

Speed Control of Brushless DC Motor by Detecting Line To Line Back EMF

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ABSTRACT: BLDC motor is becoming more popular in industrial and traction applications and the transient response or dynamic behavior of any system with motor operation depends on the controller being employed. In general, a Conventional PI controller is used for most drive applications. But the conventional PI controller is slow and its tuning is a very serious problem if the system is complex to model mathematically. Further, if the system is non-linear then PI controller cannot work effectively. This leads to the search for other suitable controllers. One of the possible options for power electronic applications is the use of a fuzzy controller design where tuning doesn't depend on any mathematical model of the system, rather it is based of defined rules which can be altered easily. Fuzzy controller has a good transient behavior, thereby making the system response faster. Also, the transient overshoot in the system is almost eliminated. Fuzzy controller is among the most suitable choices for system with non-linear Characteristics. Hence, in this work the fuzzy controller is used to control the speed of BLDC motor with good dynamic response. The main objective of this project is to maintain the constant speed of the motor irrespective of the increase in load applied across the motor upto a certain extent above normal loading conditions. So motor shows constant speed operation even when load exceeds its maximum limit. Experimental results verify the proposed method.

KEYWORDS:BLDC motor, fuzzy logic control, load variation, hall sensors.

I. INTRODUCTION

BRUSHLESS DC motor has a rotor with permanent magnets and a stator with windings. It is essentially a DC motor turned inside out. The brushes and commutator have been eliminated and the windings are connected to the control electronics. The control electronics replace the function of the commutator and energize the proper winding. The motor has less inertia, therefore easier to start and stop. BLDC motors

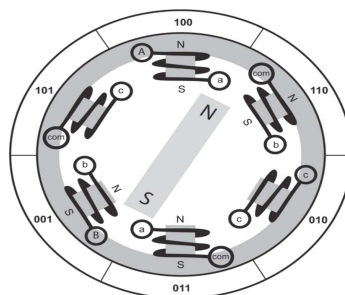


Fig. 1. BLDC Motor Star connected.

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are potentially cleaner, faster, more efficient, less noisy and more reliable. The Brushless DC motor is driven by rectangular or trapezoidal voltage strokes coupled with the given rotor position. The voltage strokes must be properly aligned between the phases, so that the angle between the stator flux and the rotor flux is kept close to 90 to get the maximum developed torque. BLDC motors often incorporate either internal or external position sensors to sense the actual rotor position or its position can also be detected without sensors. PMSBLDC motors have many advantages over brushed DC motors and induction motors. A few of these are better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation, and it has higher speed ranges. In addition, the ratio of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors. BLDC motors are used in Automotive, Aerospace, Consumer, Medical, Industrial Automation equipments and instrumentation.

This paper is organized as follows:

Section II describes the control of BLDC motor.

Section III describes the fuzzy logic controller with its special features.

In Section IV, the MATLAB simulation of constant speed regulation of BLDC motor with variable load using fuzzy controller with the results are presented.

Results are presented respectively in Sections V.

Section VI concludes the proposed work.

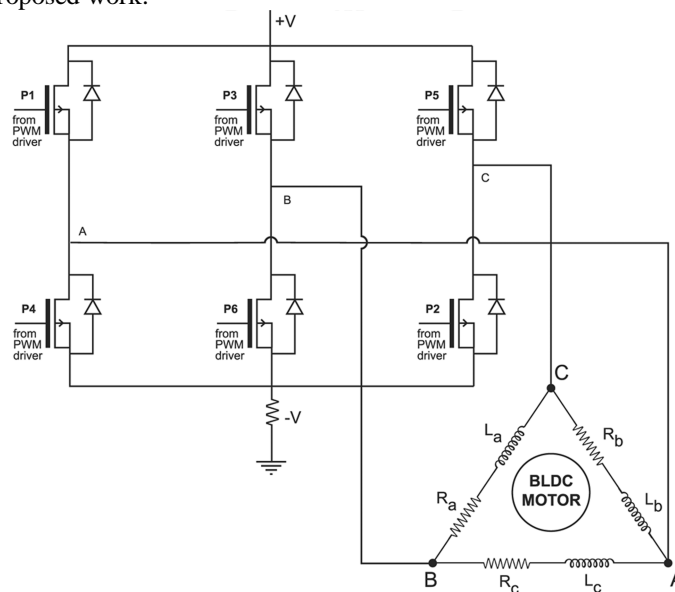


Fig. 2. Equivalent Circuit of power stage of BLDC motor.

