

A Bi-Directional DC-DC Converter Feeding PMBLDC Motor Drive System

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Abstract— This paper analyzes a bi-directional DC-DC converter having four active switches for higher transformation ratio. The converter steps up the DC voltage in forward direction and steps down in reverse direction and various modes of operation are possible. To investigate the performance of converter, simulations are performed on MATLAB/Simpower system platform. To study reverse power flow capability, PMBLDC motor is connected as load and regeneration is carried out.

Keywords—Bidirectional DC-DC Converter (BDC); PMBLDC Motor.

I. INTRODUCTION

The interest of researchers in DC micro grids has recently gone up to meet the high efficiency requirements. Moreover there is a desire to reduce the number of conversion stages in the converters to keep the design and control simple. The bidirectional dc-dc converters (BDC) have received a lot of attention due to the increasing demand of the systems, fed from DC sources like battery solar PV panels, fuel cells, super capacitors etc. The new applications of Bidirectional dc-dc converters include energy storage in renewable energy systems, fuel cell energy systems, Hybrid Electric Vehicles (HEV) and Uninterruptible Power Supplies (UPS) [1-2].

The constantly varying output from of most renewable energy resources, like wind and solar makes them improper for standalone operations as the sole source of power. A general solution to overcome this problem is to use an energy storage device with the,unstable energy resource to compensate for these instabilities and maintain a smooth and continuous power flow to the load. As the most common and economical energy storage devices in medium-power range are batteries and super-capacitors, a dc-dc converter is always required to permit energy exchange between storage device and the rest of system. Such a converter must have bidirectional power flow ability with flexible control in all operating modes [3].

In Hybrid Electric Vehicles (HEV) applications, BDCs

are required to link different dc voltage buses and transfer energy between them. For example, a BDC is used to exchange energy between main batteries (200-300V) and the drive motor with 500V dc link. High efficiency, lightweight, compact size and high reliability are some important requirements for the BDC used in such an application.

This paper analyzes a bi-directional DC-DC converter (shown in Fig. 1) that employs four high speed switches. The topology shown acts as boost converter in forward direction and buck converter when reverse power flow is needed. This arrangement is suitable for HEV like applications where the driving motor is having higher voltage requirement while the source is a battery of 12V/24V/36V/48V [4].

Isolated bidirectional DC-DC converter is used for medium and high power application [5-6] in isolated boost converter transformer is used but Non-isolated BDCs (NBDC) are simpler than isolated BDCs (IBDC) and can achieve better efficiency and less weight.

Chia-Ching Lin et. al. [7-8] has described a Bidirectional converter which steps-down the DC voltage in forward direction and steps-up in reverse direction. The same configuration is adopted in this paper, but operated in opposite way.

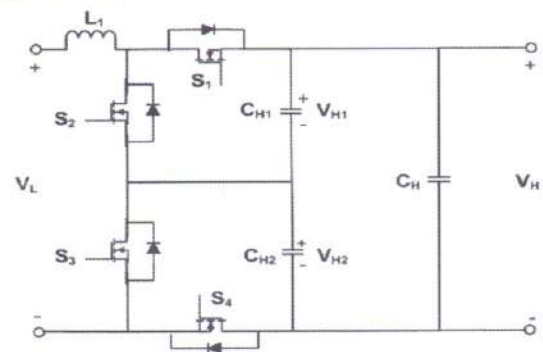


Fig. 1 Circuit configuration of the proposed converter

II. STEP-UP MODE OF THE PROPOSED CONVERTER

The proposed converter circuit configuration for step-up mode is shown in Fig. 2. This converter works in

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different modes, based on the switching of switches S1, S2, S3 and S4. The converter steps up the DC voltage in forward direction which is indicated by arrow. These modes are explained in detail as follows:

