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Operation and Control of Bidirectional DC-DC converter for HEV

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Abstract: With the increasing concern over global warming, the use of hybrid electric vehicle is being encouraged. In this the cars are fueled by a combination of traditional gasoline engine along with an electric battery, thereby reducing the dependence on fuel consumption and hence improving the performance. In Hybrid electric vehicle (HEV) there are different voltage buses for different purposes of vehicle operation. Bidirectional DC-DC converter is used in HEV to connect these buses for battery charging and regenerative braking. In this paper a control method is proposed which gives an easy, efficient and reliable method of controlling the converter by switching buck and boost operation depending on the speed of the vehicle. The simulation study is done by using PSIM simulation software

Keywords: Hybrid Electrical vehicle (HEV), Bidirectional DC-DC converter, PSIM, Renewable Energy

I. INTRODUCTION

Increasing fuel cost is one of the major factors in the development of hybrid vehicles. They are being considered important in mitigating concerns over the rapid increase in air pollution and global warming associated with greenhouse gases. A hybrid electric vehicle is a vehicle that combines in addition to its main energy sources (oil or gas), reversible storage devices like batteries [1]. A HEV produces less emission from its internal combustion engine as compared to a same sized gasoline car, since a HEVs gasoline engine is smaller than comparably sized pure gasoline burning vehicle [2-3]. They reduce idle emissions by shutting down the Internal Combustion Engine (ICE) at idle conditions and restarting it when needed. They combine the benefits of gasoline engine, electric motors and can lead to improved fuel economy, increased power or additional auxiliary power for electronic devices. Commercially available HEVs include Toyota Prius, Toyota Highlander hybrid, Honda Civic hybrid, Ford Escape hybrid etc. Power electronics converters are responsible for a large part of vehicle's energy usage. In the past power electronics converters were avoided due to cost issues. The reasons for increased interest include firstly, New Architecture by integrating switching and fusing functions into one component with higher reliability. There is possibility of implementing different control methods on power electronic converters. Secondly, Power conversion on demand by providing adjustable speed drives. Thirdly, Voltage conversion on demand as the dc voltages with different voltage levels is not possible without the use of power electronics. Lastly, precise electronic control such as ignition needs precise timing which cannot be imagined without the use of power electronics [4-5]. The power electronics circuits used in hybrid electric vehicles include rectifiers, inverters and dc-dc converters. The dc-dc converter is used to condition the voltage levels and to provide stable dc bus voltage. Bidirectional dc-dc converter is needed so that regenerative energy can be captured and stored in energy storage. Advancement in DC-DC converters control for solar PV system leads to find new innovations in HEV system [6-7]

The Fig. 1 shows the connection of bidirectional DC-DC converter in HEV. The low voltage bus is supplied by the battery and the loads are connected to this bus. The loads include lighting and air conditioners in the vehicle. The high voltage bus is used for providing power to the propulsion system and is connected to the low voltage bus through the converter. The converter controls the flow of power from the battery to the propulsion system and similarly from the propulsion system to the battery. There is a need to control the operation of converter for satisfactory operation of HEV during acceleration and braking [8-9].In this paper a control circuit for the operation for the DC-DC bidirectional converter in HEV is developed and tested in simulation. The designed control circuit is in the reliable operation and the simulation is done using PSIM software.

This paper is organized in the following sections. In sectionII the working principle of HEV is presented. In sectionIII the operation of bidirectional dc-dc converter is shown. The control of converter is given in sectionIV. SectionV focuses on simulation results. Finally the conclusion is given in section VI.

II. WORKING PRINCIPLE OF HEV

The technologies used by hybrid electric vehicle include-

1) Regenerative braking-The electric motor applies resistance to the drive-train causing the wheels to slow down. In return, the energy from the wheels turns the motor, which functions as a generator, converting energy normally wasted during braking into electricity, which is stored in the battery until required by the electric motor.

2) Electric motor drive/assist-The electric motor provides additional power to assist the engine in acceleration. This allows a smaller, more efficient engine to be used. In some vehicles, the motor alone provides power for low-speed driving conditions.

