BLDC Motor Speed Control using Fuzzy Logic PID Controller and Comparing It With PI Controller

C Akshay Kumar, Bachcha Ram Harijan, M Kiran Kumar, Manne Bharathi

Abstract: ***In this project, mathematical model of the Brushless DC motor (BLDC) is developed and the closed-loop Fuzzy PID controller has been simulated in MATLAB-Simulink environment. The three-phase (BLDC) is developed and the DC power is supplied to this machine though six step inverter whose switching state is controlled by the hall signal. The hall effect sensor senses the rotor posit ion of the motor and it generates binary digit number which is decoded and given to the six-step inverter. The mathematical model is developed using the back emf equations and torque equation of the BLDC motor. The PI controller doesn't operate properly during dynamic state and hence the fuzzy-PID-controller is better option to control and regulate the speed of the BLDC motor which has high performance in comparison to the PI controller. And, we can get the smooth speed-torque characteristics using Fuzzy PID controller.***

Keywords— ***PID controller, fuzzy logic, BLDC motor, Hall effect sensor, Electromagnetic torque.***

I. INTRODUCTION

The DC motor considered as having good torque and speed characteristic and efficiency. The DC motor are preferable than AC motor in any area like aircraft, robotics, industries and home appliances. But the brushed dc motor has some disadvantage which lead to introduce the brushless dc motor instead of the brushed-dc machine. The operation and maintenance cost of the dc motor is too high due to the presence of the commuter brushes and the brush gear and can't operate in huge hazard conductions because sparks may occur and may lead to the fire. The speed will change as the load changes, as there is variable speed not only by controlling the resistance but also by the load current. The speed control could be impossible for rapidly changing loads.

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Brushless dc motor does not any brushes, so they don't undergo any commutation, Brushless dc motor have a significantly higher efficiency and performance and compare to that it also has a very low susceptibility to mechanical parts than their brushed counterparts. Due to advantage of BLDC motor over dc motor and other ac motor control of BLDC motor is very essential. Many control techniques of BLDC motor are in the use but to improve the performances of the motor we are going to deal with the PID-fuzzy control method. In first section the overview of the BLDC motor and mathematical modelling is discussed and in second section the introduction of the PI controller and fuzzy-logic PID-controller are discussed. Third section, Simulink model of the closed loop PID-fuzzy logic control of BLDC is discussed and then next section simulation results are analysis and discussed.

II. BLDC MOTOR

A. *Construction of BLDC motor*

The Switched Reluctance machine(SRM) are gaining a specific attention in different applications for past two decades[1]-[3]. But SRM suffers from lower power density, high noise, maintenance and vibration. To overcome all the disadvantages permanent magnet (PM) type machines like stator PMS and rotor PMs are introduced like BLDC [4] and flux-reversal machine [5] respectively. And BLDC which is driven by the direct-current. It mainly consists of stator and rotor. The stator comprises of the three-phase winding for three-phase motor, which is associated in star connection. The stator is made up of the stacked steel laminations to carry the stator winding either in star or delta connection, however the most of the three BLDC motor are having the star connection. In this project we are considering the star connection of the stator winding. The motor is driven by the direct current electricity and the supply is given to the stator winding through the six-step inverter. The number of poles is varied based on the requirement of the torque and speed of the motor applications. The number of rotor poles is varied 2 to 8 pairs with alternate south and north pole in each pair of BLDC motor. The rotor is permanent magnet, so it doesn't require any excitation. Like in the brushed dc motor the commutation is required in BLDC motor also but here it done by electronically. Here, used hall-sensor for commutation process. Three hall-sensors are attached in the rotor of the BLDC and its sense the rotor position. Gate is pulse is given to the six-step inverter by converting the three-hall signal into six gate signals by decoding the hall signal to operate the inverter which is called electronically commutation.

The hall effect signal generates high and low signal. The back emf of this motor is trapezoidal and hence it is also identified as trapezoidal dc motor.

