Comparative Analysis of Brushless DC Motor drive with PI and Fuzzy Logic Speed Controller

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Abstract

In this paper a comparative study of speed control of Brushless DC (BLDC) motor drive with Proportional-Integral (PI) and Fuzzy Logic (FL) based speed controllers is evaluated. To develop and improve variable speed drive technology many efforts have been made in recent years which attempts to attain the desired speed of the motor. Unfortunately, traditional speed controllers such as proportional plus integral (PI) type controllers perform very well but only under small set of conditions. Even though they are widely used in industry due to their simple control structure and ease of implementation, these controllers do not operate properly when the system has a high degree of load disturbances, parametric variations and nonlinearity as in case of BLDC motor. In recent years, the application of fuzzy logic controller (FLC) for high dynamic performance of motor drives has become an important tool. These controllers are inherently robust to load disturbances and can be easily implemented. The modeling and simulation of both the speed controllers have been carried out in MATLAB/SIMULINK. Speed and torque response, obtained under PI and Fuzzy logic based speed controller, are compared for various operating conditions. The simulation results show that the FL based speed control of BLDC motor gives a better speed response and provides suitable output.

1. Introduction

BLDC motors are rapidly becoming popular in industries such as appliances, HVAC industry, medical, electric traction, automotive, aircrafts, military equipment, hard disk drive, industrial automation equipment and instrumentation because of their high efficiency, high power factor, silent operation, compact, reliability and low maintenance [1]. BLDC motors are a derivative of the most commonly used DC motor and they share the same torque and speed performance curve characteristics. The only major difference between the two is the use of brushes. BLDC motors do not have brushes so named "brushless DC" but the DC motors used to have brushes [2].

BLDC motor is conventionally defined as a permanent magnet synchronous motor with a trapezoidal back EMF waveform shape [3,4]. As the name implies, BLDC motor uses the electronic commutation for the process of changing the motor phase currents at the appropriate times of instants to produce rotational unidirectional torque. In a brush DC motor, the motor assembly contains a mechanical commutator which is moved by means of actual brushes in order to move the rotor. A BLDC motor has high reliability since it does not have any brushes to wear out and replace the mechanical brushes. This reduces the friction and thus, increases reliability[5]. To alternate the role of brushes and commutator, the BLDC motor requires an inverter and a speed sensor that detects rotor speed.

In this paper, a simple scheme with the speed and current controller is implemented. A PI controller is the most common controller in speed loop feedback system which is widely used in the industries due to its capabilities in controlling linear plants. However, it faces problem in controlling nonlinear plants such as electrical machines. These machines might behave as a nonlinear system, where non-linearity may appear due to armature current limitations, change of load and drive inertia [6,7]. The step response of the drive system for a given reference speed is one of the performance indicator of the speed controller. It is desired that the step response of the system can achieve fast settling response and without overshoot. However, PI controller cannot be tuned in such a way that the optimum step response is achieved for different inertia, load and speed reference. Thus, an intelligent controller such as fuzzy controller is needed for improving the speed response [8,9]. It may reduce the transient at the starting point and make it constant in short time of period. Therefore, the system would be more efficient to control the speed of BLDC motor. In general, fuzzy logic controller incorporates human intelligence into the process control application which can give better dynamic response of the system. A comparison is done between the PI speed controller and Fuzzy Logic speed controller to know which gives the better results.

2. Description of BLDC motor drive system

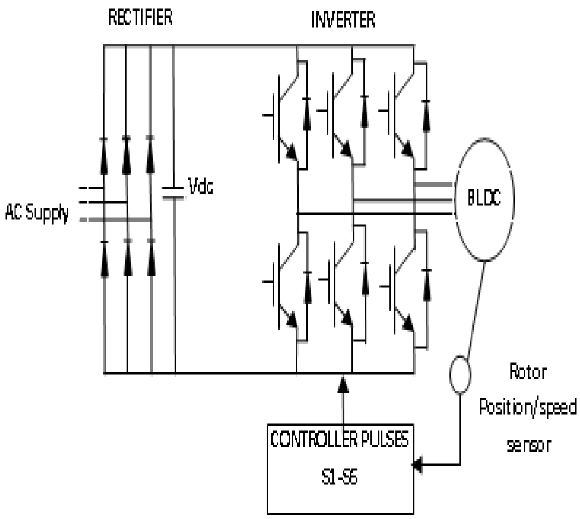

Figure.1 BLDC motor drive.

