PI HYSTERESIS CURRENT CONTROL TECHNIQUE FOR THREE PHASE INDUCTION MOTOR BY USING MATLAB AND ARDUINO

FAIZUL RIZAL B MOHAMED TAZUDIN

A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master Of Electrical Engineering

Faculty of Electrical Engineering
Universiti Tun Hussein Onn Malaysia

JANUARY 2014

ABSTRACT

When an AC motor is connected directly to the main supply, the motor will accelerate quickly and then rotate at a fixed speed which is dependent upon the electrical supply frequency and the motor design. For some applications fixed speed is acceptable and, by carefully selecting gearbox ratios, a desired final output speed can be achieved. However, for most applications, hard acceleration, unbraked deceleration and the inability to vary the speed and torque represent a serious problem. AC drives provide a solution by modifying the voltage and frequency of the AC supply to the motor. Control is achieved by either estimating the motor speed, known as open loop control, or by measuring the speed, known as closed loop control. Therefore this thesis is proposing to design a closed loop PI hysteresis (PIH) current controller for a three phase induction motor fed from an inverter. The objective by developing this control is to improve the performance of an AC induction motor output by comparing the actual measured currents of the motor with respect to their reference current. The difference is then corrected thus minimizing the current error. The controller is developed in Matlab / Simulink and interfaces with Arduino Uno controller where the controllers generates the PWM signal and send the signal to the gate driver of a three phase inverter to give a stable performance to the induction motor. A simple hardware implementation of the PIH current controller is designed and some simulation and experimental results are presented to demonstrate the validity of this approach.

ABSTRAK

Apabila motor AC disambungkan secara terus ke punca bekalan kuasa, kelajuan sesuatu motor dan kelajuan pusingannya adalah bergantung kepada frekuensi bekalan elektrik dan rekabentuk motor elektrik tersebut. Bagi sesetengah aplikasi motor, kelajuan pusingan tetap bleh digunapakai dengan syarat, pemilihan nisbah gear dibuat secara berhati – hati agar keputusan akhir yang dikehendaki tercapai. Namun, masalah utama bagi kebanyakan penggunaan motor ianya adalah sukar untuk menetapkan kelajuannya, lambat dalam mencapai tahap pecutan serta tidak berupaya mengawal tahap kelajuan dan daya kilasnya. Walaubagaimanapun, pemacu AC adalah penyelesaiannya dengan mengubah voltan dan frekuensi pada bekalan AC untuk motor. Kawalan motor boleh dicapai samada dengan menggunakan kawalan litar terbuka, atau kawalan litar tertutup. Oleh yang demikian, tesis ini bercadang untuk merekabentuk kawalan litar tertutup yang dinamakan sebagai kawalan arus menggunakan teknik PI histerisis (PIH) bagi motor aruhan tiga fasa dengan penyongsang sebagai perantara. Objektif tesis ini bertujuan untuk membangun dan merekacipta kawalan bagi untuk meningkatkan prestasi keluaran AC motor aruhan tiga fasa supaya keluaran gelombang motor ditentukan oleh arus rujukan yang telah ditetapkan adalah stabil dengan membandingkan dengan arus semasa yang diukur pada sebenar motor berkenaan dengan arus rujukan. Alat kawalan ini dibangunkan menerusi applikasi Matlab / Simulink dan applikasi Arduino Uno di mana pengawal ini menghasilkan isyarat lebar denyut modulasi (PWM) dan menghantar isyarat ini kepada pemacu daripada penyongsang tiga fasa untuk memberikan prestasi yang stabil untuk motor aruhan.

Pelaksanaan alat kawalan PIH dengan mengunakan teknik kawalan arus direka dan disimulasi agar keputusan eksperimen yang diperolehi dapat ditunjukkan kesahihan pendekatan ini.

CONTENTS

CHAPTER 2:

LIST OF FIGURE

LIST OF TABLE

LIST OF SYMBOLS AND ABBREVIATIONS

V	-	Voltage
DC	-	Direct current
AC	-	Alternating current
Vac	-	Alternating current voltage
VSI	-	Voltage source inverter
CSI	-	Current source inverter
PID	-	Proportional integral derivative
PWM	-	Pulse width modulation
DSP	-	Digital signal processing
r.m.f.	-	Rotating magnetic field
DFO	-	Direct field-oriented
FFT	-	Fast fourier transform
IC	-	Integrated circuit
SMC	-	Sliding mode controller

DTC	-	Direct torque ratio
USB	-	Universal serial bus
ADC	-	Analog to digital converter
DAC	-	Digital to analog converter
IPM	-	Interior permanent magnet
ICSP-	-	In circuit serial programming
PIH	-	Proportional integral hysteresis

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The electric motor system has always a three-closed-loop structure that includes position loop, speed loop and current loop. The current control loop is the inner one, and plays an important role to the performance of the whole system. The main task of the current controller (CC) is to force the actual current to follow the command current from the speed loop. According [1] gave an excellent review of the current control techniques, and classified them into two main groups: linear and nonlinear. Hysteresis current control (HCC) nonlinear current control has many advantages such as simple structure, fast dynamic response, robustness to the variance of load parameters, and being implemented easily [1,2,3]. However, current control switching frequency is variable in a wide range, and the frequency may be very high which is the main disadvantage of HCC is variable in a wide range, and the frequency may be very high which the main disadvantage of HCC.

Many industrial applications using motors demand variable speed and high starting torque. The DC motors were a preferred choice in such applications for many years, because the DC motors offered an easy method of speed variation and torque control by adjusting the armature voltage and the field current [4]. While the same, is not possible with an AC motors. However, with the emergence of thyristors, Mosfets, Igbt's and the continued development in semiconductor devices, induction motors are also now being used for such applications.

Due to advances of power electronics and vector control technologies, the induction motor drives has become popular and gradually taken the place of DC motor drives [5]. The various methods for the control of output voltage of inverters are external control of AC output voltage, external control of DC input voltage and internal control of inverter within the inverter itself [6]. The later is the most efficient method where its inverter is able to receive PWM signals to correct the current error. Therefore to generate this PWM signal, this thesis proposed to design a combination of passive and adaptive controller known as PI and Hysteresis (PIH) current control to overcome these limitations. The use of this hybrid controller because PI controller is a linear systems and can measure an average current error at each calculation cycle, and calculate an average inverter output voltage that corrects this error. Meanwhile, hysteresis controller is a non linear system and its can measured current to control the switching state of inverter. This controller also has many advantages such as fast deadbeat transient response, simplicity, insensitivity to load parameter variations, and direct over current protection [7]. Besides that, this thesis also using a current control technique because in many motor applications the motor current may lag the supply voltage due to the inductance in the circuit and it is often desirable to control the current directly, rather than the voltage, so that to obtain more precise or faster control of the current and hence the torque. . In this case a current transformer is used to monitor the current. The difference between the actual and reference currents is used in a high gain feedback loop to provide the necessary current regulation. Current control is particularly important for induction motors to protect the motor from excessive start up currents [8].

