HYSTERESIS CURRENT CONTROL TECHNIQUE FOR THREE PHASE INDUCTION MOTOR (MATLAB Simulink & ARDUINO)

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ABSTRACT

Three-phase induction motors have been widely used in a varities of domestic applications and industrial sectors. It is because of its reability, simple construction and low weight. The main problem is that, dynamical model of induction motor was strongly non linear in term of the torque, flux, and current regulation. This project was an overview of the developement on Hysteresis Current Control Technique which could be applied to the three phase induction motor. The objective of the controller was to control the current that supply into the induction motor. This technique was called current control technique by comparing the line current with the reference current. Thus, the hysteresis will forces the line current to track the reference current by creating the pulse width modulation (PWM) signal. The signal was fed into the gate driver circuit and injecting the output to the three phase inverter. The model was perform in MATLAB Simulink and also implements the hardware by using Arduino as a digital signal processing system. The result of the performance characteristics were explained in this report in terms of the output motor line current and effect to the induction motor.

ABSTRAK

Motor aruhan tiga fasa telah digunakan secara meluas untuk pelbagai kegunaan didalam pelbagai bidang. Ini ialah kerana sifatnya yang boleh dipercayai, pembinaan yang ringkas, dan juga kadar jisimnya yang ringan. Walaubagaimanapun, permasalahan utama yang dihadapi oleh dinamik model motor aruhan tiga fasa ialah ianya sangat tidak linear terutama dari segi daya kilas, flukes, dan arus yang tidak stabil. Projek ini adalah pandangan menyeluruh mengenai teknik pembikinan kawalan arus menggunakan Hysteresis teknik yang boleh dipraktikkan kepada motor aruhan tiga fasa. Tujuan pengawal dalam projek ini ialah untuk mengawal arus yg dibekalkan kepada motor aruhan. Teknik ini dinamakan pengawal arus teknik iaitu dengan membandingkan arus talian dengan arus rujukan. Oleh yang demikian, Hysteresis akan memaksa arus talian untuk mengesan arus rujukan dengan menghasilkan isyarat lebar denyut modulasi. Isyarat itu kemudiannya dimasukkan kedalam kaki litar pemacu dan hasilnya dihantar ke pengubah tiga fasa. Model ini telah di uji dalam Matlab simulink dan juga telah dilaksanakan dalam bentuk yang sebenar dengan menggunakan Arduino sebagai pemprosesan isyarat digital. Sebagai hasilnya, ciri-ciri prestasi telah diterangkan dalam projek ini dari segi hasil arus talian motor dan juga kesannya kepada motor aruhan.

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LIST OF SYMBOLS AND ABBREVIATIONS

m	-	Slope
C	-	Y-interset
Ω	-	Ohm
F	-	Farad
A	-	Ampere
V	-	Voltage
RMS	-	Root mean square
W	-	Watt
PWM	-	Pulse width modulation
AC	-	Alternating current
DC	-	Direct current
IM	-	Induction motor
DTC	-	Direct torque control
SMC	-	Sliding mode control
PID	-	Proportional-Integral-Derivative
FOC	-	Field oriented control
KCL	-	Kirchoff's current law
KVL	-	Kirchoff's voltage law
HB	-	Hysteresis band
AR	-	Auto regressive
USB	-	Universal serial bus

CHAPTER 1

INTRODUCTION

1.1 Project background

Three-phase induction motors have been widely used in a varities of domestic applications and industrial sectors with wide range in rating from a few hundred watts to a few mega watts. With the well known merits of reability, simple construction and low weight, it is gradually utilized in place of DC motor [1]. The main problem is that, dynamical model of induction motor was strongly non linear. Three phase induction motor has variable speed and the best way to control the speed of induction motor drives using inverter system [2]. Due to advances of power electronics, many researchers came out with various controllers to overcome the non linear characteristic of the induction motor which create an attention to the researcher to come out with other controller to replace the former one. Nowdays the controllers that had been widely used to overcome this problem are from adaptive and passive controller [3][4][5] such as Field Oriented Control (FOC), Direct Torque Control (DTC), Proportional Integral Derivatives (PID), Fuzzy, Nueral Network, Sliding Mode Control (SMC), and Hysteresis. The current regulation has played important role in current controlled pulse-width-modulated (PWM) inverter which widely applied in high performance AC drives [6][7]. Beside that there were several parameters that must be considered, such as the current control technique to the induction motor. For this case the Hysteresis Current Control Technique was being used. Recently, an embedded microcontroller system such as Arduino is rapidly developed in many applications because it is an open source and the reasonable price. Addition to that, the Arduino was directly interfaces to the MATLAB Simulink by using the Target Installer. The model was perform in MATLAB Simulink and also implements the hardware of Hysteresis Current Control Technique by using Arduino as a digital signal processing system. As a result the performance characteristics will be observed in terms of output motor line current and effect to the induction motor.

1.2 Problem statements

The trend of using three phase induction motor is obviously growing among the domestic and industrial application due to its characteristics. However the drawback of having non linear characteristic makes it difficult to be controlled. There were several parameters need to be considered before designing the controller, such as load torque, stator resistenace, rotor resistance, and output motor line current. The existance of control strategies such as Field-Oriented Control (FOC) suffers from sensitivity to the motor parameter variations even adaptive schemes tend to be sensitive but poor in the flux, torque, and current estimation especially during low speed operation. The current were varies during the operation beacuse it is depending on the torque and the load. An alternative to overcome this situation was to use the low cost and robust control techniques which take the motor’s line current as a feedback to the controller.