Figure.1 shows the BLDC motor drive with its power circuit and controller. The AC supply is rectified using the uncontrolled bridge rectifier and filtered. This DC voltage is then fed to the 3-phase inverter to get variable AC supply. This variable AC supply is then fed into the BLDC motor stator. The status of the BLDC motor parameters is given to the controller which compares it with the set point value and accordingly performs the switching of the inverter.

Figure.2 explains the control scheme for the controller. The BLDC drive here is operated in speed and current control mode. The actual speed of the motor is measured which is then compared with the reference speed and this speed error then generates the reference current with the help of reference current generator. This reference current is compared with the actual current in each phase winding and the error is processed by a current controller which generates the pulses for the proper switching of the inverter so that error could be minimized.

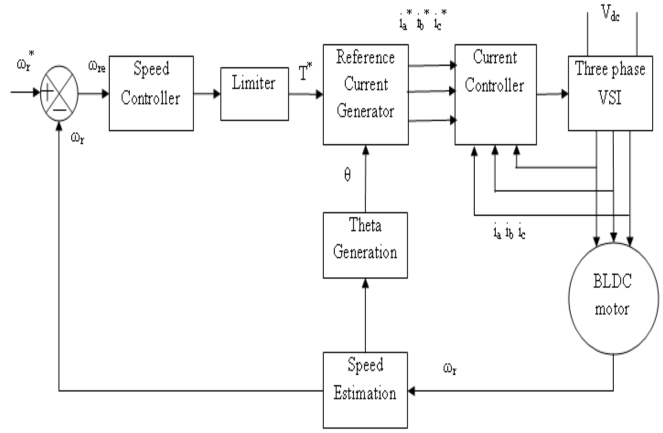

Figure. 2 BLDC control scheme

3. Mathematical model of BLDC motor

The BLDC motor has three stator windings and permanent magnets on the rotor. Since both the magnet and the stainless steel retaining sleeves have high resistivity, rotor-induced currents can be neglected and no damper windings are modeled. Hence the circuit equations of the three windings in phase variables are:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L_a & L_{ab} & L_{ac} \\ L_{ba} & L_b & L_{bc} \\ L_{ca} & L_{cb} & L_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

where V_{an} ,V_{bn} and V_{cn} are the phase winding voltage, Rs is the resistance per phase of the stator winding, while i_a, i_b, i_c are the phase current. Based on the equation (1), the equivalent circuit of motor can be obtained, as shown in Figure.3.

It has been assumed that the stator resistance of all the windings are equal. Assuming further that there is no change in the rotor reluctances with angle, then

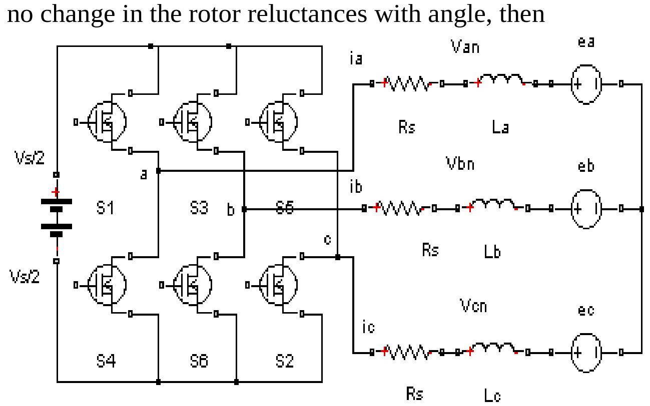

Figure.3 Equivalent ckt. of BLDC motor

$$L_a = L_b = L_c = L \quad (2)$$

$$L_{ab} = L_{ba} = L_{ac} = L_{ca} = L_{bc} = L_{cb} = M \quad (3)$$

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Substituting (2) and (3) in (1) gives the BLDC model as:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = R_s \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (4)$$

