Performance Analysis of Four Leg Voltage Source Inverter Fed Two Phase Induction Motor for Low Power Application

[1]Anuradha A. Munshi, [2]Akshay D.Kadu, [3]Aniket P.Munshi

[1,2]*Department of Electrical Engineering, Rajiv Gandhi College of Engineering & Research, Nagpur India*
[3]*Department of Electrical Engineering, Yeshwantrao Chavan College of Engineering , Nagpur, India*

Abstract: *This paper presents performance analysis of two phase induction motor (TwPIM)fed by four leg voltage source inverter (VSI) for low power applications using sinusoidal pulse width modulation technique (SPWM). The production of two phases having the phase shift of 90° is achieved by using MOSFET based four leg voltage source inverter in which SPWM control scheme is used. Mathematical model of TwPIM is developed using MATLAB as a simulation tool for achieving the required results of speed variation at different load torques. The four-leg VSI is preferred over three leg VSI as it offers good dc utilization. The proposed model can generate two phase output voltage waveform with independent control on each output phase. The proposed method can be used for low power application(less than 2.5 KW) due to its superior Torque - Speed characteristics over single phase Induction Motor. Also as compared to Three phase Induction Motor initial and running cost is also less. Hence proposed method can be said to be a cost effective and more useful for low power application.*

Keywords: *Two phase Induction Motor (TwPIM), Four leg Voltage Source Inverter (VSI), Sinusoidal Pulse Width Modulation (SPWM).*

I. Introduction

Two phase induction motor has been extensively used in low power applications like home appliances and industrial applications requiring power consumption less than 2.5KW[1]. Two-phase induction motors have identical configuration as single-phase induction motors, as in both cases stator windings are 90° phase apart. However self-determining control of the input voltage applied to the stator winding is required so that two-phase voltage is supplied[2]. In general, when ac loads are fed through inverters, output voltage of preferred magnitude and frequency is obligatory. The variation in the input dc voltage results in variable output. On the contrary if the dc input voltage is fixed and it is uncontrollable, a variable output voltage can be obtained by using internal voltage control technique like Pulse Width Modulation (PWM)[3].

This paper focuses on two phase output produced by four leg H-Bridge VSI as dc utilization in four leg H-Bridge inverter is far better than other H-Bridge topologies. Also total harmonic distortion(THD) as compared to three leg VSI will be less. With the increase in no. of switches, performance of drive improves. The switches could be FET, MOSFET, IGBT or any other controllable power device as per the required performance of the drive. In this paper MOSFET is used as a switch due to its certain remarkable advantages. MOSFET is having higher switching frequency, a high commutation speed, greater efficiency, high input capacitance and less phase current distortion than IGBT. The switching scheme used for pulse generation is unipolar SPWM as it offers less current distortion and more dc utilization[4]. The output of four leg VSI is given as input to TwPIM which was modeled with the help of mathematical equations. The equations were pertaining to dynamic model of TwPIM. Three separate Simulink blocks were made which include stator and rotor voltage equations, stator and rotor current equations and electromagnetic torque and rotor speed. With the input fed from four leg VSI output was observed in terms of change of rotor speed at various values of load torque.

To achieve above objectives of performance analysis of TwPIM fed by four leg VSI, basically main focus is on greater dc utilization and less THD in output voltage of four leg VSI, which was given as input to TwPIM and then speed variation is plotted at various load torques indicating better performance of TwPIM over single phase induction motor for low power applications.

II. Proposed Work

2.1 Basic block diagram description:

The flow of the proposed work can be explained with the help of basic block diagram as shown in fig.2.1. Four leg VSI Simulink model is developed using MOSFET as a switch. The gate pulse generation scheme used for firing the switches was SPWM. The output of this four leg VSI is given as input to TwPIM which was mathematically modeled using dynamic model of TwPIM.