1.3 Objectives

This project highlights four objectives. These objectives were listed are below:

1. To designed and implement the hysteresis current control technique as a controller to the three phase induction motor.
2. To interface the MATLAB Simulink and the ARDUINO microcontroller.
3. To control the current that supply into the three phase indcution motor.
4. To built a low cost controller for three phase induction motor by using Arduino.

1.4 Scope of the project

In this project the scope was follow six developmental stages:

1. Study of the hysteresis current control technique.
2. Design and construct a gate driver.
3. Design and construct a three phase inverter.
4. Perform design of the controller by using MATLAB.
5. Implement the controller in the embedded system, Arduino as a degital signal processing.
6. Investigate the performance of of the controller.

CHAPTER 2

LITERATURE REVIEW

2.1 Motor

A motor is nothing but an electro-mechanical device that converts electrical energy to mechanical energy. It is because of motors, life is what it is today in the 21st century. There are different types of motor have been developed for different specific purposes.

In simple word, a device that produces rotational force is a motor. The very basic principal of functioning of an electrical motor lies on the fact that force is experienced in the direction perpendicular to magnetic field and the current, when field and electric current are made to interact with each other.

The motor can be divided into three types. There are DC motor (separately excited,series,shunt), AC motor (induction and synchronous motor) and Special motor (stepper motor, reluctance motor, universal motor) [8]. All of them has advantadges and disadvantages compare to each other.

2.1.1 Induction motor

Definition of the induction is the process by which an electromotive force is produced in a circuit by varying the magnetic field linked with the circuit. Induction motors are the most commonly used electric motors. Although it is possible to use an induction machine as either a motor or a generator, it has many disadvantages and low efficiency as a generator. That is why it is rarely used in that manner. The performance characteristics as a generator are not satisfactory for most applications. For this reason, induction machines are usually referred to as induction motors [9].

The operation of induction motor exist when AC current supplied to the stator winding which produces a flux through the air gap that induces currents in the rotor windings. Rotor receives electric power by induction in exactly the same way as the secondary of 2 winding transformer. It also can be treated as a rotating transformer, one in which primary winding is stationary (stator) but the secondary is free to rotate (rotor).

Most appliances, such as washing machines and refrigerators, use a single-phase induction machine while the industrial applications will used three-phase induction motor to drive the machines.

There some advantages and disadvantages of induction motor:

Advantages

- Very simple and extremely rugged
- Low cost and very reliable
- Requires minimum of maintenance

Disadvantages

- Speed cannot be varied without sacrificing some of its efficiency.
- Speed decreases with increase in load
- Its starting torque is inferior to d.c. shunt motor

Figure 2.1: The three phase induction motor

2.2 Inverter

An inverter is a device that converts DC power (also known as direct current), to standard AC power (alternating current) by switching the DC input voltage (or current) in a pre-determined sequence to generate AC voltage(or current) [10]. Inverters are used to operate electrical equipment from the power produced by a car or renewable energy sources, like solar panels or wind turbines. DC power is what batteries store, while AC power is what most electrical appliances need to run so an inverter is necessary to convert the power into a usable form. The typical applications of an inverter is un-interruptible power supply (UPS), industrial (induction motor) drives, tranction and VHDC.

2.2.1 Three phase inverter

The dc to ac converter commonly known as inverter, depending on the type of the supply source and the related topology of the power circuit. They are classified as voltage source inverters (VSIs) and current source inverters (CSIs). Single-phase VSIs cover low-range power applications and three-phase VSIs cover medium to high power applications [11].

The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase and frequency of the voltages can be controlled. The three-phase dc/ac voltage source inverters are extensively being used in motor drives, active filters and unified power flow controllers in power systems and uninterrupted power supplies. It is to generate controllable frequency and ac voltage magnitudes using various pulse width modulation (PWM) strategies. The standard three-phase inverter shown in Figure 2.2. It has six switches the switching of which depends on the modulation scheme. The input DC usually obtained from a single-phase or three phase utility power supply through a diode-bridge rectifier and LC or C filter.

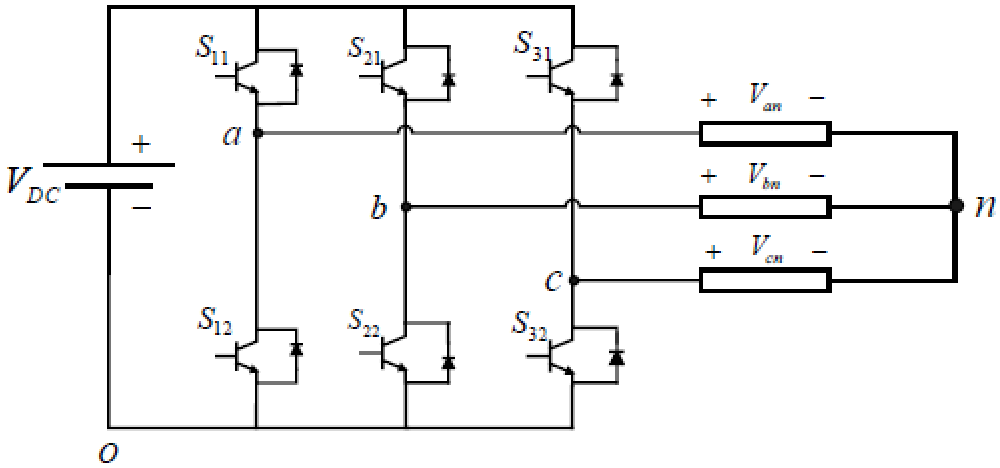

Figure 2.2: Six switch of swithing of three phase inverter

The inverter has eight switch states given in Table 2.1. In order to circuit satisfies the KVL and the KCL, both of the switches in the same leg cannot be turned ON at the same time, as it would short the input voltage violating the KVL. Thus the nature of the two switches in the same leg is complementary.

