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ICIREST-19 Arduino Based FLC Implementation of Speed Control of Induction Motor

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***Abstract**: Because of the low maintenance and robustness induction motors have many applications in the industries. The speedcontrol of induction motor is more important to achieve maximumtorque and efficiency. Various speed control techniques like, DirectTorque Control, Sensorless Vector Control and Field OrientedControl. Soft computing technique –Fuzzy logic is applied in this work .We have carried on with the hardware implementation of speed control of inductionmotor using the fuzzy logic control . Using the arduino micro controller we have developed a hardware setup which is able to control the speed of induction motor .We conclude that we have been able to get a good control over the motor.*
***Keywords—**Speed;Arudino Uno,Induction motor, Field Oriented Control, Fuzzy logic controller, Maximum torque, Membership function*

I. Introduction

Induction motors are being applied today to a widerrange of applications requiring variable speed. Generally,variable speed drives for Induction Motor (IM) require bothwide operating range of speed and fast torque response,regardless of load variations. This leads to more advancedcontrol methods to meet the real demand. The conventionalcontrol methods have the following difficulties
1. It depends on the accuracy of the mathematical modelof the systems
2. The expected performance is not met due to the loaddisturbance, motor saturation and thermal variations
3. Classical linear control shows good performance onlyat one operating speed
4. The coefficients must be chosen properly foracceptable results, whereas choosing the propercoefficient with varying parameters like set point isvery difficult

To implement conventional control, the model of thecontrolled system must be known. The usual method ofcomputation of mathematical model of a system is difficult.When there are system parameter variations or environmentaldisturbance, the behavior of the system is not satisfactory.Usually classical control is used in electrical motor drives. Theclassical controller designed for high performance increasesthe complexity of the design and hence the cost. Advanced control based on artificial intelligence techniqueis called intelligent control. Every system with artificial intelligence is called self-organizing system. In 1980's the production of electronic circuits andmicroprocessors with high computation ability and operatingspeed has grown very fast. The high power, high speed andlow cost modern processors like DSP, FPGA and ASIC IC'salong with power technique switches like IGBT made theintelligent control to be used widely in electrical drives.Intelligent control, act better than conventional adaptivecontrols. Artificial intelligent techniques divide two groups:hard computation and soft computation [14]. Expert systembelongs to hard computation which has been the first artificialintelligent technique. In recent two decades, soft computationis used widely in electrical drives. They are,
1. Artificial Neural Network (ANN)
2. Fuzzy Logic Set (FLS)
3. Fuzzy-Neural Network (FNN)
4. Genetic Algorithm Based system (GAB)
5. Genetic Algorithm Assisted system (GAA)

Neural networks and fuzzy logic technique are quitedifferent, and yet with unique capabilities useful ininformation processing by specifying mathematicalrelationships among numerous variables in a complex system,performing mappings with degree of imprecision, control ofnonlinear system to a degree not possible with conventionallinear systems.

Fuzzy logic is a technique to embody human-like thinkinginto a control system. A fuzzy controller can be designed toemulate human deductive thinking, that is, the process peopleuse to infer conclusions from what they know. Fuzzy controlhas been primarily applied to the control of processes throughfuzzy linguistic descriptions. Fuzzy control system consists offour blocks as shown in Fig. 1.

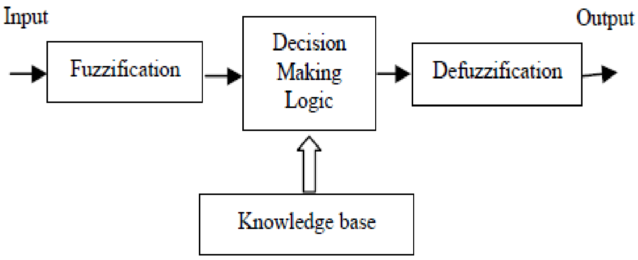


Figure1 Fuzzy Control System

This paper deals about the hardware implementation of fuzzy logic in the speed control of Induction motor. Various control techniques are discussed in Section II. The Section III discusses the induction Motor. Section IV describes the Fuzzy logic controller.SectionV describes the hardware implementation of the fuzzy logic based induction motor controller followed by conclusion in Section VI.