Thus, the error detected from the current controller will be corrected in PIH controller where the output is an analog signal. Arduino controller will convert this analog signal into digital signal (PWM) and fed it to the inverter resulting into a significant reduction of current error to give a better sinusoidal of ac waveform.

The PWM principle and PIH controller is discussed in detail and description of modeling of PIH controller is design in Matlab / Simulink. By using Simulink in Matlab users are able to create algorithms for their desired control system. Meanwhile Arduino controller has been chosen because Arduino provides a platform that helps users to understand the workflow for designing an embedded system without using manual programming.

1.2 PROBLEM STATEMENT

Three-phase induction motors have three salient poles per pole number, so a four-pole motor would have twelve salient poles. This allows the motor to produce a rotating field, allowing the motor to start with no extra equipment and run more efficiently than a similar single-phase motor. The synchronous rotational speed of the rotor is controlled by the number of pole pairs (number of windings in the stator) and by the frequency of the supply voltage. It was difficult to vary the frequency to the motor and therefore the uses for the induction motor were limited. The induction motor has no brushes and it's easy to control. Many older DC motors are being replaced with induction motors and accompanying inverters in industrial applications. For ac machine drive applications, the PWM voltage control is usually associated with stator current control because the current directly relates to the developed torque of a machine. Besides, the control of current amplitude is particularly important for power semiconductor devices of the inverter. A PWM voltage-controlled inverter may have either scalar or vector current control in outer loops. Scalar current control may be adequate for a simple low-performance drive system. In a high-performance vector or field-oriented drive control system, the vector currents Iqs (torque component of current) and $\boldsymbol{Ids}$ (flux component of current) are controlled independently to control the torque and flux, respectively. The different PWM voltage control techniques, such as sine-triangle and notch angle look-up Table, are generally difficult to implement. Besides, the current feedback loops may have delay, which will not permit instantaneous-peak current control of a device [7].

1.3 OBJECTIVE PROJECT

The objectives of this project are listed as follows:

i. To develop the combination of PID and hysteresis control for current controller technique on induction motor.
ii. To design and simulate the PI and hysteresis control approach by using MATLAB Simulink and interfacing with target installer, Arduino Uno.
iii. To implement and test hardware the performance controller design, inverter and measure the output of induction motor and interfacing with Arduino kit.

1.3 SCOPE OF PROJECT

In this project the scope of work will be undertaken in the following four developmental stages:

i. Study of the control system of induction motor for current control based on PI hysteresis control
ii. Perform simulation of PI hysteresis control. This simulation will be carried out on MATLAB platform with Simulink as it user interface.
iii. To develop the PI hysteresis program on the Arduino to control the three phase induction motor.
iv. To test and prove the validity of the concept that a controller proposed to give a better output results of induction motor.

CHAPTER 2

LITERATURE REVIEW

2.1 ELECTRIC MOTOR

An electric motor is an electromechanical device that converts electrical energy to mechanical energy. This mechanical energy is used for, for example, rotating a pump impeller, fan or blower, driving a compressor, lifting materials etc. Electric motors are used at home (mixer, drill, and fan) and in industry. Electric motors are sometimes called the “workhorses” of industry because it is estimated that motors use about 70% of the total electrical load in industry. 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) [4]. All of them have advantages and disadvantages compare to each other.

2.2 INDUCTION MOTOR

In 1824, the French physicist François Arago formulated the existence of rotating magnetic fields, termed Arago's rotations, which, by manually turning switches on and off, Walter Baily demonstrated in 1879 as in effect the first primitive induction motor [5][6][9].

The simplest of all electric motors is the squirrel-cage type of induction motor used with a three-phase supply. The stator of the squirrel-cage motor consists of three fixed coils of copper or aluminum wire wound within insulated slots. The rotor consists of a core in which are imbedded a series of solid conductors arranged in a circle around the shaft and parallel to it. With the core removed, the rotor conductors resemble in form the cylindrical cages once used to exercise pet squirrels, hence the name 'Squirrel Cage Motor'. Three-phase current flowing in the stationary stator windings generates a rotating magnetic field, and this field induces a current in the conductors of the cage. The magnetic reaction between the rotating field and the current-carrying conductors of the rotor makes the rotor turn. If the rotor is revolving at exactly the same speed as the magnetic field, no currents will be induced in it, and hence the rotor will not turn at a synchronous speed. In operation, the speeds of rotation of the rotor and the field differ by about 2 to 5 percent. This speed difference is known as slip.

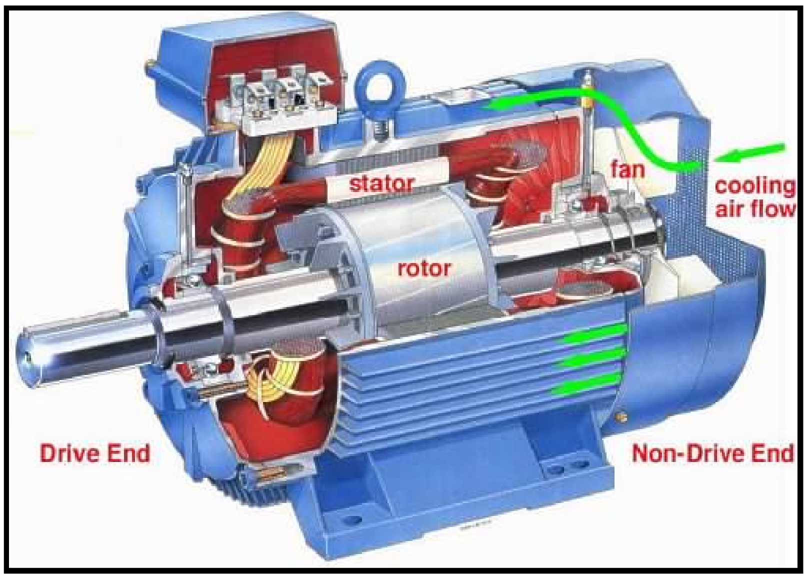


Figure 2.1: The three phase induction motor

2.2.1 ADVANTAGES OF INDUCTION MOTOR

i. Able to connect directly to the AC source
ii. Easy to program for its various uses
iii. Low maintenance cost
iv. Durability
v. Flexible design
vi. Ruggedness
vii. Speed control is expensive
viii. Inability to operate at low speeds.