Table 2.1: The switching state in three phase inverter

S_{11}	S_{12}	S_{13}	V_{ab}	V_{bc}	V_{ca}
0	0	0	0	0	0
0	0	1	0	$-V_{DC}$	V_{DC}
0	1	0	$-V_{DC}$	V_{DC}	0
0	1	1	$-V_{DC}$	0	$-V_{DC}$
1	0	0	V_{DC}	0	$-V_{DC}$
1	0	1	V_{DC}	$-V_{DC}$	0
1	1	0	0	V_{DC}	$-V_{DC}$
1	1	1	0	0	0

From the eight switching states as shown in Table 2.1, two of them produce zero ac line voltage at the output. In this case, the ac line currents freewheel through either the upper or lower components. The remaining states produce no zero ac output line voltages. In order to generate a given voltage waveform, the inverter switches from one state to another. Thus the resulting ac output line voltages consist of discrete values of voltages, which are $-V_{DC}$, 0, and $V_{DC.}$ The selection of the states in order to generate the given waveform is done by the modulating technique that ensures the use of only the valid states.

2.3 Controller

The controller have devided into two groups which are Adaptive and Passive. The example of adaptive controller is PID, Fuzzy, and Neural Network. Meanwhile the passive controller consists of Hysteresis, Relay and Sliding Mode Control.

2.3.1 Hysteresis

Hysteresis can be define as the dependence of a system which is not only on its current environment but also on its past environment. In other words, it is deficiency or lagging behind [12]. This dependence arises because of the system could be more than one internal state. To predict its future development, either its internal state or its history must be known [13]. However, loops may also occur because of a dynamic lag between input and output. This effect also often referred to as hysteresis, or rate-dependent hysteresis.

The Figure 2.3 explains the operation principle of Hysteresis band PWM for an inverter. The control circuit generates the sine reference current wave of desired magnitude and frequency, and it is compared with the actual phase current wave. As the current exceeds a prescribed hysteresis band, the output was set to high. However, when the current starts to decay, the output goes to low. The actual current wave was forced to track the sine reference wave within the hysteresis band by back-and-forth (or bang-bang) switching of the upper and lower switches. The inverter then essentially becomes a current source with peak to peak current ripple, which was controlled within the hysteresis band[14].

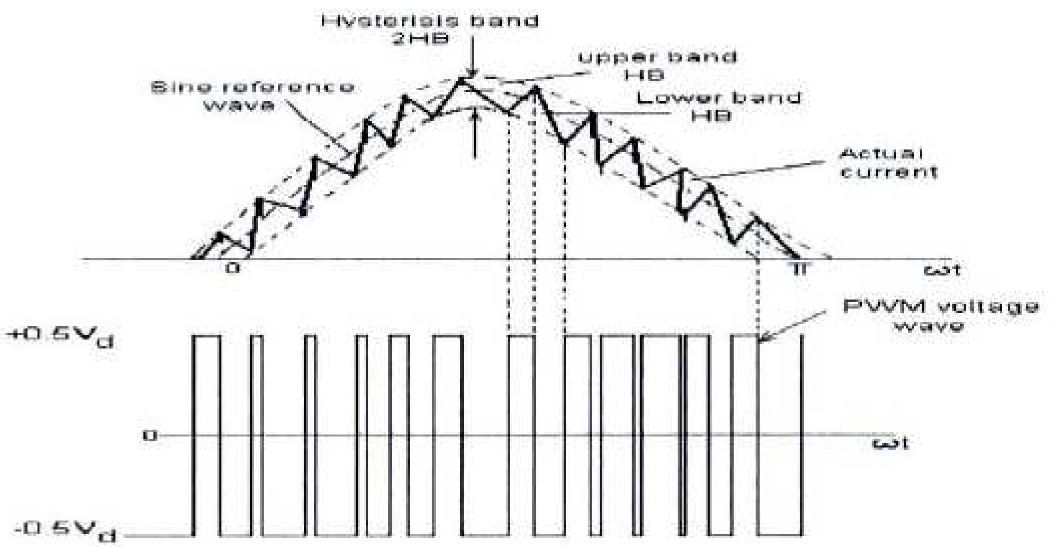

Figure 2.3: The hysteresis band control technique [15]

There were several methods that used in the hysteresis controller such as Direct torque control (DTC). Today DTC is recognized as a high performance control method for AC machines, allowing for fast torque control. In addition, DTC is very interesting and attractive from a conceptual point of view, because it integrates directly and clearly the power circuit of the inverter and the gate drive pulses generation with the behaviour of torque and flux in the machine.

In the paper [16], the speed control of an induction motor using nonlinear current control in rotating coordinates. Two hysteresis comparators and the position of the motor flux were used to generate directly the gate pulses for the power transistors of the inverter. This field oriented control method was compared with direct torque control and concluded that both control methods, although being conceptually different, have very similar features in terms of structure and performance.