Fig. 2.2 shows the circuit diagram of proposed work i.e, four Leg voltage source Inverter fed two phase Induction Motor using SPWM control scheme.
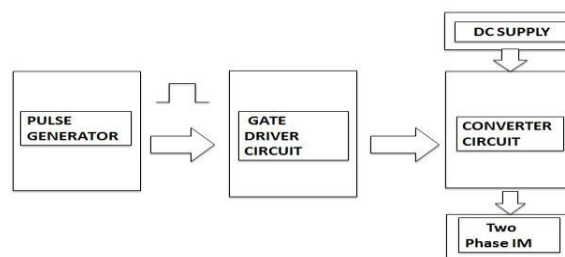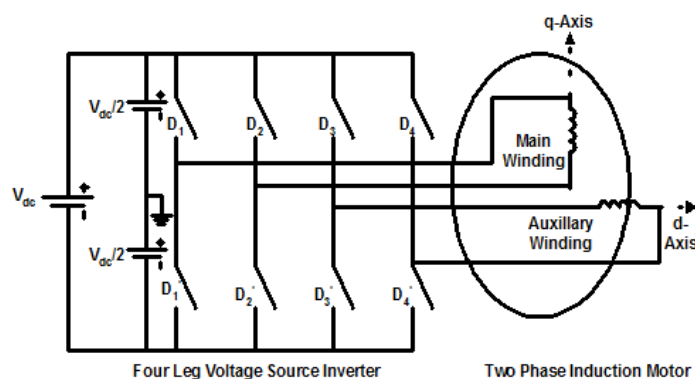

Fig.2.1: Basic block diagram of proposed work

Fig.2.2: Circuit diagram of four Leg voltage source Inverter fed two phase Induction Motor

2.2: Four Leg Voltage Source Inverter:

The 4-leg H-bridge inverter comprise of two single phase full bridge inverters. Four legs that generate two output voltages separately which ranges from – Vdc to +Vdc, where Vdc is the input dc voltage to the inverter. The load i.e, TwPIM is connected in between two separate bridges as shown in fig.2.2. These single phase full bridge inverter produces two-phase quasi square voltage waveform across the load with the waveforms phase shifted by 90° electrically from one another.

The two quasi waveforms are symmetrical and periodic .The 4-leg voltage source inverter system offers good DC utilization and lower Total Harmonic Distortion (THD). It also offers improved performance at the outlay of an increase of switching device count. In traditional PWM technique, the unbalance two phase four leg voltage source inverter using bipolar modulation scheme is used which consist of two-phase reference pole voltages Va_0^* and Vb_0^* a common triangular carrier wave Vcr and unbalanced two phase output voltages Vsd* and Vsq*. These output voltages of two-level PWM waveform between the positive and negative DC voltages have the phase displacement of 90° with respect to each other.

The method proposed in this paper uses SPWM switching based unbalance two phase four leg voltage source inverter based on a unipolar modulation technique. The unipolar SPWM switching method is used over bipolar due to its high efficiency and lower THD.

2.3: Current Direction in four Leg Inverter:

The current direction for 0°, 90°, 180° & 270° firing pulse is different. For 0°, Current flows through D_1 and D_2' and back to source and after a delay of 5 msec. current flows through D_4 and D_3' and back to source. Furthermore for 90°, Current flows through D_1 and D_2' and back to source and after a delay of 5 msec. current flows through D_3 and D_4' and back to source. Also for 180°, Current flows through D_2 and D_1' and back to source and after a delay of 5 msec. current flows through D_3 and D_4' and back to source. Finally at 270°, Current flows through D_2 and D_1' and back to source and after a delay of 5 msec. current flows through D_4 and D_3' and back to source. The switching states of two phase four leg VSI is given in Table 2.1.

2.4: Two Phase Induction Motor:

There is continuous dispute today pertaining to the "motor of the prospect" for power applications requiring less than 2.5 kW. The people are focusing on better-quality motors like brushless dc motor, permanent-magnet synchronous motor etc. because they show improved efficiency, reliability, maintenance, and overhaul life. Despite of this effort, the industry seems to be responding with apparent stiffness in altering

standard induction motor solutions when considering the installed volume into the field, the venture in built-up base, and the easiness of switching from fixed speed to variable speed.

The basic principle behind working of induction motor is mutual induction. The working of two phase induction motor is same as three phase induction motor. As compared to three phase induction motor which is not a self starting motor, two phase induction motor is self-starting motor. Also another advantage of two phase supply can be used in Scott connection.