2.2.2 DISADVANTAGES OF INDUCTION MOTOR

i. Low starting torque
ii. Have poor starting torque and high have in rush currents
iii. Induction motors always operate under lagging power factor and during light load conditions they operate at very worst power factor (0.2 to 0.4 lagging). Some of the disadvantages of poor power are increase in I^2R losses in the system, reduction in the efficiency of the system. Hence some power factor correction equipments such as static capacitor banks should be placed near to these motors to deliver the reactive power to them.
iv. One of the main disadvantages of induction motors is that speed control of induction motors is difficult. Hence for fine speed control applications dc motors are used in place of induction motors.

2.3 INVERTER

Inverters provide a controlled alternating current (AC) supply from a DC or AC source. There are two main classes of applications:

i. **Providing a fixed output from a variable source**

   Inverters designed to deliver regulated AC mains power from sources which may have a variable input voltage (either AC or DC) or in the case of AC input power, a variable frequency input. Such applications may include emergency generating sets, uninterruptible power supplies (UPS) or distributed power generation from wind and other intermittent resources. All must deliver a fixed output voltage and frequency to the load since the applications expect it and may depend on it.

ii. **Providing a variable output from a fixed source**

   On the other hand, many applications require inverters to accept a fixed AC voltage and frequency from the mains and to provide a different or variable voltage and frequency for applications such as motor speed control. .

2.3.1 THREE PHASE PWM INVERTER

Three phase PWM inverters are normally used for high power applications. Three single phase half (or full) – bridge inverters can be connected in parallel as shown in Figure 2.2 to form the configuration of a three phase inverter. The gating signals of single phase inverters should be advanced or delayed 120° with respect to each other to obtain three phase balanced (fundamental) voltages. A three phase output obtained from configurations of six transistors and six diodes as shown in Figure 2.3. Two types of control signals can be applied to the transistors, which are 120° conduction or 180° conduction. The 180° conduction has better utilization of the switches and is the preferable method.

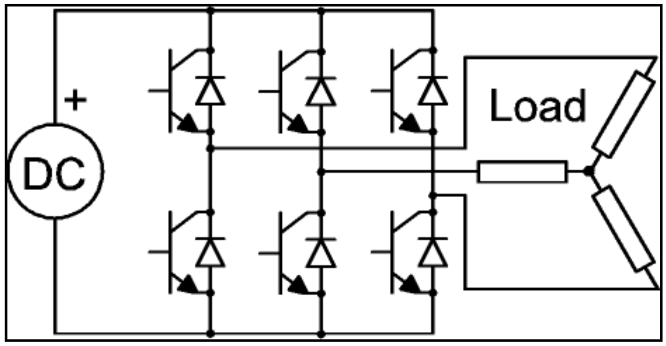


Figure 2.2: Figure 4: Full bridge voltage source inverter

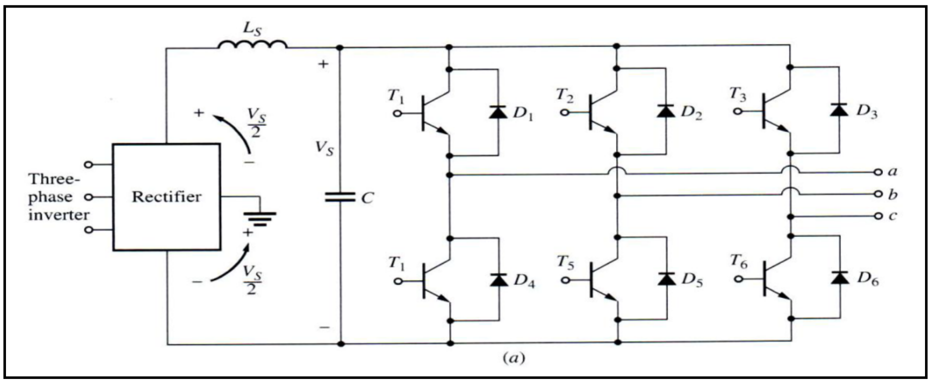


Figure 2.3: A three phase inverter using power transistors.

Generally PWM inverters are one of the most expensive types of inverter available in the market today. However, it produces a high quality output signal at minimum current harmonics. The output voltage is very close to sinusoidal. Harmonic heating, torque pulsation and acoustic noise can be reduced by PWM wave shaping of the inverters current wave. The purpose of PWM in three phase inverter is to shape and control the three phase output voltages in magnitude and frequency with an essentially constant input voltage. In order to get a balanced three phase output of three phase inverter, the same triangular waveform is compared with three sinusoidal control voltages that are 120° out of phase. The technique of PWM allows an inverter operating from a fixed voltage dc supply with variable frequency and variable output voltage. Figure 2.4 and 2.5 shows a typical output voltage waveform from a power MOSFET's inverter switching.

