

# Application of Multimode Single Leg Converter in Power Electronic Technology based Conversion System

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**ABSTRACT:** Multimode power conversion system is proposed in this paper. This consists of multimode single leg converter which replaces bidirectional and boost converter. Proposed converter performs the function of boost as well as bidirectional converter there-by increasing system efficiency and fault tolerance capacity. Proposed converter has four modes of operation. These modes are simulated using SIMULINK. This power electronic technology can be applied to renewable & alternative energy generation systems (RAEGS) and electric vehicles (EV).

**KEYWORDS:** power conversion, bidirectional converter, electronic technology, SIMULINK.

## I. INTRODUCTION

In recent years increasing prices of oil and natural gases made sources of energy such as wind, solar and fuel cells very attractive towards industrial fields. Energy conversion Technology based on Power electronics can be applied towards electric vehicles (EV) and renewable & alternative energy generation system (RAEGS). But in such systems we have to be very much concern about battery management because these systems require battery pack of high density for the operation of the components. System performance can be improved by the use of ultra capacitors which also reduces the battery stress and protects the battery. Generators, converters, inverters and battery are the main blocks of these systems and generally power conversion requires boost converter and power management requires buck- boost converter. To overcome this problem, multimode single leg converter is introduced in this paper which performs the power conversion with improved system efficiency. This converter has simple structure therefore diagnosis of problems are very easy. The proposed converter performs the function of both bidirectional and boost converter. SIMULINK is used to verify the performance characteristics of the proposed converter.

## II. MULTIMODE SINGLE LEG CONVERTER

Configuration of power conversion system for RAEGS and EV is shown in figure 1(a) and it consists of generators, converters, inverters, battery or UC and loads.

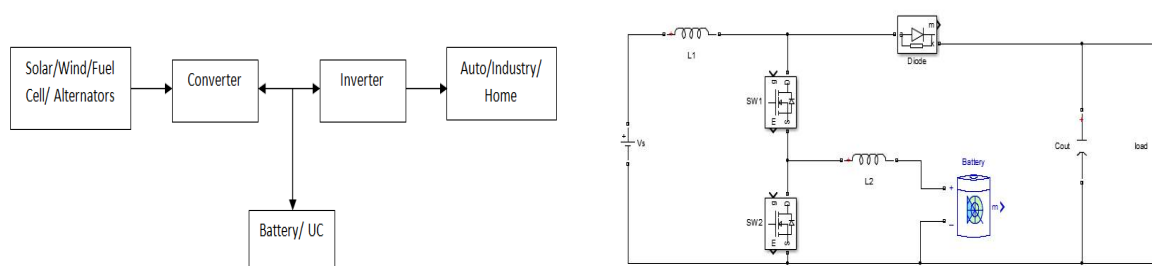


Figure 1: (a) Power conversion System in RAEGS and EV (b) Circuit of Proposed Multimode Single Leg Converter.

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Boost converter is required to boost up the supply voltage and charging, discharging of UC or battery is done through bidirectional converter. Use of these two converters make the circuit complex and increases the cost. Hence to simplify the complexity and reduce the cost, a multimode single leg converter is proposed in this paper.

Circuit diagram of proposed converter is presented in figure1 (b). This converter has two inductors, two switches, battery and a diode. In this converter, number of switches are also reduced hence loss is reduced which increases the efficiency of the conversion. Proposed converter functions as boost as well as bidirectional converter. Proposed converter operates in four modes.

They are (a) Mode1 where voltage supplied by the source is boosted up. Hence it is also called main boost mode. (b) Mode 2 in which supply voltage is boosted as well as battery also gets charged up and this mode is also named as boost –buck mode. (c) Mode3 performs boosting up of both supply voltage and battery voltage hence it is termed as boost-boost mode. (d) Mode4 is useful when input is insufficient to provide power to the load and load is supplied only by the stored charge in the battery. Hence this mode is called battery boost mode.

## A. MODE 1: MAIN BOOST MODE

In this mode ON-OFF period for  $SW_1$  and  $SW_2$  is same. Switching pattern is shown in figure 2. When both the switches are ON then inductor  $L_1$  current rises. There is no change in the battery charge.  $L_1$  ripple current is given by

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

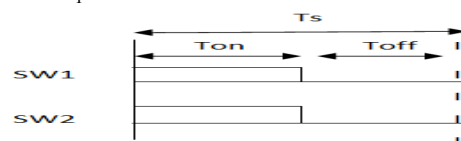


Figure 2: Mode1 Switching pattern.