Table 2.1: Switching states of four leg VSI

Switches / Degree	1	2	3	4
0°	1	0	0	1
90°	1	0	1	0
180°	0	1	1	0
270°	0	1	0	1

2.5: Mathematical model of two phase induction motor:

This paper presents an orthogonal reference frame theory for developing the model of the TwPIM is employed here. Separation of the ac capacitor from the TwPIM helps in considering different topologies for the ac drives, and the orientation frame theory takes advantages from the natural point of reference of the TwPIM in d–q coordinates. The orthogonal axes direction for each winding coincides with the magnetizing axes direction for the respective winding. Furthermore some approximations were made for the TPIM model, such as,

(i) Iron losses are ignored.
(ii) Stator windings present a sinusoidal distribution across the stator circumference.
(iii) Winding resistances are assumed to be independent of the supply frequency.
(iv) The motor is mechanically symmetrical even though the number of slots for each winding differs from one to another.
(v) The magnetic material is linear and the iron permeability is infinite.

In MATLAB/SIMULINK, two phase induction motor block is not available directly. So modelling is essential to make two phase induction motor. The two-phase induction motor is made of two asymmetrical windings. Therefore, the auxiliary winding usually has fewer turns than the main winding and is displaced at $90°$ between these windings. Fig. 2.3 shows the schematic view of a two phase induction motor, which shows α and β windings are not identical sinusoidal distributed windings, but are arranged in $90°$ in space.
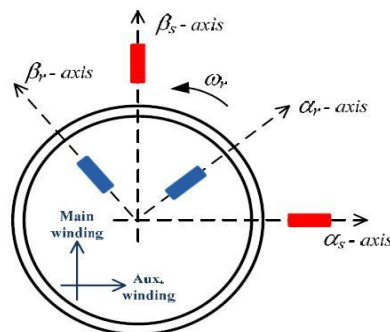

Fig. 2.3: Two Phase Induction Motor

2.6: Equivalent Model of Two Phase Induction Motor:

The equivalent circuits representing the TwPIM in stationary (αβ) reference frame are shown in Fig. 2.4. The dynamic model TwPIM can be written as αβ reference frame variables[5]. Components of stator and rotor voltage of TwPIM can be uttered as follows:

The induction machine may thus be seen as a transformer with an air gap and variable resistance in the secondary. Also the stator of the induction machine corresponds to the transformer primary, and the rotor correspond to the secondary. From the equivalent circuit the following equations can be written. The equations of stator and rotor voltages are given below. These equations we get by applying Kirchhoff's voltage law to equivalent diagram.

$$V_{s\alpha} = R_{s\alpha}I_{s\alpha} + \frac{d}{dt}\psi_{s\alpha} \text{-----------------------------------} (2.1)$$

$$V_{s\beta} = R_{s\beta}I_{s\beta} + \frac{d}{dt}\psi_{s\beta} \text{-------------------------------------} (2.2)$$
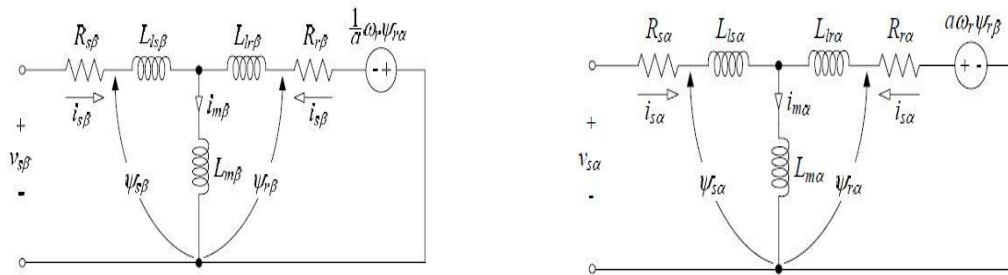
Fig. 2.4: Two Phase Induction Motor (a) Main winding in β axis (b) Auxiliary winding in α axis

$$V_{r\alpha} = 0 = R_{r\alpha}I_{r\alpha} + \frac{d}{dt}\psi_{r\alpha} + a\omega_r\psi_{r\beta} \text{-----------------------(2.3)}$$

$$V_{r\beta} = 0 = R_{r\beta}I_{r\beta} + \frac{d}{dt}\psi_{r\beta} - \frac{1}{a}\omega_r\psi_r \text{-------------------------(2.4)}$$

