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Fuzzy PI Based Motor Speed Control using DSP TMS320F2812

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Abstract: Alternating Current (AC) induction machine plays an important role in the entire industry and daily life. This is due to their robustness, inexpensive and easy to maintain in a period of time. Vector control is used in large numbers in the speed control of AC induction machine. High dynamic performance high speed precision and wide constant torque range capabilities are the key benefits of vector control. Stability of the system during transient process and a wide range of operation are assured through the application of vector control.

The purpose of this thesis is to study the vector control of AC induction machine based on the principles of the AC speed control system, vector control and fuzzy Proportional integral (PI) control, and implementing the digital vector control systems based on the digital signal processor (Digital Signal Processor - DSP TMS320F2812) from Texas Instruments. The mathematical modeling of the AC induction motor and the principles of vector control and fuzzy systems are overviewed first. Fuzzy PI regulator is then proposed to carry out the regulation of the motor speed. The fuzzy PI is an intelligent technique that has evolved in the last decades and it emulates the human way of thinking. Therefore the fuzzy PI does not need the exact mathematical model. In-depth study of fuzzy PI and the normal PI was carried out. Matlab/Simulink software is used to simulate the vector control of the AC induction motor with both fuzzy PI regulator and normal PI regulator for comparative purposes. Simulation results showed that fuzzy PI has a better performance in terms of stability, faster response and robustness, and the fluctuation ripples are also smaller. Experiments had been done on the laboratory platform of AC drive system with the help of AC speed control monitor program designed in Laboratory Virtual Instrument Engineering Workbench (LabVIEW) under variable operating conditions. The experimental waveforms were captured using the LabVIEW monitoring software. In order to carry out real time implementation, Code Composer Studio and SEEDXDS510plus Emulator are adopted to programming and testing with the DSP TMS320F2812. Experiments results show that the fuzzy PI regulator performs better than normal PI regulator, as fuzzy PI regulator indicates better waveforms of torque and speed responses during acceleration and deceleration, especially when the motor is operating on lower speeds.

Keywords: Fuzzy logic; Induction motor; Vector control; LabVIEW; DSP

Introduction

In all walks of life AC induction motors are used by the entire industrial and other sectors. This is due to their robustness, and low cost maintenance properties. Technology is evolving day by day and the AC motors are being modified to suit the ever changing needs and applications of industry leading to a reduction in the advantages of the AC induction motor. When the AC and DC motors are compared, the merits of the AC motor override the DC.

Theoretical Framework

AC speed regulation technology development

Motor control is actually a broad term that can mean any object or component that is from a simple toggle switch to a complex system with components like relays, switches and timers. All controls have a common function that is to control the operation of an electric motor, Shchur and Turkovskyi (2021) and Hammoud, Hentzelt, Oehlschlaegel and Kennel (2021). AC motors operate from alternating current (AC) power sources. The magnetic fields typically are generated using coils on the rotor and stator, and the field movement occurs naturally in the stator due to the alternating nature of the input power. These motors are inexpensive to build and operate, reliable, and usually run from standard line power. The power supply frequency determines the speed of an AC motor, so if operated from line power, the speed of rotation is always the same. Variable frequency power drives control the speed of AC motors, but such drives are expensive. Different industries use electrical motors in their applications. Electric motor drive systems are estimated to consume over half of all electricity in the United States and over 70% of all electricity in industrial application.

AC induction motor is the most common motor used in industry and mains powered home appliances. In the past decade the AC motor was said to be inferior as compared to a DC motor. This was so as the DC motor was used in various circuits for its high performance speed system. In the field of electrical and mechanical production industry all over the world a motor is a necessity. As technology is changing rapidly it has been discovered that the AC motors have overridden the DC motors as the latter suffers from various mechanical problems which in turn slows down production in the industrial production sector. Therefore the use of DC motor in industrial application has presented a number of challenges such as weight, which has an effect on the speed of rotation, high cost of maintenance and so on. Robust and precise speed control is very important in high performance drive applications. The AC motor has gained popularity due to its merits which are high power factor, low noise, robust operation, high torque to current ratio and lastly but not least high power to weight ratio, Siamaki, Storey, Wiesehoefer and Badcock (2022), Ullah, Guzinski and Mirza (2022). In the motion control industry or in the recent remarkable advances of power electronics, AC motors have gained momentum for industrial and domestic applications because of their robust structure and maintainability Shetty and Suryanarayana (2022), Reddy and Raghavaiah (2022), da Silva Barcelos, Mazzoni and Cardoso (2022), Polat, Akyun and Nory (2022).

Mathematical Modeling and Analysis of Vector Control

Vector control in AC induction speed control system

In industrial applications high dynamic performance of AC motor control still remains a challenging problem as it exhibits significant nonlinearity's and many of the parameters especially the rotor resistance which actually varies with the operating conditions. Therefore, to achieve high performance control, Field Oriented Control (FOC) or vector control of an induction machine, which achieves decoupled torque and flux producing components of the stator current, can be used in AC motors, Akin and Bhardwaj (2013).

The field oriented control techniques are attractive although they have one major demerit which is that they are sensitive to motor parameter variations such as the rotor time constant and incorrect flux measurement or estimation at low speeds Zaky (2015), Sahoo and Ray (2022).

Vector control offers more precise control of AC motors compared to scalar control. They are used in high performance drives where oscillations in air-gap flux linkages are intolerable, like robot actuators, centrifuges, servos and so on. The technique of vector control has only become possible as a result of large striders made in solid state electronics like both with microprocessors and power electronics.

The aim of vector control is to implement control schemes that produce high dynamic performance and are similar to those used to control DC machines. The control performance of AC motor drives depend on mechanical parameter variations, external torque disturbances, resistance changes, measurement noise frictional variations and system uncertainty improper field orientation in transient state. Blaschke published field oriented or vector control in 1972 and many researchers like Leon herd and Bose contributed in the development of this method. Vector control is divided into four methods that are magnetization flux, rotor flux, stator flux and rotor during decomposition of stator current to its moment and flux components.

