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PI AND FUZZY LOGIC CONTROLLED PMBLDC MOTOR

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ABSTRACT

This paper presents performance of PI and Fuzzy Logic Controlled (FLC) Permanent Magnet Brush Less DC Motor (PMBLDCM). The Fuzzy Logic (FL) approach applied to speed control leads to improved dynamic behavior of the motor drive system and immune to load perturbations and parameter variations. The FLC is designed based on a simple analogy between the control surfaces of the FLC and Proportional-Integral (PI) controller for the same application. Hysteresis current controller (HCC) is used for producing gate pulses for BLDC motor inverter. This work focuses on investigation and evaluation of the performance of a permanent magnet brushless DC motor (PMBLDC) drive, controlled by PI and Fuzzy logic speed controllers. Fuzzy logic control offers an improvement in the quality of the speed response, compared to PI control. The results are validated by simulating the PMBLDCM drive with PI and Fuzzy logic controllers using MATLAB/SIMULINK.

Keywords: Fuzzy logic controller, Hysteresis current controller, Permanent magnet brushless dc motor, Proportional integral controller.

1. INTRODUCTION

Permanent magnet motor drives, which include the permanent magnet synchronous motor (PMSM) and the permanent magnet brushless dc motor (PMBLDCM) arte extensively used for servo applications [1]. The PMSM has a sinusoidal back EMF and requires sinusoidal stator currents to produce constant torque while the PMBLDCM has a trapezoidal back EMF and requires rectangular stator currents to produce constant torque [2]. The PMSM is very similar to the standard wound rotor synchronous machine except that the PMSM has no damper windings and excitation is provided by a permanent magnet instead of a field winding [3]. Hence the d-q model of the PMSM can be derived from the well-known d-q model of the synchronous machine with the equations of the damper windings and field current dynamics removed [4]. As is well known, the transformation of the synchronous machine equations from the a-b-c phase variables to the d-q variables forces all sinusoidal varying inductances in the a-b-c frame to become constant in the d-q frame. In the PMBLDCM, since the back EMF is non-sinusoidal, the inductances do not vary sinusoidally in the a-b-c frame and it does not seem advantageous to transform the equations to the d-q frame since the inductances will not be constant after transformation. Hence it is proposed to use the a-b-c phase variables model for the PMBLDCM. In addition, this approach in the modeling of the PMBLDCM allows a detailed examination of the machine's torque behavior that would not be possible if any simplifying assumptions were made. The d-q model of the PMSM has been used to examine the transient behavior of a high performance vector controlled PMSM servo drive [5]. In addition, the a-b-c phase variable model has been used to examine the behavior of a PMBLDCM speed servo drive [6]. Application characteristics of both machines have been presented in [7].

The ac servo has established itself as a serious competitor to the brush-type dc servo for industrial applications. In the fractional to 30HP range, the available AC servos include the induction, permanent-magnet synchronous, and brushless dc motors (PMBLDCM) [8]. Typically, Hysteresis or pulse width-modulated (PWM) current controllers are used to maintain the actual currents flowing into the motor as close as possible to the rectangular reference values. Some steady-state analysis of PMBLDCM has been done [9].This paper proposes modeling, detailed simulation of PMBLDCM with hysteresis current controller, PI and Fuzzy logic controllers for speed control. Section 2 presents principle of operation of BLDCM, section 3 presents control strategy used for speed control, section 4 presents simulation of the PMBLDCM with controllers using SIMULINK, Section 5 presents simulation results and discussion and section 6 presents conclusion.

2. PRINCIPLE OPERATION OF PERMANENT MAGNET BRUSHLESS DC MOTOR

A brush less DC motor is a permanent magnet synchronous machine with rotor position feedback. The brushless motors are generally controlled using a three phase power semiconductor bridge. The motor requires a rotor position sensor for starting and for providing proper commutation sequence to turn on the power devices in the inverter bridge.

Based on the rotor position, the power devices are commutated sequentially every 60 degrees, instead of commutating the armature current using brushes, electronic commutation is used. For this reason it is an electronic motor. This eliminates the problems associated with brushes and commutator arrangement. The basic block diagram of Brushless dc motor (BLDCM) is shown Fig.1. The brush less DC motor consists of four main parts namely power converter, permanent magnet-synchronous machine (PMSM), sensors and control algorithm. The power converter transforms power from the source to the PMSM which in turn converts electrical energy to mechanical energy. One of the salient features of the BLDCM is that based on the rotor position and command signals which may be a torque command, voltage command or speed command, the control algorithm determines the gate signal to each semiconductor device in the power electronic converter. Based on the gate signals the converter will supply required current to obtain the desired speed

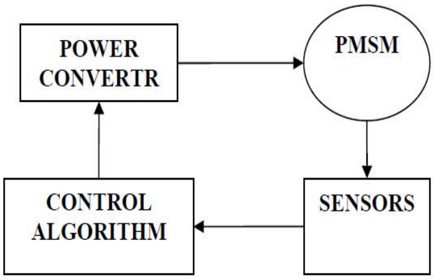

Fig.1 Block diagram of BLDC motor [10].

