PIC Microcontroller Based Speed Control of Three Phase Induction Motor Using Single Phase Supply

B. N. Jamadar[1], Dr. S. R. Kumbhar[2] & D. S. Sutrave[3]

Abstract: **In past few decades, development in the area power electronics which increases the demand for high performance industrial applications has contributed to rapid developments in digital motor control. High efficiency, reduced noise, extended reliability at optimum cost is the challenge facing by many industries which uses the electric motors. Now days, the demand of electronic motor control is increases rapidly, not only in the area of automotive, computer peripherals, but also in industrial, electrical applications. All these applications need cost-effective solutions without compromising reliability. The purpose of this system is to design, simulate and implement the most feasible motor control for use in industrial and electrical applications.**

The proposed design describes the designing and development of a three phase induction motor drive with speed sensing. It is based on PIC18F4431 microcontroller which is dedicated for motor control applications. The designed drive is a low cost motor control drive used for medium power three phase induction motor and is targeted for industrial and electric appliances e.g. washing machines, compressors, air conditioning units, electric pumps and some simple industrial drives.

The designed motor drive has another advantage that it would converts single phase into three phases supply where three phase motors are operated on a single phase supply. So it is the best option for those applications where three phase supply is not available. In such applications, three phase motors are preferred because they are efficient, economical and require less severe starting current.

This paper deals with PWM technique used for speed control of three phase induction motor using single phase supply with PIC microcontroller. The implemented system converts a single phase AC input into high DC. The high DC is converted into three phase AC voltage by using inverter circuit. The desired AC voltage can be obtained by changing the switching time of MOSFET's using PWM signals. These PWM signals are generated by the PIC microcontroller. Different PWM schemes are used for firing of MOSFET's and harmonic profiles are recorded through simulation. Out of them, best PWM firing scheme is used for the better efficiency. Speed variation of the induction motor is then recorded by changing duty cycle of the firing pulse of an inverter.

Keywords: **Pulse Width Modulation (PWM), AC Induction Motor (ACIM), Peripheral Interface Controller (PIC), Metal Oxide Semiconductor Field Effect Transistor (MOSFET), variable-frequency drive (VFD), Microprocessor (µp), Microcontroller (µc).**

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1. INTRODUCTION

Pattern Power Electronics is the branch of engineering which combines the power i.e. electric power and electronics & control systems. Power deals with the static and rotating power equipment for the generation, transmission and distribution of electric power. Electronics deals with the study of solid state semiconductor power devices and circuits for power conversion to get the desired control objectives such as to control the output voltage and output power.

The first power electronic device was developed in year 1900. Up to 1950, the other power devices like metal tank rectifier, grid controlled vacuum tube rectifier, ignitron, phanotron, thyratron and magnetic amplifier were developed and used gradually for power control applications. In 1956, the first silicon controlled rectifier (SCR) was invented and developed by Bell Lab's which was the first PNPN triggering transistor. The second electronic revolution began in the year 1958 with the development of the commercial grade thyristors. Thus the new era of power electronics was born. Moreover different types of power semiconductor devices & power conversion techniques have been introduced. The power electronics revolution is giving us the ability to convert shapes and control large amounts of power [1, 2].

In past 50 years, most of the improvement in industrial processes can be attributed to advances the variable speed motor drives. In 1950, most of the industries used DC motors because three phase induction motors could be operated only at fixed frequency. But advances in power devices and use of microcontroller, the fast, reliable and cost effective control of induction motors is seen in common place[2].

A variable-frequency drive (VFD) is a adjustable-speed drive used in electro-mechanical system to control the speed and torque of an induction motor by varying motor's input frequency and voltage [3, 4]. Over the last four decades, the technology of power electronics has reduced VFD cost and size. The performance has improved due to advances in semiconductor switching devices, drive topologies, simulation, control techniques and control of hardware and software.

