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SPEED CONTROL OF A BLDC MOTOR USING IMPROVED FUZZY PID CONTROLLER

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ABSTRACT

Brushless DC (BLDC) motors are widely used for many industrial applications because of their high efficiency, high torque and low volume. This paper proposed a improved Fuzzy PID controller to control speed of Brushless DC motor. The proposed controller is called proportional–integral–derivative (PID) controller and Fuzzy proportional–integral–derivative controller.

This paper provides an overview of performance conventional PID controller and Fuzzy PID controller. It is difficult to tune the parameters and get satisfied control characteristics by using normal conventional PID controller. As the Fuzzy has the ability to satisfied control characteristics and it is easy for computing, In order to control the BLDC motor, a Fuzzy PID controller is designed as the controller of the BLDC motor. The experimental results verify that a Fuzzy PID controller has better control performance than the conventional PID controller. The modelling, control and simulation of the BLDC motor have been done using the software package MATLAB/SIMULINK.

Keywords: BLDC-Motor, PID Controller, FUZZY PID controller

I INTRODUCTION

There are mainly two types of dc motors used in industry. The first one is the conventional dc motor where the flux is produced by the current through the field coil of the stationary pole structure. The second type is the brushless dc motor where the permanent magnet provides the necessary air gap flux instead of the wire-wound field poles. BLDC motor is conventionally defined as a permanent magnet synchronous motor with a trapezoidal Back EMF waveform shape. As the name implies, BLDC motors do not use brushes for commutation; instead, they are electronically commutated. Recently, high performance

BLDC motor drives are widely used for variable speed drive systems of the industrial applications and electricvehicles.

In practice, the design of the BLDCM drive involves a complex process such asmodeling, control scheme selection, simulation and parameters tuning etc. An expert knowledge of the system is required for tuning the controller parameters of servo system to get the optimal performance. Recently, various modern control solutions are proposed for the speed control design of BLDC motor[1][2][3]. However, Conventional PID controller algorithm is simple, stable, easy adjustment and high reliability, Conventional speed control system used in conventional PID control [4][5]. But, in fact, most industrial processes with different degrees of nonlinear, parameter variability and uncertainty of mathematical model of the system.

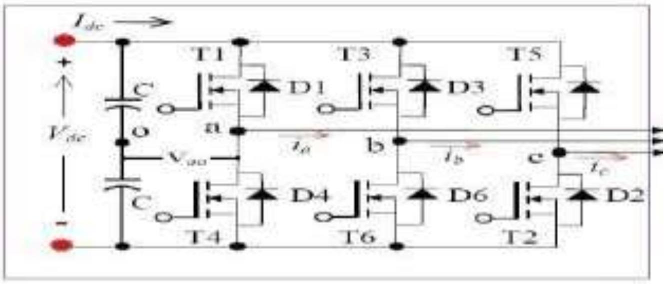


Fig. 1: Voltage Source Inverter

II BASIC CONFIGURATION OF CONTROL SYSTEM

Tuning PID control parameters is very difficult, poor robustness, therefore, it's difficult to achieve the optimal state under field conditions in the actual production. Fuzzy PID control method is a better method of controlling, to the complex and unclear model systems, it can give simple and effective control, Play fuzzy control robustness, good dynamic response, rising time, overstrike characteristics.

Fuzzy Logic control (FLC) has proven effective for complex, non-linear and imprecisely defined processes for which standard model-based control techniques are impractical or impossible [6]. Fuzzy Logic, deals with problems that have vagueness, uncertainty and use membership functions with values varying between 0 and 1. This means that if a reliable expert knowledge is not available or if the controlled system is too complex to derive the required decision rules, development of a fuzzy logic controller become time consuming and tedious or sometimes impossible. In the case that the expert knowledge is available, fine- tuning of the controller might be time consuming as well. Furthermore, an optimal fuzzy logic controller cannot be achieved by trial-and-error. These drawbacks have limited the application of fuzzy logic control. Some efforts have been made to solve these problems and simplify the task of tuning parameters and developing rules for the controller.

The aim of this paper is that it shows the dynamics response of speed with design the fuzzy logic controller to control a speed of motor for keeping the motor speed to be constant, when the load varies. This paper presents design and implements a voltage source inverter for control a speed of BLDC motor. This paper also introduces a fuzzy logic controller to the PID in order to keep the speed of the motor to be constant when the load varies. The complete block diagram of speed control of three phase BLDC Motor is below Fig.2. Two control loops are used to control BLDC motor. The inner loop synchronizes the inverter gates signals with the electromotive forces. The outer loop controls the motor's speed by varying the DC bus voltage. Voltage Source Inverter circuit of BLDC Motor is shownbelow.

