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BIDIRECTIONAL SPEED CONTROL OF BLDC MOTOR WITH DC-DC CONVERTER

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ABSTRACT

In this paper we have designed a fuzzy logic controller for the speed control of bidirectional brushless DC motor (BLDC). The speed control is achieved by using fuzzy controller. The fuzzy logic control is used in three phase BLDC motor in order to control the four quadrants operations without any loss of power. In fact energy is conserved during the regenerative period and storage of excess energy created during regenerative braking condition in the battery. The bidirectional DC-DC converters are often used for the battery charging and discharging application. The bidirectional dc-dc converter can be operated in buck boost mode. The stored energy in the battery provides maximum power to the BLDC motor, while during regenerative braking operation the energy is fed back to the source by the same bidirectional buck-boost converter. The simulation will be done for Brushless DC motor with fuzzy logic controller using MATLAB/Simulink software.

Keywords- *BLDC* motor, bidirectional DC-DC converter, fuzzy logic controller, four quadrants, battery.

1. INTRODUCTION

The bidirectional dc-dc converter is also known as buck boost converter, which has more applications such as controlled battery charging. The dc-dc converters are being increasingly used to achieve power transfer between two dc power sources in either direction [1]. The dc-dc converter can be categorized in to buck, boost and buck boost types which are of low cost, compact in size, without transformer and easy to control due to common ground. There are number of variations of this basic Buck-Boost circuit, some designs work at lower frequencies or at high voltages which may use bipolar transistors instead of MOSFET [2]. In this paper a bidirectional dc/dc converter will be developed to control power flow between the battery and BLDC motor, hence the desired control variables are both output current and voltage. The proposed bidirectional buck-boost converters are applicable in energy storage based on battery applications. Brushless DC (BLDC) motors are becoming more popular in industrial and traction applications. This motor has less inertia, therefore it is easier to start and stop the motor. BLDC motors are potentially clean, fast, less noisy, more efficient and more [3]. The Brushless DC motor is driven by rectangular or trapezoidal voltage strokes which is coupled with the given rotor position. The voltages stroke must be properly aligned in the phases, so that the angle between the stator flux and the rotor flux is kept closer to 90° in order to get the maximum torque. The actual rotor position of BLDC motor can be detected without sensors but it often incorporates internal or external position sensors to sense the position. When the acceleration command is issued, the electric machine is operated in the motor mode. Output torque of the motor is controlled by a voltage source inverter (VSI) by adjusting the direction and amplitude of the phase current. If the input phase voltage is in phase with back EMF, motoring torque is developed and when the input current is out of phase with back EMF, braking torque is developed [4]. The regenerative braking refers to charge a battery using back EMF voltage of the motor. In this paper fuzzy logic controller is used for controlling the speed of brushless DC motor using bidirectional converter [5]-[6]. BLDC motor has a wide range of speed hence speed control is very important issue for it. The efficient speed control mechanism for the motor is done using meaningful fuzzy sets and rules.

2. BIDIRECTIONAL DC-DC CONVERTER

A bidirectional buck-boost converter is shown in Fig 1. The main difference with a unidirectional DC/DC Converter is on the use of MOSFET or IGBT to switch the state of the current instead of all the diodes [7].

