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A New Bidirectional DC-DC converter for Electric Vehicles Applications

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Abstract: *Hybrid and plug-in electric vehicles use electricity as their primary fuel or to improve the efficiency of conventional vehicle design. HEVs are powered by an internal combustion engine or other propulsion source that runs on conventional or alternative fuel and an electric motor that uses energy stored in a battery. HEVs combine the benefits of high fuel economy and low emissions with the power and range of conventional vehicles. PHEVs are powered by conventional fuels and by electrical energy stored in a battery. Using electricity from the grid to charge the battery some of the time costs less and reduces petroleum consumption compared with conventional vehicles. PHEVs can also reduce emissions, depending on the electricity source. In this paper the proposed converter interfaces the energy storage device of the vehicle with the motor drive and the external charger, in case of PHEVs. The proposed converter is capable of operating in all directions in buck or boost modes with a non inverted output voltage (positive output voltage with respect to the input) and bidirectional power flow,and finally the proposed Power Interface is Fed to a Switched Reluctance Motor Drive and the performance is analyzed. The software used for this project is MATLAB-9 .*
Keywords: *Bidirectonal DC/DC convertrs, electric vehicles, energy storage system, HEV, PHEV.*

I. Introduction

ELECTRIFICATION of transportation industry is essential for better performance, and lower emissions [1]-[6]. In vehicular applications, power electronic dc/dc converters a bidirectional dc/dc converter interfaces the energy storage device with the motor drive inverter of the traction machine; i.e., the converter is placed between the battery and the high-voltage dc bus. In acceleration or cruising mode, it should deliver power from the battery to the dc link, require high power bidirectional flow capability with wide input range since the terminal voltage of energy storage devices varies with the state of charge (SoC) and load variations[7] .In the case of a hybrid electric vehicle (HEV), whereas in regenerative mode, it should deliver power from the dc of the transportation industry is essential due to the improvements in higher fuel economy, better link to the battery.

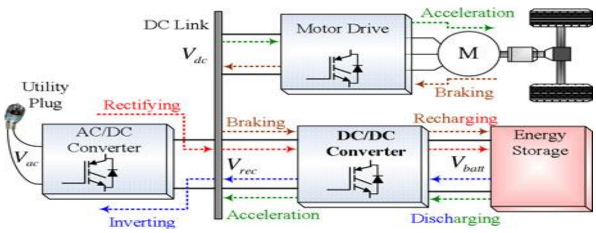

Fig. 1. Power electronic interfaces in an electric vehicle

In the case of an EV or plug-in hybrid electric vehicle (PHEV), while accomplishing the aforementioned task, the bidirectional dc/dc converter also interfaces the battery with the ac/dc converter during charging/discharging from/to grid[8].Therefore, the bidirectional dc/dc, converter should interface the battery with the charging converter, as well. Fig. 1 illustrates the role of the bidirectional dc/dc converter in the electrical power system of a plug-in electric vehicle.In grid-connected mode, the bidirectional dc/dc converter must have the capability to convert the output voltage of the ac/dc converter into a suitable voltage to recharge the batteries and vice versa when injecting power to the grid. In the next sections operating modes of proposed DC/DC converter is discussed and finally fed to switched reluctance motor.

II. Proposed Topologey

The circuit schematic of the proposed converter is depicted in Fig. 2. The converter has five power switches (*T*1-5) with internal diodes and five power diodes (*D*1–*D*5), which are going to be properly combined to select buck and boost modes of operation. Here, *V*dc represents the motor drive nominal input voltage during driving mode or the rectified ac voltage at the output of the grid interface converter during plug-in mode .The nominal voltage of the vehicle's ESS is represented by *V*batt. .

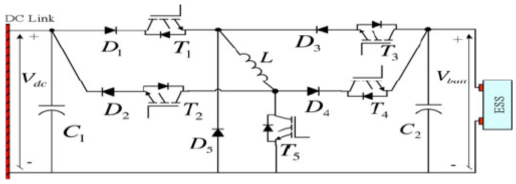

Fig.2 Proposed new bi-directional DC/DC converter

The proposed converter is capable of operating from *V*dc to *V*batt boosting, *V*dc to *V*batt bucking, *V*batt to *V*dc boosting, or *V*batt to *V*dc bucking, all with positive output voltage. In any of the four modes, only one of the power switches is operated in pulse width modulation (PWM) mode, while all the other switches are completely ON or OFF. Therefore, the switching losses are not more than that of any conventional buck or boost converter. In addition, the proposed converter requires only one high-current inductor unlike some of the existing buck and boost converter combinations or the cascaded configurations.