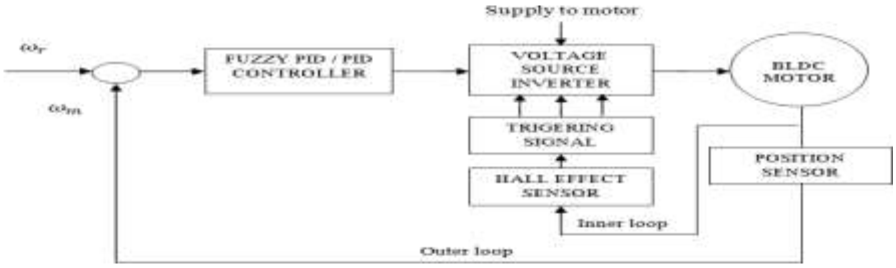


Fig.2: Block Diagram of Speed Control of BLDC Motor

Driving circuitry consists of three phase power convertors, which utilize six power transistors to energize two BLDC motor phases concurrently. The rotor position, which determines the switching sequence of the MOSFET transistors, is detected by means of 3 Hall sensors mounted on the stator. By using Hall sensor information and the sign of reference current (produced by Reference current generator), Decoder block generates signal vector of back EMF. The basic idea of running motor in opposite direction is by giving opposite current. Based on that, we have Table.1 for calculating back EMF for Clockwise of motion and the gate logic to transform electromagnetic forces to the signal on the gates is given Table.1

Table.1: Clock wise rotation and Gate logic

Hall sensor A	Hall sensor B	Hall sensor c	EMF A	EMF B	EMFC	Q1	Q2	Q3	Q4	Q5	Q6
0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	-1	1	0	0	0	1	1	0
0	1	0	-1	1	0	0	1	1	0	0	0
0	1	1	-1	0	1	0	1	0	0	1	0
1	0	0	1	0	-1	1	0	0	0	0	1
1	0	1	1	-1	0	1	0	0	1	0	0
1	1	0	0	1	-1	0	0	1	0	0	1
1	1	1	0	0	0	0	0	0	0	0	0

III CONTROLLING CIRCUIT

A. Design of PID Control

Consider the characteristics parameters – proportional (P), integral (I), and derivative (D) controls, as applied to the diagram below in Fig.3.A PID controller is simple three-term controller. The letter P,I and D stand for P- Proportional, I- Integral, D- Derivative. The transfer function of the most basic form of PID controller,is

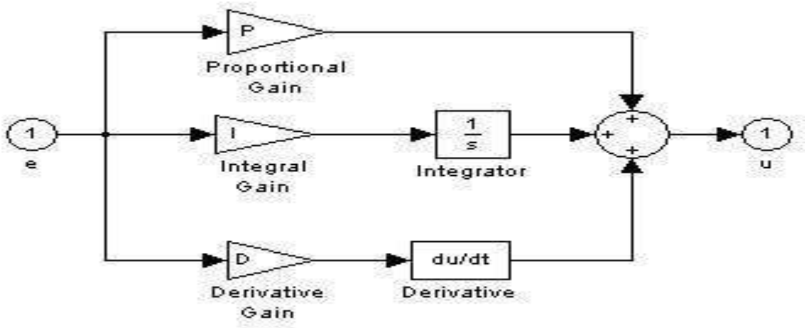


Fig.3: Simulation model of PID Controller

The control u from the controller to the plant is equal to the Proportional gain (K_P) times the magnitude of the error pulse the Integral gain (K_I) times the integral of the error plus the Derivative gain (K_D) times the derivative of the error

- The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called **three-term control**: the proportional, the integral and derivative values, denoted *P*, *I*, and *D*.

- Defining as the controller output, the final form of the PID algorithm is Where K_P=

$$u(t) = \mathrm{MV}(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{d}{dt} e(t)$$

Proportional gain, K_I= Integral gain and K_D= Derivative gain.

