

# Dual-Input Multioutput Using Non-Cloistered DC–DC Boost Converter



K. Sakthidhasan and K. Mohana Sundaram

**Abstract** This paper proposes a new non-cloistered dual-input multioutput DC–DC boost converter using a single magnetic field storage component (L). The proposed DC–DC boost converter can be used for conveying energy between different energy resources such as battery, FC, PV and ESS. In this paper, solar cell (PV) and battery are considered as a generating power source and an energy storage system (ESS) to produce two different voltage magnitudes in its output. Two different power operations like charging and discharging are defined. The main advantage of the converter module is to use least/minimum number of power electronic components. This converter is suitable for electric vehicle applications. The results of the proposed DIMO converter were verified with the help of the software (MATLAB/Simulink) and laboratory-based prototype.

**Keywords** DIMO DC–DC converter • Boost converter • Solar cell (PV) • Energy storage system (ESS) • Electric vehicle

## 1 Introduction

In this paper, based on the combination of two converters a new non-cloistered dual-input multioutput DC–DC boost converter is proposed. The proposed converter is presented in Fig. 1. In that Fig. 1 the converter interfaces two input power sources  $V_{in1}$  and  $V_{in2}$ . A multilevel inverter can be made possible with the load resistance  $R_1$  and  $R_2$  which can represent the equivalent power feeding. The control of power flow between input sources in addition to boost up the input sources voltage is possible by proper switching of switches. The outputs from this proposed

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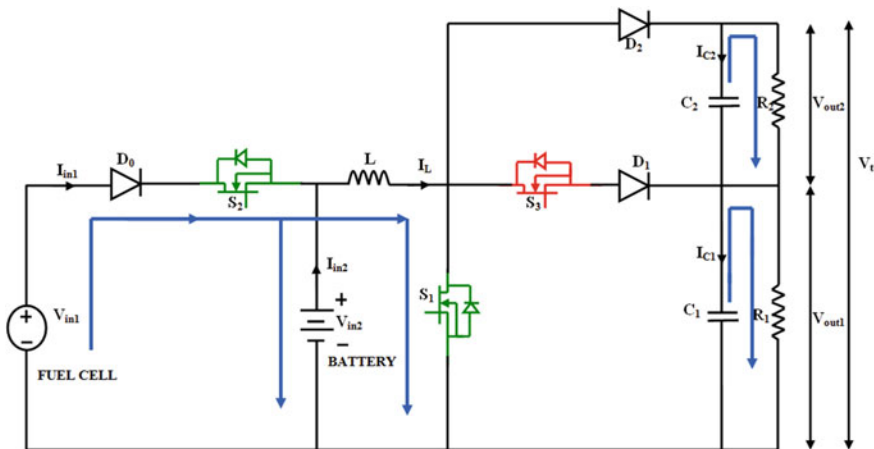


Fig. 1 Equivalent circuit for switching state 1

converter are capable to have different or equal output voltage magnitudes. This output voltage magnitudes can also be used for connecting to a multilevel inverter. The proposed converter has two input sources solar cell (PV) and energy storage system (such as battery) combination. The input source  $V_{in1}$  can deliver power to the source  $V_{in2}$  but not vice versa. In this system, solar cell (PV) which cannot be charged is located in  $V_{in1}$  and also in  $V_{in2}$  such as ESS (battery) can be charged is placed. Charging and discharging modes are used separately and it is working in single mode, i.e., DC–DC.

