Fuzzy PID Controller for Four Quadrant Operation of BLDC Motor

Ms. Amina Sathar, Ms. Femy P.H

Abstract— **In this project, the fuzzy logic controller is to implement the speed control algorithm of a brushless dc motor. The proposed method is simple and reliable. During regenerative braking mode, it conserves energy in a rechargeable battery. The MATLAB R2013a software is used to perform the simulation. The proposed controller is integrated using the fuzzy logic toolbox in MATLAB. The project proposes the concept of fuzzy PID controller for the speed control of BLDC motor. The objectives of the project are to compare the performance of PI and the proposed fuzzy PID controllers using MATLAB simulation for the speed control of BLDC motor and Practical implementation of the proposed controller using ATmega328.The performance of the two controllers are analysed on the basis of various control system parameters such as steady state error, rise time, peak overshoot and settling time. Simulation results of the two controllers have been presented and it is found that the control concept with fuzzy logic PID controller outperforms conventional PI controller in most of the aspects.**

Index Terms— **PI controller, Fuzzy logic controller, BLDC motor, MATLAB/Simulink**

I. INTRODUCTION

Brushless DC motors are commonly used in servo applications, manufacturing, robotics, machine tools and positioning devices, due to their advantageous electrical and mechanical features, high torque to volume ratio, high efficiency and low moment of inertia [1-3]. High accuracy is usually not significant for most electrical drives but in high performance drive applications, an appropriate control performance is required even when the parameters of the motor and loads are varying during the motion.

Conventional constant gain controllers used in the adjustable speed drives become reduced when the load is nonlinear and parameter deviations and uncertainties occur. Therefore, control strategy of high performance electrical drives must be robust. As a result, need for an intelligent control system for electrical drives has increased significantly within the last era and few intelligent control schemes for brushless DC motors are projected based on linear model [4,5]. Many control technique such as Proportional (P), Proportional Integral (PI), Proportional Integral Derivation (PID) and Fuzzy Logic Controller (FLC), have been developed for speed control of BLDC motors. Fuzzy logic, which is based on fuzzy set theory, was first developed by Zadeh in 1965. Control of temperature, traffic, DC motor speed etc. are the most prevalent of current fuzzy logic applications. For the most complex systems, where few numerical data exist and where only imprecise information is available, fuzzy reasoning provides a way to understand the system nature by allowing interpreting around between the observed input and the output relations of the system.

The adaptive fuzzy controller proposed here is a parallel combination of fuzzy PI and fuzzy PD structures. The adaptive property works on the basis of error signal, that is the switching action between the two controllers takes place according to the error signal. Speed error and change in speed error are given as inputs to the controllers [1]. FL (fuzzy logic) controller offers better response at higher speeds and conditions of load rejection transients, step application of reference speed. PI provided better for speed settings below one third of rated speed as well as better response to small reference speed change[2].Adaptive techniques includes fuzzy model reference adaptive control, adaptive control based on corrective factor, membership tuning adaptive control and parameter adaptive methods.The model reference adaptive control that acts directly on the control signal is more appropriate. It can improve transient and steady state parts of the response.In membership tuning adaptive controller the adaptation mechanism modifies the fuzzy controller by shifting the membership functions of the fuzzy output sets. In case of corrective factor method, the resetting of integral action takes place when the response approaches the reference with abnormal rates. Parameter adaptive method uses fuzzy techniques to detect response error peak [3]. PI controller has disadvantages such as high starting overshoot, sensitivity to controller gains as well as sluggish response to sudden changes in load. The PID controller is simple and stable, but uncertainty of mathematical model makes tuning of PID control parameters difficult and poor robustness. Fuzzy logic controller is found to be more efficient than the other two controllers. Comparison is made between PI controller and the proposed fuzzy controller. Simulation results has been presented to confirm and validity the effectiveness of the proposed controller.

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II. FUZZY LOGIC CONTROLLER

Fuzzy logic has become one of the most successful of today's technology for developing complex control system.

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The application range includes consumer products such as cameras, camcorder, washing machines and microwave ovens, industrial process control, medical instrumentation and decision-support system. The FL controllers design and tuning process is often complex because several quantities, such as membership functions, control rules, input and output gains, etc must be adjusted. The design process of a FLC can be simplified if some of the mentioned quantities are obtained from the parameters of a given Proportional-Integral controller (PIC) for the same application. The fuzzy logic controller has three main components: Fuzzification, Fuzzy inference, and Defuzzification.

