Design of Fuzzy PID Controller for Brushless DC Motor

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Abstract—

This 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 modeling, control and simulation 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.

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 electric vehicles.

In practice, the design of the BLDCM drive involves a complex process such as modeling, 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. 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][7][8][9]. Fuzzy Logic, deals with problems that have vagueness, uncertainty and use membership functions with values varying between 0 and 1. This means that if the 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 [6][7]. 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.

II. SPEED CONTROL SYSTEM OF BLDC MOTOR

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

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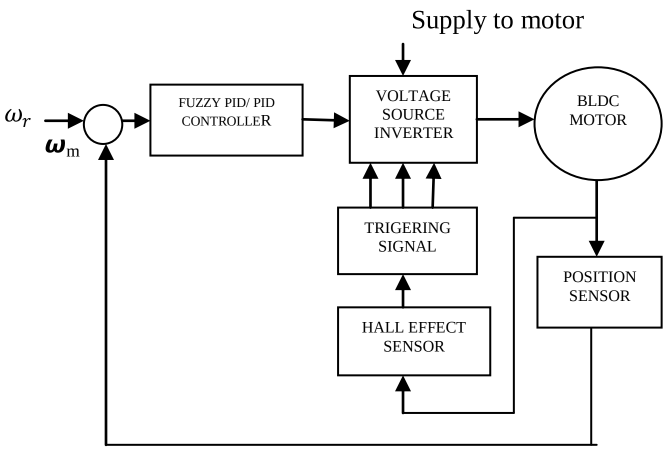


Fig. 1 Block Diagram of speed control of BLDC Motor

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 I for calculating back EMF for Clockwise of motion and the gate logic to transform electromagnetic forces 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. CONTROLLER CIRCUIT

PID Controller:

Consider the characteristics parameters – proportional (P), integral (I), and derivative (D) controls, as applied to the diagram below in Fig.2, the system

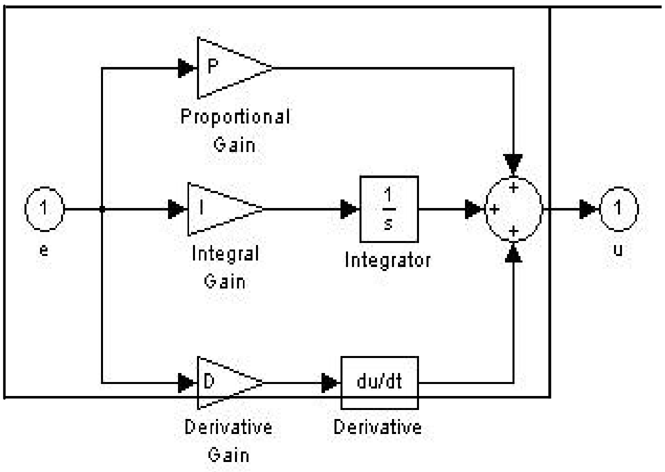


Fig. 2 Simulation model of PID Controller

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 for of PID controller is

Controller Type	***Transfer function***
P- Controller	K_P
PI- Controller	$K_P\left(1+\frac{1}{T_iS}\right)$
PD- Controller	$K_P(1+T_dS)$
PID- Controller	$K_P\left(1+\frac{1}{T_iS}+T_dS\right)$

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

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.

$$u = K_P e + K_i \int e\,dt + K_d \frac{de}{dt}$$

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.

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 need to be improved.
ii) Use K_P to decrease the rise time.
iii) Use K_D to reduce the overshoot and settling time.
iv) Use K_I to eliminate the steady-state error.

The Values of K_p, K_i and K_d values of PID Controller is shown in below are obtained by using ZN method

TABLE III. PID VALUES

controller	K_p	K_i	K_d
PID	0.8	48	0.01

Design of Fuzzy PID Controller:

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. From Fig 5 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. 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. 3.

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 which is shown in Fig. 3. The rule base structure is Mamdani type.