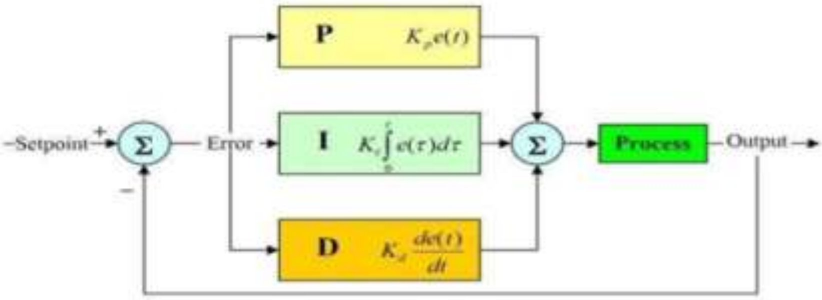


Fig. 4: Design of PID Controller

Due to its simplicity and excellent if not optimal performance in many applications PID controllers used in more than 95% of closed-loop industrial processes. The time domain specifications are

- Rise Time: the time it takes for the plant output Y to rise beyond 90% of the desired level for the first time.
- Overshoot: how much the peak level is higher than the steady state, normalized against the steady state.
- Settling Time: the time it takes for the system to converge to its steady state.
- Steady-state Error: The difference between the steady- state output and the desired output.

Typical steps for designing a PID controller are

Determine what characteristics of the system needs to be improved.

(a) Use KP to decrease the rise time.
(b) Use KD to reduce the overshoot and settling time.
(c) Use KI to eliminate the steady-state error.

The Values of Kp, Kiand Kd values of PID Controller is shown in belowTable.2 are obtained by using the ZN method.

Table.2:Representation of PID Values

Controller	Kp	Ki	Kd
PID	0.8	48	0.01

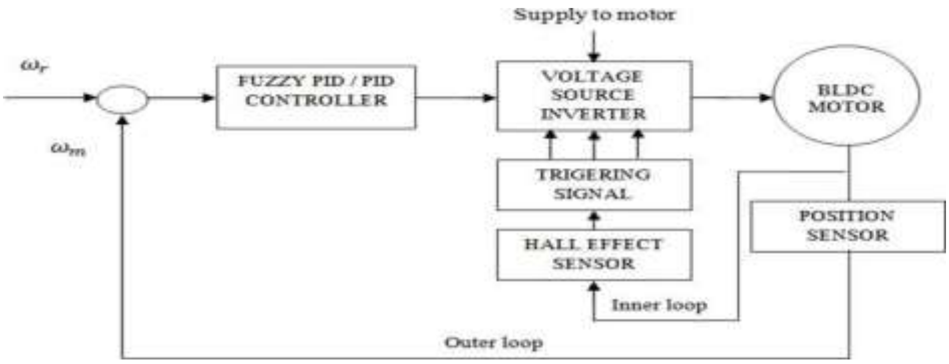


Fig.5: Implementation of PID Controller

B. FuzzyInference:

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. There are two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox: Mamdani-type and Sugeno-type. These two types of inference systems vary somewhat in the way outputs are determined.

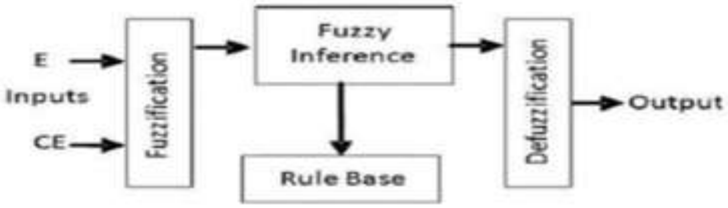


Fig.6: Block diagram of a fuzzy inference system

Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision. Because of its multidisciplinary nature, fuzzy inference systems are associated with a number of names, such as fuzzy-rule-based systems, fuzzy expert systems, fuzzy modeling, fuzzy associative memory, fuzzy logic controllers, and simply (and ambiguously) fuzzyMamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. It was proposed in 1975 by Ebrahim Mamdani [Mam75] as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. Mamdani's effort was based on Lotfi Zadeh's 1973 paper on fuzzy algorithms for complex systems and decision processes [Zad73].

The second phase of the fuzzy logic controller is its fuzzy inference where the knowledge base and decision-making logic reside.The rule base and data base from the knowledge base. The data base contains the description of the input and output variables. The decision-making logic evaluates the control rules. The control-rule base can be developed to relate the output action of the controller to the obtained inputs.

C. Defuzzification

The output of the inference mechanism is fuzzy output variables. The fuzzy logic controller must convert its internal fuzzy output variables into crisp values so that the actual system can use these variables. This conversion is called defuzzification. One may perform this operation in several ways. The commonly used control defuzzification strategies are

(i) The max criterion method (MAX)

The max criterion produces the point at which the membership function of fuzzy control action reaches a maximum value.