But

$$i_a + i_b + i_c = 0 \quad (5)$$

Therefore,

$$Mi_a + Mi_b = -Mi_c \quad (6)$$

Hence,

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = R_s \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (7)$$

The developed electromagnetic torque can be expressed as:

$$T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega_r} \quad (8)$$

The equation of motion is:

$$J \frac{d\omega_r}{dt} + B\omega_r = T_e - T_l \quad (9)$$

where J is moment of inertia in kg-m2, B is frictional coefficient in N-ms/rad, T_l is load torque in Nm. The derivative of electrical rotor position is expressed as:

$$\frac{d\theta_r}{dt} = \frac{P}{2} \omega_r \quad (10)$$

where *P* is number of pole, ω_r is the rotor speed in mechanical rad/sec and θ_r is the electrical rotor position in electrical radian.

4. Controller Description

4.1. Speed Controller

The speed controller used here is the PI controller and Fuzzy Logic Controller and the difference in the performance of the BLDC drive is presented in section 5.

1) PI Speed Controller: The actual speed of BLDC motor is obtained using the speed/position encoder and is compared with the set value and the error is processed by the PI speed controller as shown in Figure. 4 which is then used as the input of reference current block.

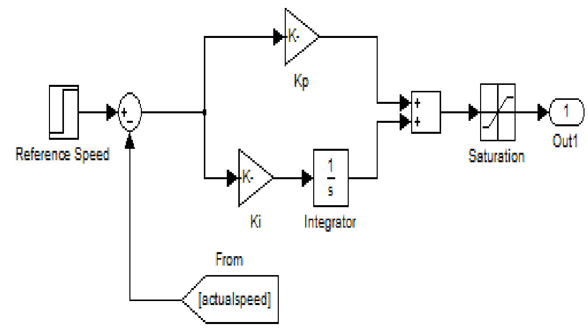

Figure.4 Block diagram of PI control system

2) Fuzzy Logic Speed Controller: Fuzzy logic control (FLC) is a control algorithm based on a linguistic control strategy which tries to account the human's knowledge about how to control a system without requiring a mathematical model. The approach of the basic structure of the fuzzy logic controller system is illustrated in Figure. 5.

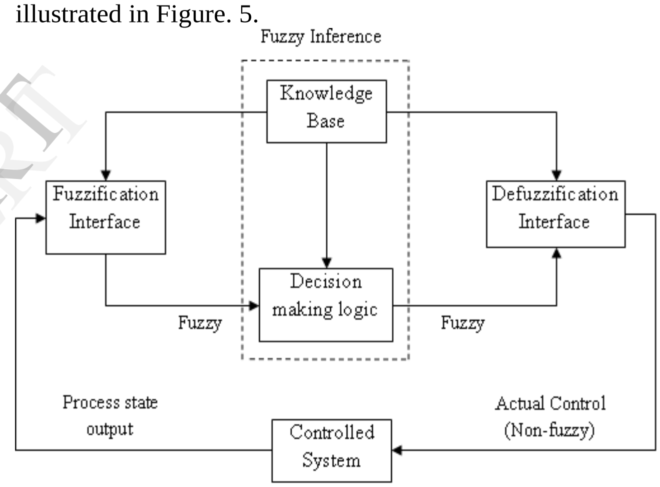

Figure.5 Structure of fuzzy logic controller

Input and output are non-fuzzy values. The basic configuration of FLC is featured in Figure. 6. In the system presented in this study, Mamdani type of fuzzy logic is used for speed controller. Inputs for Fuzzy Logic controller are the speed error e(k) and change in speed error ce(k). Speed error is calculated with comparison between reference speed, ω_{ref} and the actual speed, ω_{act}