3) Automatic start/shutoff- The HEV automatically shuts off the engine when the vehicle comes to a stop and restarts it when the accelerator is pressed. This prevents wasted energy from idling and thus improving performance of the vehicle. For example, when the vehicle is stopped such as at red light the gasoline engine and electric motor shut off automatically so that energy is not wasted in idling. The battery continues to power the auxiliarysystems such as air conditioning and dashboard displays.

During starting the gasoline engine warms up and the energy from the engine is converted into electricity and stored in the battery for later use as shown in Fig. 2.

At cruising speeds the gasoline engine powers the vehicle and if needed provides power to the battery for later use as shown in Fig. 3.

During heavy acceleration or when additional power is needed as shown in Fig.4, the gasoline engine and electric motor are both used to propel the vehicle. Additional power from the battery is also used to power the electric motor as needed.

As shown in Fig. 5, the regenerative brakes convert the wasted energy from braking into electricity and store it into the battery. In regenerative braking the electric motor is reversed so that instead of using the electricity to turn the wheels, the rotating wheels turn the motor and create electricity.Using energy from the wheels to turn the motor slows the vehicle down. If additional stopping power is needed, conventional friction brakes are also applied automatically.

III. OPERATION OF BIDIRECTIONAL DC-DC CONVERTER

There are generally twoconverters in hybrid electric vehicle applications. Oneisa high-power converter that links the hybrid powertrain battery at a lower voltage with the high voltage DC bus. The second low-power DC-DC converter links the hybrid battery with the low voltage auxiliary battery. The power flows can be controlled according to the operation of the electric motor whether in forward motoring mode or regenerative braking mode and hence theDC-DC converter provides bidirectional power transfer. The circuit topology is as shown in Fig. 6.

The bidirectional DC-DC converter consists of two switches (MOSFETs) i.e. Q1 and Q2. As the speed of DC motor can be varied by changing the voltage so the motor is represented as voltage source (Vmotor). When Q1 is turned on the buck mode will operate and in this power is transferred from battery to motor. The DC motor will move in forward direction. When Q2 is turned on, the boost mode will operate and the power is transferred from DC motor to battery. The DC motor acts as generator and starts charging the battery. The switches Q1 and Q2 are never turn on at the same time.

The converter operation mode in buck and boost mode is shown in Table 1.

In case of acceleration Q1 is turned on, Q2 is off and converter operates in buck mode. During braking Q2 is on, Q1 is off and converter operates in boost mode. This can be represented as shown in Table 2.

IV. OPERATION OF BIDIRECTIONAL DC-DC CONVERTER

This paper proposes the control mechanism of bidirectional DC-DC converter for buck and boost operation. The simulation results have been obtained in PSIM simulation software. The Fig. 7 shows the block diagram for control.The actual speed of the vehicle by F-I analogy has been represented as voltage (Vspeed). As shown in Fig. 8 there are two comparators, one for acceleration and other for braking. Reference speeds have been considered in each case and with the comparator the desired switching timing can be determined.

In case of acceleration the gate AND1 causes the Q1 switch to turn on and thereby operating the converter in buck mode where the power flows from the battery to the motor for propulsion of vehicle. In case of braking the gate AND2 causes the Q2 to turn on and thereby operating the converter in boost mode. In boost mode the power flows from the motor (now working as a generator) back to the battery known as regeneration.

A. Mathematical representation of buck and boost modes

Assume that the actual speed signal be Vspeed as shown in Fig. 8,which is supplied to the acceleration comparator. This speed is compared with reference speed Vref1 and the output obtained is s1.

Similarly, the actual speed is compared with reference speed Vref2 for braking and the output obtained is s2. The inputs to braking comparator are reversed from those of acceleration comparator as the time of occurrence of these operations in the vehicle are complimentary. The output of AND1 is denoted by M1 which is calculated as shown in equation (1).

$$M1 = s1 \text{ AND } s2' \quad (1)$$

The output of AND2 is denoted by M2 and is calculated as shown in equation (2).

$$M2 = s1' \text{ AND } s2 \quad (2)$$

These outputs (M1, M2) are further compared with saw tooth signal to obtain pulses for switching of Q1 and Q2.These generated pulses are denoted as N1 and N2 for switching of Q1 and Q2 respectively. The switching by N1 and N2 is shown in Table 3.