B. *Working principle of BLDC Machine*

The DC electricity is given to the three phase six-step inverter by the DC source and the switching states are controlled by the hall signal obtained from the hall effect sensor which further decoded to covert three hall effect signal into six-signals for the six switches of the inverter. As the commutation process is done electronically the switches of the inverter opens and closes in a sequence to create the electromagnet in the stator. The rotor is PM so that the north and the south pole of the rotor are aligned to that of the stator and due to attraction due to opposite pole and repulsion due to like pole the torque is produced in the rotor which makes the rotor to rotate.

C. *Mathematical modelling of BLDC Machine*

In three phase BLDC motor the three-phase windings are connected either in star or in delta, but mostly used star connection [6]-[9]. In this project we considering the star connected BLDC motor. The winding arrangements as shown in figure.1.

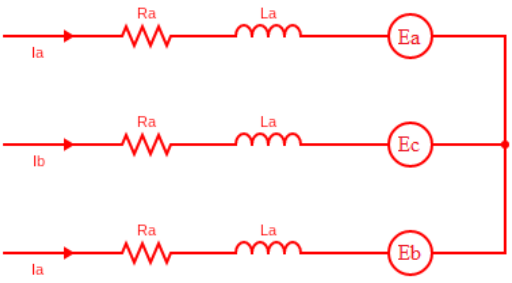


Figure.1. Winding Arrangement of BLDC machine

From fig.1 the circuit diagram stator voltages equations as

$$V_a = I_a R_a + L_a \frac{dI_a}{dt} + M_{ab}\frac{dI_b}{dt} + M_{ac}\frac{dI_a}{dt} + E_a \text{-------- (1)}$$

$$V_b = I_b R_b + L_b \frac{dI_b}{dt} + M_{ba}\frac{dI_a}{dt} + M_{bc}\frac{dI_c}{dt} + E_b \text{-------- (2)}$$

$$V_c = I_c R_c + L_c \frac{dI_c}{dt} + M_{ca}\frac{dI_a}{dt} + M_{cb}\frac{dI_b}{dt} + E_c \text{-------- (3)}$$

Where, V_a, V_b, V_c are the voltages of the stator; R_a, R_b and R_c are respective phase resistances of the stator; L_a, L_b, L_c are the stator winding self-inductances respective phases; M_{ab}, M_{bc}, and M_{ca} are the mutual inductances; E_a, E_b, E_c are the respective phase back-emfs.

Since, three-phase winding is in balanced condition so, assumed that the similar parameters of each phase are unique. Suppose the resistance, mutual inductance and inductance of each phase are R, M and L respectively. Thus, re-write the above equations as:

$$V_a = I_a R + L\frac{dI_a}{dt} + M\frac{dI_b}{dt} + M\frac{dI_c}{dt} + E_a \text{-------- (4)}$$

$$V_b = I_b R + L\frac{dI_b}{dt} + M\frac{dI_a}{dt} + M\frac{dI_c}{dt} + E_b \text{-------- (5)}$$

$$V_c = I_c R + L\frac{dI_c}{dt} + M\frac{dI_a}{dt} + M\frac{dI_b}{dt} + E_c \text{-------- (6)}$$

Since $I_a + I_b + I_c = 0$, we can deduce the equations 4, 5 and 6 as

$$V_a = I_a R + (L - M)\frac{dI_a}{dt} + E_a \text{-------- (7)}$$

$$V_b = I_b R + (L - M)\frac{dI_b}{dt} + E_b \text{-------- (8)}$$

$$V_c = I_c R + (L - M)\frac{dI_c}{dt} + E_c \text{-------- (9)}$$

The above equations can be stated as in the matrix-form

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R + (L-M)\frac{d}{dt} & 0 & 0 \\ 0 & R + (L-M)\frac{d}{dt} & 0 \\ 0 & 0 & R + (L-M)\frac{d}{dt} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix}$$

