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Analysis And Simulation of Multimode Single Leg Bi-directional Converter

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Abstract: Power electronic technology based energy conversion can be applied towards electric vehicles and renewable & alternative energy generation systems. In this approach battery pack is the prime concern since it is used for energy storage. So it is important to pay more attention for charging/ discharging and power management. The system response improvement and battery protection can be achieved by ultra capacitors. Conversion systems using power electronics technology basically contains generators, converters, power storage and inverters. In this paper to reduce cost and increase the efficiency of power conversion multimode single leg power converter is introduced. This converter provides the function of boost as well as bi-directional converter. Hence efficiency and fault tolerance capability of the system is improved. In the proposed system there are four modes of operations. Each mode is simulated using MATLAB SIMULINK.

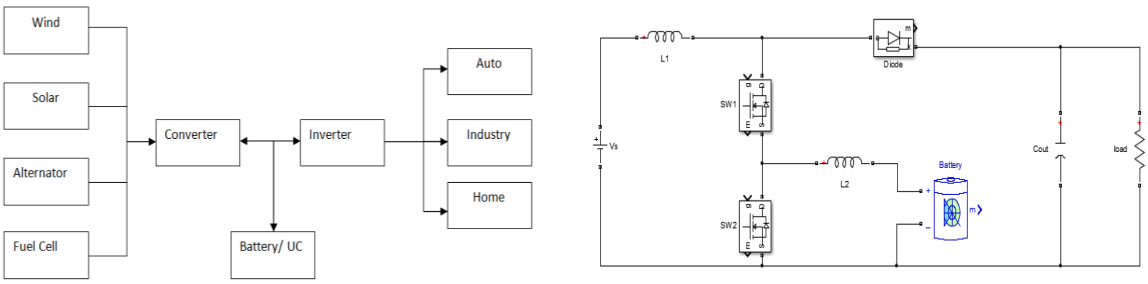
Keywords: multimode converter, conversion system, power management, MATLAB SIMULINK.

I. INTRODUCTION

In recent years increasing energy consumption, increasing oil and natural gas prices made energy sources such as wind, solar and fuel cells pay attracted attention towards industrial fields. Power electronic technology based energy conversion can be applied towards electric vehicles and renewable & alternative energy generation system. Since EV's require high density battery pack to start and operate the electronic components, battery charging/discharging and power management is of primary concern. Ultra capacitors are used to improve the system performance and power quality. It also protects the battery pack and reduces the stress. These systems consist of power generators, main converters, and battery / UC and power inverters. Usually such system requires main boost converter for power conversion and buck boost converter for power management. But in this paper power conversion with reduced cost and simple system structure is introduced through multimode conversion. This system consists of multimode single leg converter which performs the function of both boost converter as well as bi-directional converter. Hence it improves system efficiency and it is also easy to diagnose the circuit since the structure is very simple. The circuit performance characteristics are simulated using SIMULINK.

II. PROPOSED MULTIMODE SINGLE LEG CONVERTER STRUCTURE

Block diagram of a power conversion system for electric vehicles (EV) and renewable and alternative energy generation system (RAEGS) applications is shown in figure 1(a). It contains energy source, main converter, battery/ UC and power inverter for ac loads. Figure 1(b) illustrates proposed circuit structure. In proposed circuit boost converter and bi- directional converter is replaced by multimode single leg converter which performs the function of both the converters simultaneously. This circuit consists of two power switches, two inductors and a power diode which can boost up the source voltage as well as charging/ discharging of battery.



(a) (b)

(b) Fig.1. (a) Power conversion system configuration for EV and RAEGS. (b) Circuit of proposed multimode single leg converter.

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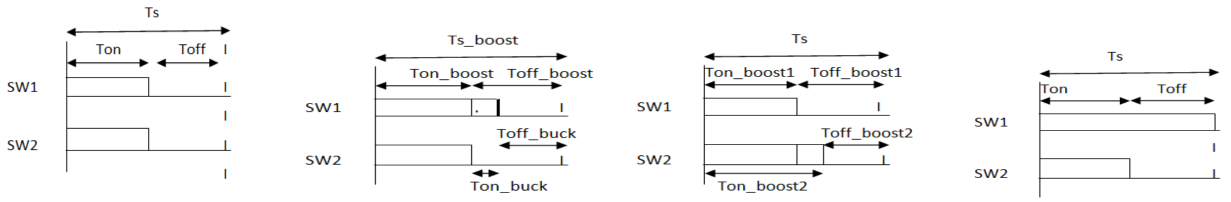