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The structure of control algorithms determine the type of BLDCM whether it is voltage source based drive or current source based drive. Both voltage source and current source based drives are used with permanent magnet synchronous machine with either sinusoidal or non-sinusoidal back EMF waveforms. Machine with sinusoidal back EMF may be controlled so as to achieve nearly constant torque. However, machine with a non sinusoidal back emf reduces inverter size and losses for the same power level. Hence in this paper BLDCM with non-sinusoidal back emf is used.

3. CONTROL STRAREGY USED FOR SPEED CONTROL OF PMBLDCM

The control strategy used for speed control of PMBLDCM includes rotor position based reference current generator, PI and Fuzzy logic controllers with Hysteresis current controller for gate signal generation.

3.1 Reference current generator

The magnitude of the three phase reference current i_{ref} is determined by using reference torque T_{ref} given in Equation (1).

$$I_{ref} = \frac{T_{ref}}{K_t} \qquad (1)$$

where K_t is the torque constant which depends on the rotor position.

The reference current generator block generates three-phase reference currents (i_a^*, i_b^*, i_c^*) which are functions of rotor position by taking the value of Reference current magnitude as i_{ref}. The reference currents are fed to the Hysteresis current controlled PWM. The reference currents for different rotor positions are shown in Table. I.

Table 1: Rotor position signal and Reference currents.

Rotor position θ_r	i_a^*	I_b^*	I_c^*
0 -60	i_{ref}	-i_{ref}	0
60 -120	i_{ref}	0	-i_{ref}
120 -180	0	i_{ref}	-i_{ref}
180 -240	-i_{ref}	i_{ref}	0
240 - 300	-i_{ref}	0	i_{ref}
300 -360	0	- i_{ref}	i_{ref}

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3.2 Hysteresis current controlled PWM

The Hysteresis current controller contributes to the generation of the switching signals for the inverter based on the reference currents generated by reference current generator. Hysteresis-band PWM is basically an instantaneous feedback current control method where the actual current continuously tracks the reference current within hysteresis-band. The operation principle of hysteresis-band PWM for half-bridge inverter is shown in Fig. 2. The control circuit generates the sine reference current which is compared with actual phase current to determine the error signal which is applied to switching logic. When the error exceeds upper limit of hysteresis band the upper switch is OFF and lower switch is ON and when the error exceeds lower limit of the band, upper switch is ON and lower switch is OFF[11]. Same procedure is adopted for phases b and c also and the switching logic is formulated.

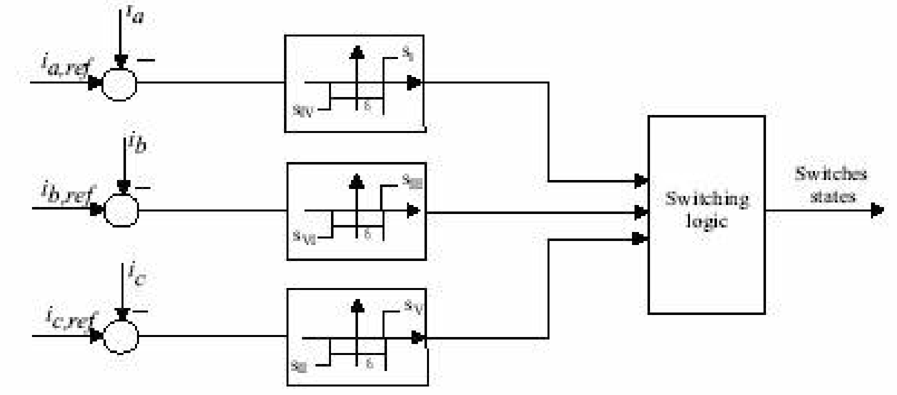

Fig.2. Hysteresis current control PWM.

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if $i_a < (i_a^* - h_b)$	Switch 1 ON and Switch 4 OFF $S_A = 1$
if $i_a < (i_a^* + h_b)$	Switch 1 ON and Switch 4 OFF $S_A=0$
if $i_b < (i_a^* - h_b)$	Switch 3 ON and Switch 6 OFF $S_B = 1$
if $i_b < (i_b^* + h_b)$	Switch 3 ON and Switch 6 OFF $S_B = 0$
if $i_c < (i_c^* - h_b)$	Switch 5 ON and Switch 2 OFF $S_C = 1$
if $i_c < (i_c^* + h_b)$	Switch 5 ON and Switch 2 OFF $S_C = 0$

where, h_b is the hysteresis band around the three phase references currents. According to above switching conditions, the inverter output voltage are given by

$$v_a = 1/3\,[\,2S_A - \mathbf{S_B} - \mathbf{S_C}\,]$$
$$v_b = 1/3\,[-S_A + 2S_B - S_C\,]$$
$$v_c = 1/3[\,-S_A - S_B + 2S_C\,]$$