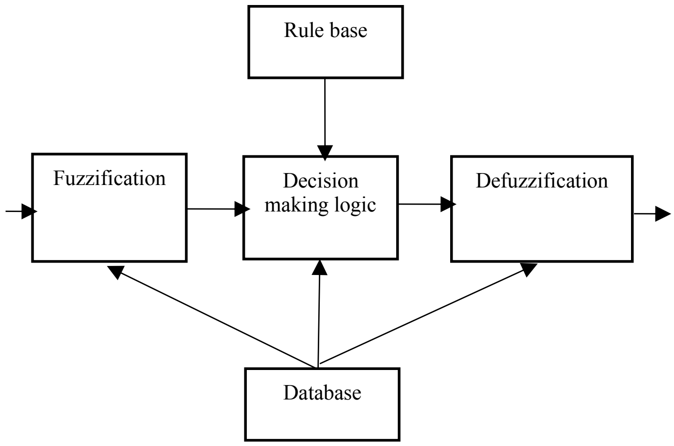

Fig 1. Structure of fuzzy logic controller

A. Motivations in choosing FLC

- It can model nonlinear systems: The design of conventional control system is based on the mathematical model of plant. If an accurate mathematical model is available with known parameters it can be analyzed by bode plots or nyquist plot, and controller can be designed for specific performances. This procedure is time consuming.

- It has adaptive characteristics: The adaptive characteristics can achieve robust performance to system with uncertainty parameters variation and load disturbances.

III. PROPOSED SYSTEM

The proposed system consists of BLDC motor, three phase voltage source inverter, speed controller, commutation logic and position sensor. BLDC motor is fed by a three phase MOSFET based inverter. The PWM gating signals for firing the power semiconductor devices in the inverter is generated by the commutation logic block. The hall sensors are used as the position sensors. They detect the rotor position. Whenever rotor magnetic poles pass near the hall sensor, they generate a high (1) or low (0) level signal, which can be used to detect the position of shaft. The commutation logic block generates emf based on the hall signals. The gating pulses are then generated based on the emf. The block diagram of proposed system is shown in fig 2.

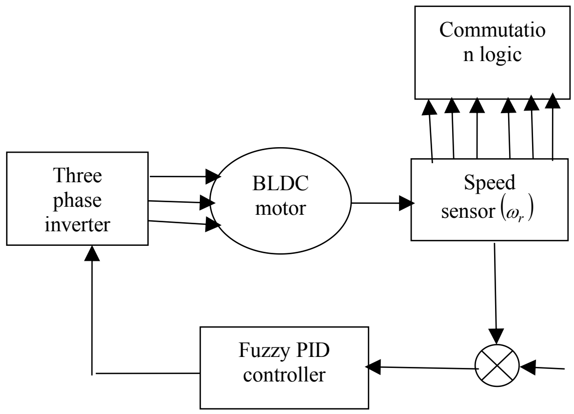

Fig 2. Block diagram of proposed system

The following truth tables show the generation of emf based on hall signal as well as the gate signal generation based on emf.

Table I
EMF generation based on hall signal output

H_A	H_B	H_C	E_A	E_B	E_C
0	0	0	0	0	0
0	0	1	0	-1	1
0	1	0	-1	1	0
0	1	1	1	0	1
1	0	0	1	0	-1
1	0	1	1	-1	0
1	1	0	0	1	-1
1	1	1	0	0	0

Table II
Gate signal generation from EMF

E_A	E_B	E_C	Q1	Q2	Q3	Q4	Q5	Q6
0	0	0	0	0	0	0	0	0
0	-1	1	0	0	0	1	1	0
-1	1	0	0	1	1	0	0	0
-1	0	1	0	1	0	0	1	0
1	0	-1	1	0	0	0	0	1
1	-1	0	1	0	0	1	0	0
0	1	-1	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0

A. Fuzzy PID Controller

The actual speed is sensed and the speed controller block generates the error signal. Fuzzy PID controller is used as the speed controller in the proposed system. For comparison, a PI controller is also included. The proposed controller is a

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parallel combination of two controllers-fuzzy PI controller and fuzzy PD controller. Speed error (e (k)) and change in speed error (ce (k)) are the inputs to the two controllers. Based on the error signal, switching takes place between these controllers. The fuzzy PI controller improves the steady state response of the system and minimizes the steady state error. The fuzzy PD controller improves the transient response of the system and minimizes the rise time. The fuzzy PID controller is shown in fig 3.