A three-level inverter-fed induction motor drive operating under Direct Torque Control (DTC) was presented in paper [17]. A triangular wave was used as dither signal of minute amplitude (for torque hysteresis band and flux hysteresis band respectively) in the error block. This method minimizes flux and torque ripple in a three-level inverter fed induction motor drive while the dynamic performance was not affected. The optimal value of dither frequency and magnitude was found out under free running condition. The technique can reduces torque ripple by 60% (peak to peak) compared to the case without dither injection, results in low acoustic noise and increases the switching frequency of the inverter.

In paper [18] told that a deterministic system with no dynamics or hysteresis, it is possible to predict the system's output at an instant in time, given only its input at that instant in time. Hysteresis control is not possible to predict the output without knowing the system's current state, and there is no way to know the system's state without looking at the history of the input. This means that it is necessary to know the path that the input followed before it reached its current value.

2.3.2 Sliding mode control (SMC)

Background of this controller was founded in the former Soviet Union as a variable structure control system, and appeared outside Russia in the mid 1970s. The concept of sliding mode is proposed by Russian mathematician, Lyapunov and had discussed his theory about nonlinear systems.

The main of the sliding mode control is to adjust feedback by previously defining a surface. The system controlled will be forced to that sliding surface, then the behavior of the system slides to the desired equilibrium point. The main feature of this control was that we only need to drive the error to a switching surface. When the system is in sliding mode, the system behavior was not affected by any modeling uncertainties and/or disturbances [19][20].

There definition of terms in sliding mode control were listed as below:

- State Space – An n-dimensional space whose coordinate axis consist of the x_1 axis, x_2 axis until x_n axis.
- State trajectory- A graph of x(t) verses t through a state space.
- State variables – The state variables of a system consist of a minimum set of parameters that completely summarize the system’s status.
- Disturbance – Completely or partially unknown system inputs which cannot be manipulated by the system designer.
- Sliding Surface – A line or hyperplane in state-space which is designed to accommodate a sliding motion.
- Sliding Mode – The behavior of a dynamical system while confined to the sliding surface.
- Reaching phase – The initial phase of the closed loop behavior of the state variables as they are being driven towards the surface.

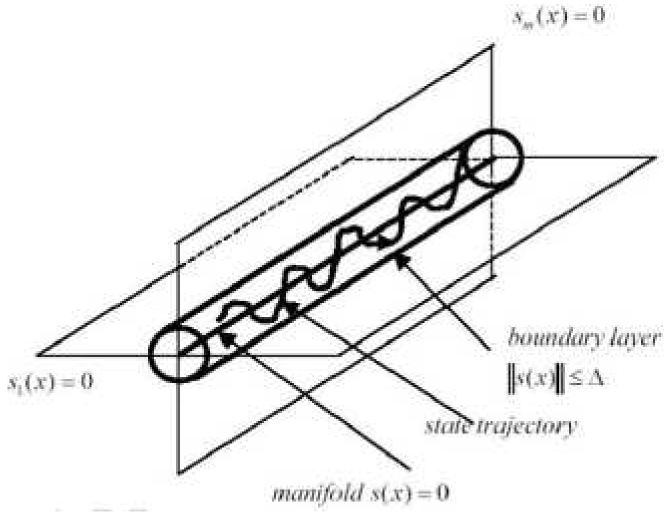

Figure 2.4: Boundary layer [20]

The paper [21] produces by V.I.Utkim deals with the basic concepts, mathematics, and design aspects of variable structure systems in the sliding mode.The main arguments in favor of sliding mode control are order reduction, decoupling design procedure, disturbance rejection, insensitivity to parameter variations, and simple implementation by means of power converters.The potential of sliding mode control methodology is demonstrated for versatility of electric drives and functional goals of control.

In paper [22] state that sliding mode control approach for induction motor drives was based on the model of an induction motor in a frame rotating synchronously with the stator current vector. As with the indirect vector control of induction motor, the method allows rotor flux and torque to be controlled by two independent control variables. Since the control law was represented in a set of inequalities instead of equalities, as the motor parameters change, the stability of the sliding mode and the feature of independent control of the flux and torque will not be destroyed as long as the corresponding inequalities hold.

2.3.3 PID controller

The PID is a combination of three elements, that known as proportional, integral and derivative. Proportional-Integral-Derivative (PID) controller is well known for its simplicity [23]. The popularity of PID controller can be attributed partly to their robust performance in a wide range of operating conditions and partly for their simplicity engineers can operate them in a simple and straightforward manner.

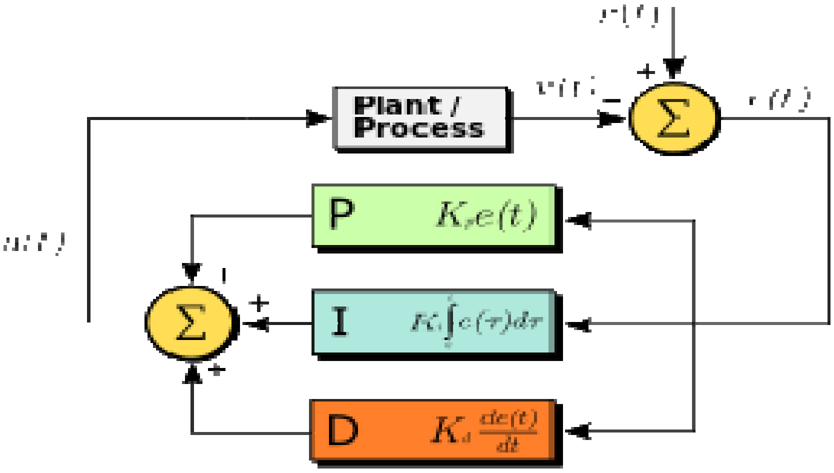

Figure 2.5: PID controlled system

Paper [24] presented a study on a predictive PID controller for DC-DC converters using an adaptive prediction error filter (PEF) in the controller feedback loop. They use specific mathematical analysis such as Auto Regressive (AR) process generator and Moving Average (MA). They come out with a result that their controller has superior performance over a classical PID approach in terms of system disturbance rejection, improved stability and output regulation.