In steps up mode the voltage gain M of the proposed converter is

$$M_{steps\ up} = \frac{V_H}{V_L} = \frac{2}{1-D} \quad (1)$$

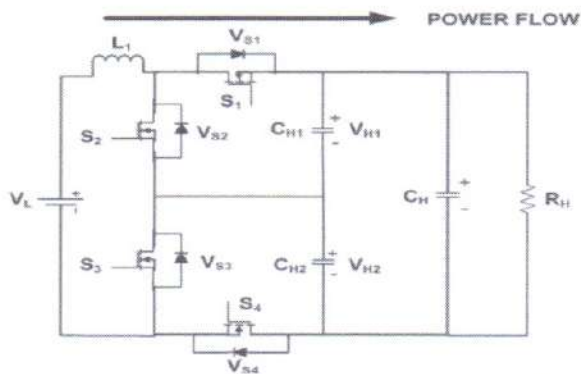


Fig. 2 Proposed converter in step-up mode

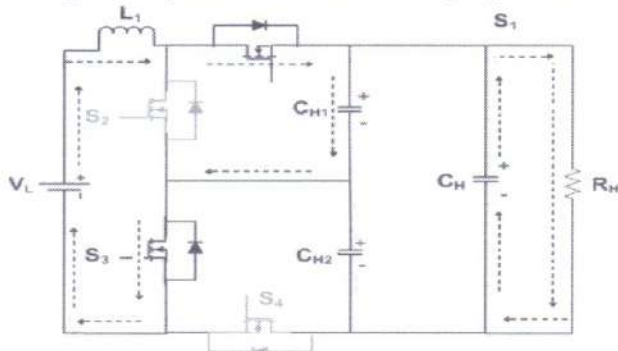


Fig. 4 Current flow path in step-up Mode 2

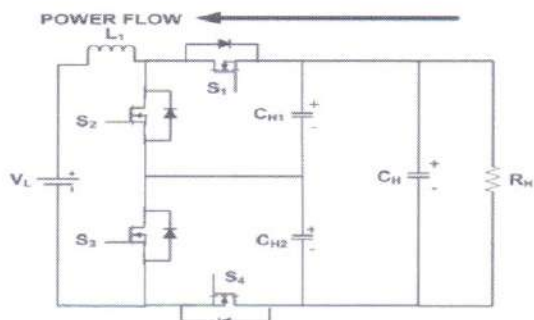


Fig. 6 Proposed converter in step-down mode

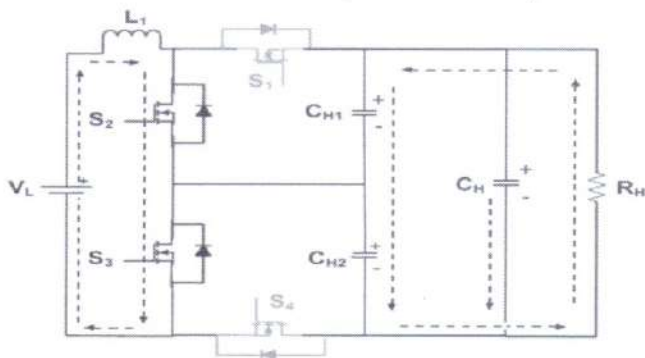


Fig. 8 Current flow path of in step-down Mode 2

1) Mode 1 & 3: In this mode, Switches S2 and S3 are ON and switches S1 and S4 are kept OFF. The source delivers the energy to the inductor as a result inductor current increases. At the same time capacitor discharges through the load. This mode configuration shown in Fig. 3.

