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Development of Regenerative Braking Concept for Electric Vehicle Enhanced with Bidirectional Converter

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Article Info	ABSTRACT
	Due to the increasing concern for environment protection and the uncertainty about oil reserves, nowadays electricity is playing a key role as an alternative energy source in the automotive sector. In this paper, non isolated bidirectional converter is used for electric vehicle application during regenerative braking process. During motoring operation, the converter supplies energy to motor through battery. In regenerative braking action, the converter supplies the available back emf to charge the battery. The recycled energy is effectively stored in the battery. The simulation is carried out in MATLAB/Simulink. The worthiness of simulation is illustrated experimentally by developing a prototype. The simulation and experimental results are presented in this paper.

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1.   INTRODUCTION

Hybrid power sources combining various combinations of fuel cell, solar and battery are popular in automotive systems, renewable energy conversion systems and in the fuel cell-based residential systems. Due to the increasing concern for environment protection and the uncertainty about oil reserves, nowadays electricity is playing a key role as an alternative energy source in the automotive sector. An Electric Vehicle (EV) significantly reduces the daily traveling costs, because the maintenance and operation costs of these vehicles are lower than the conventional ones [1]-[3]. Therefore, for electric vehicle application, bidirectional converter is used between battery and motor. In this case, proper battery management is required [4]-[6].

Non- isolated bidirectional converter have been used for isolation [7] and other several non isolated converters were introduced in [8]-[10]. The DC-DC converter with switched type capacitor is proposed in [11]-[12], but it requires more capacitors. The DC-DC converter with coupled inductor were introduced in [13]-[19], but it produced current ripple.

In electric vehicle, the electrical energy is extracted from rotational energy by using proper converter with suitable charging and discharging profiles. Hence in this paper, two half bridge converters are connected together and capable of transferring energy both in motoring and regenerative braking action. Section 2 describes the principle and modes of operation of bidirectional converter. The simulation results and hardware implementation are described in Section 3 and 4 respectively.

2.   BIDIRECTIONAL DC-DC CONVERTER

Figure 1 represents the bidirectional DC-DC converter which consists of two half bridge cells which are connected through an auxillary capacitor Ca and inductor L_a [20]. M_1 and M_2 are the low voltage side switches which operate under duty cycle 1-D and D respectively. M_3 and M_4 are the high voltage side switches which operate under duty cycle 1-D and D respectively. L_f is the filter inductance. C_1 and C_2 are output capacitors connected in series to produce high voltage gain.
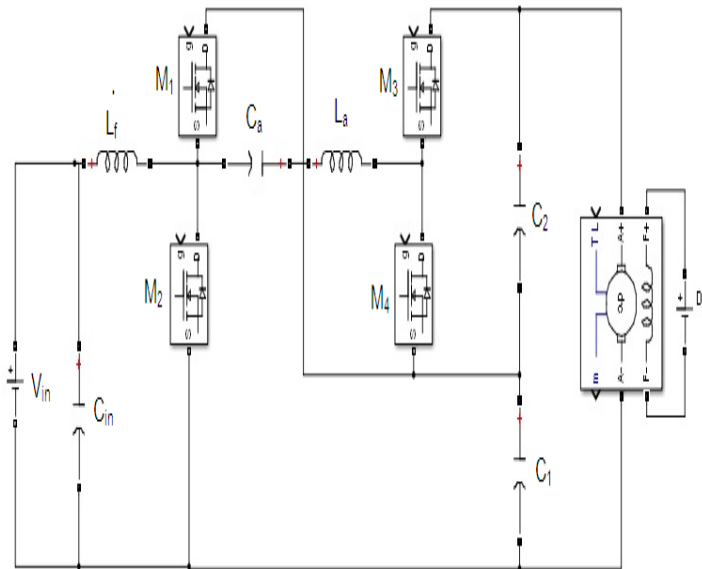

Figure 1. Bidirectional DC-DC converter using two half bridge cells

There are three modes of operation. During motoring action, the voltage of the battery is stepped up and delivers to the motor. During braking action, the back emf is used for charging the battery and thus machine act as generator.