II. Various Control Techniques

Due to advances in power electronic switches andmicroprocessors, variable speed drive system using variouscontrol technique have been widely used in many applications,namely Field oriented control or vector control, Direct torquecontrol, Sensorless vector control.

A. Direct Toque Control

The Direct Torque Control (DTC) scheme is very simple.In its basic configuration it consists of DTC controller, torqueand flux calculator and VSI. In principle, the DTC methodselects one of the inverter's six voltage vectors and two zerovectors in order to keep the stator flux and torque within ahysteresis band around the demand flux and torquemagnitudes. The torque produced by the induction motor canbe expressed as shown below

$$T_{em} = \frac{3}{2}\frac{P}{L_s}\frac{L_m}{L_r}\left|\overline{\lambda_r}\right|\left|\overline{\lambda_s}\right|\sin\alpha \qquad 2.1$$

This shows the torque produced is dependent on the stator fluxmagnitude, rotor flux magnitude and the phase angle betweenthe stator and rotor flux vectors. The induction motor statorequation is given by

$$\overline{V_s} = \frac{d\overline{\lambda_s}}{dt} - \overline{I_s} r_s \qquad 2.2$$

Can be approximated as shown below over a short time period if the stator resistance is ignored, then

$$\Delta\overline{\lambda_s} = \overline{V_s}.\Delta t \qquad 2.3$$

This means that the applied voltage vector as shown in theFig. 2 determines the change in the stator flux vector as shownin Fig. 3. If a voltage vector is applied that changes the statorflux to increase the phase angle between the stator flux androtor flux vectors, then the torque produced will increase. Twoproblems are usually associated with DTC drives which arebased on hysteresis comparators are:

i. Variable switching frequency due to hysteresiscomparators used for the torque and flux estimators

ii. Inaccurate stator flux estimations which can degradethe drive performance,some schemes have managed to maintain an average constantswitching frequency by utilizing apace vector modulation,predictive control, and dead beat control. All of thesetechniques increase the complexity of the drive systems.

B. Sensorless Vector Control

The sensorless control method is valid for both high andlow speed range. Using the traditional method, the statorterminal voltages and currents estimate the rotor angularspeed, slip angular speed and the rotor flux. In this case, around zero speed, the slip angular velocity estimationbecomes impossible since division by zero takes place.

Another strategy is, as short sampling time is assumed, wecould solve the linearized differential equations, then get analgebraic equation for the estimation of rotor parameters. Theproblem of achieving high dynamic performance in AC motordrives without the need for a shaft position/speed sensor hasbeen under study widely.

The advantages of speed sensorless operation of the drives are lower cost, reduced size of the drive machines, eliminationof the sensor cable and increased capability. The zero rotorspeed problem persisting in the sensorless speed controlscheme was resolved sacrificing the dynamic and steady stateperformance.

