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# DESIGN AND IMPLEMENTATION OF A PULSE STRATEGY BASED ON MICROCONTROLLER FOR A THREE PHASE INDUCTION MOTOR

**Prof.Dr. Saad Saad Eskander , Dr. Eid Abdelbaki, Eng. Amr Mahmoud Mohammed**
Electrical Engineering Department
Mansoura University
Egypt

## ABSTRACT

AC Induction motor (ACIM) is the workhorse of industrial and residential motor applications due to its durability, robustness and reliability. In today's energy conscious world, driving and controlling the induction motor efficiently are prime concerns. in addition, the great progress in microprocessor from its flexibility and higher speed to close and open the power electronic switches leads to decrease of using the analogue circuits and control units cost. This paper proposes an implementation of Microcontroller unit (MCU) based three-phase PWM generation and its application for ACIM control. A laboratory prototype of 1kW ACIM drive is successfully implemented using MCU PIC16F777. Experimental results are presented and analyzed to verify the stability and tracking performance of the proposed motor drive.

**KEYWORDS:** Microcontroller unit (MCU), Pulse Width Modulation (PWM), Graphic LCD, Keypad control

## INTRODUCTION

As far as the machine efficiency, robustness, reliability, durability, power factor, ripples, stable output voltage and torque are concerned, three- phase induction motor stands at the a top of the order. Motor control is a significant, but often ignored portion of embedded applications.[1]. For efficient power utilization various new PWM techniques are developed and still developing[2]. In the world of controls, the use of Microcontrollers is ever increasing. Industrial process control is one of the very important areas where we can use the Microcontrollers extensively. The flexibility offered by the system to implement various control techniques and also the flexibility offered by the system in terms of changing the control techniques is also great [3]. Nowadays PWM control method is mostly used in power converter applications. These PWM signals can be generated using analog circuit as well as digital circuit. PWM generation using analog circuit requires large number of discrete circuits such as triangular carrier wave generator circuit, sine wave generator circuit; comparator, adder circuits and phase shifters etc. Also the response of analog circuit may get affected by environmental conditions, noise, changes in the voltages and currents in the circuit and so on. Thus analog method is critical and increases complexity and cost of the circuit. Digital method of PWM generation requires only microcontroller and its minimum configuration. With the advent in the technology now many microcontrollers has in built feature of PWM generation. While some special controller ICs are also available that are designed and fabricated for three phase PWM generation and control purpose [2]. The main objectives is to

1- Generate a three phase PWM control strategy based on MCU for three phase ACIM.
2- Avoid the problem of damaging the power module.
3- Improved reliability and increased flexibility.
4- Simplicity of implementation in variable speed drives.
5- Low cost and high accuracy.
6- Change torque speed characteristics of drive by software modification.

## DESCRIPTION OF AC MOTOR DRIVE CONTROL SYSTEM:

The basic block schematic of three-phase induction motor drive is shown in Fig.1.

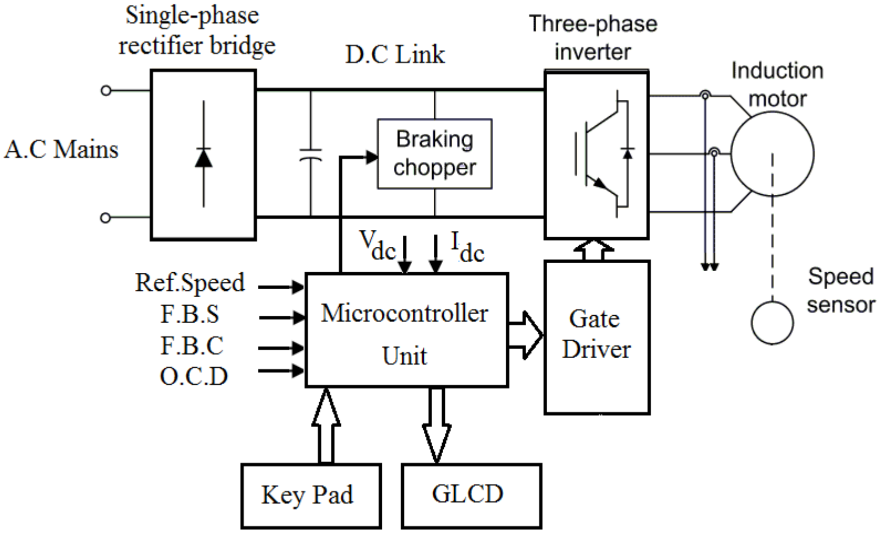


Fig. 1 Shows The Block Diagram Of An Overall Drive System.

The basic block schematic of three-phase induction motor drive is shown in Fig.1. It has single-phase full bridge rectifier, three-phase full bridge inverter, control circuit, speed and current sensing unit. In the proposed work the output of rectifier is filtered by 220µF, 450V capacitors. The three phase inverter has six switches, with the snubber circuit for each switch. The output of inverter is applied to the three-phase induction motor. The digital control of motor is achieved by applying gate pulses from the control circuit to each the MOSFET’s switch through optoisolation and gate driver circuit.[1]

## A. Control Circuit Description

### 1) PIC Microcontroller System

Fig.2 illustrates the PIC Microcontroller used with the proposed controller which has the type of **16F777**. it has 14 channels of 10-bit Analog-to-Digital (A/D) converter, 3 timers, 3 Capture/Compare/PWM functions, the synchronous serial port can be configured as either 3-wire Serial Peripheral Interface (SPI™) or the 2-wire Inter-Integrated Circuit (I²C™) bus and a Universal Asynchronous Receiver Transmitter (USART), 2 comparators, internal RC oscillator and Advanced Low Power Oscillator controls. All of these features make it ideal for applications including automotive, appliance, battery, RF, motor control and utility metering[4].