The electromagnetic torque can be derived as,

$$T_e = \frac{I_a E_a + I_b E_b + I_c E_c}{W_m} \text{-------------- (10)}$$

T_e is the electromagnetic torque and ω_m angular speed in radian per second of the BLDC motor. The generalized torque equation can be expresses as

$$T_e T_j = j\frac{dw_m}{dt} + B_v W_m \text{---------------------- (11)}$$

J= Inertia constant, T_L= Load torque, and B_v= Friction coefficient. The relation between number of poles and electrical position of the rotor as

$$\frac{d\theta r}{dt} = \frac{p}{2} \text{-------------------------------------(12)}$$

Where, p is the poles of the rotor and θr is the rotor position in electrical degrees.

III. PI AND FUZZY LOGIC PID-CONTROLLER

A. *Closed-loop controller*

Feedback does not need for open-loop systems, so if any disturbance in output, that output disturbance is not nullified by open-loop and in closed-loop, compare the output with reference. Closed loop consists of the feedback, which monitors the obtained output with respect to the desired output and reference value. The Fuzzy PID is used to regulate the output characteristics of torque and speed using which the ripple content can be minimized and the smooth waveform can be obtained [10].

B. *Closed-Loop PID controller*

PID controller (proportional-integral-derivative) is adapted in the different areas in the engineering payable to its power, tuning parameters and reliability easily. A PID controller continuously determines the error as the variation between the desired setpoint and a measured processed variable and subjected based on proportional, integral, and derivative. It continuously applies a responsive correction and an accurate value to a control function [10]. The PID controller block-diagram as illustrated in figure.2.

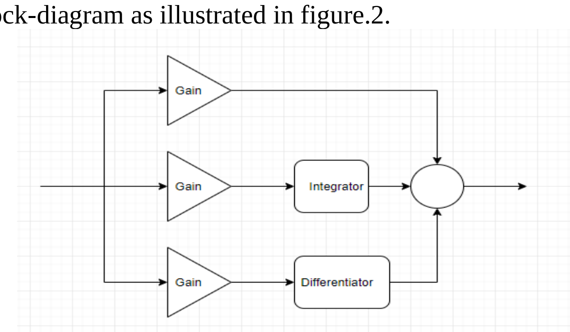


Fig.2. PID controller basic-block-diagram

The PID-controller comprises of the proportional, the integral and the differential constant whose values depend on the parameters we want to change for example maximum overshoot, rise time, settling time etc.

C. *PI Contrller for BLDC motor*

PID controller design depends on the application and design the PID controller need to find the K_d, K_p, and K_i values of PID controller. PID controller Simulink-model can be modelled using equation as

$$u(t) = k_p e(t) + k_d \frac{d_s(t)}{dt} + k_i \int e(t)dt$$

where, e(t) = Error signal, u(t) = Output of the controller and respective, K_d, K_p, and K_i are derivative, proportional and integral constant respectively.
After applying Laplace transform, obtained an expression given as

$$u(s) = \left(k_p + sk_d + \frac{k_i}{s}\right) E(s)$$

$$G(s) = k_p + sk_d + \frac{k_i}{s}$$

Where, G(s) is overall gain for PID controller.
Using this transfer function and our requirement for of the characteristic of the output wave we can design the PID controller as per our application for BLDC motor.

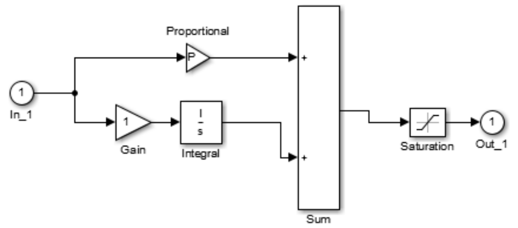


Fig.3. PI controller simulink-diagram.