## 2 Different Mode of Operation

### 2.1 Battery Charging Mode

In this mode of operation, input source  $V_{in1}$  not only supplies to the load but also delivers power to  $V_{in2}$  (battery). This condition occurs when load power is low and battery requires to be charged. For each switch, a specific duty is considered.  $S_1$  is switched to regulate the total output voltage  $V_t = V_{out1} + V_{out2}$  to a desired value. The output voltage  $V_t$  is controlled by switch  $S_2$ . It is clear that by regulation of  $V_t$  and  $V_{out1}$ , the output voltage  $V_{out2}$  is regulated too. In Fig. 4, the gate signals of switches and voltage and current waveforms of inductor are shown. According to different switching states, there are three different operation modes in one switching period is given as follows;

**2.1.1 Switching State 1 ( $0 < T < D_{T1}$ )**

In this state, switches  $S_1$  and  $S_2$  are turned ON, switch  $S_3$  is OFF and cannot be turned ON. The diode  $D_2$  is reverse biased and does not conduct. In this state  $V_{in1}$  charges inductor  $L$ , and it increases the proposed converter for this state is shown in Fig. 1. Also in this mode, capacitors  $C_1$  and  $C_2$  are discharged and deliver their stored energy to load resistance  $R_1$  and  $R_2$ . The  $L$  and  $C$  equations are as follows;

$$\left. \begin{aligned} L \frac{di_L}{dt} &= V_{in1} \\ C_1 \cdot \frac{dv_{out1}}{dt} &= \frac{V_{out1}}{R_1} \\ C_2 \cdot \frac{dv_{out2}}{dt} &= \frac{V_{out2}}{R_2} \end{aligned} \right\} \quad (1)$$

**2.1.2 Switching State 2 ( $D_{T1} < T < D_{T2}$ )**

In this state, switch  $S_1$  is OFF, and switch  $S_2$  and  $S_3$  switch is turned ON. The diode  $D_2$  is reverse biased and does not conduct. In this state, inductor  $L$  is discharged and delivers its stored energy to  $C_1$  and  $R_1$ , so inductor current decreases. Figure 2 shows the equivalent circuit of the proposed system.  $C_1$  is charged and capacitor  $C_2$  is discharged and deliver their stored energy to load resistance  $R_2$ . The  $L$  and  $C$  equations in this mode are as follows;

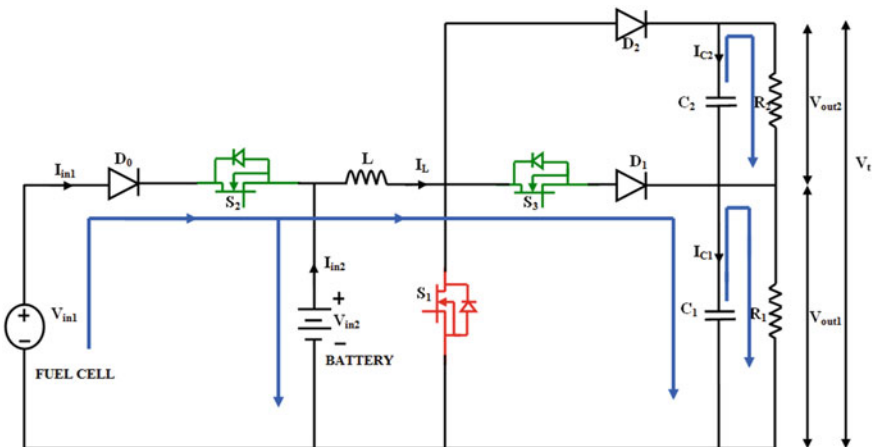


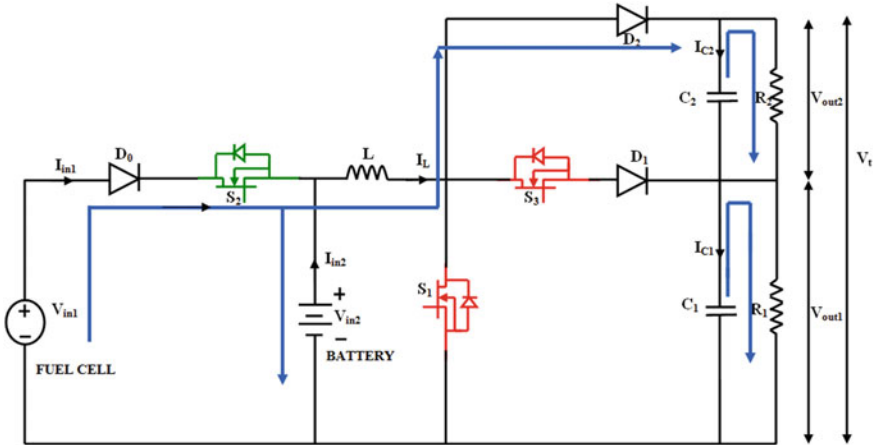
Fig. 2 Equivalent circuit for switching state 2

