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A closed loop analysis of speed control of BLDC drive with Fuzzy-PID controller

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ABSTRACT- BLDC motors are very popular and replacing brush motors in numerous applications. Because the BLDC motor does not require commutator and due to its superior electrical and mechanical characteristics and its capability to operate in hazardous conditions it is more reliable than the DC motor. Traditionally, three-phase inverters are generally used to control these motors, requiring a rotor position sensor for starting and for providing the proper commutation sequence to stator windings.

The disadvantages of PI motor control system are increased cost and size of the motor, and need special mechanical arrangement for mounting the sensors. Another problem associated with BLDC motor control is the use of Conventional controllers; these controllers poses difficulties under the conditions of nonlinearity, load disturbances and parametric variations. This paper presents the design and implementation of a fuzzy logic controller for the sensor less speed control of brushless dc motors which will be helpful in solving problems associated with sensory control and conventional controllers in order to reduce cost and complexity of the drive system without compromising the performance.

Keywords: Brushless (BLDC) motor; (PID) controller; Fuzzy PID controller

1. INTRODUCTION

Permanent magnet machines are applicable in key applications of critical importance, such as aerospace industry, tool drives, actuators and electric vehicle propulsion system since this need to cater to servo applications. Hence, the necessity for precise control with quick response time is evident and obvious. Further these applications warrant the weight-density to be low and torque speed characteristics to be good. Also the inherent disadvantage of the conventional DC machines which necessitate the use of mechanical brushes and commutates problems has obviated these motors applied to such high performance applications**.**

In this project Speed Control of Permanent Magnet Brushless motor, which can cater to large torque for high acceleration and deceleration rates is evaluated for its performance with respect to the parameters of the motor which need to include also the effects of reluctance variations and other effects of magnetic saturation. The modeling of the PMBLDC. The PMBLDC drive system which involves inherently an inverter controller arrangement which controls the duty cycle of the Inverter using PWM technique has been taken up for implementation.

II. SPEED CONTROL SYSTEM OF BLDCMOTOR

The complete block diagram of speed control of three phases 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.

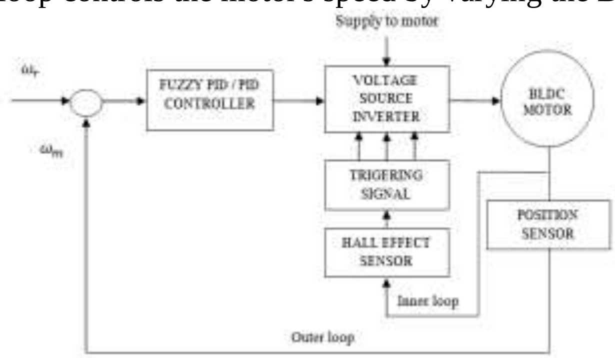

Fig.1 Block Diagram of speed control of BLDC Motor

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 I

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TABLE I. CLOCKWISE ROTATION

Hall sensor H1	Hall sensor H2	Hall sensor H3	Phase A	Phase B	Phase C
1	0	0	NC	+ve	-ve
0	0	1	+ve	NC	-ve
0	1	1	+ve	-ve	NC
0	1	0	NC	-ve	+ve
1	1	0	-ve	NC	+ve

III. PROPORTIONAL INTEGRAL CONTROLLER DESIGN

The model of PI speed controller is given by,

$$G(S)=Kp + Ki/S \quad \ldots\ldots\ldots\ldots(18)$$

Where G(S) is the controller transfer function which is torque to error ratio in s-domain, Kp is the proportional gain and Ki is the integral gain. The tuning of these parameters is done using Ziegler Nichols method using the phase and gain margin specifications. The specifications of the drive application are usually available in terms of percentage overshoot and settling time. The PI parameters are chosen so as to place the poles at appropriate locations to get the desired response. These parameters are obtained using Ziegler Nichols method which ensures stability. From the dynamic response obtained by simulation, the percentage overshoots Mp and settling time twitch are the measures of transient behavior are obtained. The speed loop of the typical BLDC motor is under no load condition. The closed loop transfer function of the system shown in Figure.2 is given by