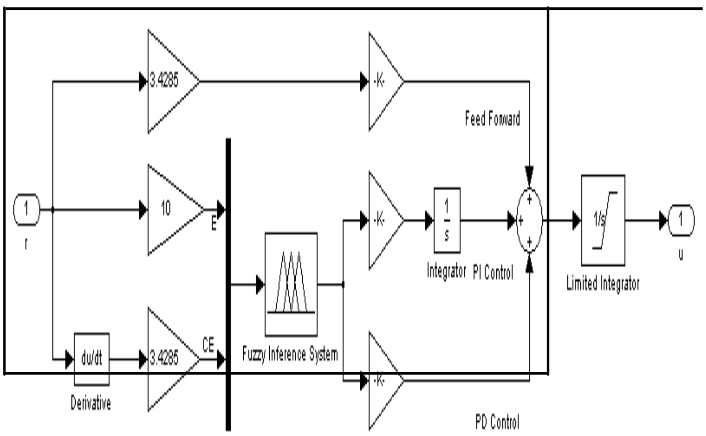
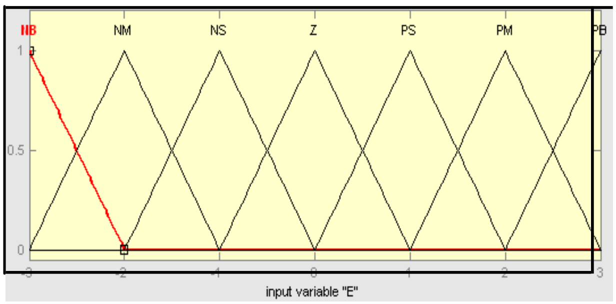
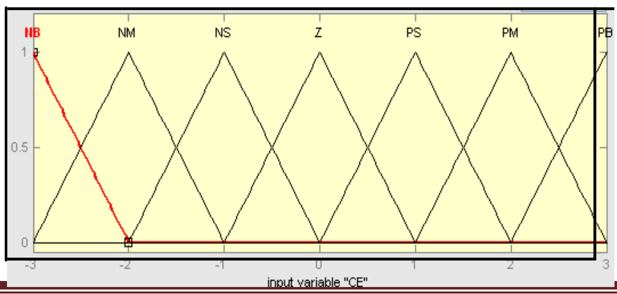


Fig. 3 Simulation of Fuzzy PID Controller

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 [-3,3] as shown in Fig. 4.



(a)



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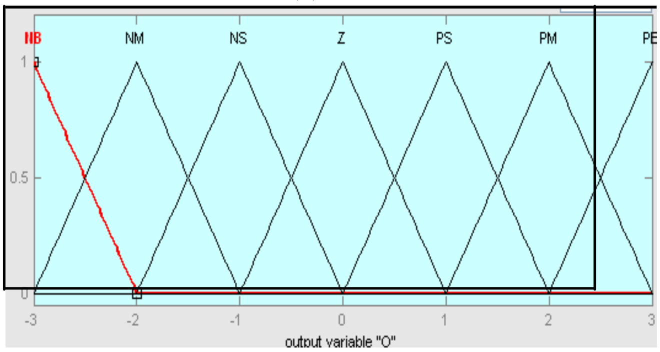


(c)

Fig. 4 Membership functions of output

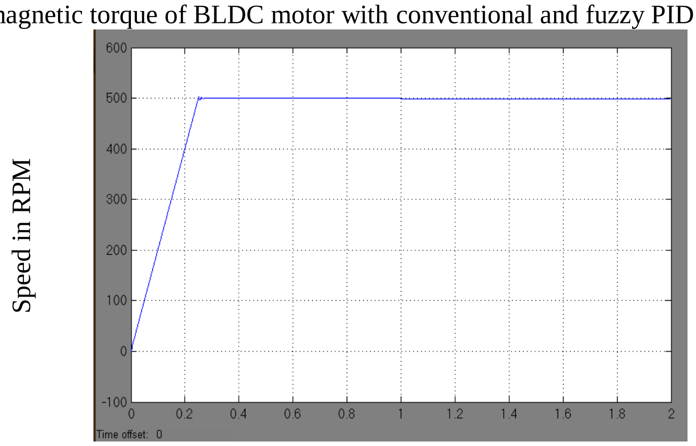
The linguistic labels used to describe the Fuzzy sets were 'Negative Big' (NB), 'Negative Medium' (NM), 'Negative Small' (NS), 'Zero' (Z), 'Positive Small' (PS), 'Positive Medium' (PM), 'Positive Big' (PB). It is possible to assign the set of decision rules as shown in Table IV. The fuzzy rules are extracted 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 rules.

