverter.

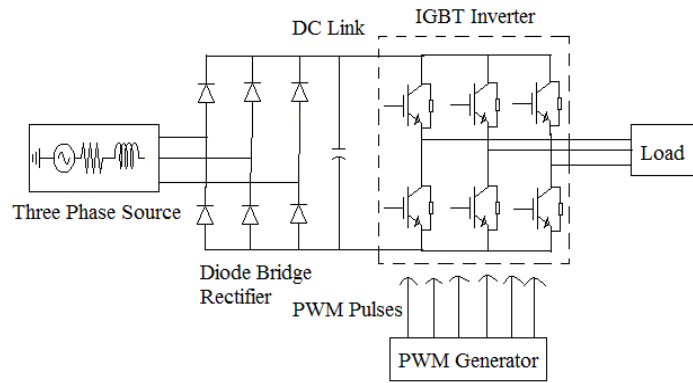


Fig.2 Circuit Diagram of Proposed Model

3 MATLAB Simulation

3.1 Open Loop Simulation

Simulation is carried out in discretized domain with a sample time 2 μ sec. The simulation model is as shown in the figure 3.

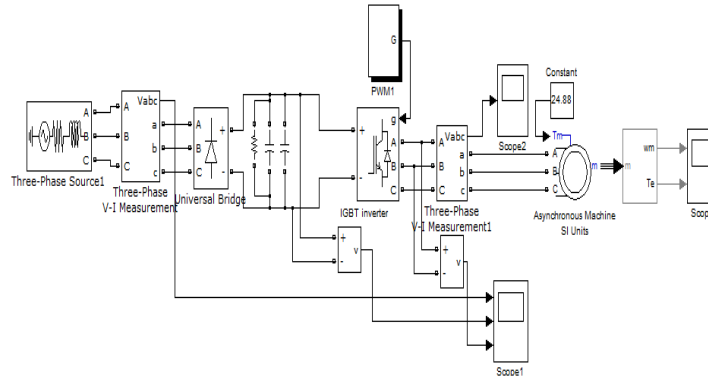


Fig. 3 Open Loop Simulation Model

The symmetric three phase voltage supply is taken representing equivalent AC supply from grid. Phase to phase rms voltage of 265.41 V is supplied as AC voltage to a universal bridge. The 4700 μ F of capacitor is connected for providing the constant voltage across inverter switches. The snubber resistance and capacitor is connected in

parallel to the DC link capacitor for protection purpose. The DC voltage is converted to AC output voltage by IGBT inverter.

The SPWM technique is used to trigger the switches of inverter. The reference wave is compared with a sine wave to generate pulses at 2250 Hz. The amplitude of reference wave decides the generated AC voltage amplitude and the frequency of reference wave adjusts the generated AC voltage frequency. Figure 4 represents the pulses generated by SPWM for three top switches of three legs of inverter. For bottom switches pulses with 180 degree phase difference are provided so as to avoid short circuit.

