

# Cost Effective B4 Inverter Fed Induction Motor Drive

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**Abstract:** The aim of this paper is to analyze a B4 Inverter for induction motor drive. In this approach, instead of conventional 6-switch, 3-phase (SSTP) PWM inverter, a B4 inverter is utilized. This reduces both the cost of the inverter and the computation for real-time implementation. The advantage of this inverter is lesser switching losses, lower electromagnetic interference (EMI), less complexity of control algorithm and reduced interface circuits. A low cost of motor drive is the more advantageous factor that can be achieved using the proposed drive system. A simulation model of the drive system is developed and analyzed in order to verify the effectiveness of the approach. Furthermore in this project Sinusoidal Pulse Width Modulation (SPWM) and Random Pulse Width Modulation techniques are being compared. These techniques are used to generate their respective output PWM signals, which are then compared, based on harmonic content and distortion using the THD measure of various output voltages. In the present work, we propose a study of RPWM technique in a drive system based on a Four Switch Three-Phase inverter, feeding an induction motor. RPWM provide better responses when compared with the conventional PWM Techniques. Random Pulse Width Modulation (RPWM) approach can make the harmonic spectrum of inverter output voltage to be continuously distributed without affecting the fundamental frequency component. The control strategy of the proposed drive system of three phase induction motor is based on Model Predictive Control technique. Simulation results are carried out in Matlab/Simulink to analyze and explore the characteristics of the proposed drive system.

**Keyword:** Model Predictive Control technique, Induction motor, Pulse Width Modulation (PWM), Random PWM, Sinusoidal PWM and Total Harmonic Distortion (THD).

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## 1. INTRODUCTION

Induction motor has been considered as the work-house of various industries because of its very wide industrial applications and well known advantages such as simplicity and robustness. In recent years, the industries are focusing on the low cost ac drives to meet the need for reducing the cost particularly when power demanded by the target application is within the low power range. Also in rural electric systems and in remote areas, the cost of bringing three phase power is often high due to high cost of three phase extension. Moreover the rate structure of three phase service is higher when compared to single phase service. For these above mentioned criteria, a cost effective drive has to be designed. The low cost could be gained by reducing the power switches in the inverter feeding the electric motor.

A variable speed motor with wide speed range offers the designer to get better operating features. This can be obtained by the using three phase motor, which is readily available. Therefore, the use single to three phase converter is best suited for these situations where three phase power is not available. Researchers have investigated different methods including static phase converter, rotary phase converters, reduced topology power electronic converters & novel motor designs [1-4]. The components reduction is possible by making alternatives to the conventional three phase bridge configuration for a voltage fed inverter, since this circuit utilizes six switching devices and six reactive power diodes. This leads to a bridge

circuit with only four switching devices and four reactive power diodes. It has been demonstrated that a two-level current control can be implemented to yield quasi sinusoidal currents in the three phase load [5,6]. The variable speed ac motor drive utilizes three phase (B6) inverters with high speed power semiconductor devices. Traditionally these inverters (B6) have been widely used for drives but they have some major drawbacks which include the switching losses, complex control algorithm and on board interfacing circuits to generate six PWM signals. This can be overcome through the reduction in topology of the inverter in the armature which has two legs (four switches) instead of three legs (six switches) in conventional inverters.

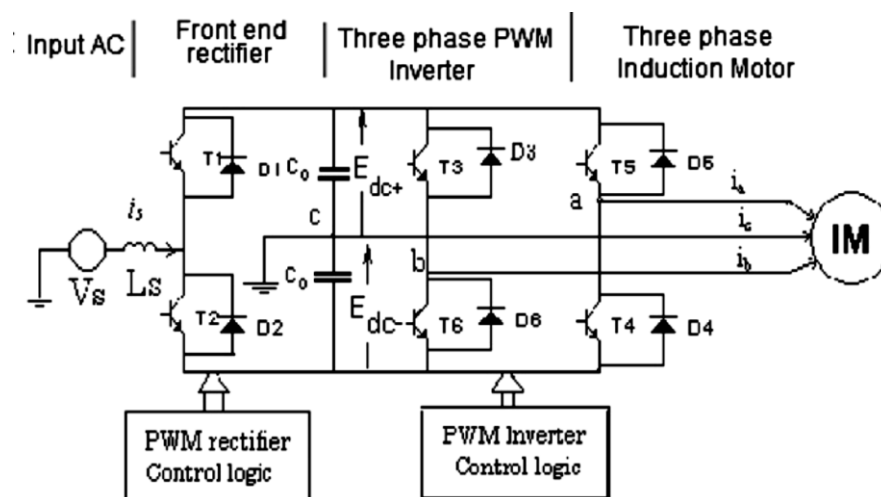
In this paper a B4 (Four Switch Three Phase) Inverter for a cost-effective induction motor drive is developed. The overall drive system employs only six IGBT transistors for the rectifier and inverter structure. The B4 inverter has the following advantageous factors over the traditional B6 inverter, they are

- switching loss minimization,
- reduced count of interface circuits to provide logic signals,
- ease of control algorithm to generate logic commands,
- the chances of destroying the switches because of reduced interaction between switches get minimized and
- for real time application, the computational burden are reduced.

The past research works on B4 inverter for induction motor drive did not paid much attention for closed loop control using Model Predictive Control (MPC) technique. In this paper, the proposed approach consists of B4 inverter fed induction motor drive with MPC technique. The paper is organized as stated below: In the first section, the B4 inverter topology is described. Next the analysis and comparison of different switching strategies namely SPWM & RPWM for FSTP inverter are presented. Taking into account the comparison results on THD basis, the control strategy with MPC technique is being implemented. Finally the paper presents B4 inverter fed induction motor drive system incorporating the Model Predictive Control Technique. The simulation results are carried out using Matlab/ Simulink to explore the performance characteristics of the low cost drive.