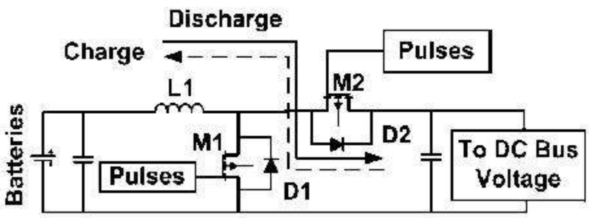

Fig. 1 Bidirectional DC-DC Converter

The magnitude of the voltage and current as well as the placement of the energy storage items, the bi-directional DC-DC converter can either operate as a Buck converter by stepping down a higher voltage to a lower voltage or as a Boost converter by stepping up from a lower voltage to a higher voltage. Indeed, diodes do not allow current to flow in both directions, but with MOSFET the period of each position can be easily controlled [8]. The kinetic energy is wasted as heat energy in previous methods whereas this method involves the conversion of kinetic energy into electric energy which is rectified and stored in a chargeable battery in automotive applications most DC/DC converters have to exchange power between two voltage sources [9]. To accomplish this power transfer the current must be able to go through the circuit in both directions.There are a lot of for this kind of converters, because the use of a battery implies the capacity of charging and discharging so the use of a bidirectional converter allows avoiding a complex system of twin circuits to accomplish the charge and the discharge of the battery.

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2.1 Converter Mode of Operation

In motoring mode of operation, switch S1 is operated at constant frequency and variable duty- cycle. When switches S_1 is ON and S_2 is OFF, the battery supplies energy to the motor. Thereby the voltage V_{dc}at the output capacitor terminals can be regulated accordingly by adjusting the duty cycle of switch S_1. Therefore the inductor voltage V_L is expressed as

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

Then the inductor ripple current is given by

$$\Delta iL = V_{Bat} - V_m / L * DT \quad (2)$$

Where, $D = T_{on} / T * 100$

At the next state when the switches S_1 is turned offendS_2 is turned on, the energy stored in the inductor L and capacitor C will supply the motor. We can obtain the inductor voltage V_L as.

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

3. SPEED CONTROL OF BRUSHLESS DC MOTOR

The block diagram of the speed control of fuzzy based BLDC motor using bidirectional converter is shown in Fig 2.

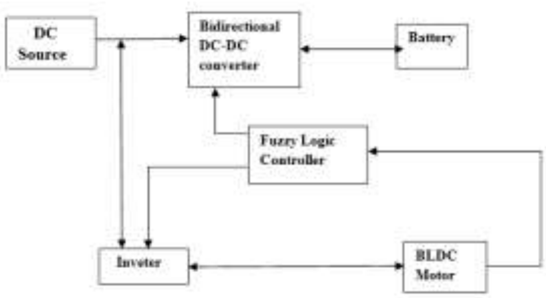

Fig. 2 Block diagram of proposed system

The DC-DC converter can be operated in two modes namely buck and boost modes. During boost mode, the converter boosts the voltage from battery and supplies the motor through the voltage source inverter [10]. The batteries need to be charged and discharged via bidirectional DC-DC power converter .The battery must be able to supply power to the BLDC motor drive. The brushless motor can operate in all four quadrants. The excess energy created during regenerative braking condition is stored in the battery.The brushless motor is controlled using a fuzzy logic controller. The difference between the actual speed and reference speed determine the error. [11]-[12] The error signal is generated as the result of variation in the reference speed and the actual speed of the motor which is sensed by the hall signal utilized for the formulation of fuzzy rules which results in the generation of the gate signals to drive the switching circuit [13].

3.1 Motor driving mode:

While user selects this mode, the handle signal, which is an adjustable dc voltage, will be detected to control the duty cycle of the motor driving inverter, further, to regulate the motor speed. The bi-directional converter will enter Mode I when the handle signal is detected, i.e., the battery offers energy for driving motor. Conversely, the system will detect whether BEMF occurs or not. If not, it represents system idle, and the program will return to initial state. On the other hand, the electric bike may be decelerated or in descent state as the BEMF occurs. And then, the system will automatically select Mode III or Mode IV to recycle energy to battery according to whether the BEMF higher than battery voltage or not.

3.2 Battery charging mode:

The proposed bi-directional converter will behave as a buck converter when this mode is employed. Both having precise SOC estimation and suitable control strategy are essential for aWell-designed charger. Generally, the open-circuit voltage method is used to estimate the initial battery capacity under no load. Besides, the kilometric estimation method can providesaccurate measurement in normal operating state. In this paper, we combine the open-circuit voltage method and the kilometric estimation method to estimate the battery capacity.