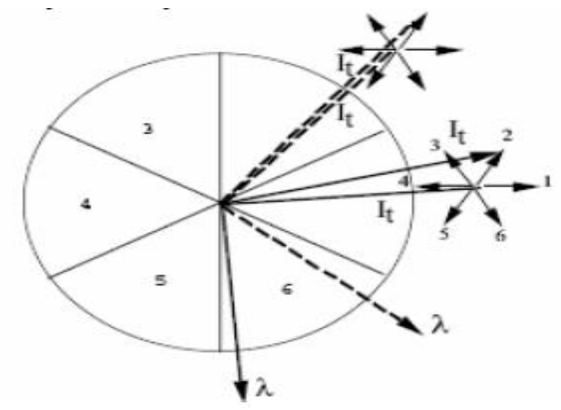


Figure 2.1 Applied Voltage Vector

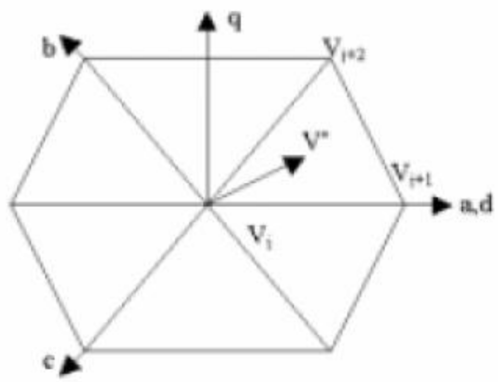


Figure 2.2 Stator Flux Vector

C. Field Oriented Control

Field oriented control (FOC) technique is intended tocontrol the motor flux, and thereby be able to decompose theAC motor current into "flux producing" and "torqueproducing" components. These current components can betreated separately, and then recombined to create the actualmotor phase currents. This gives a solution to the boostadjustment problem, and also provides much better control ofthe motor torque, which allows higher dynamic performance.Some approaches which yield the maximum torque havebeen published. Xu and Novotny [3] insisted that a methodwhich set the stator flux reference inversely proportional to therotor speed should produce more output torque than aconventional method, which set the rotor flux referenceinversely proportional to the rotor speed. However, in their method, there exist some speed ranges where the maximumtorque cannot be obtained.

Kim and Sul [1] suggested a voltage control strategy for themaximum torque operation of induction motors in the fieldweakeningregion, considering the voltage and currentconstraints. However this approach neglects the stator resistorfor the analysis.Wallace and Novotny [4] suggested an instantaneousmaximum-torque generation method for induction motors. Inthis approach, the entire current input is used for generatingthe rotor flux before the torque is developed. Then, at themoment that the rotor flux reaches the steady state value, theentire input current is switched to produce torque currentcomponent.

III. Induction Motor

In order to accomplish field oriented control, the controllerneeds to have an accurate "model" of the motor. Over the lastseveral years a large number of different schemes have beenproposed to accomplish the "flux and torque control" desired.Many of the today's technique involve some sort of selftuningat startup in order to obtain information which helps todesign accurate model of the motor to produce more optimalcontrol. In addition, there are also techniques by which themodels can adaptively adjust to changing conditions such asthe motor temperature going from cold to warm which willhave an impact of slip. The state equations of the inductionmotors can be expressed in the synchronously rotating *d*-*q*reference frame as follows [19].

$$\frac{dX}{dt} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} X + \begin{bmatrix} B_1 \\ 0 \end{bmatrix} U \qquad 3.1$$

Where,

$$X = \begin{bmatrix} i_{ds} & i_{qs} & \phi_{dr} & \phi_{qr} \end{bmatrix}^T \qquad 3.2$$

$$U = \begin{bmatrix} V_{ds} & V_{qs} \end{bmatrix}^T \qquad 3.3$$

$$A_{11} = \begin{bmatrix} -\frac{R_s}{\sigma L_s} - \frac{(1-\sigma)R_r}{\sigma L_r} & \omega_e \\ -\omega_e & -\frac{R_s}{\sigma L_s} - \frac{(1-\sigma)R_r}{\sigma L_r} \end{bmatrix} \qquad 3.4$$

$$A_{12} = \begin{bmatrix} \frac{L_m R_r}{\sigma L_s L_r^2} & \frac{L_m}{\sigma L_s L_r}\omega_r \\ -\frac{L_m}{\sigma L_s L_r}\omega_r & \frac{L_m R_r}{\sigma L_s L_r^2} \end{bmatrix} \qquad 3.5$$

$$A_{21} = \begin{bmatrix} \frac{L_m R_r}{L_r} & 0 \\ 0 & \frac{L_m R_r}{L_r} \end{bmatrix} \qquad 3.6$$

$$A_{22} = \begin{bmatrix} -\frac{R_r}{L_r} & \omega_e - \omega_r \\ -\omega_e - \omega_r & -\frac{R_r}{L_r} \end{bmatrix} \qquad 3.7$$

$$B_1 = \begin{bmatrix} \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \end{bmatrix} \quad 3.8$$