3.3. PI Speed controller

The block diagram of PMBLDCM with PI speed controller is shown in Figure.3. The drive consists of PI speed controller, reference current generator, current controlled PWM, position sensor, the PMBLDCM and IGBT based current controlled voltage source inverter (CC-VSI). The rotor speed is measured and compared with reference speed to generate speed error which is fed to PI controller. The output of PI controller is considered as the reference torque. A limit is put on the speed controller output depending on permissible maximum winding current. The reference current generator block generates the three phase reference currents i_a^*, i_b^*, i_c^* using the limited peak current magnitude decided by the controller and the position sensor. The reference currents have the shape of quasi-square wave in phase with respective back EMF which develops constant unidirectional torque. The PWM current controller regulates the winding currents i_a, i_b, i_c within a small band around. The reference currents (i_a^*, i_b^*, i_c^*) are compared with the motor currents (i_a, i_b, i_c) and the switching commands are generated to drive the inverter switches.

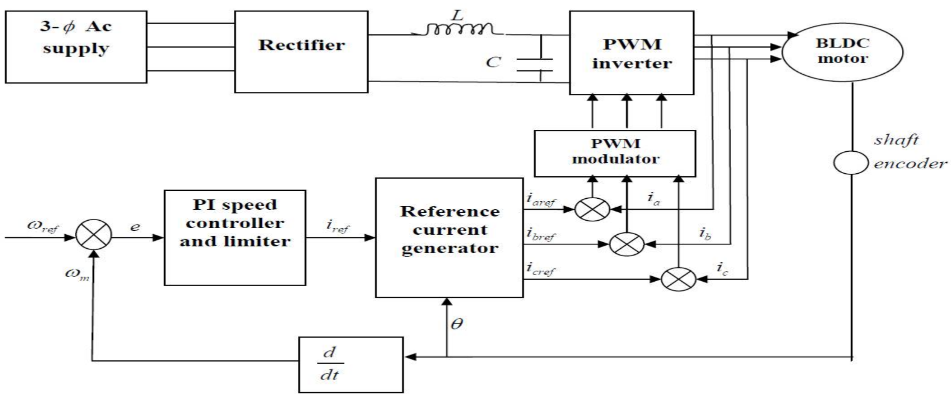


Fig 3 PI speed controller based BLDCM drive.

3.4 SIMULINK Model of PMBLDC motor with PI controller

The SIMULINK model of PMBLDCM with PI controller is shown in Fig. 4.

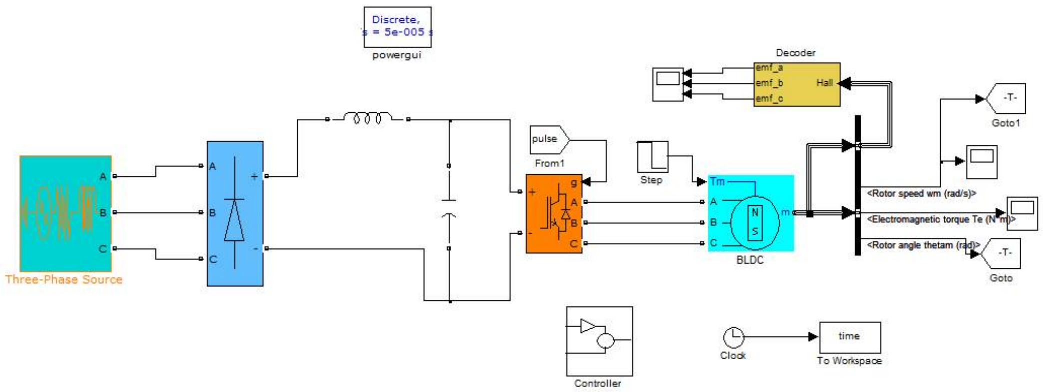


Fig.4 Simulink model of PI controller based PMBLDCM.

The simulink model of PI controller based BLDCM consists a 3-phase AC source of voltage 230V(rms)/phase to neutral, 50 Hz frequency and connected to diode bridge rectifier with LC filter (L= 1mH ,C=5 µF) which is connected to Universal bridge and supplying AC to 3-phase BLDC motor

3.4.1 Simulink model of PI controller

The SIMULINK model of PI controller with hysteresis current control is shown in Fig. 5. The K_p and K_i values taken are 0.2 and 48 respectively. The hysteresis band value is taken as 1.