SYSTEM DESCRIPTION AND OPERATING MODES

TABLE 1: Operation Modes of the a new bi-directional DC/DC Converter

Direction	Mode	T_1	T_2	T_3	T_4	T_5
$V_{dc} \rightarrow V_{batt}$	BOOST	ON	OFF	OFF	ON	PWM
$V_{dc} \rightarrow V_{batt}$	BUCK	PWM	OFF	OFF	ON	OFF
$V_{batt} \rightarrow V_{dc}$	BOOST	OFF	ON	ON	OFF	PWM
$V_{batt} \rightarrow V_{dc}$	BUCK	OFF	ON	PWM	OFF	OFF

If the rated dc link voltage is less than battery's rated voltage, the dc link voltage should be stepped-up during charging in grid connected mode and in regenerative braking during driving. Under the same voltage condition, the battery voltage should be stepped-down during plug-in discharging in grid-connected mode, and in acceleration or cruising during driving.

Mode 1) *V*dc → *V*batt *Boost Mode for Plug-in Charging and Regenerative Braking.* Switch *T*5 is in PWM switching mode, when it is turned ON, the current from *V*dc flows through*D*1, *T*1, *L*, and *T*5 while energizing the inductor. When *T*5 is OFF, both the source and the inductor currents flow to the battery side through *D*4 and *T*4.

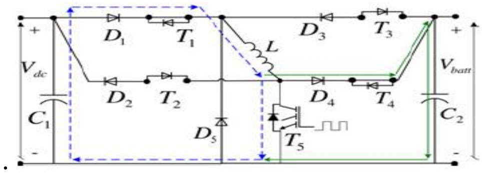

Fig. 3. *V*dc -to-*V*batt boost mode of operation.

*Mode 2) V*batt → *V*dc *Buck Mode for Plug-in Discharging and Acceleration:* The PWM switching signals are applied to switch *T*3 . Therefore, from *V*batt to *V*dc, a buck converter is formed by *T*3, *D3,D5, L, T*2 , and *D*2 . When *T*3 is turned ON, the current from the battery passes through *T*3, *D3, L, T*2, and D2, while energizing the inductor. When *T*3 is OFF, the output current is freewheeled through the *D*5, *T*2, and *D*2, decreasing the average current transferred to the load side. *D*3 and *D*2 are forward-biased, whereas *D*1 and *D*4 do not conduct. *D*5 only conducts when *T*3 is OFF.

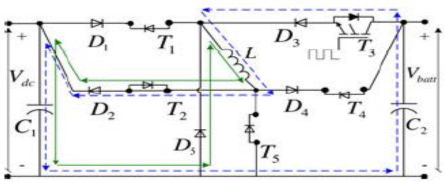

Fig. 4. *V*batt -to-*V*dc buck mode of operation

*B. Case 2: V*dc > *V*batt

If the rated dc link voltage is more than the battery's rated voltage, dc link voltage should be stepped-down during charging in grid-connected mode and in regenerative braking while the vehicle is being driven. Under the same voltage condition, the battery voltage should be stepped-up during plug-in discharging in grid-connected mode and in acceleration or cruising while driving.

*Mode 3) V*dc → *V*batt *Buck Mode for Plug-in Charging and Regenerative Braking:* converter is made up by *D*1, *T*1,*D*5, *L*,*D*4 , and *T*4 as shown in Fig. 5. When *T*1 is turned ON, the current from *V*dc passes through *D*1, *T*1, *L*,*D*4 , and *T*4 while energizing the inductor. When *T*1 is OFF, the output current is recovered by freewheeling diode *D*5 decreasing the average current transferred from dc link to the battery. *D*5 only conducts when *T*1 is OFF.