Current flows during ON- OFF period of  $SW_1$  and  $SW_2$  is described in figure 3(a) and 3(b). During OFF period both the switches are OFF then inductor  $L_1$  current decreases and supply voltage along with inductor voltage is transferred to the load. Now ripple current in the inductor is given by

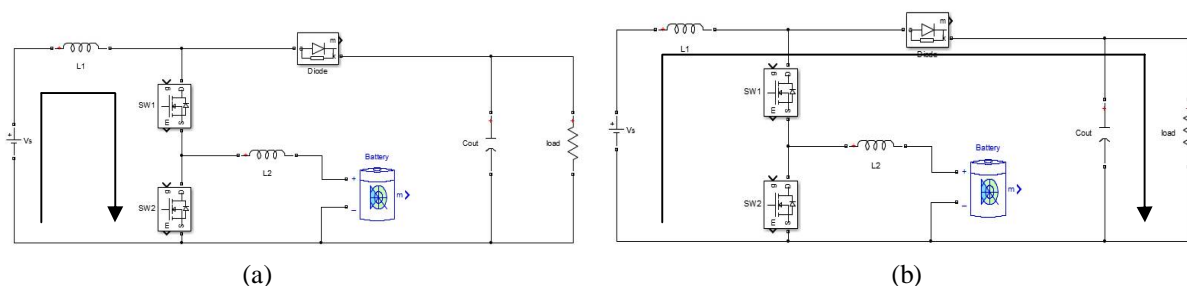


Figure 3: Mode1 current flow (a) during ON period and (b) during OFF period

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

Equating above equations gives load voltage

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

Where

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

## B. MODE 2: BOOST-BUCK MODE

Proposed converter operates as boost and buck converter in this mode. Where supply is boosted up and at the same time battery is also gets charged up.

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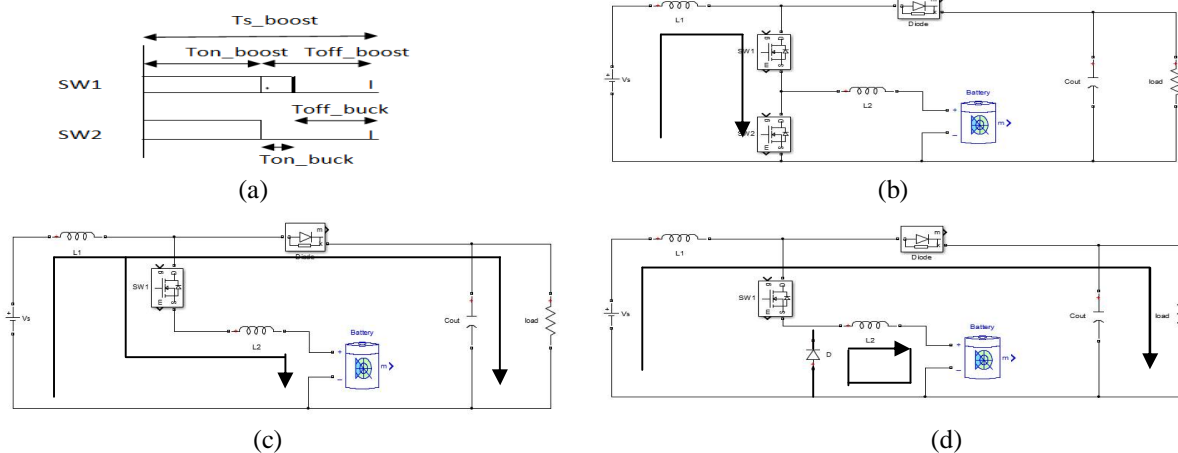


Figure 4: Mode2 (a) Switching Pattern. Current flows during (b)  $T_{on\_boost}$  (c)  $T_{on\_buck}$  (d)  $T_{off\_buck}$