V. FIGURES AND TABLES

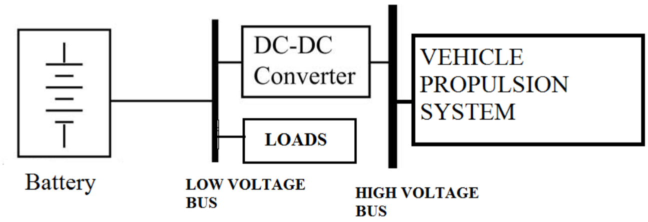

Fig.1

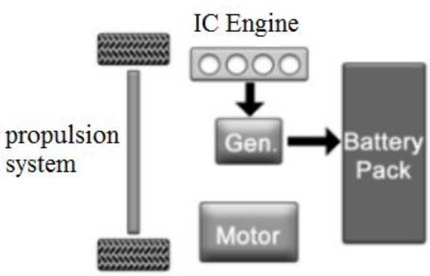

Fig. 2. Operation during starting of HEV

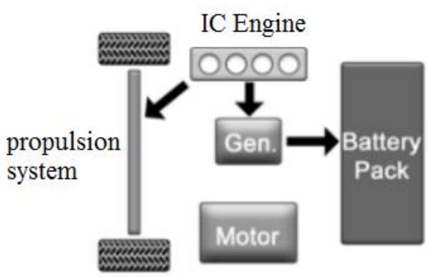

Fig. 3. Operation of HEV at cruising speeds

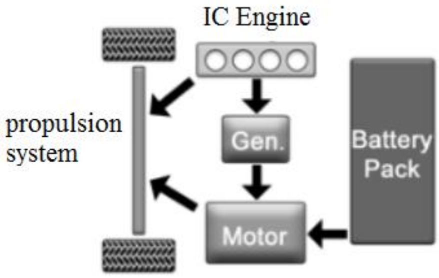

Fig. 4. Operation during acceleration

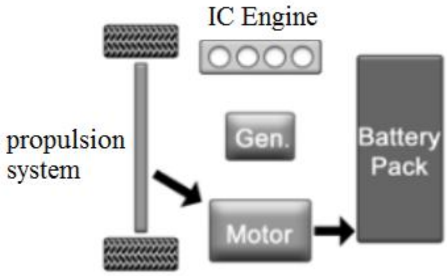

Fig. 5. Operation of HEV during braking

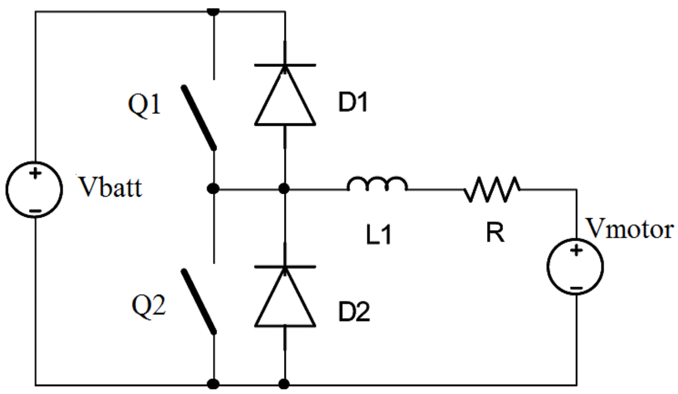

Fig. 6. Schematic diagram of Bidirectional DC-DC converter in HEV

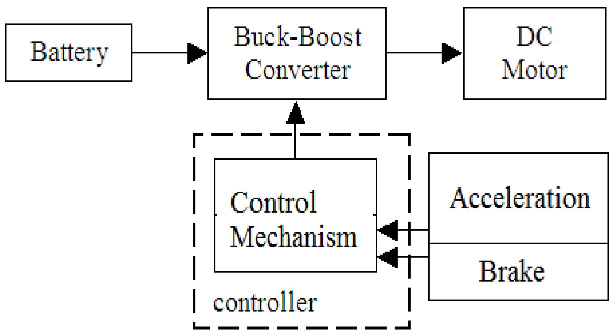

Fig. 7. Block diagram of Bidirectional DC-DC converter control in HEV.