Induction motors are widely used in control systems and home appliances because of their reliability, robustness, ruggedness and simplicity of control. Before few years, the induction motor could be plugged directly into the AC mains or controlled by means of V/f method. When an induction motor is directly connected to ac mains at the given specifications, it operates only at the rated speed. With this method, even simple speed variation is impossible and its system design is totally dependent on the motor design. However most of the applications are required variable speed operation. The V/f method is able to provide speed variation but does not control transient condition. It is useful only for steady state condition. This method is most suitable for applications where position control not required or there is no need of high accuracy speed control [5-10].

Simulation and neural network approach are widely used for predicting and studying the steady state, transient analysis of the induction drives. There are little efforts made in the digital switching in three phase induction motor drives.

Now, digital switching devices are made easier to control the drives. So microcontroller and DSP based drives are used in industrial applications. With advent in power semiconductor devices, the PWM technique has been used more frequently to improve the quality of output signal. Use of turn-off device and application of PWM technique for power converter have brought distinct improvements in the characteristics [11-17].

The proposed design describes the design and development of three phase motor drive for variable speed operation. It is based on PIC18F4431 microcontroller which is dedicated for motor control applications. The implemented system is designed for low to medium power three phase induction motors and is targeted for applications in both industrial and electrical appliance fields. The designed drive incorporates both hardware and software parts of the system which operates in open loop form.

2. BLOCK DIAGRAM AND WORKING

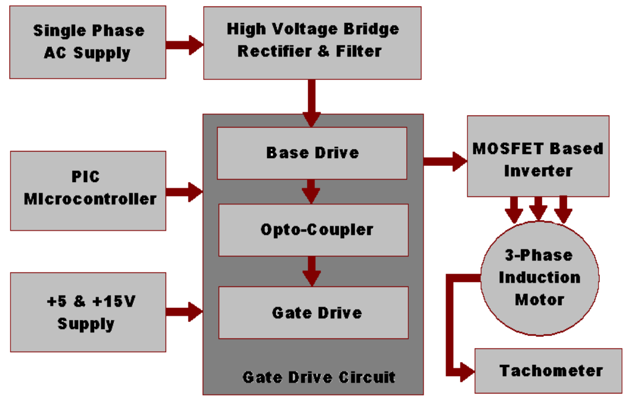

Fig.1 Block diagram of three phase induction motor drive system.

The block schematic of implemented three phase induction motor drive system is shown in above fig.1.The system is divided into two parts; 1) a power circuits 2) a control circuit.

The power circuit consists of the single phase high voltage bridge rectifier, capacitor filter and MOSFET based three phase inverter. Standard single phase AC supply is converted into a DC voltage by using KBPC3510 bridge rectifier. The output of rectifier has some ripples. A capacitor filter is used to filter out the ripples from DC bus and assist the DC stabilization. This DC bus is used for the generation of variable voltage and variable frequency power supply. A power inverter circuit converts the DC into the required AC voltage & frequency. Now the desired phase voltage is fed to an induction motor.

The inverter has six MOSFET's that are controlled by PWM signals in order to produce the desired AC output from DC bus. These PWM signals are generated by PIC microcontroller. The controlled phase voltage can be obtained by changing duty cycle of the PWM signals. At a time, only two MOSFET's are in the conducting state, one from upper and other from lower. The sequences of conducting the MOSFET's are 1&5, 2&6, 3&4 and repeats. When any pair of MOSFET is conducted, the current starts flows from DC bus through one of the motor winding and motor is rotated. Motor windings are inductive in nature; it holds the energy in the form of current. So that the freewheeling diodes are connected across the MOSFET's which provides the path for current dissipation while MOSFETs are in the non conducting state. Upper & lower MOSFETs of the same limb should not be conducted at the same time which prevents DC supply shorted. The mentioned sequence of conducting MOSFET's, each pair of MOSFET conducts after 120°. Thus we get balanced voltages across the induction motor.