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

IV. SIMULATION RESULT AND DISCUSSION

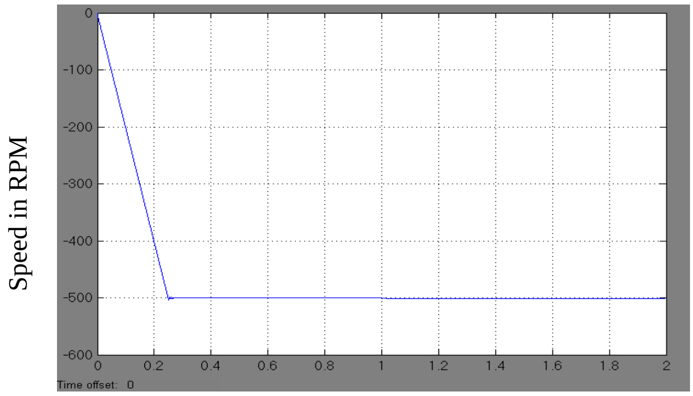
The simulation results show various outputs such as speed of BLDC motor, three phase currents, and three phase back EMFs and electromagnetic torque of BLDC motor with conventional and fuzzy PID controller.



Time in Sec

Fig. 5 Speed of BLDC motor in forward direction with fuzzy PID controller

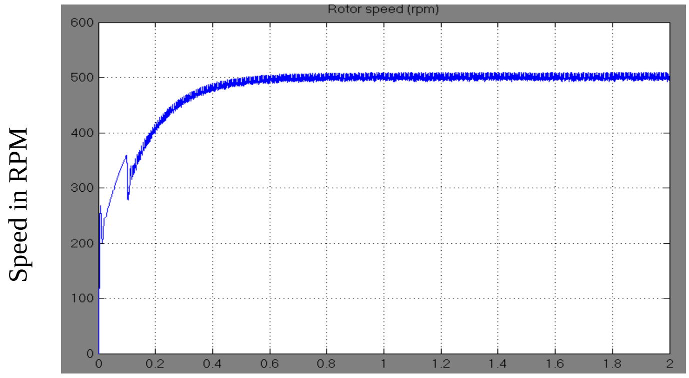
The figure 5 shows speed response of BLDC motor with fuzzy PID controller in forward direction, which not has any oscillations and speed settled in desired value of 500 rpm at 0.24 sec. Compare to PID controller it has less settling time and steady state error.



Time in Sec

Fig. 6 Speed of BLDC motor in reverse direction with fuzzy PID controller

The figure 6 shows speed response of BLDC motor with fuzzy PID controller in reverse direction, which not has any oscillations and speed settled in desired value of 500 rpm at 0.24 sec. And PID controller does not produce output in reverse direction.



Time in Sec

Fig. 7 Speed of BLDC motor with conventional PID controller

The figure 7 shows speed response of BLDC motor with conventional PID controller in forward direction, which has oscillations at starting period and speed settled in desired value of 500 rpm at 0.6 sec. Compare to fuzzy PID controller it has large settling time and steady state error.