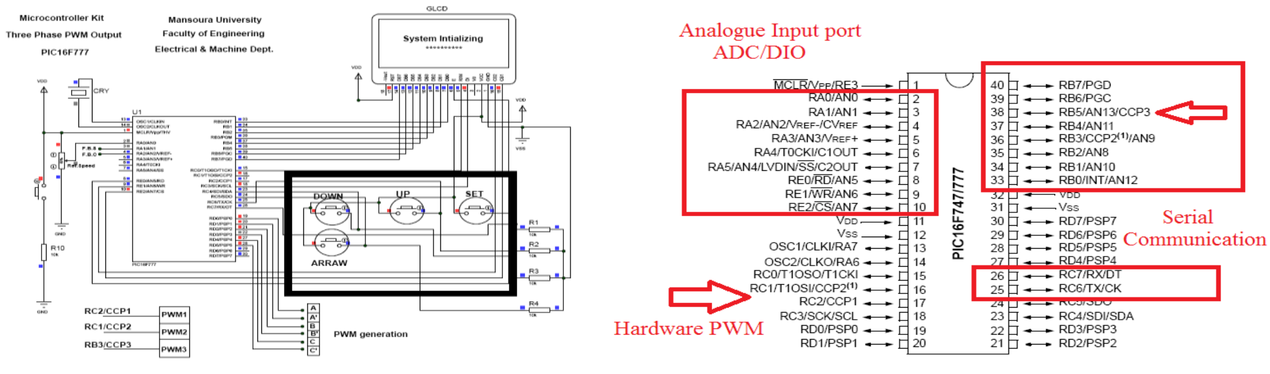


Fig. 2 PIC Microcontroller System

### 2) Interface and gate driver Circuit Design

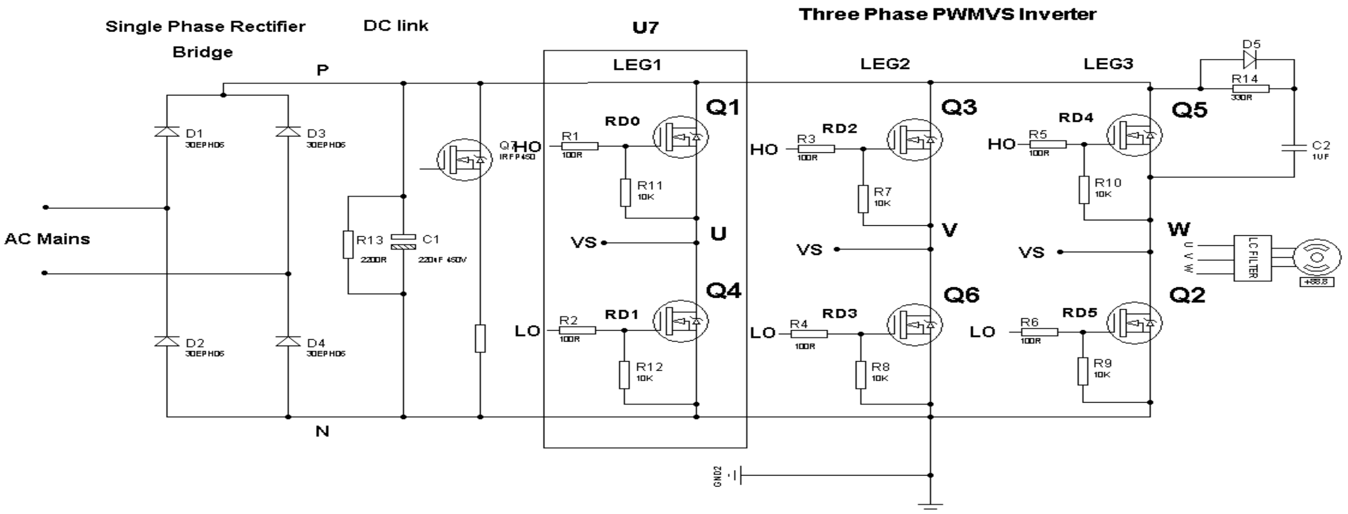
The interface circuit shown in the Fig.3 is used for interfacing between the PIC Microcontroller output and the gate of the power switch.

**Fig. 3 Interface Circuit**

The resistors form R13 to R18 are used for limiting the output current of the PIC so as not to exceed the forward current $\mathbf{I_F}$ of the diode (from data sheet)[5]. The IR2110 is a high voltage, high speed power MOSFET and IGBT driver with independent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. Logic inputs are compatible with standard CMOS or LSTTL outputs. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. Propagation delays are matched to simplify use in high frequency applications. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 500 volts. The MOSFET driver IR2110 is used to apply the switching pulses coming from the microcontroller to the MOSFET switches. The sinusoidal PWM signals are produced by the microcontroller and used to drive the MOSFETs. [6].

### B. Power Circuit Description

Fig.4 illustrates the power circuit which contains The AC grid, single phase bridge rectifier, parallel circuit contains resistor **R** (discharging resistor) and capacitor **C**, Three phase PWM inverter using the power **MOSFET** which is used for controlling the load according to the programming strategy into the PIC Microcontroller and RC snubber circuit used to protect the power switch.