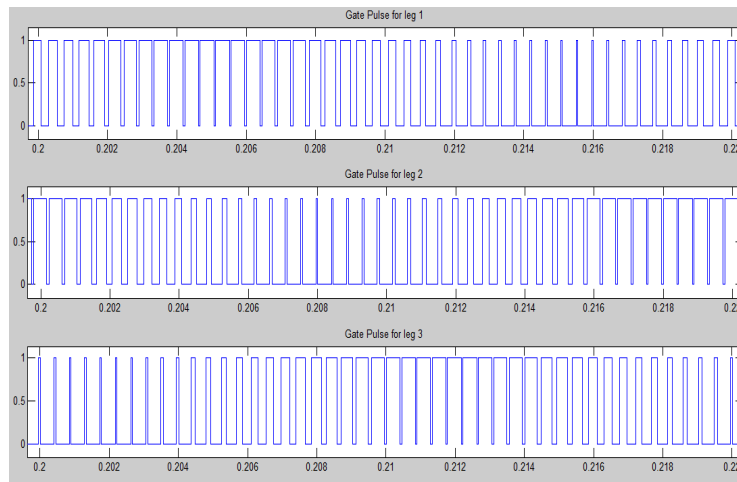


Fig. 4 Gate pulses by SPWM method

An induction motor is connected as a load to the inverter. Initially the load torque applied to the motor is kept zero. After comparing with open loop real time results, closed loop simulation can be done by applying some reduced torque than rated. It is calculated depending on power and speed relation. The waveform quality can be improved by LC filter at the output of the PWM inverter. For the convenience of comparison, output voltage without LC filter is considered in this paper. The simulation run time is fixed at 0.5 sec and results are summarized. System takes 11.042sec in real time to complete this simulation.

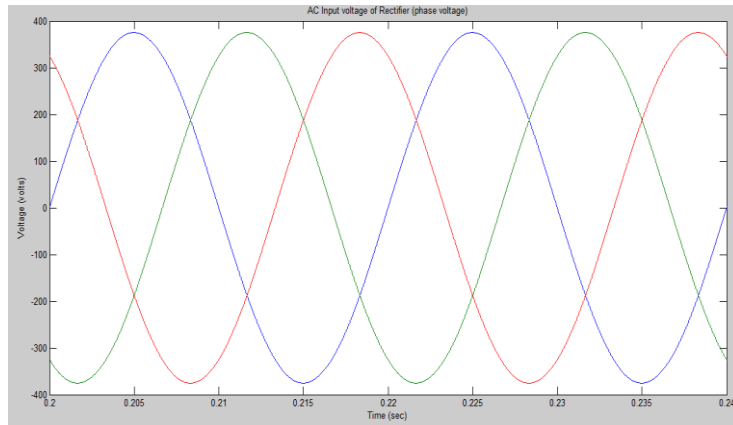


Fig. 5 Three phase input voltage for one cycle

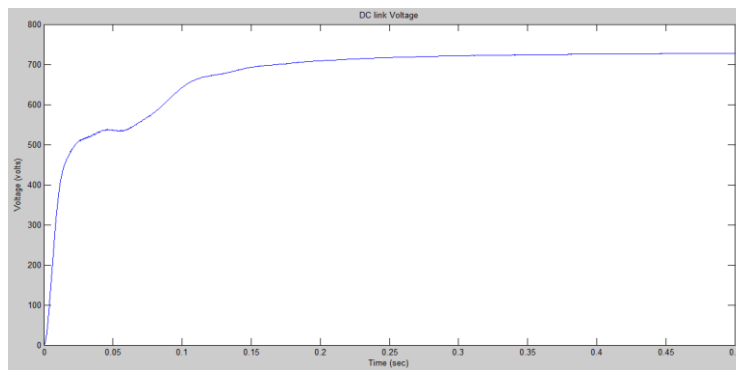


Fig. 6 DC link voltage

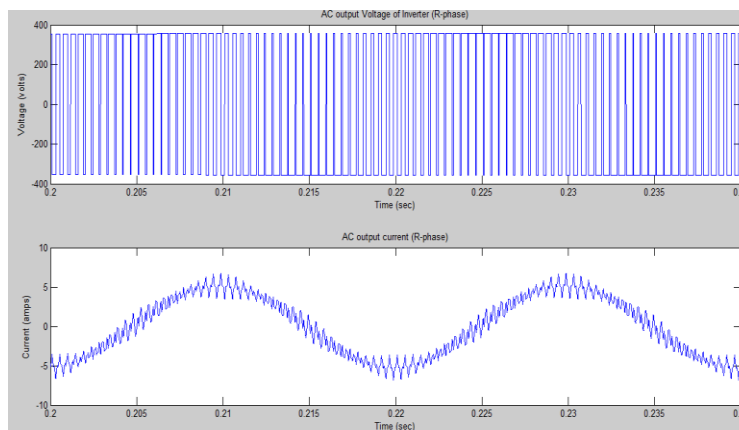


Fig. 7 Three phase AC output voltage and current

Figure 5 is the input three phase voltage waveform showing phase voltages for two cycles each of 20 ms period. The DC link voltage and AC output phase voltage and current waveforms obtained are shown in figure 6 and 7.