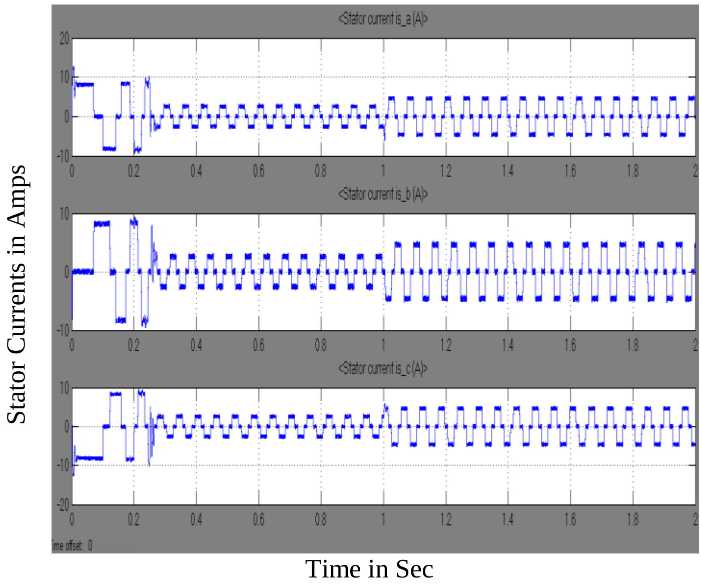


Fig. 8 Three phase Stator current of BLDC motor with fuzzy PID controller

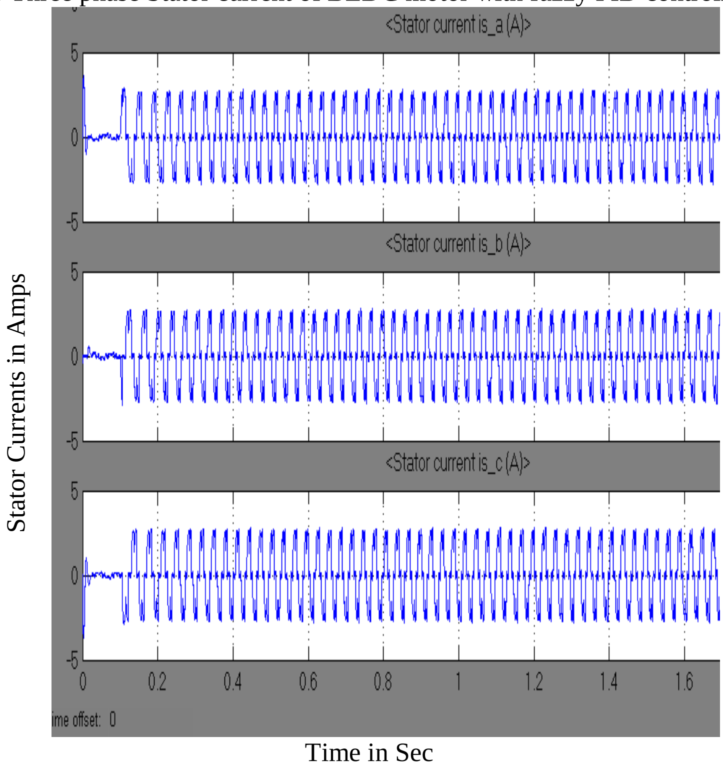


Fig. 9 Three phase Stator current of BLDC motor with Conventional PID controller

The figure 8 & 9 shows simulation results of three phase stator currents of BLDC motor with fuzzy and conventional PID controllers. Fuzzy PID controller given trapezoidal shape current wave forms hence Response of fuzzy PID controller is better than conventional PID controller.

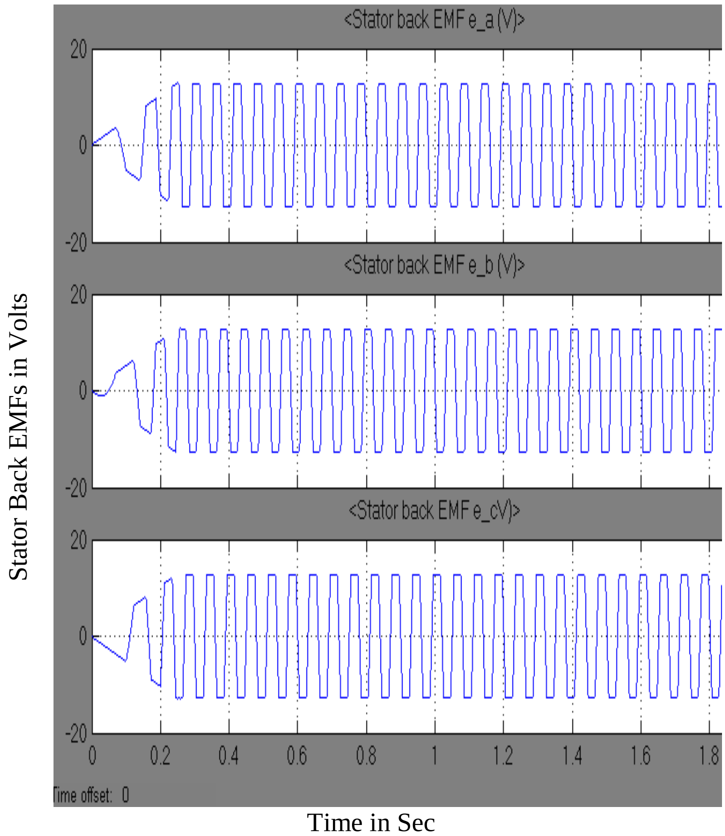


Fig. 10 Three phase Back EMF of BLDC motor with fuzzy PID controller.