The components of stator and rotor flux linkages equations can also be articulated as:

$$\psi_{s\alpha} = L_{s\alpha}I_{s\alpha} + L_{m\alpha}I_{r\alpha} \text{-------------------------------------(2.5)}$$

$$\psi_{s\beta} = L_{s\beta}I_{s\beta} + L_{m\beta}I_{r\beta} \text{-------------------------------------(2.6)}$$

$$\psi_{r\alpha} = L_{m\alpha}I_{s\alpha} + L_{r\alpha}I_{r\alpha} \text{-------------------------------------(2.7)}$$

$$\psi_{r\beta} = L_{m\beta}I_{s\beta} + L_{r\beta}I_{r\beta} \text{-------------------------------------(2.8)}$$

Using equation (2.5)-(2.8), the stator and rotor currents equations are given by:

$$I_{s\alpha} = \frac{L_{r\alpha}\psi_{s\alpha} - L_{m\alpha}\psi_{r\alpha}}{L_{s\alpha}L_{r\alpha} - L_{m\alpha}^2} \text{-----------------------------------(2.9)}$$

$$I_{s\beta} = \frac{L_{r\beta}\psi_{s\beta} - L_{m\beta}\psi_{r\beta}}{L_{s\beta}L_{r\beta} - L_{m\beta}^2} \text{-----------------------------------(2.10)}$$

$$I_{r\alpha} = \frac{L_{s\alpha}\psi_{r\alpha} - L_{m\alpha}\psi_{s\alpha}}{L_{s\beta}L_{r\beta} - L_{m\beta}^2} \text{-----------------------------------(2.11)}$$

$$I_{r\beta} = \frac{L_{s\beta}\psi_{r\beta} - L_{m\beta}\psi_{s\beta}}{L_{s\beta}L_{r\beta} - L_{m\beta}^2} \text{-----------------------------------(2.12)}$$

The equation of electromagnetic torque produced by the machine is then given by the equation:

$$T_e = P_p (L_{m\beta}I_{s\beta}I_{r\alpha} - L_{m\alpha}I_{s\alpha}I_{r\beta}) \text{-------------------------------------(2.13)}$$

and the mechanical torque is modeled by the equation

$$J\frac{d}{dt}\omega_r = T_e - T_l \text{---(2.14)}$$

Where, $V_{s\alpha}$, $V_{s\beta}$, $V_{r\alpha}$, $V_{r\beta}$ are the stator and rotor voltages. $I_{s\alpha}$, $I_{s\beta}$, $I_{r\alpha}$, $I_{r\beta}$ are the stator and rotor currents, $\psi_{s\alpha}$, $\psi_{s\beta}$, $\psi_{r\alpha}$, $\psi_{r\beta}$ are the stator and rotor flux linkages, $R_{s\alpha}$, $R_{s\beta}$, $R_{r\alpha}$, $R_{r\beta}$ are the stator and rotor resistances, $L_{s\alpha}$, $L_{s\beta}$, $L_{r\alpha}$, $L_{r\beta}$ are the stator and rotor inductances, $L_{m\alpha}$, $L_{m\beta}$ are the magnetizing inductances, ω_r is the electrical rotor angular speed, T_e is the electromagnetic torque, T_L is the load torque, J is the rotor moment of inertia, d/dt is the differential operator and a is the main per auxiliary winding turns ratio.

III. Proposed System Parameters

3.1: Four Leg VSI parameters for simulation:

Four leg VSI with MOSFET as a controllable switch provided with pulse generation using SPWM switching scheme is developed in MATLAB simulink to fulfill the standard test system parameters of two phase induction motor. The dc link voltage for inverter is taken as 227volts to fulfill the input requirement 220V (rms) of TwPIM. For SPWM switching scheme sine wave frequency is taken as 50Hz where as carrier wave frequency is taken as 1KHz.