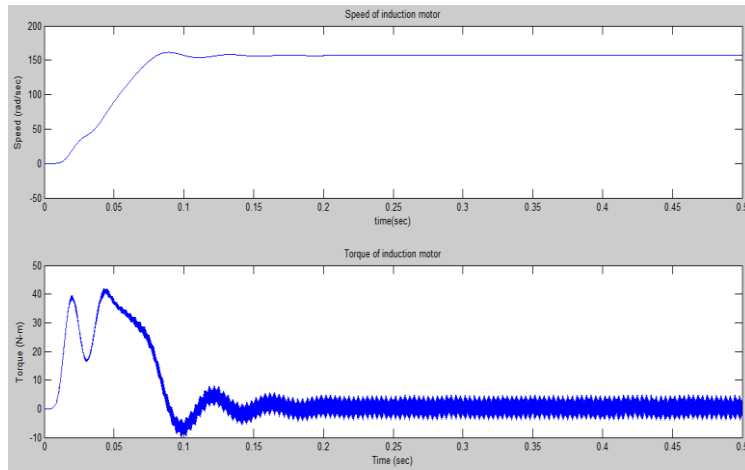


Fig. 8 Speed and Torque of induction motor

Figure 8 illustrates open loop operation of motor that it is running at rated speed since no load torque is applied.

3.2 Closed Loop Simulation

In DC/AC converters which are used in AC motor drives and for continuous AC power supplies basically we need to have a sinusoidal AC output whose magnitude and frequency can both be controlled.

In this paper, the voltage control of three-phase pulse width modulated voltage source inverter has been implemented in the rotating D-Q reference frame. Block diagram for proposed closed loop D-Q voltage control of ac-dc-ac converter is shown in figure 9. With the control of V_d and V_q voltages using a closed loop, speed of induction motor is controlled.

Parks transformation is performed to transform a-b-c reference frame parameters of feedback current into d-q reference frame parameters. Speed controller generates I_{qref} which is a speed or torque component of current in d-q frame. I_{dref} (flux component

of current) is manually kept fixed so that flux should not get affected while controlling speed. This is done by using decoupling principle.

A PI controller is designed in such a way that controlled V_d and V_q are being generated based on errors in I_d and I_q respectively. The gain of PI controller is decided based on relation between V_d , V_q and I_d , I_q .

$$v_d = Ri_d - L\omega i_q$$

$$v_q = Ri_q + L\omega i_d$$

With the help of Parks Transformation voltages in d-q frame are transformed in a-b-c frame as a modulating voltage signal for a discrete PWM generator. The PWM pulses triggers IGBT switches so that inverter output voltage given to stator of induction motor is controlled. Actual time elapsed during simulation of closed loop is 107.1593 sec.