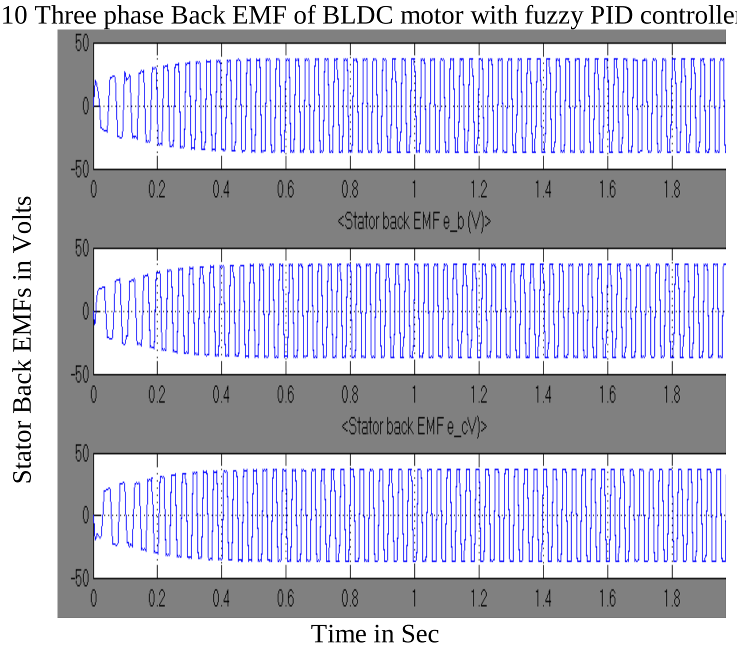
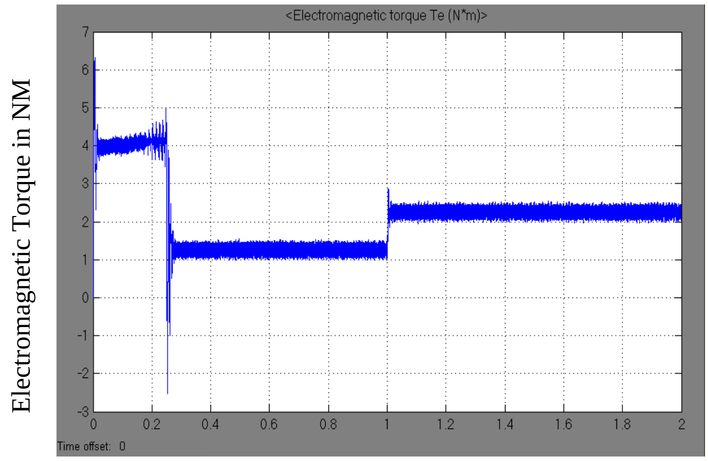


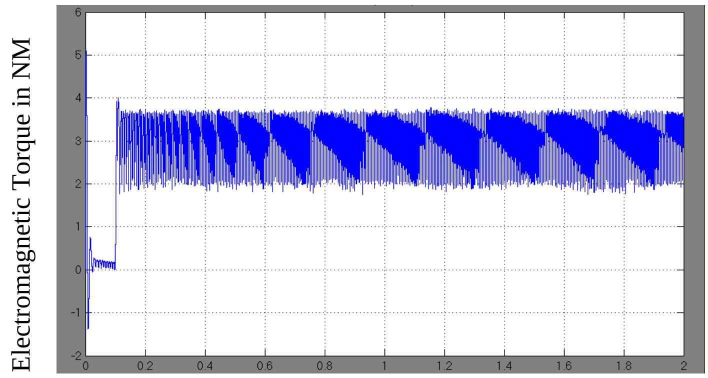
Fig. 11 Three phase Back EMF of BLDC motor with Conventional PID controller.

The figure 10 & 11 shows simulation results of three phase back EMF of BLDC motor with fuzzy and conventional PID controllers.



Time in Sec

Fig. 12 Electromagnetic torque of BLDC motor with fuzzy PID controller



Time in Sec

Fig. 13 Electromagnetic torque of BLDC motor with Conventional PID controller

The figure 12 & 13 shows electromagnetic torque of BLDC motor with fuzzy and conventional PID controllers. The electromagnetic torque wave form with fuzzy PID controller has less ripples compare to conventional PID controller. Hence fuzzy PID controller reduce the large ripples present in the electromagnetic torque

V. CONCLUTION

Simulation results shown performance of the Fuzzy PID controller and Conventional PID Controller of BLDC Motor with Reference speed of 500rpm .This paper presents simulation results of Fuzzy PID controller of three phase BLDC Motor. The simulation results shows various outputs such as speed of BLDC motor, three phase currents, and three phase back EMFs and electromagnetic torque of BLDC motor with conventional PID and fuzzy PID controller. The simulation result of speed of BLDC with fuzzy PID controller does not has any oscillations, less settling time and steady state error, hence Fuzzy PID controller given satisfactory performance and conventional PID controller cannot control reverse mode operation, Fuzzy PID controller give good output response in the reverse direction.

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