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SCALAR CONTROL OF INDUCTION MACHINE SPEED USING FUZZY LOGIC CONTROLLER

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ABSTRACT

This paper presents design of Scalar Control of Induction machine Speed Using Fuzzy Logic controller (FLC). The design was done using MATLAB/SIMULINK software. This speed control employed scalar Volt/Hertz control method where the magnitude of the stator supply voltage and frequency are varied in the same proportion as V/F ratio remain constant by using PWM voltage source inverter. The closed loop scalar control block using FLC is designed to operate such that when a reference (desired) speed value is set, the FLC evaluates the speed error according to defined membership functions and rule base of IF THEN statement .The feedback technique provides slip frequency to scalar V/f control block which generate switching pulses for inverter switches, inverter then supply variable frequency voltage to the three phase induction motor, And motor run at speed that equal reference speed.. The SIMULINK model was simulated with PI and FLC controller and their simulation results were analyzed and compared. It was discovered That FLC offer better performance of the motor with fast dynamic response than conventional PI controller. The fuzzy logic controller showed robustness to any disturbance like change in load torque and improves sluggish response demerit of conventional scalar control technique.

Keywords: *Constant V/F control, Sinusoidal pulse width modulation (SPWM), Voltage source Inverter (VSI), Fuzzy logic controller (FLC)..*

I. INTRODUCTION

Ac motors particularly the squirrel – cage induction motor (SCIM) [2] finds wide application in industry and in its single-phase form in several domestic applications. More than 85% of industrial motor used today are induction motors [3]. Induction motor is used for variable speed applications, it has several inherent advantages like low cost, reliability, rugged design, high robustness, high efficiency, good self-starting capability and maintenance –free electrical drives [2][4] Induction motor provides better power/mass ratio and simpler maintenance cost and it has been used in industrial applications that do not require high performance for a long time.[5] It is classified into two types namely; single and three phase induction motor [1]. Both types have stator and a rotor which is wound with definite number of poles. The greater the number of poles, the lesser the speed of the motor and vice versa. However, it is not used in high performance application because it exhibits significant non-linearity and many of the parameters mainly rotor resistance, vary with the operating conditions [2] in addition to this other demerit include, load dependent on slip, fixed –speed design and requirement of position sensor. Due to the challenges mentioned, development of a control system for induction in operation becomes imperative. The emergence of AC drive (power electronics) has made induction motors popular today, speed control in induction motor is possible and easy [1]. Variable– speed drives for induction motors require wide operating range of speeds and fast torque response, regardless of load variation, and acts as industrial energy savers. Voltage source inverter– fed induction motors are most preferred for variable speed drive applications [6]. There are a number of speed control methods available for induction motors including: scalar control, vector or field-oriented control, direct and flux control, sliding mode control and the adaptive control [2]. In all the various speed control mechanisms, the volts/Hertz control scheme is very popular because it provides a wide range of speed control with good running transient performance also known as scalar control mode. The PID– type controllers, because of their simple structures and having good performances in a wide range of operating conductions is most widely used in industrial application. But the conventional control methods mention above have these demerits; dependence on accuracy of the mathematical model of the system; unsatisfactory performance due to motor saturation and thermal variation, choosing the right coefficient with varying parameters, accurate performance is exhibited only at one operating speed [6]. Also, unnecessary mathematical rigorosity, preciseness and accuracy involved with the design are the challenges [2]. To overcome this drawback from conventional controllers and scalar control method mentioned above, Fuzzy logic controller (FLC) is being used for motor control purpose, the FLC is designed and implemented in many motor control applications, owing to its knowledge-based algorithm [2][6]. In Fuzzy logic control, the linguistic description of human expertise in controlling a process is represented as Fuzzy rules or relations [5]. Scalar control method offers simple configuration, low steady state error using constant V/F control technique [8]. But this method is suitable without the need of high accuracy of speed control due to poor performance, it has sluggish response in its operation but easy to implement [9]. The scalar V/F control provide wide range of speed control where the input and output are speed unlike vector control where input is torque/flux and out is reference current [6]. Nitin et al [7] demonstrated the performance analysis of SPWM inverter fed 3 phase induction motor using MATLAB/SIMULINK with different simulation techniques. The simulation results show that by varying modulation index from low to high value total harmonic distortion (THD) of phase current and line stator voltage is improved using fuzzy logic controller (FLC) compared to result of PI controller. The result shows FLC gives better performance than PI controller. Akpama et al [6] presented performance evaluation of fuzzy logic control of induction motor. The fuzzy logic control technique is employed and the system is model and simulated in MATLAB/SIMULINK. The results obtained using a conventional PI and the designed fuzzy logic controller has been compared. The fuzzy logic controller presents better performance in term of stability, precision and reliability when compared to the PI. The FLC has faster response and less THD compared to PI. Fuzzy logic is a class of artificial intelligence. It is a modern method to think like human into the control scheme, FLC is normally designed to imitate human thinking [10] the aim of FLC is planting human intelligence in a system so that the system can think intelligently like human being [11]. Components of fuzzy logic controller; Fuzzy logic have five components which are:

- Fuzzification module (fuzzifier)
- Knowledge base
- Rule base
- Interface engine
- Deffuzzification module (defuzzifier) [12].

II. DESIGN METHODOLOGY

In this work, the method to be used is scalar control technique in design of scalar close loop control using fuzzy logic controller (FLC) for induction machine speed, this is done with the help of fuzzy logic toolbox in MATLAB/SIMULINK software. The speed control system is designed for three phase induction motor feds by voltage source inverter (VSI). also, PI controller is incorporated in SIMULINK model for comparison of the motor performance.

A Input linguistic variable

The reference speed or command speed value is 2500 rpm

The two input variables to FLC are

(a) Speed error (e)

(b) Change in error or derivative of speed error (Δe)

The speed error is expressed as;

$$e = \omega_{ref} - \omega_m \quad (1)$$

$$\Delta e = \frac{de}{dt} \quad (2)$$

The Fuzzy logic controller output i,e 'change in control' is $\omega_{sl.}$

B Rule base if then statements

The rule base that decides the output of the inference system is derived from the 7 speed error variables and 7 change in speed error variables making a total of 7 x 7 or 49 rules Shown in tableI which forms the 49 IF THEN rule that define the behaviour of the system.

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Table I: Fuzzy rule base table for output (w_{sl}) of FLC

e/Δe	NB	NM	NS	Z	PS	PM	PB
NB	NVB	NVB	NB	NBM	NM	NS	Z
NM	NVB	NB	NBM	NM	NS	Z	PS
NS	NB	NBM	NM	NS	Z	PS	PM
Z	NBM	NM	NS	Z	PS	PM	PBM
PS	NM	NS	Z	PS	PM	PBM	PB
PM	NS	Z	PS	PM	PBM	PB	PVB
PB	Z	PS	PM	PBM	PB	PVB	PVB

The 49 IF-THEN statement of the rule base cover a whole universe of discuss according to table I for the design of Fuzzy logic controller (FLC).

c Design of the fuzzy logic controller in matlab/simulink

The MATLAB/SIMULINK software have control tool box in its library, so design of fuzzy logic controller is done with the fuzzy Inference System (FIS) window. The mandani inference system is used. membership functions (MFs) are chosen with their appropriate range, centroid method is the defuzzification method used. The FIS file IF THEN statements are entered for 49 Rulebase which can be checked with the help of FIS editor. The 49 rule is saved with extension.FIS, The FIS file ruleview and surface plot are viewed with the FIS editor.