**2. B4 INVERTER TOPOLOGY**

The single to three phase converter configuration is shown in Fig.2.1. The circuit consists of a front end rectifier, three phase PWM inverter and three phase induction motor. The switches T1 and T2 form the front-end rectifier and two split capacitors form the DC link. The power circuit of the FSTPI fed IM drive has 4 switches, namely T3, T4, T5 and T6 and a split capacitor. The switches are controlled in order to generate an AC output from the DC input. The two phases ‘a’ and ‘b’ are connected through two legs of the inverter, while the third phase ‘c’ is connected to the center point of the DC link capacitors, C1 and C2. The capacitance value of C1 and C2 are equal. The front end rectifier converts a single phase utility ac supply voltage to dc voltage. A boost inductor  $L_s$  is connected in series with the utility supply voltage.



It is assumed that the 4-power switches are denoted by the binary variables S1 to S4. The binary ‘1’ corresponds to an ON state and the binary ‘0’ corresponds to an OFF state. The states of the upper (S1, S2) and lower (S3, S4) switches of a leg are complementary that is  $S3 = 1 - S1$  and  $S4 = 1 - S2$ .

Considering a 3-phase Y-connected Induction Motor, the terminal voltages  $V_{as}$ ,  $V_{bs}$  and  $V_{cs}$  can be expressed as the function of the states of the upper switches as follows:

$$V_{as} = V_c/3 (4S1 - 2S2 - 1) \tag{2.1}$$

$$V_{bs} = V_c/3 (-2S1 + 4S2 - 1) \tag{2.2}$$

$$V_{cs} = V_c/3 (-2S1 - 2S2 + 2) \tag{2.3}$$

where,  $V_{as}$ ,  $V_{bs}$ ,  $V_{cs}$  are the inverter output phase voltages. ‘ $V_c$ ’ is the voltage across the DC link capacitors. ‘ $V_{dc}$ ’ is the voltage across the capacitor C1 and C2 ( $V_{dc} = V_c/2$ ). S1, S2 are taken as the switching functions for the 2-switches. In matrix form the above equations can be written as:

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \frac{V_c}{3} \begin{pmatrix} 4 & -2 \\ -2 & 4 \\ -2 & -2 \end{pmatrix} \begin{bmatrix} S1 \\ S2 \end{bmatrix} + \frac{V_c}{3} \begin{bmatrix} -1 \\ -1 \\ 2 \end{bmatrix}$$

**TABLE.I: SWITCHING STATES AND OUTPUT PHASE VOLTAGE**

Switching States		Output States		
S1	S2	V <sub>as</sub>	V <sub>bs</sub>	V <sub>cs</sub>
0	0	-V <sub>c</sub> /3	-V <sub>c</sub> /3	-2V <sub>c</sub> /3
0	1	-V <sub>c</sub>	V <sub>c</sub>	0
1	0	V <sub>c</sub>	-V <sub>c</sub>	0
1	1	V <sub>c</sub> /3	V <sub>c</sub> /3	-2V <sub>c</sub> /3

### 3. INVERTER SWITCHING SCHEMES

#### A. Pulse Width Modulation:

Pulse Width Modulation is a powerful technique used to control the analog and digital circuits. The objective of PWM technique is to provide better controllable output voltage with reduced harmonics. The PWM technique is employed in inverters to have a steady output voltage of 230 or 110V AC irrespective of the load. The output voltage from an inverter can be adjusted by exercising a control within inverter itself. The most efficient method of doing this is by pulse-width modulation control used within an inverter. In this method a fixed DC input voltage is given to the inverter and a controlled AC output voltage is obtained by adjusting the ON and OFF periods of the inverter components. This is the most popular method of controlling the output voltage and this is termed as PWM control.

The advantages of using PWM are: the output voltage control is easier and can be achieved without any additional components, the lower order harmonics are either minimized or eliminated altogether, it has very low power consumption, the entire control circuit can be digitized which reduces the susceptibility of the circuit to interference.

#### B. PWM Classification:

The classification of PWM techniques include

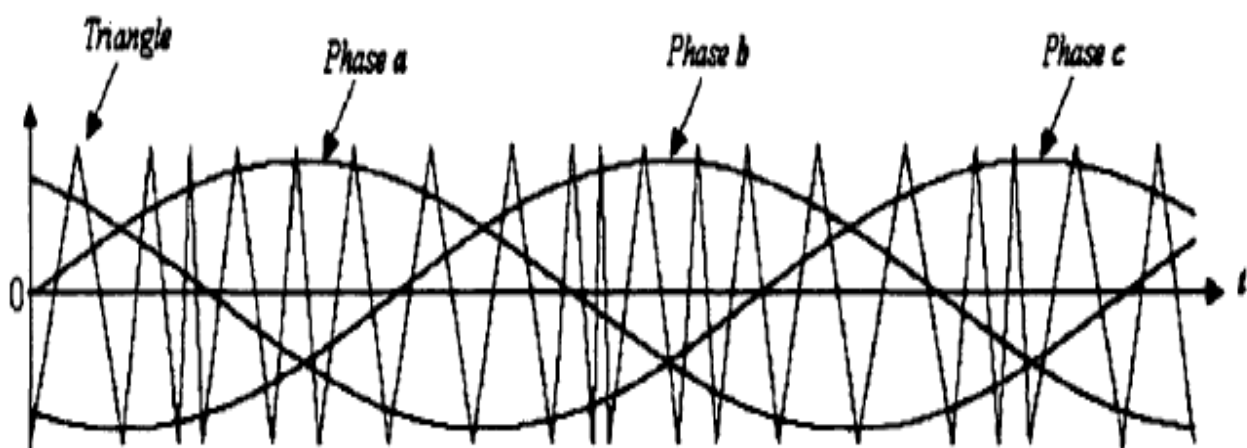
- ⇒ Sinusoidal PWM (SPWM)
- ⇒ Selective Harmonic Elimination (SHE) PWM

- ⇒ Minimum Ripple Current PWM
- ⇒ Space Vector Pulse Width Modulation (SVPWM)
- ⇒ Random Pulse Width Modulation (RPWM)
- ⇒ Hysteresis band current control PWM
- ⇒ Sinusoidal PWM with instantaneous current control

There are several techniques to vary the inverter gain. The efficient method of controlling the gain (and output voltage) is to incorporate pulse width modulation (PWM) control within the inverters. The commonly used techniques are sinusoidal and space vector pulse width modulation, but the emerging technique is the Random Pulse Width Modulation. To overcome the drawbacks of more acoustical noise and more harmonic distortion at higher modulation indices, this work is focused on the Random Pulse Width Modulation (RPWM) technique. In this paper a comparative study is performed on SPWM & RPWM based B4 inverter feeding an induction motor drive.