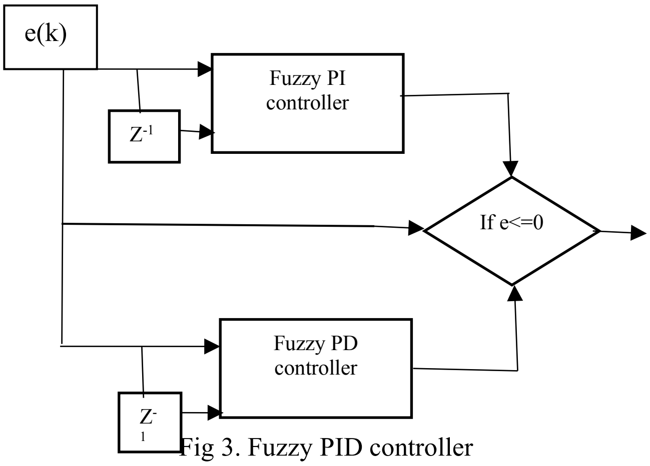

Fig 3. Fuzzy PID controller

The switching action between the two controllers takes place according to the control signal. The output of the fuzzy proportional integral controller is the gain FK_{PI}. The output of the fuzzy proportional derivative controller is the gain FK_{PD}. The fuzzy variable error and change in error has seven sets: positive big (PB), positive medium (PM), positive small (PS), zero (ZE), and negative small (NS), negative medium (NM) and negative big (NB), with each set having its own membership function. Triangular membership functions are used. As the next step, the fuzzy IF–THEN inference rules are chosen. The conjunction of the rule antecedents is evaluated by the fuzzy operation intersection, and is implemented by the min operator.

Table III

Rules for fuzzy PI controller

e/ce	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PB	PB	NM	ZE	ZE
NM	PB	PB	PB	PM	PS	ZE	ZE
NS	PB	PM	PS	PS	PS	ZE	ZE
ZE	PB	PM	PS	ZE	NS	NM	NB
PS	ZE	ZE	NM	NS	NS	NM	NB
PM	ZE	ZE	NS	NM	NB	NB	NB
PB	ZE	ZE	NM	NB	NB	NB	NB

Table IV

Rules for fuzzy PD controller

e/ce	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PB	PB	PM	PS	ZE
NM	PB	PB	PB	PM	PS	ZE	NS
NS	PB	PB	PM	PS	ZE	NS	NM
ZE	PB	PM	PS	ZE	NS	NM	NB
PS	PM	PS	ZE	NS	NM	NB	NB
PM	PS	ZE	NS	NM	NB	NB	NB
PB	ZE	NS	NM	NB	NB	NB	NB

IV. SIMULATION

The simulation of four quadrant operation of BLDC motor speed control with PI controller and fuzzy PID controller is performed using MATLAB/SIMULINK.

A. Speed Control using PI Controller

Simulation diagram for speed control of BLDC motor using PI controller is as shown in fig 4.

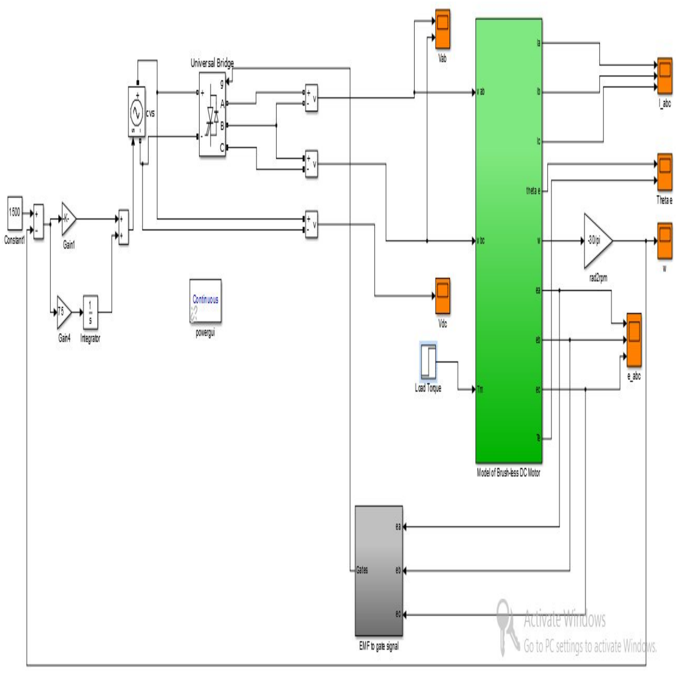

Fig 4. Speed control with PI controller

The reference speed is set at 1500 rpm and the load torque is kept constant (say 2 Nm).The PI controller is manually tuned and the values of proportional and integral terms are 0.15 and 75 respectively. The output of the controller is connected to a controlled voltage source which then provides the necessary input voltage to the inverter. The inverter switches are numbered in the sequence in which they are fired. The gate pulses generated based on the hall signal output are used to trigger the switches.