In control circuit consists of the PIC18F4431 microcontroller; Opto-Coupler and gate drive circuit. To obtain a variable AC voltage from inverter circuit, pulse width modulation is required to control ON time and OFF time of the MOSFET's. The dead time is required between two corresponding pair to avoid shorting the DC bus. PIC 18F4431 is used to generate three PWM signals using C language which is executed in the assembly language. PWM technique is used for controlling the power to inertial electrical devices, made practical by modern electronic power switches like MOSFET's. The average value of voltage and current fed to the load is controlled by turning the MOSFET between supply and load ON and OFF at a proportion of ON time to the OFF time of signals gives the required power to the load. Tachometer is connected to motor for measurement of speed.

3. HARDWARE OVERVIEW

A. Gate drives circuit

Fig.2 shows three phase motor drive circuit. It consists of NOT gate, buffer (BC547 and 2N3019), Opto-isolator, Darlington pair amplifier and MOSFET driver.

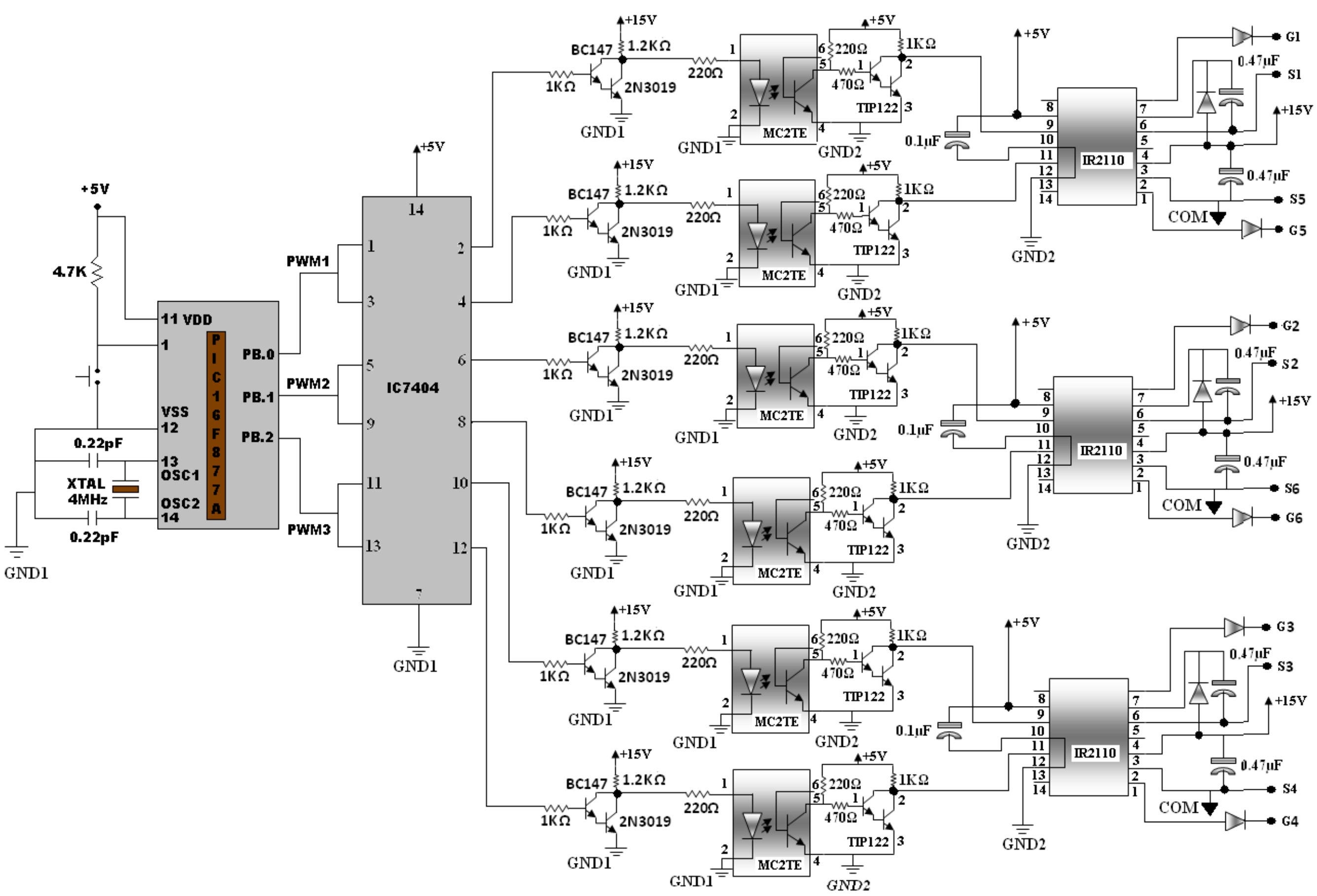

Fig.2 Gate drives circuit *source from DVB Journal, PIC Based Speed Control of Three Phase Induction Motor Via Single Phase Supply, b.n.jamadar

1) Buffer Circuit

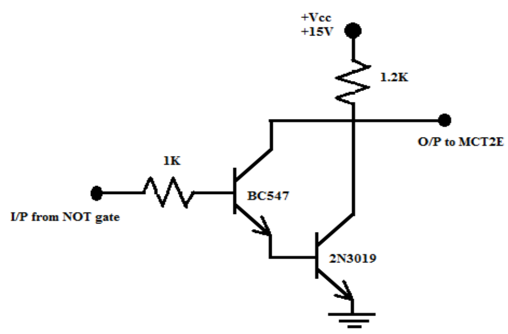

Fig.3 Buffer circuit.