We have two types of controls namely scalar and vector control. Scalar control out veils excellent steady performance hence the dynamic response is not good at all. There is a deviation of air gap flux in phase and magnitude. Vector control overrides the scalar control on the control of AC motors. Vector control is classified into direct and indirect vector control. In direct vector control the rotational angle of the i^{s}_{qs} vector with respect to the stator flux ψ^{s}_{qr} is directly determined. In the case of indirect vector control the rotor angle is measured indirectly, thus by measuring the slip speed. Indirect vector control is therefore mainly implemented and commercialized in the AC systems.

AC vector merits and demerits

Merits of AC vector are that it: has high dynamic response, uses standard inductor motor, is high in accuracy and has as a very wide speed range. Demerits of AC vector include highly complexity, high cost, usually needs special motor, and motor cooling problem.

Mathematical description of the AC induction motors

There are various models for AC induction motor and a model used for vector control design can be obtained by utilizing space vector theory. The 3-phase induction motor has quantities expressed in terms of complex space vectors the likes of voltages, magnetic flux, currents, motion and many more. This type of model is valid for any instantaneous variation of voltage and current and adequately describes the performance of the machine in steady- state and transient operations. Therefore the complex space vectors can be described using two orthogonal axes usually we look at the motor as a 2-phase machine and utilize it to reduce the number of equations and thus in turn simplifies the control design.

Mathematical modeling of a 3-phase motor

Induction motor is a nonlinear system and its mathematical model can be simplified by involving the stator currents that is to achieve decoupling, and the coordinate transformation is then linked to this. According to the vector control 3-phase stationary coordinate system conversion to a mathematical model of 2-phase stationary coordinate system or two phase rotating coordinates system is seen, and the 3-phase stationary coordinate system conversion to the mathematical model of 2-phase stationary coordinate or 2-phase.

Mathematical model coordinate system of a stationary 2-phase induction motor

The coordinates of the stationary 2-phase induction are $3S/2S$. Flux, torque, voltage, and equations of motion are used to obtain the parameters of the 2-phase rotating rotor to 2-phase stationary coordinate's transformation which is $2R/2S$.

These named equations are given as:

(1) Flux equation:

$$\begin{bmatrix}\psi_{s\alpha}\\ \psi_{s\beta}\\ \psi_{r\alpha}\\ \psi_{r\beta}\end{bmatrix}=\begin{bmatrix}L_s & 0 & L_m & 0\\ 0 & L_s & 0 & L_m\\ L_m & 0 & L_r & 0\\ 0 & L_m & 0 & L_r\end{bmatrix}\begin{bmatrix}i_{s\alpha}\\ i_{s\beta}\\ i_{r\alpha}\\ i_{r\beta}\end{bmatrix} \quad (1\text{-}0)$$

Where, the coordinates are transformed as mutual inductance L_m stator inductance L_s and rotor inductance L_r .

(2) Electromagnetic torque equation: The electromagnetic torque is given by

$$T_e = n_p L_m \left(i_{s\beta} i_{r\alpha} - i_{s\alpha} i_{s\beta}\right) \quad (1\text{-}1)$$

(3) Voltage equation:

$$\begin{bmatrix}u_{s\alpha}\\ u_{s\beta}\\ u_{r\alpha}\\ u_{r\beta}\end{bmatrix}=\begin{bmatrix}R_s & 0 & 0 & 0\\ 0 & R_s & 0 & 0\\ 0 & 0 & R_r & 0\\ 0 & 0 & 0 & R_r\end{bmatrix}\begin{bmatrix}i_{s\alpha}\\ i_{s\beta}\\ i_{r\alpha}\\ i_{r\beta}\end{bmatrix}+p\begin{bmatrix}\psi_{s\alpha}\\ \psi_{s\beta}\\ \psi_{r\alpha}\\ \psi_{r\beta}\end{bmatrix}+\begin{bmatrix}0\\ 0\\ \omega_r\psi_{r\beta}\\ -\omega_r\psi_{r\alpha}\end{bmatrix} \quad (1\text{-}2)$$

$U_{s\alpha}$ and $U_{s\beta}$ are the stator voltages and $U_{r\alpha}$ and $U_{r\beta}$ are the rotor voltages in the 2-phase coordinate

$i_{s\alpha}$ and $i_{s\beta}$ are the stator currents and $i_{r\alpha}$ and $i_{r\beta}$ are the rotor currents in the 2-phse stationary coordinate system.

$\psi_{s\alpha}$ and $\psi_{s\beta}$ and the stator flux and $\psi_{r\alpha}$ and $\psi_{r\beta}$ are the rotor fluxes in the 2-phase stationary coordinate system.

R_s is the resistance of the stator and R_r stand for the rotor resistance. ω_r stands for the rotor speed

(4) Mechanical equations of motion

$$T_e = T_L + \frac{J}{n_p}\frac{d\omega_r}{dt} \quad (1\text{-}3)$$

$$T_e = T_L + \frac{J}{n_p} p\omega_r \quad (1\text{-}4)$$

T_e, T_L stands for-Load resistance and moment of inertia.

Mathematical model coordinate system of a rotating 2-phase induction motor

Coordinates of the rotating 2-phase induction motor are $2S/2R$

Equations are:

(1) Flux:

$$\begin{bmatrix} \psi_{sd} \\ \psi_{sq} \\ \psi_{rd} \\ \psi_{rq} \end{bmatrix} = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix} \tag{1-5}$$

(2) Electromagnetic torque:

$$T_e = n_p L_m \left(i_{sq} i_{rd} - i_{sd} i_{rq} \right) \tag{1-6}$$

(3) Voltage:

$$\begin{bmatrix} u_{sd} \\ u_{sq} \\ u_{rd} \\ u_{rq} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 & 0 \\ 0 & R_s & 0 & 0 \\ 0 & 0 & R_r & 0 \\ 0 & 0 & 0 & R_r \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix} + p \begin{bmatrix} \psi_{sd} \\ \psi_{sq} \\ \psi_{rd} \\ \psi_{rq} \end{bmatrix} + \begin{bmatrix} -\omega_1 \psi_{sq} \\ \omega_1 \psi_{sd} \\ -\omega_{sl} \psi_{rq} \\ \omega_{sl} \psi_{rd} \end{bmatrix} \tag{1-7}$$

U_{sd} and U_{sq} are the stator voltages U_{rd} and U_{rq} are rotor voltages in the 2-phase rotating coordinates system values.

i_{sd} and i_{sq} are stator currents and i_{rd} and i_{rq} are rotor currents in the 2-phase coordinate system.

