



FUZZY LOGIC BASED FOUR QUADRANT OPERATION OF ELECTRIC VEHICLES

Muhammed Ejas A K	UG Scholar, Department of Electrical And Electronics, TKM Institute of Technology , Kollam
Feby V S*	UG Scholar, Department of Electrical And Electronics, TKM Institute of Technology , Kollam *Corresponding Author
Lakshmi G	UG Scholar, Department of Electrical And Electronics, TKM Institute of Technology , Kollam
Lekshmi R S	UG Scholar, Department of Electrical And Electronics, TKM Institute of Technology , Kollam
Sajid Ali A	Assistant Professor, Department of Electrical And Electronics, TKM Institute of Technology , Kollam

ABSTRACT In this paper we have designed the speed control of bidirectional brushless DC motor using fuzzy logic controller. The speed control of BLDC motor is achieved by using fuzzy controller. In three phase BLDC motor, the fuzzy logic control is used to control the four quadrants operations without power loss. During regenerative period the energy is conserved and excess energy created during the regenerative braking condition is stored in the battery. The bidirectional dc-dc converter is operated in the buck boost mode. The energy stored in the battery provides maximum power to the BLDC motor and the energy is fed back to the source by the same buck boost converter during the regenerative braking operation. The simulation is done using MATLAB/SIMULINK software for brushless dc motor with fuzzy logic controller.

KEYWORDS : Brushless DC motor, Buck-Boost converter, Four quadrants, Fuzzy logic controller, Battery.

INTRODUCTION

The bidirectional dc-dc converter has application such as controlled battery charging. It is also known as buck boost converter. To achieve power transfer between two dc power sources in either direction [6], dc-dc converters are increasingly used. The dc-dc converter can be categorized into buck, boost and buck boost type. They are of low cost, compact in size and due to common ground they are easy to control. Buck boost circuit has number of variations, some are designed to work at lower frequencies or at high voltages which may use bipolar transistors instead of MOSFET[1]. In this paper power flow between the battery and BLDC motor is controlled by bidirectional dc/dc converter, so the desired control variables are both voltage and output current. In energy storage based on battery application we propose bidirectional buck-boost converters.

Brushless DC motors are becoming more popular in industrial and traction application. As the motor has less inertia it is easier to start and stop the motor they are fast, less noisy, clean, more reliable and more efficient[2]. Using rectangular or trapezoidal voltage strokes coupled with given rotor position, the brushless DC motor is driven. The stroke must be properly aligned in phases, so the angle between rotor flux and stator flux is kept nearer to 90°. It is done in order to get the maximum torque. Internal or external position sensors are used to detect the actual rotor position of BLDC motor even though it can be detected without sensors. To operate the electric machine in the motor mode, acceleration command is issued. Voltage source inverter(VSI) is used to control the output torque by adjusting the amplitude and direction of the phase current. Motoring torque is developed [3] when the input phase voltage is in phase with back EMF and braking torque is developed when input current is out of phase with back EMF[4]. To charge a battery back EMF voltage of the motor is known as the regenerative braking. In this paper the speed of dc motor is controlled by fuzzy logic controller using bidirectional converter. As the BLDC motor has wide range of speed, it is very important issue to control the speed. By using fuzzy sets and rules, the efficient speed control mechanism for the motor is done.

SPEED CONTROL OF BLDC MOTOR

The block diagram of BLDC motor by fuzzy logic controller using buck-boost converter is shown in Figure 1. The buck-boost converter can be operated in buck and boost modes. The converter boosts the voltage from battery and supplies the motor through the voltage source inverter during the boost mode. Using bidirectional DC-DC power

converter the batteries are charged and discharged. BLDC motor drive should get supply from the battery[5]. Four quadrants operation is done in brushless motor. The excess energy is stored in the battery during the regenerative braking condition.

