HYBRID FUZZY- PID CONTROLLER
OF AN INVERTER
FOR AC INDUCTION MOTOR

BY

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ABSTRACT

The usage of the AC induction motor (ACIM) becomes widely increased in the industrial applications as well as in the domestic usages, due to the good features of the ACIM and the new technologies of the electronic switching topologies. Different approaches are used to control the speed of the ACIM. One of these approaches is the Frequency variation of the sinusoidal wave form applied to the ACIM; this is achieved by using DC to AC converter (inverter). This research develops a voltage source inverter (VSI), which its output is a variable frequency sine wave between (20 and 60) Hz to control the speed of the ACIM. Proportional-integral-derivative (PID) controller will be used to improve the inverter output, while the significance of this research is the implementation of the fuzzy logic controller (FLC) as an additional controller and its rule to enhance the performance of the system. Hybrid FLC - PID controller of an inverter for ACIM is described in this research. The speed of the ACIM will be changed according to the change of the generated sine wave frequency. The output voltage error and its derivative are used as input variables for the FLC to adjust the error of the system, and FLC output will be subtracted from the output of the PID controller to reduce the error signal and eventually optimize the dynamic response of the speed controller of the motor. Simulated results show the performance of PID controller and the rule of FLC in improving the speed controller performance. Experimental results show that the variation of reference sign wave at the input can lead to variation at the output sine wave frequency; this is adequate for the variation of the motor speed. Both the VSI and FLC boards were fabricated based on programmable microcontrollers, PIC16F877A was used in the inverter circuitry to generate the pulse width modulation (PWM) and to generate internal sine wave with variable frequency to control the speed of the motor accordingly, while for the FLC circuitry it will process the rule base inference engine and calculate the FLC output upon on that. Using such a PIC controller in the inverter and FLC circuits will simplify the design, minimize the hardware and accordingly reduce the cost, at the same time it will increase the reliability of the proposed system.

ملخص البحث

يهدف هذا البحث الى ان استخذام المحرك المتناوب المحتث أصبح في تزايد مستمر في التطليقات الصناعية والاستخدامات المنزلية على حد سواء بسبب ميزات هذا المحرك وكذلك بسبب التقنيات الحديثة في الألكترونيك . هناك طرق عديدة تستخدم في السيطرة على سرعة المحركات من هذه الطرق هي تغيير والسيطرة على ترددات الموجة الجيبية التي تغذي المحرك. وذا يتم عن طريق محول التيار المستمر الى المتناوب (العاكسة) . ان هذا البحث يهدف الى تصنيع عاكسة والتي خرجها هو فولتية جيبية ذات تردد من 20 هرتز الى 60 هرتز للسيطرة على سرعة المحرك. كما تم اضافة مسيطر تناسبي- تكاملي- تفاضلي لتحسين اداء العاكسة في حين ان الاضافة الحقيقية لهذا البحث هي بتطبيق احدى طرق الذكاء الصناعي (fuzzy) كمسيطر اضافي. ان بناء منظومة هجينة من المسيطر (التناسبي- التفاضلي –التكاملي) مع الـ (fuzzy) للسيطرة على اداء العاكسة المسيطرة على سرعة المحرك المتناوب ان فولتية الخطأ مع مشتقتها سوف تدخل على دائرة الـ (fuzzy) وكذلك فولتية الخطأ سوف تغذى الى مسيطرة التناسبي- التفاضلي – التكاملي وانه سيتم طرح خارج هاتين الدائرتين والناتج يغذى الى دائرة العاكسة. ان النتائج التي تم الحصول عليها تؤكد على دور الـ (fuzzy) وأهميته في تحسين اداء المنظومة . ثم تصنيع اللوحات الالكترونية بأستخدام ال PIC وبأستخدام برنامج EAGLE .