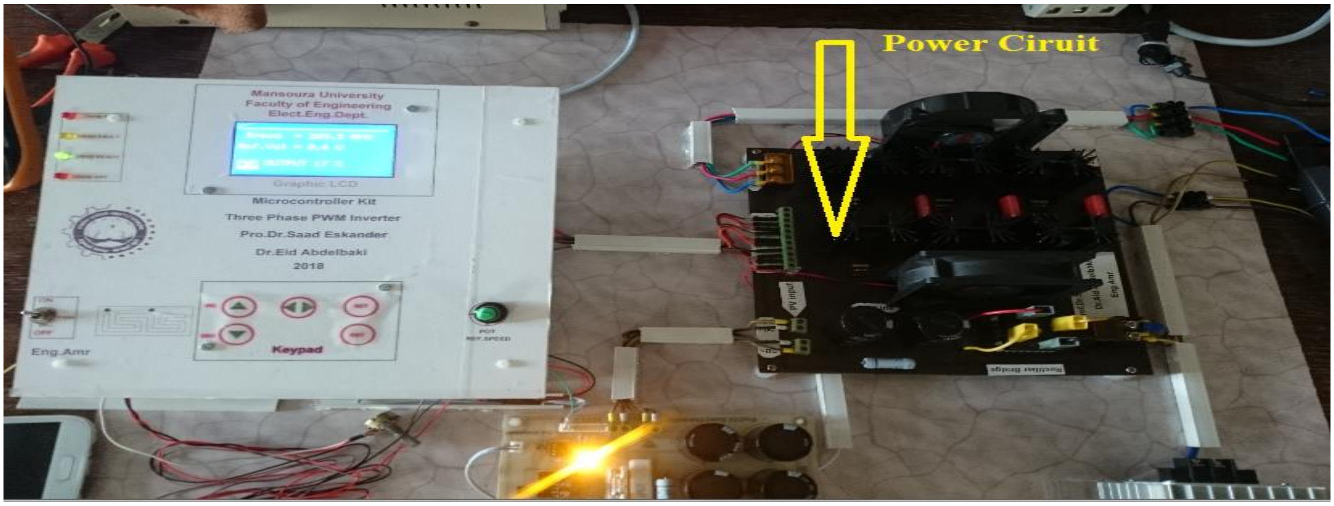


**Fig. 4 Power Circuit**

### 1) RC Snubber Circuit Protection:

RC type of snubber circuit protection is designed to protect the power switches against the voltage transient and ringing that occurs when the switch opens and also eliminate voltage spikes caused by circuit inductance when a switch either mechanical or semiconductor opens. The object of the snubber is to eliminate the voltage transient and ringing that occurs when the switch opens by providing an alternate path for the current flowing through the circuit's intrinsic leakage inductance a typical snubber circuit is shown in Fig. 5(a) [7].

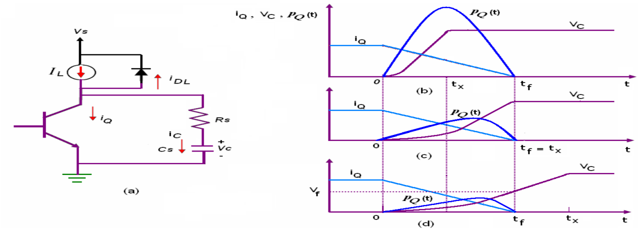


**Fig. 5 (a) Converter with a transistor snubber circuit (b-d) Turn-Off waveforms with a snubber with increasing values of capacitance.**

The transistor and snubber-capacitor current during turn-off are expressed as:

$$i_Q(t) = \begin{cases} I_L\left(1 - \dfrac{t}{t_f}\right) & \text{for } 0 \le t < t_f \\ 0 & \text{for } t \ge t_f \end{cases} \tag{5}$$

$$i_C(t) = \begin{cases} I_L - i_Q = \dfrac{I_L t}{t_f} & \text{for } 0 \le t < t_f \\ I_L & \text{for } t_f \le t < t_x \\ 0 & \text{for } t \ge t_x \end{cases} \tag{6}$$

Where $t_x$ **:** is the time at which the capacitor voltage reaches its final value.
The capacitor is chosen on the basis of the desired voltage at the instant the transistor current reaches to zero. The capacitor voltage in Fig.5 (d) is expressed as:

$$V_C(t) = \begin{cases} \frac{1}{C}\int_0^t \frac{I_L t}{t_f} dt = \frac{I_L t^2}{2 C t_f} & \text{for} \quad 0 < t < t_x \\ \frac{1}{C}\int_{t_f}^t I_L dt + V_C(t_f) = \frac{I_L}{C}\left(t - t_f\right) + \frac{I_L t_f}{2C} & \text{for} \quad t_f < t < t_x \\ V_S & \text{for} \quad t > t_x \end{cases} \tag{7}$$