(ii) The height method

The centroid of each membership function for each rule is first evaluated. The final output U_0 is then calculated as the average of the individual centroids, weighted by their heights as follows:

$$U_0 = \frac{\sum_{i=1} u_i \mu(u_i)}{\sum_{1=}^{n} \mu(u_i)} \qquad (1)$$

(iii) The centroid method or centre of area method (COA)

The widely used centroid strategy generates the centre of gravity of area bounded by the Membership function cure.

$$\bar{y} = \frac{\int \mu_r Y(y).y\,dy}{\int \mu_r Y(y)\,dy} \qquad (2)$$

IV IMPLEMENTATION OF PROPOSED SYSTEM

The fuzzy logic controller was applied to the speed loop by replacing the classical polarization index (PI) controller.The fuzzy logic controlled BDCM drive system block diagram is shown in fig.7

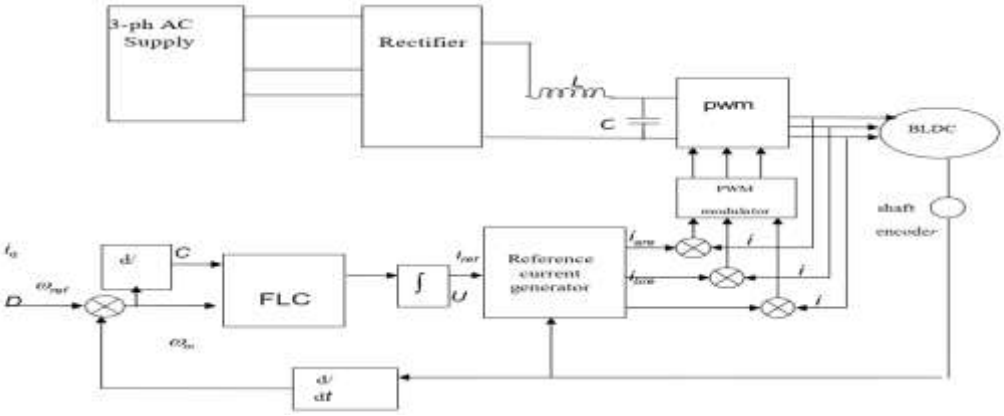


Fig.7: Fuzzy speed control block diagram of the BLDC motor

The input variable is speed error (E) and the change in speed error (CE) is calculated by the controller with E.The output variable is the torque component of the reference (i_{ref}) where $i_{ref}$is obtained at the output of the controller by using the change in the reference current.

There are two inputs signals to the fuzzy controller, the error E= $\square_{ref}$ - $\square$m and the change in error CE,which is related to the derivative dE/dt=ΔE/Δt=CE where CE=ΔE/T_s in the sampling time T_s ,CE is proportional to dE/dt.The controller output DU in brushless dc motor drive is Δi_{qs}^* current .The signal is assumed or integrated to generate the actual control signal U or current i_{qs}^* .Where K_1 and K_2 are nonlinear coefficients or gain factors including the summation process shown in figure 7.

$$\int DU = \int K_1Edt + \int K_2CEdt\ U \quad (3)$$

$$= K_1\int E\,dt + K_2E \quad (4)$$

which is nothing but a fuzzy P-I controller with nonlinear gain factors.Thenon linear adaptive gains in extending the same principle we can write a fuzzy control algorithm for P and P-I-D. The fuzzy member’s ship function for the input variable and output variable are chosen as follows:

PositiveBig:	PB	Negative Big:	NB
PositiveMedium:	PM	Negative Medium:	NM
PositiveSmall:	PS	NegativeSmall:	NS
Zero:	ZO		

The input variable speed error and change in speed error is defined in the range of

$$-1 \leq \square e \leq +1 \quad (5)$$

$$-1 \leq \square_{ce} \leq +1 \quad (6)$$

the output variable torque reference current change $\Delta i_{qs}$is defined in the range of

$$-1 \leq \Delta i_{qs} \leq +1 \quad (7)$$

The triangular shaped functions are chosen as the membership functions due to the resulting best control performance and simplicity. The membership function for the speed error and the change in speed error and the change in torque reference current are shown in Fig. 8 (a). (b) and (c).For all variables seven levels of fuzzy membership function are used in Table .3 shows the 7 *7 rule base table that was used in the system.