And
Vqs,*Vds*,*q*- and *d*- axes stator voltages;
iqs,*ids* , *q*- and *d*- axes stator currents;
Rs,*Rr*stator and rotor resistances;
φ*qr*,φ*dr*, *q*- and *d*- axes rotor fluxes;
ωrrotor speed;
ωesynchronous speed.
The generating torque of the induction motor is

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\frac{L_m}{L_r}\left(i_{qs}\phi_{dr} - i_{ds}\phi_{qr}\right) \quad 3.9$$

where,
P = pole number;
Lm =mutual inductance;
Lr =rotor inductance;
From the above the continuous- time model of the inductionmotors, a discrete-time model can be derived with thefollowing assumptions
1) The sampling time is sufficiently small enough toachieve a good approximation of a continuous-timemodel.
2) Since the mechanical time constant is much larger thanthe electrical one, rotor speed of an induction motor isassumed to be constant during the sampling period.
3) Stator currents, rotor flux, and input voltages are alsoconsidered constant during the sampling period.
Using the above assumptions, a discrete-time model of
induction motors can be expressed as

$$X(k+1) = A_d X(k) + B_d \hat{U}(k) \quad 3.10$$

Where

$$A_d = e^{AT} \quad 3.11$$

$$B_d = \left(\int_0^T e^{A\alpha} d\alpha\right) B \quad 3.12$$

T sampling time

The discrete model is used in the simulation.

Maximum torque generation

$$\text{Maximize} \quad T_e = K i_{ds} i_{qs} \quad 3.13$$

Under constraints

$$V_{qs}^2 + V_{ds}^2 \le V_{max}^2 \quad 3.14$$

$$i_{qs}^2 + i_{ds}^2 \le I_{max} 2 \quad 3.15$$

where,

$$K = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\frac{L_m^2}{L_r} \quad 3.16$$

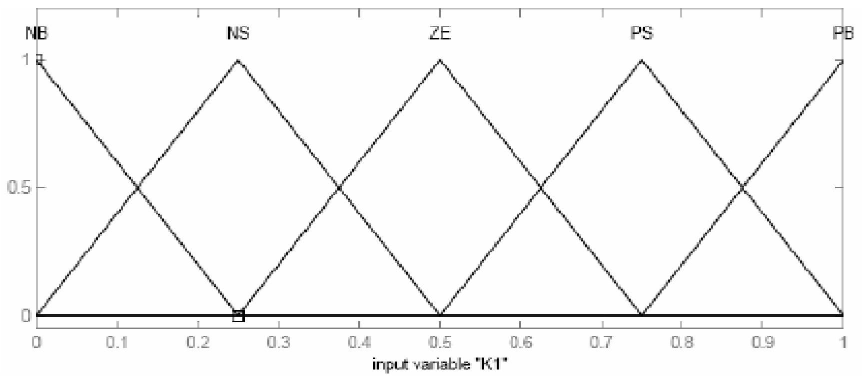
$$V_{ds} = R_s i_{ds} - \omega_e \sigma L_s i_{qs} \quad 3.17$$

