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Comparative Study of Controller Design for Four Quadrant Operation of Three Phase BLDC Motor

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Abstract

Brushless DC motor drives are becoming more popular in industrial and traction applications. The control of BLDC motor in four quadrants is very vital. The three-phase permanent magnet brushless dc motor inherently needs an electronic commutation circuit to drive it, because it is not a self-commutating motor. It is contrary to the conventional brush motor which commutates itself. This paper presents a comparison study of three type of control such as PI, PID & fuzzy. The characteristics of the three control methods are investigated intensely and the advantages, disadvantages of each are compared to the others with the help of MATLAB simulink software.

Keywords: BLDC-motor, simulation comparison of PI, PID& FLC

Introduction

The performance of BLDC motor is similar to DC motor but it works without brushes. It is also known as electronically commutated motor and it is powered by DC electricity and it has many like reliable operation, low maintanence,high dynamic speed, better control performance. Here the BLDC motor consist of rotating rotor with rare earth magnet and a stator. Rare earth permanent magnet improves the power density and dynamic performance of the machine. Some of the rare materials are Alnico, Ceramic or ferrite magnets, samarium cobalt, Neodymium iron boron those materials were had hard magnet material having a very high hysteresis property and working in second quadrant of B-H loop. The quality of permanent magnet is characterized by B_r,H_c,$(B_H)_{max.}$

B_r –retentive flux density
H_c - Coercive force

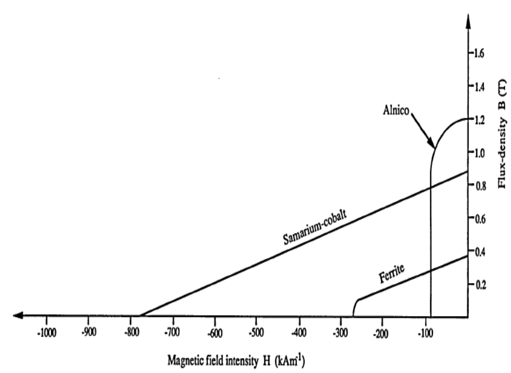

Fig 1.B-H curve for permanent magnet materials

	Alnico (5-7)	ceramic	SmCo	NdFeB
B_r	1.35T	0.405T	1.06T	1.12T
M_0H_c	0.074	0.37	0.94	1.06
$(BH)_{max}(MGO_e)$	7.5	3.84	26.0	30

Table 1.Properties of permanent magnet materials

The curve shown in figure 1 clearly explains that Alnico has high retentive flux density but low coercive force. Hence the possibility of demagnetization is high, whereas ceramic magnet have low B_r and high H_c.But in SmCo and NdFeB have high B_r and very much higher coercive force than Alnico. Although the NdFeB has largest Br and

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Hc value but it curie temperature lower than sumarium cobalt. Cost of the Sumarium cobalt is higher than NdFeB. Due to the higher cost most of the BLDC motor prefer NdFeB.

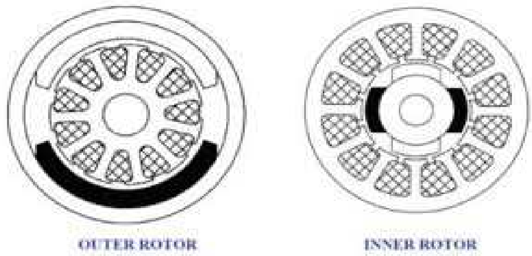

Fig 2.Rotor of BLDC motor

The construction of BLDC motor is opposite to that of conventional DC Motor.The stator is made up of silicon steel stampings with slots in its interior surface.There slots are accommodated either in closed or open distributed armature winding.This winding is wound for specified number of poles and it is connected to DC supply through a solid state inverter circuit. Rotor accommodates a permanent magnet and the number of poles of the rotor is same as that of the stator. Here the rotor shaft carries rotor position sensor(Hall sensor)it provides information about position of shaft at any instant to the controller. In section I explain the introduction to BLDC motor. Section II explains about the four quadrant operation. Section III explains about the controllers and section IV explains about the simulink model. Section V describes the simulation results.

Four Quadrant Operation of Three Phase BLDC Motor

There are four possible modes or quadrants of operation using a Brushless DC Motor. When BLDC motor is operating in the first and third quadrant, the supplied voltage is greater than the back emf which is forward motoring and reverse motoring modes respectively, but the direction of current flow differs. When the motor operates in the second and fourth quadrant the value of the back emf generated by the motor should be greater than the supplied voltage which are the forward braking and reverse braking modes of operation respectively, here again the direction of current flow is reversed. These motor initially made to rotate in clockwise direction but when the speed reversal command is obtained the control goes into regeneration mode and brings motor into standstill position. The position of rotor is sensed by using Hall effect sensor, if the machine has reverse its direction the ideal moment for energizing the stator phase so that the machine can start motoring in counter clockwise direction.