A comparison paper are explained in [23] based on speed control of induction motor using PI controller and PID controller. The finding conclude that PID controller gives better speed response in terms of settling time, rise time and steady state error.

2.4 Proposed controller

There are two common techniques that widely used to control the three phase induction motor. They are voltage source control technique and the current source control technique. Both of the control technique quite similar in terms of comparing an internal voltage/current feedback loop and also correct the error occurs using the passive or active controller.

For this project, hysteresis current control technique was used as a controller. It is because the hysteresis control was not possible to predict the output without knowing the system's current state, and there is no way to know the system's state without looking at the history of the input. This means that it is necessary to know the path that the input followed before it reached its current value[18].

Besides that, a current control technique were apply to the hysteresis control as a part of the controller to control the current that supply into the induction motor. The current control technique operate by comparing every each of the line current from the three phase induction motor with a reference current. After that, the controller will correct the current’s error until the line of the current approximately same with the reference current.

In other words, the controller will minimize the differences between the line of the current and the reference current by sending the Pulse Width Modulation (PWM) to the three phase inverter.

2.5 Arduino

In 2005, Massimo Banzi and David Cuartielles create an embedded system named as Arduino which are less expensive than other prototyping systems available at the time. They began producing boards in a small factory located in Ivrea, a town in the Province of Turin in the Piedmont region of northwestern Italy.

Arduino is a single-board microcontroller designed to make the process of using electronics in multidisciplinary projects more accessible. The hardware consists of a simple open source hardware board designed around an 8-bit Atmel AVR microcontroller, though a new model has been designed around a 32-bit Atmel ARM. The software consists of a standard programming language compiler and a boot loader that executes on the microcontroller [25]. Micro- controllers are also attracted to Arduino because of its agile developement capabilities and its facility for quick implementation of ideas.

The Arduino is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter [17].

There are specifications of Adruino:

Table 2.2: Specifications of Arduino

Microcontroller	Atmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (Atmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (Atmega328)
EEPROM	1 KB (Atmega328)
Clock Speed	16 MHz

The advantages of the Arduino are stated below:

- Inexpensive - Arduino embedded devices are inexpensive compared to other microcontroller embedded devices.
- Cross-platform - Most microcontroller systems are limited to Windows. Different with Arduino, it can runs on Windows, Macintosh OSX, and Linux operating systems.
- Simple, clear programming environment - The Arduino programming environment is easy to use for beginners.
- Open source - The Arduino software is published as open source tools, so the user could easily get the information from the experienced programmers.

The applications of the embedded system like the Arduino rapidly growth due to its advantages. According to the paper [26], a novel Open loop phase control method is developed by coding a program using ARDUINO software in which ARDUINO controller takes input from the user and generates firing pulses for the TRIAC which controls the speed of the Induction motor. The total process is executed with the help of an ARDUINO controller kit where ARDUINO and Tera-Term softwares are used for micro controller and for serial monitor.

Figure 2.6: The Arduino microcontroller [25]

CHAPTER 3

METHODOLOGY

3.1 Block diagram

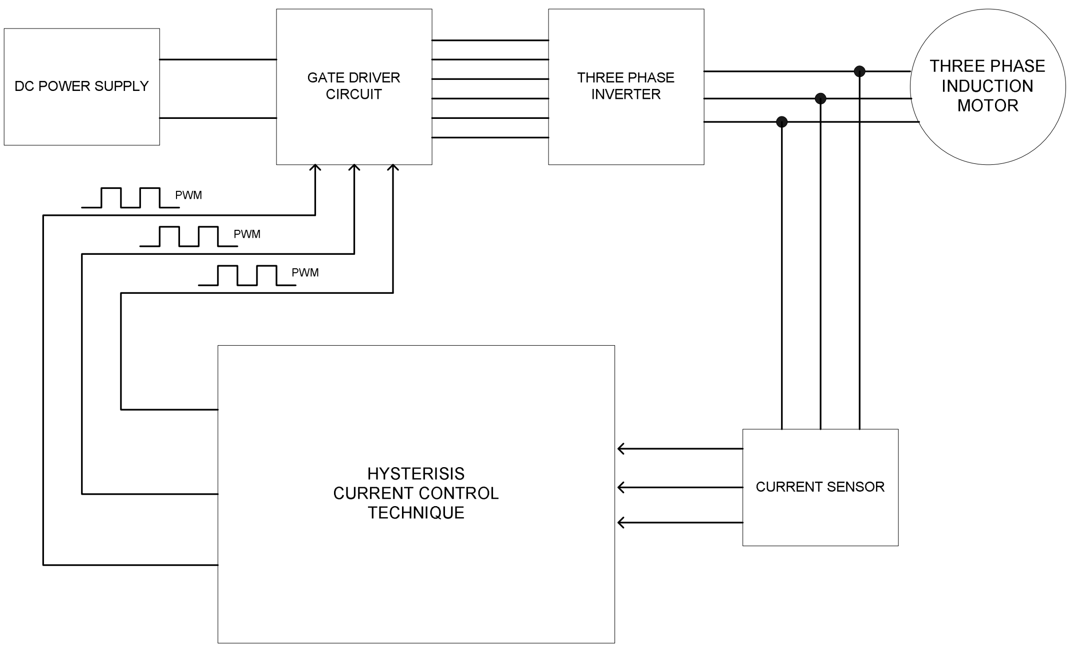

Figure 3.1: Block diagram of the project

The Figure 3.1 shows the block diagram of the project. it consists of 6 mains parts which are the DC as the input, the gate driver circuit, the three phase inverter, the three phase induction motor as a load, the current sensor as a feedback and the controller to give the system more robustness performance.