Figure 1. Membership functions of input error

And the change in control or output (Wsl) membership functions is below

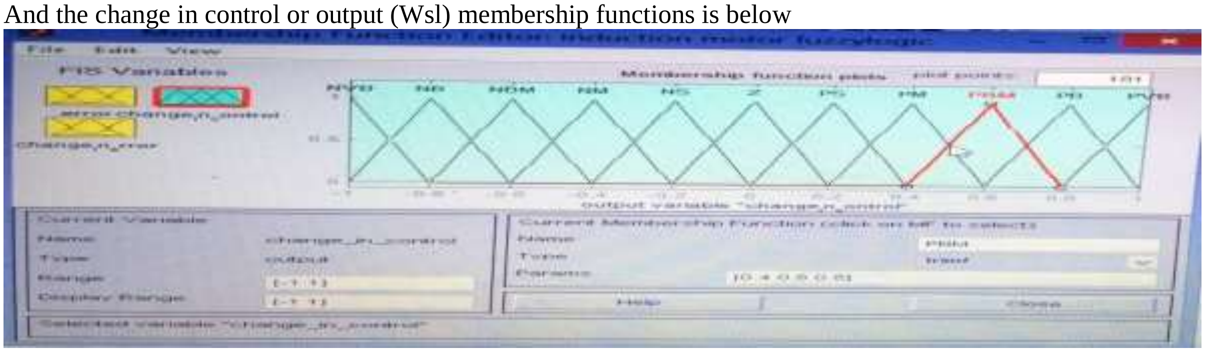

Figure 2 Membership functions of input change in control (Wsl.

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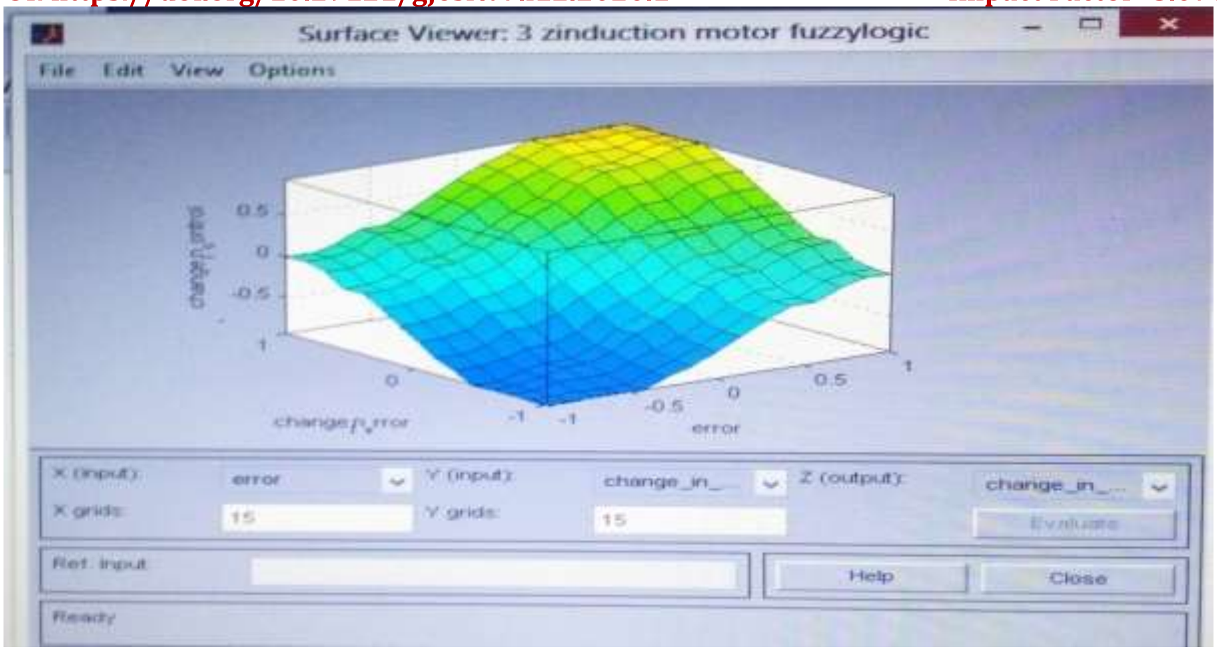