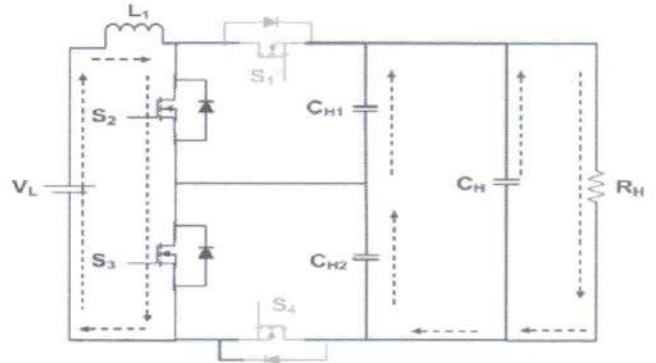


Fig. 3 Current flow path in step-up Mode 1 & 3

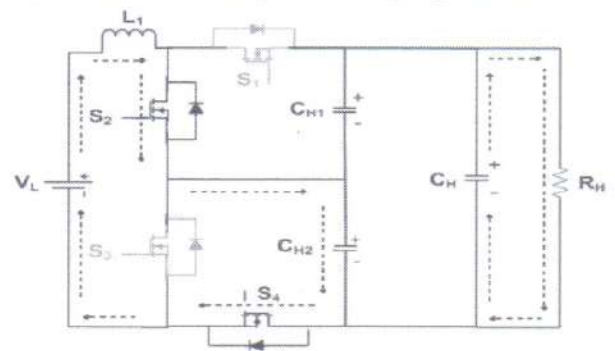


Fig. 5 Current flow path in step-up Mode 3

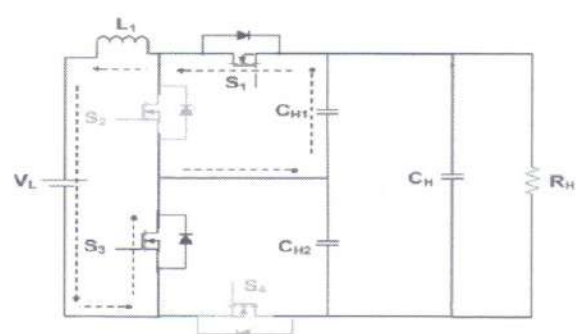


Fig. 7 Current flow path in step-down Mode 1

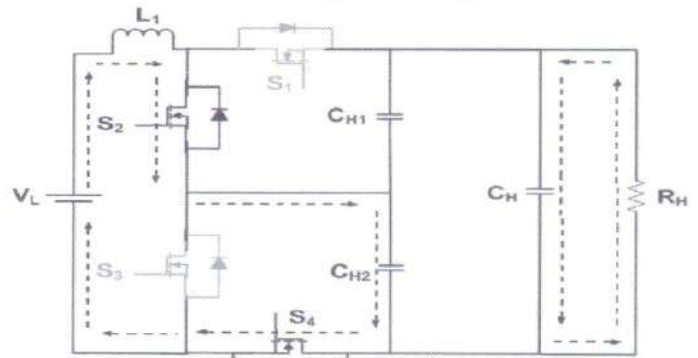


Fig. 9 Current flow path in step-down Mode

2) Mode 2: In this mode, body diode of S_1 and S_3 are ON and switches S_2 and S_4 are kept OFF. This mode is shown in Fig. 4

3) Mode 4: In this mode, switch S_2 and body diode of S_4 are ON and switches S_1 and S_3 are kept OFF. This conduction mode is shown in Fig. 5.

III. STEP-DOWN MODE OF THE PROPOSED CONVERTER

In step down mode, the proposed converter circuit configuration is shown in Fig. 6. Similarly step-up mode, this converter works in different modes, based on the switching of S_1, S_2, S_3 and S_4 . The converter steps down the DC voltage in reverse direction which is indicated by arrow. These modes are explained in detail as follows:

In steps down mode the voltage gain M of the proposed converter is:

$$M_{steps\ down} = \frac{V_L}{V_H} = \frac{D}{2} \quad (2)$$

1) Mode 1: In this mode, switch S_1 and body diode of S_3 are ON and switches S_2 and S_4 kept OFF. This mode is shown in

2) Mode 2 & 4: In this mode switches S_2 and S_3 , are ON and switches S_1 and S_4 are kept OFF. In this condition the stored energy in L_1 decrease. This mode is shown in Fig. 8.

3) Mode 3: In this mode switches, S_2 and body diode of S_4 , are ON and switches S_1 and S_3 are kept OFF. This mode is shown in Fig. 9.