$$e(k) = \omega_{ref} - \omega_{act} \quad (11)$$

$$ce(k) = e(k) - e(k-1) \quad (12)$$

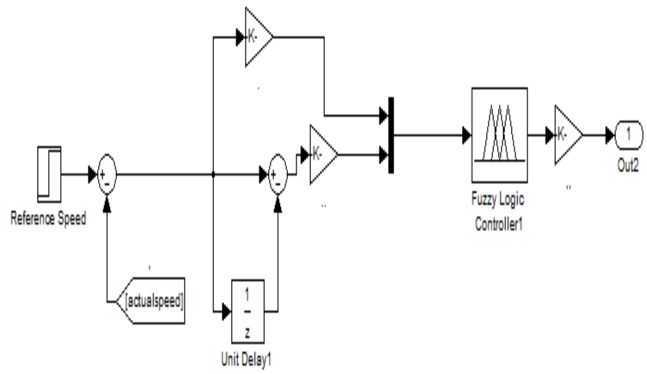

Figure.6 Block diagram of fuzzy control system

The output of the fuzzy controller u(k) is given by:

$$u(k) = e(k) - ce(k) \quad (13)$$

The fuzzy logic controller was used to produce an adaptive control so that the motor speed, ω_{act} can accurately track the reference speed, ω_{ref} . The most important things in fuzzy logic control system designs are the process design of membership functions for inputs, output and the process design of fuzzy if-then rule knowledge based. Figure. 7 shows the membership function of speed error e, change in speed error ce and output u variables.

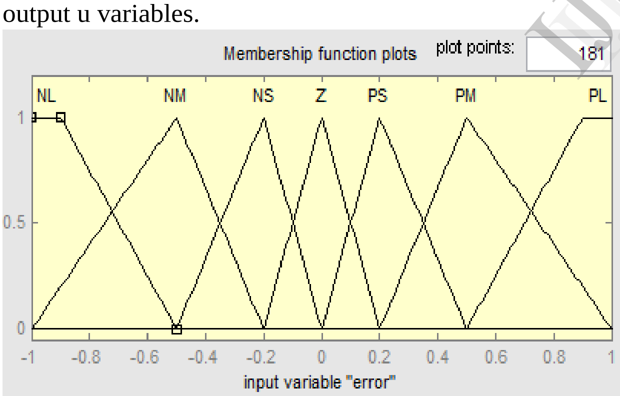

Figure.7 Membership function of e, ce, u

In practice, one or two types of membership functions are enough to solve most of the problems. Triangular and trapezoidal shapes were chosen as the membership function due its simplicity. The next step is to define the control rules. There are no specific method to design the fuzzy logic rules. However, the results from PI controller give an opportunity and guidance for rule justification. Therefore, after through a series of analysis, the total 49 rules have been justified as shown in Table 1. The membership function is divided into seven sets:

Negative Large (NL), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Large (PL). Each fuzzy variable is a member of the subsets with a degree of membership μ varying between 0 and 1.

Table 1. Rule base for the fuzzy logic speed controller

e / ce	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	Z
NM	NL	NL	NL	NM	NS	Z	PS
NS	NL	NL	NM	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PM	PL	PL
PM	NS	Z	PS	PM	PL	PL	PL
PL	Z	PS	PM	PL	PL	PL	PL

4.2. Reference Current Generator

The output of the speed controller is reference torque and the reference current is derived from the torque by the expression:

$$T^* = K_T I^* \quad (14)$$

4.3. Hysteresis Current Controller

The reference currents are compared with the actual stator currents and the resulting error is is given as the input to the Hysteresis current controller. as shown in Figure. 8 to generate necessary PWM signal for the inverter.