If the switch current reaches zero before the capacitor fully charges, the capacitor voltage is determined from the first part of Eq.7. Letting $\boldsymbol{V_c}\,(t_f) = V_f$,

$$V_f = \frac{I_L t_f^{\,2}}{2\,C\,t_f} = \frac{I_L t_f}{2\,C} \tag{8}$$

Solving for *C*,

$$C = \frac{I_L t_f}{2V_f} \tag{9}$$

The capacitor is sometimes selected such that the switch voltage reaches the final value at the same time that the current reaches zero, in which case :

$$C = \frac{I_L t_f}{2V_s} \tag{10}$$

The power absorbed by the transistor is reduced by the snubber circuit. The power absorbed by the transistor before the snubber is added is determined from the waveform of Fig.5(c). Turn-off power losses are determined from:

$$P_Q = \frac{1}{T}\int_0^T P_Q dt. \tag{11}$$

The resistor is chosen such that the capacitor is discharged before the next time the transistor turns off. A time interval of three to five times constant is necessary for the capacitor discharge. Assuming five times constant for complete discharge, the on time for the transistor is;

$$R < \frac{ton}{5C} \tag{12}$$

The capacitor discharges through the resistor and the transistor when the transistor turns on. The energy stored in the capacitor is;

$$W = \frac{1}{2} C V s^2 \qquad (13)$$

This energy is transferred mostly to the resistor during the on time of the transistor. The power absorbed by the resistor is energy divided by time, with time equal to the switching period:

$$P_R = \frac{1}{2} C V s^2 f \qquad (14)$$

Where $f$ : is the switching frequency [8].

### 2) Modeling of AC Machine

The traditional methods of variable-speed drives are based on the equivalent circuit representation of the motor shown in Fig. 6.

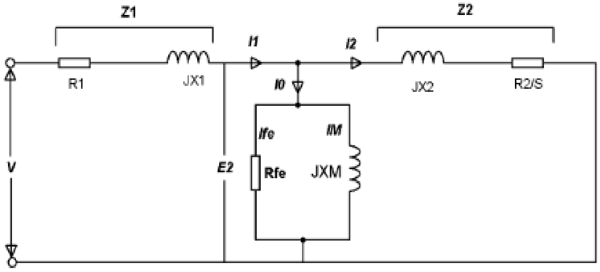
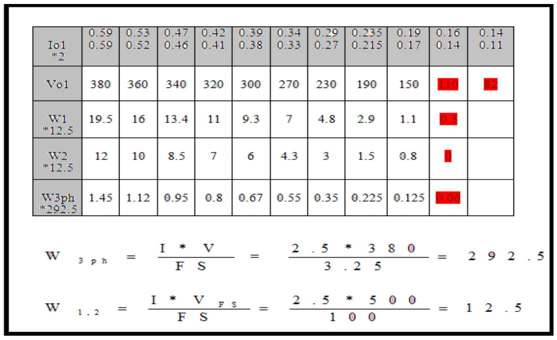


**Fig. 6 Steady-State Equivalent Circuit Of An AC Induction Motor.**

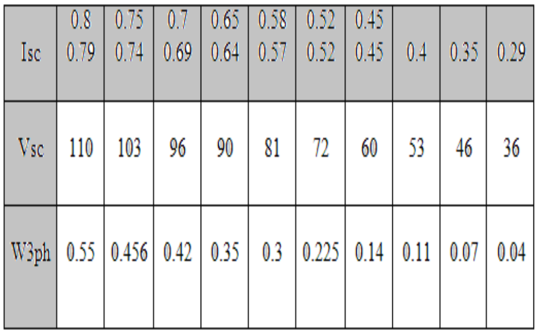


| Io1 *2 | 0.59<br>0.59 | 0.53<br>0.52 | 0.47<br>0.46 | 0.42<br>0.41 | 0.39<br>0.38 | 0.34<br>0.33 | 0.29<br>0.27 | 0.235<br>0.215 | 0.19<br>0.17 | 0.16<br>0.14 | 0.14<br>0.11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Vo1 | 380 | 360 | 340 | 320 | 300 | 270 | 230 | 190 | 150 | 110 | 82 |
| W1 *12.5 | 19.5 | 16 | 13.4 | 11 | 9.3 | 7 | 4.8 | 2.9 | 1.1 | 0.3 | |
| W2 *12.5 | 12 | 10 | 8.5 | 7 | 6 | 4.3 | 3 | 1.5 | 0.8 | 0 | |
| W3ph *292.5 | 1.45 | 1.12 | 0.95 | 0.8 | 0.67 | 0.55 | 0.35 | 0.225 | 0.125 | 0.06 | |

$$W_{3ph} = \frac{I * V}{FS} = \frac{2.5 * 380}{3.25} = 292.5$$

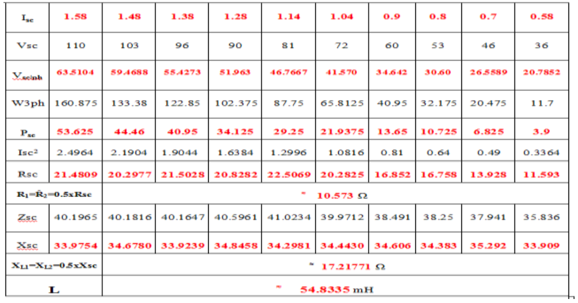
$$W_{1,2} = \frac{I * V_{FS}}{FS} = \frac{2.5 * 500}{100} = 12.5$$

(a)

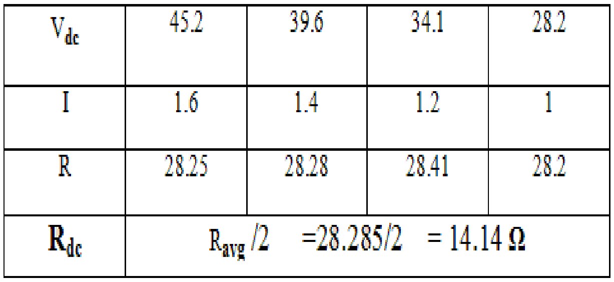


| Isc | 0.8<br>0.79 | 0.75<br>0.74 | 0.7<br>0.69 | 0.65<br>0.64 | 0.58<br>0.57 | 0.52<br>0.52 | 0.45<br>0.45 | 0.4 | 0.35 | 0.29 |
|---|---|---|---|---|---|---|---|---|---|---|
| Vsc | 110 | 103 | 96 | 90 | 81 | 72 | 60 | 53 | 46 | 36 |
| W3ph | 0.55 | 0.456 | 0.42 | 0.35 | 0.3 | 0.225 | 0.14 | 0.11 | 0.07 | 0.04 |