### C. Sinusoidal and Random Pulse Width Modulation (SPWM & RPWM):

The random pulse width modulation (RPWM) has become an established means of mitigation of undesirable side effects in PWM converters, the voltage source inverters in adjustable speed ac drives in particular. Randomizing the switching frequency has been found to be the most effective method of RPWM. Fig 3.1 depicts the randomization procedure in the sine-triangle PWM where successive triangular waveform period lengths are varied pseudo-randomly.



**Fig.3.1: Random sine-Triangle PWM**

In converters with fixed switching frequency, the power is concentrated in discrete harmonics of the output voltage. In contrast to that, in converters with randomly varying switching frequency, the harmonic power is transferred to the continuous spectrum. RPWM is provided in the following manner. The method begins by determining a switching period randomly for a switching cycle subsequent to a current sampling cycle. The method then determines a switching pattern from a reference voltage generated from signals detected and processed in the current sampling cycle. Switching signals are then generated to make a specific switching pattern. The switching signals are then transmitted to switches of the converter during the switching cycle. The Simulation model of RPWM based B4 inverter fed induction motor drive is shown in fig 3.2. In accordance to the method of this invention, the switching period may be determined as follows. In one exemplary embodiment, the calculation of the period may start by generating a first random number. A first delay between the switching cycle and a coincident sampling cycle is determined by multiplying the random number by the period of the coincident sampling cycle. A second random number is generated and multiplied by the period of a sampling cycle to determine the second delay. The second delay is the delay for the switching cycle subsequent to the cycle being calculated. The period of switching cycle is then calculated by subtracting the first delay from the period of the sampling cycle and adding the second delay to the result.

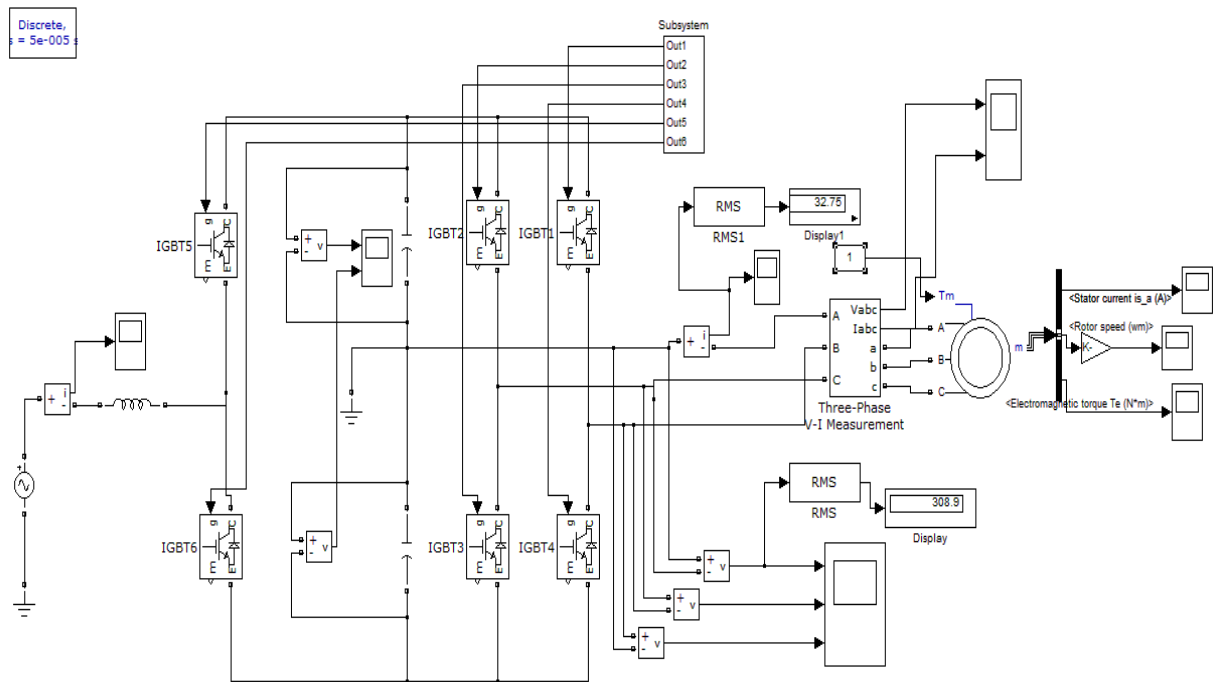


Fig.3.2: Simulation model of RPWM based B4 inverter fed induction motor drive

#### 4. MODEL PREDICTIVE CONTROLLER

Model Predictive Control (MPC) also known as receding horizon control or moving horizon control, uses the range of control methods, making the use of an explicit dynamic plant model to predict the effect of future reactions of the manipulated variables on the output and the control signal obtained by minimizing the cost function. The concept of MPC is based on the calculation of the future behavior of the system, in order to use this information to calculate optimal values for the actuating variables. The Model Predictive Controller scheme is shown in fig 4.1. The controller uses the model to compute a trajectory of a future manipulated variable  $u$  to optimize the future behavior of the plant output  $x$  (controlled variable). MPC uses the model and the current measurements of the process to calculate the future actions of manipulated variables and ensures the controlled variables and manipulated variables to satisfy the constraints, and then MPC controller puts the first element of the calculated variable sequences to the process plant.

The main advantage of this predictive controller is System constraints can be handled systematically and can be considered in the model, filtering of measured variables without phase displacement can be integrated and Automatic identification of model parameters is possible. Execution of the predictive algorithm can be divided into three main steps, estimation of the variables that cannot be measured, prediction of the future behavior of the system, and optimization of outputs, according to a previously designed control law.