$$\left. \begin{aligned} L \frac{di_L}{dt} &= V_{in1} - V_{out1} \\ C_1 \cdot \frac{dv_{out1}}{dt} &= i_L - \frac{V_{out1}}{R_1} \\ C_2 \cdot \frac{dv_{out1}}{dt} &= \frac{V_{out2}}{R_2} \end{aligned} \right\} \quad (2)$$

**2.1.3 Switching State 3 ( $D_{T2}, D_{T3} < T < T$ )**

In this state, switch  $S_1$  is OFF and  $S_2$  is turned ON. The diode  $D_2$  is forward biased and the diode  $D_1$  is reverse biased and does not conduct, consequently  $S_3$  is OFF. Equivalent circuit of proposed converter for this state is shown in Fig. 3. In this state, inductor  $L$  is discharged and delivers its stored energy to capacitors  $C_1$  and  $C_2$  and load resistance  $R_1$  and  $R_2$  and thus capacitors  $C_1$  and  $C_2$  are charged. The inductor and capacitors equations in this mode are as follows (Fig. 4);

$$\left. \begin{aligned} L \frac{di_L}{dt} &= V_{in1} - V_t \\ C_1 \cdot \frac{dv_{out1}}{dt} &= i_L - \frac{V_{out1}}{R_1} \\ C_2 \cdot \frac{dv_{out1}}{dt} &= i_L - \frac{V_{out2}}{R_2} \end{aligned} \right\} \quad (3)$$



**Fig. 3** Equivalent circuit for switching state 3

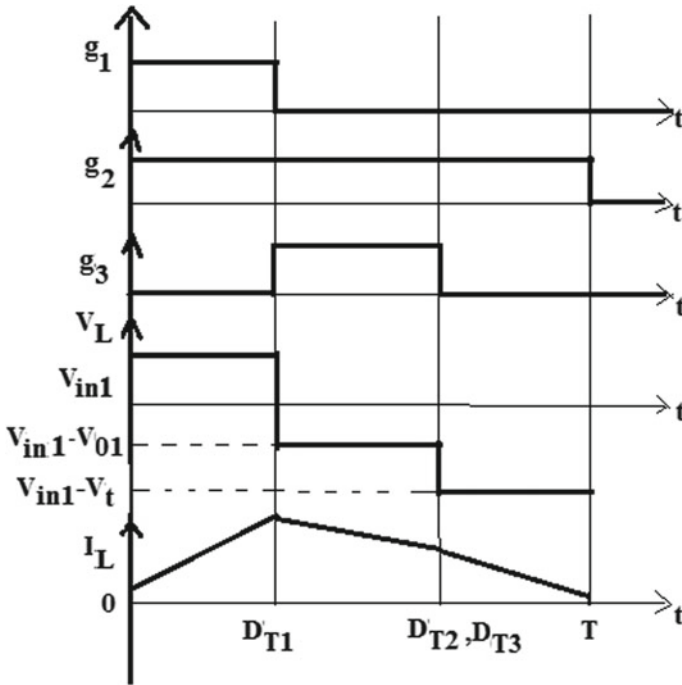


Fig. 4 Steady state waveform for battery charging mode

## 2.2 Battery Discharging Mode

In this mode, two input power sources  $V_{in1}$  and  $V_{in2}$  are responsible for supplying the loads. For each switch, a specific duty is considered. Here,  $S_1$  is active to regulate the battery current to a desired value by controlling inductor current. Output voltage  $V_{out1}$  is controlled by switch  $S_2$ . It is obvious that by regulation of  $V_t$  and  $V_{out1}$ , the output voltage  $V_{out2}$  is regulated too. Gate signals of switches and also voltage and current waveforms of  $L$  are shown in Fig. 8. The total output voltage  $V_t$  is regulated as  $V_t = V_{out1} + V_{out2}$ .