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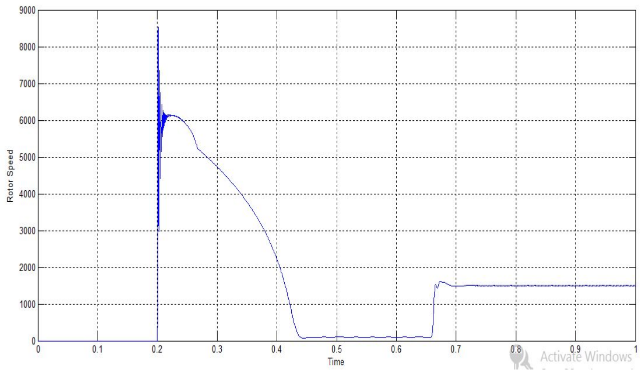

Fig 5(a).Speed response

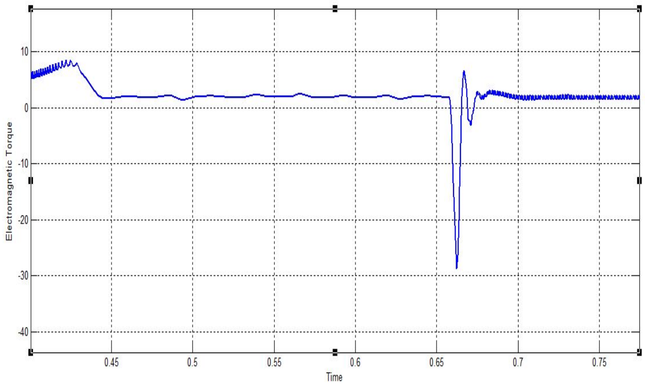

Fig 5(b). Electromagnetic torque

From the speed response curve, the settling time, overshoot and steady state error can be calculated which is found to be 0.7s, 45% and 0 respectively.

B. Speed Control using Fuzzy PID Controller

The subsystem in the simulation diagram for speed control of BLDC motor is as shown in fig 6.

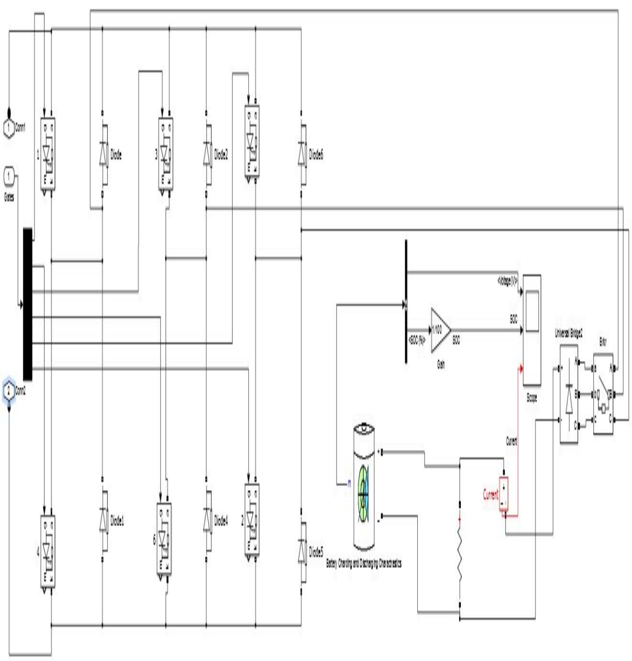

Fig 6. Subsystem

Simulation of speed control of BLDC motor using fuzzy PID controller is shown in fig 7.