4. MODELLING OF PMBLDC MOTOR

BLDC motor also known as Permanent Magnet DC Synchronous motor is one of the motor types which have gained more popularity, mainly due to their better characteristics and performance [14]. The stator windings are star connected to an internal neutral point. The rotor is non-salient pole type with trapezoidal flux pattern in the air gap. The Hall signals and the actual rotor speed are obtained as output from the motor [15]-[16].

5. FUZZY LOGIC CONTROL

Fuzzy logic controller is a rule-based controller. The fuzzy logic control is designed using the fuzzy inference systems (FIS) with the defined input and output membership functions. The fuzzy sets and rules are designed and accordingly the motor can be controlled [17]-[18]. The inputs for fuzzy logic controller are the speed error (e) and change in speed error (Δ_e). Speed error is calculated with comparison between reference speed and the actual speed. The simulation diagram of fuzzy logic controller is shown in Fig 5. [19]. Fuzzy rule has 7*7 decision table with two input variables and one output variable The look up table with the input and output rules defined with seven linguistic variables such as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB) respectively are given in Table.1.The membership function for speed error (e), change in speed Table.1 FUZZY RULE BASE error (Δ_e)shown in Fig 3.

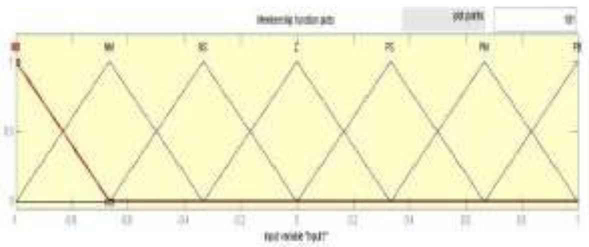

Fig.3 Membership functions for error andchange in error

Table.1 Fuzzy rule base

e/Δ_e	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

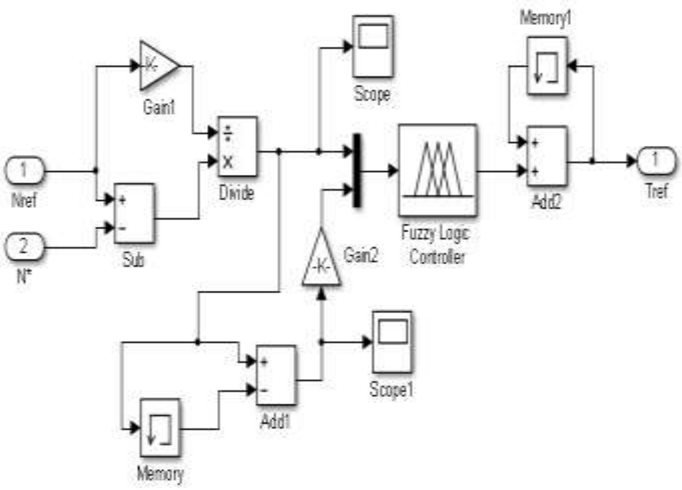

Fig.4 Simulation diagram of Fuzzy logic controller

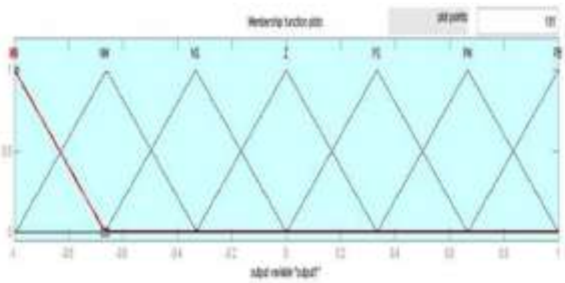

Fig.5 Membership functions for fuzzy output

The membership functions of output variable shown in Fig.5Brushless DC (BLDC) motors are widely used for many industrial applications because of their high efficiency, high torque and low volume. This paper proposed a improved Fuzzy PIC controller to control speed of Brushless DC motor.