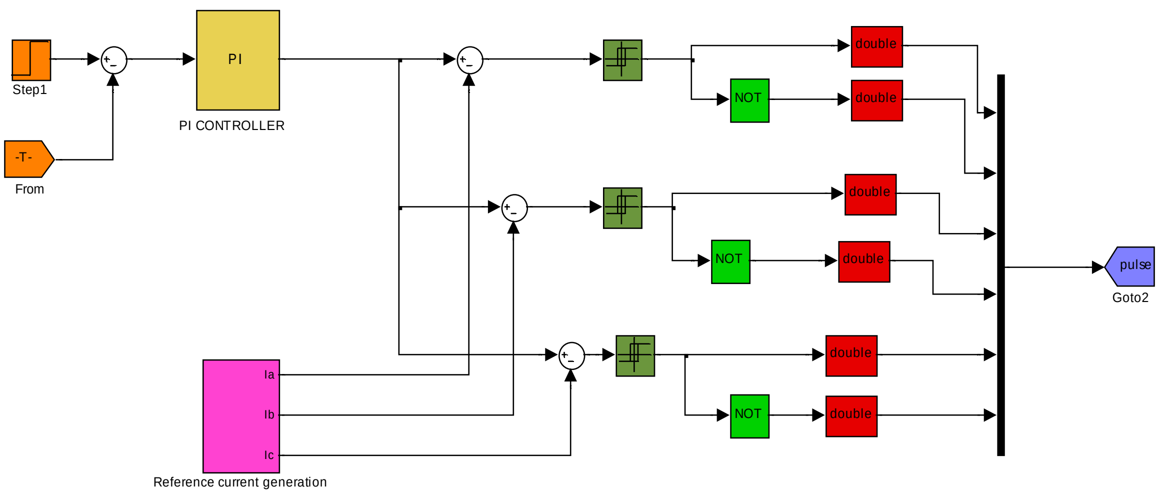


Fig. 5 PI controller SIMULINK model.

3.4.2 Reference current generator

The SIMULINK model used to determine the reference compensating current is shown in Fig. 6. It determines reference current based on rotor position.

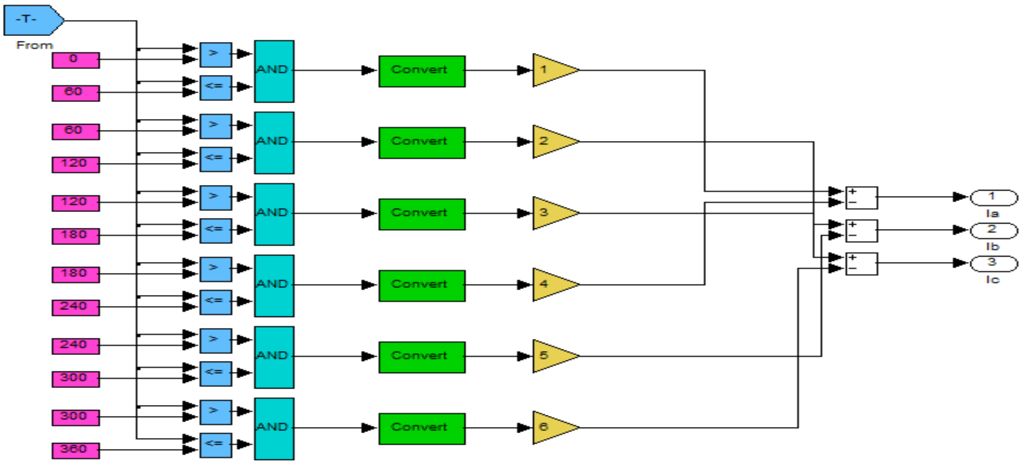


Fig. 6 SIMULINK model for rotor angle measurement

3.4.3 Rotor speed measurement

The SIMULINK model used for measuring speed of PMBLDCM is shown in Fig. 7.

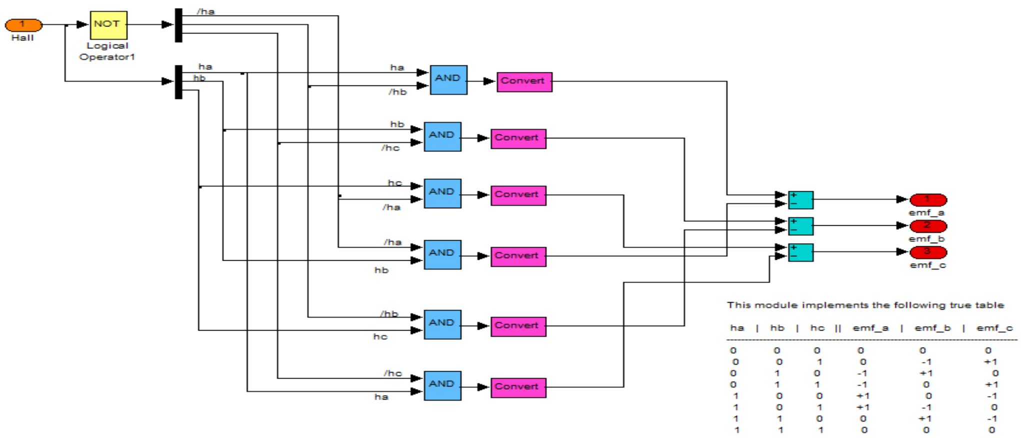


Fig.7 Simulink model for rotor speed measurement

3.5. Fuzzy logic controller based BLDC motor

The block diagram of PMBLDCM drive with Fuzzy logic speed controller is shown in Figure.8.