(b)



| $I_{sc}$ | 1.58 | 1.48 | 1.38 | 1.28 | 1.14 | 1.04 | 0.9 | 0.8 | 0.7 | 0.58 |
|---|---|---|---|---|---|---|---|---|---|---|
| Vsc | 110 | 103 | 96 | 90 | 81 | 72 | 60 | 53 | 46 | 36 |
| $V_{sc/ph}$ | 63.5104 | 59.4688 | 55.4273 | 51.963 | 46.7667 | 41.570 | 34.642 | 30.60 | 26.5589 | 20.7852 |
| W3ph | 160.875 | 133.38 | 122.85 | 102.375 | 87.75 | 65.8125 | 40.95 | 32.175 | 20.475 | 11.7 |
| $P_{sc}$ | 53.625 | 44.46 | 40.95 | 34.125 | 29.25 | 21.9375 | 13.65 | 10.725 | 6.825 | 3.9 |
| $Isc^2$ | 2.4964 | 2.1904 | 1.9044 | 1.6384 | 1.2996 | 1.0816 | 0.81 | 0.64 | 0.49 | 0.3364 |
| Rsc | 21.4809 | 20.2977 | 21.5028 | 20.8282 | 22.5069 | 20.2825 | 16.852 | 16.758 | 13.928 | 11.593 |
| $R_1=\hat{R}_2=0.5xRsc$ | ≈ 10.573 Ω | | | | | | | | | |
| Zsc | 40.1965 | 40.1816 | 40.1647 | 40.5961 | 41.0234 | 39.9712 | 38.491 | 38.25 | 37.941 | 35.836 |
| Xsc | 33.9754 | 34.6780 | 33.9239 | 34.8458 | 34.2981 | 34.4430 | 34.606 | 34.383 | 35.292 | 33.909 |
| $X_{L1}=X_{L2}=0.5xXsc$ | ≈ 17.21771 Ω | | | | | | | | | |
| L | ≈ 54.8335 mH | | | | | | | | | |



| $V_{dc}$ | 45.2 | 39.6 | 34.1 | 28.2 |
|---|---|---|---|---|
| I | 1.6 | 1.4 | 1.2 | 1 |
| R | 28.25 | 28.28 | 28.41 | 28.2 |
| $R_{dc}$ | $R_{avg}/2$ =28.285/2 = 14.14 Ω | | | |

(c) (d)

Table (a) no load test (b)short circuit test (c) estimation of R,L (d) DC estimation

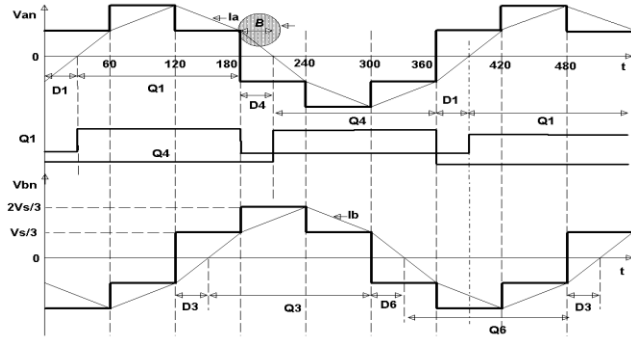


**Fig. 7 Waveforms Of Phase Voltage And Line Current .**

The most important problem to be considered is the dead time control. Dead time period must be suitable to avoid the problem of damaging the switch and harmonic problem. If the dead time is short, it will cause damage to the switches and if it is long, it will cause increase in the total harmonic distortion [9,10]
From the following equation

$$i(\omega t) = \frac{Vm}{Z}\left( \sin(\omega t - \phi) + \sin(\phi) e^{-\frac{\omega t}{\tan\phi}} \right) \qquad (15)$$

Where

Φ : is the angle between current and voltage

$$\phi = \tan^{-1}\frac{\omega L}{R} \qquad (16)$$

Starting from ωt = π ,as ωt increases, the current would keep decreasing. For some value of ωt , say β, the current would be zero. If ωt > β, the current would evaluate to a negative value. Since the diode blocks current in the reverse direction, the diode stop conducting when ωt reaches β. The value of β can be obtained by substituting $i(\omega t) = 0 \downarrow_{\omega t=\beta}$ .

$$i(\beta) = \frac{Vm}{Z}\left( \sin(\beta - \phi) + \sin(\phi) e^{-\frac{\beta}{\tan\phi}} \right) = 0 \qquad (17)$$

By using the numerical analysis we can get the value of β. The simplest method is by using the simple iteration technique by assuming [11].

$$\Delta = \frac{Vm}{Z}\sin(\beta - \phi) + \frac{Vm}{Z}\sin(\phi) e^{-\frac{\beta}{\tan\phi}}$$