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science Mechatronic Engineering

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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LIST OF SYMBOLS

Φ_m	Flux
V	Voltage
F	Frequency
T	Torque
P	Power
I	Current
x	State variable input
A_i	Fuzzy variable for input x
y	State variable output
C_i	Fuzzy variable to classify out put y
U	Fuzzy linguistic universe
U_X	Fuzzy linguistic universe for the input x
U_y	Fuzzy linguistic universe for the output y
μ	Midpoint of the membership function
μ_G	Midpoint of Gaussian membership function
μ_L	Midpoint of linear membership function
σ	Width of the membership function
σ_G	Width of Gaussian membership function
σ_L	Width of linear membership function
X	Membership function
X_{PV}	Positive membership function
X_{ZE}	Zero membership function
X_{NV}	Negative membership function
$\underline{x}$	Fuzzy vector
x_{NV}	Negative membership value
x_{ZE}	Zero membership value
x_{PV}	Positive membership value
R_i	ith typical rule
x_i	*i*th fuzzy variable
x^1	First linguistic variable (input-1)
x^2	Second linguistic variable (input-2)
$\underline{x}^1$	First input of fuzzy vector
$\underline{x}^2$	Second input of fuzzy vector
$\underline{X}^1$	Membership function for the fuzzy vector (input-1)
$\underline{X}^2$	Membership function for the fuzzy vector (input-2)
X^n_{NV}	Membership functions for the negative fuzzy variable for input n
X^n_{ZE}	Membership functions for the zero fuzzy variable for input n

X_{PV}^{n}	Membership functions for the positive fuzzy variable for input n
x_i^1	Degree of membership of input-1 into the *i*th fuzzy variable's category.
x_j^2	Degree of membership of input-2 into the *j*th fuzzy variable's category.
R_{ij}	ith jth typical rule
C_{ij}	ith jth output value
R_j	jth typical rule
w_i	Strength of the overall rule evaluation
x_i^k	Membership value of the k_{th} input into the i_{th} fuzzy variable's category
y^{COG}	Output centre of gravity
y^{MOM}	Output mean of maxima
C_+	positively charged capacitor
$C\_$	Negatively charged capacitor
S_+	Switch in the positive half
$S\_$	Switch in the negative half
D_+	Diode in the positive half
D_-	Diode in the negative half
v_i	Input voltage
i_o	Output current
$\hat{v}_{o1}$	Amplitude of fundamental component
$\hat{v}_{ab1}$	Amplitude of the harmonic component
m_a	Over modulation region
m_f	Normalized carrier frequency
v_c	Sinusoidal modulating signal
v_{aN}	Phase voltage
v_{bN}	Phase voltage 120° out of phase with v_{aN}
$\hat{v}_{aN1}$	First harmonic amplitude of phase voltage
f_h	Normalized odd frequencies
h	*M*ultiples of normalized harmonic frequencies
f_p	Normalized even frequencies
v_{cN}	Phase voltage
$\hat{v}_c$	Amplitude of modulating signal
$\hat{v}_{\Delta}$	Amplitude of carrier signal
$\vec{v}$	Voltage space vector
Ω	Ohm
Q	Transistor
R	Resistor
JP	Connector
K_P	Proportional gain
K_i	Integral gain

K_d	Derivative gain
R_f	Feedback resistor
R_i	Input resistor
V_o	Output voltage of the PID controller
V_i	Input voltage of the PID controller
µf	Microfarad
R_d	Derivative resistance
C_d	Derivative capacitor
V_e	Error voltage
dV_e	Error voltage derivative
τ_C	Time constant
τ_S	Settling time
τ_r	Rising time
M_P	Overshoot percentage

LIST OF ABBREVIATIONS

AC	Alternating Current
ACC	Acceleration
ACIM	Alternating Current Induction Motor
ADC	Analogue to Digital Converter
ASD	Adjustable Speed Drive
BJT	Bipolar Junction Transistor
BLDC	Brush Less Direct Current
C	Compiler
CFI	Current-Fed Inverter
CMCON	Comparator Configuration
COG	Centre of Gravity
CSI	Current Source Inverter
DAC	Digital to Analogue Converter
DC	Direct Current
DPE	Derivative of Position Error
DTC	Direct Torque Control
FACTS	Flexible AC Transmission Systems
FICO	Fuzzy Input Crisp Output
FIFO	Fuzzy Input Fuzzy Output
FIS	Fuzzy Inference System
FLC	Fuzzy Logic Controller
FFT	Fourier Transform Block
FOC	Field Oriented Control
GA	Genetic Algorithim
GND	Ground
GTO	Gate Turn Off
Hz	Hertz
IC	Integrated Circuit
IGBT	Insulated-Gate Bipolar Transistor
IM	Induction Motor
LC	Inductive Capacitor
MCT	Metal Oxide Semiconductor- Controlled Thyristors
MOM	Mean of Maxima
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
NB	Negative Big
NL	Negative Large
NMS	Negative Medium Small
NS	Negative Small
NV	Negative
OPAMP	Operational Amplifier
PB	Positive Big
PCB	Printed Circuit Board
PE	Position Error
PI	Proportional Integral
PIC	Programmabl Interface Controller