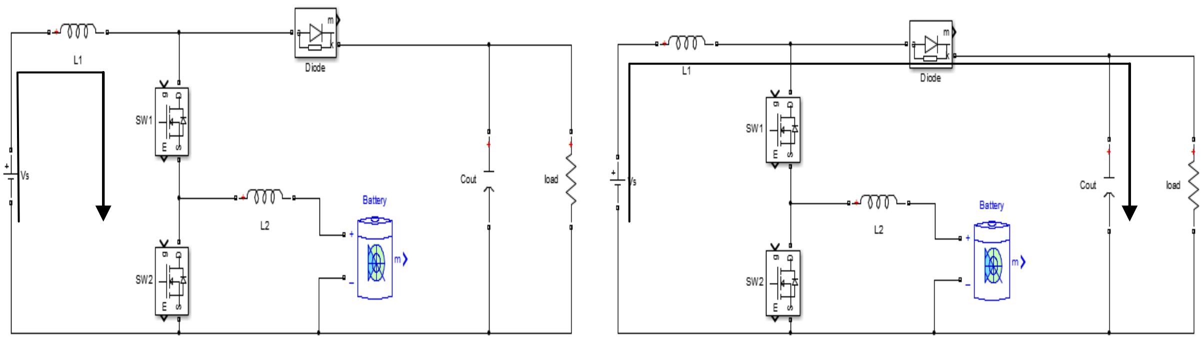
(a) (b) (c) (d)

Fig.2. Sw1 & SW2 ON- OFF period for (a) mode1 (b) mode2 (c) mode3 and (d) mode4

There are four different modes to analyse the functions of the proposed circuit. They are (1) main boost mode,(2) boost-buck mode, (3) boost- boost mode and (4) battery boost mode. During main boost mode input voltage is boosted to output voltage and there is no change in battery voltage. At boost- buck mode input voltage is boosted to output voltage and at the same time battery is also charged. In mode 3 if load is increased then output voltage decreases below the specified voltage at this moment stored energy in the battery will be discharged through inductor L_2. If input energy source is not sufficient to provide power then power to the load is delivered only by the battery i.e. battery boost mode. Figure 2 shows on and off period for SW_1 and SW_2.

A. Mode 1 (main boost)

In this mode input voltage is boosted to output voltage and battery voltage remains same. Figure (3) illustrates current flow during ON and OFF period of two switches.



(a) (b)

Fig.3. Mode 1 current flow during (a) SW_1 & SW_2 ON and (b) SW_1 & SW_2 OFF period.

When SW_1 & SW_2 are ON then inductor L_1 is charged and current I_{L1} increases. Ripple current is given by

$$\Delta I_{L1} = \frac{(V_s . T_{on})}{L_1} \qquad (1)$$

When SW_1 & SW_2 are OFF input voltage and stored energy in the inductor is transferred to the load. Then inductor ripple current is given by

$$\Delta I_{L1} = \frac{(V_{out} - V_s) T_{off}}{L_1} \qquad (2)$$

Eqn (1) and (2) is equated to obtain output voltage

$$V_{out} = \frac{V_s}{1-D} \qquad (3)$$

Where

$$D = \frac{T_{on}}{T_s} \qquad (4)$$

Therefore it shows that output voltage depends on duty cycle.

B. Mode 2 (boost- buck)

In this mode input voltage is boosted to output voltage and same time battery will also be charged i.e. buck mode. During Ton boost inductor L_1 current rises and boosted input voltage is supplied to the load when both the switches are OFF. When SW_1 is ON and SW_2 is OFF then inductor L_2 current starts rising and battery gets charged. Fig 4 illustrates current flow in this mode. When SW_1 and SW_2 are ON inductor L_1 is charged and inductor current increase. Ripple current is given by