II. CONTROL OF BLDC MOTOR

A. BLDC Motor

Brushless DC Motors are driven by DC voltage but current commutation is controlled by solid state switches. The commutation instants are determined by the rotor position. The rotor shaft position is sensed by a Hall Effect sensor, which provides signals to the respective switches [1] and [2]. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating either N or S pole is passing near the sensors. The numbers shown around the peripheral of the motor diagram in Fig. 1 represent the sensor position code. The north pole of the rotor points to the code that is output at that rotor position. The numbers are

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the sensor logic levels where the Most Significant bit is sensor C and the Least Significant bit is sensor A. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined. These signals are decoded by combinational logic to provide the firing signals for 120 conduction on each of the three phases. The rotor position decoder has six outputs which control the upper and lower phase leg MOSFETs of Fig. 2.

B. Commutation

The commutation sequence for clockwise and anti clockwise rotation is given in following tables 1 and 2.

The actual rotor position in Figure 1 corresponds to the Hall sensors' state ABC[110]. The actual voltage pattern can be derived from the Table 1. Phase A is connected to the positive DC bus voltage by the transistor P1, phase C is connected to

Table.1 Commutation Sequence For Clockwise Rotation

Hall SensorA	Hall SensorB	Hall SensorC	Phase A	Phase B	Phase C
1	0	0	-V	+V	NC
1	0	1	NC	+V	-V
0	0	1	+V	NC	-V
0	1	1	+V	-V	NC
0	1	0	NC	-V	+V
1	1	0	-V	NC	+V

Table.2 Commutation Sequence For Counter Clockwise Rotation

Hall SensorA	Hall SensorB	Hall SensorC	Phase A	Phase B	Phase C
1	0	0	+V	-V	NC
1	1	0	+V	NC	-V
0	1	0	NC	+V	-V
0	1	1	-V	+V	NC
0	0	1	-V	NC	+V
1	0	1	NC	-V	+V

ground by transistor P2, and phase B is not powered. As soon as the rotor reaches a next position (see Figure 1), the Hall sensor state changes its value from ABC[110] to ABC[100]. From Table 1, a new voltage pattern is selected and applied to the BLDC motor. As can be seen, with a six-step control technique there is no possibility of keeping the angle between the rotor flux and the stator flux precisely at 90°. The real angle varies from 60° to 120°. The commutation is repeated for each 60 electrical degrees. The angular (time) accuracy of the commutation event is critical. Any deviation causes torque ripple leading to variation in speed.

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III. FUZZY LOGIC CONTROLLER

The main idea of FLC is to use the control ability of human beings which includes experience and intuition of experts. It is one of useful control techniques for uncertain and ill-defined nonlinear systems . Control actions of a FLC are described by some linguistic rules. This property makes the control algorithm easy to understand. Basic structure of fuzzy logic controller is depicted in Fig.3.

A fuzzy logic control consists of:

i. *Fuzzification*: This process converts the measured inputs (crisp values) into fuzzy linguistic values.

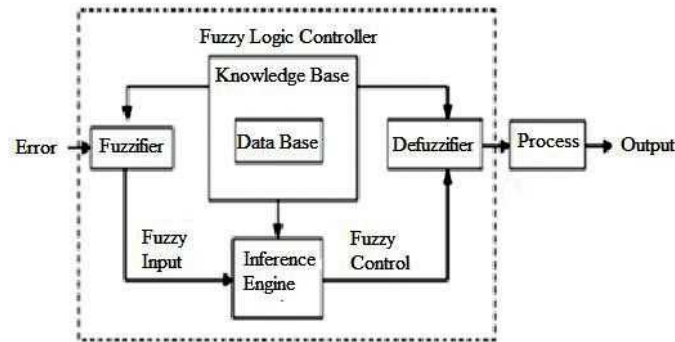


Fig.3. Structure of Fuzzy Logic Controller

ii. *Rule Base*: A collection of the expert rules needed to achieve the control goal.

iii. *Defuzzification*: This is the process of converting the fuzzy outputs from the systems to crisp values.