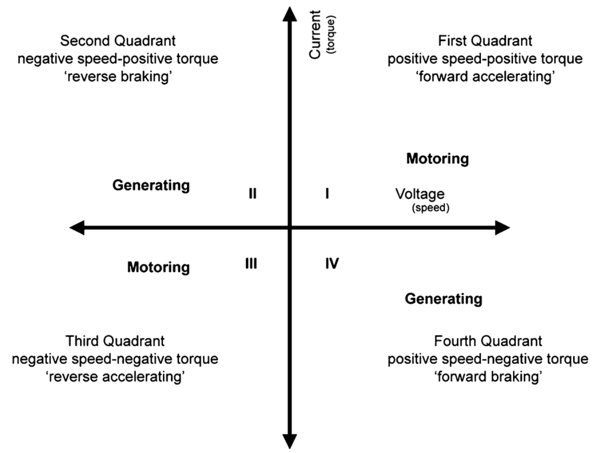

Fig 3. Four quadrant operation

Mathematical Model

The electrical part of DC brushless motor and relationship between cur rents , vol tage , and back electromotive force and rotor velocity is deriving using Kirchhoff's voltage law

$$R_a = R_a i_a + i_a \frac{di_a}{dt} + M_{ab}\frac{di_b}{dt} + M_{ac}\frac{di_c}{dt} + a_a$$

$$R_b = R_b i_a + i_b \frac{di_b}{dt} + M_{ba}\frac{di_a}{dt} + M_{bc}\frac{di_c}{dt} + a_b$$

$$R_c = R_c i_c + i_c \frac{di_c}{dt} + M_{ca}\frac{di_a}{dt} + M_{cb}\frac{di_b}{dt} + a_c$$

A mathematical relationship between the s haft angular velocity and voltage input to the DC brushless motor is derived using Newton's law of motion

$$I\frac{d\omega_r}{dt} = T_e - T_m - F\omega_r$$

The angular position is obtained from an integration of the angular velocity.

$$\theta_r = \omega_r dt$$

Generated electromagnetic torque for this3 phase BLDC motor is dependent on the current, speed and back-EMF waveforms, so the instantaneous electromagnetic Torque can be represented as

$$T_{em} = \frac{1}{\omega_m}(e_a i_a + e_b i_b + e_c i_c)$$

Design of PID Controller Using Ziegler-Nichols Method

The gain tuning of PID is done by increasing the proportional gain until the system oscillates; that gain is *Ku*.At this instant, time interval is measured between peaks to get *Tu*. Table 2 gives approximate values for the controller gains.

controller	K_p	T_i	T_d
PID	$0.8 \times K_u$	$T_u/2$	$T_u/2$

Table 2.Values of PID Controller

Fuzzy Logic Controller

A simple Fuzzy Logic Control system has the following features:Fixed and uniform input and output scaling factors.Flat, single partition rule-base with fixed and non interactive rules.Fixed membership functions.Limited number of rules, which increase exponentially with number with the number of inputs.Fixed knowledge.Low-Level control and no hierarchical rule structure .

Fuzzy Rules:

E\CE	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

Table 3. Rule table

In this paper fuzzy logic is used to control the speed of the three phase BLDC Motor.Mamdani type of method is used.Defuzzication method is centroid which is used in this paper.

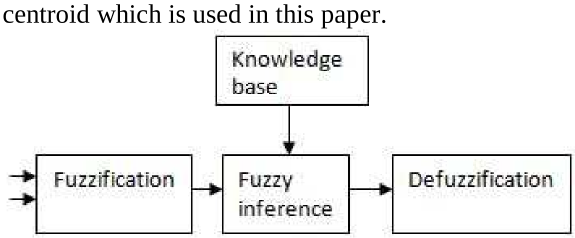

Fig 4.Fuzzy model

PWM Module

The PWM module simplifies the task of generating multiple synchronized Pulse width modulation(PWM)outputs. It has six PWM I/O pins with three duty cycle generators. The three PWM duty cycle registers are double buffered to allow glitch less updates of PWM outputs. For each duty cycle, there is a duty cycle register that will be accessible by the user while the second duty cycle registers holds the actual compared value used in the present PWM period. The output compare module generates an interrupt to trigger the relay circuit during regenerative mode.

Simulink Model

BLDC motor has three stator windings and permanent magnets on the rotor. The Fig 6 shows the simulink model of three phase BLDC motor. The speed can be controlled in all the four quadrants using fuzzy. The DC supply is given to the inverter which converts DC to AC. The AC supply is given to the three phase BLDC motor. The hall sensor is used to sense the rotor position. The sensing speed is fed to the fuzzy controller. The actual speed and reference speed is compared and error is produced using fuzzy. The output of fuzzy is fed to the PWM generator. The Pulse Width Modulation (PWM) pulses applied to the inverter circuit at the appropriate time to trigger the appropriate switches are the control signals to the circuit. It depicts that the motor is running in the forward direction, after a time interval brake is applied, the motor stops decelerating at this point the battery starts charging. From the PWM generator the output is fed to the inverter. The energy is conserved in battery during the regenerative period.