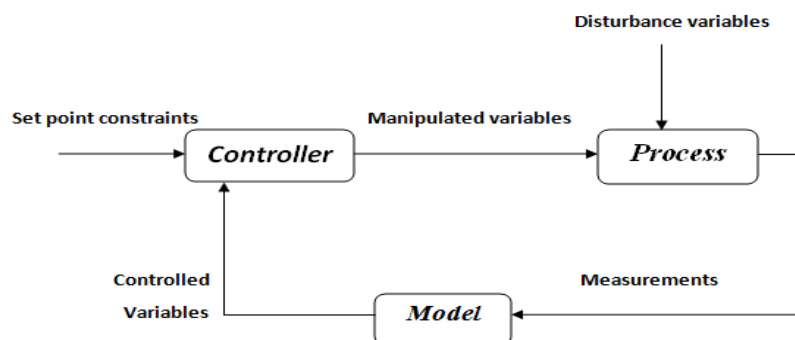


Fig.4.1: Model Predictive Controller Scheme

MPC presents a different approach for the control of the power converter. MPC takes advantage of the discrete nature of the power converters. Using the same scheme it is possible to control different variables like: Current, Voltage, Power, Spectrum, Torque, Flux & others. Constraints and non linearities can be easily included in the model. The control scheme is simple and can be easily applied to any converter topology.

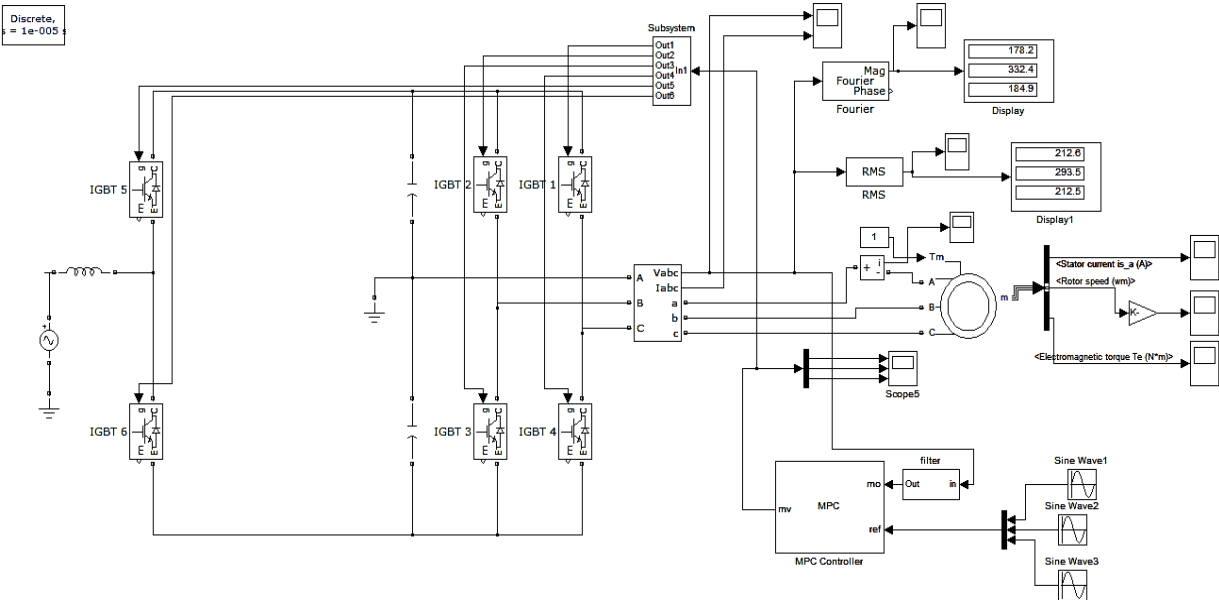


Fig.4.2: Simulation Circuit model of B4 Inverter fed induction motor drive with MPC controller

The simulation circuit model of B4 Inverter fed induction motor drive with MPC controller is shown in Fig 4.2. For motor drive applications, the measured variables is  $w$ , and a mathematical model of the machine are used to estimate the variables that cannot be measured such as the rotor & stator flux. Then the same model is used to predict the future behaviour of the variables for every control action. Finally, the voltage vector that produces the optimum reference tracking is selected as the switching state for the next sampling step. The model of the machine is the most important part of the controller, because both estimations & predictions depend on it.

5. SIMULATION RESULTS AND DISCUSSION

A computer simulation model has been developed in MATLAB/ Simulink Software to test the proposed RPWM technique. Weighted Total Harmonic Distortion is used to evaluate the performance of the B4 inverter fed induction motor drive system.

