Speed Performance Enhancement and Analysis of a Three Phase Induction Motor Driving a Pump Load using Vector Control Technique

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Abstract**—**Speed control of an induction motor driving a pump load using vector control technique with proportional integral derivative controller, fuzzy logic controller and hybrid of proportional integral derivative fuzzy logic controllers is presented in this paper. The induction motor drive was designed and simulated with these controllers using MATLAB/Simulink software package. The performance of the induction motor using proportional integral derivative(PID) controller, fuzzy logic controller (FLC) and hybrid controller (FLC-PID) on this load was studied and compared .steady state error of PID, FLC, and FLC-PID are 0.5rad/sec, 0.5rad/sec, and 0,1rad/sec respectively, while the undershoot are also respectively 20%, 6% and 4%.FLC-PID further gives arise and settling time of 0.1sec and 0.05sec respectively. From the results obtained, the hybrid controller provides a far more superior performance in enhancing the speed performance of the induction motor.

Keywords— Induction motor, Speed control, hybrid controller, pump load, MATLAB/Simulink.

I. Introduction

Induction motors are mostly involve in industrial operation like robotics, conveyors, paper, textiles mills etc, due to its attractive characteristics like ruggedness, simple construction, reliability, and low maintenance requirement. Also, induction motor is the most used AC machine in industrial operations. However, induction motor is a constant speed drive, and high performance control is so challenging due to stator field and rotor current coupling effect, and lots of its parameters and temperature vary with different operating conditions [1][2][3].

Vector control technique is mostly used in controlling the speed of an induction motor for achieving a superior dynamic response, and field oriented control is a technique that simplify the speed control process making an induction behaves similarly like a DC motor. There are basically two type of field oriented control which are direct field oriented control (DFOC) and field oriented control which are indirect field oriented control (IFOC).The difference between the two field oriented control technique is a way the rotor position is being determine. Conventional controllers such as the proportional-integral (PI), and proportional-integral-derivative (PID) controllers are normally use for the speed control of an induction motor. However, these conventional controllers have a major weakness of poor external load rejection and sensitive to variation in system parameters. Fuzzy logic controller is a nonlinear controller that can be used to control a complex nonlinear drive like induction motor drive[4]. In fuzzy logic controller, no mathematically model is require as compared with the classical controllers. Fuzzy logic controller being a nonlinear controller can enhanced the speed performance and robustness of an induction motor in terms of external load rejection and stability .In as must as the fuzzy logic controller is so effective in handling the non-linearity of the induction motor drive, it still has some weakness which may not be suitable for some modern industrial operations [5]. Hybrid controller is a combination of two or more controllers as a controller and it takes advantage of the strength of the controllers involve in system control. Induction motor performed differently with different load types, hence the control depends largely on the type of load that is driven by the motor, and the electromagnetic torque produce depend on this. [6][7]There are several type of loads depending on the torque to speed characteristic, these include: Constant torque type load , Torque proportional to speed (generator type load) , Torque proportional to square of the speed (fan and pump load type) , etc.

In this paper, performance analysis of vector control of an inductor is done using proportional integral derivatives controller (PID), fuzzy logic controller (FLC) and hybridization of PID and FLC with pump load (Torque proportional to square of rotor speed). The performance of these controllers are analyzed and compared. Hybrid controller is expected to eliminate the weakness of conventional controller such as overshoot, undershootand oscillation, and the drawback of FLC such as steady state error. MATLAB/ Simulink software package is use for the simulation and analysis. [8]-[10] discussed the performances of induction on pump loads, but speed control and enhancement were not discussed, which is the main aim of this paper