Table.3: 7×7 Rule base table used in the system

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

The steps for speed controller are as

- Sampling of the speed signal of the BLDC.
- Calculations of the speed error and the change in speed error.
- Determination of the fuzzy sets and membership function for the speed error and Change in speed error.
- Determination of the control action according to fuzzy rule.
- Calculation of the $\Delta i_{qs}$by centre of area defuzzification
- Sending the control command to the system after calculation of $\Delta i_{qs.}$

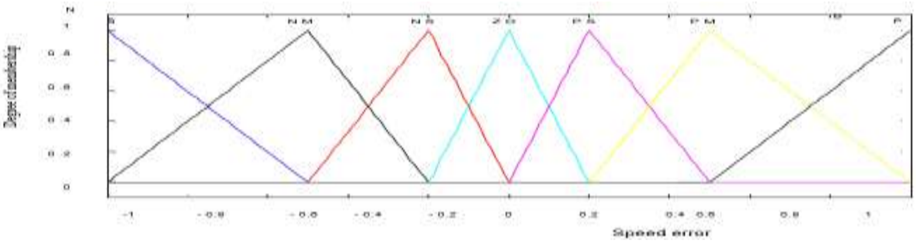


Fig. 8. (a): Fuzzy membership function for the speed error

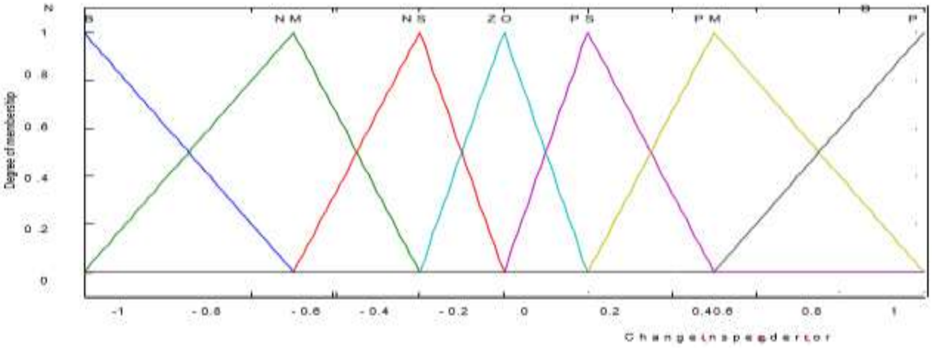


Fig. 8. (b): Fuzzy membership function for the change in speed error

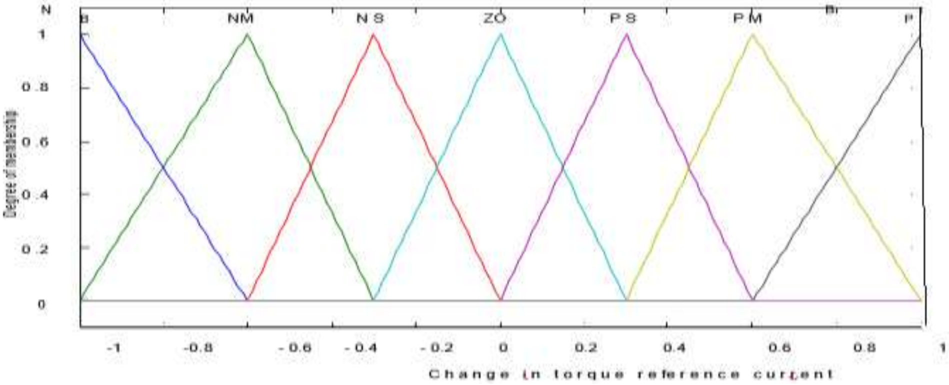


Fig. 8.(c): Fuzzy member shipfor the change in torque reference current

V SIMULATION RESULTS

Design of Fuzzy PID Control

In drive operation, the speed can be controlled indirectly by controlling the Voltage Source inverter. The speed is controlled by fuzzy logic controller whose output is the inner dc Voltage controller. The Voltage is controlled by varying the dc voltage. The drive performance of voltage source controller is improved by employing two sets of fuzzy logic controllers. One set of fuzzy logic controller is used in the inner loop for controlling the torque of the motor which is proportional to DC link current Idc, and another set is used in the outer loop for controlling the actual motor speed.