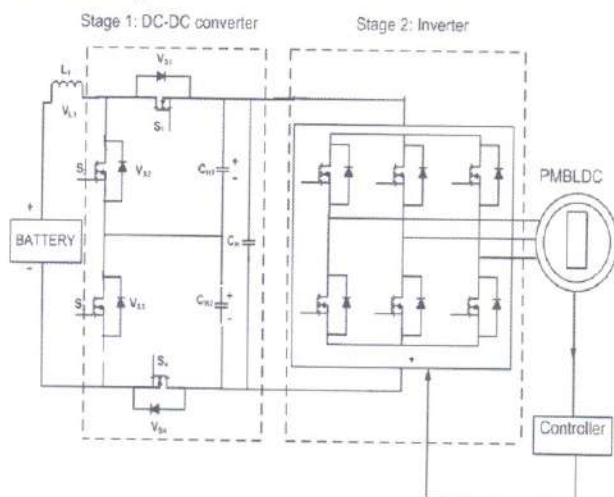


Fig. 10 Converter configuration with PMBLDC motor load.

IV. STEP- UP MODE OF THE PROPOSED CONVERTER WITH PMBLDC MOTOR

In step-up mode the load is a PMBLDC motor, fed from a battery of 48V through the boost converter. Step-

up converter configuration with motor load is shown in Fig. 10.

In the given Fig. 10 the battery is supplying a constant dc output. This constant dc is converted into a variable dc by a dc to dc converter i.e. chopper. The variable dc output of chopper is then applied to a three-phase inverter. It converts dc into three-phase ac voltage which is then fed to a PMBLDC motor..

V. SIMULATION OF DRIVE SYSTEM

The developed Matlab simulation of drive system is shown in

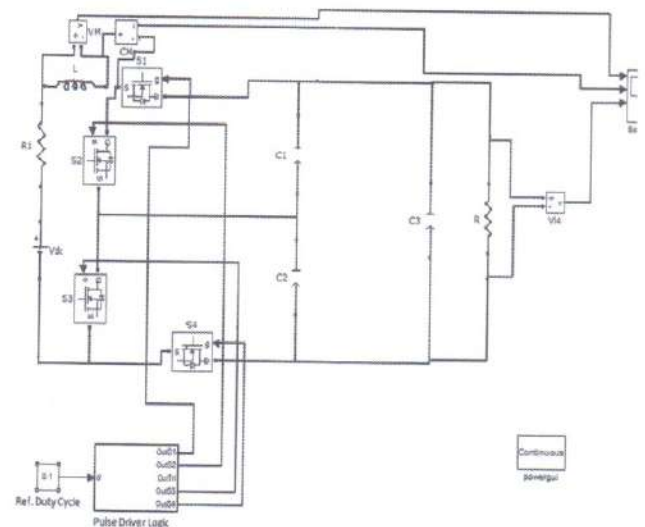


Fig. 11 Simulation diagram of drive systema

TABLE I
VALUE OF OUTPUT VOLTAGES FOR DIFFERENT DUTY CYCLE & LOAD FOR $V_1 = 48V$

| S NO. | Duty Cycle D | Output Voltage (Volts) [For RH = 2.5Ω] | Output Voltage (Volts) [For RH= 5Ω] | Output Voltage (Volts) [For RH= 5Ω] |
|-------|--------------|---|--------------------------------------|--------------------------------------|
| 1 | 0.1 | 110 | 120 | 120 |
| 2 | 0.2 | 120 | 130 | 140 |
| 3 | 0.3 | 130 | 140 | 150 |
| 4 | 0.4 | 140 | 150 | 160 |
| 5 | 0.5 | 150 | 170 | 180 |
| 6 | 0.6 | 170 | 200 | 210 |
| 7 | 0.7 | 200 | 240 | 260 |
| 8 | 0.8 | 240 | 300 | 350 |
| 9 | 0.9 | 180 | 250 | 370 |