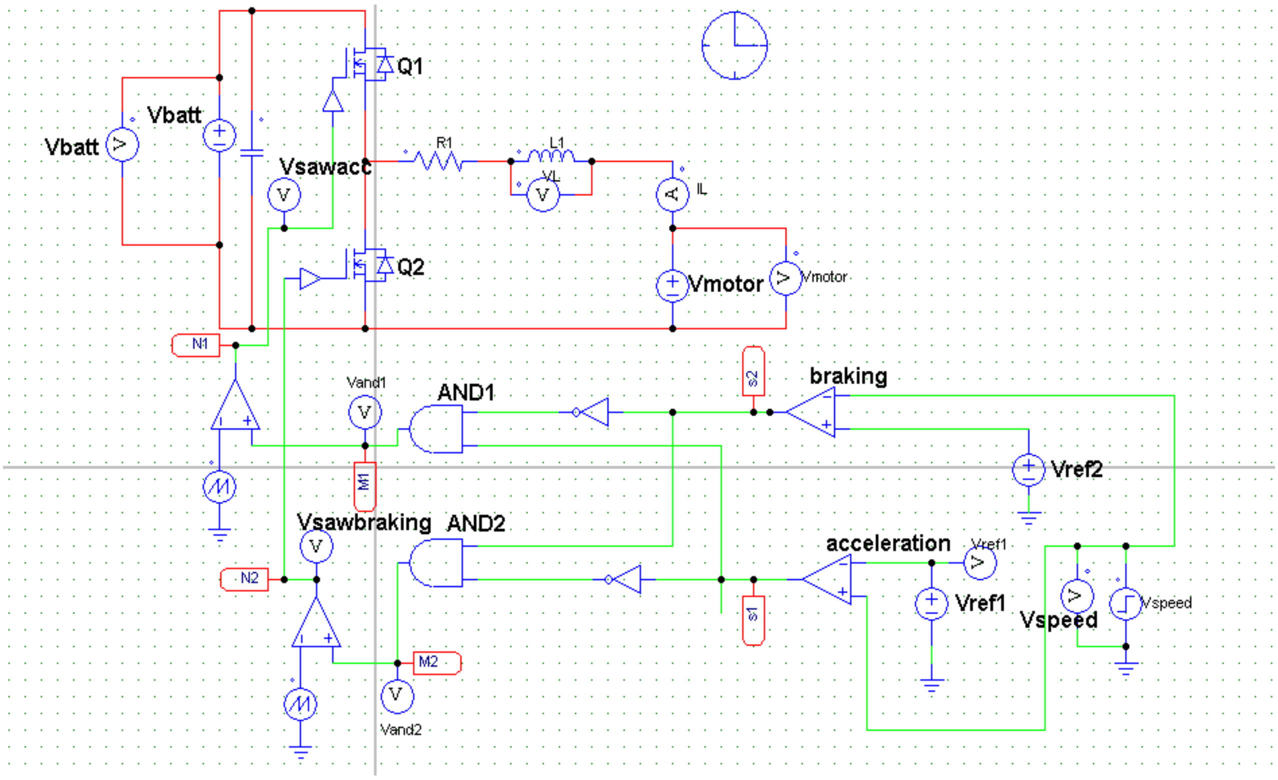

Fig. 8. Control circuit as simulated in PSIM Simulation Software

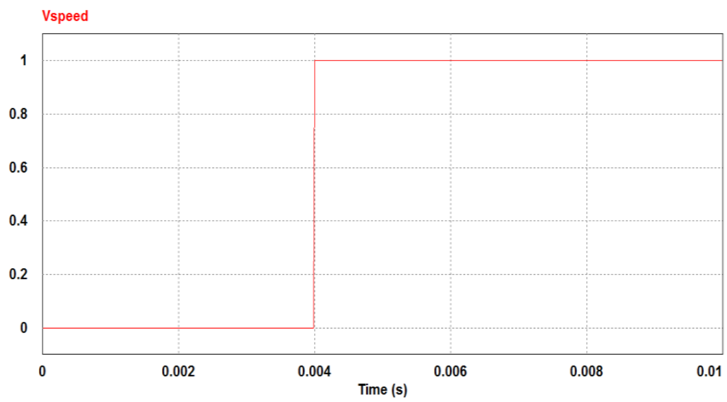

Fig. 9. The actual speed of the vehicle

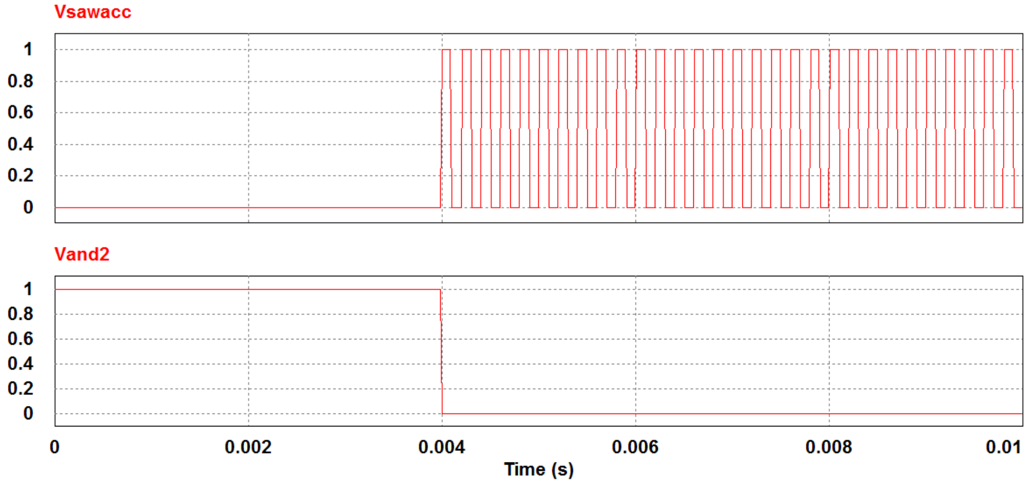

Fig. 10. Acceleration or buck mode timings in simulation

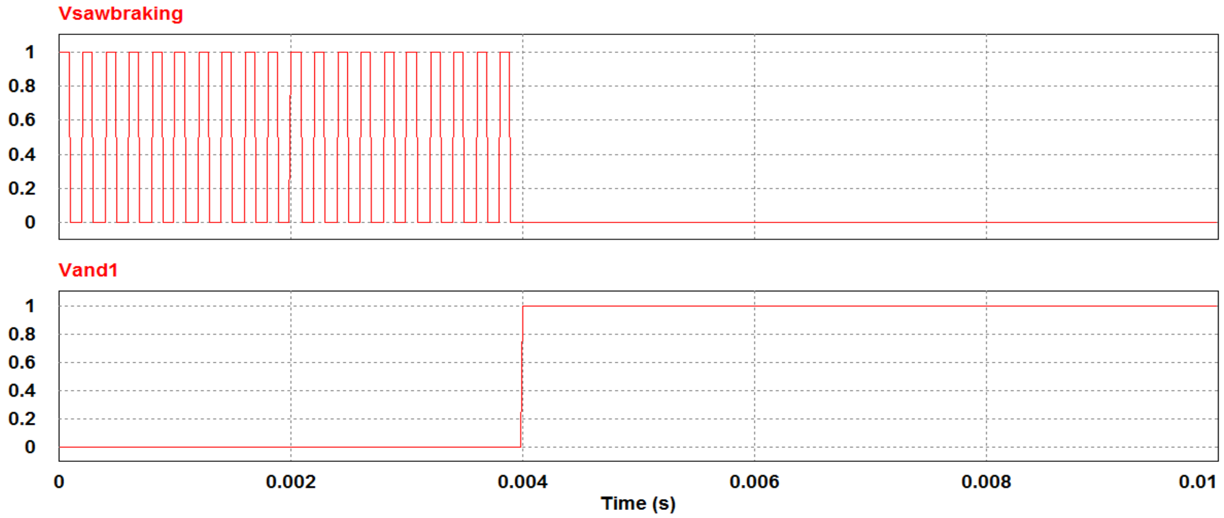

Fig. 11. Braking or boost mode timings in sImulation

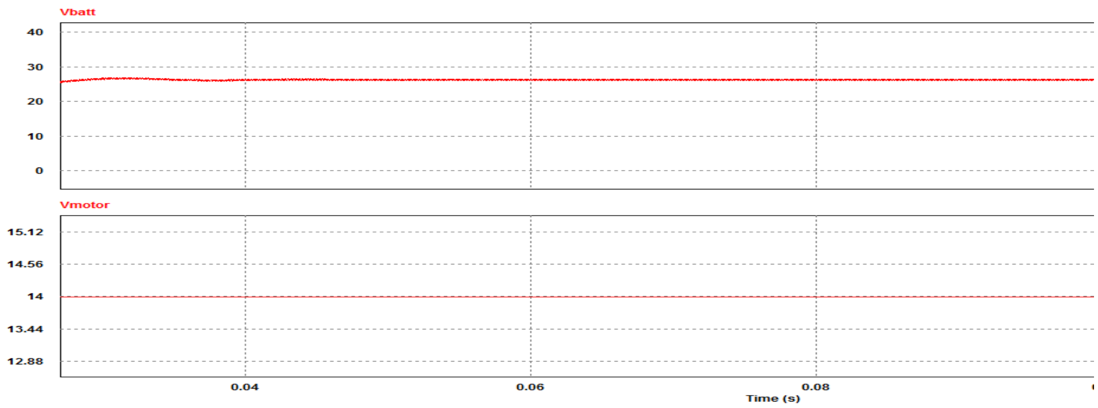

Fig. 12. Boost or braking mode operation of HEV

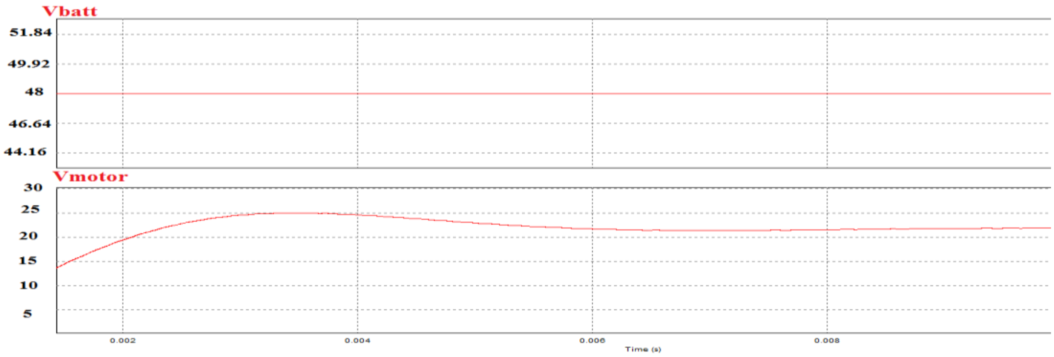

Fig. 13. Buck or acceleration mode operation of HEV

TABLE 1- CONVERTER MODE OF OPERATION

Mode Operation	Device Activated
BOOST	Q2, D1
BUCK	Q1, D2