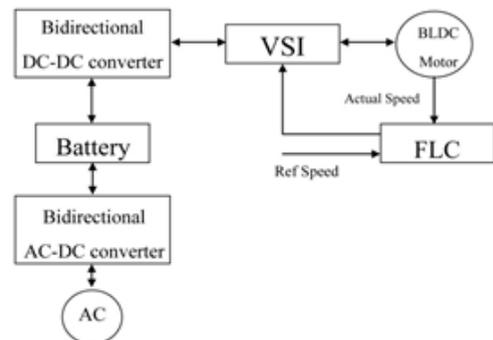


Figure 1. Block diagram of proposed system

Fuzzy logic controller is used to control the brushless motor the error is determined by taking the difference between actual speed and reference speed as the result of variation in the reference speed and actual speed the error signal is generated. It is sensed by the whole signal used for the formulation of the fuzzy rules. It results in the generation of gate signals which drive the switching circuits.

A. Four Quadrant Operations

In a three phase BLDC motor, there are four modes of operations. When BLDC motor is operating in the first quadrant it is in forward motoring and when in third quadrant it is in reverse motoring mode and the supplied voltage is greater than the back EMF. But the direction of current is different. When the motor operates in the second quadrant it is in forward braking and in four quadrants it is in reverse braking and the value of back EMF generated is greater than the supplied voltage and reverses the direction of current flow.

The BLDC motor first rotates in the forward direction and rotates in reverse direction when the speed command is given when the control goes into forward braking mode and current flows from motor to battery and the rotor is in its standstill position.

BIDIRECTIONAL DC-DC CONVERTER

A dc-dc converter is shown in Figure 2. The difference of dc-dc converter is on the use of IGBT or MOSFET to switch the state of current instead of all the diodes. The bidirectional DC-DC converter can operate as both buck and boost converter. It is operated as buck converter by stepping down voltage and as a boost converter by stepping up voltage. Using MOSFET the period of each position can be controlled[8].

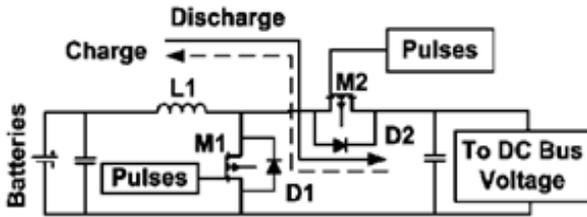


Figure2. Bidirectional DC-DC Converter

In previous method of speed controls, the kinetic energy is wasted as heat energy but in this method the kinetic energy is converted in to electrical energy which is stored in a chargeable battery in automotive application automotive application to exchange power between two voltage sources after rectification. The current must go through the circuit in both directions to accomplish the power transfer.

B. Converter Mode of Operation

Switch S₁ is operated at constant frequency and variable duty cycle in motoring mode of operation. The battery supplies energy to the motor when S₁ is ON and S₂ is OFF. By adjusting the duty cycle of switch S₁, voltage V_{dc} at the output capacitor terminals are regulated.

There for the inductor voltage V_L is

$$V_L = V_{bat} - V_m = L \frac{di_L}{dt} \quad (1)$$

Then the inductor ripple current is

$$\Delta i_L = \frac{V_{bat} - V_m}{L} DT \quad (2)$$

Where

$$D = \frac{T_{ON}}{T} * 100\%$$

When the switches S1 is turned off and S2 is ON, the motor will get supply from energy stored in the inductor L and capacitor C.

$$V_L = -V_m = L \frac{di_L}{dt} \quad (3)$$

MODELLING OF PMBLDC MOTOR

BLDC motor has gained more popularity due to their characteristics and performance. They are also known as permanent magnet DC synchronous motor. To an internal neutral point, the stator windings are star connected. The rotor has a trapezoidal flux pattern in the air gap and is of non-salient pole type. The output of motor gives the actual rotor speed and hall signals. The mathematical model of motor is shown in Figure 3.

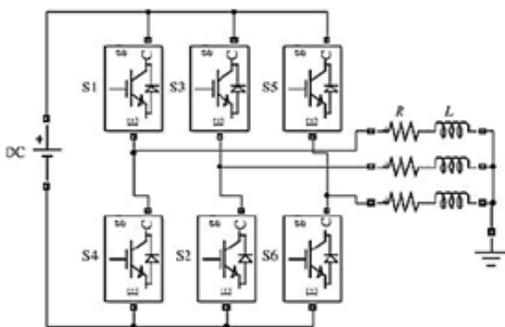


Figure3. Equivalent circuit of brushless motor

$$V_a = R_a I_a + L \frac{di_a}{dt} + e_a \quad (4)$$

Where

R_a = Stator resistance of phase ‘A’