II. Vector Control

Vector control principle in induction motor was founded by F. Blaschke [11]. This is the main principle of field oriented control (FOC) where an induction motor is operated like a separately excited DC motor, and this technique is widely use in a lots of modern industrial operations. DC machine-similar performance can be obtain in an induction motor by separating and controlling independently the field and armature fluxes in the motor by orienting the stator current with respect to the rotor flux. In this research work, Proportional Integral differential controller and fuzzy logic controllers are designed and these two controllers are hybridize to form a single controller, and is use to control the speed of the induction motor with Indirect field oriented control (IFOC) technique (block diagram is shown in fig. 5). The position of rotor flux is predicted from the model of induction motor. Knowing the magnitude and position of rotor flux is very vital in induction motor vector control For the decoupling of flux and torque producing components, induction motor the rotor equations can be in [1].equations (1) –(7), show the realization of the rotor angle,

$$\omega_{sr} = \frac{L_m}{\psi_r}\frac{R_r}{L_r} i_{qs} \quad (1)$$

$$\omega_{sl} = \frac{L_m i_{sq}^*}{T_e \Psi_r^*} \quad (2)$$

$$Te = \frac{3}{2}\left(\frac{P}{2}\right)\frac{L_m}{L_r}\psi_r i_{qs} \quad (3)$$

Where $i_{sd}^*, \Psi_r^*, L_m$and T_e^* are reference direct – axis stator current reference flux, ,mutual inductance and reference torque respectively.Quadratic – axis stator current reference i_{sq}^* can be calculated by reference torque T_e^*, equation (3)

$$i_{sq}^* = \frac{T_e^*}{K_i \Psi_r^*} \quad (4)$$

$$i_{sd}^* = \frac{\Psi_r^*}{L_m} \quad (5)$$

$$K_i = \frac{3pL_m}{2L_r} \quad (6)$$

Rotor flux angle for coordinate transformation is gotten from the speed of rotation of the rotor speed ω_r and slipspeedω_{sl}this is shown in equation 20. Slip speed is obtained from reference stator current i_{sq}^* with motor parameters as shown in equation (2)

$$\theta_e = \int(\omega_r + \omega_{sl})dt \quad (7)$$

Where Te is electromagnetic torque,L_m is mutual induction, ψ is flux linkage, θ_eRotor flux angle

Rotor flux angle θ_e for coordinate transformation is obtained from equation (7)

III. MODELLING OF PID CONTROLLER

The block diagram of PID controller is shown in figure 1.From figure 1, the output of PID controller u (t), is equal to the sum of proportional gain k_p, plus the signal obtained , derivative gain k_d and the signal obtained integral gain k_i,. The output of PID controller is given by equation (8). Defining $u(t)$ as the controller output, the final form of the PID algorithm is:

$$u(t) = k_p.e(t) + k_i \int e(t)dt + k_d \frac{de(t)}{dt} \quad (8)$$

Where, e : Error ,t : Time or instantaneous time (the present)
The gain values of PID controller is shown in table 1
Table 1: Gain values of PID controller.To adequately control a complex drive like induction motor drive, the system has to be linearized. Normal PID MATLAB linearization was a challenge due to the stiffness of the system, this was overcome through system identification (data acquisition). After successful linearization of the motor drive, the transfer system equation is shown in equation (9).The summer computes the error value between the reference speed and the actual speed of the motor. The Ks parameters of PID is shown in the table 1, these was realized by automatic tuning of PID in Simulink software that compensated the error.

$$G(S) = k * \frac{1+TZ*S}{2*Zeta*TW*S+1+(WT*S)^{\wedge 2})(1+Tp3*S)} \quad (9)$$

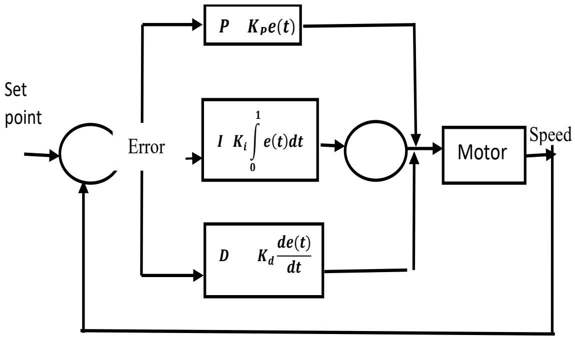

Fig. 1. Block diagram of PID controller

Where $k = 1.5103, TZ = -0.00063876, Zeta = 0.9, WT = 0.010001, Tp3 = 2.1507e-06$