Figure 3 three-dimensional view of control surface

III. CLOSED LOOP SCALAR V/F CONTROL OPERATION

The closed loop scalar control block with fuzzy logic controller is designed to operate such that when a reference (desired) speed value is set, the fuzzy logic controller evaluates the speed error according to defined membership functions and rule base of IF THEN statement without mathematical model of the motor. The feedback technique provides slip frequency to scalar V/f control block which generate switching pulses for inverter power switches, the SPWM voltage source inverter supplies variable frequency voltage to the three-phase induction motor, and motor run at speed that equal reference speed.

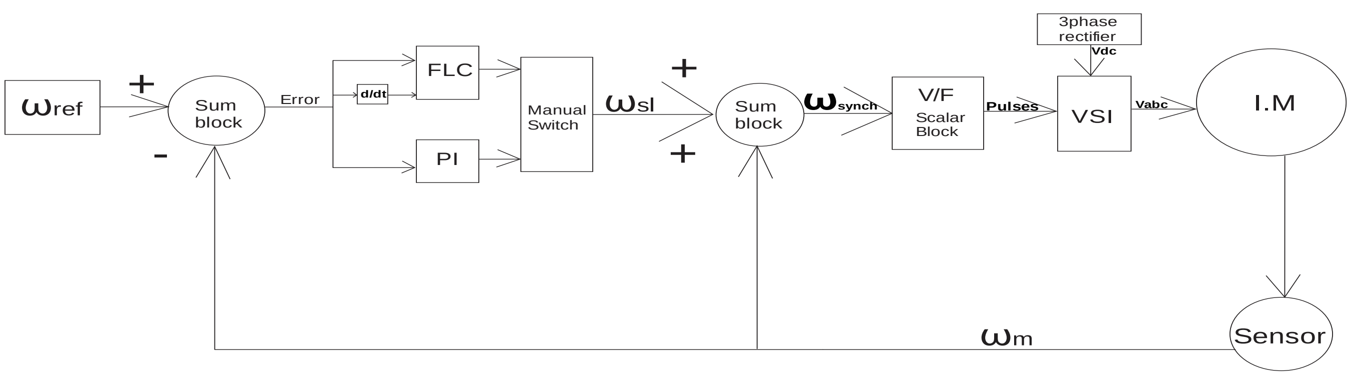


Figure 4. Block diagram of the speed control system.