Fuzzy-controller

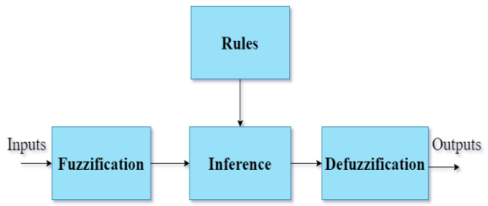


Fig.4. Fuzzy-cotroller block diagram.

Fuzzy controller is used to control any signal. Binary logic is consisting of 1 and 0 i.e. either on or off but in daily life it does not satisfy all the conditions for example the temperature I either hot or very hot or moderate of low or very low. So, this is the fuzzy logic but 0 and 1 if binary logic. The fuzzy logic controller consists of Fuzzy rules, inference, the fuzzification, and defuzzification. The fuzzification block convert the binary logic into the fuzzy logic and there are some rules which is in rule block. Based on the input taken from the fuzzification the output is analysed with the fuzzy rules with the help of the inference block and the result is again converted into the machine understandable logic i.e. logic 1 and 0. Thus, the fuzzy controller is recommended to control the one or more input and based on the given rules and number of the output signal required the output is obtained which is used to control the different parameters.

IV. CLOSED-LOOP CONTROL PID-FUZZY LOGIC (FLC) CONTROLLER

The conventional FLC-PID algorithm is stable, high reliability and easy adjustment. Conventional speed-controlled technique is used in fuzzy PID controller. This is mostly used in the industry processes with nonlinear systems of various degrees, uncertainty in model of the system and parameter variability. it is too difficult to control the parameters under optimal state field conditions in actual and production. FLC-PID controlled method is a best to give an effective control [11]-[12].

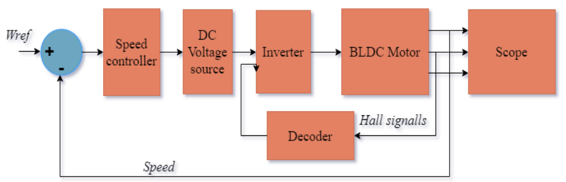


Fig.4. block diagram of Fuzzy-PID Controller of BLDC

FLC controller block consists of the PID and fuzzy logic. In this controller fuzzy rules are used to calculate the various parameter constants of the PID controller based on the feedback gained from the speed sensor [13]-[14]. The error signal is assigned to the speed controller loop and the speed controller gives the required signal to control the voltage of the controlled voltage. And the voltage is controlled by the speed controller. The voltage obtained from the controlled dc output is given to the three-phase inverter, which converts the dc output voltage into the three-phase square ac source. Thus, the three-phase inverted power is supplied to the three- phase BLDC machine. The hall sensor used in the BLDC motor measures the rotor position of the BLDC and three hall signals is given by the three hall sensors and these hall signals are converted into the equivalent emf and converted in to the six gate pulses with the help of decoder for the six switches of the inverter[15]-[16].

A. *Fuzzy logic membership functions(FLMF)*

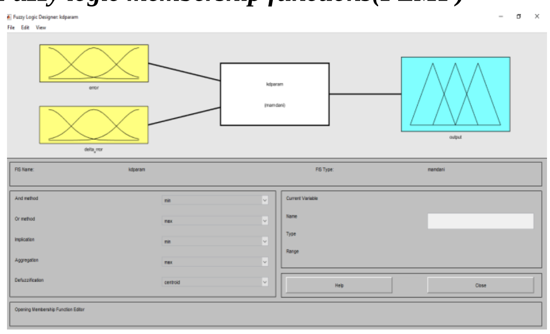
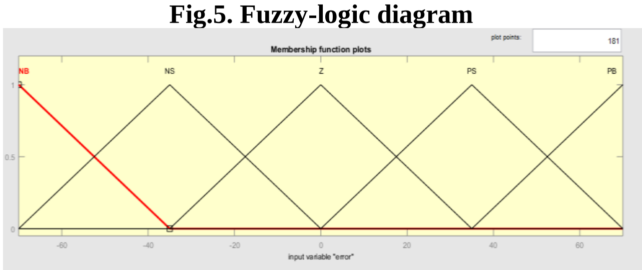