For Our motor parameters L= 54.83 mH and R= 10.57 Ω

$$\phi = \tan^{-1}\frac{\omega L}{R} = \tan^{-1}\frac{314 * 54.833 * 10^{-3}}{10.573} = 1.02007 \text{ rad}$$

$$\tan\phi = 1.6284$$

$$Z = \sqrt{R^2 + (\omega L)^2} = \sqrt{(10.573)^2 + (314 * 54.833 * 10^{-3})^2} = \mathbf{20.2047}\Omega$$

$$i(\omega t) = \frac{220 * \sqrt{2}}{20.2047}\left( \sin(\omega t - 1.02) + 0.852 e^{-0.614\omega t} \right)$$

$$i(\omega t) = 15.3987\sin(\omega t - 1.02) + 13.1197e^{-0.614\omega t}$$

The value of **β** can be obtained from the above equation by substituting for i(β)=0. Then by using the simple iteration method and substitute different values of β in the region $\pi < \beta < 2\pi$ till we get the minimum value of delta the corresponding value of β is the required value.

$$\Delta = 15.3987\sin(\beta - 1.02) + 13.1197e^{-0.614\beta}$$

### C. Generation of 3 phase PWM Using PIC16F777

There are two modes of operation that has been used in this prototype the first is to generate a three phase PWM using six step mode and the other one is a SPWM.

The most common AC drives today are based on sinusoidal pulse-width modulation SPWM. However, voltage source inverters with constant volts/Hertz are more popular, especially for applications without position control requirements, or where the need for high accuracy of speed control is not crucial [12]

SPWM techniques are characterized by constant amplitude pulses with different duty cycle for each period. The width of this pulses are modulated to obtain inverter output voltage control and to reduce its harmonic content. Sinusoidal pulse width modulation is the mostly used method in motor control and inverter application [13, 14, 16]. To generate this signal, triangular wave is used as a carrier signal is compared with sinusoidal wave, whose frequency is the desired frequency. The proposed alternative approach is to replace the conventional method with the use of microcontroller [15].

The control signals and the dead time for the six switches of the inverter are shown in Fig.8 and Fig.9.

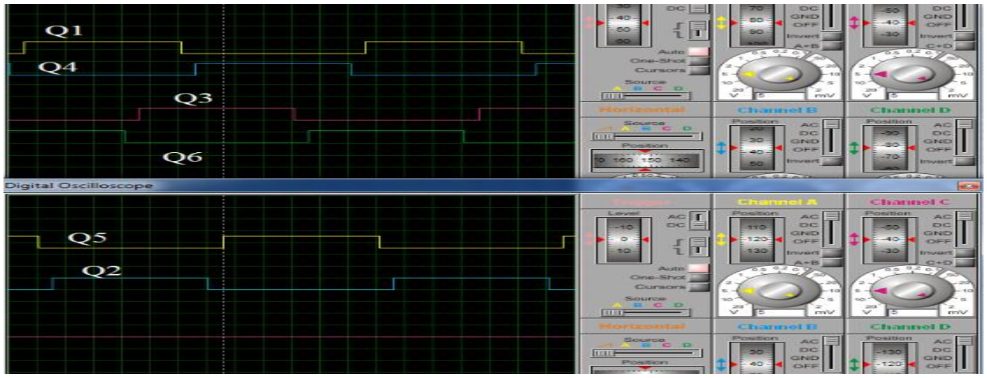


**Fig.8 Power Module Gate Control Signals**

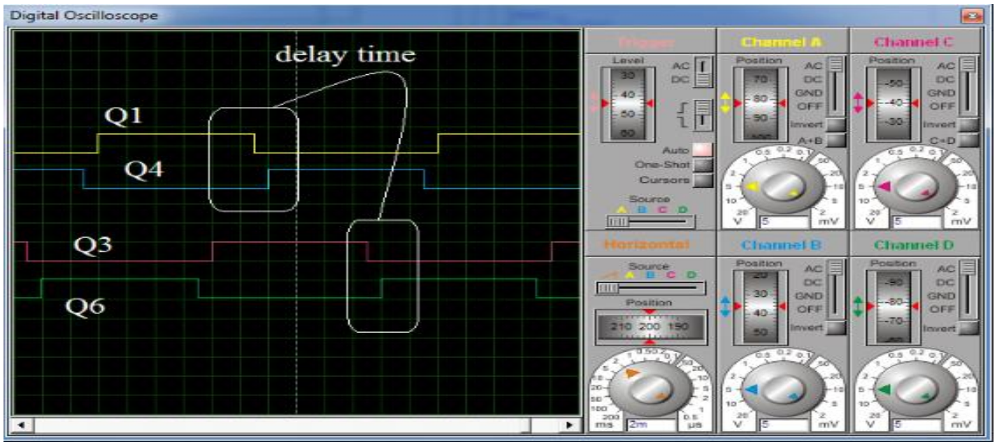


**Fig.9 Dead Time Between The Signals In The Same Leg.**

## EXPERIMENTAL RESULTS:

The experimental results are recorded using digital storage oscilloscope communicated with the computer. Fig. 10, Fig. 11, Fig. 12, Fig. 13 and Fig. 14 are represent the PWM output gate control signals of PIC Microcontroller , the phase shift between phases and the dead time of the same leg. Fig. 15 and Fig. 16 are representing the line to line voltage and line to neutral voltage.