$$\Delta I_{L1} = \frac{V_{s} . T_{on\_boost}}{L_1} \qquad (5)$$

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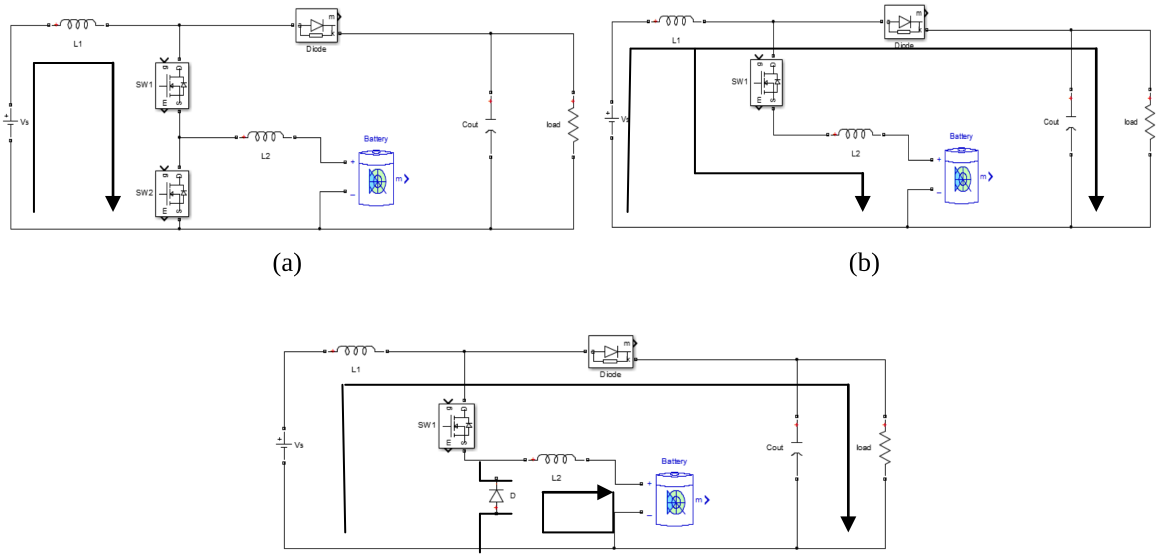

(a) (b)

(c)

Fig.4. Mode 2 current flow during (a) boost ON (b) buck ON and (c) buck OFF period.

When SW_2 is OFF then energy transfer takes place. The ripple current is given by

$$\Delta I_{L1} = \frac{(V_{out} - V_s)\, T_{off\_boost}}{L_1} \qquad (6)$$

Equating eqn (5) and (6) to obtain output voltage

$$V_{out} = \frac{V_s}{1 - D_{boost}} \qquad (7)$$

Where

$$D_{boost} = \frac{T_{on\_boost}}{T_{s\_boost}} \qquad (8)$$

During buck mode when SW_1 is ON and SW_2 is OFF then inductor L_2 current increases and its ripple current is given by the equation

$$\Delta I_{L2} = \frac{(V_s - V_{battery})\, T_{on\_buck}}{L_2} \qquad (9)$$

During T_{on_boost} and T_{off_buck} inductor L_2 current decreases .

$$\Delta I_{L2} = \frac{V_{battery} \cdot (T_{on\_boost} + T_{off\_buck})}{L_2} \qquad (10)$$

Equating (9) and (10) gives battery voltage as

$$V_{battery} = V_s \cdot D_{buck} \qquad (11)$$

Where

$$D_{buck} = \frac{T_{on\_buck}}{T_{s\_boost}} \qquad (12)$$

C. Mode 3 (boost-boost)

The purpose of this mode is to boost input voltage to output and at the same time battery are also discharged i.e. proposed converter acts as 2 boost converters. Fig. 5.shows the current flow during boost- boost mode.

When SW_1 and SW_2 are ON inductor L_1 is charged and inductor current increases. Ripple current is given by the equation

$$\Delta I_{L1} = \frac{V_s \cdot T_{on\_boost1}}{L_1} \qquad (13)$$

If SW_2 is on and SW_1 is OFF then energy transfer to the load takes place. Ripple current for L_1 is given by

