A Brushless DC Motor Speed Control By Fuzzy PID Controller

M D Bhutto , Prof. Ashis Patra

Abstract— **Brushless DC (BLDC) motors are widely used for many industrial applications because of their low volume, high torque and high efficiency. This paper introduced 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 analysis of performance conventional PID controller and Fuzzy PID controller. It is not easy to tune the specification and get satisfied control characteristics by using normal conventional PID controller. As the Fuzzy has the efficiency to satisfied control characteristics and it is easy for computing, to control the BLDC motor, a Fuzzy PID controller is designed as the controller of the BLDC motor. This verify the experimental results a Fuzzy PID controller has better control performance than the conventional PID controller. The modeling, simulation and control of the BLDC motor have been done using the software package MATLAB/SIMULINK.**

Keywords*:* ***Brushless DC (BLDC) motors; Proportional Integral Derivative (PID) controller; Fuzzy PID controller.***

INTRODUCTION

There is mostly two types DC motor used in industry. The first one is the brushless dc motor where the permanent magnet provides the necessary air gap flux instead of the wire-wound field poles. The second is the conventional dc motor where the flux is produced by the current through the field coil of the stationary pole structure. BLDC motor is conventionally defined as a permanent magnet synchronous motor with a trapezoidal Back EMF waveform shape. BLDC motors do not use brushes for commutation; instead, they are electronically commutated are synchronous motors that are powered by a DC electric source. Recently, high performance BLDC motor drives are widely used for variable speed drive systems of the electric vehicle and industrial applications.

In practice, the design of the BLDCM drive involves a complicated process such as modeling, parameters tuning, simulation and control scheme selection etc. An expert knowledge of the system is required for tuning the controller parameters of servo system to get the optimal performance. There are various modern control solutions are proposed for the speed control design of BLDC motor [1][2][3]. However, Conventional PID controller algorithm is simple, high reliability, easy adjustment and stable, Conventional speed control system used in conventional PID control [4][5]. But, in fact, most industrial processes with different degrees of nonlinear, uncertainty of mathematical model and parameter variability of the system. Tuning PID control parameters is very complex, poor solidity; therefore, it's difficult to achieve the optimal state under field conditions in the actual production. Fuzzy PID control method is a superior method of controlling, to the unclear model systems and complex, it can give simple and effective control, Play fuzzy control robustness, rising time, overstrike characteristics, good response.

Fuzzy Logic control (FLC) has proven effective for imprecisely, non-linear and complex defined processes for which standard model based control techniques are impossible or impractical [6]. Fuzzy Logic, deals with problems that have uncertainty, vagueness and use membership functions with values varying between 0 and 1[7]. This means that if the reliable expert knowledge is not available or if the controlled system is too complicated to derive the required decision rules. Evolution of a fuzzy logic controller becomes time consuming and sometimes impossible or tedious. In the case that the expert knowledge is available. The fine-tuning of the controller might be time consuming as well [8][9]. Furthermore, In trial & error, a optimal fuzzy logic controller cannot be achieved. These drawbacks have limited the application of fuzzy logic control. Some implements made to solve these problems and developing rules for the controller and simplify the task of tuning parameters.

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 is present design and implements a voltage source inverter for speed control of BLDC motor. This paper also purposed a fuzzy logic

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controller to the PID in order to keep the speed of the motor to be constant when the load varies.

II. SPEED CONTROL SYSTEM OF BLDCMOTOR

The complete block diagram of speed control of three phase BLDC Motor is below Fig. 1. Two types of 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 shown below Fig. 2.