PID	Proportional Integral Derivative
PM	Positive Medium
PS	Positive Small
PSPIES	Simulation Program with Integrated Circuit Emphasis
PV	Positive
PVS	Positive Very Small
PWM	Pulse Width Modulation
RMS	Root Mean Square
RPM	Revolution per Minute
SE	Speed Error
SHE	Selective Harmonic Elimination
SIT	Static Induction Transistors
SP	Speed
SPWM	Sine wave Pulse Width Modulation
SVSI	Sinusoidal Voltage Source Inverter
THD	Total Harmonic Distortion
UPS	Uninterruptible Power Supply
V	Volt
VC	Vector Control
VFD	Variable Frequency Drive
VFI	Voltage Fed Inverter
VSI	Voltage Source Inverter
Z	Zero

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

AC induction motors (ACIM) are the most common motors used in industrial motion control systems, as well as in main powered domestic appliances. Simple design, rugged, low maintenance, low cost, and direct connection to an AC power source are the main advantages of AC induction motors (Parekh, 2009). They are also robust and immune to heavy loading (Abdul Wahab and Sanusi, 2008).

Although the ACIM is easier to design than DC motor, the speed and the torque control in various types of ACIM require a greater understanding of the design and the characteristics of these motors (Rashid, 2006). The induction motor drives can be categorized as:

a) Servo drives. Uses precise control scheme, they are used with applications including computer peripherals, machine tools and robotic tools.

b) Adjustable drives. Uses speed control with braking; they are used in applications including fans, compressors, pumps, blowers (Agrawal, 2001).

In order to achieve the speed variation of the ACIM, different approaches can be cooperating to achieve this task. One of these approaches is the frequency variation. The synchronous speed of the induction motor (IM), and hence the motor rotor speed can be controlled by varying the frequency of the stator AC supply (Boss, 2006). Frequency conversion techniques can be considered to cover this method by which it is possible to take a fixed frequency or DC source, and convert this energy to provide a load with a different or variable frequency supply (Lander, 2001).

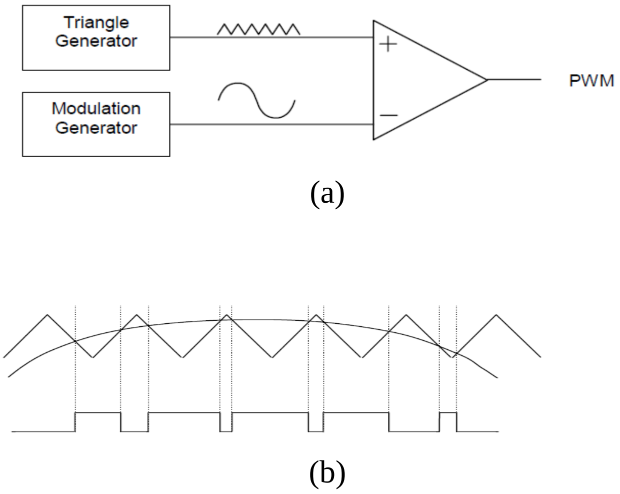
This conversion from DC supply or fixed frequency to AC variable frequency is known as DC to AC converters or simply as inverters (Rashid, 2006).There are different types of inverters that control the speed of the IM.

1- Pulse width modulation (PWM) voltage fed inverters, used by the largest segment of applications.

2- Current fed inverter drives are used in higher power ranges (Boss, 2006).

3- An advanced scalar control technique based on direct torque and flux control (DTC) (Boss, 2006).

The term pulse width modulation (PWM) refers to a train of variable width pulses. These PWM pulses are the result of the comparison between the modulated sine wave and 2000Hz saw tooth carrier frequency. In Figure 1.1(a) the triangular signal is the carrier or switching frequency of the inverter, while the modulation generator produces a sine wave signal that determines the width of the pulses, both the sine wave and the triangular signals are compared, consequently the output of the comparison is the PWM signal, as illustrated in Figure 1.1 (b) (Agrawal, 2001).