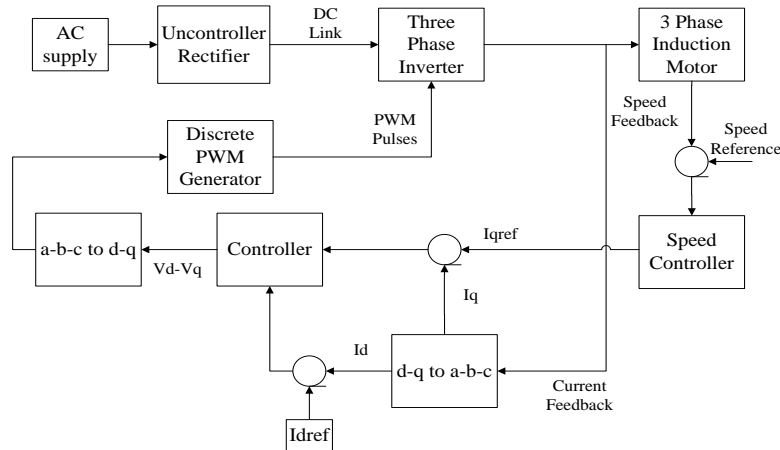


Fig. 9 Block diagram of closed loop D-Q control

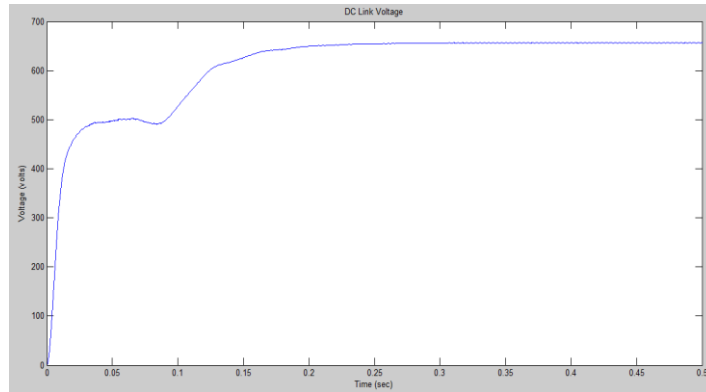


Fig. 10 DC link voltage for closed loop simulation

Figure 10 shows that transients in DC link voltage are reduced in closed loop. A disturbance in terms of step change in I_{dref} is given at 0.3 sec of simulation. Since, I_{dref} is flux component of current it will change only change flux and not the speed.

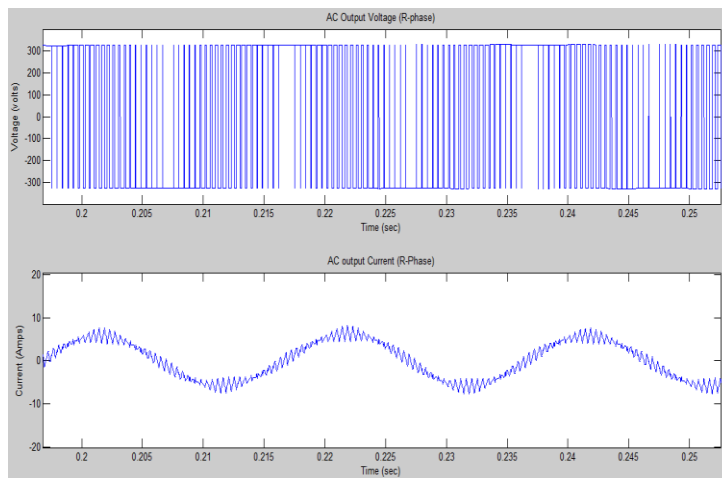


Fig. 11 AC output voltage and current (R-Phase)

Figure 11 shows AC output voltage and current of inverter with very less harmonics. It is shown for two cycles. Speed and torque observed for induction motor is shown in figure 12 below without any distortions for zero load torque condition.

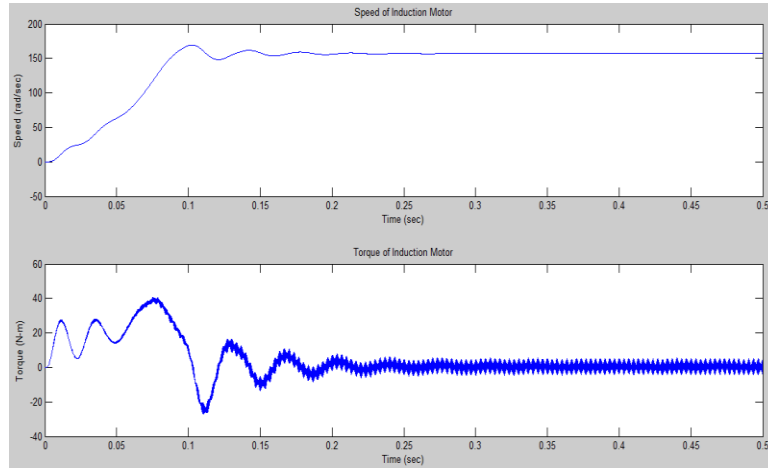


Fig. 12 Speed and Torque of induction Motor

With speed as a feedback, speed component of current (I_{qref}) is generated through a speed controller, which is then compared with actual value of I_q for controlled V_q . Speed is getting settled at 155 rad/sec which is the set reference speed provided.