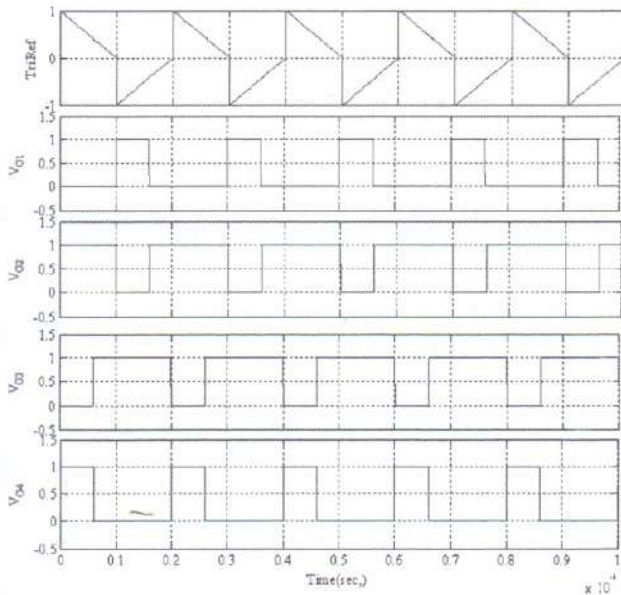


Fig. 12 Gate pulses for switches (Boost operation in forward direction)

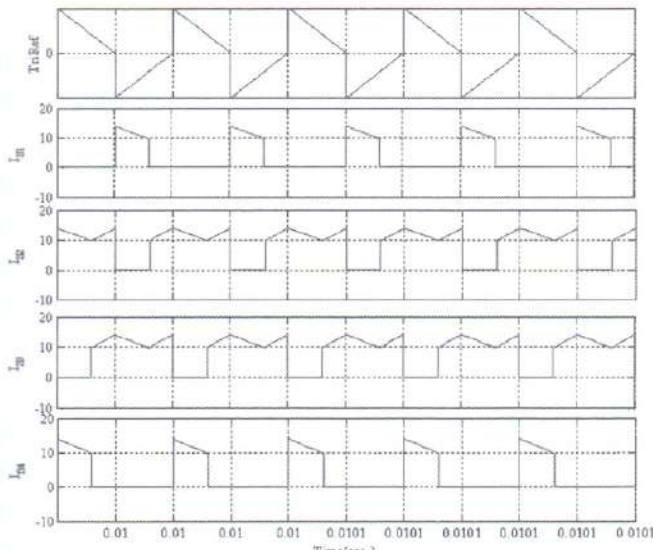


Fig. 13. Current waveforms for switches S_1 , S_2 , S_3 , and S_4 .

Fig. 11. In this figure source to the four high speed switches. These switches work simultaneously according to the gate drive system.

VI. RESULTS & DISCUSSION

Waveforms of switches current are shown in Fig. 13.

In this configuration input voltage V_L is 48Ω load resistance R_H value change form 2.5, 5 and 10 according these resistance value the output voltage value are change shown in following Table I. According to resistance value and duty cycle value the output voltage change it is shown in Fig. 14.

The graph between the output voltage and duty cycle is shown in Fig. 14. The variation of output voltage with duty

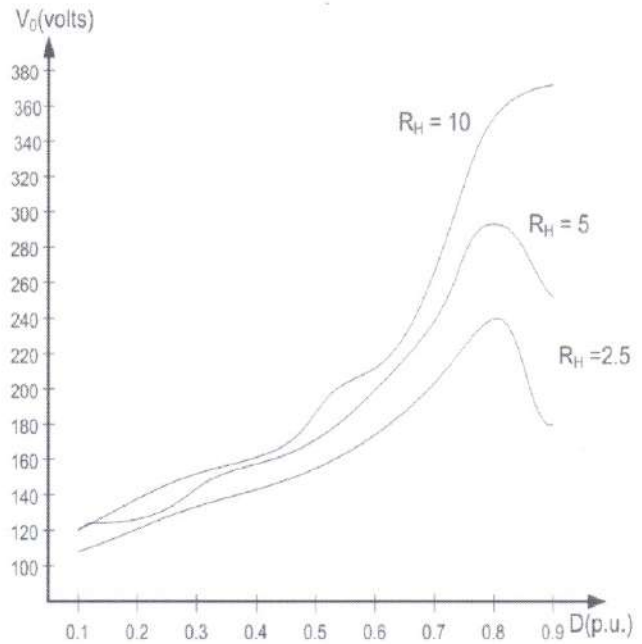


Fig. 14 Graph between output voltage and duty cycle for different values of load resistance.