The first part is an input which is the DC voltage that fed to a three phase inverter and also power up the whole system. The gate driver use a 5 Vdc while the inverter input voltage depend on the load that need to be powered. Second part is the gate driver circuit functioning to double up the signal PWM from the arduino. The gate driver will doube up the number and the amplitude of the signal PWM to the three phase inverter. For this project, the gate driver will produce six PWM signal.

The three phase inverter is a third part of the project. The general function of the inverter is to convert the DC voltage to the AC voltage. It is needed in the system because the three phase induction motor act as a load. The three phase inverter also known as the six swith inverter type or full bridge inverter. It will receive the output PWM from the gate driver.

The three phase induction motor from the hps SystemTechnik was used as a load. The rating of the three phase induction motor is 0.37 kW, 400 V, and 1 A. As stated before, the three phase induction motor was known because of its non linear characteristics and for that reason the controller is needed. Meanwhile the current sensor is used to measure each of the line current that flow to the IM. Its function is not only to measure the line current but the output of the current sensor will be used as a feedback to the controller.

The important part of the system is the controller. The hysteresis current control technique will act as a controller to the system. The controller will compare the motor current with the reference current and if there is an error, the controller will generate the pulse width modulation to fed into the three phase inverter. By fedding the PWM to the inverter, it will rescalling the ouput to power up the load. This process will looping in the feedback until the error pproximately to zero. By adding the controller to the system, it can give high level of controlling the current that supply to the IM.

3.2 Gate driver design

The gate driver circuit is an important circuit to drive up the three phase inverter by sending the PWM into the gate pin at the power transistor.The main fuction of this curcuit is to double up the input PWM from the controller in term of the number and amplitude of the signal. The circuit consists of several components as listed in the Table 3.2.

Table 3.2: List of the components for gate driver circuit

No	Component	Unit
1.	IL0515S	6
2.	IN4748A	6
3.	Capacitor 1nF	6
4.	Resistor 4.3kΩ	2
5.	Resistor 560Ω	2
6.	Resistor 10Ω	2
7.	Resistor 10kΩ	12
8.	IC 7414	3
9.	IC 4081	3
10.	HCPL3120	6

Figure 3.2 shows the schematic diagram of gate driver circuit that design by using the Proteus Professional 8 software. The signal PWM generate by the controller will split into two by the Hex Schmit-Trigger Inverter (IC 7414) and flow through the zener diode as a protection to the circuit. The first ouput of the IC 7414 will remain the same with the output of the controller but the second ouput are invert from the first output.

Then both of the output from the IC 7414 flow into the the IC 4081 which are Quad 2-input AND gate. The IC 7414 consists of four AND gate. Two output signal from the IC 7414 were add to each other to double up the amplitude of the PWM before flow into the Gate Drive Optocoupler (HCPL3120).

The HCPL3120 consists of gaAsp LED optically coupled to an integrated circuit with a power output stage. This optocoupler is ideally suited for driving power IGBT’s or power MOSFET’s used in a motor control inverter application. The minimum supply voltage of this optocoupler is 15V that are taken from the IL0515S which are the DC-DC conveter.