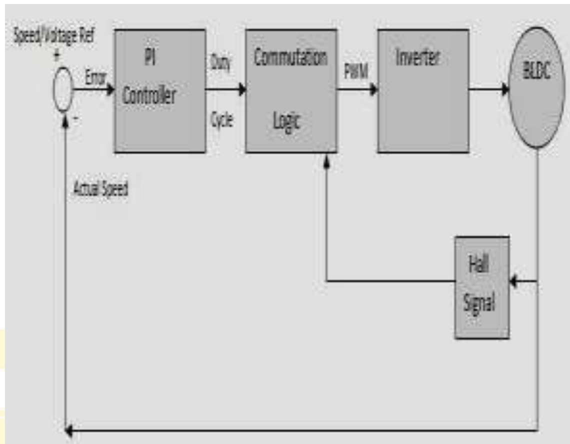

Fig.2 Closed Loop Speed Control

IV DESIGN OF FUZZY CONTROLLER

Error (E) and change in error (CE) are the inputs for the fuzzy controller whereas the output of the controller is change in duty cycle (ΔDC). The error is defined as the difference between the ref speed and actual speed , the change in error is defined as the difference between the present error and previous error and the output, Change in duty-cycle ΔDC is which **c**ould be either positive or negative is added with the existing duty-cycle to determine the new duty-cycle . Fig. 2 shows the basic structure of fuzzy logic controller. The fuzzy controller is composed of the following four elements: fuzzification, fuzzy rule-base, fuzzy inference engine and defuzzification.

FUZZIFICATION

Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting a numerical variable in to a linguistic variable is called fuzzification.

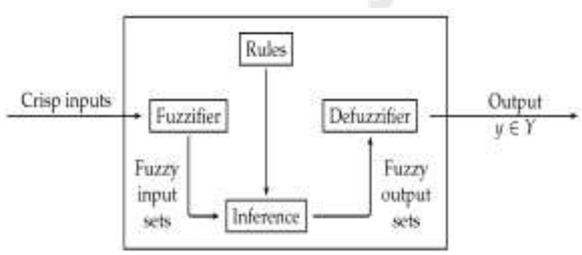

Fig.3 Fuzzy logic controller

The fuzzy includes two parts: choice of membership function and choice of scaling factor. The fuzzy variables error, change in error and change in duty-cycle are quantized using the linguistic terms NB, NM, NS, Z, PS, PM, and PB (negative big, negative medium, negative small, zero, positive small, positive medium and positive big respectively). The motor maximum range of speed is 0-3000 rpm.The possible range of error is -3000 to +3000 rpm. The universe of discourse for error is -3000 rpm to +3000 rpm and for the change in duty cycle, defined as -100 % and +100 %. In order to achieve faster control action and simplification, the inputs and output are normalized to +/-100 rpm, +/-100 rpm and +/-100 respectively. The membership functions used for inputs and output are given in figure.4

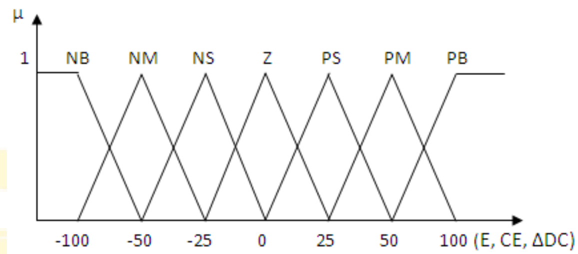

Fig.4 Membership functions for Error Change in Error and Change in Duty-Cycle.

V. RULE BASE AND INFERENCE ENGINE

A sliding mode rule-base, used in the fuzzy logic controller is given in below Table.2The fuzzy inference operation is implemented by using the 49rules. The centric method generate the center of gravity of the area by membership,

In Fuzzy controller there are two variables taken as input variables those are Rotor position and corresponding supply current values and output crisp values depends on those values. The 49 rules are gives various accurate output comments to the duty cycle of Electronic commutator..

Some of these rules are

1. If error (E) is NB and change in error (CE) is NB then output is PB.
2. If error (E) is NB and change in error (CE) is NM then output is PB
3. If error (E) is NB and change in error (CE) is NS then output is PB
4. If error (E) is NB and change in error (CE) is NS then output is PM

Table.2 Rules formation table

	NB	N	NS	Z	PS	P	PB
NB	PB	PB	P	P	PS	PS	Z
N	PB	P	P	PS	PS	Z	NS
NS	P	P	PS	PS	Z	NS	NS

Z	P	PS	PS	Z	NS	NS	N
PS	PS	PS	Z	NS	NS	N	N
P	PS	Z	NS	NS	N	N	NS
PB	Z	NS	NS	N	N	NB	NB

DEFUZZIFICATION

Finally the fuzzy output is converted into real value output by the process called defuzzification. Centroid method of defuzzification is used because it can be easily implemented and requires less computation time. The defuzzified output is obtained by the following equation

$$z = \frac{\sum_{x=1}^{n} \mu(x)x}{\sum_{x=1}^{n} \mu(x)}$$

Where z is the defuzzified value, μ(x) is the membership value of member x [5].