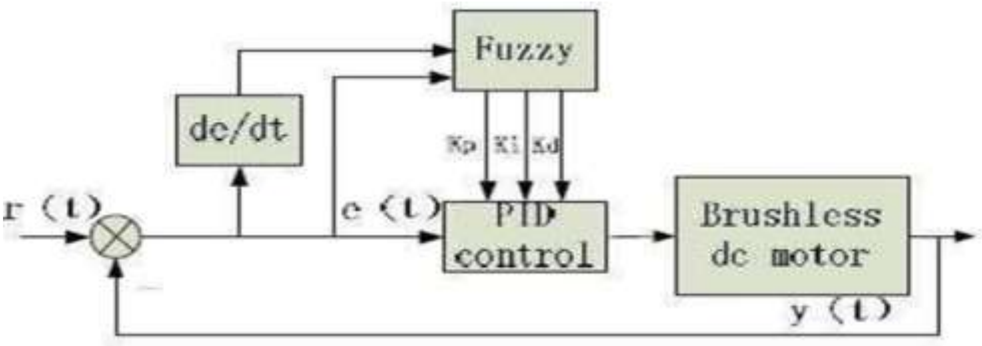


Fig 9: BLDC Control by Fuzzy PID controller

Fuzzy PID controller used in this paper is based on two input FLC structure with coupled rules. The overall structure of used controller is shown in Fig. 9Real interval of variables is obtained by using scaling factors which are Se, Sde and Su. The fuzzy control rule is in the form of If e=Ei and de=dEj then UPD=UPD(i,j). These rules are written in a rule base look-up Table IV. The rule base structure is Mamdani type.FLC has two inputs and one output. These are error (e), error change (de) and control signal, respectively. Linguistic variables which imply inputs and output have been classified as: NB, NM, NS, Z, PS, PM, PB. Inputs and output are all normalized in the interval of [-10,10] as shown in Fig. 10. Simulation diagram shown in Fig.11.