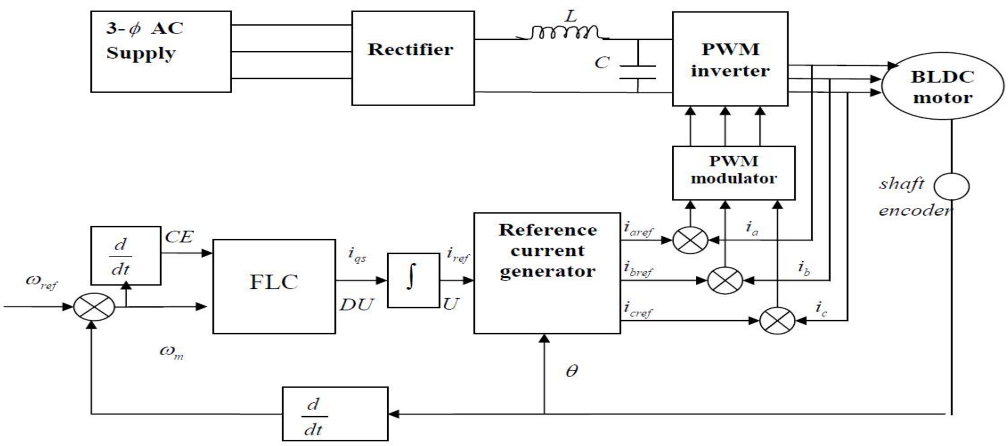
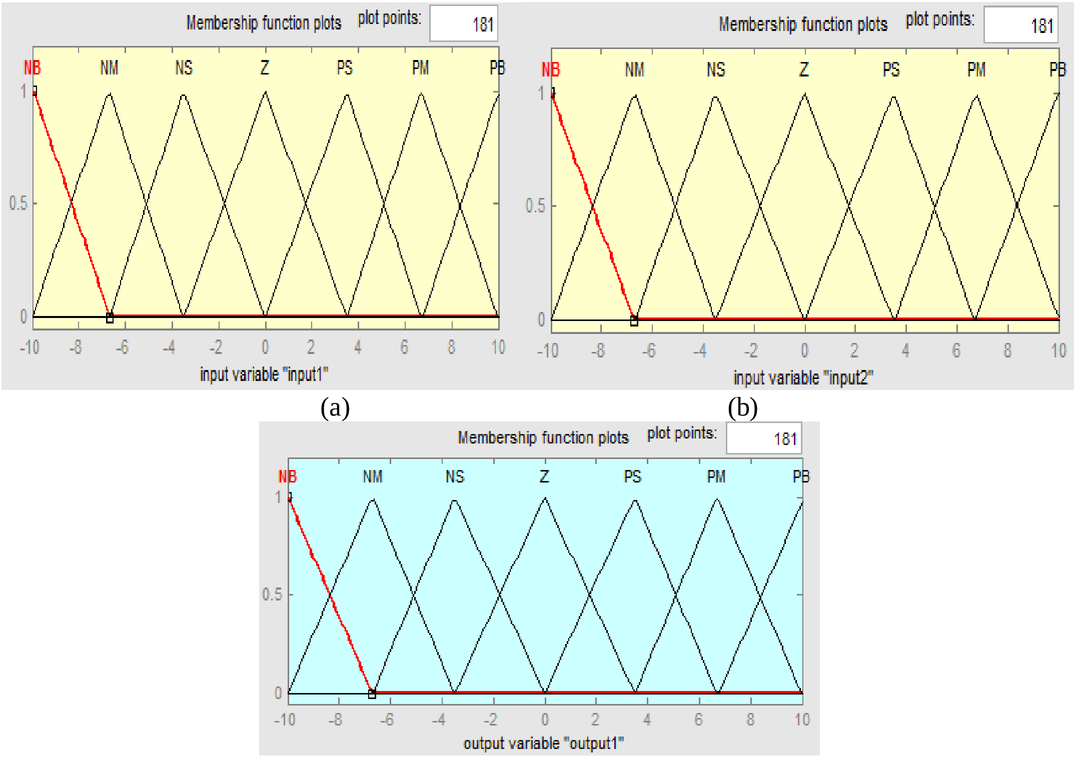


Fig.8 Block diagram of the BLDC motor with Fuzzy logic speed controller.

In this model Fuzzy logic controller is used to control the speed of PMBLDCM. The two inputs to Fuzzy logic controller are speed error (ω_e) and change in speed error (ω_{ce}) and the output is torque reference current change (Δi_{qs}). Seven triangular member ship functions namely Positive Big (PB), Positive Medium(PM), Positive Small(PS),Zero(ZO), Negative Small(NS), Negative Medium(NM) and Negative Big(NB) are taken for each input and output variable. The input variable speed error and change in speed error are defined in the range of $-1\leq \omega_e \leq +1$ and $-1\leq \omega_{ce} \leq +1$ and the output variable torque reference current change Δiqs is define in the range of $-1\leq \Delta i_{qs} \leq +1$. The membership function for the speed error and the change in speed error and the change in torque reference current are shown in Fig.9. Table. II shows the 7×7 rule base that is used in the fuzzy logic controller.