PWM signals from microcontroller are not able to operate the Opto-isolator. So buffer circuit is used. Buffer circuit consists of BC547 and 2N3019 is as shown in above Fig.3. The microcontroller fed PWM signal to the base of BC547. The output is 180^0 out of phase with respect to input but output current is amplified which operates the opto coupler. The voltage of the inverter IC is 4.8V. The required current to turn ON BC547 is = 5mA. Therefore Base resistance of BC 547 is R_B = 4.8V / 5mA = 0.96KΩ = 1KΩ

Current through BC 147 is, $I_C = V_{CC} / R_C$ = 15 V / 1.2 K

I_C = 12.5mA

2) Opto-Isolators

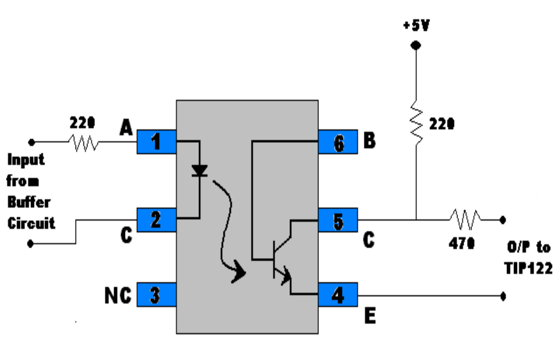

Fig.4 Internal circuit of Opto-isolator.

Above fig.4 shows the internal architecture of Opto-isolator (MCT2E). It has IR LED and NPN phototransistor. The rise time and fall time of phototransistor are very small about 5µS. The phototransistors turn-on time t_{on} =2-5 µS and turn-off time t_{off} = 300nS which limits the use in high frequency application.

Buffer circuit fed the input signal to the light emitting diode. LED conducts and emit the light which falls on the phototransistor. Therefore, phototransistor would be ON and inverted signal is produced at collector. The main function of Opto-Isolator is to isolate the power circuitry from the control circuitry. Unfortunately, if inverter is short, the opto-isolator will protect microcontroller circuit from severe short circuit current.