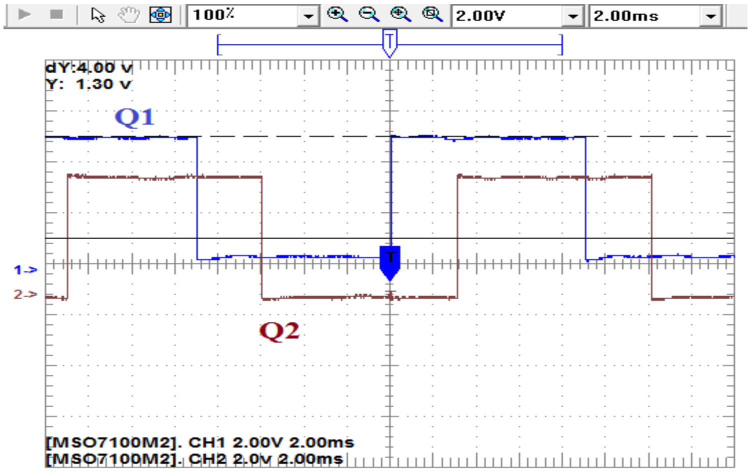


**Fig.10 PWM Output Signal between Q1&Q2 (Phase Diff.60$^o$).**

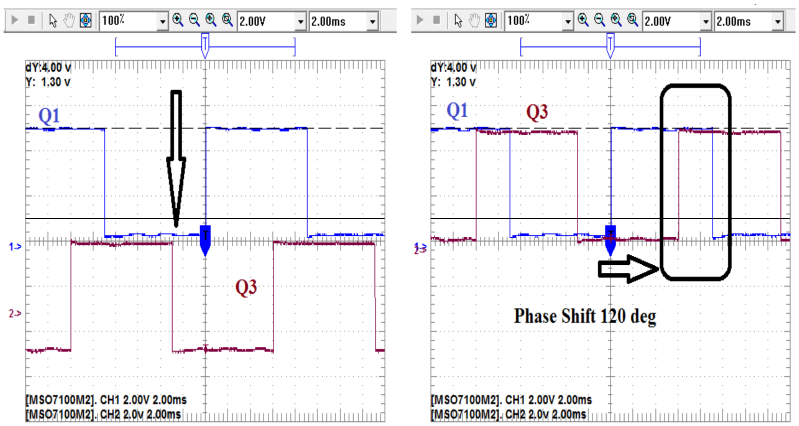


**Fig.11 phase shift between Q1&Q3 (phase diff.120$^o$).**

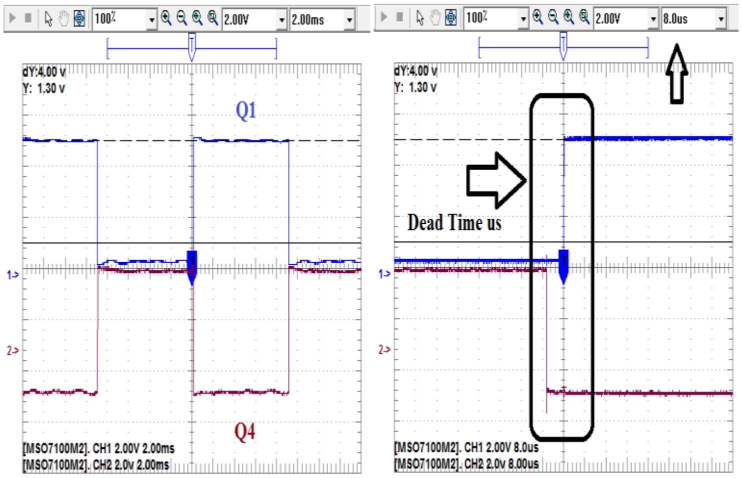


**Fig.12 Gate Control Signal and Dead Time between Q1&Q4**

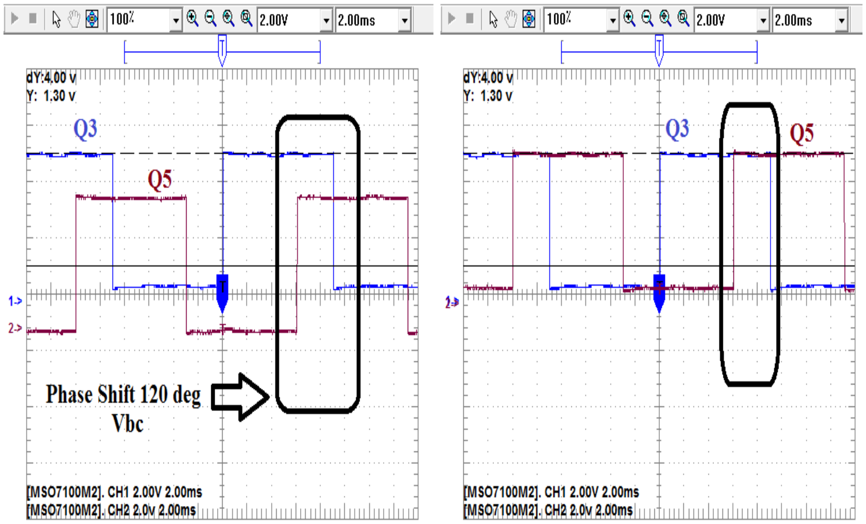


**Fig.13 Phase Shift Between Q3&Q5 (Phase Diff.120$^o$).**

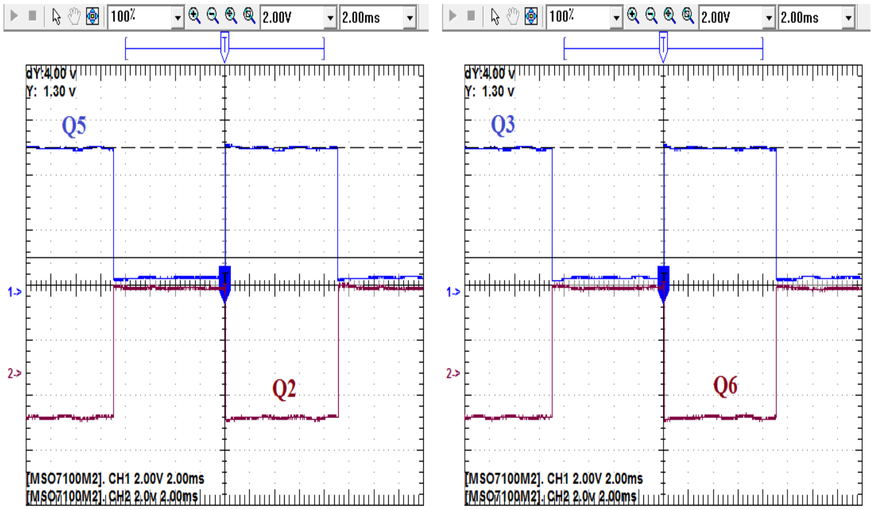


**Fig.14 Gate Control Signal Between Q5&Q2 And Q6&Q3.**

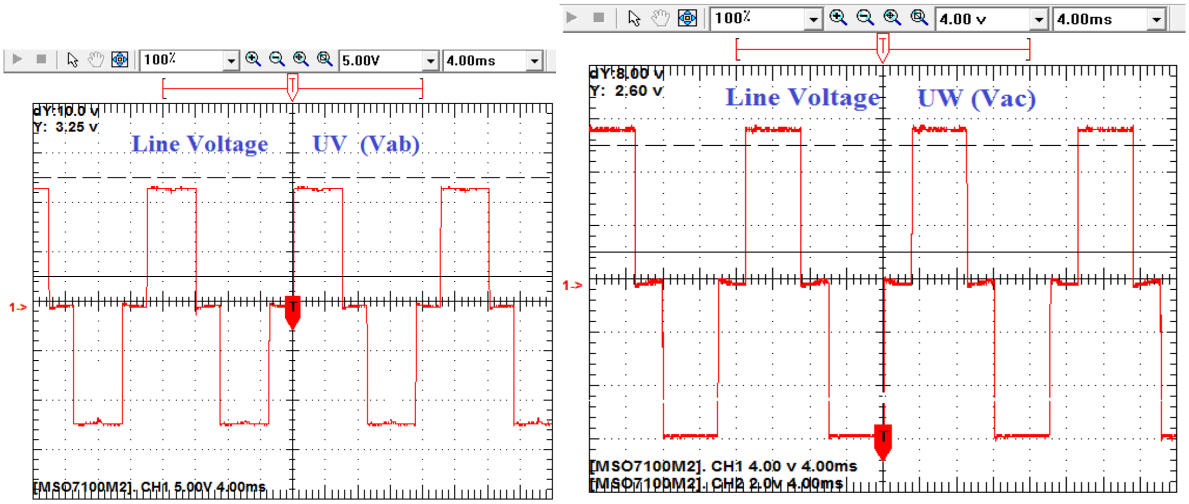


**Fig. 15. Line To Line Output Voltage (150 V) Of The Inverter.**

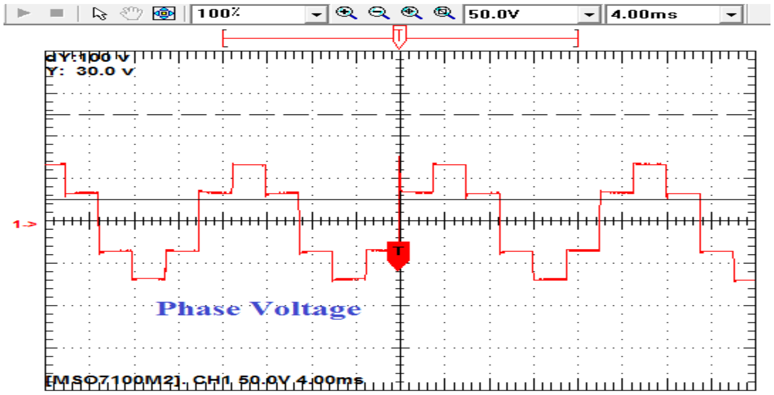


Fig. 16. Three Phase Load Line To Neutral Voltage (150V)

The harmonic content of line and phase voltages is the same. The different waveforms are due to a different phase relationship between the harmonics and the fundamental. Only odd harmonics of the order K=6n±1 are present, Where n is an integer. The triplen (multiples of 3) harmonics are absent, hence there is no circulating current in a delta-connected stator winding [17, 18]

**Photograph of Practical Circuits:**

Photographs of power and control circuits of ACIM drive which constructed in the laboratory are shown below in Figs.17 a, b and (c).

(a)

(b)

**Figs. 17 Power and Control Circuits of ACIM Drive Laboratory Boards**

## CONCLUSIONS

This research introduces the full design of all circuits for controlling the speed of ACIM. A real-time PID digital controller has been developed that controls the speed of a ACIM in a closed loop manner. A laboratory model of AC motor drive was successfully implemented using MCU PIC16F777 and tested. The electrical performance of all circuit is measured using digital storage oscilloscope connected to the PC. We could conclude that:

- The motor can be started/stopped and made to retain a set speed irrespective of the load.
- The motor can be run as low as 100rpm and as high as 1500rpm, also the torque is controlled through this period.
- Program interface is user-friendly enabling flexible and simple operation.
- PID controller enables the motor to reach the speed smoothly and within an acceptable period of time

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