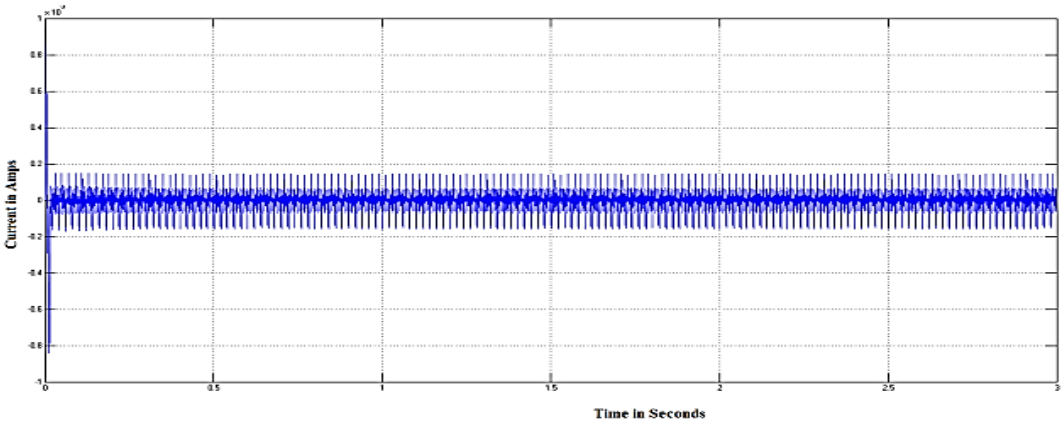


Fig.5.1: Input Current Waveform of RPWM based B4 Inverter

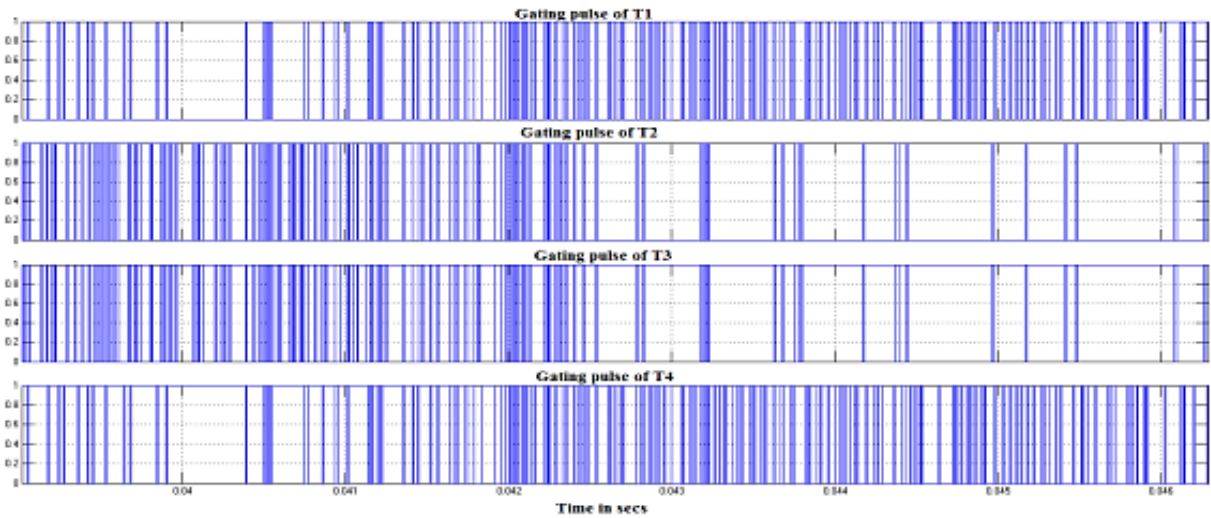


Fig.5.2: Pulse pattern Waveform of RPWM based B4 Inverter

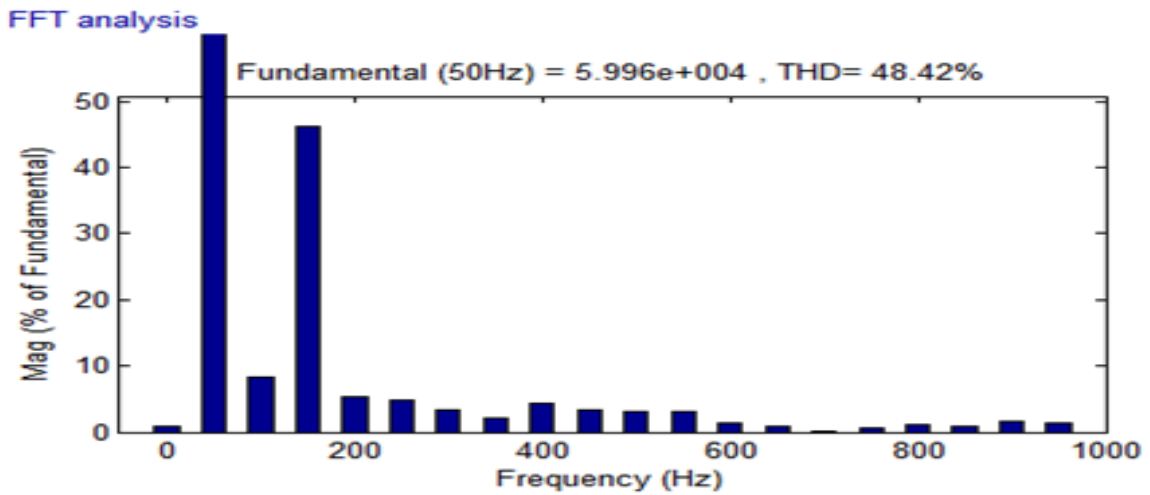


Fig.5.4: Total Harmonic Distortion of the Input Current (RPWM based B4 inverter fed Induction Motor)

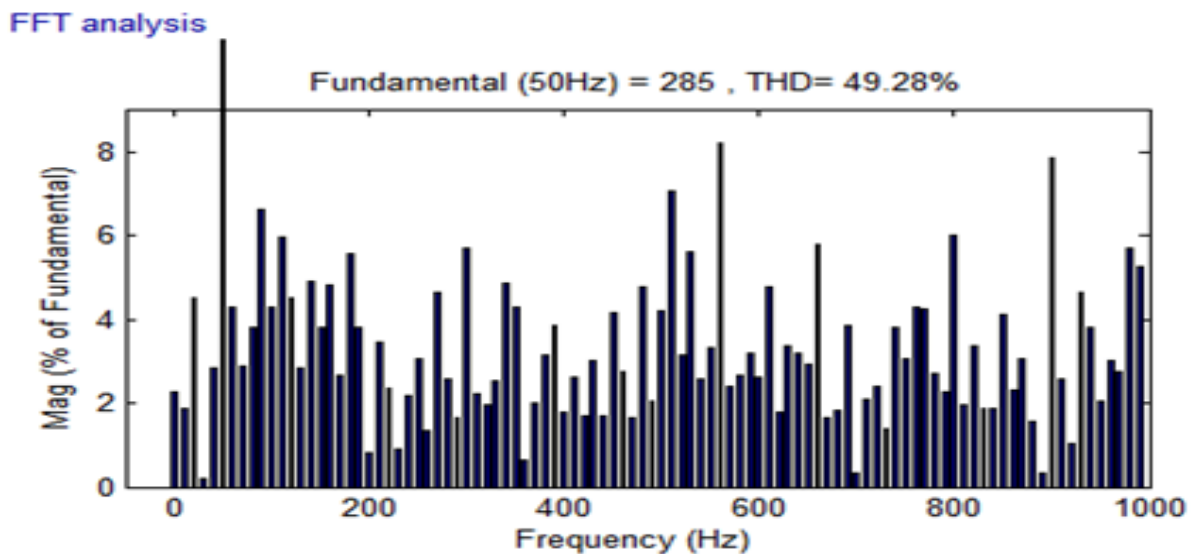


Fig.5.5: Total Harmonic Distortion of the Output Voltage (RPWM based B4 inverter fed Induction Motor)