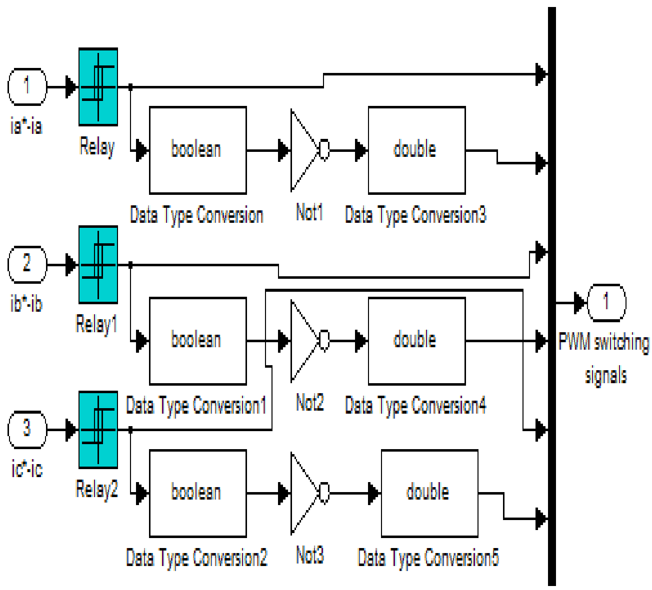

Figure. 8 Hysteresis current controller

5. Simulation Results

Simulation of BLDC motor is carried out using MATLAB/SIMULINK. Complete specifications of the BLDC motor are given in Table 2. The simulation is done to compare the performance of BLDC motor when PI and Fuzzy Logic speed controller is used. The BLDC motor was simulated under the following different conditions. The motor speed and electromagnetic torque is observed for each case.

Table 2. Simulation parameter of BLDC motor

PARAMETERS	VALUES
Pole Pairs	4
Stator Resistance per phase	1.5Ω
Stator Inductance per phase	8.5mH
Torque Constant(Nm/Apeak)	1.4
Voltage Constant(VpeakL-L/krpm	146.077
Moment of Inertia	0.008kgm^2
Friction Coefficient	0.001Nms

CASEI: At no-load condition

Figure. 9 show the performance of BLDC motor during no-load condition with PI and Fuzzy Logic speed controller. The motor is set for a reference speed of 3000 rpm. From the speed and torque response it is observed that there is smooth change in speed and torque with FLC.

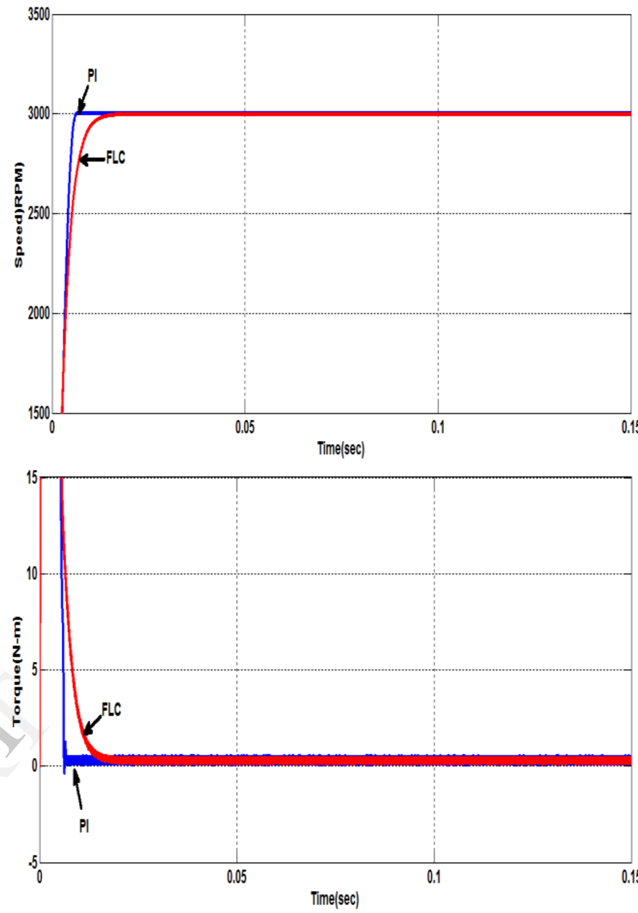

Figure.9 Comparison of speed and torque response at no-load condition

CASEII: At load condition

Sudden change in load is applied to the motor from no-load to 2 N-m at 0.05 sec. At this point wave form is distorted for a few second or there is a fluctuation in speed for few second as shown in Figure. 10. The sudden application of load on motor results in small dip in motor speed. From the torque response it is observed that the torque produced by PI controller contains ripples at the time of change in load and also at the start while there is a smooth change in torque with change in load when FLC is used.