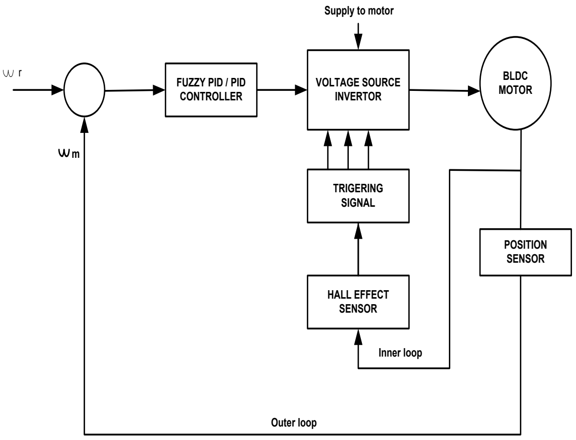

Figure 1. Block Diagram of speed control of BLDC Motor

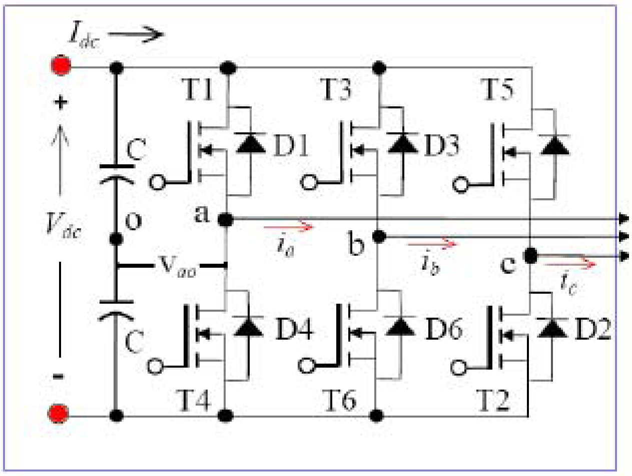

Figure 2. Voltage Source Inverter

In this circuit consists of three phase power convertors, which make use of six power transistors to energize two BLDC motor phases all together. 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 the sign of reference current (produced by Reference current generator) and Hall sensor information, Decoder block generates signal vector of back EMF. The basically running motor in opposite direction is by giving opposite current. We have Table I for calculating the gate logic to transform electromagnetic force and back EMF for Clockwise of motions to the 6 signal on the gates is given Table II.

TABLE I. CLOCKWISE ROTATION

Hall sensor A	**Hall sensor B**	**Hall sensor C**	**EMF A**	**EMF B**	**EMF 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 LOGIC

EMF A	**EMF B**	**EMF 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

III. CONTROLLING CIRCUIT

A. Design of Fuzzy 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

$$C(s) = K_p + \frac{K_I}{S} + K_D s$$

$$\frac{K_D S^2 + K_P S + K_I}{S} \qquad (1)$$

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

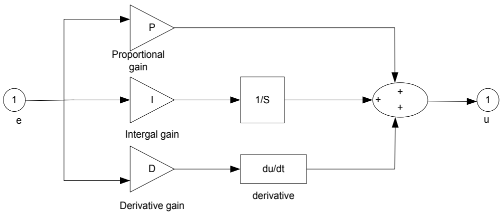

Figure 3. Simulation model of PID Controller

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The control u from the controller to the plant is equal to the Proportional gain (KP) times the magnitude of the error pluse the Integral gain (KI) times the integral of the error plus the Derivative gain (KD) times the derivative of the error.

$$U = K_P e + K_I \int e\,dt + K_D \frac{de}{dt} \qquad (2)$$

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

We are most interested in four major characteristics of the closed-loop step response. They are

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

Typical steps for designing a PID controller are

i) Determine what characteristics of the system needs to be improved.
ii) Use KP to decrease the rise time.
iii) Use KD to reduce the overshoot and settling time.
iv) Use KI to eliminate the steady-state error.

The Values of Kp, Ki and Kd values of PID Controller is shown in below Table III are obtained by using the ZN method.

TABLE III. PID VALUES

controller	Kp	Ki	Kd
PID	0.8	48	0.01

B. Design of Fuzzy PID Control

In drive operation, indirectly the speed can be controlled by controlling the Voltage Source inverter. The Voltage is controlled by varying the dc voltage and speed is controlled by fuzzy logic controller whose output is the inner dc Voltage controller. The drive execution of voltage source controller is improved by employing two sets of fuzzy logic controllers. First 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. Another set is used in the outer loop for controlling the actual motor speed.

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. 4.

Real 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 THAN UPD=UPD(i,j). These rules are written in a rule base look-up Table IV. The rule base structure is Mamdani type

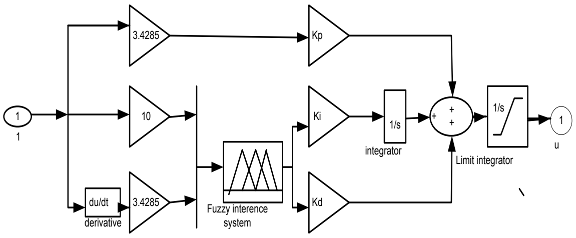

Figure 4. Simulation of Fuzzy PID Controller

FLC has two inputs and one output. These are error (e), error change (de) and control signal, respectively. A linguistic variable which implies 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. 5

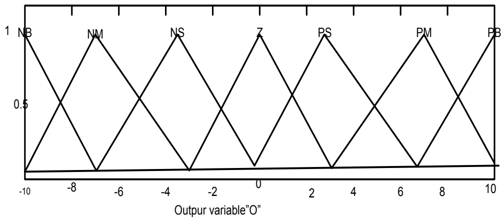

Figure 5. Membership functions of output

The two input fuzzy controller with coupled rules formed by combining both PI and PD actions.