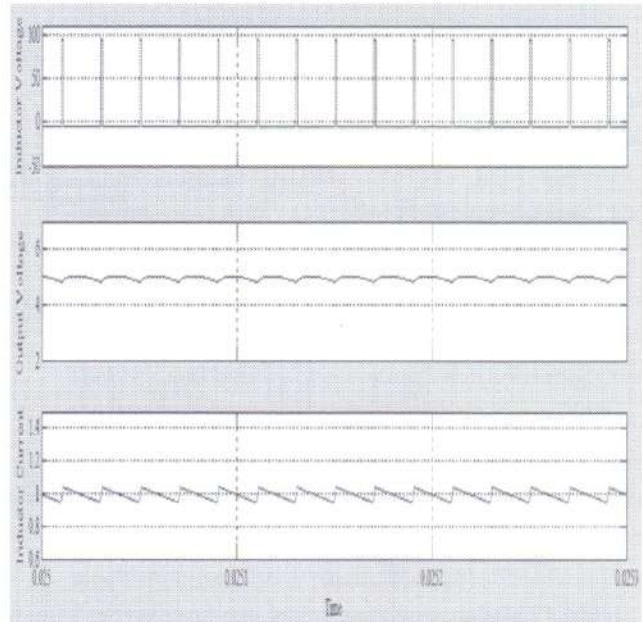


Fig. 15 Waveform of step-down converter: inductor voltage, output voltage and inductor current.

cycle is observed with variation of load resistance. It is observed that the converter can be suitably operation up to duty cycle of 0.8.

The output waveform of step-down converter shown in Fig. 15. In this figure shows inductor voltage, output voltage and inductor current.

The output waveform of step-up converter shown in Fig. 16. Finally simulation model of step-up converter with PMBLDC motor shown in Fig. 17.

In this figure the motor speed output feedback on PI controller for improved stability. Where rotor speed and time required are provided Table II:

TABLE II
ROTOR SPEED AND TIME REQUIRED

| S NO. | Torque | Speed | Time Required (SEC) |
|-------|--------|-------|---------------------|
| 1 | 5 | 1000 | 0.5 |
| 2 | 5 | 1500 | 0.75 |
| 3 | 5 | 2000 | 1 |

Matlab model of motor is shown in Fig. 18 where the capacitor output connected to the input of chopper then chopper output connected to the inverter, and inverter output connected to the motor.

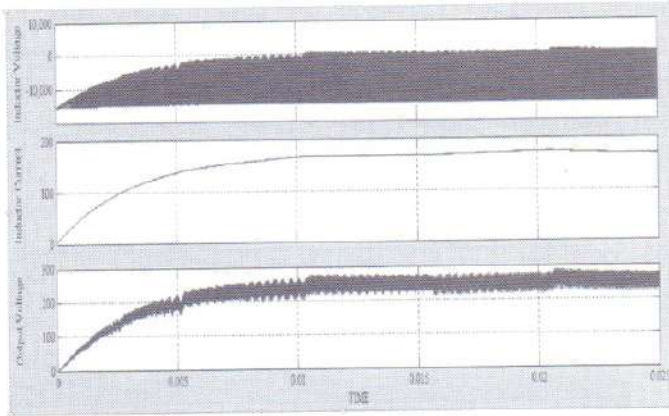


Fig. 16 Step-up converter waveform: inductor voltage, inductor current and boost output voltage.