I_a = Phase Current

L = Inductance

e_a = Back EMF

Similarly

$$V_b = R_b I_b + L \frac{di_b}{dt} + e_b \quad (5)$$

$$V_c = R_c I_c + L \frac{di_c}{dt} + e_c \quad (6)$$

We can represent the Back EMF as function of Rotor position,

$$E_a = K\omega f(\theta_e)\omega \quad (7)$$

$$E_b = K\omega f\left(\theta_e - \frac{2\pi}{3}\right)\omega \quad (8)$$

$$E_c = K\omega f\left(\theta_e + \frac{2\pi}{3}\right)\omega \quad (9)$$

Kω = Per phase back EMF constant

θ_e = Electrical Rotor angle (rad)

ω = Rotor speed (rad/sec)

The electromagnetic torque is given by

$$T_e = \frac{(e_a i_a + e_b i_b + e_c i_c)}{\omega} \quad (10)$$

The mechanical torque is given by

$$T_m = J \frac{d\omega}{dt} + B\omega + T_L \quad (11)$$

FUZZY LOGIC CONTROL

The fuzzy inference system is used to design the fuzzy logic control. The fuzzy inference system (FIS) has defined input and output membership functions. Fuzzy logic controller is a rule based controller. Speed error(e) and change in speed error(Δe) are the inputs for the controller. Comparison between reference speed and actual speed gives the speed error. The simulation diagram is shown in Figure 4. Fuzzy rule has 7*7 decision table with input and output variables [7]. The seven linguistic variables are defined along with input and output rules in the lookup table 1. They are Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM) and Positive Big (PB)

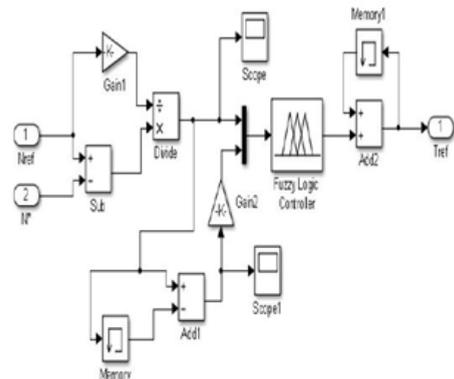


Figure 4. Simulation diagram of Fuzzy Logic Controller

TABLE.1 FUZZY RULE BASE

e/Δe	NB	NM	NS	Z	PS	PM	PS
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

The membership function for speed error (e), change in speed error (Δe) in Figure 5.

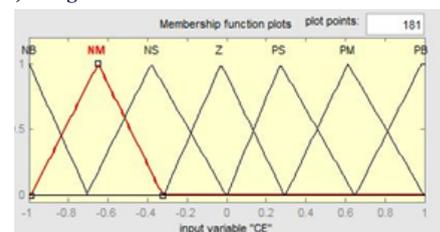


Figure.5 Membership functions for error and Change in error

The membership functions of output variable shown in Figure 6.

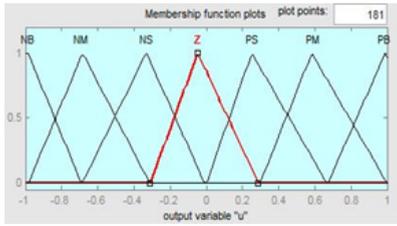


Figure.6 Membership functions for fuzzy output

TABLE 2. BLDC MOTOR SPECIFICATIONS

Parameters	Specification
No of poles	8
Rated voltage	24V
Maximum peak current	10.6A
Rated speed	4000rpm
Rated torque	0.125Nm
Torque constant	0.036Nm/A
Resistance per phase	1.08Ω
Moment of inertia	48e-7Kgm2

SIMULATION AND RESULTS

MATLAB/Simulink is used for the simulation of fuzzy logic controller based speed control of BLDC. The developed MATLAB model is shown in Figure 7. The fuzzy logic controller is used as the speed control circuit.

The output is fed to a controlled voltage source inverter. FIS editor is used to design the fuzzy logic controller and is exported to the MATLAB workspace. FIS editor used mamdani type of inference engine. Two modes of operation of brushless motor is achieved by setting negative and positive speed.

The analysis of BLDC motor is done by the simulation of fuzzy logic control.