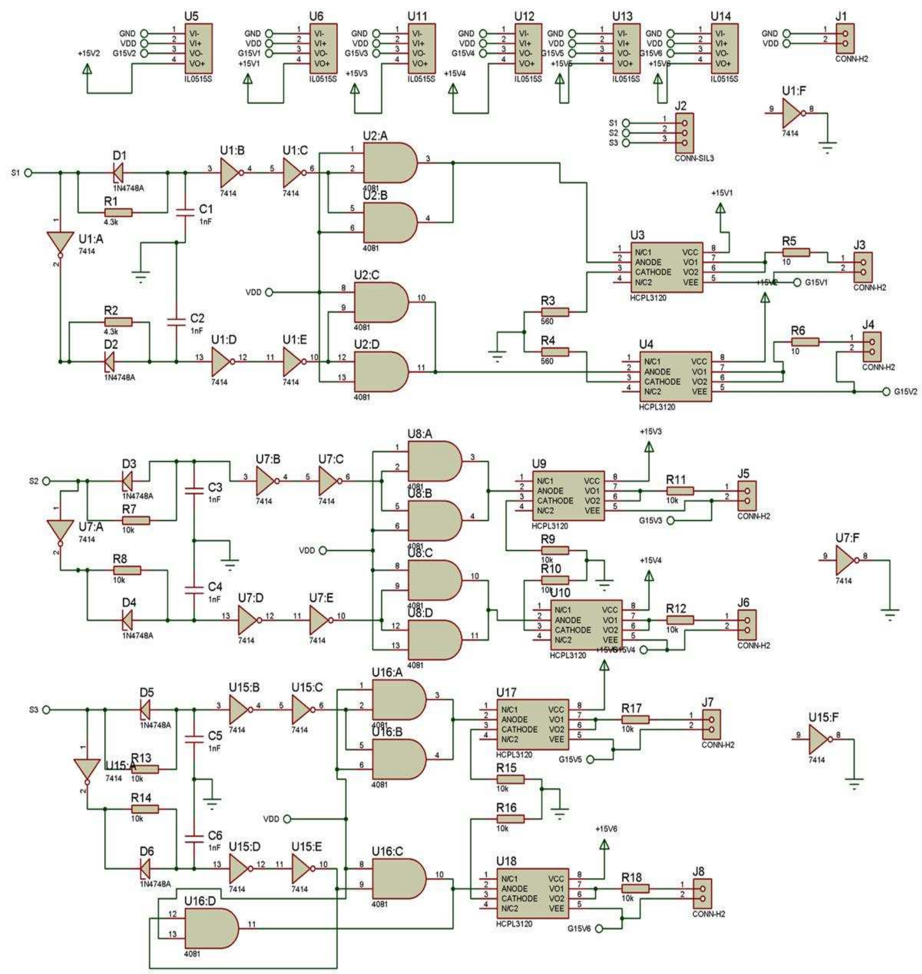

Figure 3.2: The schematic diagram of the gate driver circuit

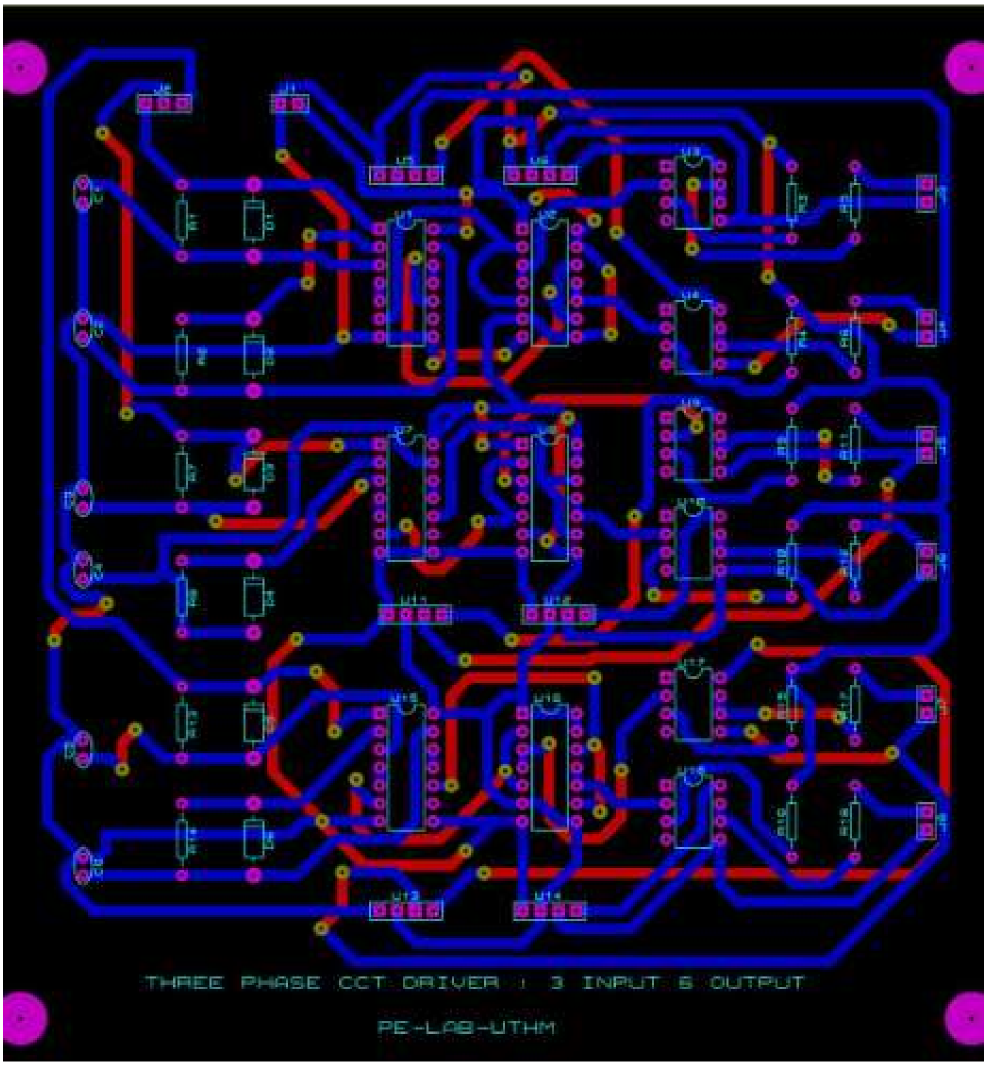

Figure 3.3: Layout design of the gate driver circuit

The Figure 3.3 shows the layout design of the gate driver circuit from the Proteus Professional 8 software. The layout is the final layout after routing process of the lines and components. The blue and the red line is the bottom and top copper. The red line also known as the jumper. Because of the circuit have too much jumpers, the circuit must be constructed in double sided PCB.

3.3 Inverter design

The schematic diagram for the three phase inverter are shown in the Figure 3.4. It consists of Power Transistor (MOSFET SPP11N60C3) and a capacitor. The circuit also known as the voltage source inverter or full bridge inverter. The general function of the inverter is to produce an AC power to power up the three phase induction motor.