2.1. Mode 1

In this mode, switches M_2 and M_4 are off and switch M_1 is ON and M_3 is in switching mode. In this mode, the converter step up the required voltage to motor. This mode comes in to operation during motoring action.

2.2. Mode 2

In this mode, switches M_2 and M_4 are off and switch M_1 is ON and M_3 is in switching mode. In this mode, the DC machine voltage is stepped down and given to the battery. This mode comes in to operation when the back emf is greater than voltage of the battery during braking action.

2.3. Mode 3

In this mode, switches M_1 and M_4 are off, switch M_3 is ON and M_2 is in switching mode. This mode comes in to operation only when back emf is less than voltage across the battery during braking action.

3.   SIMULATION RESULTS

Figure 2 represents the simulation circuit diagram of bidirectional DC-DC converter with DC motor on load side through auxillary capacitor C_a= 30µF and inductor L_a=12µH . The filter inductance L_f=37.5µH is used. The output capacitors C_1=30µF and C_2=30µF are connected in series across the motor to achieve high voltage gain. Initially the converter step up the input voltage from 6V to 18V and this voltage is supplied to the motor. The switching frequency of 50 kHz is used. At 4.5sec the input voltage is reduced to 1V and the converter operates in braking mode. In this braking mode, the back emf of 0.6V generated by the DC machine is stored in the battery.
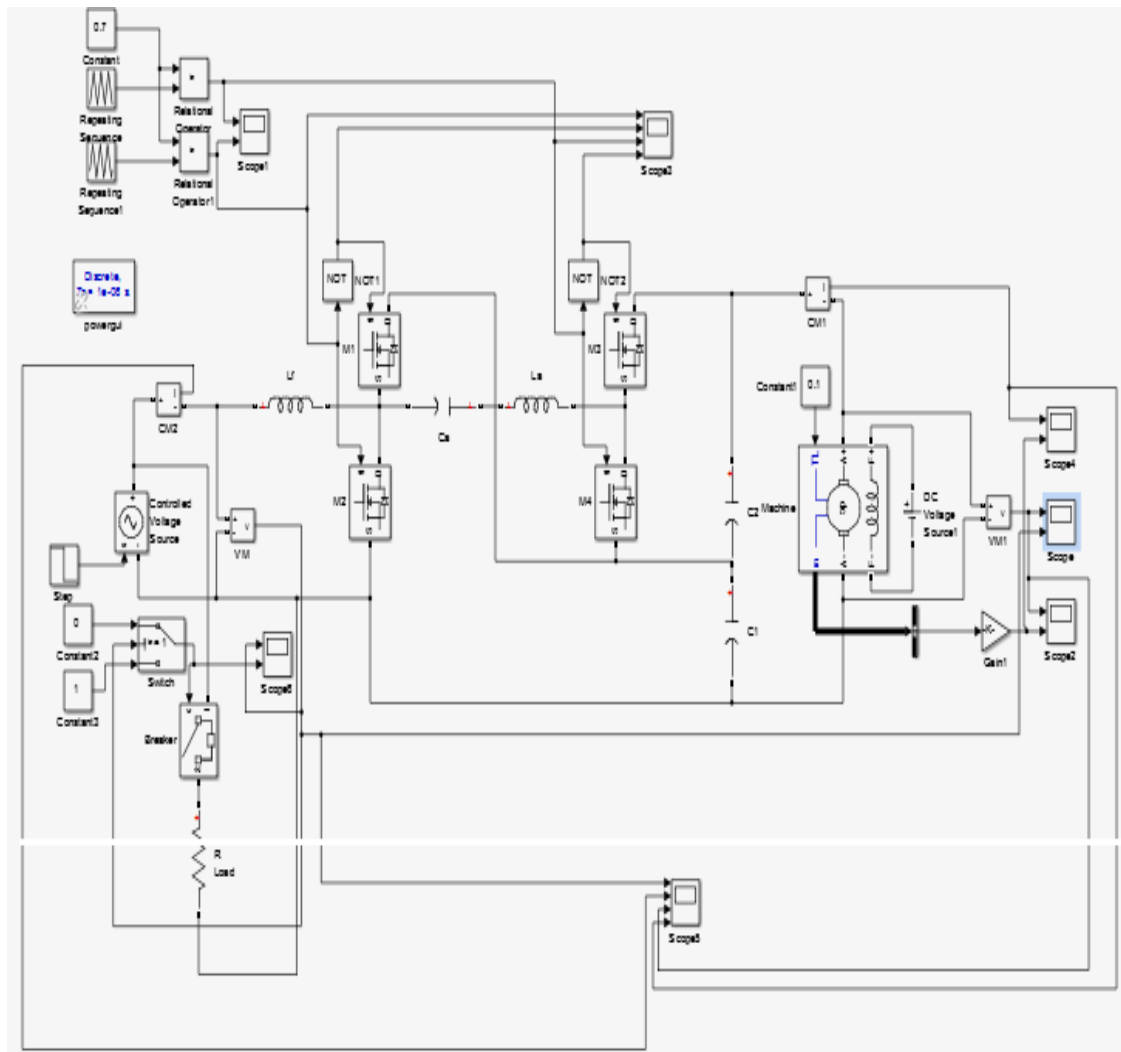
Figure 2. Simulation Diagram of Passive Clamp based DC-DC converter fed by Photovoltaic Module