3.2: Two Phase Induction Motor Parameters:

A standard test system is taken with parameters shown in table 3.1 actually measured for TwPIM having ratings as 220v, 50Hz, 0.5 HP, 4 poles ,2.8 A. The torque varied from 0.25 to 2 N-M.

Table 3.1: Two Phase Induction Motor Parameters

$R_{s\alpha}$ = 45.26 Ω	$R_{r\alpha}$ = 25.76 Ω	$L_{s\alpha}$ = 1.08 H	$L_{r\alpha}$ = 0.9884H	$L_{m\alpha}$ = 0.9179 H	J = 2.5×10^{-3} Kg-m^2
$R_{s\beta}$ = 9.06 Ω	$R_{r\beta}$ = 7.46 Ω	$L_{s\beta}$ = 0.7926 H	$L_{r\beta}$ = 0.7688 H	$L_{m\beta}$ = 0.7489 H	a = 1.70

IV. Results and Discussions

The four leg VSI with MOSFET as a switch is developed in MATLAB Simulink with SPWM technique as a switching control. The parameters taken as discussed in section 3.1. For SPWM, comparison of sine wave as reference signal and a triangular wave as carrier signal is as shown in fig.4.1 The four different sine waves are shown for the four legs of the two phase four leg H-bridge inverter. The amplitude of the carrier signal is 1V.
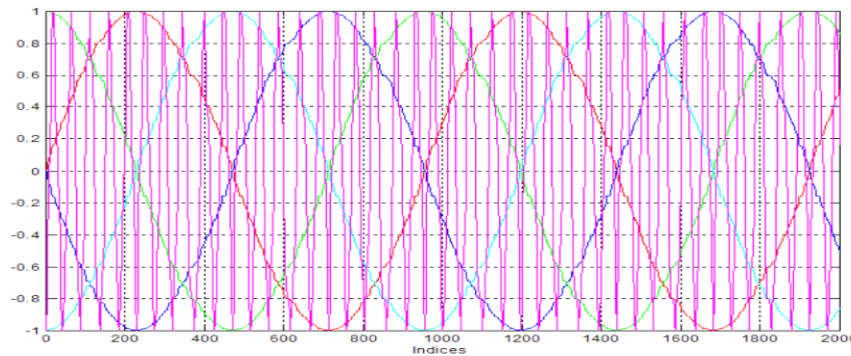

Fig. 4.1: Comparison of carrier and reference wave for SPWM

Fig.4.2. shows the simulated waveforms of two phase 4-leg inverter. It shows that the two voltage waveforms are shifted by 90° which are obtained from two H-bridges. It shows two phase output across 4-leg H-bridge inverter.
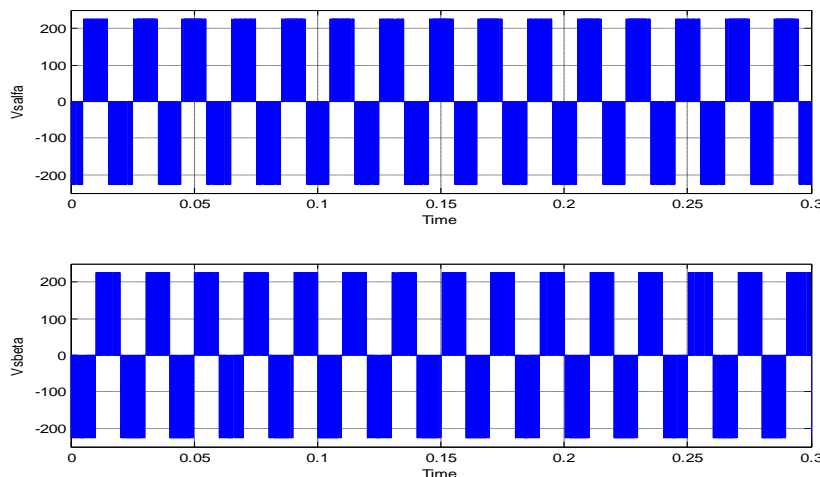

Fig. 4.2: Simulation result of two phase 4-leg inverter (phase voltage)