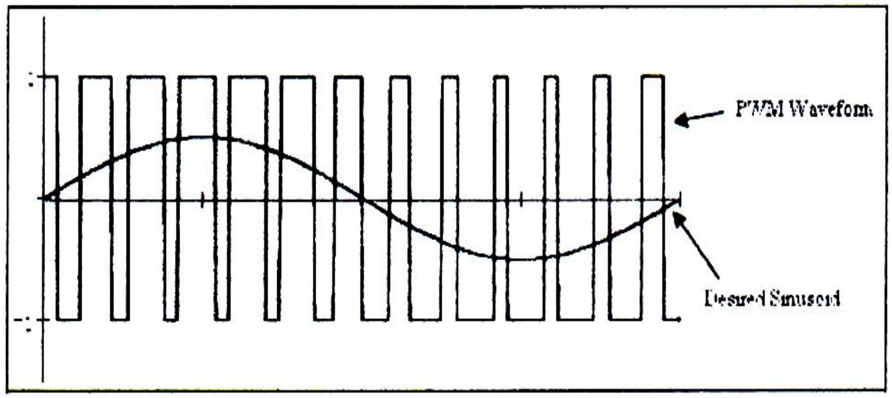


Figure 2.4: Typical PWM waveform

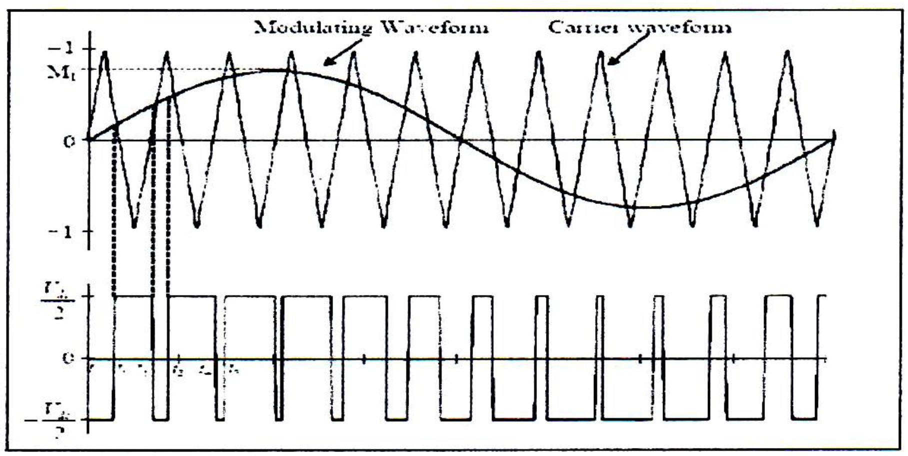


Figure 2.5: PWM

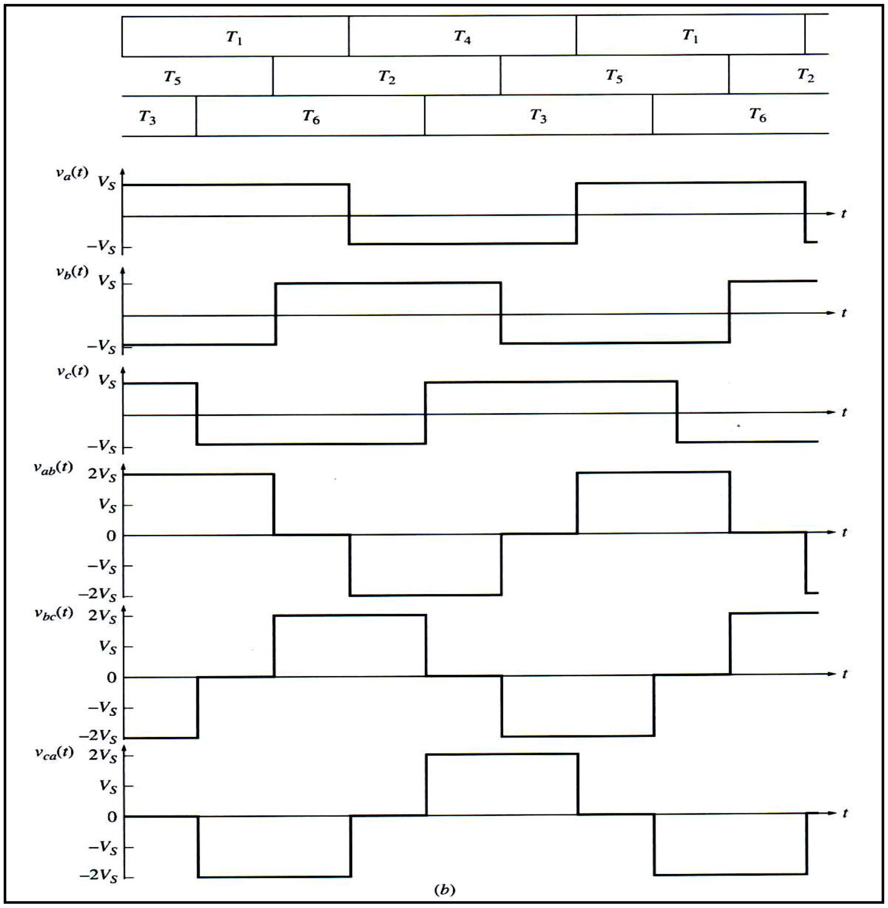


Figure 2.6: The output phase and line voltages from the inverter.

The amplitude of the output wave is determined by the level of the DC supply voltage to the inverter block but it can be varied by thyristor (SCR) control of the rectifier circuit to provide a variable voltage at the DC link.

Instead of transistor switches, the inverter may use MOSFETs, IGBTs or SCRs.
Free-wheeling diodes connected across the transistors to protect them from reverse bias inductive surges due to motor field decay which results when the transistors turn off by providing freewheeling paths for the stored energy.

2.3.2 VOLTAGE SOURCE INVERTER (VSI)

Generally there were two types of inverter, named as Voltage Source Inverter and Current Source Inverter. Voltage waveform is the independently controlled AC output in the VSI topologies. Meanwhile, in CSI topologies, the independently controlled AC output is a current waveform. In this thesis, VSI was selected as inverter that used as study. VSI can be further divided into three categories which are PWM Inverter, Square Wave Inverter and Single-phase Inverters with Voltage Cancellation. The structure of VSI is more widely used in the industrial application due to the voltage source requirement.

Three phase DC/AC VSI schematically shown in Figure 2.7, are now used extensively in motor drives, active filters and unified power flow controllers in power system and interrupted power supplies to generate controllable frequency and AC voltage magnitudes using various pulse width modulation (PWM) strategies [10].