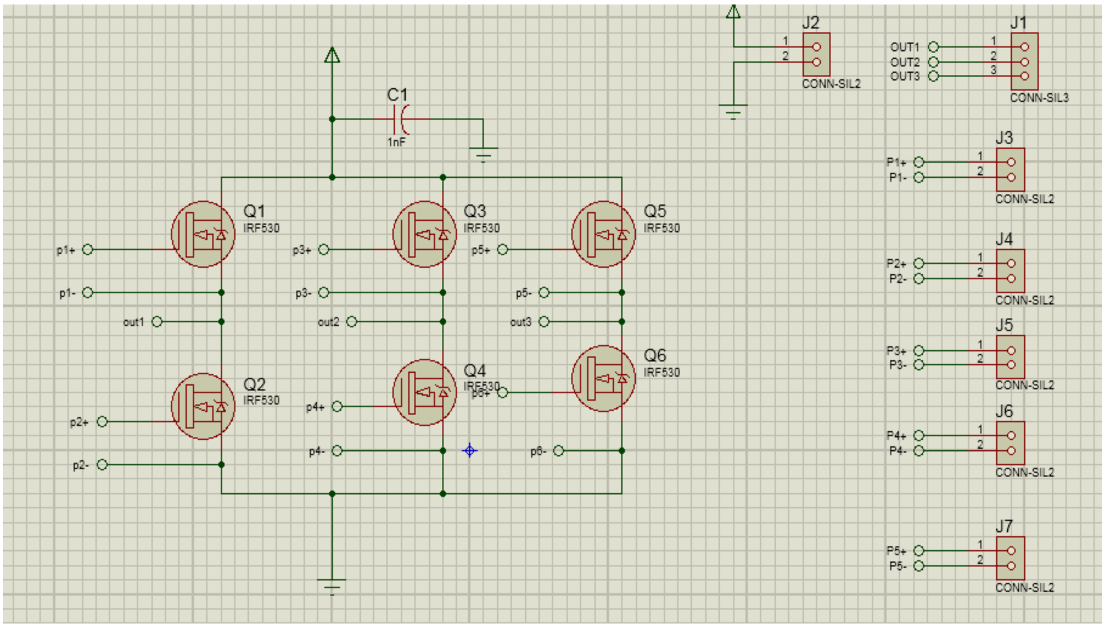

Figure 3.4: The schematic diagram of three phase inverter

Table 3.3 show the list of components on the inverter circuit. The MOSFET (power transistor) has three legs which are drain, gate, and source. The power transistor is capable handling the maximum voltage up to 600 V. It also the main component for this circuit to generate the three line voltage in a difference phase via injecting the PWM signal at the gate pin. The three phase AC voltage depend on the switching condition which are refer to the PWM signal that been inject into the gate pin at the power transistor. The minimum rating to trigger the gate pin is 12 V. Since the output PWM from the microcontroller is 5 V, three phase inverter are connected to the gate driver circuit to receive the minimum rating of the PWM signal.

Table 3.3: List of components for three phase inverter circuit

No	Component	Unit
1.	MOSFET SPP11N60C3	6
2.	Capacitor 470µF (450V)	1

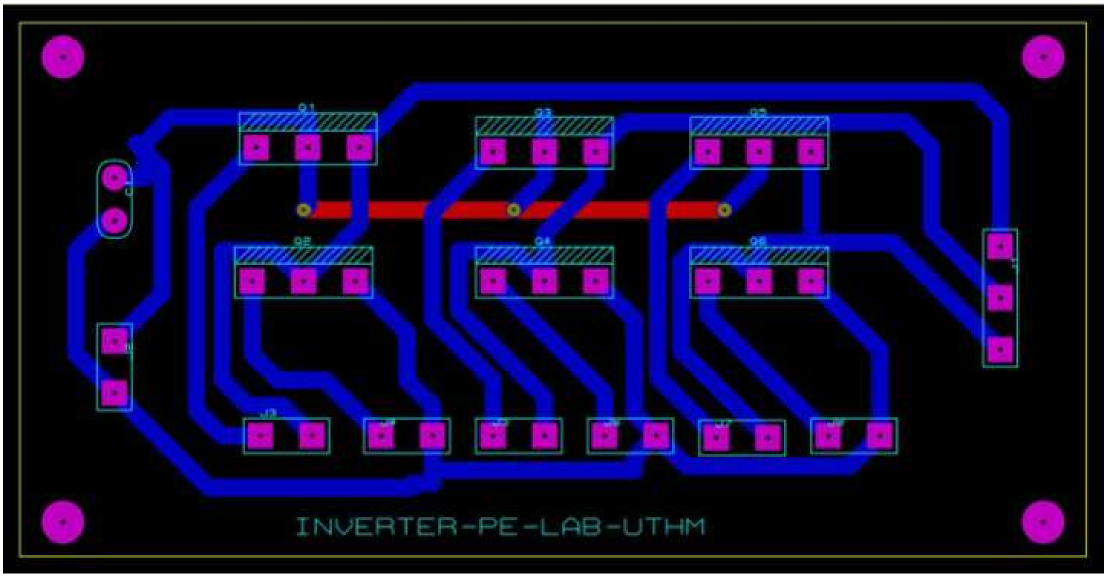

Figure 3.5: Layout design of the three phase inverter circuit

The Figure 3.2.2 show the layout design of the three phase inverter. The blue line is the bottom copper of the PCB. The bottom copper of the layout inverter are more bigger than the gate driver because of the inverter circuit are handling higher voltage rating.

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