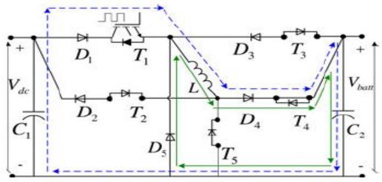

Fig. 5. *V*dc -to-*V*batt buck mode of operation

*Mode 4) V*batt → *V*dc *Boost Mode for Plug-in Discharging and Acceleration* .When *T*5 is turned ON, the current from *V*batt passes through *T*3,*D*3, *L*, and *T*5 while energizing the inductor. When *T*5 is OFF, both inductor and the source currents pass through *T*2 and *D*2 to the dc link. In this mode, *D*3 and *D*2 are forward-biased and they conduct, whereas *D*1,*D*4 , and *D*5 are reverse-based and do not conduct as shown in fig.6.

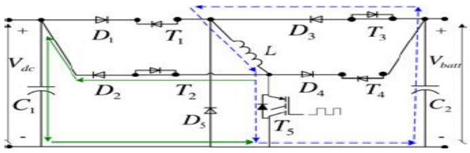

Fig. 6. *V*batt -to-*V*dc boost mode of operation

III. Simulink Model

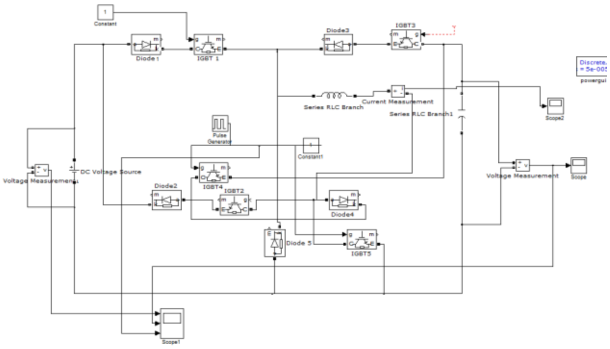

FIG 7

During this mode of Fig.7, *V*dc and *V*batt sequentially become the input and output voltages. Since the inductor current is a state variable of this converter, it is controllable. Therefore, the charging power delivered to the battery in plug-in mode or high-voltage bus current in regenerative braking can be controlled.

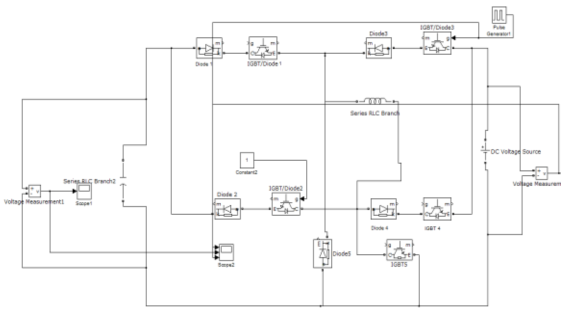

FIG 8

In this mode, *V*batt and *V*dc are the input and output voltages, respectively. During stepping-down the battery voltage while delivering power from battery to the dc link, the inductor is at the output and its current is a state variable. Therefore, the dc link voltage and the current delivered to the dc link can be controlled in driving mode.

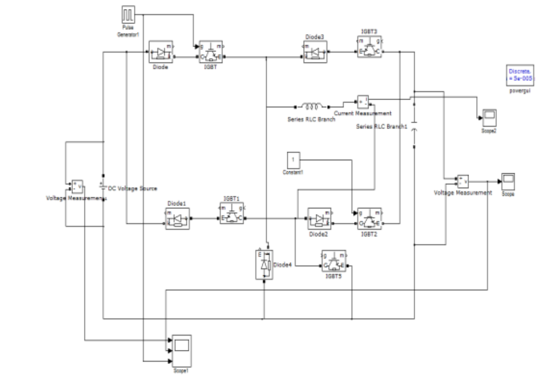

FIG 9

In this mode, *V*dc and *V*batt are the input and output voltages, respectively. The dc link voltage can be regulated in driving mode (regenerative braking) by controlling the current transferred to the battery. In plug-in charging mode, the current or power delivered to the battery is also controllable.