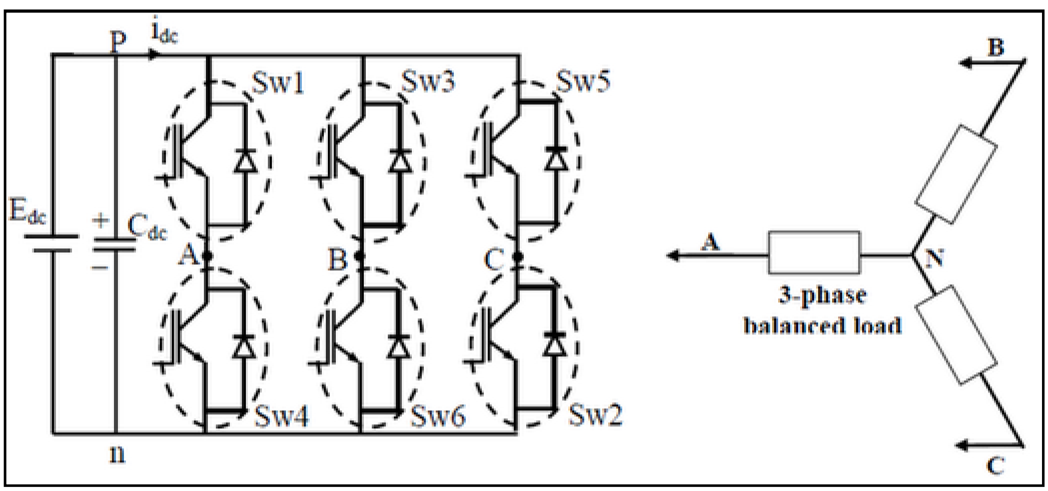


Figure 2.7: A three phase VSI

2.3.3 ADVANTAGES OF INVERTER

The advantage of inverter is to reduce the consumption of power by converting direct current (dc) to alternating current (ac). This alternated power can be maintained in any frequency or voltage with the use of an appropriate transformers, circuits and switches to support the electrical equipments at home and office.

2.3.4 DISADVANTAGES OF INVERTER

i. Not ideal for inductive AC and motor loads
ii. Sensitive electronics devices can be damaged by poor waveforms.

2.4 VARIOUS CONTROL ALGORITHMS FOR A THREE PHASE INDUCTION MOTOR.

Three phase induction motor is very popular electrical and mechanical equipment and get more attention from researchers and practitioners due to the nonlinearities. There are various control algorithm have been developed to improve the performance of three phase induction motor.

2.4.1 PID CONTROLLER

Proportional-Integral-Derivative (PID) controller is well known for its simplicity [11]. A PI controller is a common instrument used in industrial control applications. A PID controller can be used for regulation of speed, temperature, flow, pressure and other process variables. The PI is stand from combination of three elements, that known as proportional, integral and derivative. Defining $u(t)$ as the controller output, the final form of the PID algorithm is:

$$u(t) = MV(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t) \qquad (2.1)$$

K_p = proportional gain, a tuning parameter.

K_i = integral gain, a tuning parameter.

K_d = derivative gain, a tuning parameter.

e = error.

τ = time or instantaneous time.

The theory of proportional is the error is multiplied by a negative (for reverse action) proportional constant P, and added to the current output. P represents the band over which a controller's output is proportional to the error of the system.

For integral, the error is integrated (averaged) over a period of time, and then multiplied by a constant I, and added to the current control output. I represent the steady state error of the system and will remove measured value errors.

And last but not list, derivative is the rate of change of the error is calculated with respect to time, multiplied by another constant D, and added to the output. The derivative term is used to determine a controller's response to a change or disturbance of the process temperature. The larger the derivative term, the more rapidly the controller will respond to changes in the process value.

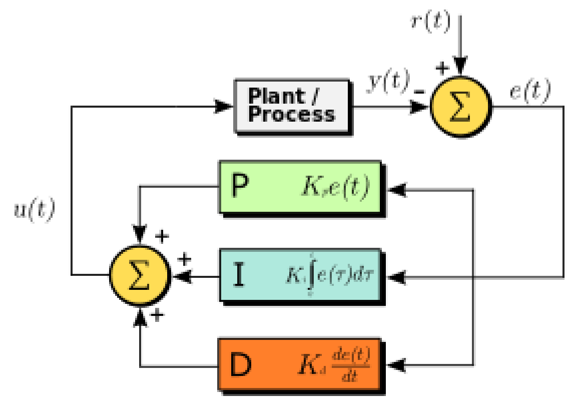


Figure 2.8: A block diagram of a PID controller in a feedback loop.

2.4.2 HYSTERESIS CURRENT CONTROLLER

The hysteresis is basically an instantaneous feedback current control method of PWM where the actual current continually tracks the command current within a specified hysteresis band [12].

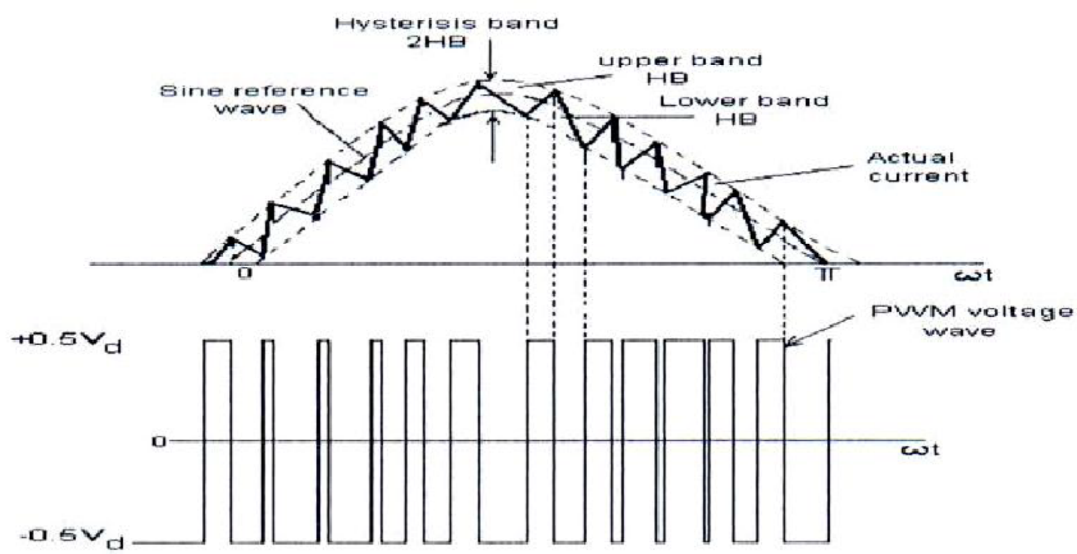


Figure 2.9: Principle of hysteresis band current control

The Figure 2.9 above explains the operation principle of HBPWM for a half bridge 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 upper switch in the half-bridge is turned off and the lower switch is turned on. As a result the output voltage transitions from +0.5V to-0.5V, and the current starts to decay. As the current crosses the lower band limit, the lower switch is turned off and the upper switch is turned on. The actual current wave is thus 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 is controlled within the hysteresis band irrespective of v_d fluctuation.