$$V_{qs} = R_s i_{qs} - \omega_e L_s i_{ds} \quad 3.18$$

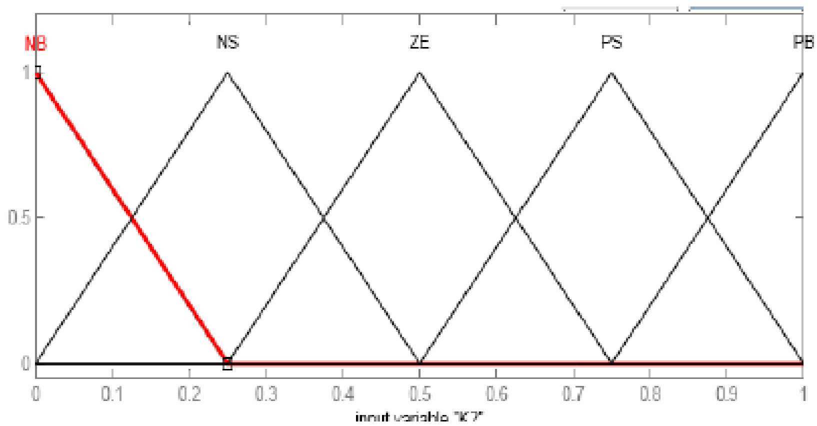
IV. Fuzzy Logic Controller

To obtain fuzzy based model of the motor, the trainingsystem derives information from two main sources,a. The static flux linkage curves of the motor, whichprovides important information about the electromagneticcharacteristics of the motor

b. The dynamic real time operating waveforms of themotor, which can include real-time operating effects,such as mutual coupling between phases, temperaturevariations, eddy currents and skin effects.During the training phase, each input-output data pair,which consists of a crisp numerical value of measured fluxlinkage, current, angle and voltage is used to generate thefuzzy rules.To determine a fuzzy rule from each input-output data pair,the first step is to find the degree of each data value in everymembership region of its corresponding fuzzy domain. Thevariable is then assigned to the region with the maximumdegree.When each new rule is generated from the input-output datapairs, a rule degree or truth is assigned to that rule, where thisrule degree is defined as the degree of confidence that the ruledoes in fact correlate to the function relating voltage andcurrent to angle. In the developed method a degree is assignedwhich is the product of the membership function degree ofeach variable in its respective region.Every training data set produces a corresponding fuzzy rulethat is stored in the fuzzy rule base. Therefore, as each inputoutputdata pair is processed, rules are generated. A fuzzy ruleor knowledge base is in the form of two dimensional table,which can be looked up by the fuzzy reasoning mechanism Speed error is calculated with comparison betweenreference speed and speed signal feedback. Speed error andspeed error changing are fuzzy controller inputs. Inputvariables are normalized with a range of membershipfunctions specified and the normalization factors are named asK1 and K2. Suitable normalization has direct influence inalgorithm optimality and faster response.
Fig. 4.1 shows normalized membership functions for inputand output variables. A fuzzy logic controller operation is
based on the rules formed.



(4a)



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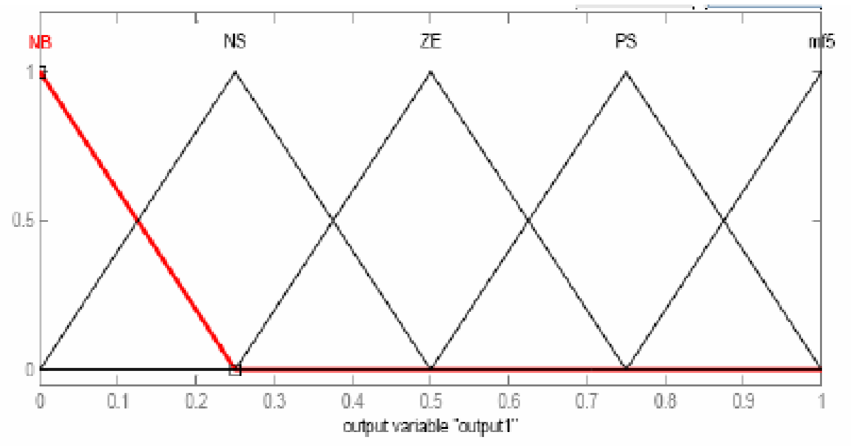

(4c)

Figure -4 (a) Membership function for input variable K1
(b) Membershipfunction for input variable K2
(c) Membership function for output variable

V. Results

Fuzzy Controller results: Input variables are required to benormalized with ranges of membership functions specified.