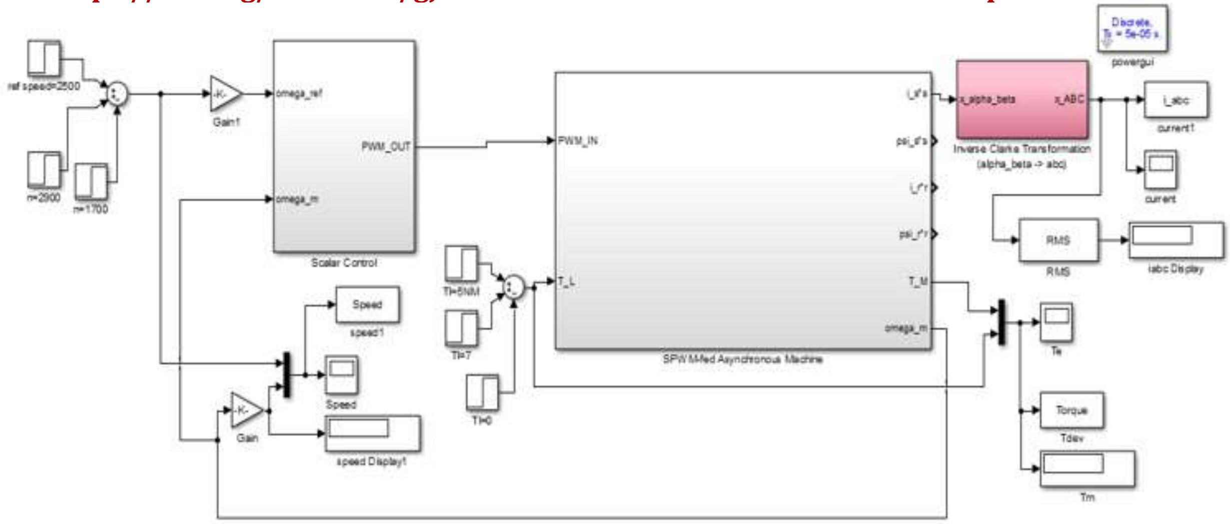


Figure 5. Complete SIMULINK diagram of the speed control system for induction motor.

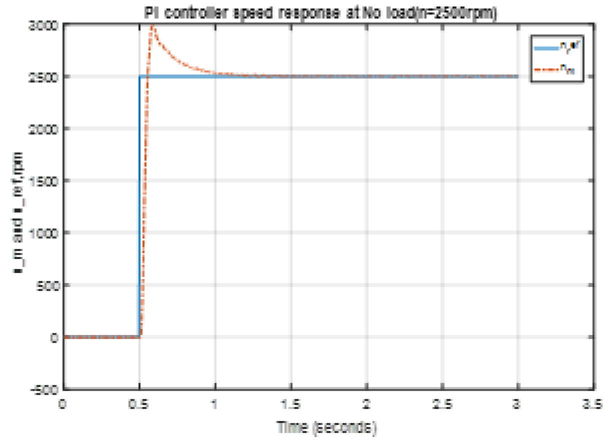
Table II: Machine Data with PID controller gain values.
MACHINE DATA

Power	2.2	Kilowatt (KW)
DC bus Voltage	660	Volts (V)
Current	6.4	Amperes (A)
Frequency	50	Hertz (Hz)
Rated torque	7.3	Newton-meter (N-m)
Rated speed	2890	Revolution per minute (rpm)
Stator resistance	2.3	Ohms (Ω)
Rotor resistance	2.9	Ohms (Ω)
Mutual inductance	0.34	Henry (H)
Stator inductance	0.340	Henry (H)
Rotor inductance	0.340	Henry (H)
Kp	0.5	
Ki	3.0	
Kd	0	

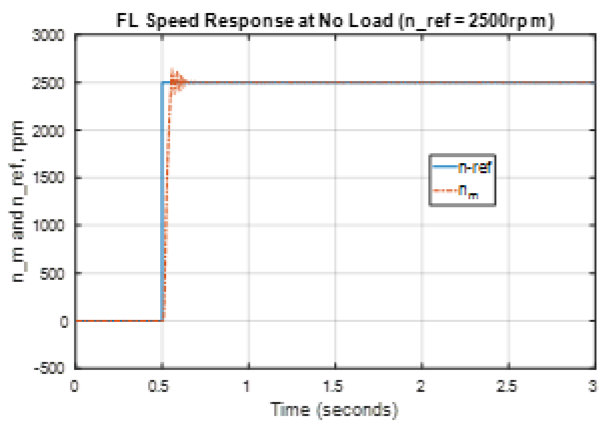
IV. SIMULATION RESULTS PRESENTATION AND DISCUSSION

This section presents the simulation results obtained from the complete SIMULINK control system block diagram in figure 5. The simulations were carried out using MATLAB/ SIMULINK. The simulation duration runs from zero to 3seconds and 5seconds in case of step change in applied load torque.

Speed response with no load (Reference speed=2500 rpm)



(a)PI



(b) FLC

Figure 6: Speed versus time response for step reference input of (2500 rpm), without load using FL and PI controller.