Switching pattern is shown in figure 4(a). During  $T_{on\_boost}$  both the switches are ON which makes the inductor  $L_1$  to get charged and stored charge is delivered to the load when  $SW_2$  is OFF. Current flows during this mode are shown in figure 4(b), (c) and (d). During  $T_{on\_buck}$  battery starts charging. Ripple current for inductor  $L_1$  is given by

$$\Delta I_{L1} = \frac{V_s \cdot T_{on\_boost}}{L_1} \quad (5)$$

Energy transfer to the load takes place when  $SW_2$  goes OFF. Ripple current is obtained as

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

Output voltage is obtained by equating above equations

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

Where

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

When  $SW_2$  is OFF during  $T_{on\_buck}$ ,  $SW_1$  continues to be ON which makes the inductor  $L_2$  to get charged up and its ripple current is given by

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

During  $T_{on\_boost}$  and  $T_{off\_buck}$  inductor  $L_2$  current decreases .

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

From equations (9) and (10) we get battery voltage

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

Where

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

## C. MODE 3: BOOST-BOOST MODE

In this mode proposed converter acts as two boost converter in which supply voltage as well as battery voltage gets boosted up. Switching pattern and current flows during ON period of both the switches are shown in figure 5.

Inductor  $L_1$  and  $L_2$  is charged when both the switches are ON.

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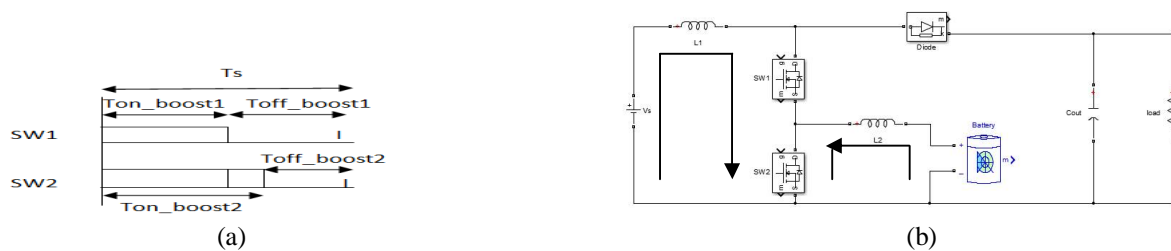


Figure 5: Mode 3 (a) Switching Pattern, (b) Current flows during  $T_{on\_boost1}$ .

This boost and boost mode is utilised when input alone is not sufficient to supply the power to the load then battery charge is also needed. During  $T_{on\_boost2}$  SW<sub>1</sub> is OFF which makes the inductor  $L_1$  to discharge but  $L_2$  is continued to be charged from battery since SW<sub>2</sub> is ON. At the end of this period  $L_2$  also discharges. It is described in figure 6(a) & (b).

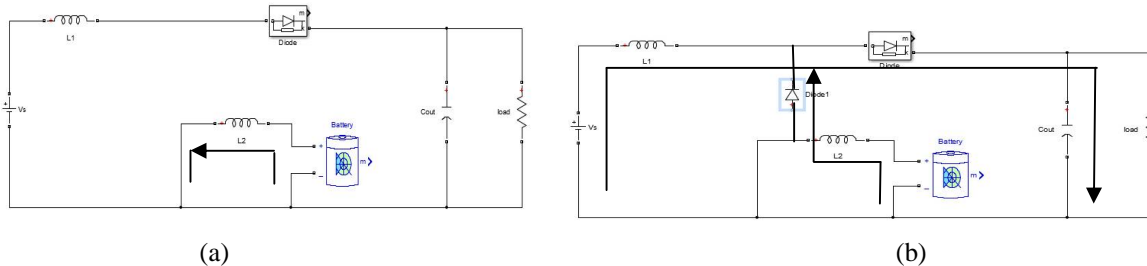


Figure 6: Mode 3 Current flows during (a)  $T_{on\_boost 2}$  &  $T_{off\_boost1}$  and (b)  $T_{off\_boost2}$

Inductor  $L_1$  current increases when both the switches are ON and its ripple current is given by

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

During  $T_{on\_boost2}$  and  $T_{off\_boost1}$ , inductor  $L_1$  current decreases and its ripple current is given by

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

Solving equations (13) and (14) gives output voltage

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

Where

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

Inductor  $L_2$  current increases when SW<sub>2</sub> is ON and its ripple current is given by