FLC is used to improve the dynamic response and reduce the overshoot before the motor reaches the desired speed. The inputs of FLC are speed error and the change in speed error. The output of controller is the change in command torque. In order to facilitate computation, triangular and trapezoidal membership functions are utilized for both the inputs and output membership functions. The Mamdani type inference is adopted here because it is one of the most widely used inference methods. Centre of Gravity method is used for Defuzzification.

The **output** of the fuzzy controller $u(k)$ is given by,

$$u(k) = Ff [e(k) - ce(k)].$$

Where Ff is a non-linear function determined by fuzzy parameters, $e(k)$ and $ce(k)$ are the error and change of error respectively.

The first input, **speed error** is given by

$$e(k) = N^*(k) - N(k)$$

Where $N^*(k)$ is the reference speed and $N(k)$ is the actual speed.

The fuzzy variable “error” has seven sets: negative big (NB), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM), positive big (PB).

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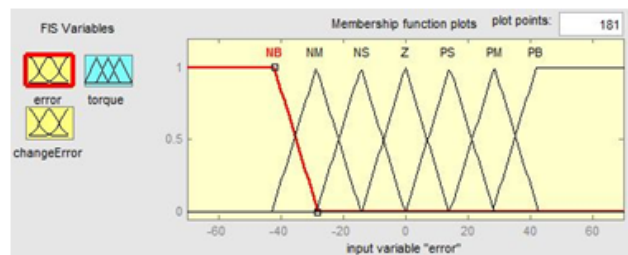
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The other input, **change in speed error** is the difference in the present and the previous error.

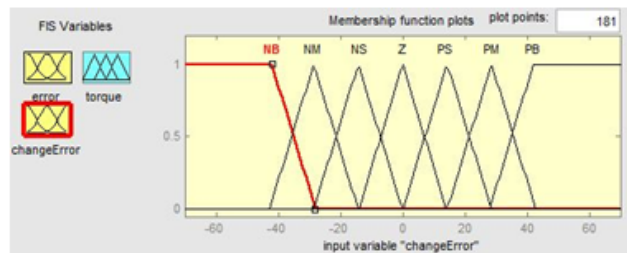
$$ce(k) = e(k) - e(k-1)$$

Table.3 Linguistic Control Rules

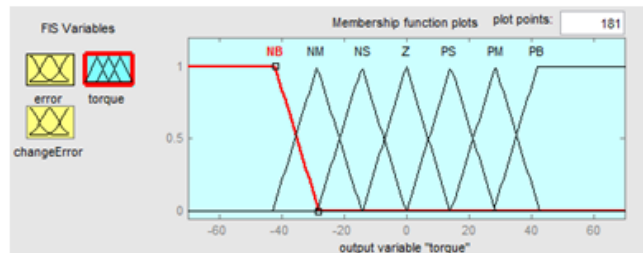
$e \setminus \Delta e$	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NM	NS	NS	Z
NM	NB	NM	NM	NM	NS	Z	PS
NS	NB	NM	NS	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PS	PM	PB
PM	NS	Z	PS	PM	PM	PM	PB
PB	Z	PS	PS	PM	PM	PB	PB



(a) Speed error, e



(b) Change in speed error, ce



(c) Torque, T

Fig.4 Membership functions in fuzzy variable

Where $e(k)$ is the present speed error and $e(k-1)$ is the previous speed error.

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The fuzzy variable “change in speed error” also has same seven sets: negative big (NB), negative medium (NM), negative small (NS), zero(Z), positive small (PS), positive medium (PM), positive big (PB).

Fig 4 shows the membership functions of speed error e , change in speed error ce that are the input fuzzy variables, and Torque that is the output fuzzy variable.

The two fuzzy inputs result in 49 linguistic rules for the BLDC drive system as quoted in table 3.

IV. SIMULINK MODEL

A. Clockwise and counter-clockwise rotation using decoder circuit

The gate signals for the inverter is generated using the decoder circuit. The decoder circuit is designed after studying the switching sequence of inverter circuit using the clockwise and anticlockwise rotation switching table that was predefined. Further using K map the switching sequence is generated. Hall effect sensors are used to get the position of rotor and the hall effect signals are used for designing the decoder circuit i.e the logic circuit.