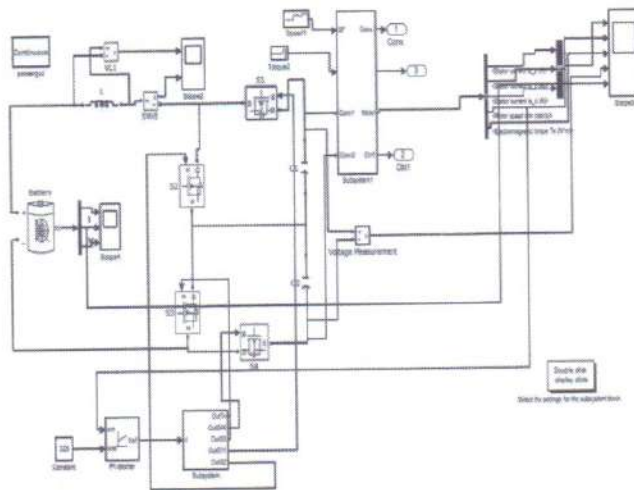


Fig. 17 Matlab simulation model step-up converter with motor.

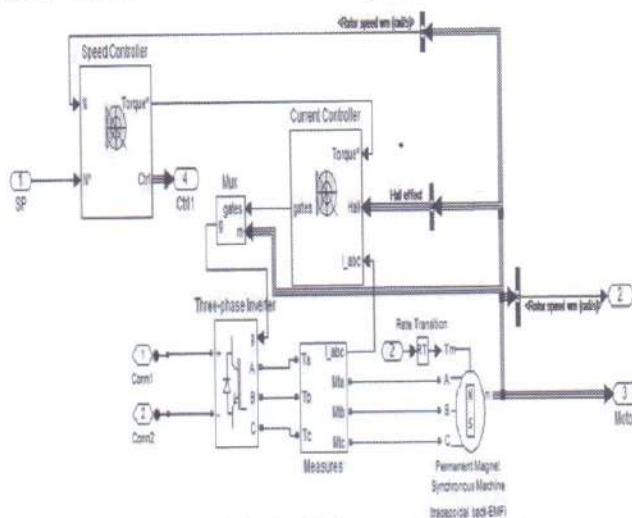


Fig. 18 Matlab simulation model of Motor.

To illustrate the significance and facilitate the understanding of theoretical results obtained in the simulation are listed in the tables III, IV, and V:

Waveform of State-of-Charge of the battery, battery current and voltage shown in Fig. 19

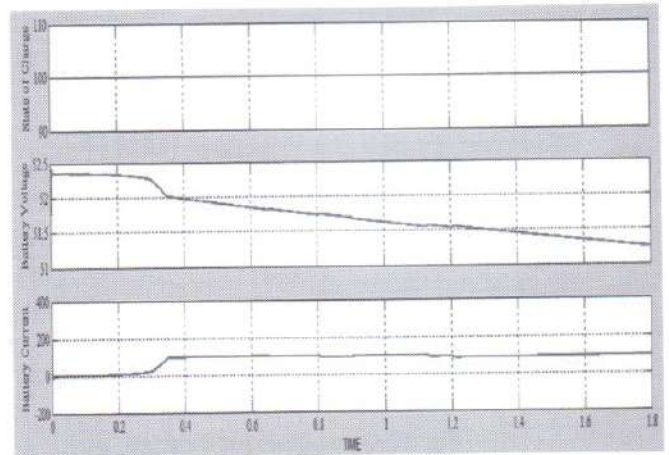


Fig. 19 Waveforms of State-of-Charge of battery, battery voltage and battery current

Waveforms of Stator current, stator speed, electromagnetic torque and capacitor voltage are shown in Fig. 20.

In these waveforms first shows stator current A, stator current B, and stator current C. second waveform of rotor speed this speed varies according to time and third waveform electromagnetic torque this is also varies with time. Regenerative waveforms are shown in Fig. 21.

VII CONCLUSIONS

Bidirectional converter is being designed and speed control of the PMSM motor has been achieved with the designed bidirectional dc-dc converter. Different voltage and current waveform of the bidirectional dc-dc converter are obtained.