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

When SW<sub>1</sub> and SW<sub>2</sub> both are OFF, Inductor current decreases

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

We get output voltage From eqn (17) and (18) as

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

Where

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

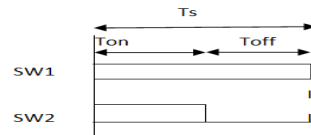
## D. MODE 4: BATTERY BOOST MODE

This mode is used if power generated by the source is low or there is any fault in the supply. Switching pattern for mode 4 is shown in figure 7 which also describes the period when Switches has to be ON and OFF.

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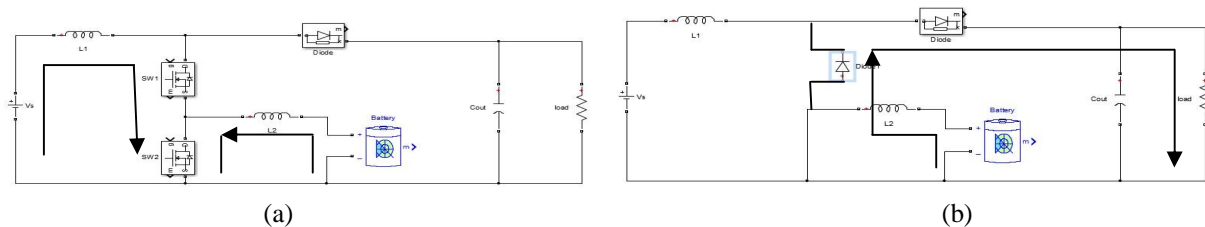
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(a)  
Figure 7: Switching Pattern for Mode 4

During fault condition or low input then supplying power from the source to the load is not possible. Hence battery must supply the power to the load. This operation can be done by controlling SW<sub>2</sub>. When supply voltage is less than reverse diode of SW<sub>1</sub> is used to discharge the energy from the battery to the load. Current flows during these actions are shown in figure 8.



(a) (b)  
Figure 8: Mode 4 current flows during (a) T<sub>on</sub> and (b) T<sub>off</sub>

Inductor L<sub>2</sub> current increase during ON period and its ripple current is given by

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

When SW<sub>2</sub> goes off then energy in the inductor L<sub>2</sub> and battery gets transferred to the load through reverse diode of SW<sub>1</sub>. Current ripple is expressed as

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

Equations (21) and (22) are equated to get the output voltage

$$V_{\text{out}} = \frac{V_{\text{battery}}}{1-D} \quad (23)$$

Where

$$D = \frac{T_{\text{on}}}{T_s} \quad (24)$$

## III. SIMULATION RESULTS

To verify the performance of all the four modes, the proposed multimode single leg converter is simulated using SIMULINK with V<sub>in</sub>=12V, V<sub>out</sub>=60V, L<sub>1</sub>=2.4mH, L<sub>2</sub>=1.16mH, Capacitor=100μF, Resistor=150Ω, Frequency=20KHz and Battery= 8V,1Ah. Simulation result for mode 1 and mode 2 is shown in figure 9(a) & (b) respectively. During mode 1, when both the switches are ON then inductor L<sub>1</sub> current rises and there is no change in the battery voltage. During OFF period both the switches are OFF then inductor L<sub>1</sub> current decreases. In mode 2, supply voltage is boosted up and at the same time battery is also gets charged. During T<sub>on\_boost</sub> both the switches are ON which makes the inductor L<sub>1</sub> to get charged and stored charge is delivered to the load when SW<sub>2</sub> is OFF. Battery gets charged up through inductor L<sub>2</sub>.