TABLE 2- BUCK BOOST OPERATION OF CONVERTER

Accelerator	Brake	Q1	Q2
OFF	OFF	OFF	OFF
OFF	ON	OFF	ON
ON	OFF	ON	OFF
ON	ON	OFF	OFF

TABLE 3-SWITCHING OF Q1 AND Q2

N1	N2	Switch operated	Operation
ı	˜	Q1	Buck or acceleration
˜	ı	Q2	Boost or braking
˜	˜	˜	[illegible]peration
ı	ı	˜	Invalid

VI. RESULT & DISCUSSION

The control design presentedabove is simulated in PSIM software and the results are obtained as follows. The Actual speed is represented in the circuit using step signal for convenience as shown in Fig. 9.The acceleration and braking timings are represented by Vsawacc and Vsawbraking pulses as shown in Fig. 10 and

Fig. 11, which shows that the switching in vehicle occurs at 0.004 seconds. In case of Vsawacc pulses the braking signal from AND2 represented by Vand2 is not present as shown in Fig. 10.Similarly, in case of Vsawbraking pulses the acceleration signals from AND1 represented by Vand1 is not present as shown in Fig. 11. The simulation parameters are specified in the following manner. The voltage magnitude of battery (Vbatt) is 48V and the voltage of Motor (Vmotor) iskept at 14V.The inductance of inductor (L1) is 100mΩ and the resistance (R1) is of 100Ω and the capacitance of capacitor is 100uF.The Tstep of Vspeed is kept at 0.004seconds in order to enable switching and the Vref is taken at 0.2V.