Table 1: Gain values of PID controller

Gain	Proportional Gain	Integral Gain	Derivative Gain
Value	1.3028	87.087	0.0040017

IV. MODELLING OF FUZZY LOGIC CONTROLLER

The design of a Fuzzy Logic Controller is influence by the choice of Membership Functions. A rule base is created when the appropriate membership functions are chosen. It consists of a number of Fuzzy If-Then rules that completely define the behaviour of the system. These rules very much resemble the human thought process, thereby providing artificial intelligence to the system. In the speed control of induction motor which is the main focus in this work, Sugeno type 2 of fuzzy logic controller (FLC) was used because of the induction motor nonlinear behavioralcharacteristics[13][14]. Fig2. shows the three dimensional view of the control surface where the error and change in error ranging [-50, 50] and [-30, 30].

The membership function used to fuzzify two input values which are eventually defuzzify to have a single output .Fuzzy

Table II: The Rule base of fuzzy logic controller

		e							
		NB	NM	NS	Z	PS	PM	PB	
ce	NB	NVB	NVB	NVB	NB	NM	NS	Z	
	NM	NVB	NVB	NB	NM	NS	Z	PS	
	NS	NVB	NB	NM	NS	Z	PS	PM	
	Z	NB	NM	NS	Z	PS	PM	PB	
	PS	NM	NS	Z	PS	PM	PB	PVB	
	PM	NS	Z	PS	PM	PB	PVB	PVB	
	PB	Z	PS	PM	PB	PVB	PVB	PVB	du

logic logic control technique uses membership function to initiate the control. Mmbership function is a curve that determine the value of the input signal to the fuzzy controllers. The propose fuzzy logic design has seven triangular membership function for error E, , change in error CE, and nine triangular membership functions for the output U. The propose fuzzy linguistic sets for membership functions of the input and output are:Z = zero, PS = Positive small, NB = negative big, PM = positive medium, NM = negative medium, NVB = negative very big, PVB = positive