The proposed controller is called PIC controller and Fuzzy PIC controller. This paper provides an overview of performance conventional PIC controller and Fuzzy PIC controller.

BLDC MOTOR SPECIFICATIONS

Table.2 Parameters and Specifications

Parameters	Specifications
No of pole	8
Rated voltage	24 V
Maximum peak current	10.6 A
Rated speed	1500 RPM
Rated torque	0.125 Nm
Torque constant	0.036 Nm/A
Resistance per phase	1.08 Ω
Moment of inertia	48 e-7 Kg-m2

6. SIMULATION RESULTS

The simulation of fuzzy logic controller based speed control of brushless dc motor using bidirectional converter is performed using MATLAB/Simulink model. The fuzzy logic controller is used as speed controller is used as speed control circuit. The output of the controller is fed to a controlled voltage source which feeds the inverter. The fuzzy logic controller is designed through fuzzy inference system (FIS) editor and is exported to the MATLAB workspace. Mandeni type of inference engine is used in the FIS editor. By setting positive and

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negative speed we get two modes of operation of Brushless motor. The simulation results provide the necessary wave forms for the analysis of speed control of BLDC motor drive.

6.1 Boost mode simulations

In Fig. 8 The speed will be high and maintain constant by using dc-dc converter.

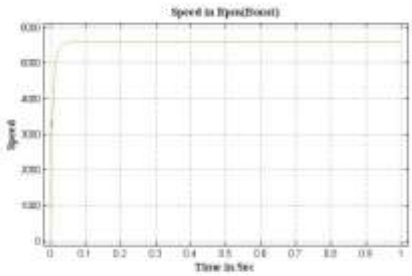

Fig.8Boost Speed in Rpm

In Fig. 9 The battery power is discharge, because run the BLDC motor with the supply voltage

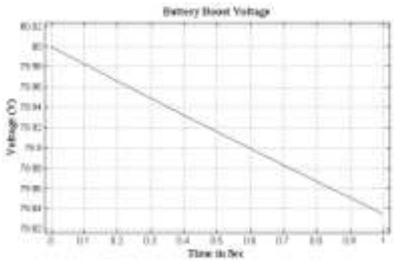

Fig.9 Battery Boost Voltage (V)

In Fig. 10The state of charge is the supply voltage given to the battery in boost mode to run the BLDC motor

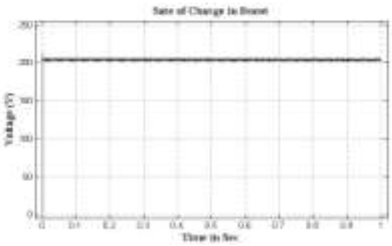

Fig.10 SOC in Boost Voltage (V)

In Fig. 11 The stator current is the variable current in boost mode

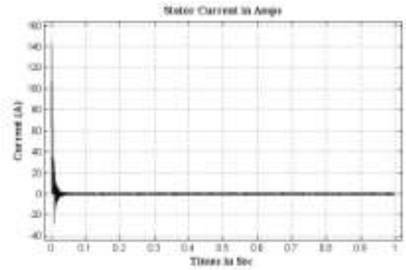

Fig.11 Stator Current (A)

.6.2 Buck mode simulation

In Fig. 12 The speed will be constant by using the bi-directional converter to run the BLDC motor

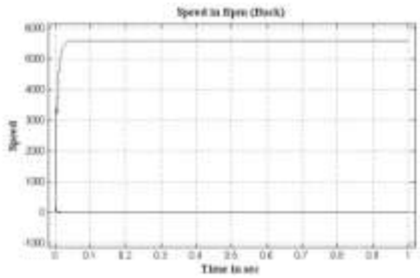

Fig.12 Buck Speed in Rpm

In Fig. 13 The battery will be charging by bi-directional the energy taken from the speed