Simulation Results

The simulation results shows the waveforms of the speed, torque, current of the three phase BLDC motor using PI,PID, Fuzzy. The comparative results of the three controllers are shown in the table 1.The simulation results are obtained using the MATLAB/SIMULINK software.

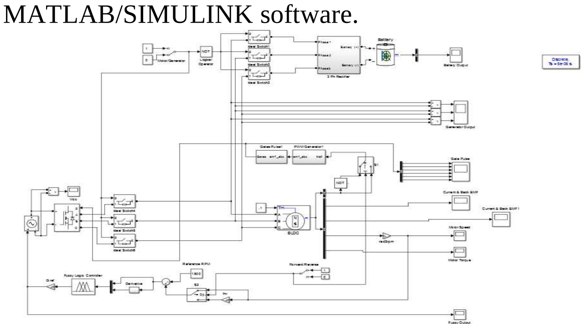

Fig.5 Simulink mode

Fig 6 shows the speed for motoring mode using PI. The speed is settled at 1500 rpm as shown in figure 6

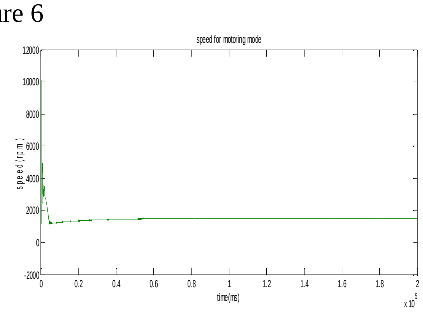

Fig 6 output speed for motoring mode using PI

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Fig 8 shows the output speed for generating Mode using PI controller. By using PI controller the speed is not settled as shown in figure 8

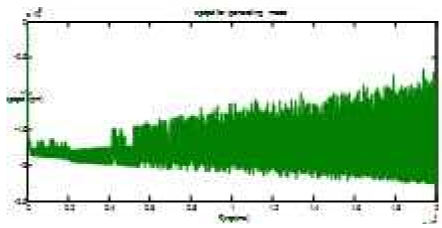

Fig 8 Speed for generating mode using PI

Fig 7 shows the torque for motoring mode using PI controller.The torque ripples are high compared to fuzzy as shown in fig 8.

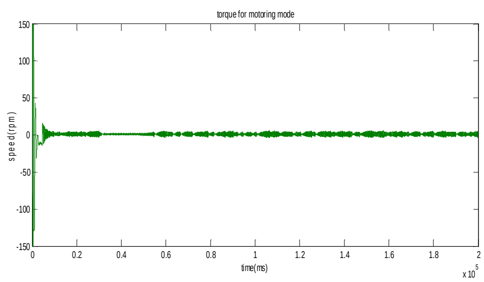

Fig 7 Torque for motoring mode using PI

Fig 9 shows the output torque for generating mode using PI controller.By using PI controller the torque contains ripple as shown in fig 9.

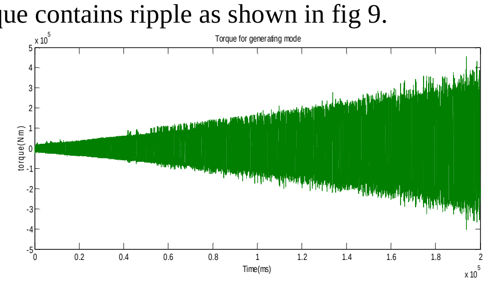

Fig 9 Torque for generating mode using PI

Fig 10 shows the output speed for motoring mode using PID controller .The speed is settled at 1500 rpm as shown in figure 10.

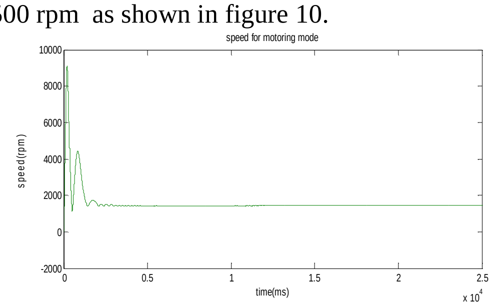

Fig 10 Speed for motoring mode using PID

Fig 11 shows the torque for motoring mode using PID controller. The torque ripples are high compared to fuzzy as shown in fig 11.