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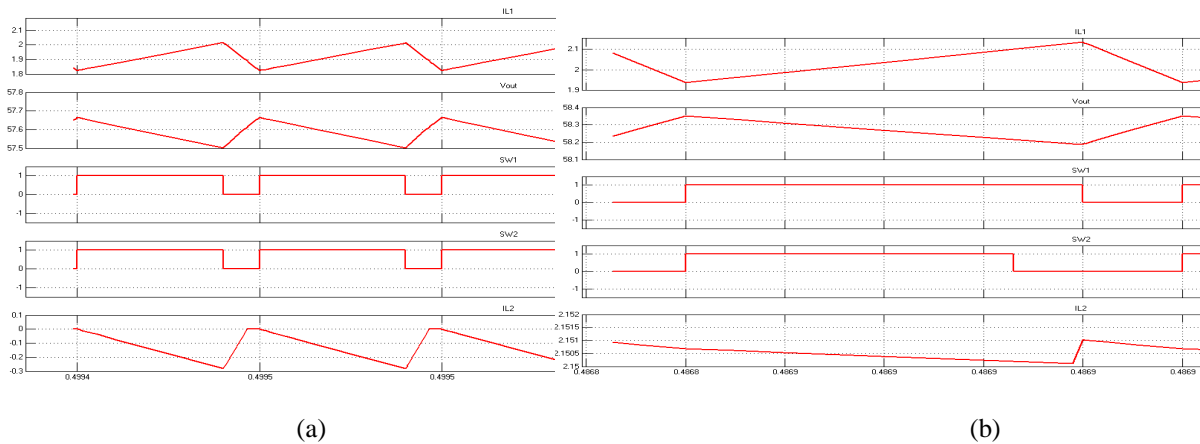


Figure 9: Simulation result for (a) Mode 1 (b) Mode 2

Simulation result for mode 3 and mode 4 is shown in figure 10(a) & (b) respectively. In mode 3, inductor  $L_1$  and  $L_2$  is charged when both the switches are ON. During  $T_{on\_boost2}$   $SW_1$  is OFF which makes the inductor  $L_1$  to discharge but  $L_2$  is continued to be charged from battery since  $SW_2$  is ON. At the end of this period  $L_2$  also discharges. In mode 4 battery must supply the power to the load since input is insufficient. This operation can be done by controlling  $SW_2$ . When supply voltage is less then reverse diode of  $SW_1$  is used to discharge the energy from the battery to the load.

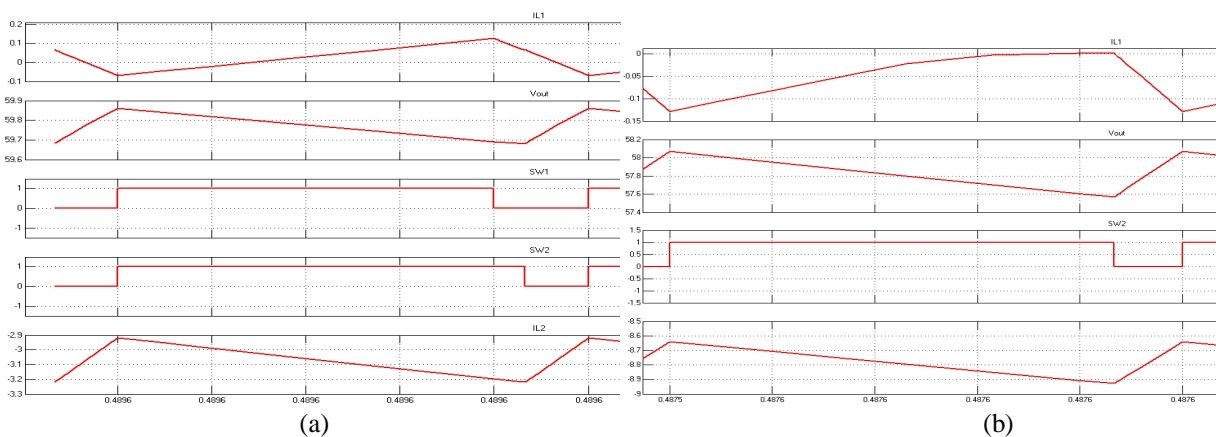


Figure 10: Simulation result for (a) Mode 3 and (b) Mode 4

## IV. CONCLUSION

This paper introduces multimode single leg converter for power electronic technology based conversion system. The proposed converter replaces boost and bidirectional converter in conventional power conversion system. Therefore number of switches are reduced which results in less switching losses and increased efficiency. Proposed converter makes the system structure simple hence system cost is reduced and diagnosis of the circuit is also simplified. This converter operates in four modes and its performance characteristics are verified by simulating the circuit using SIMULINK. Different power conversion systems can make use of this proposed converter.

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