Figure 6 shows step reference speed response of the speed control system using both FL and PI controllers respectively, it is noticed that PI controller have higher settling time(ts) as it took 0.98second for the motor speed to stabilized at final steady state value(2500rpm). PI experienced maximum overshoot (Mp) of speed rise of up to 2900rpm and low rise time (tr) of 0.090 second, with no steady state error (ess). By Comparison, FL controller shows faster performance where settling time (ts) is 0.18second which is less, as the motor speed stabilized after 0.18 second and no overshoot (Mp) rather minor oscillation occurred at the start of motor ,also motor took little rise time(tr) of 0.059 second before it reached final steady state speed value as it tracked reference speed(desired) value.

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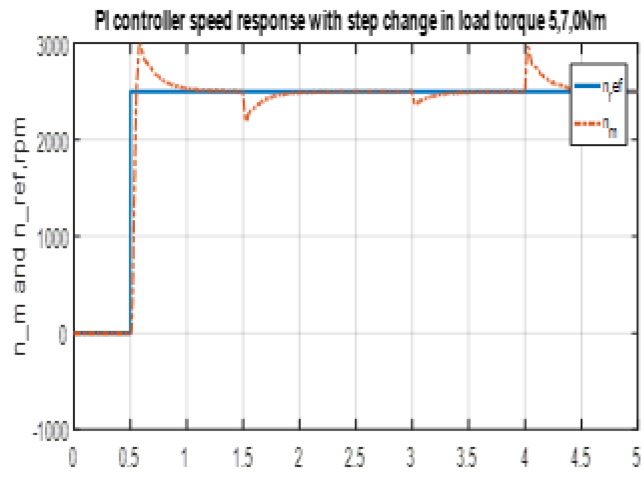
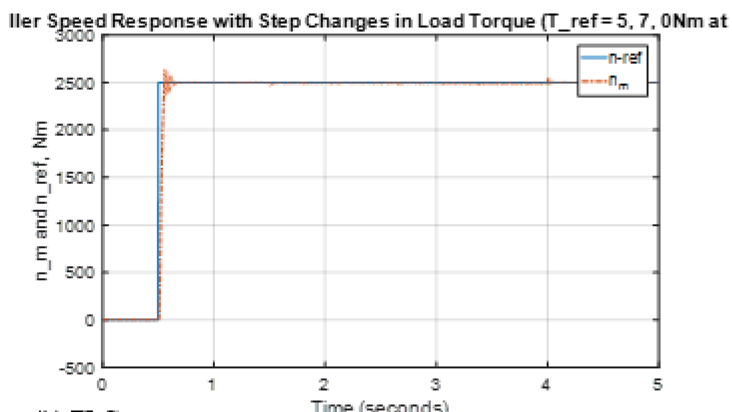
Speed response with step change in load torque



(a)PI



(b) FLC

Figure 7: speed versus time response with step change in applied load torque (0 ,5,7,0 Nm) using FL and PI controller.

From figure 7, it is noticed that speed response of motor as it run at reference speed of 2500 rpm with step change in torque. At 0.5second motor start running and at 1.5 second a load of 5NM is applied then after 3seconds 7NM is applied and load torque was removed at 4seconds. It is observed that when running the motor with PI controller, there is a significant drop in motor speed value(2370rpm) at 1.5second as load torque of 5NM is applied. Similar drop in speed (2200rpm) was observed at 3seconds when the load torque increase to 7Nm). And at 4seconds when load torque was removed, speed significantly increased to 2700rpm and finally settled to desired steady state value of 2500rpm after 0.8second. In all the instances of load torque changes or disturbances, the close loop control system PI controller evaluates the speed error and cancel out the disturbance effect and maintain desired steady state speed value after 0.8 second.

By comparing PI result to FLC result, FLC showed high level of robustness with very little o no fluctuation as the close loop control system cancel out the disturbance effect within 0.16second at all instances of step change in load torque which is almost unnoticed. There is no overshoot when load was removed at 4seconds, as compared to that of PI controller. the FL controller resolved and maintain desired steady state speed value with no steady state error. as external load torque is applied at 1.5 second and at 3 seconds. FLC continued to tracked the reference speed value and at 4seconds when load torque was removed, the desired speed value is maintained.