Fig.5. Fuzzy-logic diagram



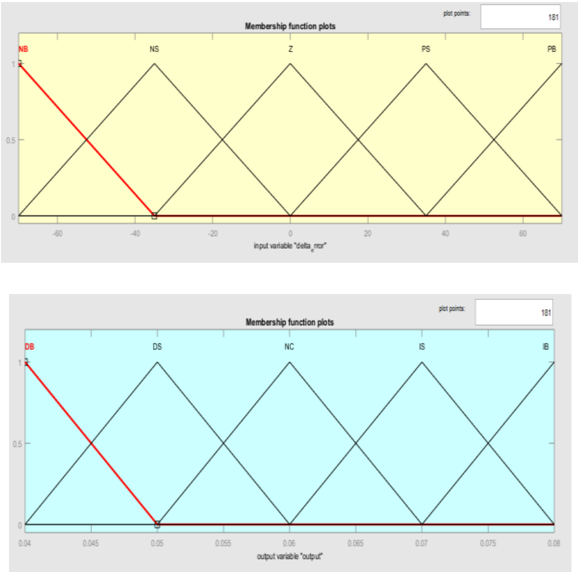


Fig.6. Fuzzy membership funtions

B. *Fuzzy inference rules*

Table.1. Fuzzy inference rule

Change in error / Error	DB	DS	NC	PS	PB
DS	**DB**	**DB**	**DS**	**NC**	**IS**
DB	**DB**	**DB**	**DB**	**DS**	**NC**
NC	**DB**	**DS**	**NC**	**IS**	**IB**
PB	**NC**	**IS**	**IB**	**IB**	**IB**
PS	**DS**	**NC**	**IS**	**IB**	**IB**