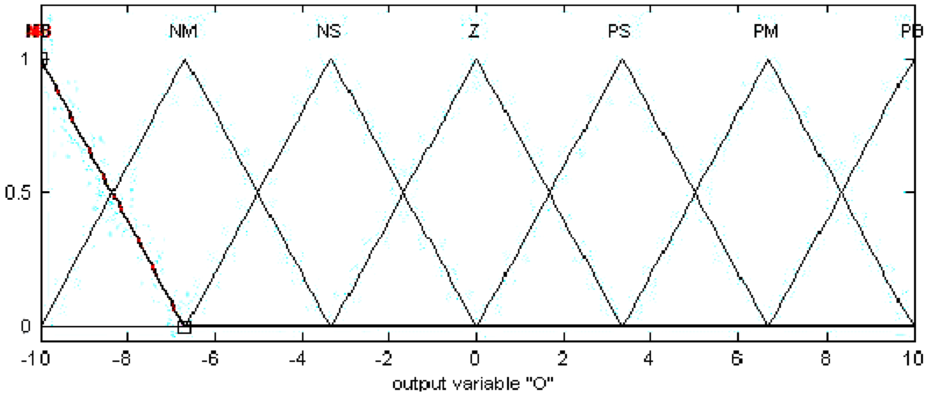


Fig.10: Membership functions of output

Performance Analysis

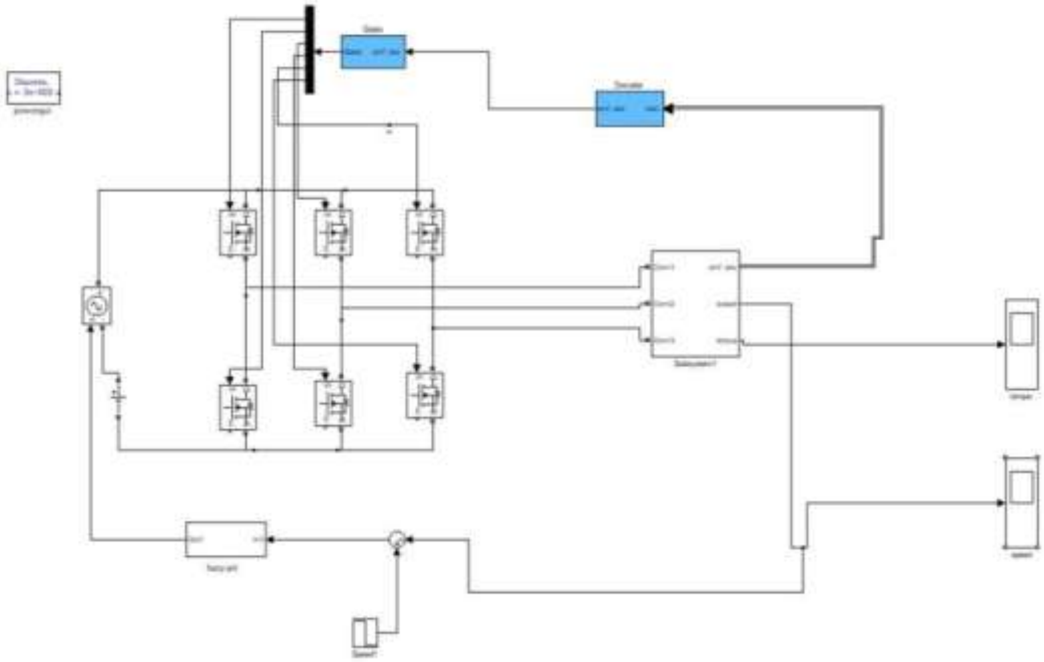


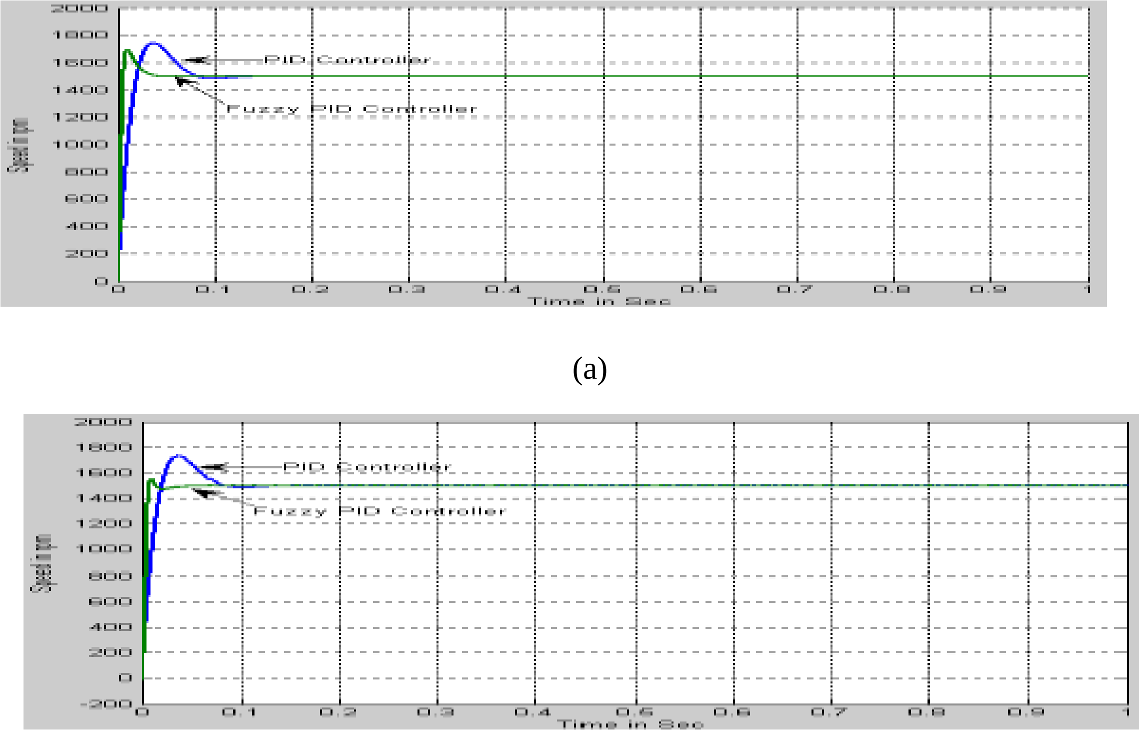
Fig.11: Simulation Diagram of Fuzzy based BLDC motor

To evaluate the performance of the system, a series of measurements has been accomplished. The performance comparison between PID controller and Fuzzy PID controller of three phase BLDC Motor is shown in below Table 4. We consider the following characteristics Rise Time (t_r), overshoot (M_p) and Settling Time (t_s).