3) Darlington Pair Amplifier

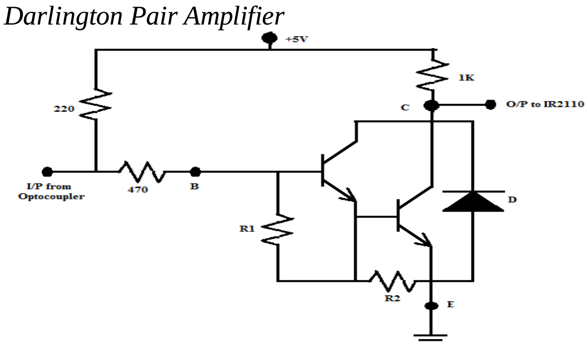

Fig.5 Darlington Amplifier circuit.

The TIP122 is popular Darlington pair NPN power transistor rated as 100V, 5A and gain over 1000 with power dissipation of 50W. The Darlington amplifier circuit is shown in above fig.4. The voltage gain is 1 but output is 180^0 out of phase with input. It intended for use in power, linear and switching applications.

4) IR 2110

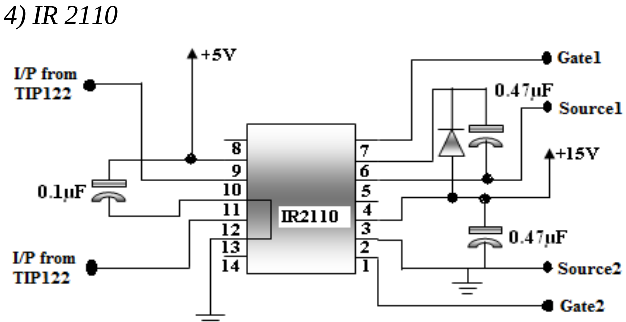

Fig.6 Connection of IR2110

IR2110 is a high voltage, high speed MOSFET drivers with independent high side and low side output voltage channels. It is capable to control two inputs at a time and produces high side and low side output pulses. Logic inputs are compatible with down to 3.3V logic. The output driver feature a high pulse current buffer stage designed for minimum driver cross section. The floating channel can be used to drive MOSFET in the side configuration which operates up to 500-600V. The gate drive requirements for a power MOSFET utilized as a high-side switch, the drain is connected to the high voltage rail, driven in full enhancement (i.e., lowest voltage drop across its terminals) is archived by using IR 2110.

B. Inverter

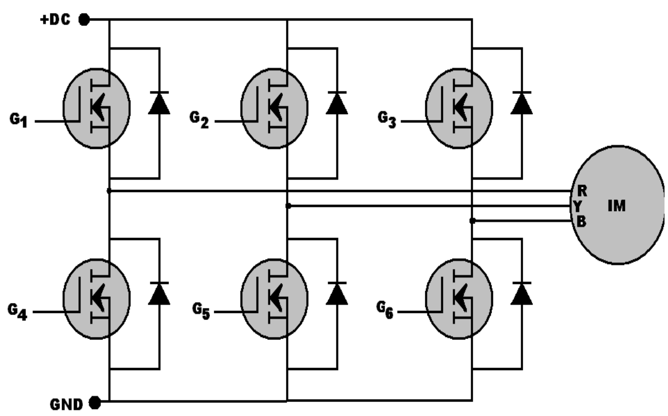

Fig.7 Power Inverter.