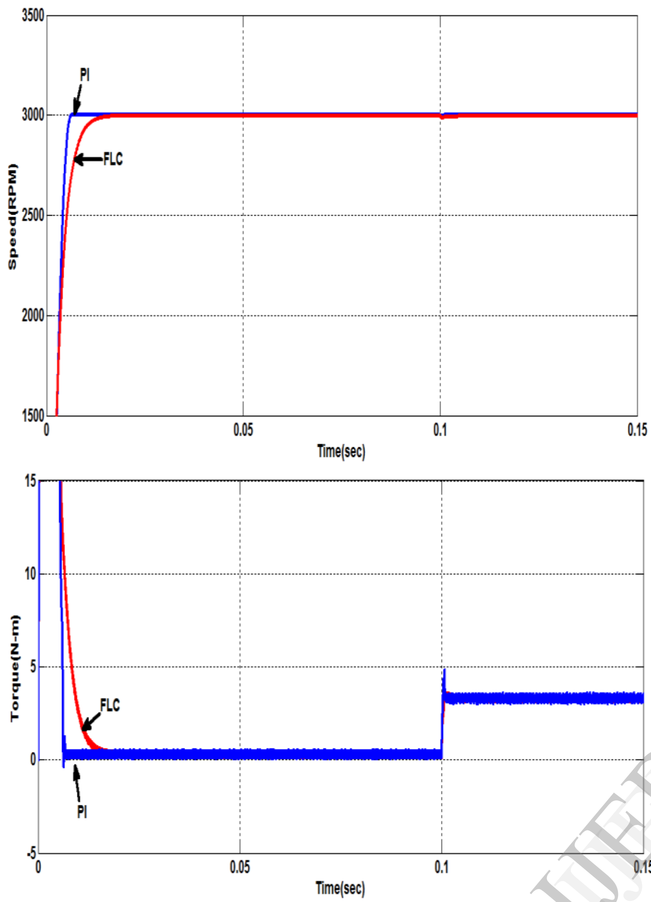

Figure. 10 Comparison of speed and torque response at load condition

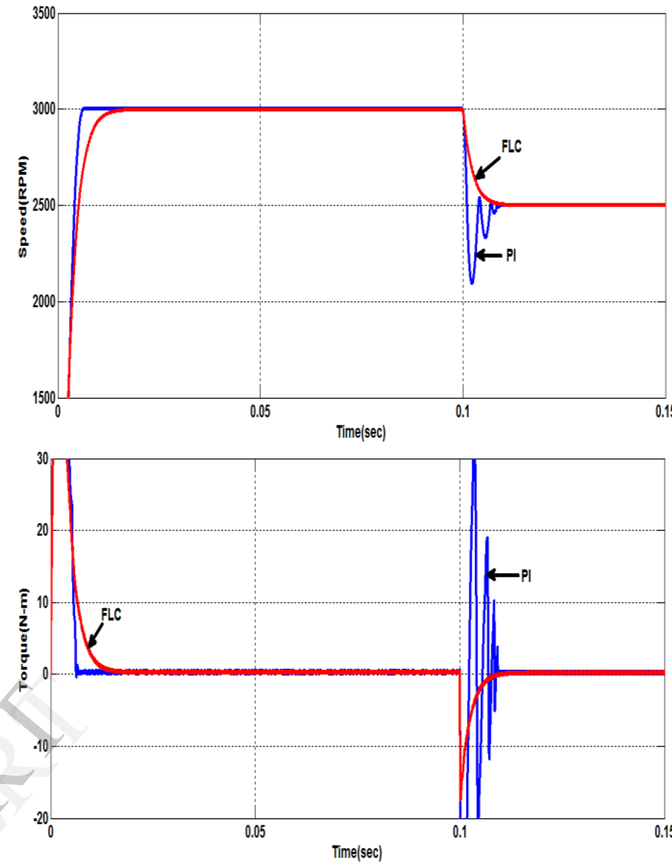

Figure. 11 Comparison of speed and torque response with change in reference speed condition