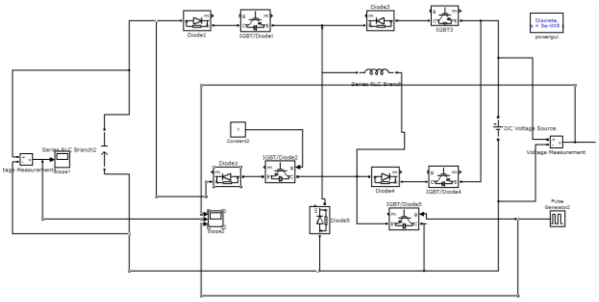

FIG 10

In this mode, *V*batt and *V*dc are sequentially the input and output voltages. The dc link voltage can be regulated in driving mode (regenerative braking) by controlling the current drawn from the battery. In plug-in charging mode, the current or power drawn from battery is also controllable.

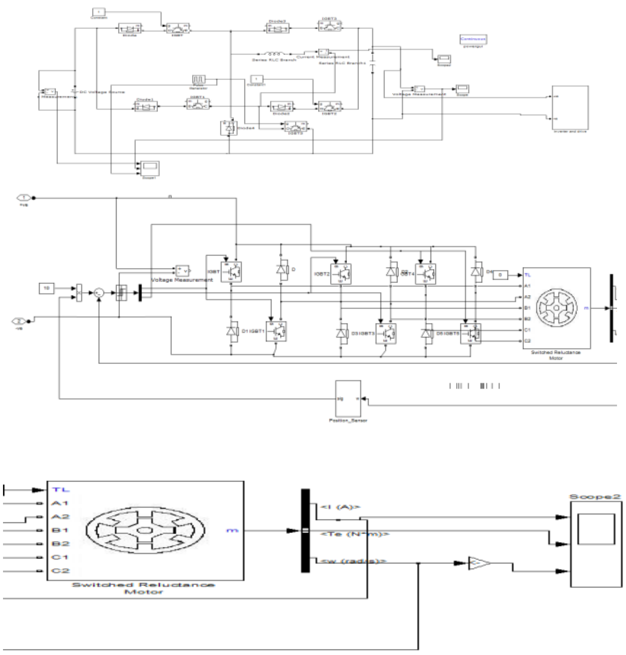

FIG 11

The above Fig .11 shows the one of the mode is connected to switched reluctance motor. By using this we can read the characteristics' of the switched reluctance motor

IV. Results

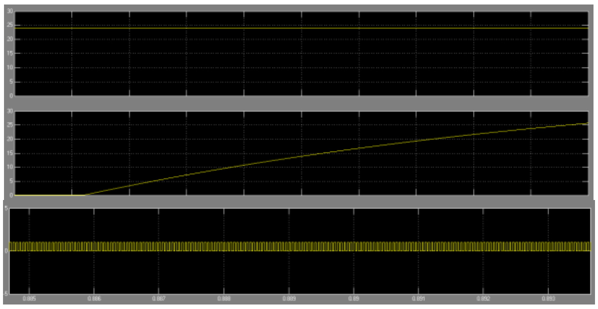

Fig. 12. V_{dc} -to-V_{batt} boost mode

The experimental results for this mode of operation are presented in g. 12 where the first is V_{dc}, second is V_{batt} , and third is the switching signal of switch T_5 . As shown in Fig. 12, 24-V V_{dc} voltage is boosted to slightly more than the 30 V, battery rated voltage V_{batt} .

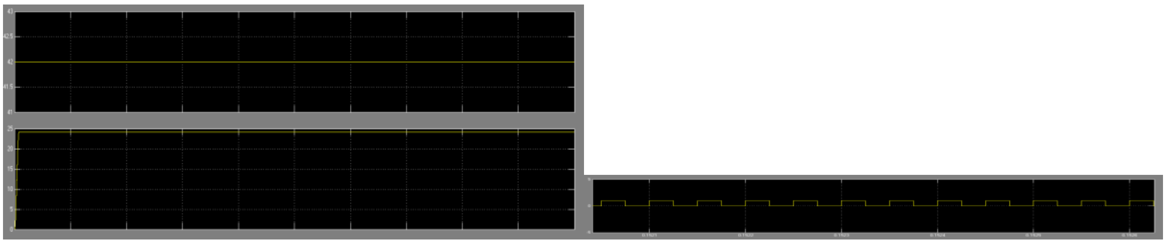

Fig.13. V_{batt} -to- V_{dc} buck mode

The experimental results for this mode of operation are presented in Fig. 13, where channel 1 is V_{dc}, channel 2 is V_{batt} , channel 3 is output current after the capacitor, and channel 4 is the switching signal of switch T_3 . The input voltage V_{batt} is stepped-down to about 24 V (V_{dc}