$$\Delta I_{L1} = \frac{(V_{out} - V_s)\, T_{off\_boost1}}{L_1} \qquad (14)$$

Solving for Output voltage from (13) and (14) we get

$$V_{out} = \frac{V_s}{1 - D_{boost1}} \qquad (15)$$

Where

$$D_{boost1} = \frac{T_{on\_boost1}}{T_s} \qquad (16)$$

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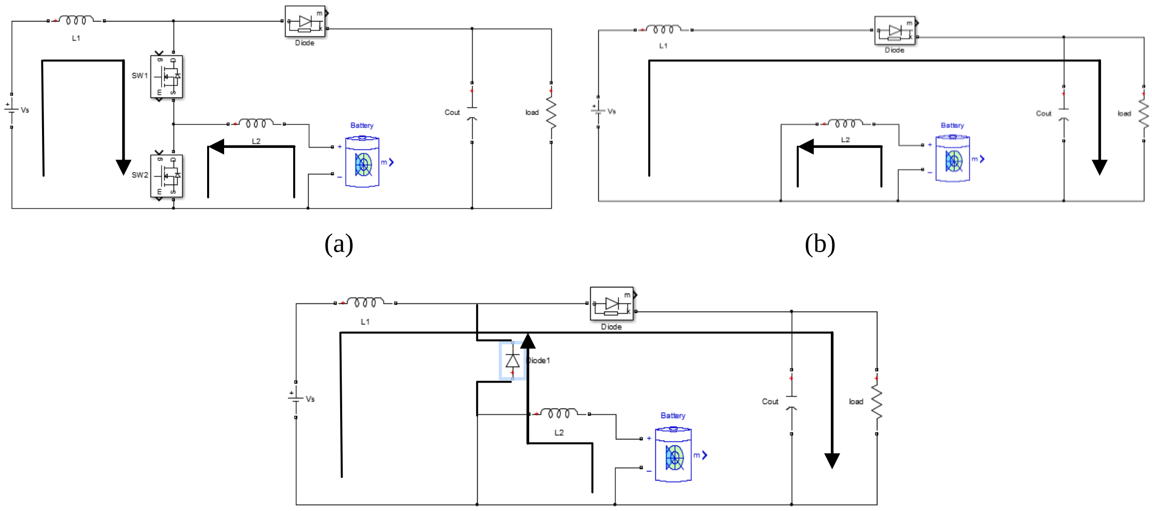


(a) (b)

(c)

Fig. 5.Mode 3 current flow during (a) T_{on_boost1} (b) T_{on_boost2} & T_{off_boost1} (c) T_{off_boost2}.

When SW_2 is ON then inductor L_2 current rises and is given by

$$\Delta I_{L2} = \frac{V_{battery} \cdot T_{on\_boost\ 2}}{L_2} \quad (17)$$

Inductor current decreases when SW_1 and SW_2 both are OFF

$$\Delta I_{L2} = \frac{(V_{out} - V_{battery})\ T_{off\_boost\ 2}}{L_2} \quad (18)$$

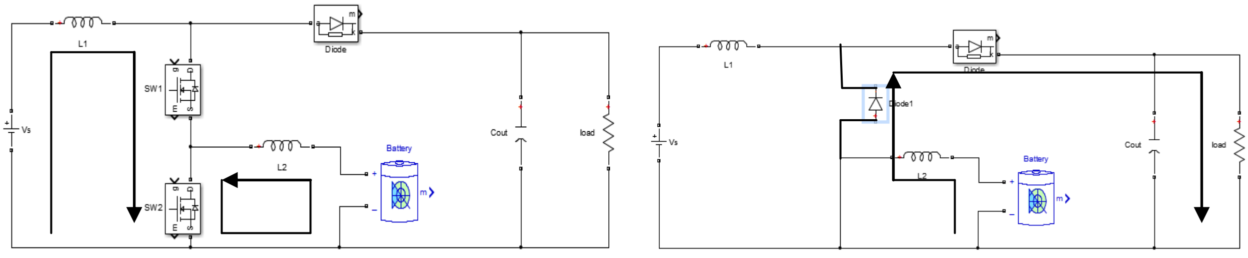
From eqn (17) and (18) we get output voltage as follows:

$$V_{out} = \frac{V_{battery}}{1-D_{boost2}} \quad (19)$$

Where $$D_{boost2} = \frac{T_{on\_boost2}}{T_s} \quad (20)$$

D. Mode 4 (battery boost)

When input voltage is insufficient to supply energy to the load then battery boost mode is used i.e. energy is supplied only from the battery. When battery voltage is greater than supply voltage during this period stored energy in the battery is discharged to the load through reverse diode of SW_1. Figure 6 presents current flow during this mode.



(a) (b)

Fig. 6. Mode 4 current flow during (a) ON period (b) OFF period.

During ON period inductor L_2 current increases and is given as

$$\Delta I_{L2} = \frac{V_{battery} \cdot T_{on}}{L_2} \quad (21)$$

During OFF period when SW_2 is OFF then stored energy in the inductor and battery is transferred to the load. Inductor current is given as

$$\Delta I_{L2} = \frac{(V_{out} - V_{battery}) \cdot T_{off}}{L_2} \quad (22)$$

Equating (21) & (22) we get output voltage as

$$V_{out} = V_{battery} \quad (23)$$

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1-D

Where $$D = \frac{T_{on}}{T_s} \qquad (24)$$

III. SIMULATION RESULTS

The proposed converter is simulated using SIMULINK based on the parameters shown in table I and Fig.7 shows inductor current I_{L1}, output voltage, PWM pattern for SW_1 & SW_2 and inductor current I_{L2} for all the four modes. During mode1ie main boost mode, when SW_1 & SW_2 are ON, inductor current I_{L1} increases. When the switches are OFF then I_{L1} decreases and energy transfer takes place to the load. There is no change in battery voltage in this mode. Current and voltage waveforms are shown in Fig.7 (a). During mode2, PWM pattern of SW_1 controls inductor current I_{L1} and SW_2 controls I_{L2}. When SW_2 is OFF then SW_1 remains ON and battery starts charging. Waveforms for boost-buck mode are shown in Fig.7 (b). During mode3 when SW_1 is OFF, SW_2 remains ON which makes battery voltage to boost up and when both the switches are OFF then energy is supplied to the load from input and battery simultaneously hence inductor L_2 current goes negative.Fig.7(c) presents waveforms for this mode. In mode4, no power is supplied to the load from the input because supply voltage is very low. Hence energy to the load is supplied from the battery and the battery current is decreased i.e. it becomes negative. Resulting waveforms are shown in Fig.7 (d).