ω_1 and ω_{sl} are synchronous motor speed and slip speed.

(4) Motion: The equations remain unchanged.

Basically the mathematical model of the rotating coordinates system have merits the likes of AC induction motor is able to control torque-current component which decouples each other and the exciting current is transformed by synchronous rotation, Li, Zhang and Li (2022). Sun (2022), Fu, Zhu, Zheng, Sun, Yang and Lu (2022).

Continuous–time model of the induction motor

The state equations of the induction motors can be expressed in the rotating $d-q$ reference frame as:

$$\frac{dx}{dt} = \begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix} X + \begin{pmatrix} B_1 \\ 0 \end{pmatrix} U \tag{1-8}$$

Where,

$$X = \left[i_{ds}\, i_{qs}\, \phi_{dr} \phi_{qr} \right]^T$$

$$U = \left[V_{ds}\, V_{qs} \right]^T$$

$$A_{11} = \begin{pmatrix} -\dfrac{R_s L_r^{\ 2} + R_r L_m^{\ 2}}{\sigma L_s L_r^{\ 2}} & \omega_e \\ -\omega_e & -\dfrac{R_s L_r^{\ 2} + R_r L_m^{\ 2}}{\sigma L_s L_r^{\ 2}} \end{pmatrix} \tag{1-9}$$

$$A_{12} = \begin{pmatrix} \dfrac{L_m R_r}{\sigma L_s L_r^{\,2}} & \dfrac{L_m}{\sigma L_s L_r}\omega_r \\ \\ -\dfrac{L_m}{\sigma L_s L_r}\omega_r & \dfrac{L_m R_r}{\sigma L_s L_r^{\,2}} \end{pmatrix} \qquad (1\text{-}10)$$

$$A_{21} = \begin{pmatrix} \dfrac{L_m R_r}{L_r} & 0 \\ \\ 0 & \dfrac{L_m R_r}{L_r} \end{pmatrix} \qquad (1\text{-}11)$$

$$A_{22} = \begin{pmatrix} -\dfrac{R_r}{L_r} & \omega_e - \omega_r \\ \\ -\omega_e + \omega_r & -\dfrac{R_r}{L_r} \end{pmatrix} \qquad (1\text{-}12)$$

$$B_1 = \begin{pmatrix} \dfrac{1}{\sigma L_s} & 0 \\ \\ 0 & \dfrac{1}{\sigma L_s} \end{pmatrix} \qquad (1\text{-}13)$$

Where:

V_{qs} , V_{ds} q and d -axes are stator voltages;

i_{qs} , i_{ds} q and d -axes stator currents;

ϕ_{qr} , ϕ_{dr} q and d - axes rotor flux;

ω_r is the Rotor speed;

ω_e is the Induction speed.

The generating torque of the induction motor is:

$$T_e = \left(\frac{3}{2}\right)\left(\frac{p}{2}\right)\frac{L_m}{L_r}\left(i_{qs}\phi_{dr} - i_{ds}\phi_{qr}\right) \qquad (1\text{-}14)$$

Where, p =pole number; L_m =mutual inductance; L_r=rotor inductance.

Vector control of induction motor using fuzzy controller

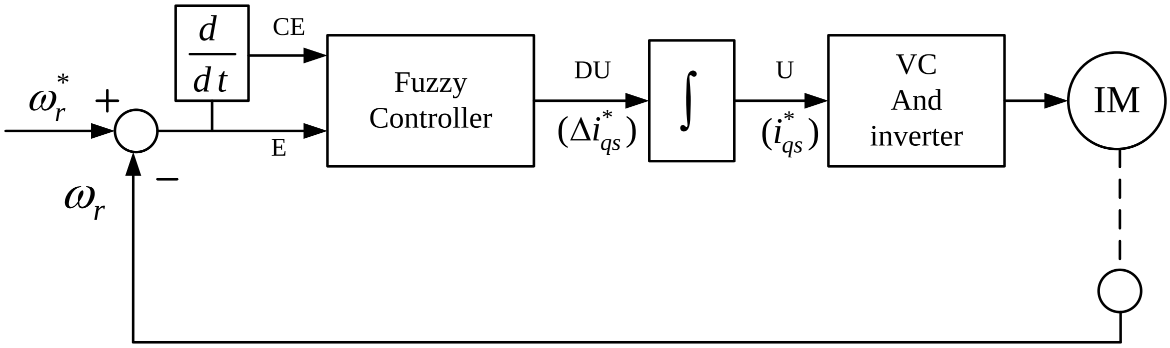


Fig. 1: Block diagram of vector control of induction motor using fuzzy controller

Diagram description:

The induction motor is fed by a current controlled PWM inverter which is built using a Universal Bridge block. The speed control loop uses a fuzzy logic controller instead of a simple PI controller to produce the quadrature-axis current reference IQ^* which controls the motor torque. The speed error signal is observed by the controller to update the output DU. DU is updated to match the actual speed ω_r and the command speed $\omega_r{}^*$. Error E and change in error CE are the input signals. In a vector control drive DU is $\Delta i_{qs}{}^*$ and it is integrated to generate the actual control signal U or $i_{qs}{}^*$, Mukhopadhyay, Choudhuri and Sengupta (2022). He, Zheng, Jin, Gong, and Dong (2022), Hashemi, Qin and Khajepour (2022).

The basic principles of space vector pulse width modulation

PWM control is the key technology of an active power filter and there are 3 different schemes of this technology that is the triangular wave modulation, hysteresis band control and Space Vector Pulse Width Modulation. PWM is a fundamental of the inverter and in AC motor control applications. The two-level 3-phase inverter is widely utilized because of the simple construction. SVPWM will be applied as it has powerful merits over the other controls.

Merits of SVPWM are that : it has low costs, it is flexible, switching losses are reduced/less harmonic content, the DC side voltage use factor is high/efficiency utilization is high, implementing the modulation scheme digitally is easy and can be used as flux tracking control current control in motor drives, Yan, , Xiao, Chen, Yuan, Xu and Zhao, (2022). Dabour, Alotaibi, Abd-Elaziz, Alshahat, Abdallah, Eltamaly, Abdel-Khalik, Massoud and Ahmed (2022) and Liu, Wang, Wheeler, Zhou and Zhu (2022).