Figure 3 shows the input voltage waveform during motoring action and in braking action. Figure 4 shows the input-output voltage and current waveform of the converter. Figure 5 shows that during motoring action, 18V is supplied to the motor and during braking mode, about 0.6V is generated by the DC machine.
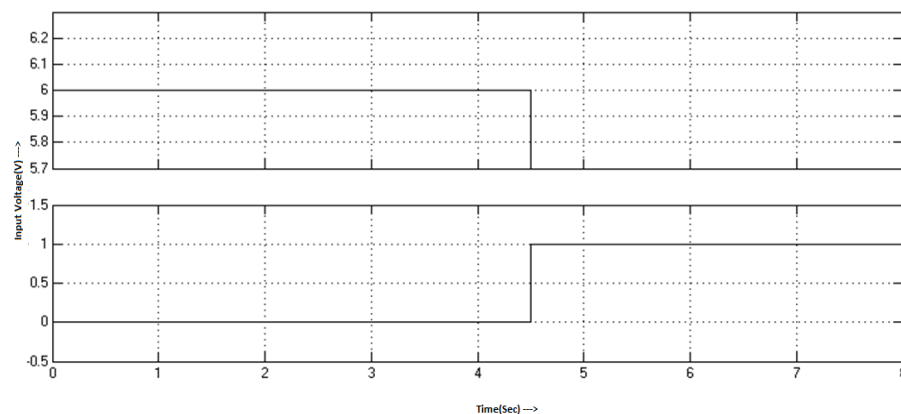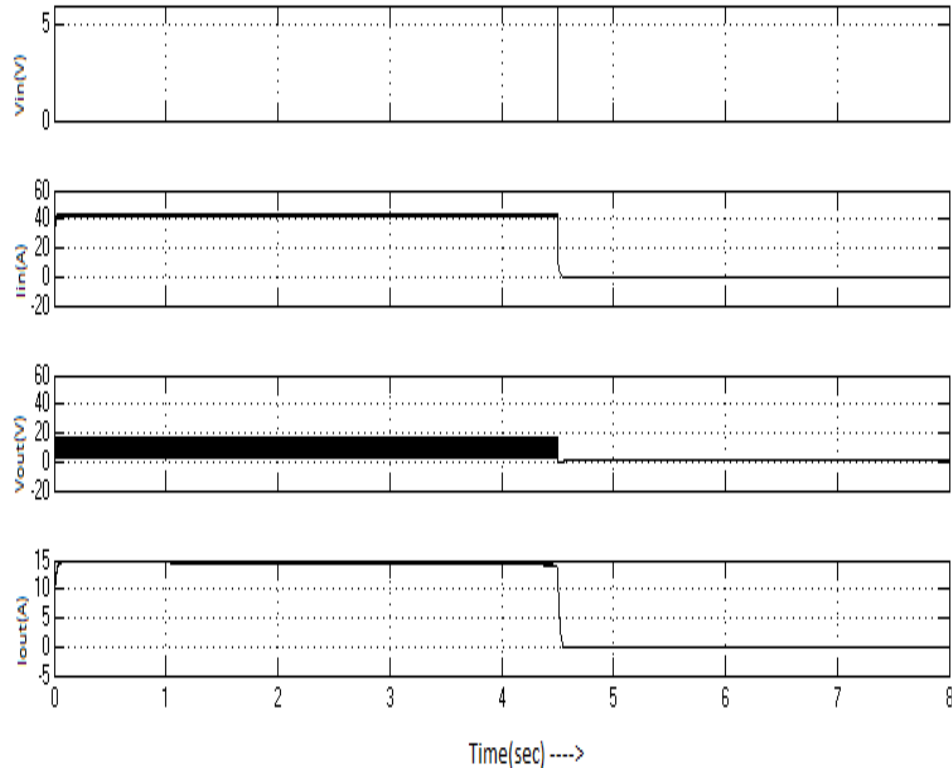