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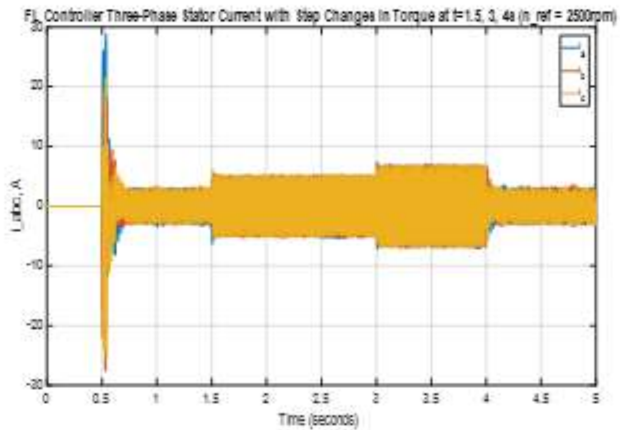
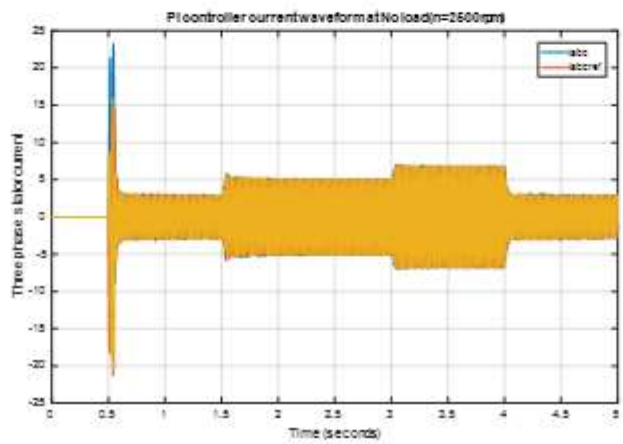
Stator current waveform with step change in load torque



(a) PI



(b) FLC

Figure 8 stator current versus time plot for step change in load torque at reference speed (2500rpm).

Figure 8. shows motor stator current waveform against time at variable load torque,
The PI controller showed distortion in the envelope of stator current waveform at the start of the machine before the motor reaches steady state value due to transient. Also, the magnitude of current envelope increased as applied load torque increased. its highest at load torque of 7NMs.after 3 seconds and at 4seconds when load torque was removed, its magnitude decreased to its initial value at the start of motor.

Similarly, FLC shows almost the same waveform, the amplitude of stator current waveform increased when load torque was applied, and later decreased to at 4seconds when load torque as removed. However, FLC showed steady state sinusoidal waveform and the current magnitude was less than that of PI controller.