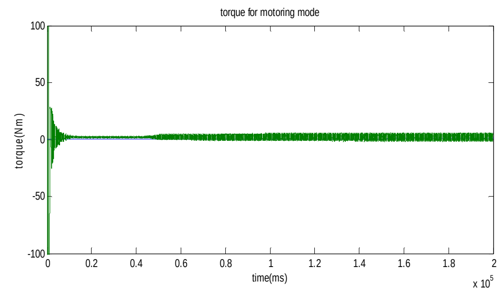

Fig 11 Torque for motoring mode using PID

Fig 12 shows the output speed for generating Mode using PID controller. By using PID controller the speed is not settled as shown in figure 12.

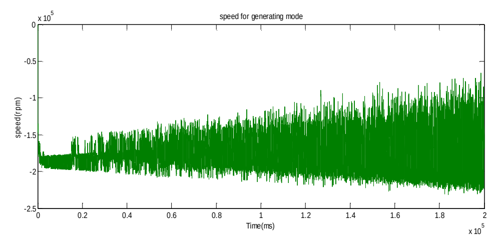

Fig 12 Speed for generating mode using PID

Fig 13 shows the output torque for generating mode using PID controller.By using PID controller the torque contains ripple as shown in fig 13.

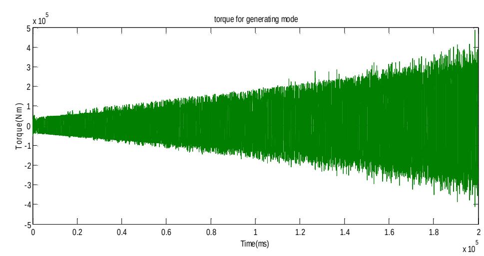

Fig 13 Torque for generating mode using PID

Fig 14 shows the output speed for motoring mode using fuzzy logic controller.The speed is maintained constant at 1500 rpm as shown in fig 14.

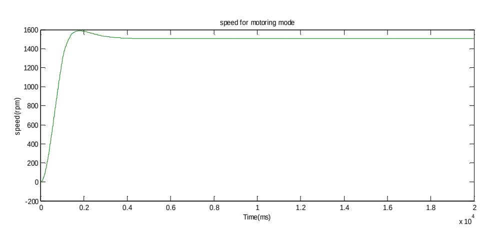

Fig 14 Speed for motoring mode using fuzzy

Fig 15 shows the output torque for motoring mode using fuzzy logic controller.The torque ripple is less compared to PI and PID controller.

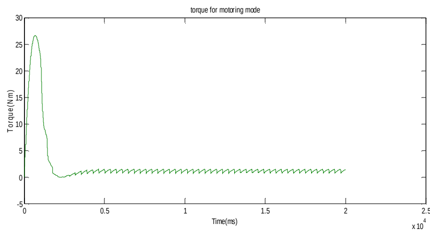

Fig 15 Torque for motoring mode using fuzzy

Fig 16 shows the output speed for generating mode using fuzzy logic controller.The speed is maintained constant at 1500 rpm as shown in fig 16.

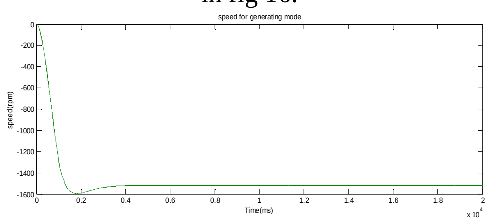

Fig 16 Speed for generating mode

Fig 17 shows the output torque for generating mode using fuzzy logic controller.The torque ripple is less compared to PI and PID controller.

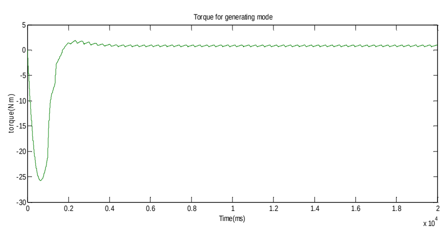

Fig 17 Torque for generating mode using fuzzy

	PI	PID	FUZZY
SPEED(rpm)	1500	1500	1500
Settling time of speed	0.8	1.8	0.4
Speed fluctuations	±20rpm	±10rpm	-
Torque ripples	±6	±0.5	±0.05

Table 4. Comparison table for motoring mode

	PI	PID	FUZZY
Speed(rpm)	1500	1500	1500
Settling time of speed	1.6	1.8	0.4
Speed fluctuations	±500	±500	-
Torque ripples	±4	±5	±0.2

Table 5. Comparison table for motoring mode

Conclusion

In this paper a control scheme is proposed for BLDC motor to change the direction from CW to CCW and the speed control was achieved and the comparative control analysis of four quadrant operation were discussed. The comparison table shows the advantages of using Fuzzy. The speed control is shown in the waveforms . It is possible to control the speed and maintain the torque constant. The simulation results are shown. The advantages of this proposed method are:, excellent speed control, smooth transition between the quadrants and efficient conservation of energy.

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