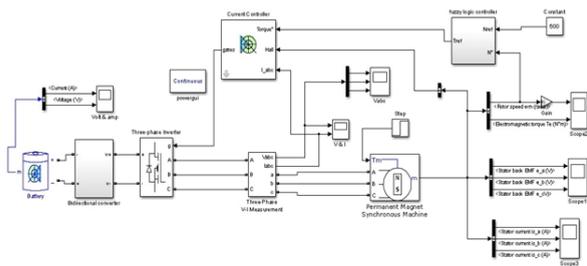


Figure 7.Simulation diagram of proposed speed control of BLDC motor with Fuzzy Logic Controller

The rotor speed and electromagnetic torque response of BLDC motor with Fuzzy controller as shown in the Figure 8.

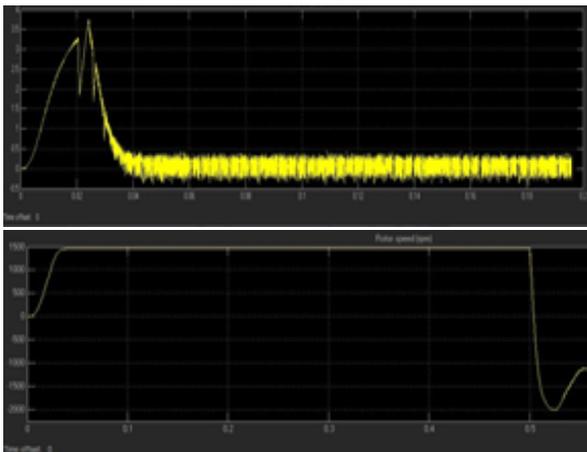


Figure 8.Rotor speeds and torque response of BLDC motor

The three phase stator back EMF is shown in Figure 9. The phasor back EMF is trapezoidal as shown

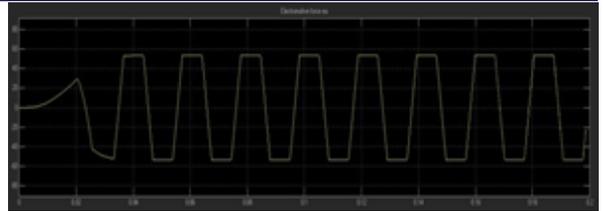


Figure 9.Back EMF of BLDC motor

The stator current of BLDC motor as shown in Figure 10.

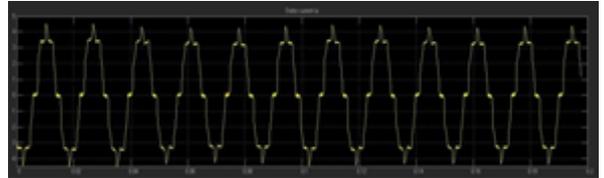


Figure 10.Stator current of BLDC motor

The battery Current, Voltage and SOC behavior as shown in Figure 11.

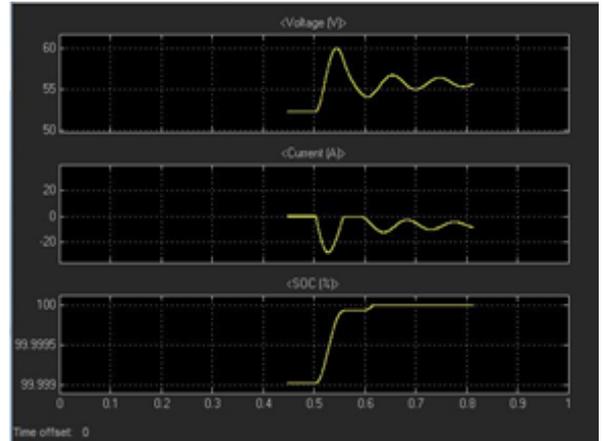


Figure11.Current, Voltage and SOC behavior of Battery

CONCLUSION

In this paper, speed control of brushless motor by fuzzy logic control scheme using buck boost converter is proposed. In braking modes of operation, kinetic energy is stored in a battery instead of wasting. Based on the bidirectional converter, the excess energy is effectively stored in the battery. Simulation was conducted to evaluate the performance of proportional integral controller and fuzzy logic controller. Excellent speed control, smooth transition between the quadrants and efficient conservation of energy are the advantages of the proposed system.

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