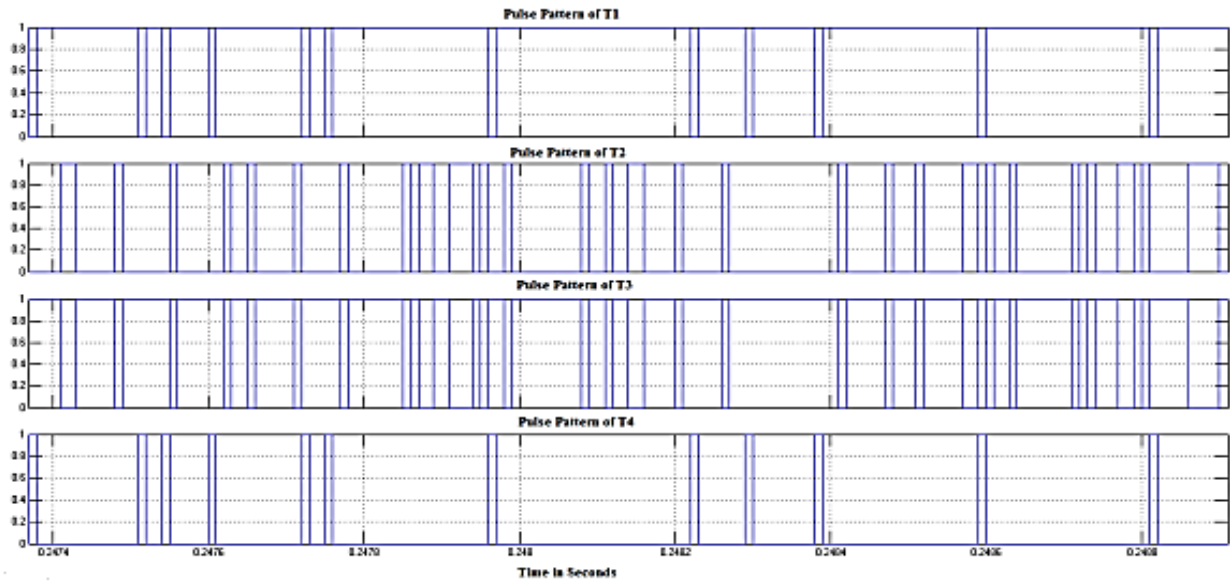


Fig.5.6: Pulse Pattern of B4 Inverter fed induction motor drive with MPC controller

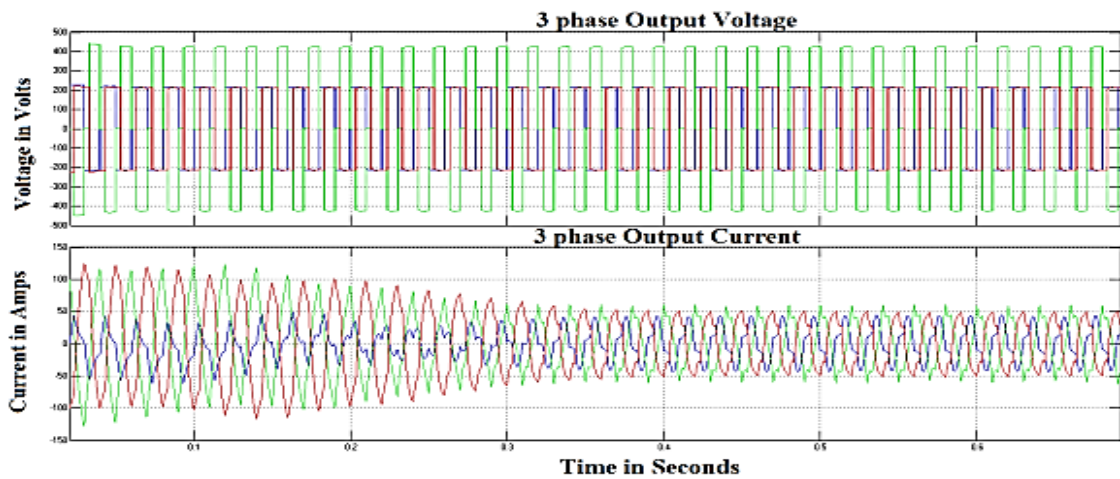


Fig.5.7: Inverter Output voltage & current waveforms of B4 Inverter fed induction motor drive with MPC controller