SVPWM is widely used in many kinds of fields because it can provide the electronic source with the variable frequency and amplitude. SVPWM is widely used as it has an easy implementation in digital control system, excellent performance and high DC voltage utilization ratio. The typical application of SVPWM is in motor control and basing on the motor and the inverter it makes use of a float neutral point of the motor with star connection. Because its formulas are complicated, computer simulation can be used as a tool to analyze its applications and the simulation model to be used is Matlab software.

Simulation of normal PI using Matlab/Simulink

Normal PI simulation platform model is seen in Fig. 2 below.

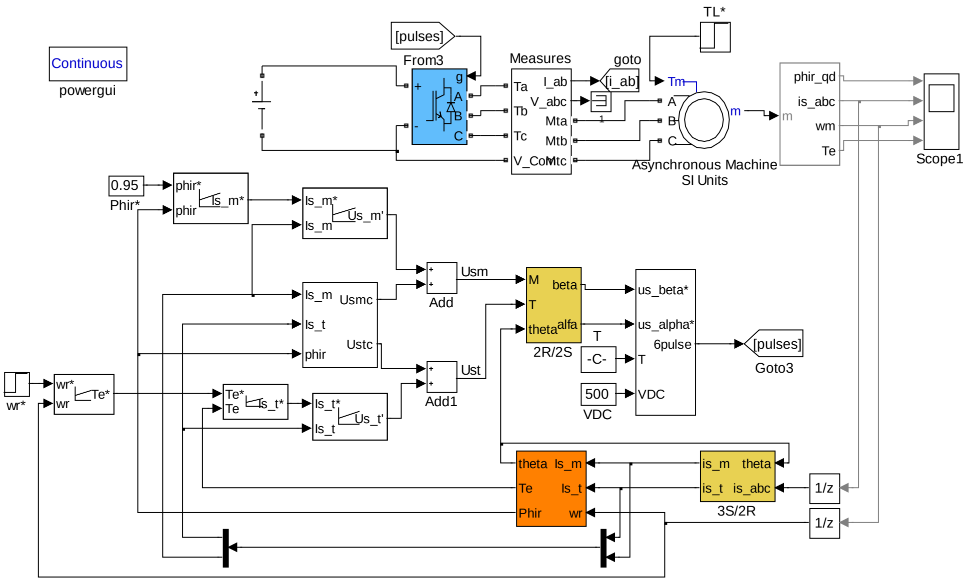


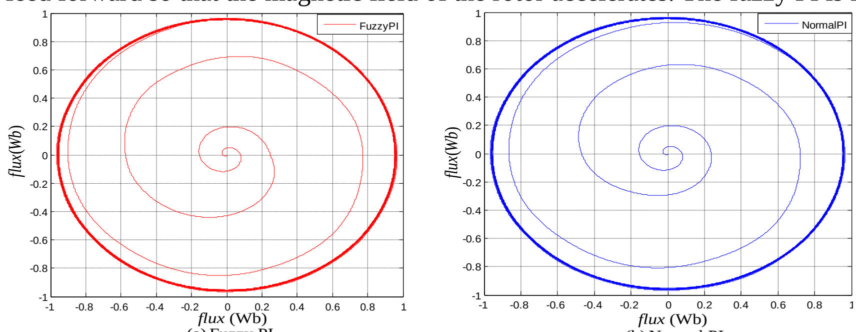
Fig. 2: Simulation model of vector control

Fuzzy PI and normal PI simulation results

The simulation is carried out using Matlab/Simulink and the responses of fuzzy PI and normal PI are presented for the justification of their reliability as controllers. The simulation responses constitute of rotor flux trajectory, speed and torque.

Fuzzy PI and normal PI rotor flux trajectory response

The rotor flux trajectory amplitude of the fuzzy PI and normal PI in Fig. 3(a) and (b) is $0.95Wb$. The trajectory is round and smooth for both controllers. Due to the rapid increase of torque, it results in enhanced flux loop voltage feed forward so that the magnetic field of the rotor accelerates. The fuzzy PI is faster.



(a) Fuzzy PI (b) Normal PI

Fig. 3: Rotor flux trajectory of fuzzy PI and normal PI

Fuzzy PI and normal PI speed response

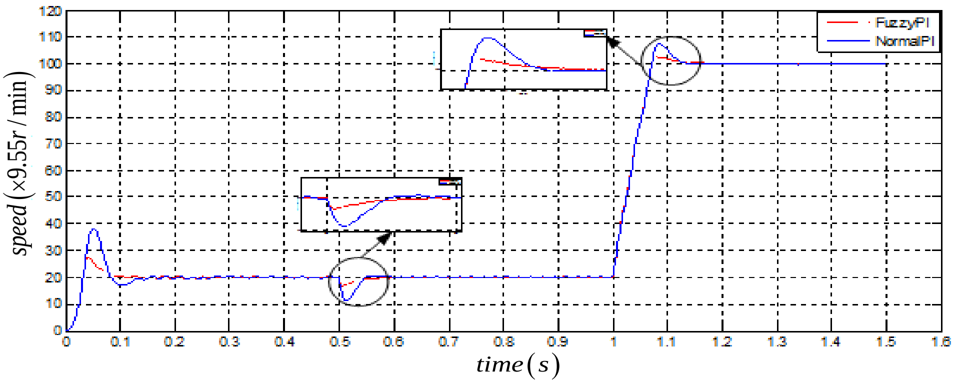


Fig. 4 Speed response curves of fuzzy PI and normal PI

In no-load start up process, the speed overshoot for the fuzzy PI control is relatively small. At a time response of $0.5s$ and sudden load of $10N \cdot m$, the dynamic response speed for fuzzy PI is stable. At time of 1s the speed is re-set to a given value of $955r/\min$. The speed response normal PI in no-load start up process is shown in Fig. 4 above. The speed normal PI it is $171.9r/\min$. From the curve at a response time of $0.5s$ there is a sudden load of $10N \cdot m$ on the normal fuzzy and the dynamic response process of the speed control amplitude drops. At a time of 1s, the speed is set to $955r/\min$ of which the normal PI has $76.4r/\min$ speed overshoot. Normal PI does not respond well as it has a high overshoot, not stable and not fast.