Fig. 4.3 and 4.4 illustrates the advantage of four leg VSI over three leg VSI in terms of dc utilization and THD. For the same dc link voltage of 227 volts it is observed that for three leg VSI fundamental of output voltage seems to be 189.5Volts whereas for four leg VSI it is 220.2Volts. Also THD of output voltage of three leg VSI is 71.29% whereas for four leg VSI it is 58.24%. Both these figures of THD and fundamental output voltage are indicative of better performance of four leg VSI over three leg VSI at the cost of increased no. of switches. Hence for low power applications where input dc is of mere importance, the proposed model can be a great solution. Also as this output is ultimately going as input to TwPIM, automatically the performance increases in terms of Torque-speed characteristics. If we compare the torque speed characteristics of TwPIM with single phase induction motor, TwPIM torque has variation from 0 to the rated value which is not in case of single phase induction motor[6].
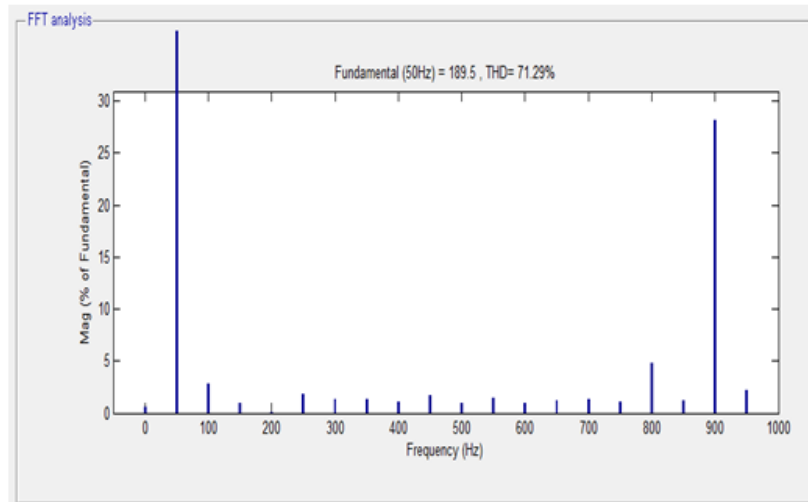
Fig. 4.3: Output voltage Fundamental and THD of Three Leg VSI
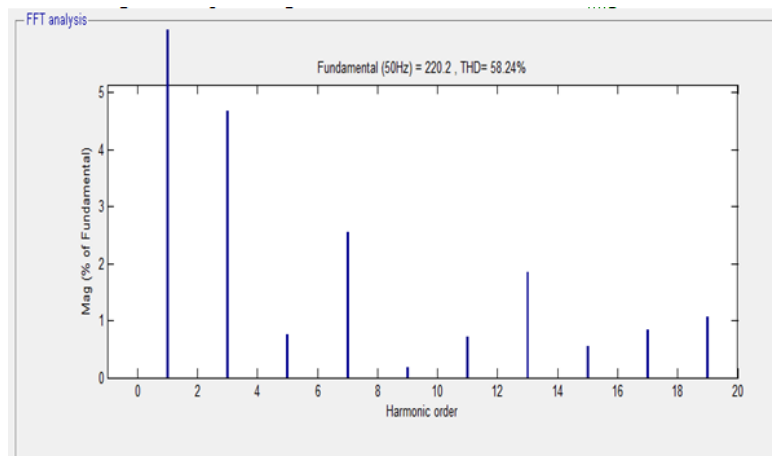