Suitable normalization has direct influence in algorithm andresults in optimality and faster response. The fuzzy logic controller operation is based on thecontrol operation shown in Table I.

TABLE I
FUZZY CONTROLLER OPERATIONS

	Δe	NB	NS	ZE	PS	PB
e	o/p					
NB		NB	NB	NS	NS	ZE
NS		NB	NS	NS	ZE	PS
ZE		NS	NS	ZE	PS	PS
PS		NS	ZE	PS	PS	PB
PB		ZE	PS	PS	PB	PB

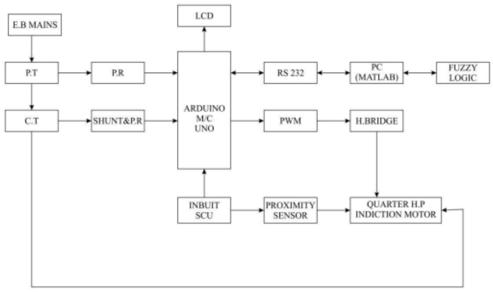

Figure 5.1 The Block Diagram

The supply from the mains is given to the potential and the current transformer which measures the voltage and the current. This voltage and current is applied through the precision rectifiers to the controller which is Arduino Uno. The microcontroller uses this voltage and current to generate PWM pulses . These PWM pulses are used to drive the H-Bridge which drives the induction motor. The fuzzy logic controller provides the controlling scheme through the microcontroller which helps in controlling the speed of the motor.

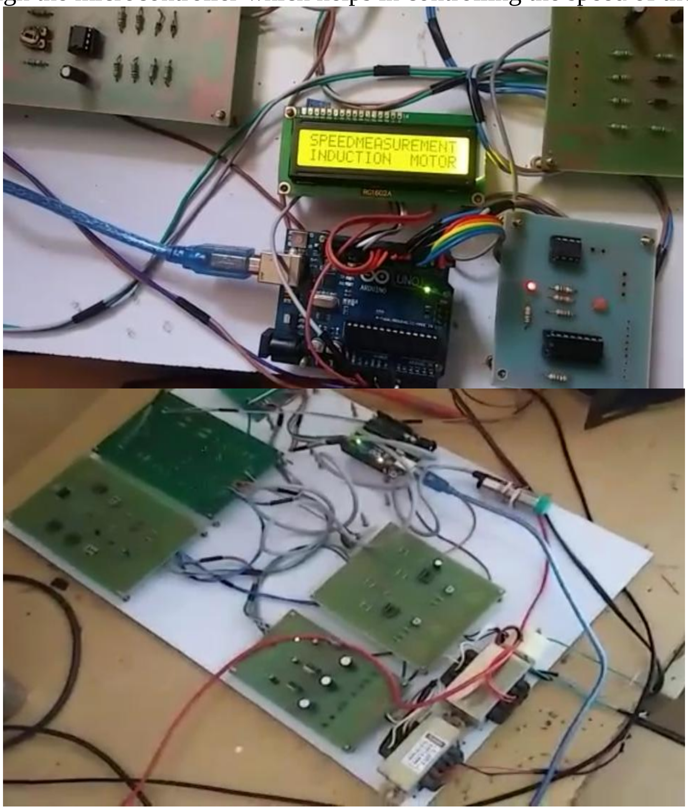

Figure 5.2 The Implemented Module

VI. Conclusion

Thus we conclude that we have been able to present a hardware implementation of speed control of induction motor using the fuzzy logic control . Using the Arduino Uno micro controller we have developed a hardware setup which is able to control the speed of induction motor .The fuzzy logic controller along with the microcontroller, the PWM pulse and the H-Bridge together controls the speed of the induction . This scheme can be used to drive the motor at the desired speed.

We also conclude that in future which necessary modification this scheme can be implemented for various other motors and the system can be escalated to work through an Android app as well as it can be controlled through the cloud.

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