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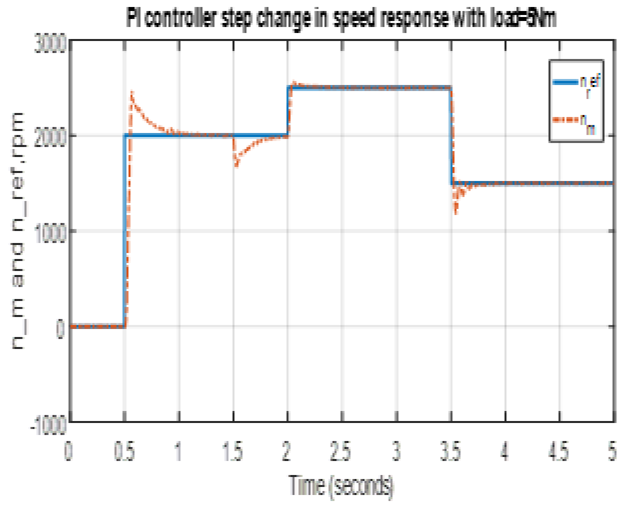
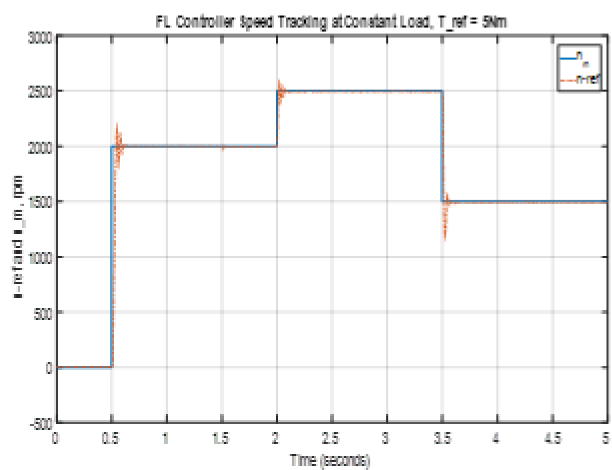
Step change in reference speed response with fixed load torque (TL=5NM)



(a) PI



(b) FLC

Figure 9, shows plot of step change in reference speed against time at fixed load torque of 5Nm

The PI controller showed overshoot as the motor starts and later attained an undershoot as the load torque of 5Nm is applied at 1.5second., similar overshoot occurrence was seen when reference speed was increased to 2500rpm at 2 seconds, also when the reference speed was reduced to 1500rpm, undershoot occurred at 3.5 seconds as the actual motor speed dropped significantly to 1300rpm PI before tracked the new set speed value with no steady state error occurred. FLC showed a fast- transient response as no overshoot is noticed apart from minor oscillation at the start of the motor, less settling time of 0.2second compared to PI controller response. FLC showed robustness at each instant of step change in reference or command speed value with no steady state error. Also, similar undershoot is observed at 3.5 seconds, when reference speed was decreased to 1500 rpm which is lesser than that of PI result. FLC react fast to settled at its steady state value within 0.1second.

Table III : table of performance indices of controllers in induction motor control system

Reference speed(rpm)	Load (Nm)	Controller	Rise time(secs)	Settling time(secs)	Maximum Overshoot (%)	Steady state error
1000	0	FL PI	0.038 0.110	0.12 0.80	6.3 56.3	0 0
	5	FL PI	0.050 0.165	0.20 0.70	3.8 24.8	5 0
1400	0	FL Pi	0.041 0.084	0.16 0.85	7.6 42.1	0 0
	5	FL PI	0.055 0.140	0.16 0.60	3.5 15.7	6 0
2500	0	FL PI	0.059 0.090	0.18 0.98	5.6 19.3	0 0
	5	FL PI	0.084 0.130	0.18 0.90	1.6 16.4	4 0

From table III shows the Time domain dynamic response for both controllers in term of performance indices, it is discovered from the above table values that fuzzy logic controller provides almost zero overshoot except oscillation effects, lesser settling time, zero or little steady state error and slightly lesser rise time while PI controller exhibits higher settling time, maximum overshoot, less rise time and zero steady state error.

V. CONCLUSION

This paper has successfully presented scalar control of induction machine speed using Fuzzy logic controller (FLC), scalar constant v/f scalar control technique is employed. PI controller is also incorporated for induction motor speed control, From the two controllers performances based on simulation results verification, It was discovered that FLC provides a better performance compared to that of conventional PI controller as FLC showed fast transient response during sudden change in load torque, motor speed stabilizes at lesser settling time , zero overshoot and nearly zero drop in speed value when external disturbance(load change) occurred. Hence fuzzy logic controller is highly recommended to be used in control of induction machine as it overcome the sluggish response of scalar control method when conventional controllers are used, it is easy to design without mathematical model of the system. In addition, scalar control scheme has simple configuration, it is easy to implement, it showed effectiveness, wide speed range and robustness.

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