Figure 3. Input voltage waveform

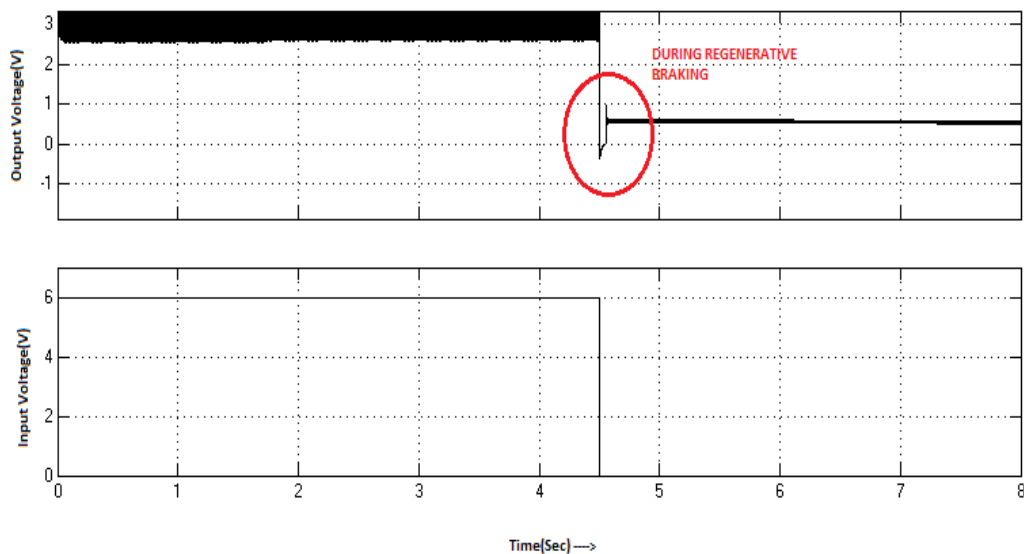Figure 4. Input-output voltage and current waveform