Inverter circuit is the main power conversion stage of entire system. Fig.7 shows the MOSFET based power inverter circuit. It consists of six MOSFET's & six freewheeling diodes are connected in three limbs. Freewheel diodes in each inverter leg may be internal to the main power switches or may be separate discrete devices in the case of standard MOSFETs which providing path of current for dissipation while MOSFETs are in the non conducting state. The MOSFET's in an inverter are controlled by PWM signals through driver circuit. At a time, only two MOSFET's are switched ON. The sequences of conducting the MOSFET's are 1&5, 2&6, 3&4 and repeats. When any pair of MOSFET is conducted, the current starts flows through corresponding motor winding. The waveforms of PWM pulses generated by PIC simulated in Proteus software as shown in fig.8. So MOSFET's are controlled in order to provide the device currents in limit, and hence control the motor torque, and to set the direction and speed of rotation of the motor. The torque is determined by the average current in each phase when it is energized. As the motor current is equal to the DC link current then the torque is proportional to the DC input current. The motor speed is synchronous with the applied voltage waveforms and so is controlled by setting the frequency of the inverter switching sequence.
As mentioned, the sequence of conducting MOSFET's, the desired phase voltage is obtained at each phase terminal of an induction motor. The motor is rotated at required speed.

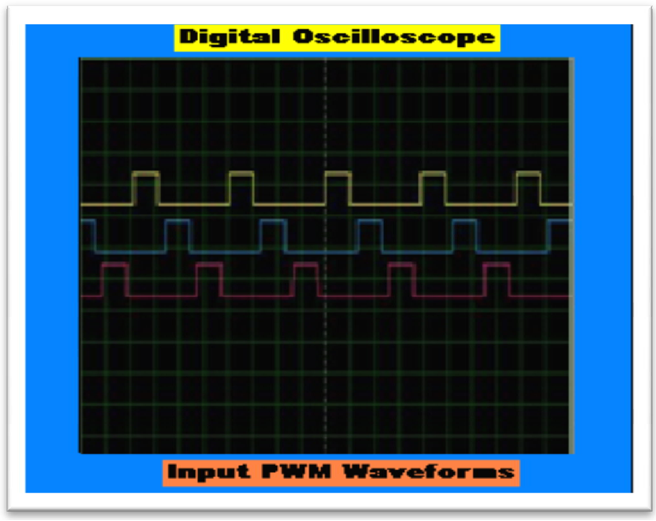

Fig.8 Input PWM Pulses.

4. TABLES AND GRAPHS

A) Table 1: RPM, Simulated efficiency & Actual efficiency.

RPM	Simulated efficiency	Actual efficiency
800	65.4	63.3
850	67.8	66.4
900	71.4	69.6
950	73.8	71.6
1000	75.7	73.2
1050	78.9	76.1
1100	81.8	79.7
1150	80.4	78.2
1200	77.9	75.6
1250	75.2	73.5
1300	72.3	69.3
1350	69.5	67.2

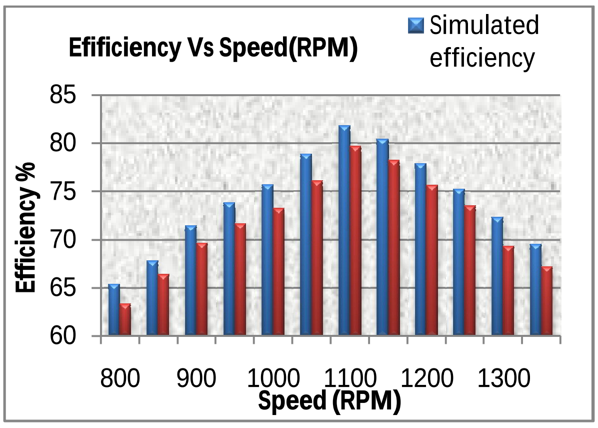

Fig.9 Graph of RPM Vs Simulated efficiency & Actual efficiency

B) Table 2: Load voltage & RPM.