### 2.2.1 Switching State 1 ( $0 < T < D_{T1}$ )

$S_1$  is ON, and switch  $S_2$  is OFF. The diode  $D_1, D_2$  are reverse biased and does not conduct, so switch  $S_3$  is turned OFF. In this state, the  $V_{in2}$  charges inductor  $L$  charge is increases. Equivalent circuit of proposed converter for this state is shown in Fig. 5. Also in this mode capacitors  $C_1$  and  $C_2$  will get discharge and deliver its stored energy to load resistance  $R_1$  and  $R_2$ . The inductor and capacitors equations in this mode are as follows;

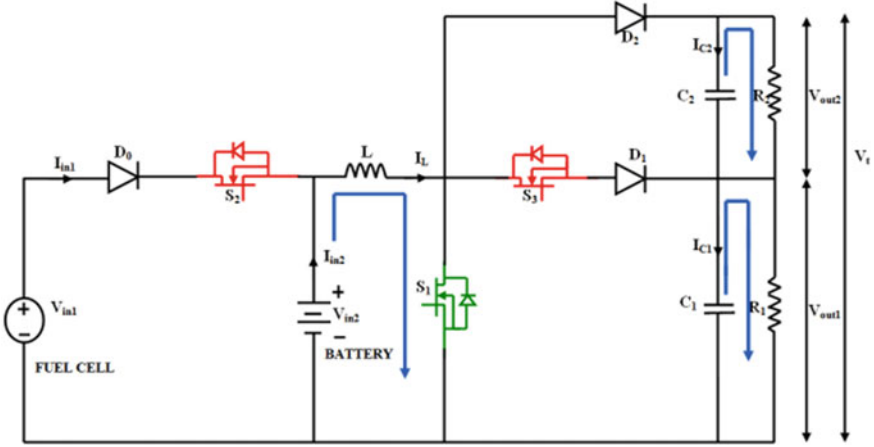


Fig. 5 Equivalent circuit for switching state 1

$$\left. \begin{aligned} L \frac{di_L}{dt} &= V_{in2} \\ C_1 \cdot \frac{dv_{out1}}{dt} &= -\frac{V_{out1}}{R_1} \\ C_2 \cdot \frac{dv_{out2}}{dt} &= -\frac{V_{out2}}{R_2} \end{aligned} \right\} \quad (4)$$

**2.2.2 Switching State 2 ( $D_{T1} < T < D_{T2}$ )**

In this state, switch  $S_1$  is OFF and  $S_2$  is turned ON. The diode  $D_2$  is forward biased and the diode  $D_1$  is reverse biased and does not conduct, consequently  $S_3$  is OFF. Equivalent circuit of proposed converter for this state is shown in Fig. 6. In this state, inductor  $L$  is discharged and delivers its stored energy to capacitors  $C_1$  and  $C_2$  and load resistance  $R_1$  and  $R_2$  and thus capacitors  $C_1$  and  $C_2$  are charged. The inductor and capacitors equations in this mode are as follows;

$$\left. \begin{aligned} L \frac{di_L}{dt} &= V_{in1} - V_t \\ C_1 \cdot \frac{dv_{out1}}{dt} &= i_L - \frac{V_{out1}}{R_1} \\ C_2 \cdot \frac{dv_{out1}}{dt} &= i_L - \frac{V_{out2}}{R_2} \end{aligned} \right\} \quad (5)$$