V. RESULTS AND DISCUSSIONS

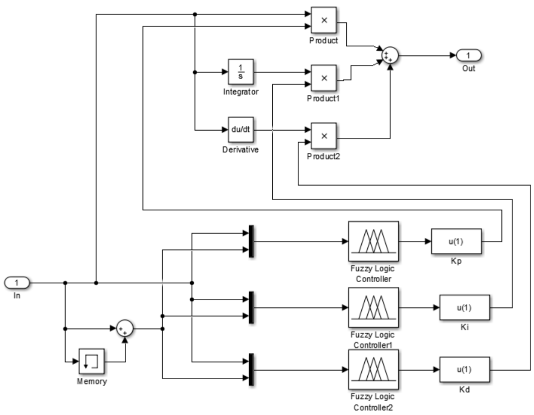


Fig.7. Simulink diagram for fuzzy logic PID-controller

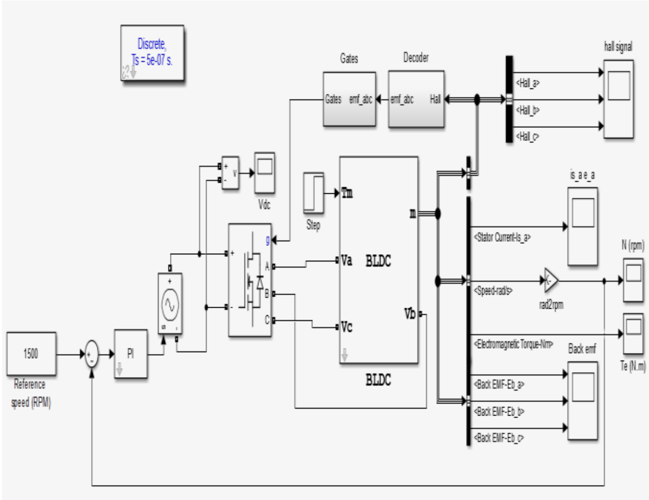


Fig.8. Simulation model using PI controller

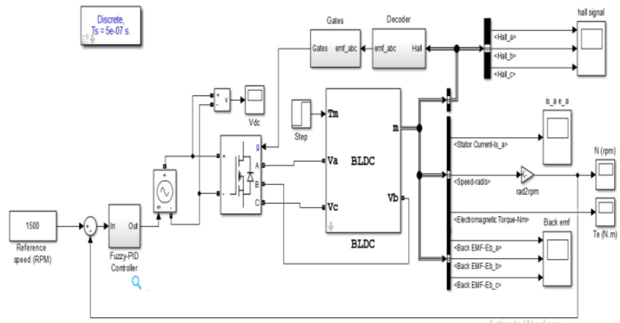


Fig.9. Simulation diagram using PID-Fuzzy controller

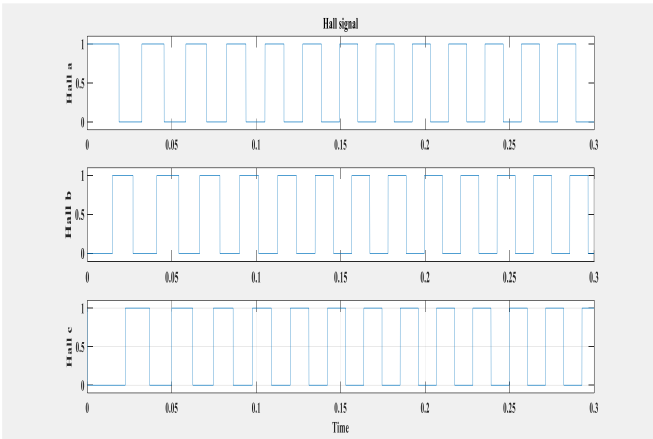


Fig.10. Hall signal waveforms

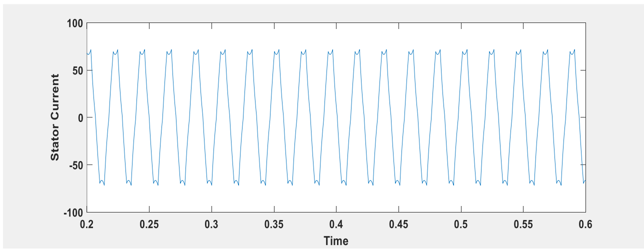


Fig.11. Stator current of BLDC motor of one phase.

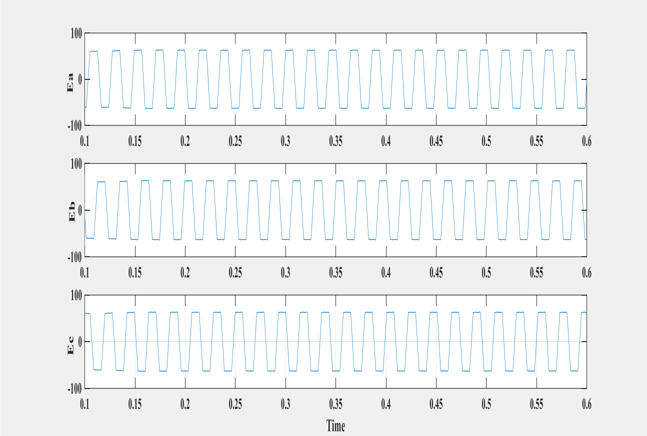


Fig.12. BLDC motor back emf .