Load Voltage	RPM
0	0
25	26
50	87
75	175
100	310
125	461
150	605
175	761
200	915
225	1065
250	1270

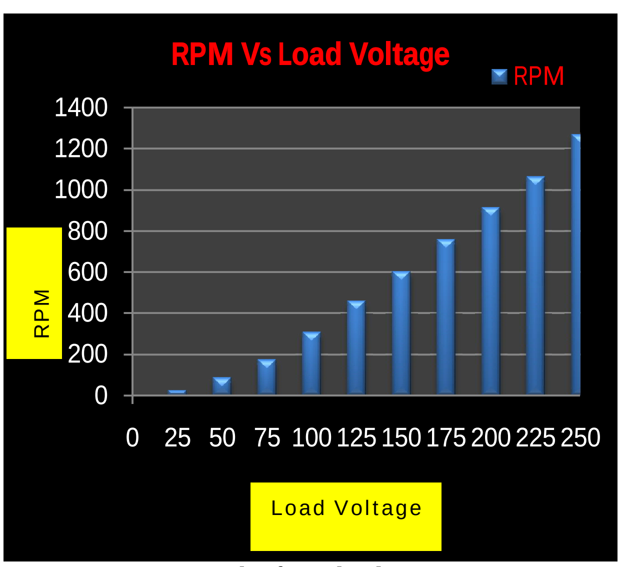

Fig.10 Graph of Load voltage Vs RPM.

C) Table 3: Torque & Speed.

Speed	Torque
100	1.012
200	0.844
300	0.785
400	0.646
500	0.52
600	0.438
700	0.352
800	0.29
900	0.247
1000	0.22
1100	0.158
1200	0.121
1300	0.048

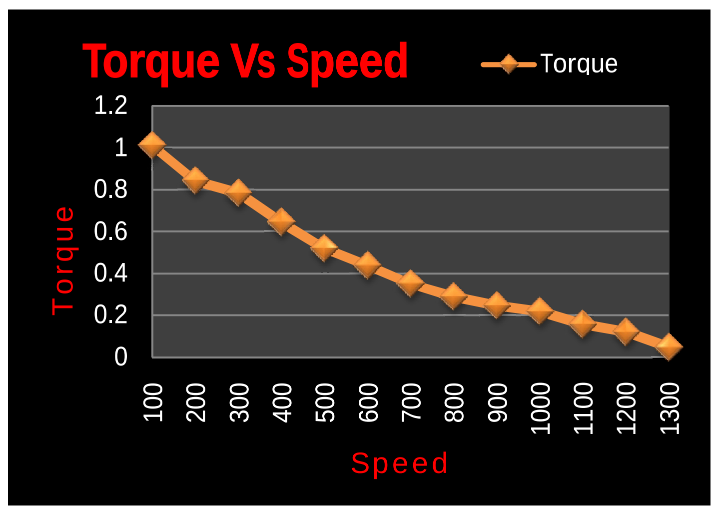

Fig.11 Graph of Torque Vs Speed.

5. RESULT and DISCUSSION

The present work is to design and development of PIC microcontroller based three phase induction motor drive system and to measure the speed, torque of the induction motor involved. The proposed drive is tested for single pulse of pulse width modulation. The system is simulated and compared with experimental results for different speeds. The experimental measurements of voltage, torque, speed, efficiency etc. are carried out by varying the gate pulse width of inverter. The performance of the motor is tested during the load and data is recorded.

The simulated and test results under the load are similar. The slight differences in the experimental results are due to the losses in the switching device and error in the measuring instrument.

Fig.9 shows the graph of speed against efficiency. It is seen that, initially as the speed increased the efficiency increases and attains maximum value at 1100 RPM and then decreases. This decrease in efficiency is due to the switching losses.

Fig.10 shows the graph of load voltage against RPM of motor. From the figure it is seen that as the load voltage increased the speed of motor also increases linearly. Initially the graph is non linear and it can be corrected by applying the correction factor through software.

Fig.11 shows the graph of torque against speed of motor. From the figure it is seen that as the speed increased, initially the torque of motor decreases sharply and then decreases slowly.

6. CONCLUSION

A PIC Microcontroller based PWM controlled three phase drive system has been designed and implemented successfully. It can be effectively used for speed control of the three phase induction motor using single phase supply.

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