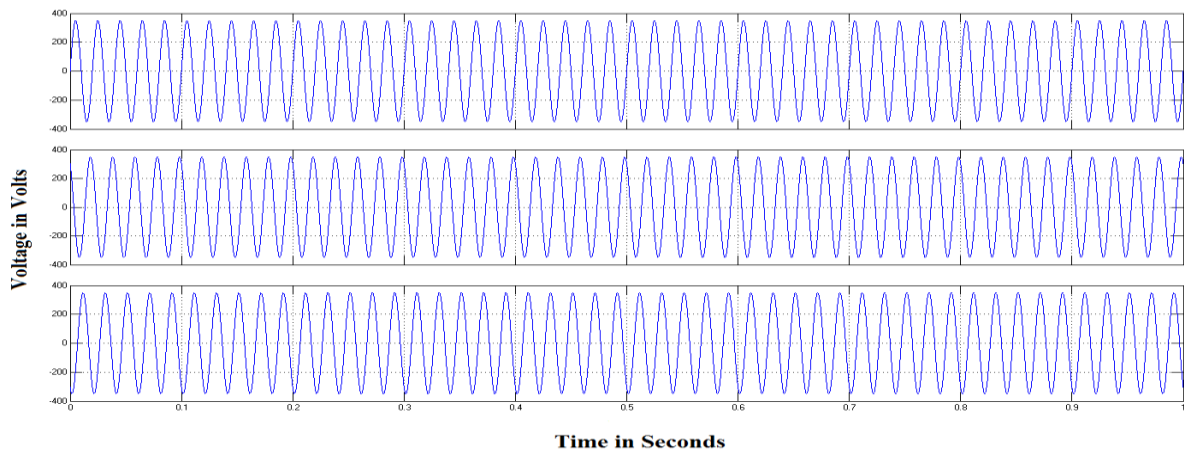


Fig.5.8: Measured voltage waveforms of the MPC controller



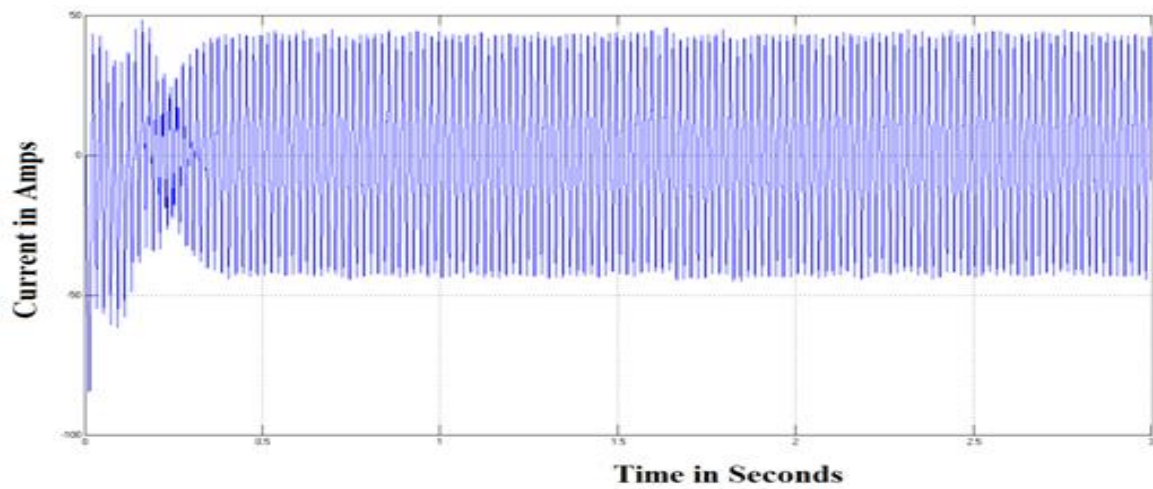


Fig.5.9: Stator current waveform of B4 Inverter fed induction motor drive with MPC controller

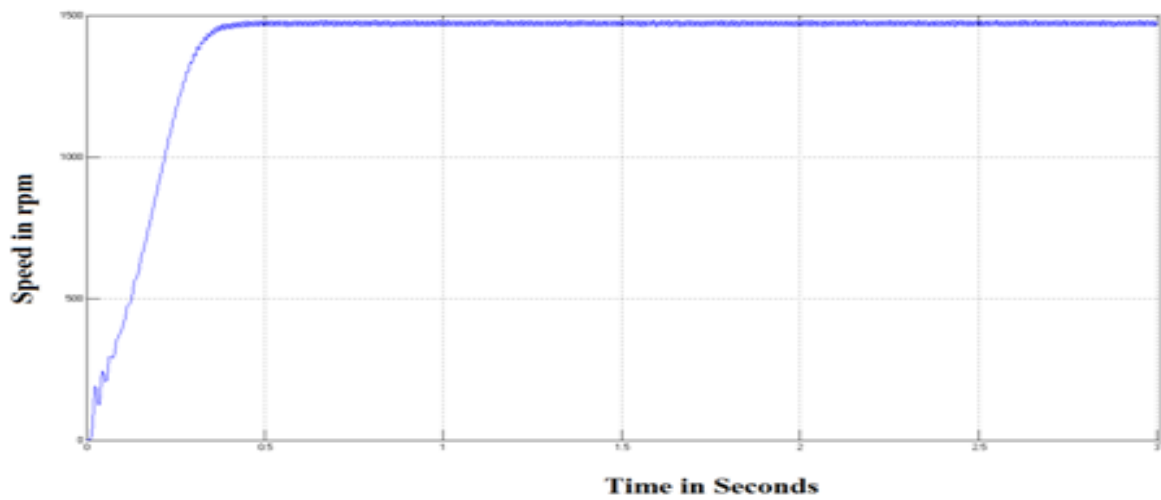


Fig.5.10: Rotor Speed waveform of B4 Inverter fed induction motor drive with MPC controller

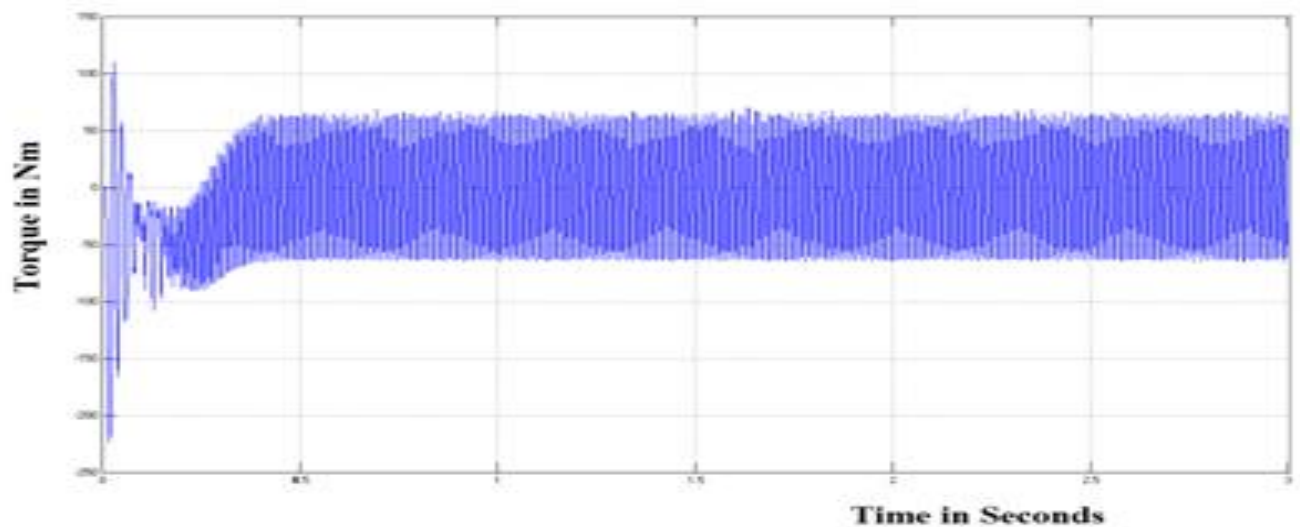


Fig.5.11: Electromagnetic Torque waveform of B4 Inverter fed induction motor drive with MPC controller