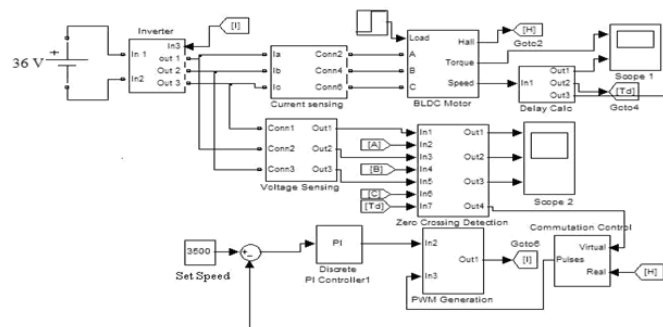


Fig. Simulink model of fuzzy controller

B. Constant speed regulation using fuzzy logic controller with variable loads applied across BLDC motor

The Simulation diagram of BLDC motor under the closed loop condition is shown in the Fig. 4.3. The Hall Effect sensors are used to sense the rotor positions of BLDC motor. The Hall Effect signals are then given as input to the current controller. The speed that is measured is given as input to the fuzzy logic controller, and the other input to the controller is the reference

speed we provide. The output from the controller is the torque that will be the output fuzzy variable that will be discussed further in detail. Output from fuzzy controller is also given as input to the current controller. The current controller further develops the PWM pulses that is given as gate signals to the inverters. Thus the speed of BLDC motor is controlled.

The load across the BLDC motor is varied using the input torque that we can set. The ‘final value’ in the load torque (in

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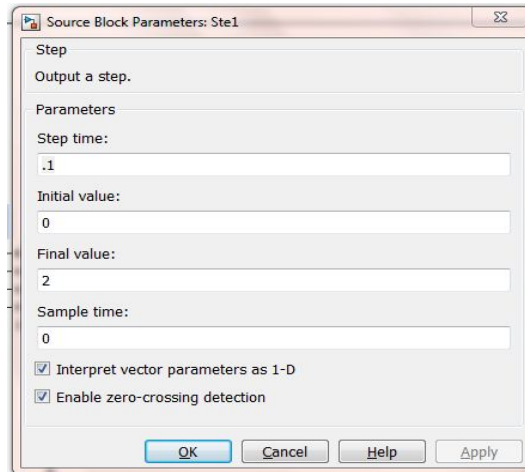


Fig.9 Source block parameter for load torque

the source block parameter) can be varied between 1 and 5 as shown 2 in figure 9. And then when system is simulated we can analyse the speed that remains constant with every varied load value. But the current increases with the load torque.

VIII. RESULTS

To validate the control strategies as described, digital simulation were carried out using MATLAB/SIMULINK.

Fig. 11 shows the phase current waveforms of the BLDC motor when the rotor position at 1000 rpm. The phase difference between Ia, Ib and Ic is approximate to 120 degrees. The peak currents value is approximate to 3.2 A for all Ia, Ib and Ic.

Fig. 12 shows the speed for FLC by developed model. The speeds reach the desired value 1000rpm at the time 3.5ms.