The hysteresis band inverter control method is shown in the Figure 2.10 below. The inputs to the HBPWM controller are three phase current errors and the outputs are the switching patterns to the PWM inverter. K in the Figure represents the normalization factor and is used for the purpose of scaling the current error input to the HBPWM controller. PS is the pulse separation circuit for the separation of pulses to the IGBTs in the upper and lower leg of the inverter [13].

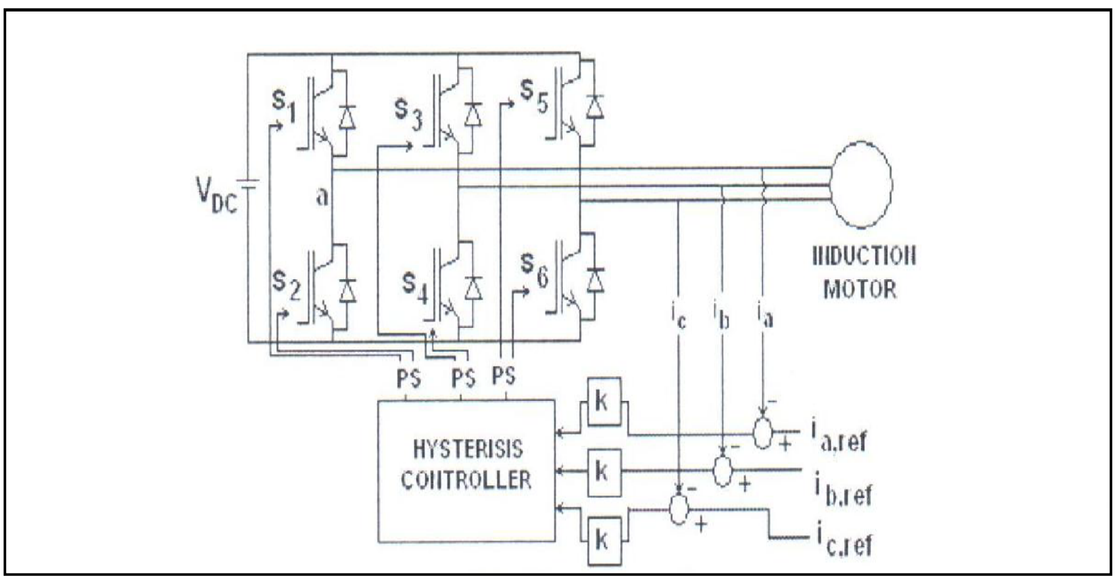


Figure 2.10: Conventional hysteresis inverter control method.

The hysteresis current controller gives output pulses to the inverter according to [14]; $| i_{m,ref} - i_m | < \varepsilon$ keeps the output pulse at the same state, $i_{ref} - i_m > \varepsilon$ let output pulse = 1 (high). , $i_{ref} - i_m < -\varepsilon$, let output pulse = 0 (low), where m = a, b, c phase meanwhile ε is the hysteresis band.

The algorithm for this scheme is:

$i_{m, ref}(t) = i_{m, ref} \sin(wt)$

Upper band $\quad i_u = i_{m, ref}(t) + \Delta i \quad$ (2.2)

Lower band $\quad i_1 = i_{m, ref}(t) - \Delta i \quad$ (2.3)

Where Δi = hysteresis band limit.

If $i_m > i_u$, $\quad V_{mo} = - V_{dc} / 2 \quad$ (2.4)

If $i_m < i_u$, $\quad V_{mo} = V_{dc} / 2 \quad$ (2.5)

Else, maintain the same state. Where m = a, b, c phases, i is load current and V_{dc} is the link voltage of the inverter [12].

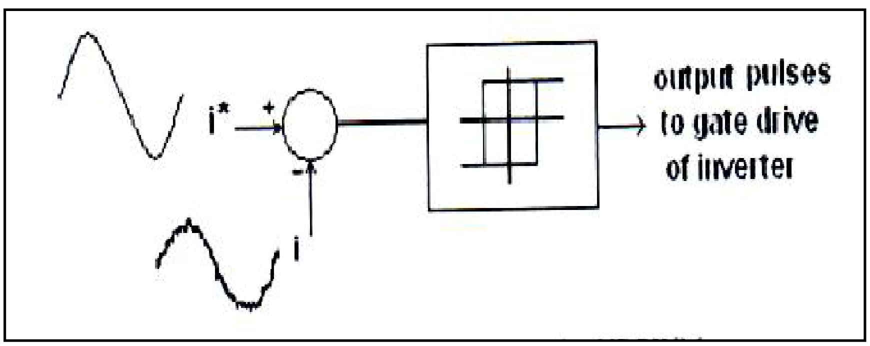


Figure 2.11: Control block diagram for HBPWM

The main drawback of this method is that the PWM frequency is not constant and as a result non optimum harmonics will result [15].

2.4.3 FUZZY LOGIC CONTROLLER

Fuzzy Logic is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers to large, networked, multi-channel PC or workstation-based data acquisition and control systems. It can be implemented in hardware, software, or a combination of both. Fuzzy Logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. Fuzzy Logic incorporates a simple, rule-based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically. The FL model is empirically-based, relying on an operator's experience rather than their technical understanding of the system.

According [16] produced a thesis on Fuzzy Logic Speed Control of Three Phase Induction Motor Drive where the thesis presents an intelligent speed control system based on fuzzy logic for a voltage source PWM. Using traditional indirect vector control system of induction motor introduces conventional PI regulator in outer space loop and PI proved that the low precision of the speed regulator debases the performance of the whole system. This problem is overcome by introducing fuzzy set controller theory. From their results, they have confirmed that the fuzzy logic controller has very good dynamic performance and robustness during transient period and sudden loads.

Meanwhile [17], presented a thesis on fuzzy logic speed control of an induction motor. The thesis described on fuzzy logic techniques to control the three phase induction motor speed. They use Matlab/Simulink and fuzzyTECH MCU96 as software development tools for the system design. They evaluated the system performance in comparison with a traditional PI control scheme. From their result that concluded that fuzzy logic controller slightly dynamic performance when compared with a PI controller in terms of insensitivity to changes of model parameter and the speed noise. This finding can be important requirement in speed/position schemes using electrical machines, namely in robotic.