Fig. 4.4: Output voltage Fundamental and THD of Three Leg VSI

This simulated output of four leg VSI is given as input to two phase induction motor which has the specification as 220V, 50Hz, 2.8A, with 4 poles. Initially the TwPIM run with the pure sinusoidal supply to see the speed characteristics at load torque (T_l) =0.25 N-M. So it is observed that initially with less load torque speed changes from 0 to 1490 rpm. Fig. 4.5 shows the speed variation at load torque equals to 0.25 N-M. The output of the four leg VSI is then given as input to TwPIM. The two phase induction motor can be controlled within specific speed range by V/F control using four leg voltage source inverter. Due to two H-bridge in four leg h-bridge inverter, the output voltages can be controlled independently. The inverter is constantly supplied by the constant DC link voltage of 220 Volts. The output frequency command and the switching frequency were selected to be 50 Hz and 1 kHz, respectively. Fig. 4.6 shows speed variation at different load torques. Rotor speed (N_r) during motor acceleration, the motor starts under the rated voltage and frequency without mechanical load torque. It is seen that the rotor speed for the motor drive operating at start-up from standstill to 1500 rpm. During this time the output currents are sinusoidal with unequal amplitude consequent unbalance output voltages and parameters of machine. As torque is inversely proportional to speed, at different torque we get different speed and vice versa.
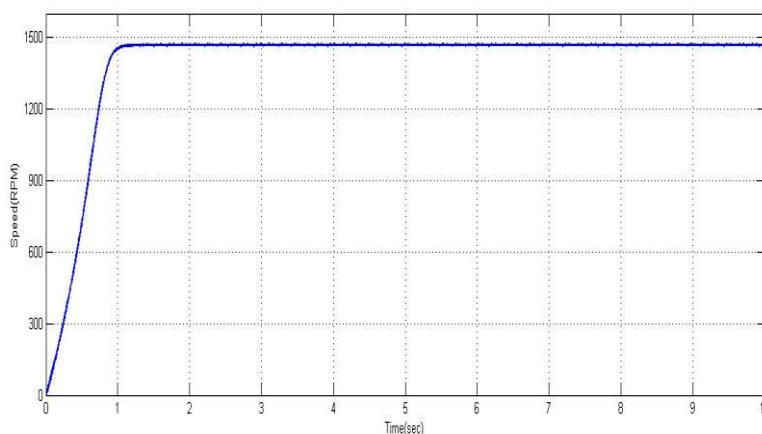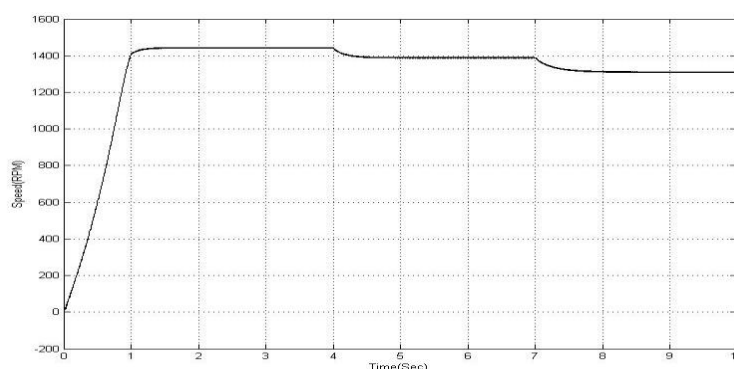
Fig. 4.5: Speed characteristics at no load

Fig. 4.6: Speed characteristics at different load torques

Table 3.3 shows the simulated load torque values with different rotor speed. As load torque increase the rotor speed decreases.

Table 3.4: Rotor speed at different load torque.

Load Torque T_1(N-m)	Rotor Speed N_r (RPM)
1	1493
1.25	1480
1.5	1466
1.75	1452

V. Conclusion and Future Scope

After simulating complete model of 4 leg h bridge inverter with two phase induction motor, speed reaches from 0 to 1490 RPM at load torque 0.25N-m. For this motor supplied voltage is 220 V AC through output of inverter. Owing to two H bridges in four leg H bridge inverter, the output voltage can be controlled independently which become a major benefit of two phase induction motor. Also using inverter as a source we can control the speed of drives by changing the frequency, which is not possible in normal AC supply. The output frequency and switching frequency is 50 Hz and 1 KHz. From torque speed characteristics it is concluded that torque is inversely proportional to speed and at different load torque gives different speed as shown in table 3.4. Also as the torque increases the speed of the induction motor decreases. With the help of SPWM technique, harmonics can be reduced to a greater extent. Hence it not only decreases the cost of filter but also improves the transient response.

Two phase induction motor can be used instead of three phase induction motor for low power application. Two phase induction motor can also be used in pumps and drills as the starting torque of the two phase induction motor is more as compared to the single phase induction motor. Two phase induction motor can also be used in compressors. Hardware implementation of the proposed model can be done which will be cost effective in both initial and running cost.

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