For the purpose of study we have considered that the buck operation occurs at approximately 0.0015 seconds. The desired buck operation during acceleration is shown in Fig. 13, where the power flows from the battery to the motor and as shown the motor voltage rises and stabilizes at approximately 24V. For study, boost operation has been considered at approximately 0.004seconds. The boost mode during braking is shown in Fig. 12 where regenerative braking occurs and the voltage across the battery rises and settles down at approximately 28V.During regenerative braking the power flows back from the motor to the battery where it can be stored for later use.

VII. CONCLUSION

In order to universally increase the energy utilization efficiency of advanced vehicular drive trains, the percentage of electrically controlled vehicles (HEV) is steadily rising. In addition, even higher electrical energy is needed for advanced electrical loads. Thus, there is a strong demand for the development of advanced power system architectures for future HEV applications. A HEV produces less CO2 emissions and has a much more energy efficient engine. The control of Bidirectional DC-DC converter is essential for the satisfactory operation of HEV. With the use of proposed control strategy using comparators and logic gates, easy and efficient control of converter is seen. The switching of vehicle in case of acceleration and braking is easily achieved with the help of power electronic devices.

REFERENCES

[1] Yantono Song and Bingsen Wang, "Evaluation methodology and control strategies for improving reliability of HEV power electronic system," *IEEE Trans. Veh. Technol.*, vol.6, no.8, pp.3661-3676,Oct.2014.

[2] Ali Emadi, Sheldon S. Williamson, and AlirezaKhaligh, "Power electronics intensive solutions for advanced electric, hybrid electric, and fuell cell vehicular power systems," *IEEE Trans. Power Electron..*, vol. 21, no. 3, pp. 567-577, may 2006.

[3] Hanna Plesco, JurgenBiela, JormaLuomi, and Johann W. Kolar, "novel concepts for integrating the electric drive and auxiliary DC-DC converter for hybrid vehicles," *IEEE Trans. Power Electron.,*vol. 23, no. 6, pp. 3025-3034, Nov. 2008.

[4] MamadouBailoCamara, Hamid Gualous, Frederic Gustin, and Alain Berthon, "Design and new control of DC/DC converters to share energy between supercapacitors and batteries in hybrid vehicles," *IEEE Trans. Power Electron.,* vol. 57, no. 5, pp. 2721-2735, Sep. 2008.

[5] QuXiandong, Wang Qingnian, and Yu YuanBin, "Power demand analysis and performance estimation for active- combination energy storage system used in hybrid electric vehicles," *IEEE Trans. Veh. Technol.,* vol. 63, no. 7, pp. 3128-3136, Sep. 2014.

[6] A. Haque, "Maximum Power Point Tracking (MPPT) Scheme for Solar Photovoltaic System," *Energy Technol. Policy,* vol. 1, no. 1, pp. 115–122, 2014.

[7] Zaheerudin, Sukumar and M. Ahteshamul, "Performance evaluation of modified perturb & observe maximum power point tracker for solar PV system," *Int. J. Syst. Assur. Eng. Manag.*, vol. 7, no. 1, pp. 229–238, 2015.

[8] Jian Cao and Ali Emadi, "A new battery/ultra capacitor hybrid energy storage system for electric, hybrid, and plig-in hybrid electric vehicles," *IEEE Trans. Power Electron.,* vol. 27, no.1, Jan. 2012.

[9] Jian Cao and Ali Emadi, "A new battery/ultra capacitor hybrid energy storage system for electric, hybrid, and plig-in hybrid electric vehicles," *IEEE Trans. Power Electron.,* vol. 27, no.1, Jan. 2012.