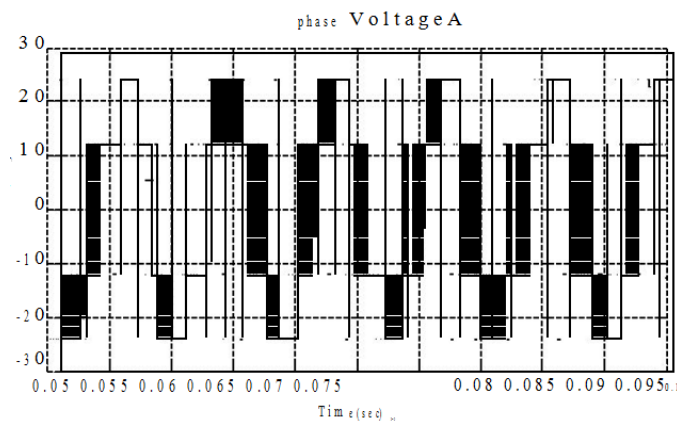


Fig.10 Electromagnetic Torque

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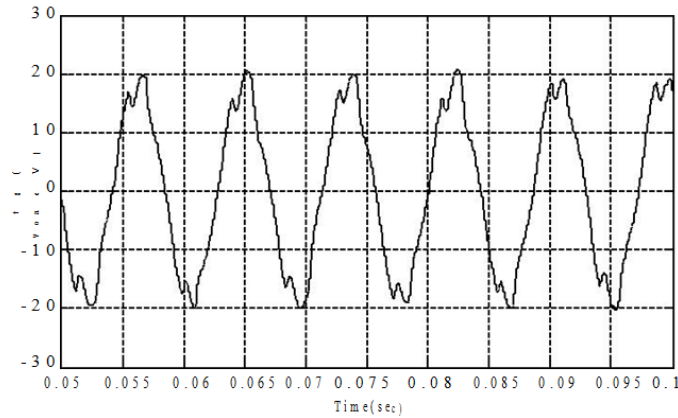
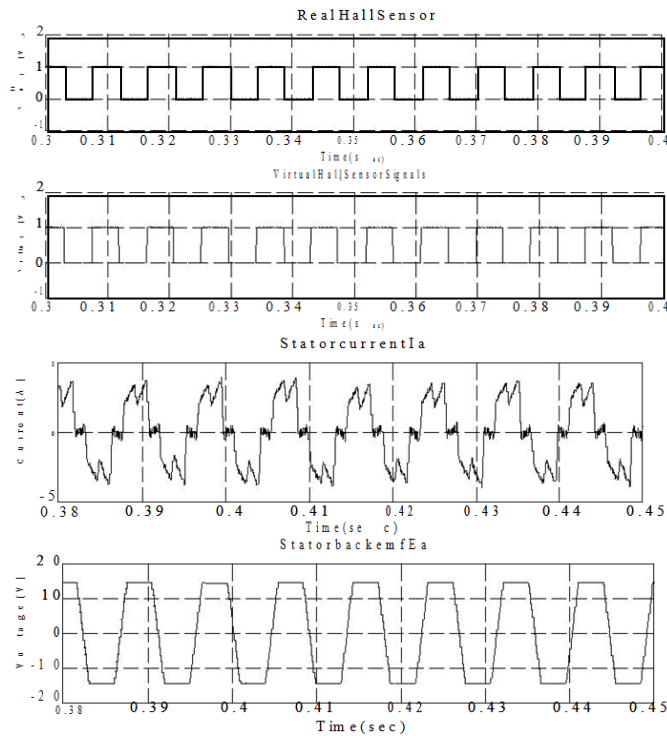


Fig.11 Stator Currents in phases A, B and C



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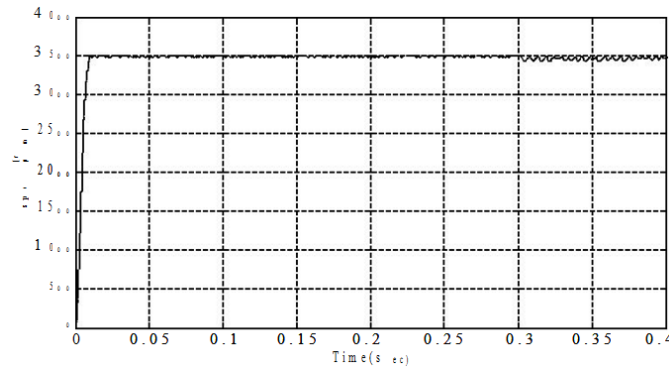


Fig.12 Speed of BLDC Motor

IX. CONCLUSION

As a conclusion, a comprehensive analysis of brushless DC drive system has been performed by using fuzzy logic controller. The simulation model which is implemented in a modular manner under MATLAB environment allows dynamic characteristics such as phase currents, rotor speed, and mechanical torque can be effectively considered. It is seen that the desired real speed and torque values could be reached in a short time by FLC controller even with sudden load changes or disturbance. The result paired with simulink is a good simulation tool for modeling and analyzing fuzzy logic controlled brushless DC motor drives. Load variation across the motor upto a certain extent above maximum does not effect the speed regulation of the motor. The designed and implemented prototype model may be implemented even for higher rated motors.

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