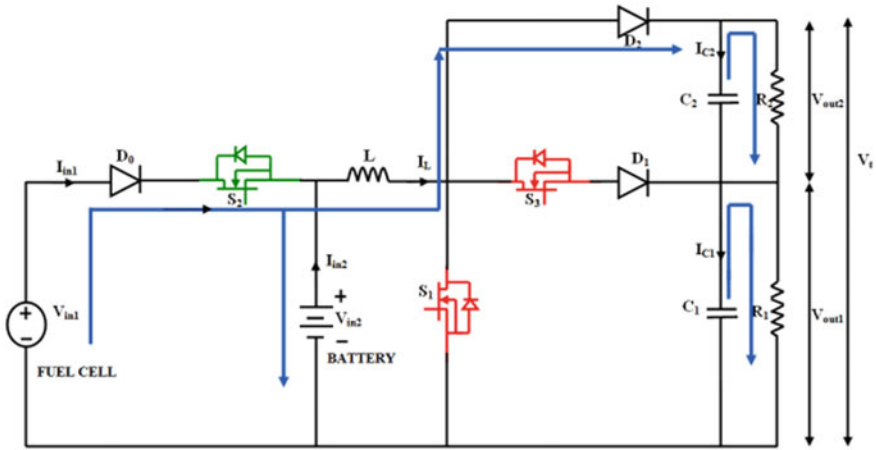


Fig. 6 Equivalent circuit for switching state 2

2.2.3 Switching State 3 ( $D_{T2}, D_{T3} < T < T$ )

In this state, switches  $S_1$  and  $S_2$  are OFF and  $S_3$  switch is turned ON. The diode  $D_1$  is forward biased and the diode  $D_2$  is reverse biased and does not conduct. Equivalent circuit of proposed converter for this state is shown in Fig. 7. In this state, inductor  $L$  is discharged and delivers its stored energy to  $C_1$  and  $R_1$ , so inductor current decreases. Also in this mode capacitor  $C_1$  is charged and capacitor  $C_2$  is discharged and deliver its stored energy to load resistance  $R_2$ . The inductor and capacitors equations in this mode are as follows (Fig. 8);