4 Performance of Controller

Working of controller is verified by giving a step change in I_{dref} signal. When flux component reference value is changed, it has no effect on speed component of current. I_q will keep on tracking I_{qref} . From the figure 13 and 14, we can observe that speed component is almost tracking speed component reference. This reveals that speed controller is properly tuned.

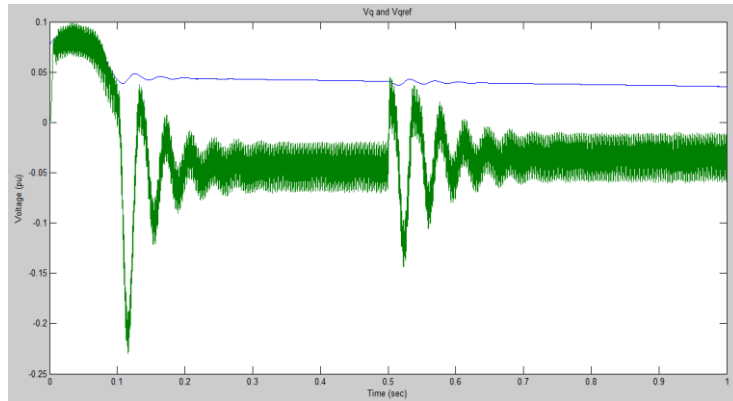


Fig. 13 I_q and I_{qref} with disturbance in I_{dref} at 0.3 sec

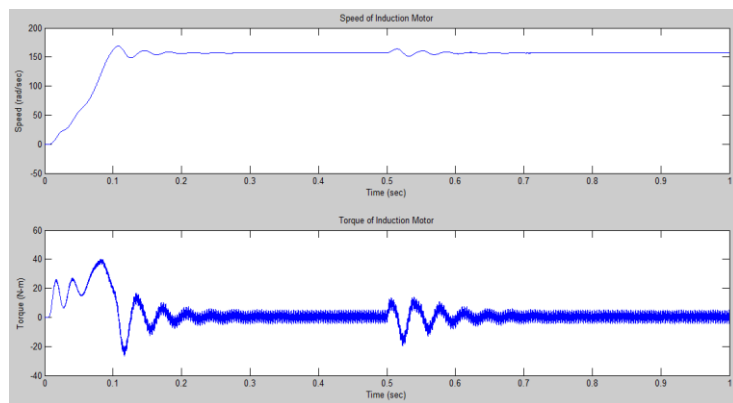


Fig. 14 Speed and Torque of Induction Motor

Also from above figure, we can see that speed remains constant irrespective of changes in flux reference. So D-Q control is achieved.

5 Hardware Circuit Description

The circuit description can be divided into two sections as the control and the power circuit. The opto-couplers are provided as a separator between them.

The control circuit section is having three parts namely PC, DSP board and IGBT driver. DSP is programmed to produce gate pulses by comparing a triangular carrier wave of 2250 Hz and a sinusoidal reference wave of 50 Hz. The amplitude of

reference wave decides the generated AC voltage amplitude and the frequency of reference wave adjusts the generated AC voltage frequency. Opto-coupler amplifies the DSP output signal to the level required to trigger IGBT and isolated DSP from power circuit. TLP250 is used as isolator.