Fuzzy PI and normal PI torque response curve

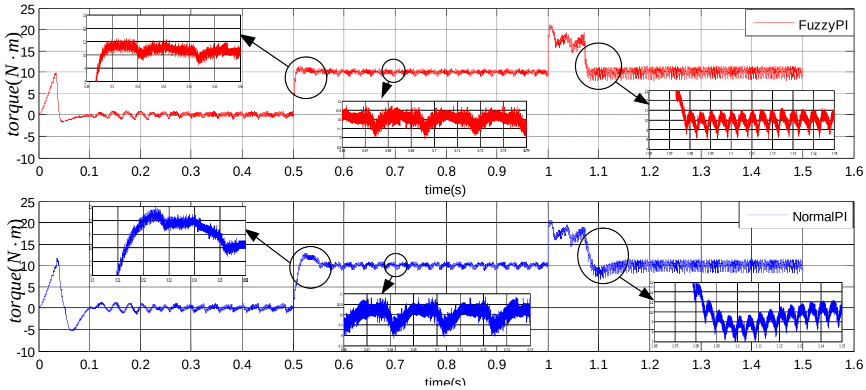


Fig. 5: Torque response curves of fuzzy PI and normal PI respectively

Fig. 5 above shows the torque response of the fuzzy PI and normal PI controller in no-load start up process. The fuzzy PI adjusts the electromagnetic torque at $-2N \cdot m$. At time 0.1s the two controllers are stable. The fuzzy has small fluctuation ripples. Also at time of 0.5s and 1.1s fuzzy PI controls better as seen from the magnified curve. At 0.7s the torque fluctuation of the fuzzy PI has smaller ripples. The normal PI adjusts $-5N \cdot m$. The torque adjustment for the normal PI is actually larger. At a time response of $0.1s$, the electromagnetic torque of the controller is stable but the ripple fluctuations are big. At time of 0.7s the torque ripples of normal PI are bigger than the fuzzy PI.

Fuzzy PI and normal PI simulation conclusion

The comparisons of both controllers is indicated by the given curves showing the flux trajectory, speed and torque responses. The fuzzy PI has proved to be more effective as it has a faster response and the fluctuation ripples are smaller than the normal PI.

Fuzzy PI controller Design and Implementation

Coordinate transformation of an induction motor can be simplified in a mathematical model and implemented in the torque decoupling between components and stator excitation current. We then find that because fuzzy control is an intelligent control method or technique, it does not rely on the controlled object. Therefore a precise mathematical model is able to overcome the nonlinear factors and changes in the parameters of the controlled object and is robust. In the normal PI closed-loop control of AC variable speed system, the speed of the outer ring of PI parameters will directly affect the systems speed performance. The fuzzy PI is simple in construction, steady-state, non-static and poor benefits also it is difficult to solve the smoothness, fastness and accuracy, Li, Sun, and Hou, (2022) and Tian, (2022).

The use of fuzzy PI controller meets various modes of performance requirements in the induction motor which is a high order, nonlinear, strong coupling of the complex time-varying systems. Thank you to the engineers, scholars, researchers and students who have studied and are still studying a variety of on-line real-time intelligent ways to adjust the PI parameters. Proposed error $e(t)$ adjusts the range division and real-time parameters of the fuzzy PI control method. When the $e(t)$ exceeds the maximum for a given range, the maximum allowable capacity of the system of output, as soon as possible to eliminate errors; when *e (t)* within a given range, the scaling parameter K_p and the integration parameters K_i respectively. According to $e(t)$ and

$\dot{e}(t); e(t)$ and $\int e(y)dy$ adjust the rate to certain adjustments. To achieve real-time adjustments more than two PI parameters are used in the system so as to get optimum control, but still there are some limitations the likes of:

(i) There is need to identify more than one factor and it is difficult to adjust as the fuzzy is based on knowledge which is difficult to prove.

(ii) One must experience on the PI parameter adjustment.

A detailed analysis of a variety of operating conditions to determine correct adjustments of a program is needed.

Materials and Methods

Matlab/Simulink for modeling and simulation, Lab VIEW software interface, Implementation of the AC variable speed system using Digital Signal Processor (DSP TMS320F2812), AC Induction motor , Experimental combined control box, power supply, 3-phase voltage regulator, AC-DC non controller convertor, inverter 3-phase induction motor, current speed sensor, DC generator, oscilloscope, electrical cables, digital multimeter and personal computer.

Fig. 6: Experimental setup diagram

Results

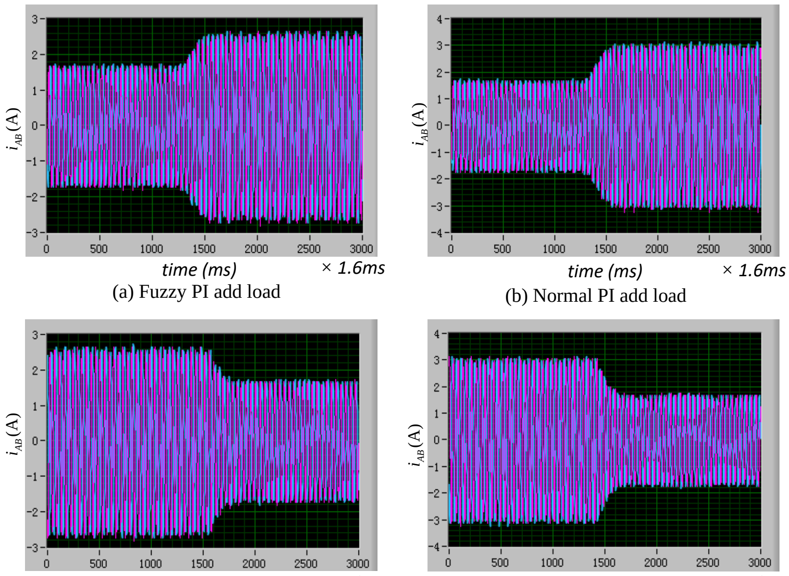
Various laboratory tests have been accomplished for the verification purposes of fuzzy PI and normal PI in the motor speed control of an induction motor to prove the efficiency and robustness of the system. Also various operating conditions were applied to the system the likes of current I_{AB}, torque responses when the motor load is changed, flux trajectory and stator flux when the motor is started, steady flux trajectory, speed and torque responses starting the motor at no load and lastly speed and torque responses at sudden addition of load. The performance of the fuzzy PI and the normal PI is compared in the implementation of these controllers in regulating the motor speed.