TABLE 4. Performance Comparison

Speed	**PID Controller**			**Fuzzy PID Controller**		
	T_r	$\%M_p$	t_s	T_r	$\%M_p$	t_s
1500 noload	0.0202	16.53	0.35	0.0061	13.13	0.10
3500 noload	0.0206	16.60	0.35	0.0390	1.37	0.25
1500 withload	0.0209	15.53	0.40	0.0077	3.6	0.15
3500 withload	0.0210	15.71	0.40	0.0522	0.42	0.25
1000 – 1500 noload	0.0201	16.40	0.35	0.0042	55.10	0.15
3000 - 3500 noload	0.0205	16.60	0.35	0.0391	0.86	0.20
1000 - 1500 withload	0.0209	15.40	0.35	0.0051	40.30	0.15
3000 - 3500 withload	0.0209	15.70	0.35	0.0556	0.23	0.20
1500 - 1000 noload	0.0202	16.53	0.35	0.0061	13.13	0.15
3500 - 3000 noload	0.0206	16.60	0.35	0.039	1.37	0.25
1500 - 1000 withload	0.0209	15.53	0.35	0.0077	3.6	0.15
3500 - 3000 withload	0.0210	15.71	0.35	0.0522	0.42	0.25
1500 load impact	0.0202	16.53	0.35	0.0061	13.13	0.15
3500 load impact	0.0206	16.60	0.35	0.0390	1.6	0.25

From performance comparison a Fuzzy PID controller has better control performance than the conventional PID controller. Fig.12 as shown performance of the Fuzzy PID controller and Conventional PID Controller of BLDC Motor on Reference speed of 1500rpm with no load condition of (a)Speed and (b)Torque.

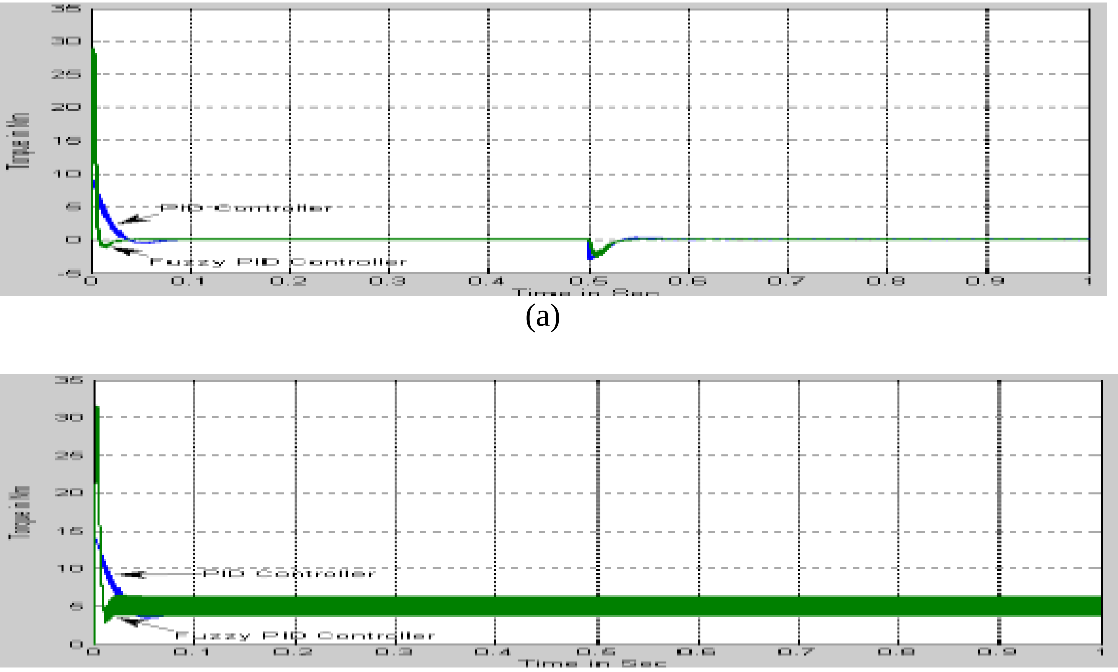


(a)

(b)

Fig.12. Reference speed of 1500 rpm with no load (a) Speed and (b) Torque

The results show that conventional PID controller reach settling time is 0.35 sec, but in fuzzy PID controller reach the settling time of 0.10 sec.



(a)

(b)

Fig.13. Reference speed of 1500 rpm with load (a) Speed and (b)Torque

The load of 5 N.m is applied to BLDC motor, the results show that conventional PID controller reach settling time is 0.40 sec, but in fuzzy PID controller reach the settling time of 0.15 sec.

VI CONCLUSIONS

This paper presents simulation results of conventional PID controller and Fuzzy PID controller of three phase BLDC Motor. In conventional PID control it is not necessary to change the control parameters as the reference speed changes. With results obtained from simulation, it is clear that for the same operation condition the BLDC speed control using Fuzzy PID controller technique had better performance than the conventional PID controller, mainly when the motor was working at lower and higher speeds. In addition, the motor speed to be constant when the load varies.

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