TABLE I: SIMULATION PARAMETERS

Supply voltage	12V	Output voltage	60V	Capacitor C	100µF
Inductor L1	0.96mH	Inductor L2	0.46mH	Frequency	50KHz
Resistor	150Ω	Battery	8V		

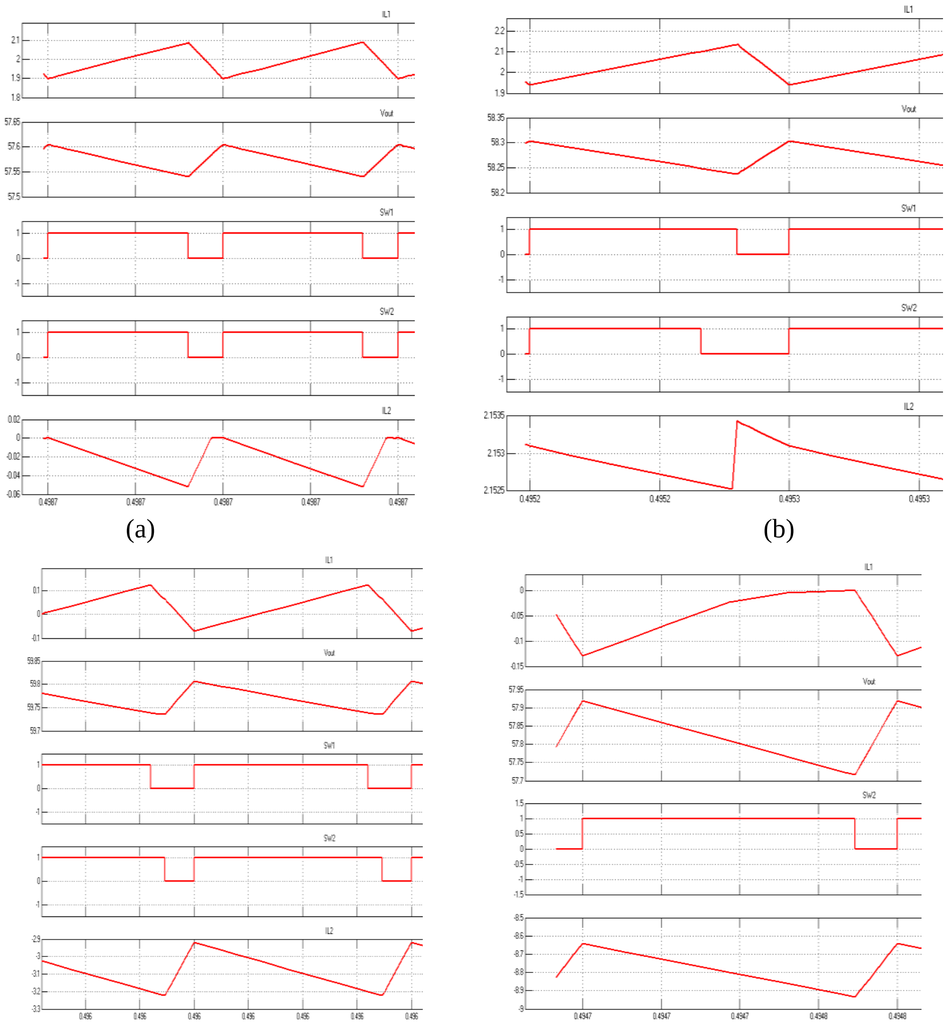

Fig.7. simulation result for (a) Mode1 (b) Mode2 (c) Mode3 and (4) Mode4

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CONCLUSION

In this paper to increase the efficiency and fault tolerance capability of the system a multimode single leg converter is proposed which reduces the number of switches. Proposed converter operates as boost converter and bidirectional converter which control the power flows between source and load. . There are four modes of operation. Proposed converter is simulated using SIMULINK and four modes are verified to observe the feasibility of the converter. This new topology can be applied to wide range of power electronic applications including energy conversion.

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