Laboratory Experimental responses of the fuzzy PI and normal PI

The results show the differences and similarities of the two controllers in a laboratory platform. The fuzzy PI is a promising controller as its performance is better than that of the normal PI in terms of speed, transient response, stability and robustness.

(i) Current (IAB) responses during the addition and reduction of load

During the starting of the motor when load is added in fuzzy PI Fig. 7(a) current starts to increase at time response of about $2s$. Current increases from $\pm 1.7A$ to $\pm 2.6A$ then maintain at a constant rate. Also when load is added in normal PI Fig. 7(b), current starts to increase at a time response of $2.08s$. In this case, current increases from $\pm 1.78A$ to $\pm 3A$. In Fig. 7(c) for the fuzzy PI, load is reduced and current also decreases from $\pm 2.6A$ to $\pm 1.7A$. Fig. 7(d) for the normal PI when the load is reduced, also current reduces from $\pm 3A$ to $\pm 1.78A$. Comparing the two controllers, fuzzy PI performs better than the normal PI as it is faster in response.



(a) Fuzzy PI add load

(b) Normal PI add load

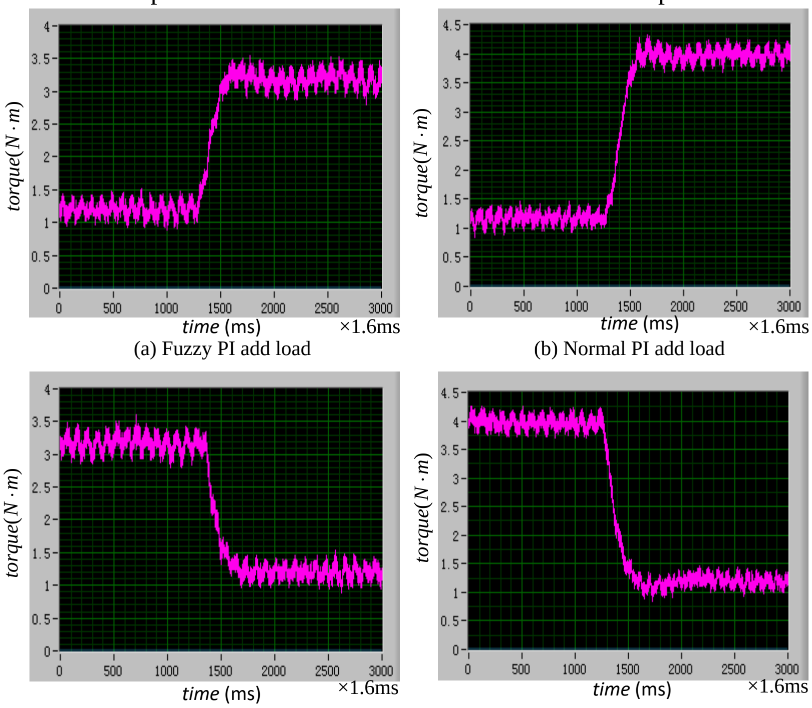
(c) Fuzzy PI reduce load

(d) Normal PI reduce load

Fig. 7: Fuzzy PI and normal PI current I_{AB} responses

(ii) Torque responses when the motor load is changed

The induction motor is started and Fig. 8 shows the response of torque for fuzzy PI and normal PI when the motor load is changed. Fig. 8(a) shows fuzzy PI torque increasing from $1.3N \cdot m$ to $3.2N \cdot m$. It then stabilizes at a response time is $1.92ms$. Fig. 8(b) is the response for normal PI when the set point of torque increases to $4N \cdot m$. Fig. 8(c) shows the fuzzy PI when load is reduced; the set point of torque drops to $1.2N \cdot m$ and then stabilizes. Fig. 8(d) shows that the normal PI torque drops to $1N \cdot m$ and slightly increases to $1.1N \cdot m$ and stabilizes. The controllers operate at different conditions, the torque measurement is not the same and the y-axis is different. Though fuzzy PI does not seem doing well at a torque lower than the normal PI, it performs better when compared at the same condition as it has a faster response and few fluctuation ripples.



(a) Fuzzy PI add load

(b) Normal PI add load

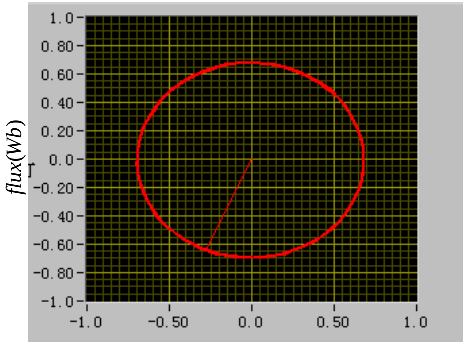
(c) Fuzzy PI reduce load

(d) Normal PI reduce load

Fig. 8: Fuzzy PI and normal PI torque responses

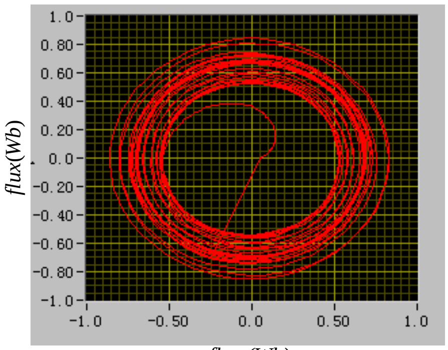
(iii) Flux trajectory and stator flux responses when the motor is started

In Fig. 9(a), it shows the flux trajectory response when the set point of flux falls at $\pm 0.7Wb$ and fuzzy PI is used. The trajectory is round and almost smooth. Fig. 9(b) shows that the flux trajectory of the normal PI falls at $\pm 0.8Wb$ and is not smooth as predicted. Fig. 9(c) shows that the stator flux for the fuzzy PI falls at $\pm 0.7Wb$. Relating to the stator flux trajectory of the normal PI in Fig. 9(d), it initially falls at $0.19Wb$ and $-0.6Wb$. Then increase a bit and falls at $\pm 0.8Wb$ at a response time of $0.32s$. Then it drops to $\pm 0.58Wb$ at $0.8s$ then increases to $\pm 0.7Wb$ of which it then stabilizes. The fuzzy PI performs better than the normal PI.