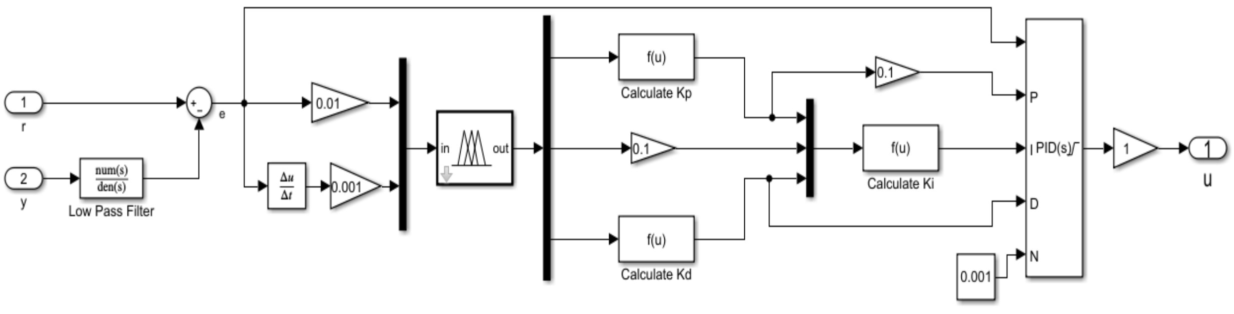

Fig. 3. Simulink model of FLC- PID controller

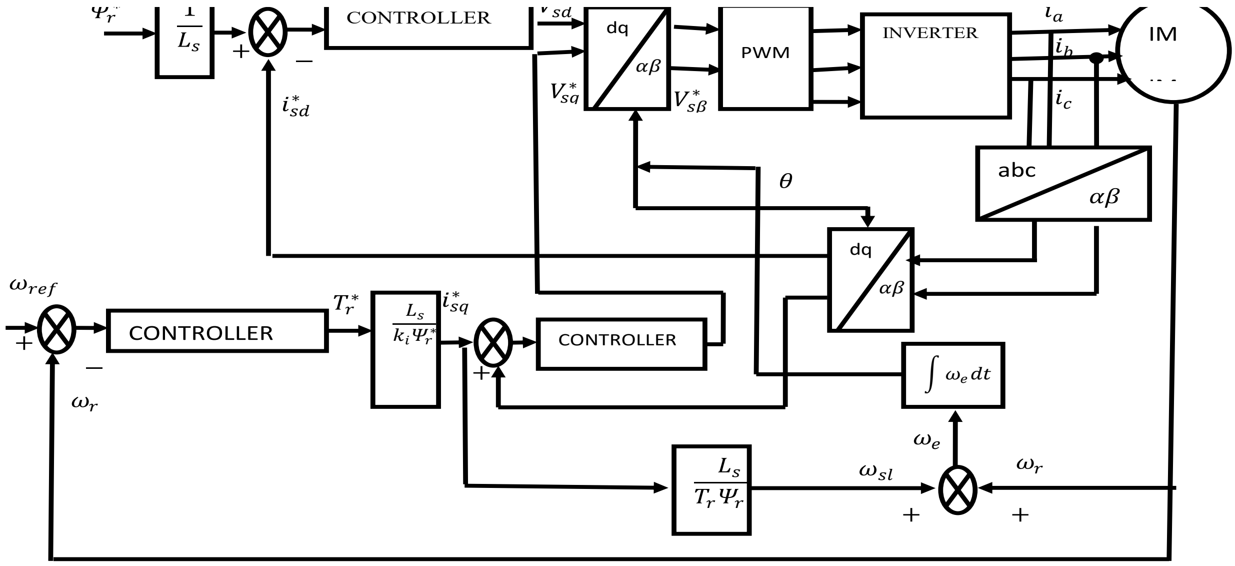

Fig. 4. Block diagram of IFOC of an Induction motor.

very big, NS = negative small, PB = positive big. Knowledge

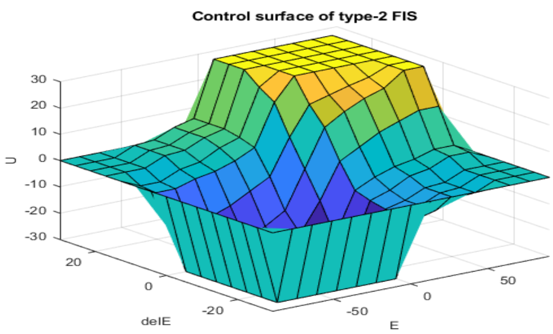

Fig. 2. Three dimensional view of control surface

and inference mechanism link the relationship between the output with the input. The fuzzy logic controller has two input and one out with seven membership function each, which the combination with these two input will lead to forty nine combination, in a forty nine rules.
IF (Error IS NL) AND (Change In Error IS ZE) THEN (ChangeOfControl IS NM). IF (Error IS NM) AND (ChangeInError IS ZE) THEN (ChangeOfControl IS NMS) the rules are presented at table 2

V. Design of Hybrid Speed Controller

The hybrid controller in this work, is the hybridization of PID and FLC, and is also use as a single controller to control the speed of an induction motor using vector control technique. The hybrid model design in simulink is shown in fig3. The inputs of the the fuzzy controller are the error E and the change in error CE, and the output of the fuzzy logic controller serve as an input (error signal) to the PID error signal. Due to the combination of the strength of the two controllers, hybrid controller allows a high levels of systemlevels of system stability against load variations.