VI. HARDWARE DESIGN

Top view of Hardware Setup is shown Figure 4. Hardware consists of five elements brushless DC motor, a voltage source, a voltage regular circuitry motor driver circuit, back-emf detector circuit, opt-coupler circuit and a dsPIC30F4011 microcontroller board.

The duty-cycle of the devices are controlled based on the fuzzy controller output to control the armature voltage and hence the speed of the motor. The set speed is generated through a switch and it is given as another input to the A/D converter to determine the set speed. The function of the microcontroller is to compute the error and change in error, store these values, compute the fuzzy controller output, determine the new duty cycle for the switching devices and perform electronic commutation

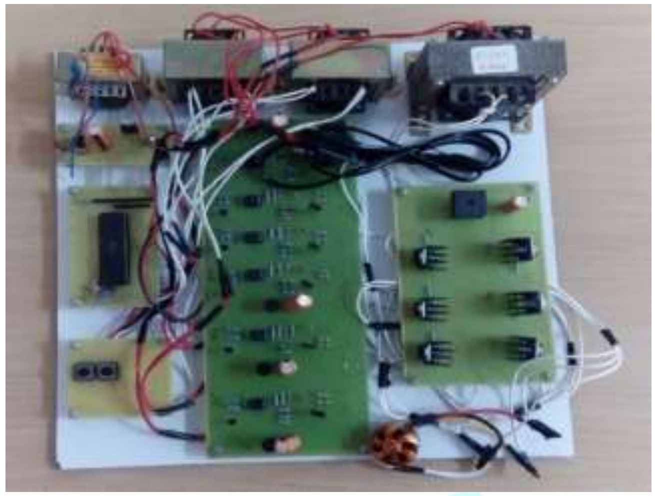

Fig .5 Top View of Hardware circuit

VII. PID CONTROLLER BASED PMBLDC MOTOR

The tables 5 and 6 show the differences between PID and Fuzzy logic controller at various speed ranges. Compare with PID controller the Fuzzy controller gives the more accurate and better results. Fuzzy controller also has a smooth recovery when load torque is applied.

VIII. FUZZY LOGIC CONTROLLER BASED PMBLDC MOTOR

Table 3. Output of Fuzzy controller

setpoint speed	Settling time t_s (ms)	Rise time t_r (ms)	Dead time t_d (ms)	SteadyStateError
25 % of Rated Speed	18	20	60	± 90 RPM
50 % of Rated Speed	19	32	60	± 85 RPM
75 % of Rated Speed	21	30	60	± 90 RPM
100 % of RateSpeed	30	32	70	± 80 RPM

The advantages of fuzzy are there is a reduction in computational time and produces lower errors in speed drop than PID. In speed reference change there is a slight overshoot in PID as compared to fuzzy. By proper design a fuzzy logic controllers is much better then PID controllers for the speed control of dc motor drives. In speed reference change there is a slight overshoot in PID as compared to fuzzy.

IX.RESULT

In this project the process of speed control of BLDC motor is done by using FUZZY LOGIC controller. The small three phase BLDC motor is controlled by using the ATMEGA 8 microcontroller. The specification of the BLDC motor is given in the Table 7. The sample PWM waveform obtained from the inverter for motor.

The speed of the BLDC motor depends upon the ON and OFF time of the PWM waveform. By controlling the ON and OFF time of the PWM waveform the set speed of the motor can be attained. When the ON time of the PWM wave given to the motor is high the speed of the motor is high and the motor speed is reduced by reducing the ON time and increasing the OFF time.

X.CONCLUSION

Closed loop controlled VSI fed PMBLDC motor using PWM control is modeled and simulated. Feedback signals from the PMBLDC motor representing speed and position are utilized to get the driving signals for the inverter switches. The simulated results shown are at par with the theoretical predictions. The simulation results can be used for implementation of PMBLDC drive. The speed oscillations are minimized using closed loop system. The various parameters monitoring and characteristics also analyzed by using PID and Fuzzy logic controller .The outputs of Fuzzy logic controller are more accurate and flexible.

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Saravsarana Kumar received a B.E. degree in Electrical and Electronics Engineering from SNS College of Technology, affiliated with Anna University, Chennai, India, in 2010, and an M.E. in Power Electronic Drives and Control from Anna University Regional Campus, India, in 2013. He is currently pursuing a Master of Research at Central Queensland University, Melbourne Campus, Australia, focusing on speed control of BLDC drives in hybrid electric vehicles.With over ten years of experience, he has worked in both technical sectors and academia, including teaching engineering students from 2011 to 2015. His current research interests include power electronics, hybrid vehicles, and battery management systems. He is also a Life Member of the Indian Society for Technical Education (MISTE).Kumar has published three papers, including two in IEEE International Conferences, and is continuing his research in the core of BLDC technology.

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