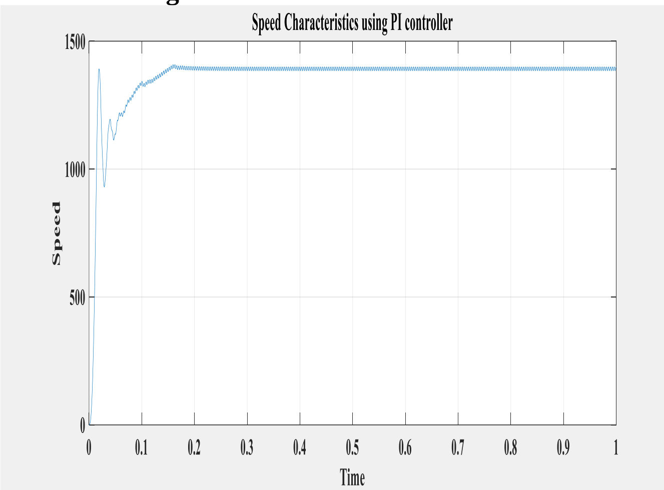


Fig.13. Speed Characteristics with respect to PI-controller of of BLDC motor

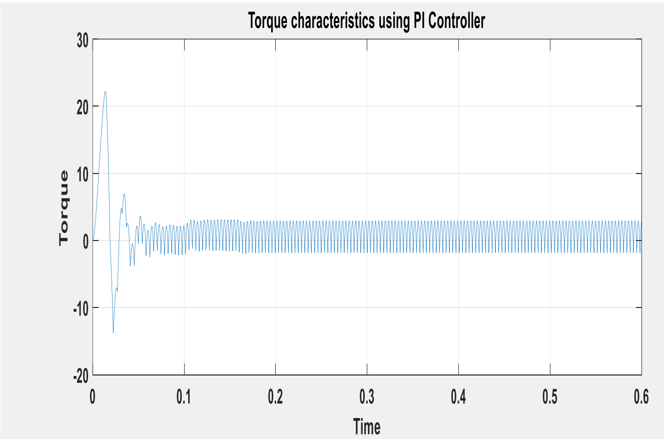


Fig.14. Torque waveform with-respect to PI- controller of BLDC motor

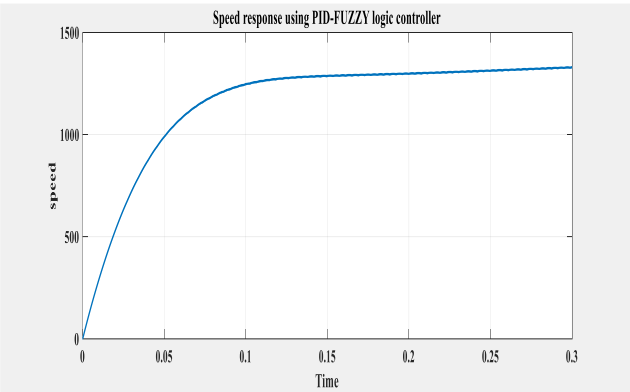


Fig.15. Speed waveform with-respect to FLC-PID of BLDC motor

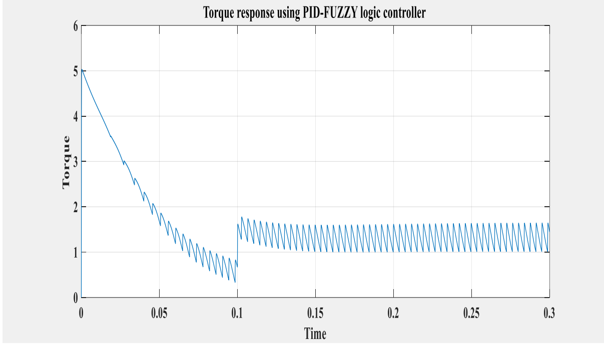


Fig.15. Torque waveform with-respect to FLC-PID of BLDC motor

VI. CONCLUSION

PM-BLDC machines are agreeing for all specific high-performance because it has high torque density, high-power density, less noise and high efficiency. BLDC motor dynamic mathematical modelling has been done successfully and also developed PI and FLC-PID to control the speed of BLDC. Thus, from simulation results can be analyzed by comparing PI and FLC-PID that speed and torque fluctuations are more by using PI controller. And the torque response and speed response with the PID-fuzzy logic controller are smooth and less fluctuation. So, obtained the good speed and torque response by usage the PID-Fuzzy logic controller.

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