VI. Pump Load

The pump load model equation that was use in the analysis is given in equation 10, where it is assume to have a torque - speed characteristic of torque proportional to square of the rotor speed [12].Theperformance of the motor was assessed using vector control technique with PID, FLC and hybrid FLC-PID controller under rise time, settling time, steady state error, undershoots and overshoots.

$$T_L = 0.5e^{-0.24} + 1.1e^{-3}(rotor\ speed)^2 \tag{10}$$

VII. Simulation Results and Analysis

This section shows the simulation performance of the motor with PID, FLC, and the hybrid FLC-PID controller with pump load using vector control technique .simulation is done by using the Simulink toolbox of MATLAB, and the parameters of the motor of rated speed of 1435,power of 2.2Kw,pole of 4 and supply frequency of 50Hz..fuzzy logic controller was designed using the fuzzy tool box that is available in MATLAB.The performance of the motor is analyzed with and without these controllers

A. Perfromance of the motor without controller

The transient behavior of the motor driving a pump load was studied. Fig 5 shows the speed response of the motor driving a pump load with the corresponding electromagnetic torque which is presented in fig6. From the speed response in fig.8, the speed could not settling for more than 2 seconds, and it makes the system very unstable.

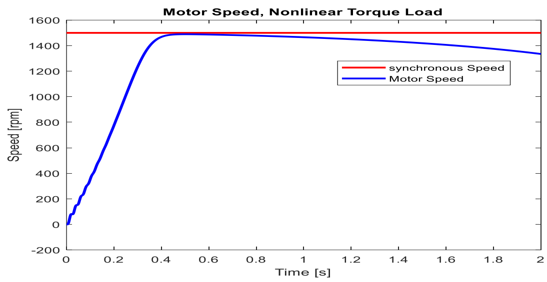

Fig. 5. Rotor Speed Response at Pump load

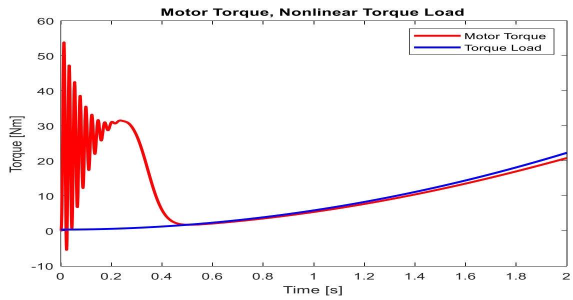

Fig. 6. Torque Response at Pump load

B. Performance of the motor with PID and FLC controller

Induction motor drive was simulated while driving the pump load, and PID and FLC controller were used with the reference speed of 30rad/s. The response of speed and electromagnetic torque of PID controller are shown in fig 7 and fig 8 respectively. From the speed response of PID there was an initial ripples, that lasted for 0.8 seconds and the speed settles after 0.8 seconds, with zero overshoots. It also worthy of note that despise the stiffness of the system, the controller was able to track the desire speed of 30rad/s.The response of speed, and electromagnetic torque of FLC are presented in fig 9, and fig 10 respectively. From the speed response, the initial ripples was reduced compare to the response of PID, the ripple that lasted for 0.7 seconds. The speed settles after 0.7 seconds, with zero overshoots. Fuzzy logic controller was able to track the desire speed of 30rad/s in less time compare to PID.

Table III: Performance of different speed controllers for Induction motor at pump load

PARAMETERS	PID	FUZZY LOGIC (FLC)	FLC-PID
Steady Sate Error [rad/s]	0.5	0.5	0.1
Overshoot [%]	0	0	4.8
Settling Time [sec]	0.7	0.75	0.1
Rise Time [sec]	0.7	0.75	0.05
Undershoot [%]	20	6	4