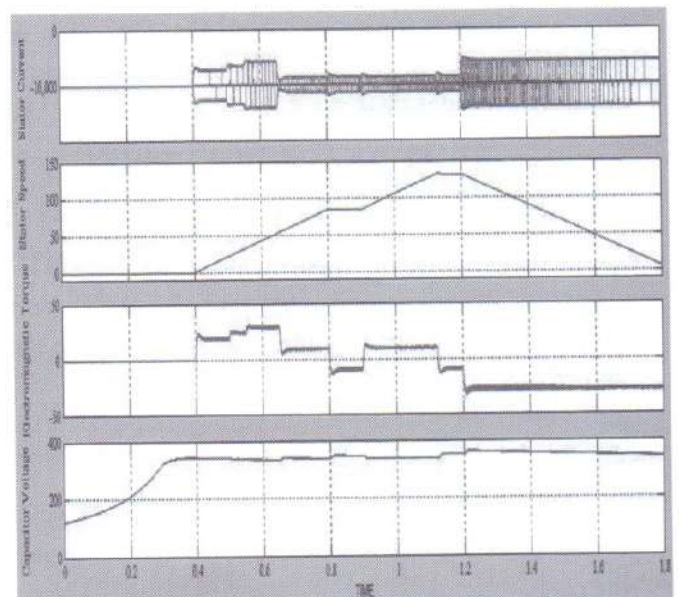


Fig. 20 Waveforms of Stator current, stator speed, electromagnetic torque and capacitor voltage.

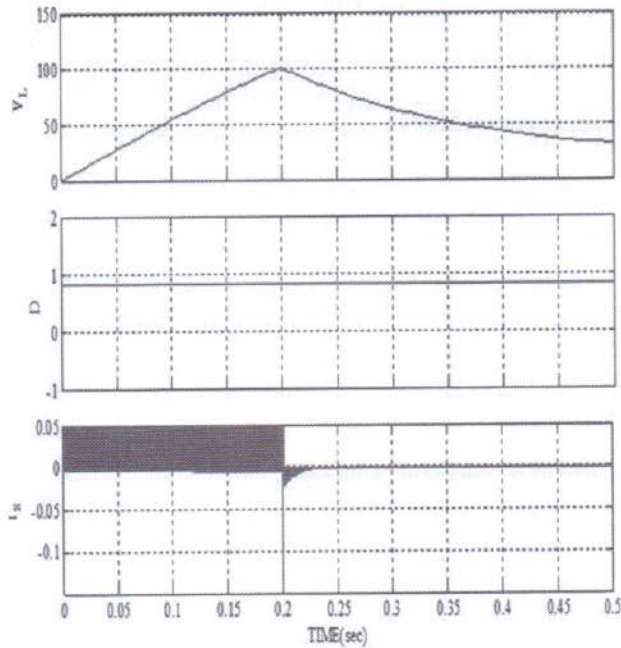


Fig. 21 Regenerative waveforms.

TABLE III
MOTOR PARAMETER

| S. No. | Parameters | Value |
|--------|-------------------------|-------------------------|
| 1 | Stator Phase Resistance | 0.2Ω |
| 2 | Stator Phase Inductance | 8.5* 10 ⁻³ H |
| 3 | Flux Linkage (Magnets) | 0.175 V.s |

TABLE IV
BATTERY PARAMETERS

| S. No. | Battery Parameter | Value |
|--------|-------------------------|----------|
| 1 | Norminal Voltage | 48 Volts |
| 2 | Rated Capacity | 150 Ah |
| 3 | Initial State of Charge | 100 % |

TABLE V
CONVERTER PARAMETERS

| S. No. | Converter Parameter | Value |
|--------|------------------------------|------------------------------|
| 1 | Inductor (L) | 0.1* 8.5* 10 ⁻³ H |
| 2 | Capacitor (C _{H1}) | 100* 10 ⁻⁶ F |
| 3 | Capacitor (C _{H2}) | 100* 10 ⁻⁶ F |
| 4 | Capacitor (C _L) | 100* 10 ⁻⁶ F |
| 5 | Swiatching Frequency (F) | 60 Hz |

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