(a) (b) (c)

Fig.9. Fuzzy logic membership functions for (a) speed error (b) Change in speed error and (c) output.
In this paper Mamdani is used for Fuzzyfication and centroid method is used for defuzzification.

The MATLAB/SIMULINK model of Fuzzy speed controller with Hysteresis control is shown in Figure 10.

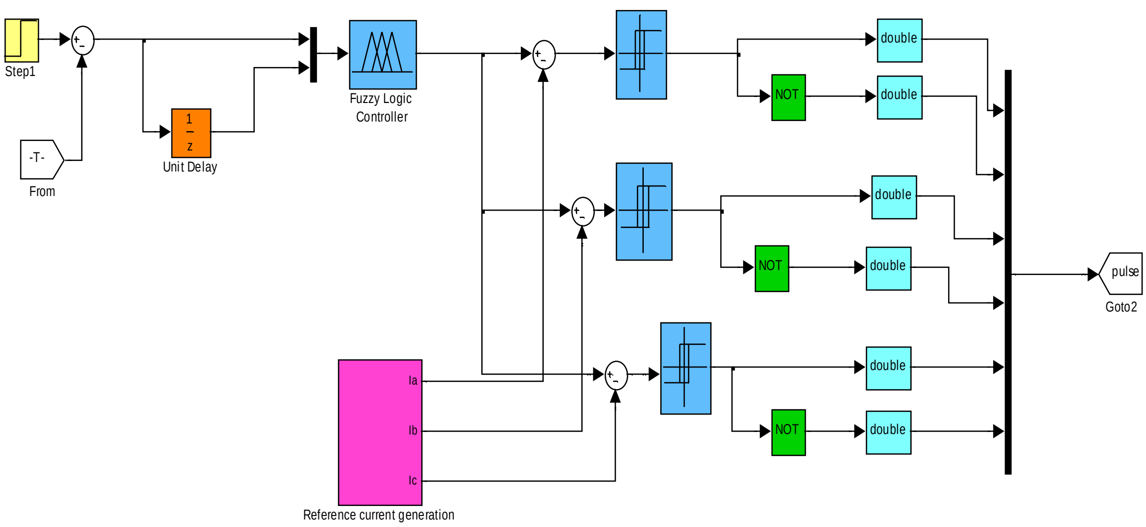


Fig:10. Simulink model of Fuzzy logic speed controller.

4. SIMULATION RESULTS AND DISCUSSION

The MATLAB simulation results for PMBLDCM with PI and fuzzy logic speed controllers are discussed in sections 4.1 1and 4.2 respectively.

4.1 Simulation results of BLDCM with PI speed controller

The Figure 11 shows the rotor speed of BLDCM with PI controller. From this it is observed that speed is maintained constant with narrow band of 5 rad/sec. Figures 12 and 13 show the back EMF and Electromagnetic torque of BLDCM with PI controller respectively.

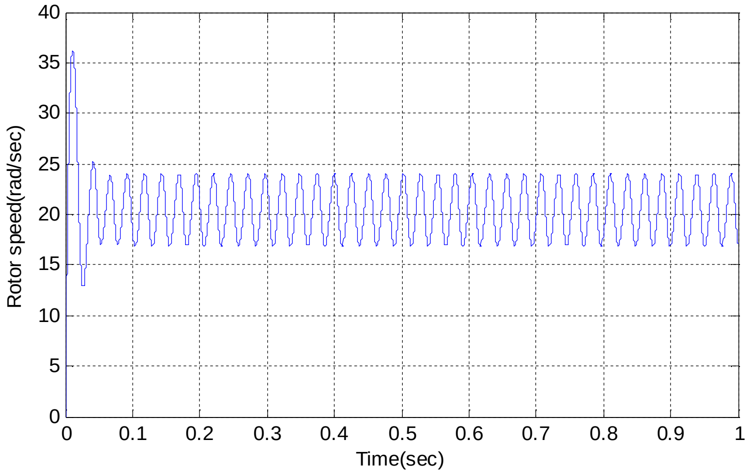


Fig. 11 Rotor speed of BLDCM with PI speed controller.

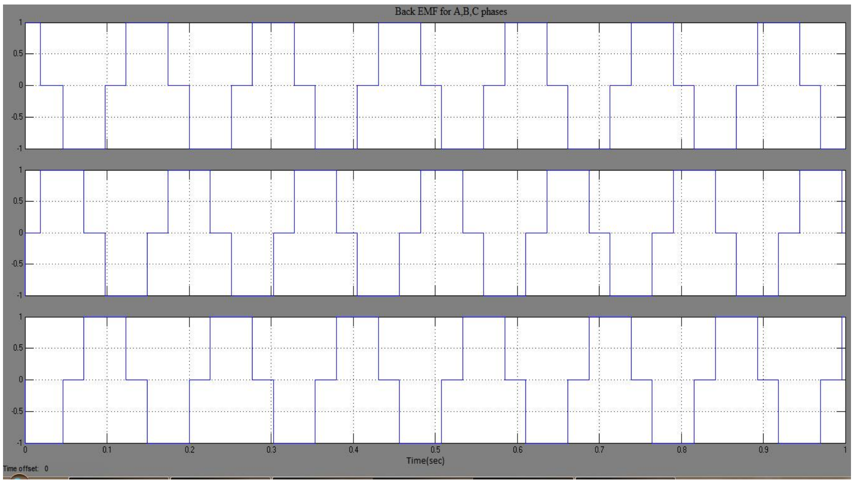


Figure 12. Emf waveforms of BLDCM with PI controller.