(a) PWM generator (b) Output of PWM generator

Figure1.1 PWM signal generator

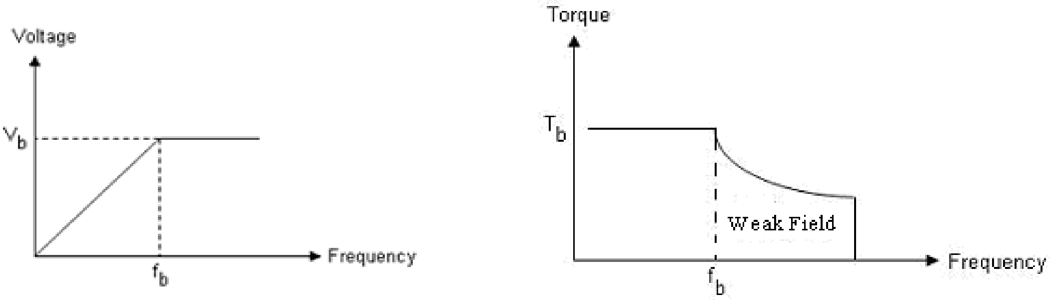
Recent advancements in PWM generation and control techniques have been combined with state-of-the-art control algorithms in a pre-programmed solution which is designed to dramatically minimize front development costs and time to market in variable speed AC motor control applications (Wilson and Lucas, 2005), for these reasons the recent inverters design have been related to the PIC and microprocessors rather than conventional design.

The type proposed in this research is PWM voltage source inverter (VSI), which produces a sine wave with a variable frequency between (20 and 60) Hz to meet the project requirements. Selecting the upper frequency limit equal to 60 Hz because for frequencies less than 60 Hz any increase in frequency will lead to increase the voltage as shown in Figure 1.2 (a). Consequently voltage to frequency ratio will be constant to keep the flux ϕ_m constant as in Equation (1.1).

$$\phi_m = K_2 * \frac{V_1}{f_1} \tag{1.1}$$

$$T = K_1 * \phi_m * I_2 \tag{1.2}$$

Until the base rated frequency (60 Hz) is reached. Increasing the frequency beyond 60 Hz will cause the voltage to be constant as shown in Figure 1.2 (a). This will reduce the flux and according to Equation (1.2) the torque will be reduced as shown in Figure 1.2 (b).



(a) Voltage Vs Frequency (b) Torque Vs Frequency

Figure 1.2 Characteristics of ACIM

While the reason for choosing the frequency more than 20 Hz, because for less than 20 Hz the voltage will be constant until the frequency 20 Hz, then the voltage to frequency ratio will be increased due to frequency increase causing a change in the speed without reducing the flux as shown in Figure 1.3 below (Bowling, n.d.)