Thesis [18], presented a thesis on fuzzy logic control for a dc motor. From their results they concluded that by using fuzzy logic controller produces a smooth speed control with less overshoot and no oscillations, variations of reference speed attention

2.5 PROPOSED CONTROLLER

For this thesis, PI hysteresis controller has selected to be a controller because basically this controller is an instantaneous feedback current control method of PWM where the actual current continually tracks the command current within a specific hysteresis band [18]. Besides that, the advantages of this controller because of its simple implementation, fast transient response, direct limiting of device peak current and practical insensitivity of dc link voltage ripple that permits a lower filter capacitor.

PI controller technique is chosen as to combine with hysteresis current control because to overcome undesirable drawback of classical hysteresis current controller. The input of PI controller is an error in the current between the reference current and motor current for each phase as shown in Figure 2.11 below. The proportional gain is used to improve the rise time and integral gain is used to eliminate the steady state error. This parameter can be deduced by many methods such as, trial and error, Ziegler Nicholas method and internal model control [19].

Besides that, a current source control technique is another part of the controller to control the current that supply to the induction motor. The current source control technique operates by comparing the output line current with a current reference at three phase induction motor. The error that produces will send to main controller to correcting the error. The PIH will correct the error by sending a Pulse Width Modulation (PWM) to a three phase inverter.

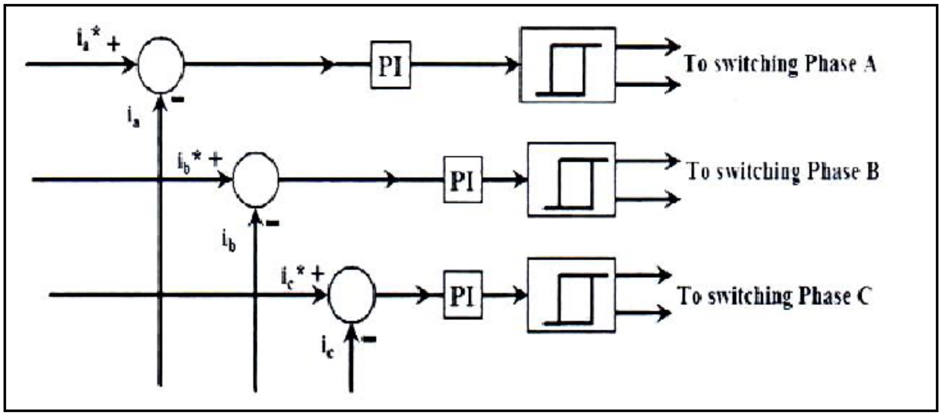


Figure 2.12: PI hysteresis current controller block diagram

2.6 ARDUINO CONTROLLER

The Arduino Uno 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.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the index of Arduino boards.

In this thesis [22] had observed the problem of voltage levels, which affects the speed of induction motor. In this thesis 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. They had executed with the help of an Arduino controller kit.

Arduino is an open-source single-board microcontroller, descendant of the open-source Wiring platform, designed to make the process of using electronics in multidisciplinary projects more accessible. The hardware consists of a simple open hardware design for the Arduino board with an Atmel AVR processor and on-board input/output support. The software consists of a standard programming language compiler and the boot loader that runs on the board. Arduino hardware is programmed using a Wiring-based language (syntax and libraries), similar to C++ with some slight simplifications and modifications, and a Processing-based integrated development environment. The Arduino project received an honorary mention in the Digital Communities category at the 2006 Prix Ars Electronics. This arduino uno was implemented in this experiment to as a controller [21]. To run simulink models on Arduino, the target to Arduino installer must be install. Hence, simulink block library can configuring and accessing Arduino sensor, actuators and communication interfaces. It will provide support for various peripherals available on the Arduino hardware.

In Arduino, the list of port that can be use in order to build controller, are as below [22]:

Table 2.1: The summary of the Arduino Uno.

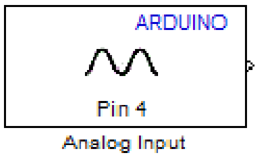
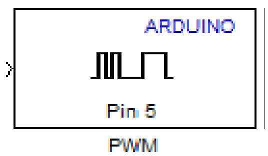
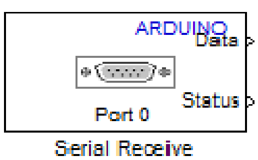
Block	Purpose	Description
• Analog input • Pin 0 to 5 	Measure voltage of analog input pin	Measure the voltage of an analog pin relative to the analog input reference voltage on the Arduino® hardware. Output the measurement as a 10-bit value that ranges from 0 to 1023.
• Pwm • Pin 3, 5, 6, 9, 10 and 11. 	Generate PWM waveform on analog output pin	Use pulse-width modulation (PWM) to change the duty-cycle of square-wave pulses output by a PWM pin on the Arduino® hardware. PWM enables a digital output to provide a range of different power levels, similar to that of an analog output. The range of valid outputs is 0 to 255.
• Serial receive and transmit • Port 0 	Get one byte of data from serial port and Send buffered data to serial port.	Serial receive: Get one byte of data per sample period from the receive buffer of the specified serial port. Serial transmit: Send buffered data to the specified serial port.

Table 2.2: The specification of Arduino Uno

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 (ATmega32

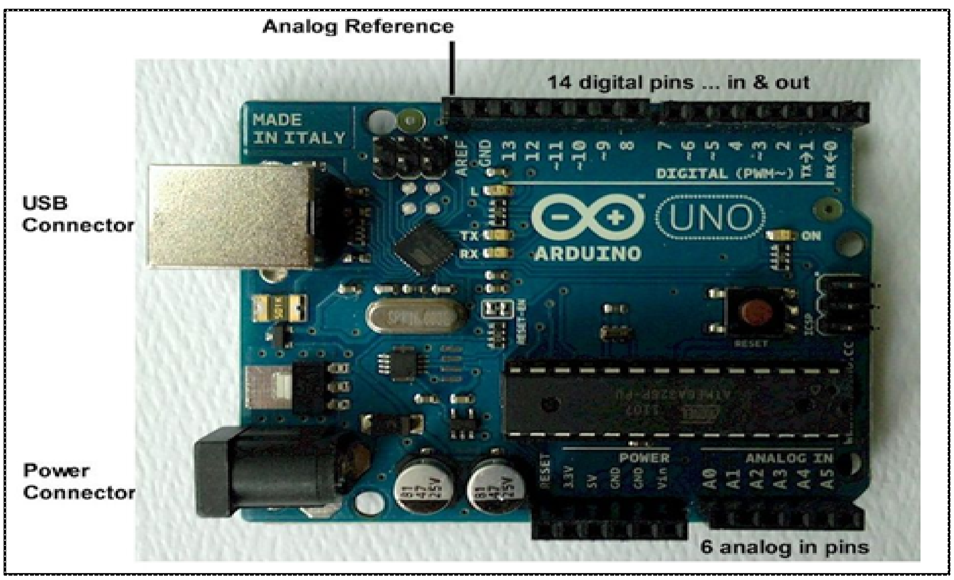


Figure 2.12: Arduino Uno controller

The advantages of the Arduino are stated below:

(i) Inexpensive – Arduino embedded devices are inexpensive compared to other microcontroller embedded devices.