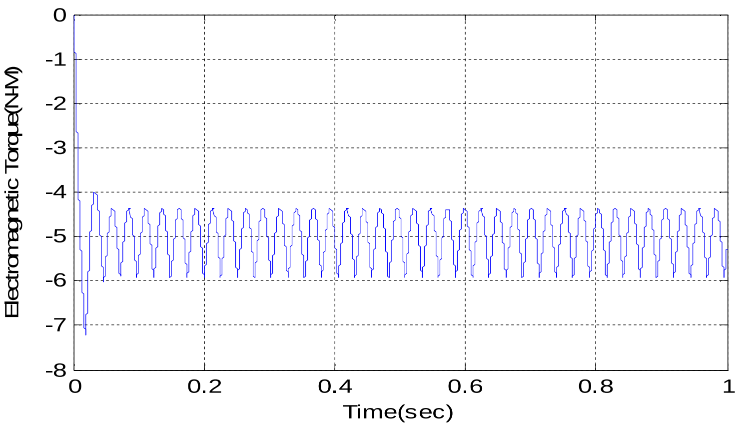


Figure 13. Electromagnetic torque of BLDCM with PI controller.

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4.2 Simulation results of BLDC motor with fuzzy speed controller

The variation of speed with Fuzzy logic controller for the PMBLDCM is shown in Fig.14 and it is observed that speed is maintained constant with a variation of 2.5 rad/sec. The back EMF and the electromagnetic torque developed in the BLDCM are shown in Figures 15 and 16 respectively. Thus the variation in speed is reduced from 5 rad/sec to 2.5 rad/sec with fuzzy logic controller when compared to PI controller.

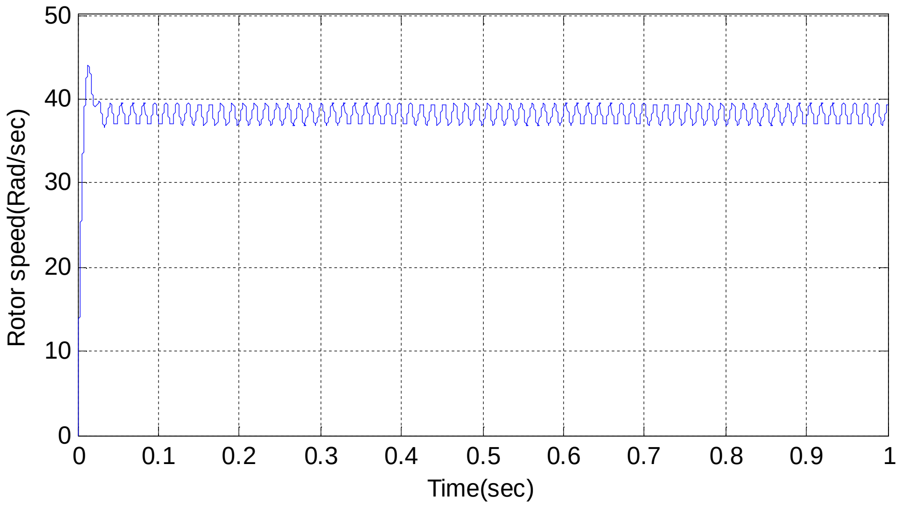

Fig. 14 Rotor speed of BLDCM with Fuzzy logic controller.

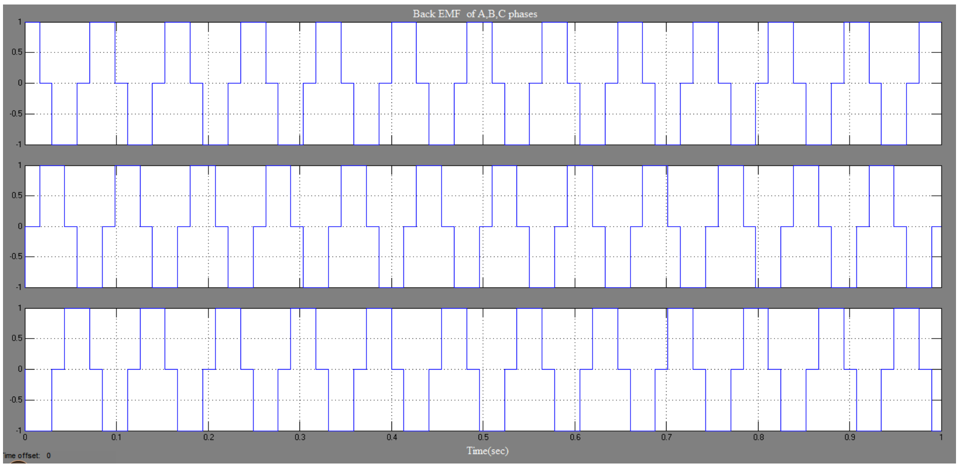

Fig. 15 Emf waveforms of BLDCM with Fuzzy logic controller.