The power circuit section consists of four parts namely uncontrolled converter, full bridge inverter, DC link capacitor and load. The inverter and rectifier are self content blocks with inbuilt DC link capacitor. The waveform quality can be improved by LC filter at the output of the PWM inverter.

6 DSP Implementation

The open loop system model is implemented in real time hardware setup using DSP-MATLAB interface and the circuit description as specified. Using the target support package tool of MATLAB, the DSP TMS320F28335 is connected to PC. ePWM Module is used to generate six pulses at a time from ePWM pins of DSP. These pulses are being fed to opto-coupler TLP 250 which boosts up the voltage level to an extent at which IGBT switches can be triggered. The system setup is shown in the fig. IGBT gate pulses are observed in digital signal oscilloscope.

Figure 15 represents the block diagram of the Hardware Setup. The firing pulses for the H-bridge inverter are given from DSP board.

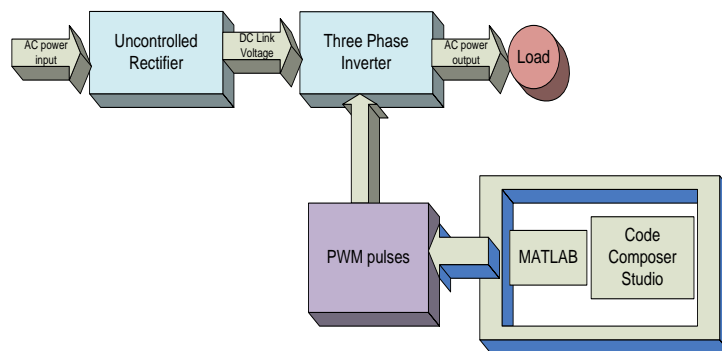


Fig. 15 Block Diagram of Hardware Setup

TMS320F28335 eZdsp is a floating point DSP so it is flexible for advanced calculations. The in-built property of 12-bit ADC with a sequencer allows conversion of multiple analog signals sequentially from DSP.

The pulse pattern can be obtained by connecting a digital oscilloscope with a DSP kit. F28335eZdsp includes a module Event Managers which can be used for pulse generation. Each Event Manager module contains General Purpose (GP) timers and PWM circuits and output logic. The DSP processor has ePWM output. This DSP has 6 ePWM (Enhanced PWM) modules, which can generate the desired PWM signals [22] [23].

MATLAB2009b has target support package library which supports the DSP implementation [8]. The library contains ePWM blocks which are used for generating pulse patterns. The PWM logic was developed as a simulink model. One of the models developed in MATLAB is given below:

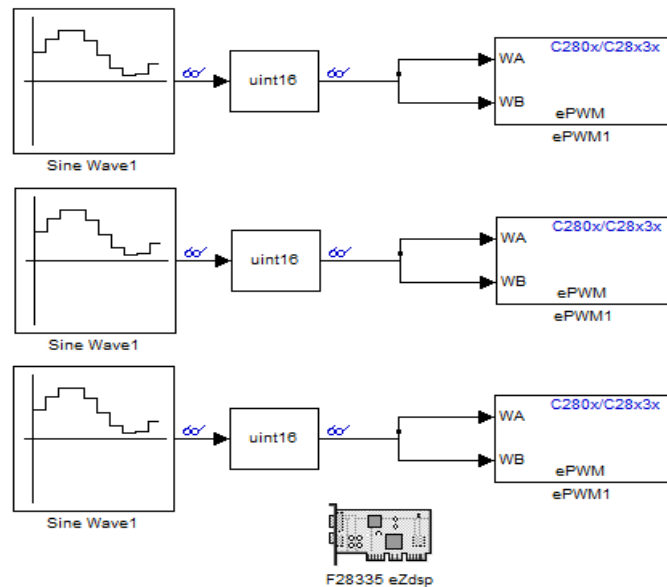


Fig. 16 MATLAB/Simulink model

Figure 16 shows the logic generation of bipolar PWM for three phase inverter. The sine wave block is taken and is sampled with respect to time with a sample time of 64/80000. The sine wave is taken at a fundamental frequency of 50Hz. The amplitude

and the bias value were calculated according to the count given for the timer period value (TxPR). The bias point is half of the TxPR value and the amplitude of sine wave is taken as 86% of the bias value. The sine wave block is converted into as per the data type and the scaling of the output [14] [16].