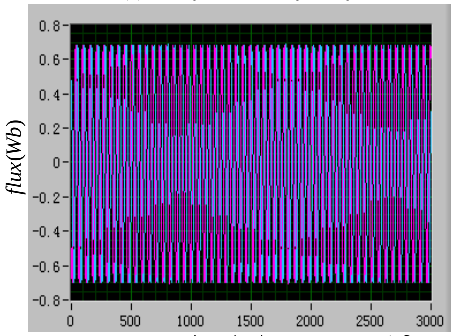
flux (Wb)

(a) Fuzzy PI flux trajectory



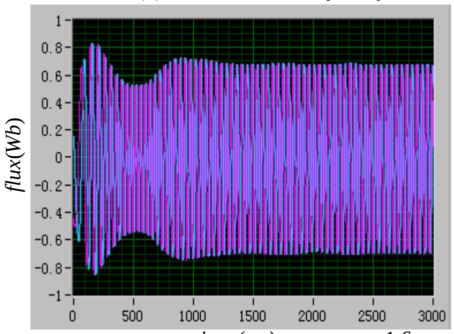
flux (Wb)

(b) Normal PI flux trajectory



time (ms) ×1.6ms

(c) Fuzzy PI stator flux

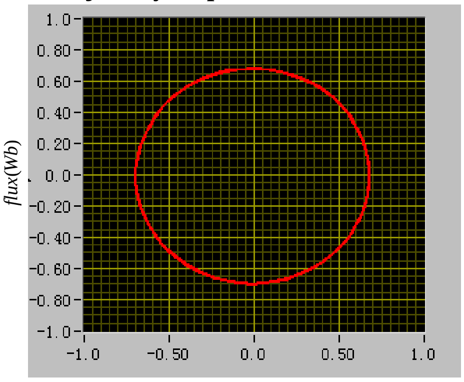


time (ms) ×1.6ms

(d) Normal PI stator flux

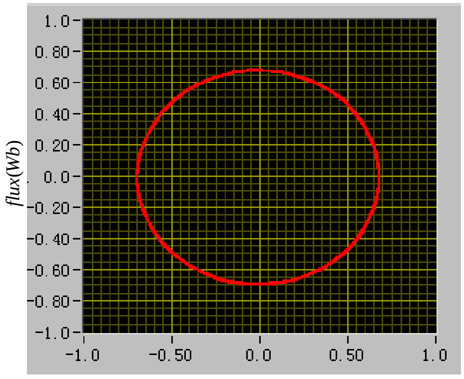
Fig. 9: Fuzzy PI and normal PI stator and flux trajectory responses

(iv) Steady flux trajectory responses



flux (Wb)

(a) Fuzzy PI steady flux trajectory



flux (Wb)

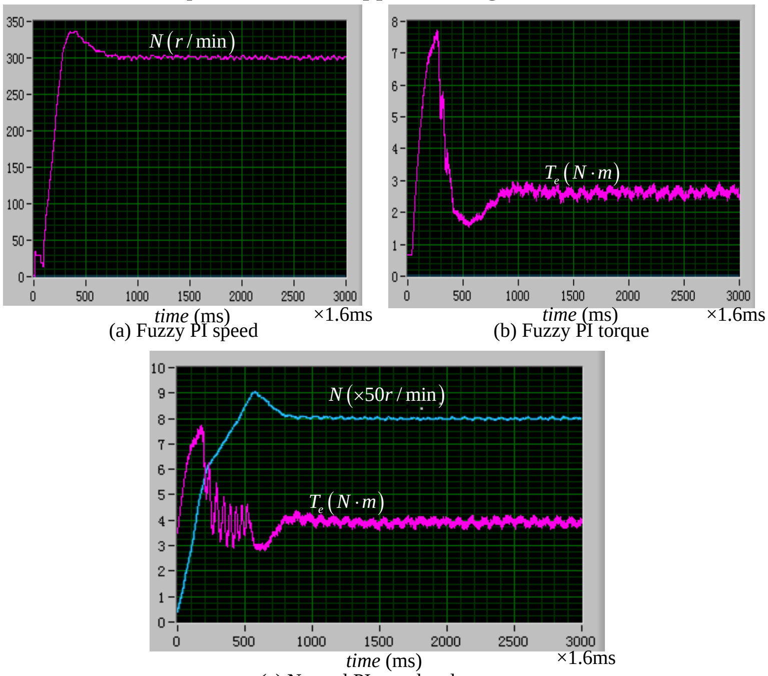
(b) Normal PI steady flux trajectory

Fig. 10: Fuzzy PI and normal PI steady flux trajectory responses

The steady flux trajectory of both the fuzzy PI and normal PI is the same as shown in Fig. 10(a) and (b). When the set point of steady flux trajectory falls at $\pm 0.7Wb$ the trajectory of both controllers is perfectly round and smooth. In varying conditions the fuzzy PI performs better than the normal PI.

(v) Speed and torque responses starting motor at no load

At no load the motor is started and speed and torque responses for fuzzy PI and normal PI are compared. Fig. 11(a) indicates the speed response for fuzzy PI, and the speed accelerates from $0-335r/\min$ then drops to $300r/\min$ at a time of $1.28s$ and stabilizes. Fig. 11(b) shows that torque increases from $0.8N\cdot m$ to $7.7N\cdot m$ when fuzzy PI is used. It then decreases to $2.5N\cdot m$ and increase again to $2.8N\cdot m$ then stabilizes. The oscillation ripples are small. Fig. 11(c) shows the torque and the speed responses when the normal PI is used. Torque increases from $3.4N\cdot m$ to $7.8N\cdot m$ then decreases at a time of $2.16s$ to $2.8N\cdot m$. It increases again to $4N\cdot m$ and then stabilizes. The speed increases from $12.5r/\min$ to $300r/\min$ and then accelerates again to $450r/\min$. It decreases to $400r/\min$ at a time of $0.96s$ and then stabilizes. The fuzzy PI speed and torque response curves are more stable and faster in time response. The normal PI speed is not fast and the torque fluctuation ripples are big.