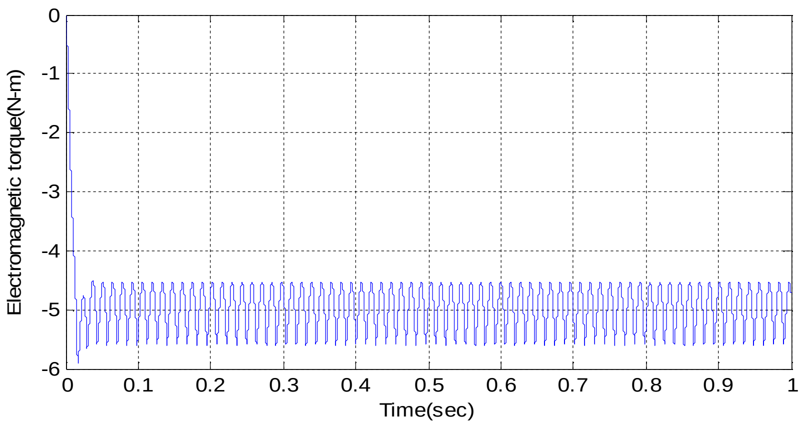

Fig. 16 Electromagnetic torque of BLDCM with Fuzzy logic controller.

5. CONCLUSION

A fuzzy logic controller (FLC) is simulated using simulink for the speed control of PMBLDC motor drive and the results are analyzed and presented. The complete simulation of the drive system with PI and fuzzy logic controllers is described in this paper. Hysteresis current controller is effectively simulated and implemented to produce required gating signals. A performance comparison between the fuzzy logic controller and the conventional PI controller has been carried out by simulation runs confirming the validity and superiority of the fuzzy logic controller. The implementation of fuzzy logic controller is adjusted such that manual tuning time of the classical controller is significantly reduced.

REFERENCES

[1]. Bianchi. N, Bolognani.S, Jang.J.H, Sul.S.K., Comparison of PM motor structures and sensorless control Techniques for Zero-speed rotor position detection, IEEE Transactions on Power electronics, 2007, 22, p.p. 2466-2475.
[2]. Hubic.V, Sveda.M, Singule. V., On the development of BLDC motor control run – up algorithms for Aero space applications, In proceedings of the 13th Power Electronics and Motion control conference(EPE-PEMC -2008), Poznan, Poland, pp.1620-1624.
[3]. P. Pillay and R. Krishnan, “Modeling, simulation and analysis of permanent magnet brushless DC motor drive, IEEE Transactions on Industrial Applications, No. 26. 2002, pp 124-129.
[4]. R. Krishnan, “Selection criteria for servo motor drives,” in Proc.IEEE IAS Annu. Meeting, 1986, pp. 301-308.
[5]. T. M. Jahns, “Torque production in permanent-magnet synchronous motor drives with rectangular current excitation,” IEEE Trans. Ind. Appl., vol. IA-20, no. 4, pp. 803-813,July/Aug. 1984.
[6]. Su.G.J, McKeever. J.W., Low cost sensorless control of Brushless DC Motors with improved speed range, IEEE Transactions on Power Electronics, 2004,19, p.p. 296-302.
[7]. Damodharan.P, Vasudevan. K., Indirect back-emf Zero crossing detection for sensorless BLDC motor operation, In Proceedings of the International conference on power electronics and drives systems(PEDS 2008), Kuala Lumpur, Malaysia. Nov. 2008, p.p. 1107- 1111.
[8]. M. V. Ramesh, J. Amarnath , S. Kamakshaiah and G. S. Rao ,“Speed Control Of Brushless Dc Motor By Using Fuzzy Logic PI controller”, Journal of Engineering & Applied Sciences,2011.
[9]. R. Arulmozhiyal, and R.Kandiban "An Intelligent Speed Controller for Brushless DC Motor" presented at Industrial Electronics and Applications (ICIEA), 2012 7th IEEE Conference on, 18-20 July 2012.
[10]. Jiancheng Fang, Haitao Li and Bangcheng Han,”Torque Ripple Reduction in BLDC Torque Motor With Nonideal Back EMF,” IEEE
[11]. Transactions On Power Electronics, Vol. 27, No. 11, November 2012.
[12]. Sreekala.P, and Prof.Dr.A.Sivasubramanian "Speed Control Of Brushless Dc Motor With Pi And Fuzzy Logic Controller Using Resonantpole Inverter" presented International Journal of Computer Applications (0975 – 8887) Volume 109 – No. 10, January 2015