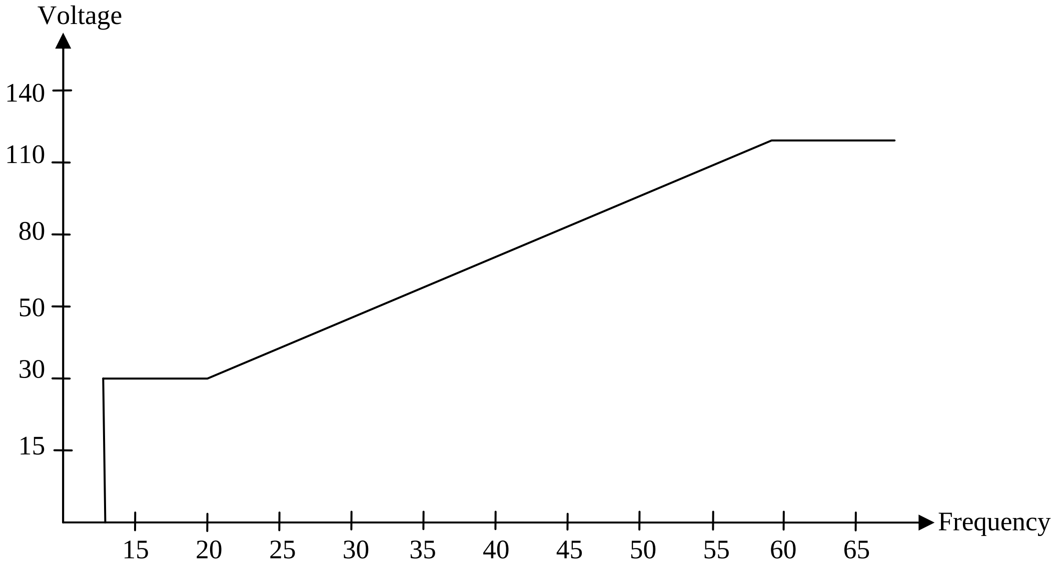


Figure 1.3 Frequency and voltage relationship for ACIM

Basic inverter switching, normally results in a non-sinusoidal output voltages and currents, which may affect the performance of a non-linear load, Thus the usage of LC filter to shape the square waveform and eliminate the sharp angles at the output of the inverter H-bridge is important (Cortés et al, 2009), moreover this LC filter will add smoothness to the rotation of the ACIM (Santiago, 2004). The generation by the inverter of an AC waveform with low harmonic content is extremely important, harmonic filters are not an option, when controlling speed, due to the large range in the frequency spectrum at the inverter output (Leão et al, 2000).

The performance of the speed controller has been enhanced by adding a fuzzy logic controller (FLC) and proportional-integral-derivative (PID) controller. The FLC and PID controller of an inverter for single phase AC Induction motor is described in this thesis. Figure 1.4 shows the block diagram of the proposed system. The speed of the ACIM will be changed according to the change of the VSI sine wave frequency. The error and its derivative are used as input variables for the FLC to adjust the error of the system, it will be subtracted from the output of the PID controller to enhance the performance of the system and minimize steady state error for the speed of the motor. While implementing the FLC to the system will eliminate the overshoot of the speed and improve the dynamic response of the system.

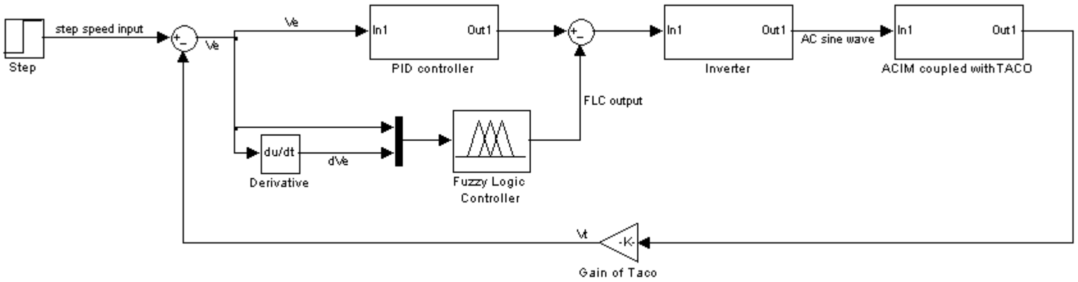


Figure 1.4 Block diagram of the proposed system

To add more rigidity and simplicity in addition to minimize the cost of the circuit, inverter circuitry and FLC circuit was designed based on PIC16F877A microcontroller to generate the pulse width modulation PWM and to generate internal sine wave with variable frequency to control the speed of the motor accordingly. Using such PIC controller in the inverter circuits will simplify the design, hardware, and will increase the reliability of the proposed system (Wilson and Lucas, 2005).

As a measure to the quality of the inverter output sine wave the harmonic components power should be very small so that the total harmonic distortion (THD) should be as equal or less than 5%. THD can be defined as the sum of the power ratios of all harmonic components to the power of the fundamental frequency (Tzou et al, 1999).

$$THD = \frac{\Sigma \, harmonic\ powers}{fundamental\ frequency\ power} = \frac{P_2 + P_3 + P_4 + --- + P_n}{P_1} \tag{1.3}$$

For typical high quality sine wave inverter output harmonic components should be minimized to obtain $THD \leq 5\%$ .As a measure of the inverter output quality, results prove that the proposed system is able to produce a low THD in the inverter output.

1.2 PROBLEM STATEMENT and ITS SIGNIFICANCE

ACIM speed controllers, using SPWM VSI, designed for a particular frequency variation should be adequate. However, inverter exhibit poor performance concerning the steady state response of the system due to the power shortage if using the inverter alone. Thus the involving of PID controller will be necessary. Contribution of the PID will be obvious in minimizing steady state error due to the inverter shortage in power.

Moreover the rule of the PID controller of an inverter in the speed controller can be improved by implementing FLC as an additional controller to adjust the error of the system. Contribution of the FLC additional controller will be obviously regarded during the simulation results. This research developed a hybrid fuzzy PID controller to improve the response of the speed controller system.