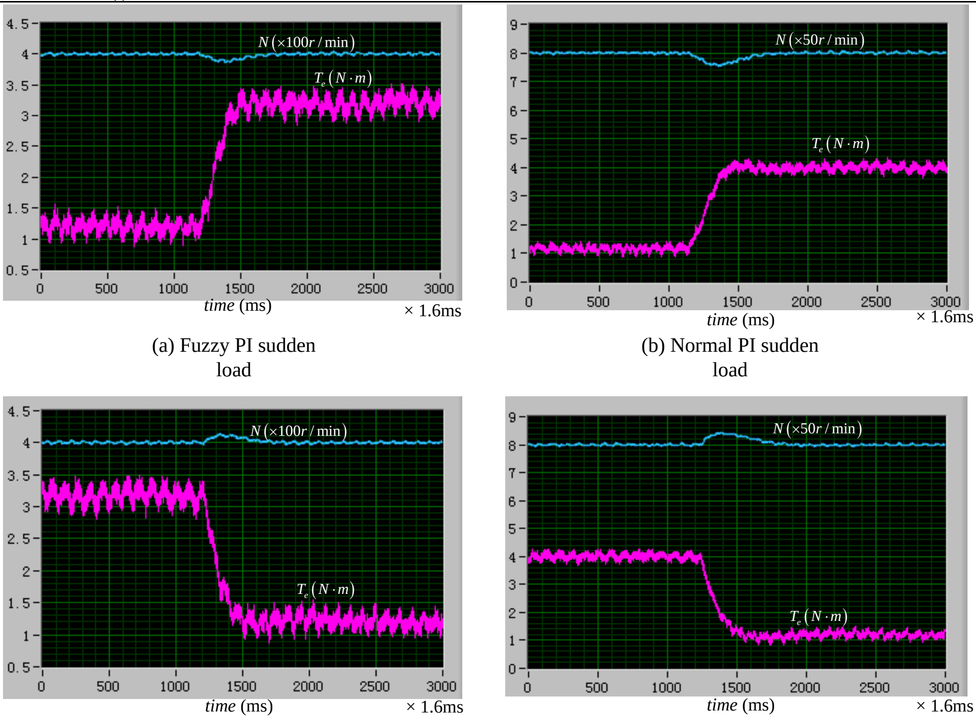
(a) Fuzzy PI speed (b) Fuzzy PI torque

(c) Normal PI speed and torque

Fig. 11: Fuzzy PI and normal PI speed and torque responses starting the motor at no load

(vi) Speed and torque responses at sudden addition of load

Fig. 12 indicates the responses for fuzzy PI and normal PI at sudden load at a speed of $400r/\min$. Fig. 12(a) indicates fuzzy PI at sudden load and the speed decelerates slightly to $389r/\min$ and gains momentum thus retaining to its original speed. The response time is $2.56s$ and it then stabilizes. The torque increases from $1.2N\cdot m$ to $3.3N\cdot m$ then stabilize. Fig. 12(b) shows the deceleration of speed for the normal PI to $374.5r/\min$. The response time is $2.56s$ and it stabilizes. The torque increases from $1N\cdot m$ to $4N\cdot m$ then stabilize. Fig. 12(c) shows sudden addition of load and the speed increases to $410r/\min$ when fuzzy PI is used. The response time is $2.56s$. Fig. 12(d) shows increase of speed to $420r/\min$ and it stabilizes. The response time is $2.88s$. The fuzzy PI has a smaller torque when compared to the normal PI and has a faster response.



(a) Fuzzy PI sudden load

(b) Normal PI sudden load

(c) Fuzzy PI reduced load

(d) Normal PI reduced load

Fig. 12: Fuzzy PI and normal PI sudden load responses

Discussions and Conclusion

Vector control technology as a high-performance motor control method occupies a very important position in the field of AC variable speed control. However, the rotor flux observer model and the static field PI parameters limit the use and development of vector control technology in the real system. For this reason, this thesis is dedicated in the study of modern control theory. The control algorithm is introduced in the vector control system to improve the control performance of the system. Fuzzy is an intelligent control method not only that it does not rely on accurate system parameters and a precise mathematical model, but also improves the robustness of the system when it is introduced to the vector control. It can be achieved using the PI parameters of the dynamic adjustment to adapt to the changing dynamic process.

The purpose of the research is to improve the performance of the machine control. In-depth study of fuzzy and vector control has been conducted. In order to facilitate a comparative analysis of the two controllers, simulation was done using Matlab/Simulink. Verification of the theoretical studies is accomplished through the comparative analysis of the simulation results. The fuzzy PI control algorithm performs better than the normal PI. Study of programming using the control chip DSP TMS320F2812 was carried out to enhance real-time algorithm. Various related experiments in the exchange control platform were carried out for the current I_{AB} during addition and reduction of load, torque responses when the motor load is changed, flux trajectory and stator flux responses when the motor is started, steady flux trajectory responses, speed and torque responses when the motor is started at no load and speed and torque responses at sudden addition of load. The experimental results show that the fuzzy PI has a faster response, stable, robust under varying operating conditions. The simulation and the experimental results are the same and fuzzy PI is the proposed control algorithm.

In this paper, although theoretical control was verified for the fuzzy PI control algorithm correctness and feasibility by investigating through simulation and experimentally, there are still some limitations that need to be further studied and improved. Therefore to complete the thesis the future works I can contribute are:

1. There is still need to test and compare other controllers the likes of artificial neural networks, multilateral controller and other modern controllers as technology is advancing day by day so as to improve the quality control algorithm for the performance of the induction motor.
2. There is also need for in-depth research to find the exact parameters of the controllers so as to get smoother waveforms.

3. The system might function better if separate DSP for monitoring and controlling the system are incorporated in the system.
4. Modification of the models used is also necessary to further improve the performance.

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