CASEIII: With change in reference speed condition

When there is change in reference speed from 3000 rpm to 2500 rpm at 0.05sec, it is observed that the motor reach the set value with a smooth change in speed with FLC speed controller while the speed contains few ripples before reaching to desired set value when PI controller is used as shown in Figure. 11. From the torque response it is observed that the toque contains high ripples with PI speed controller as compared to FLC speed controller at the time of change in reference speed.

6. Conclusion

This paper is proposed to evaluate the performance of two controllers namely, PI and Fuzzy Logic controllers for speed control of BLDC motor drive system. Fuzzy Logic was used in the design of speed controllers of the drive system and the results are compared with that of PI controller. It has been observed that the fuzzy logic controller overcomes the limitations of PI controller like the overshoot in speed, thus the starting current overshoot can be reduced. The advantages of the Fuzzy controller are that it reduces computational time, learns faster and produces lower errors than other method. By proper design a Fuzzy Logic controllers is much better then PI controllers for the speed control of BLDC motor drives.

7. References

[1] K. Naga Sujatha, K. Vaisakh and Anand. G. 2010. Artificial Intelligence based speed control of brushless DC motor. IEEE 978-1-4244-6551-4/10.

[2] Pragasan Pillay and R. Krishnan,"Modeling Simulation and Analysis of Permanent Magnet Motor Drives, Part II: The Brushless DC Motor Drives", *in IEEE Trans. on Industrial Applications*, vol. 25, no. 2, pp. 274-279, MarchiApril 1989.

[3] J. Karthikeyan, R. Dhana Sekaran, “Current Control of Brushless DC Motor Based on a Common DC Signal for Space Operated Vehicles,” in *Electrical Power and Energy Systems*, vol. 33, pp. 1721-1727, August 2011.

[4] F. Farkas, A. Zakharov and S.Z. Varga, *“Speed and position controller for dc drives using fuzzy logic”*, Studies in Applied Electromagnetics and Mechanics (Vol. 16): Applied Electromagnetics and Computational Technology II, Amsterdam: IOS Press, 2000.

[5] Zulkifilie Ibrahim and Emil Levi, "A comparative analysis of fuzzy logic and pi speed control in high-performance ac drives using experimental approach", *IEEE Trans. on Industry Applications* 38(5): pg 1210-1218, 2002.

[6] Balogh Tibor,Yiliam Fedak, Frantisek Durovsky, "Modeling and Simulation of the BLDC Motor in MATLAB GUI," International Symposium on Industrial Electronics (ISIE), pp. 1403-1407,2011.

[7] Ii Hua, Zibo, Li Zhiyong, "Simulation of Sensorless Permanent Magnetic Brushless DC Motor Control System" Proceedings of the International Conference on Automation and Logistics Qingdao, pp. 2847-2851, 2008.

[8] Tan chee Siong, Baharuddin Ismail, Siti Fatimah Siraj, Mohd Faridun Naim Tajuddin, Noor Shahida Jamoshid, Mohd Fayzul Mohammed, “Analysis of Fuzzy Logic Controller for Permanent magnet Brushless Dc Motor Drives”, *Proceedings of the IEEE Student Conference on Research and Development*, pp. 436-441, December 2006.

[9] V. M. Varatharaju, B.L. Mathur, “Speed Control of PMBLDC Motor using MATLAB/SIMULINK and Effects of Load and inertia Changes”, *IEEE International Conference on Mechanical and Electrical Technology*, pp. 543-547, 2010