(ii) Cross-platform – Most microcontroller systems are limited to Windows. Different with Arduino, it can runs on Windows, Macintosh OSX, and Linux operating systems.

(iii) Simple, clear programming environment – The Arduino programming environment is easy to use for beginners.

(iv) Open source – The Arduino software is published as open source tools, so the user easy to get the information experienced programmers.

REFERENCES:

[1] Marian P. Kazmierkowski and Lui Malesani,“ Current control techniques for three-phase voltage-source PWM converter: a survey”, IEEE Transanctions on industrial electronics,1998,Vol.45, No.5,pp.691-703.

[2] Dinu A., Burton D. ,Holme M.G., Roadley-Battin J. and Hubbard R. “Space vector-based hysteresis current controller with self monitoring mechanism”, IEEE International Symposium on Industrial Electronics, 2008, pp. 25-30,

[3] Lekshmi A., Dr. Sankaran R. and Dr. Ushakumari, “Comparision of performance of a closed loop PMSM drive system with modified predictive current and hysteresis controllers”, Proceedings of the 11th International Conference on Electrical Machines and Systems, ICEMS 2008, Wuhan, China,pp. 2876-2881.

[4] T.A. Lipo, “Recent progress in the development of solid state of Ac motor drives”, IEEE Trans, Power Electronics, Vol. 3, No. 2, April 1988, pp. 105-117.

[5] *Madhavi L. Mhaisgawali, Mrs S.P.Muley “Speed Control of Induction Motor using PI and PID controller” IOSR Journal of Engineering (IOSRJEN), vol. 3, Issue 5 (May2013).*

[6] Dr. P.S Bimbhra: “Power Electronics” – Khanna Publications, 2nd edition, 1998.

[4] S. J. Chapman, “Electric Machinery and Power System Fundamental”, McGraw Hill, 1st ed, 2002

[5] Babbage, C.; Herschel, J. F. W. (Jan. 1825). "Account of the Repetition of M. Arago's Experiments on the Magnetism Manifested by Various Substances during the Act of Rotation". *Philosophical Transactions of the Royal Society of London* **115** (0): 467–496. doi:10.1098/rstl.1825.0023. Retrieved 2 December 2012.

[6] Thompson, Silvanus Phillips (1895). *Polyphase Electric Currents and Alternate-Current Motors* (1st ed.). London: E. & F.N. Spon. p. 261. Retrieved 2 December 2012.

[7] Donald Grahame Holmes, Reza Davoodnezhad, Brendan P. McGrath, “An Improved Three-Phase Variable-Band Hysteresis”, IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 28, NO. 1, JANUARY 2013

[8] Bimal K Bose, "An Adaptive Hysteresis-Band Current Control Technique of a Voltage-Fed PWM Inverter for Machine Drive System", IEEE Transactions On Industrial Electronics, Vol. 31, No. ***5,*** October 1990

[9] Baily, Walter (June 28, 1879). "A Mode of producing Arago's Rotation". *Philosophical magazine: A journal of theoretical, experimental and applied physics* (Taylor & Francis).

[10] Badder. U and Depenbrock. M (1992); "Direct self control (DSC) of inverter-fed induction machines: A basic for speed control without speed measurement", IEEE Transactions on Industrial Application, Vol. 28, No. 3, pp. 581-588, West Germany.

[11] Jingwei Xu; Xin Feng; Mirafzal, B.; Demerdash, Nabeel A., "Application of Optimal Fuzzy PID Controller Design: PI Control for Nonlinear Induction Motor," *Intelligent Control and Automation, 2006. WCICA 2006. The Sixth World Congress on*, vol.1, no., pp.3953, 3957, 0-0 0.

[12] MATLAB 6.5: Help Documentation – Release Notes 13.

[13] I. Bodela & S.A Nasar: "Vector control of AC Drives".

[14] Bor–Ren Lin and Richard G–Hoft: " Power Electronics Inverter Control with Neural Network, in IEEE-APEC, San Diego, pp. 128-134,1993.

[15] Srinivasa Rao Jalluri and B .B Sanker Ram, "Performance of Induction Motor Using Hysteresis Band PWM Controller", Int. Journal Of Adv. In Eng. & Tech., May 2013.

[16] www.waset.org/journals/waset/v60/v60-252.pdf

[17] Jaime Fonseca, João L. Alfonso, Júlio S. Martins ,Carlos Couto "Fuzzy Logic Speed Control Of An Induction Motor" Department of Industrial Electronics, Minho University Largo do Paco, Portugal .

[18] Jaydeep Chakravorty, Ruchika Sharma " Fuzzy Logic Based Method of Speed Control of DC Motor" International Journal of Emerging Technology and Advanced Engineering, ISSN 2250 -2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 4, April 2013.

[19] B Ventaka Ranganandh, A. Mallikarjuna Prasad, Madichetty Sreedhar, " Modelling And Simulation Of Hysteresis Band Pulse Width Modulated Current Controller Applied To A Three Phase Voltage Source Inverter By Using Matlab", Int. Journal of Adv. Research in Electrical, Electronic & Inst. Engineering, Vol. 2 , Issue 9, Sept 2013.

[20] Hamdy Mohamed Soliman and SM El Hakim, “Improved Hysteresis Current Controller to Drive Permanent Synchronous Motors through The Field Oriented Control,” International Journal of Soft Computing and Engineering, Vol 2, No.4, September 2012, pp.40-46.

[21] Hossein Madadi Kojabadi, ”A comparative analysis of different pulse width modulation methods for low cost induction motor drives, Energy Conversion and Management 52 (2011) 136–146

[22] Y. V. N. Kumar, P. H. Bindu, A. D. Sneha and A. Sravani, “A novel implemetation of phase control technique for speed control of induction motor using Arduino,” IJETAE,Vol. 3, Issue 4, Apr 2013, 469-472.