Figure 5. Output voltage during regenerative braking

4.   HARDWARE IMPLEMENTATION

The worthiness of simulation results are validated by prototype. Figure 6 shows the experimental setup. The hardware consists of step down transformer, rectifier, bidirectional converter, microcontroller, sensing unit and gate driver circuit. The 230V AC supply is stepped down to 12V AC by a step down transformer. The 12V AC supply is converted in to DC by a bridge rectifier. The output of bridge rectifier is given to voltage regulator IC7805 to obtain constant 5V DC supply which is given to PIC16F887 microcontroller. The micro controller produces control signal for the bidirectional converter switches which is not sufficient to drive the switch. Therefore an optocoupler is used to produce required driving pulse for switch. The generated pulses are given to bidirectional converter switch. Output voltage of the converter

depends on switching duty cycle. In forward mode of operation, the flow of energy is from battery to motor which turns the wheel of the vehicle providing kinetic energy to move. In this mode, input voltage of 6V is stepped up to 12V and supplied to flywheel motor of rating 12V, 2A, 1500rpm. Figure 6 shows the speed of the motor. During braking action, when the input supply voltage is cut off, then the motor works as generator and produces back emf of 1.65V which is stored in the battery as shown in Figure 7. So a good proportion of energy which was lost by braking is returned to the battery and can be reused.
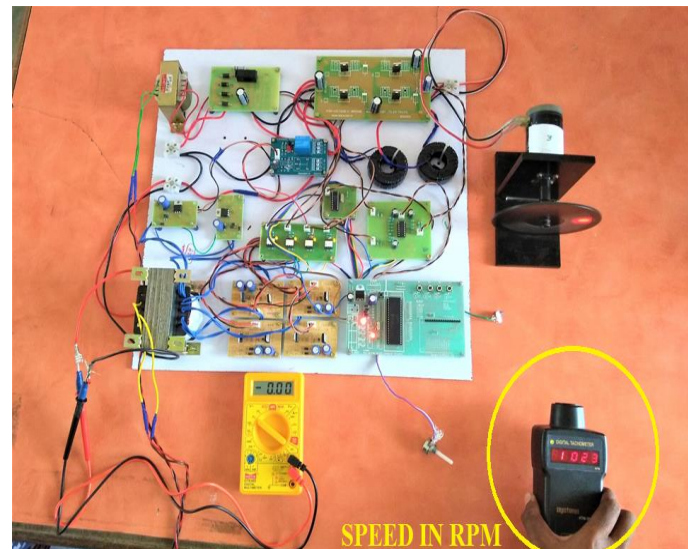

Figure 6. Speed of flywheel DC motor

Figure 7. Output voltage during braking action
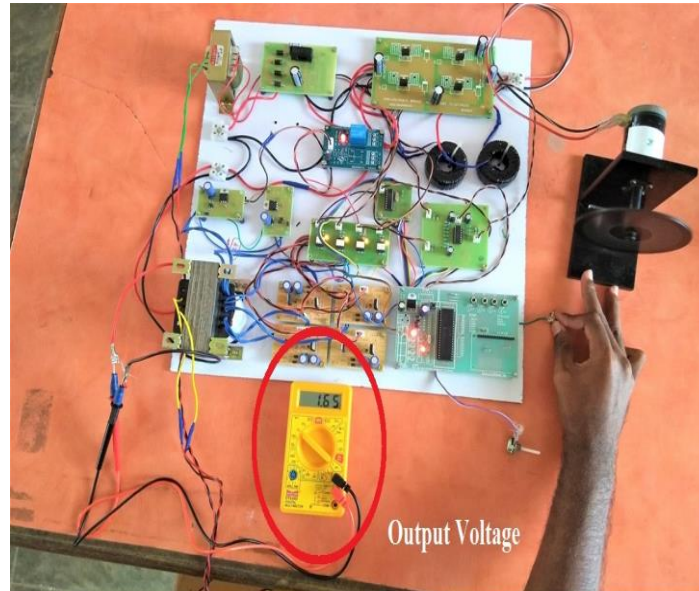
5. CONCLUSION

The non- isolated bidirectional converters with two half bridge cells are used for electric vehicle application. During regenerative braking mode, the bidirectional converter stores the energy to battery which was generated by DC machine. So a good proportion of energy which was lost by braking is returned to the battery and can be reused.

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