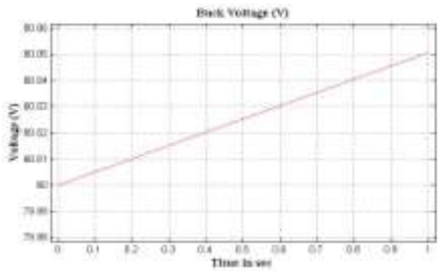

Fig.13 Battery Buck Voltage (V)

In Fig. 14The state of charge is the supply voltage given to the battery in buck mode to run the BLDC motor

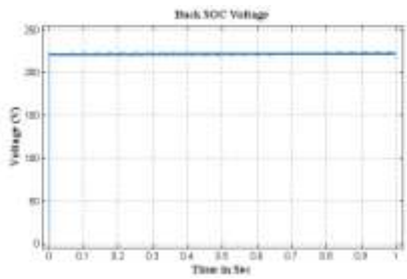

Fig.14 SOC in Buck Voltage (V)

In Fig.15 The stator current is the variable current in boost mode.

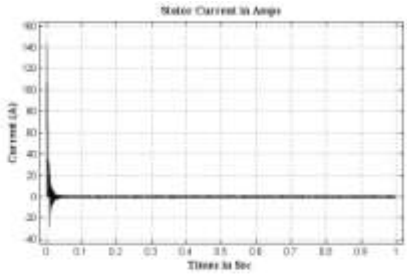

Fig.15 Stator Current (A)

7. HARDWARE DISCRIPTION

The Fig shows the overall hardware circuit of our project. It consists of three sections namely, Inverter circuit, converter circuit, PIC controller circuit, BLDC motor circuit.

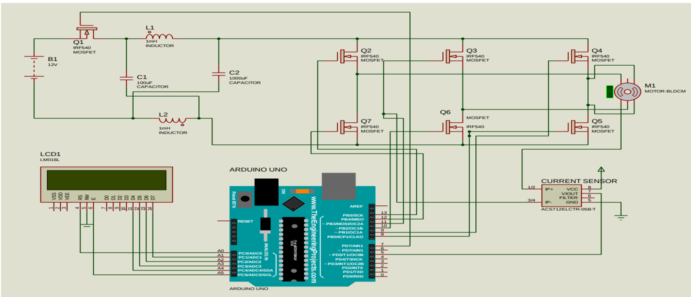

Fig.16 Overall Hardware diagram

The Overall Hardware Circuit Fuzzy Logic Rule is implemented in PIC Microcontroller the controller which controlled a MOSFET switches in DC-DC converter and Inverter Circuit and in fuzzy logic Speed will be compared given of error signal

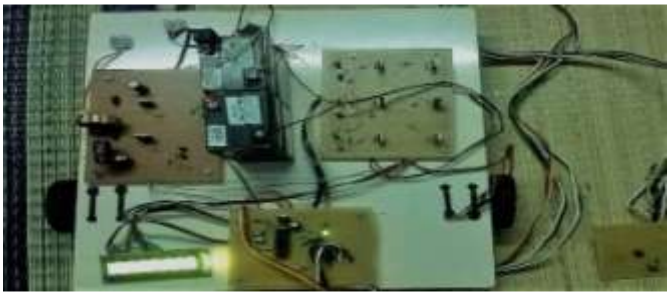

Fig.17 Hardware Module

In Hardware Module Circuit a model Vechile can be Design and the speed will controllrd by the Variable potentio meter and displaying a speed of the Motor and Battery Charging and Discharging Mode

CONCLUSION

In this paper, fuzzy logic control scheme for the speed control of Brushless motor using bidirectional converter is proposed. In braking modes of operation, instead of wasting kinetic energy it can be stored in a battery. The excess energy is effectively stored in the battery based on the mode of operation of the bidirectional converter. Simulation studies were conducted to evaluate the performance of both proportional integral controller and fuzzy logic controller based speed control method. The advantages of this proposed method are excellent speed control, smooth transition between the quadrants and efficient conservation of energy.

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