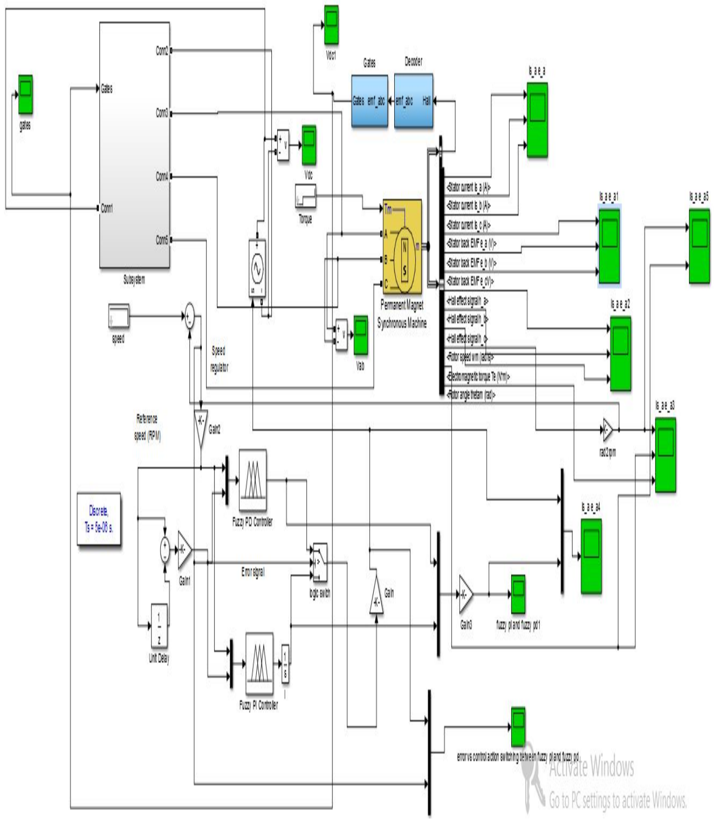

Fig 7. Speed control using fuzzy PID controller

Table V
Reference parameters

Speed reference	Time(s)	0	0.5
	Amplitude	300	-300
Torque reference	Time(s)	0.5	1.5
	Amplitude	11	21

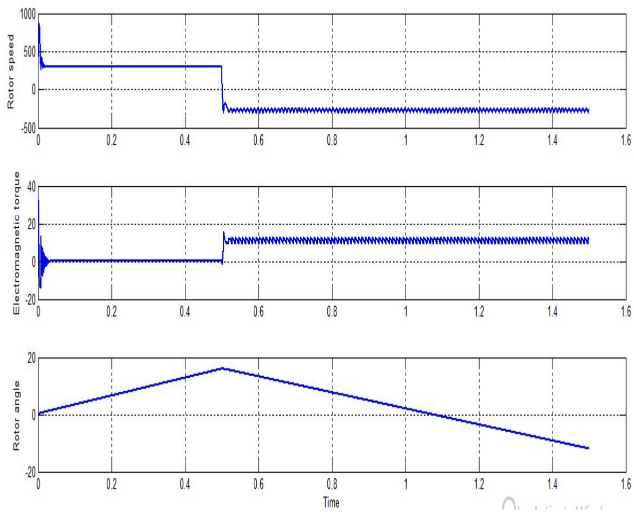

Fig 8. Speed response,torque,rotor angle

From the speed response curve, the settling time, overshoot and steady state error can be calculated which is found to be 0.016s, 0 and 0 respectively. In order to verify the proposed control method, experiments were performed by a designed laboratory prototype.

ISSN: 2278 – 7798

V. HARDWARE IMPLEMENTATION

The system consists of ATmega328 microcontroller. It compares the actual and reference speeds and generates the error signal and provides the gate pulses for the inverter switches based on the fuzzy logic control concept. The set speed and actual speed are displayed using an LCD display. Two keypads are also provided for for varying the set speed and for resetting the microcontroller respectively. 30 V supply is used to provide the dc voltage to the inverter. The output of the inverter drives the bldc motor. The reference speed possible for the bldc motor is upto 500rpm.The speed of the bldc motor is sensed using a proximity sensor.