The final fuzzy PID controller signal can be given as:

$$U_{PID}(t) = S_U \left\{ K_{PI} \sum_{i=0}^{t} U_{PD}(i) + K_{PI} U_{PD}(t) \right\} \qquad (3)$$

The linguistic labels used to describe the Fuzzy sets were 'Negative Big' (NB), 'Negative Medium' (NM), 'Negative Small' (NS), 'Zero' (Z), 'Positive Small' (PS), 'Positive Medium' (PM), 'Positive Big' (PB). It is possible to assign the set of decision rules as shown in Table IV. The fuzzy rules are extracted from fundamental knowledge and human experience about the process. These rules contain the input/the output relationships that define the control strategy. Each control input has seven fuzzy sets so that there are at most 49 fuzzy rule.

TABLE IV. TABLE OF FUZZY RULE

CE E	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

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IV. SIMULATION RESULT AND DISCUSSION

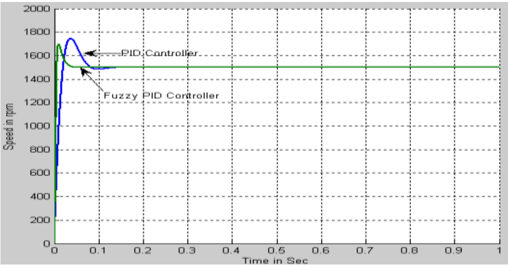
To evaluate the performance of the system, a series of measurements has been accomplished. The performance comparison between PID controller and Fuzzy PID controller of three phase BLDC Motor is shown in below Table V. We consider the following characteristics Rise Time (t_r), overshoot (M_p) and Settling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

TABLE V. PERFOMANCE COMPARATION

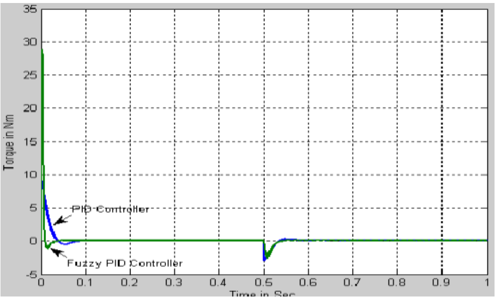
Speed	**PID Controller**			**Fuzzy PID Controller**		
	t_r	$\%M_p$	t_s	t_r	$\%M_p$	t_s
1500 noload	0.0202	16.53	0.35	0.0061	13.13	0.10
3500 noload	0.0206	16.60	0.35	0.0390	1.37	0.25
1500 withload	0.0209	15.53	0.40	0.0077	3.6	0.15
3500 withload	0.0210	15.71	0.40	0.0522	0.42	0.25
1000 – 1500 noload	0.0201	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. 6 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. 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.



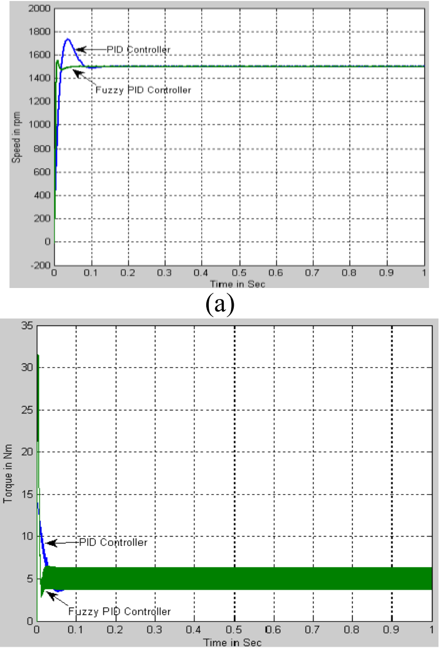
(a)



(b)

Figure 6. Reference speed of 1500 rpm with no load (a) Speed and (b) Torque

Fig. 7 as shown performance of the fuzzy PID controller and Conventional PID Controller of BLDC Motor on Reference speed of 1500rpm with load condition of (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.

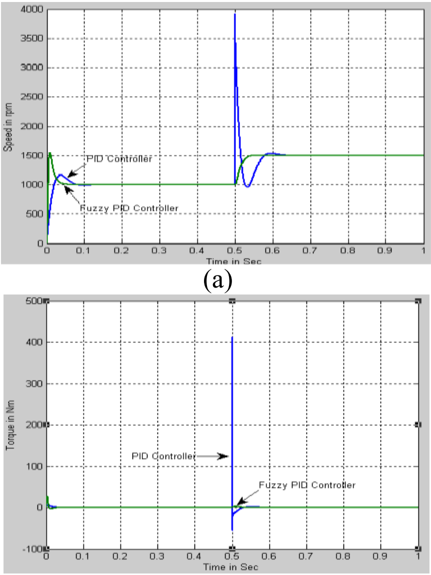


(a)

(b)

Figure 7. Reference speed of 1500 rpm with load (a) Speed and (b) Torque

Fig. 8 as shown performance of the fuzzy PID controller and Conventional PID Controller of BLDC Motor on Stepup speed of 1000 - 1500rpm no load condition of (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 0.15 sec.