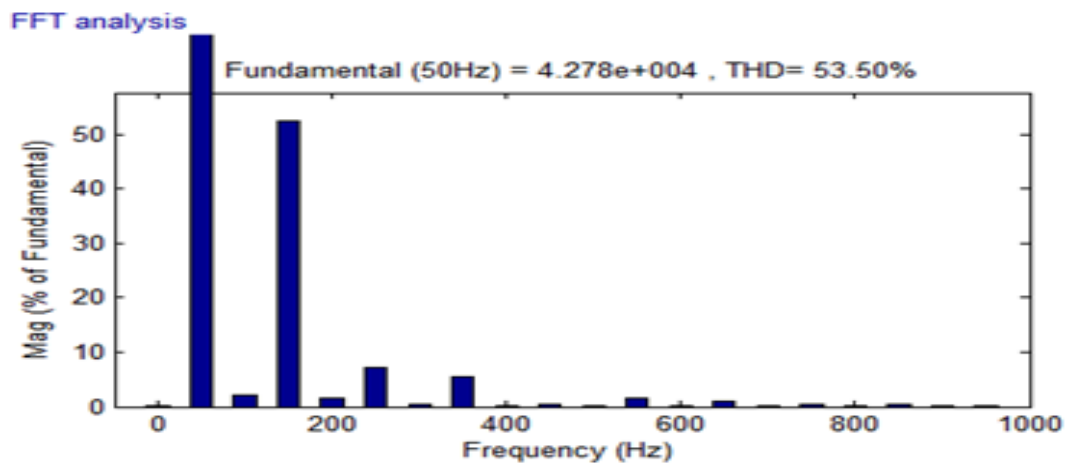


Fig.5.12: THD waveform of B4 Inverter fed induction motor drive with MPC controller

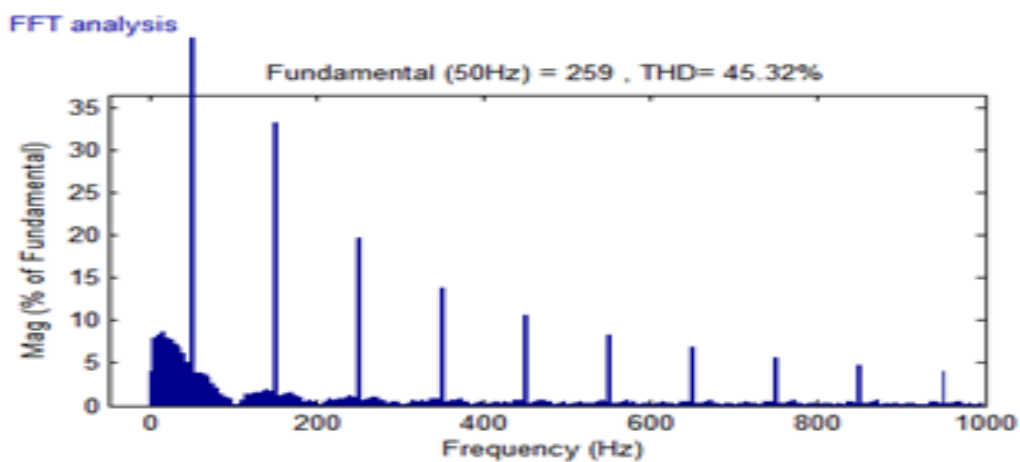


Fig.5.13: THD waveform of B4 Inverter fed induction motor drive with MPC controller

- Fig.5.1.** Implies the input current waveform of random pulse width modulation of B4 inverter fed induction motor drive with frequency of reference wave (f) = 50Hz.
- Fig.5.2.** Shows the pulse pattern waveform of Random pulse width modulation of B4 inverter fed induction motor drive with frequency of reference wave (f) = 50Hz.
- Fig.5.3.** Depicts the output voltage waveform of Random pulse width modulation of B4 inverter fed induction motor drive with the output voltage =310V and frequency of reference wave (f) = 50Hz.
- Fig.5.4.** Illustrates the Total Harmonic Distortion response of the input current waveform obtained by Random Pulse Width Modulation based B4 inverter fed Induction Motor.
- Fig.5.5.** Depicts the Total Harmonic Distortion response of the output voltage waveform obtained by Random Pulse Width Modulation based B4 inverter fed Induction Motor.
- Fig.5.6.** Indicates the Pulse Pattern of B4 inverter fed induction motor drive with Model based Predictive Current controller.
- Fig.5.7.** Shows the inverter Output voltage & current waveforms of B4 inverter fed induction motor drive with MPC controller.
- Fig.5.8.** points the measured voltage waveform obtained from the controller.

**Fig.5.9.** Depicts the stator current waveform of Four Switch Three Phase inverter fed induction motor drive with MPC controller at a rated power of 1.1 KW.

**Fig.5.10.** Illustrates the rotor speed waveform of Four Switch Three Phase inverter fed induction motor drive with MPC controller at a rated power of 1.1 KW

**Fig.5.11.** Depicts the simulation result of the electromagnetic torque waveform of four switch three phase inverter fed induction motor drive with model based predictive controller.

**Fig.5.12.** Indicates the Total harmonic distortion response the input current waveform obtained from Four Switch Three Phase Inverter fed induction motor drive with Model based Predictive Current controller. The %THD obtained is 53.50

**Fig.5.13.** Indicates the Total harmonic distortion response of the output voltage waveform obtained from B4 inverter fed induction motor drive with Model based Predictive Current controller. The %THD obtained is 45.32

**TABLE.II: %THD MEASURES FOR OPEN & CLOSED LOOP**

Methodology	Techniques Used	THD%	
		Input Current	Output Voltage
Open Loop	RPWM	48.42	49.28
Closed Loop	MPC	53.50	45.32

## 6. CONCLUSIONS

This project has presented a single to three phase converter for low cost induction motor drive. This converter provides variable output voltage and frequency. The proposed system investigates the RPWM based B4 inverter for induction motor drive. The influence of the PWM technique on the output voltage symmetry, current waveform and switching frequency are examined. The results obtained by employing the RPWM technique are presented. The Total Harmonic Distortion (THD) analysis of B4 inverter by computer simulation is performed. Based on the Predictive Current Control technique, a control strategy of the proposed converter to induction motor drive has been implemented. The results have been shown the efficacy of the low cost ac drive system.

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