The ePWM module is taken from the target support package library and in this block the carrier wave of required frequency was generated. The counting mode was specified as up-down counting and the compare value for the ePWM A and ePWM B pulses were given from input port i.e. sine wave. Now whenever the compare match occurs a pulse is generated. The timer period value can be calculated from the following formula:

$$\text{TxPR} = (\text{CPU clock frequency}) / (\text{Desired frequency} * 2)$$

Figure 17 (a) below shows the hardware setup of the system described. The PWM pulses generated at the output of the opto-coupler is in figure 17 (b). Figure 17 (c) reveals that output voltage between two phases is closely matching with that of the simulation results. First waveform represents phase-phase voltage output with the multiplier of 100 and lower one represents the phase-phase current waveform output.



Fig.17 (a) Hardware setup of the system

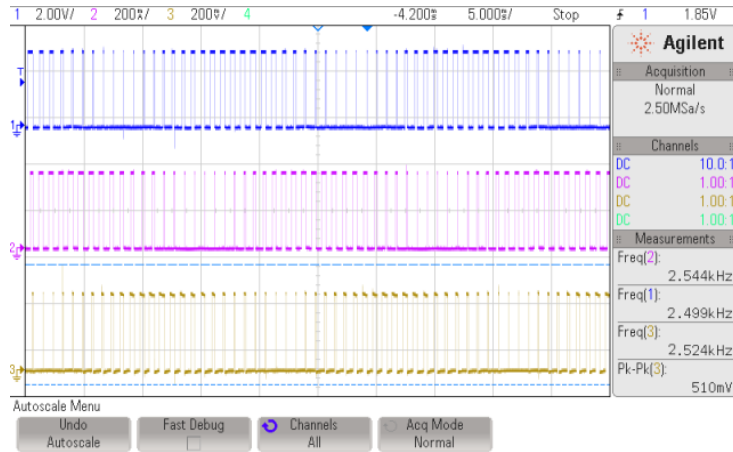


Fig. 17 (b) Gate Pulses from ePWM Pins of DSP for One Cycle

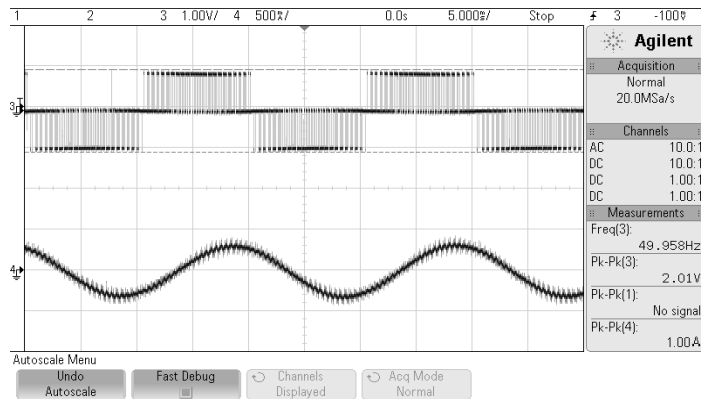


Fig11 (c) Phase-Phase output Voltage and Current Waveform

7 Conclusion

This paper presents the analysis and design of a digitally controlled three-phase PWM inverter to develop more theoretical and practical knowledge for control applications. The software optimization and Hardware installations for proposed system is achieved. The real time simulation is done effectively using TMS320F28335 DSP at 2.55 kHz switching frequency. Speed is maintained as per the reference provided with a simple closed loop d-q voltage control. The very close similarity between simulation

and actual hardware results of output voltage waveforms illustrates the efficiency, accuracy of PWM inverter.

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