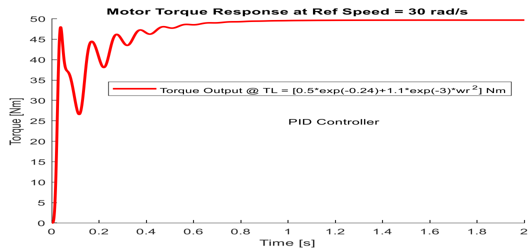

Fig.7.Torque response at pump load with PID controller

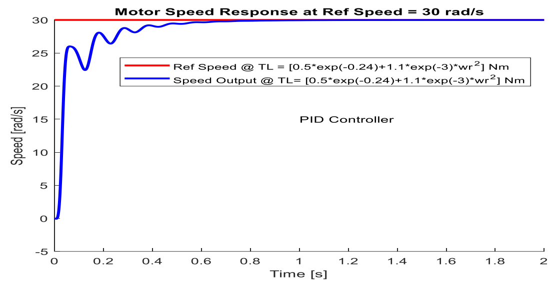

Fig. 8. Rotor Speed at pump load with PID controller

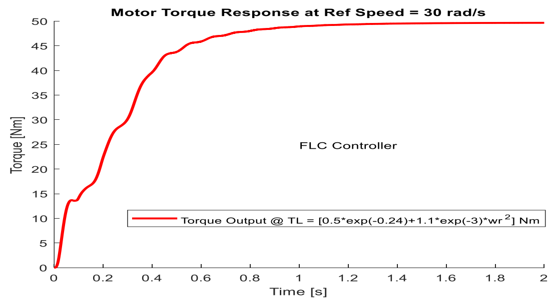

Fig. 9.Torque response at pump load with FLC controller

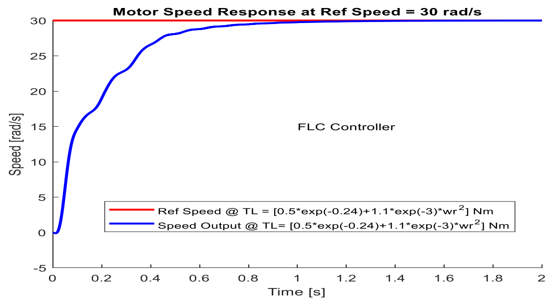

Fig.10.Speed response at pump load with FLC controller

C. *Performance of the motor with hybrid controller*

The propose hybrid controller is the hybridization of FLC and PID and as expected the speed response of the hybrid controller was greatly enhanced compare to FLC and PID controller. With the pump load torque on this model, fig.11 and fig12 arespeed and electromagnetic torque respectively from fig. 11, there was no serious ripples as compare to FLC and PID, and the settling time is less than 0.2 seconds. Finally, the speed response was able to tract the reference speed with less time

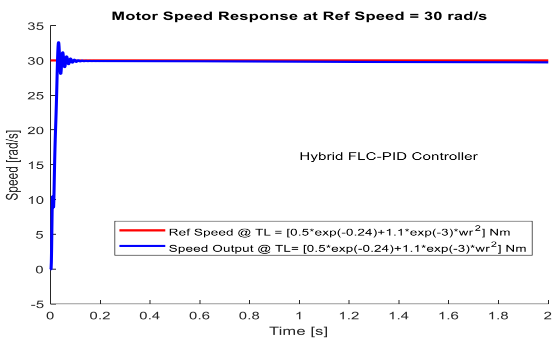

Fig.11.Torque response at pump load with PID-FLC controller

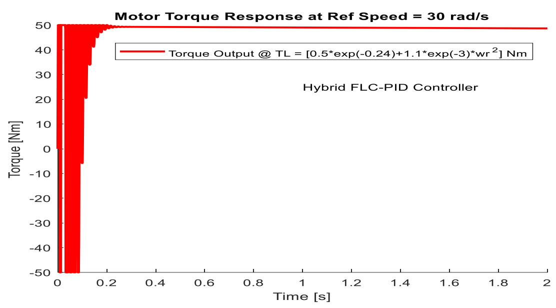

Fig. 12 Torque response at pump load with PID-FLC

VIII. Conclusion

This paper demonstrated the vector control of an induction motor driving a pump load. With the use of vector control, the coupling effects problem of inductor motor which makes the system to response sluggishly and easily prone to instability was eliminated. PID, FLC and hybrid FLC-PID are designed and simulated in MTALAB /Simulink. The dynamic performance of the conventional controller, fuzzy logic and the hybrid controller were accessed in terms of steady state error, peak time, rise time , settling time , and peak overshoot . From the simulation results, the response from the hybrid is very good, compare to that of fuzzy logic and PID. The summary of the performance of these controllers are shown in table III. The hybrid controller being integrated in the induction motor vector model has eliminated the weakness of the conventional controller and that of fuzzy logic control. From table III, the hybrid controller has gives the best performance in terms of settling time, rise time, undershoots, and peak time.

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