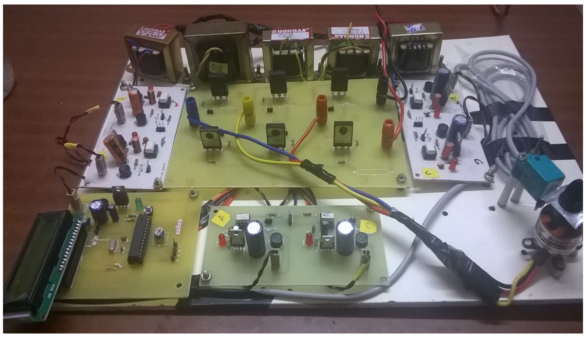

Fig 9. Hardware setup

The actual speed of the motor is measured by means of a proximity sensor. Whenever a magnet or metal piece is brought near the coil of the sensor, the emf induced gets disturbed and this change in emf gives the pulses. That is when the metal piece crosses the coil, the pulse becomes low (0) and becomes high (1) when not crossing. The pulses thus obtained are fed to the timer (pin 15) of the first PIC thereby obtaining the speed. The reference speed possible for the motor is upto 500rpm.The reference speed and actual speeds of the motor are compared and the difference between them, i.e. the error signal is transmitted to the second microcontroller. Pin 25 of the first PIC acts as the transmitting pin(TX) and pin 26 of the second PIC acts as the receiving pin(RX).The second PIC incorporates the control algorithm for the generation of switching pulses of the inverter switches .The waveforms for the gate pulses with the proposed controller is obtained. The gate pulse waveforms are displayed using a CRO.The hardware set up is to validate the effectiveness of the proposed controller. The switching pulses are generated on the basis of the proposed fuzzy control concept.

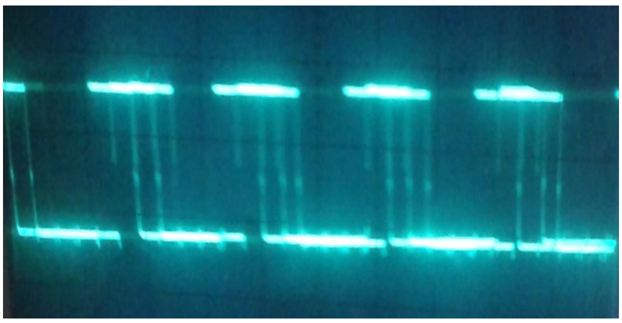

Fig 10. Gate pulse

The specifications for BLDC motor is as shown below.

Table VI
BLDC motor specifications

Description	Value
Rated Voltage	12 V DC
Rated Current	2 A
Rated Power	30 W
Rated Speed	1500 RPM

VI. CONCLUSION

The performance of three phase BLDC motor with conventional PI and fuzzy PID speed controllers are analysed on the basis of various control system parameters such as steady state error, rise time, peak overshoot and settling time. The fuzzy logic PID controller outperforms conventional PI controller. It has the combined advantages of both fuzzy PI and fuzzy PD controllers. From the simulation results of the two controllers it is found that the control algorithm with fuzzy logic PID controller beats conventional PI controller in most of the aspects.

REFERENCES

[1] Dr.B.V.Manikandan and K. Premkumar "Adaptive FuzzyLogic Speed Controller for Brushless DC Motor", *2013 International Conference on Power, Energy and Control (ICPEC)* .

[2] Gopal.K.Dubey, "Fundamentals of Electrical Drives",*Narosa,1994.*

[3] Neethu U.,Jisha V. R. "Speed Control of Brushless DC Motor: A Comparative Study,"*2012 IEEE International Conference on Power Electronics, Drives and Energy Systems December16-19, 2012, Bengaluru, India .*

[4] Zulkifilie Ibrahim and Emil Levi, "A Comparative Analysis of Fuzzy Logic and PI Speed Control in High Performance AC Drives Using Experimental Approach", *IEEE Transactions on Industry Applications, vol. 38, no. 5, pp. 1210-1218, 2002.*

[5] P. Pillay, R. Krishnan, "Modelling, Simulation and Analysis of Permanent-Magnet Motor Drives Part II: The Brushless DC Motor Drive", *IEEE Transaction on Industry Applications*, pp. 274-279, September 2008.

[6] Fouad Mrad and Ghassan Deeb, "Experimental Comparative Analysis of Adaptive Fuzzy Logic Controllers", *IEEE Transactions on Control Systems Technology, vol. 10, no. 2, pp. 250-255, 2002.*

[7] Hwi-Beom Shin and Jong-Gyu Park, "Anti-Windup PID Controller With Integral State Predictor for Variable-Speed Motor Drives", *IEEE Transactions on Industrial Electronics, vol. 59, no. 3, pp. 1509-1516,2012 .*

[8] El-Sharkawi M.A, "Development and implementation of high performance variable structure tracking control for brushless motors", *IEEE Trans. on Energy Conversion, vol. 6, pp. 114-119, 1991.*

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