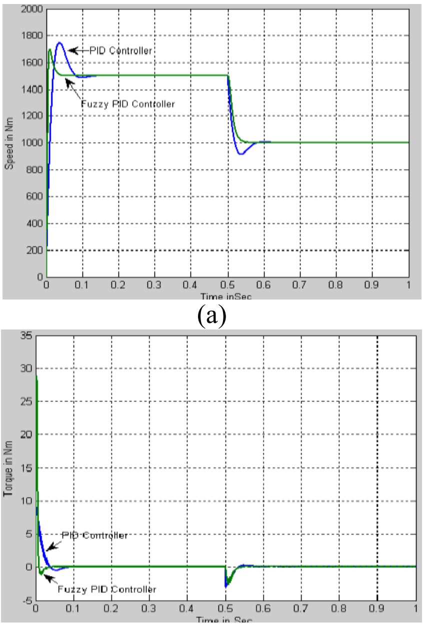


(a)

(b)

Figure 8. Step up speed of 1000 - 1500 rpm with no load (a) Speed and (b) Torque

Fig. 9 as shown performance of the fuzzy PID controller and Conventional PID Controller of BLDC Motor on Step-down speed of1500 - 1000rpm with no load condition of (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 0.15 sec.

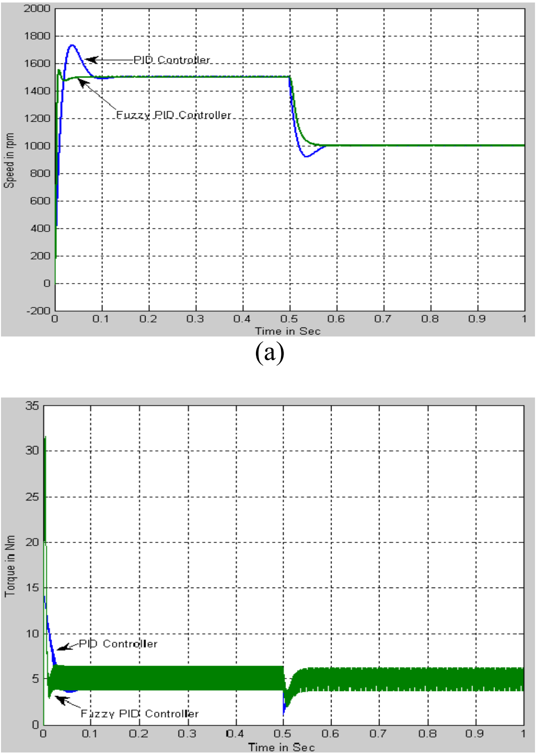


(a)

(b)

Figure 9. Stepdown speed of 1500 - 1000 rpm with no load (a)Speed and (b) Torque.

Fig. 10 as shown performance of the fuzzy PID controller and Conventional PID Controller of BLDC Motor on Stepdown speed of1500 - 1000rpm withload condition of (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 0.35 sec, but in fuzzy PID controller reach the settling time of 0.15 sec

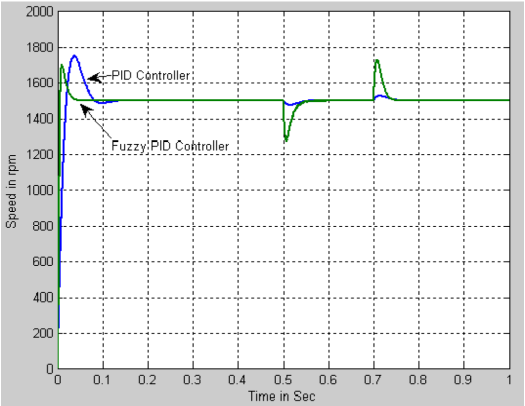


(a)

(b)

Figure 10. Step down speed of1500-1000rpm with load (a)Speed and (b) Torque

Fig. 11 as shown performance of the fuzzy PID controller and Conventional PID Controller of BLDC Motor on speed of 1500rpm with load impact condition of (a) speed and (b)Torque. During running conduction of BLDC motor, suddenly the load of 5 N.m is applied at time of 0.5 sec and released at 0.7 sec. The results show that conventional PID controller reach settling time is 0.35 sec, but in fuzzy PID controller reach the settling time of 0.15 sec.



(a)

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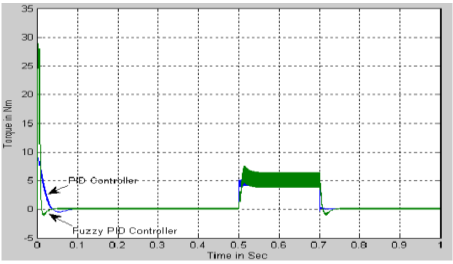

(b)

Figure 11. Reference speed of 1500 rpm with load impact (a) Speed and (b) Torque

V. CONCLUSION

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

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