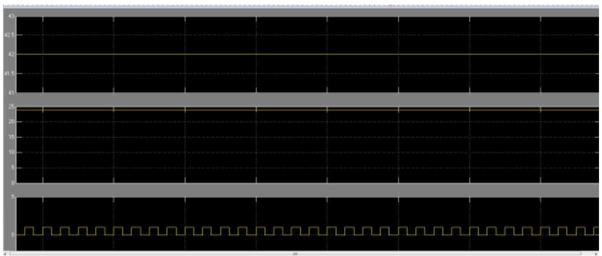

Fig.14.V_{dc} -to-V_{batt} buck mode

The experimental results for this mode of operation are presented in Fig. 14 where channel 1 is V_{dc}, channel 2 is V_{batt} channel 3 is output current after the capacitor, and channel 4 is the switching signals of the switch T_1 . From Fig. 14, it is seen that the input voltage of V_{dc} is stepped down to 24 V of the battery terminal voltage.

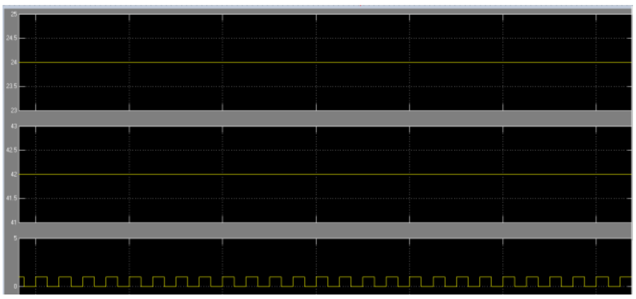

Fig.15. V_{batt} -to- V_{dc} boost mode

The experimental results for this mode of operation are presented in Fig. 15, where channel 1 is V_{dc}, channel 2 is V_{batt} , channel 3 is input current before the capacitor, and channel 4 is the switching signal of switch T_5 . It can be seen from Fig. 15 that the modified converter is capable of boosting the 24 V of V_{batt} voltage to about 42 V of V_{dc} output voltage.

V. Motor Characteristics

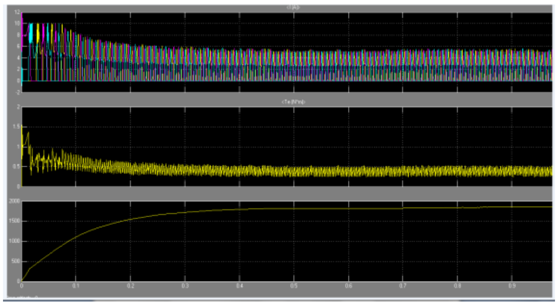

Fig.16

The Fig 16 shows the Current, Torque and speed characteristics of switched relutancce motor. The proposed Power Interface is Fed to a Switched Reluctance Motor Drive and the performance is analyzed.

VI. Conclusion

This study presents a novel dc/dc converter structure that is suitable for both industrial needs and the retrofit electric vehicle conversion approaches for all EV, HEV, and PHEVs regardless of their rated dc link voltage and motor drive inverter voltage as well as the battery nominal voltage. The functionalities of the proposed converter provide a broad range of application areas. Due to the operational capabilities, the proposed converter is one of a kind plug-and-play universal dc/dc converter that is suitable for all electric vehicle applications. The proposed topology is suitable not only for conversion approaches but also is a good candidate to reduce the number of dc/dc converters from two to one in commercially available vehicles such as Toyota Prius., the functionalities for two different cases with four different modes have been verified. In each case, bidirectional power flow is provided with fully directional bucking and boosting capabilities. In the future, a full-scale dc/dc converter will be built for a typical mid-size sedan vehicle and the converter will be implemented for a real-world application.

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