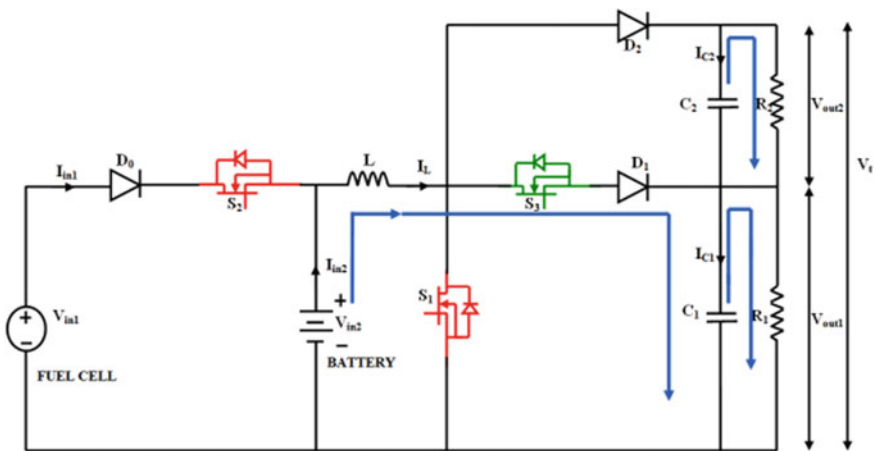


Fig. 7 Equivalent circuit for switching state 3

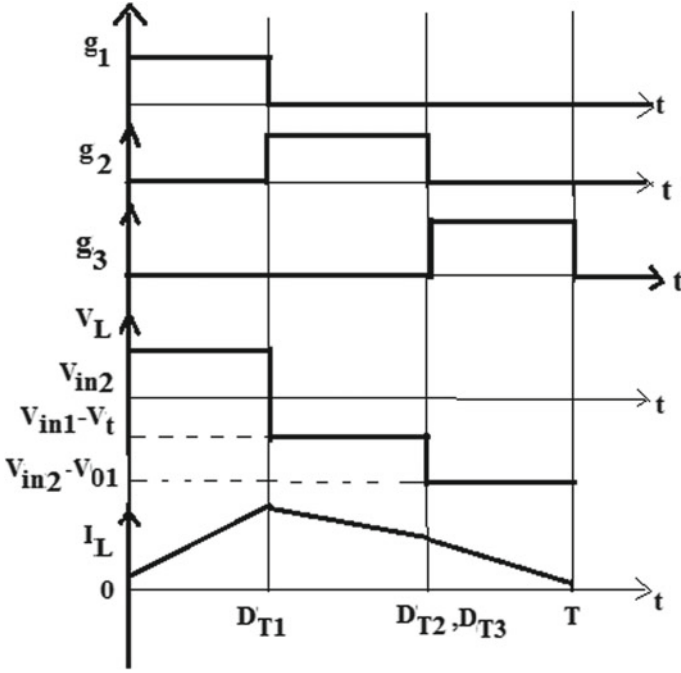


Fig. 8 Steady state waveform for battery discharging mode

$$\left. \begin{aligned} L \frac{di_L}{dt} &= V_{in2} - V_{out1} \\ C1. \frac{dv_{out1}}{dt} &= i_L - \frac{V_{out1}}{R_1} \\ C2. \frac{dv_{out1}}{dt} &= -\frac{V_{out2}}{R_2} \end{aligned} \right\} \quad (6)$$

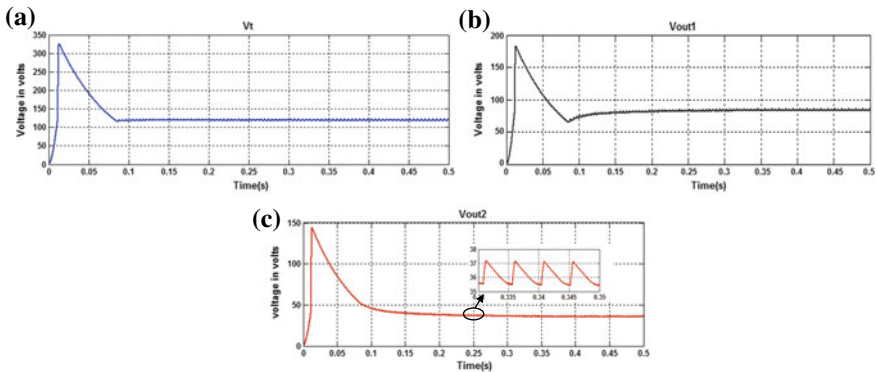
### 3 Simulation Results

Simulations are done for both charging and discharging modes of battery are using MATLAB/Simulink software in order to verify the performance of the proposed converter. The simulation parameters of the proposed converter are listed in Table 1. The simulation input voltage sources value for the proposed converter is given as  $V_{in1} = 45 \text{ V}$  and  $V_{in2} = 36 \text{ V}$ . The fuel cell (FC) is considered as input voltage source ( $V_{in1}$ ) with the combination of battery ( $V_{in2}$ ) is suitable for electric vehicle applications. Depending on the utilization state of the battery, charging and discharging modes of operation are defined for the proposed converter. The



**Table 1** Simulation parameters for the proposed boost converter

S. No.	Values	Parameters
1.	2.5 mH	Inductance ( $L$ )
2.	1000 $\mu$ F	Capacitors ( $C_1, C_2$ )
3.	10 kHz	Switching frequency ( $f_s$ )
4.	45 V	Input voltage ( $V_{in1}$ )
5.	36 V	Input voltage $V_{in2}(V_{battery})$
6.	70 $\Omega$	Resistance ( $R_1, R_2$ )



**Fig. 9** a The total output voltage ( $V_t$ ), b the output voltage ( $V_{out1}$ ), c the output voltage ( $V_{out2}$ )

converter module consists of three controllable switches. The required gate signals are given to each switch through PWM. The PI controller acts as an error minimize, here the response of the PI controller is compared with carrier and reference signal to produce the desired PWM. For each switch, a specific duty ratio ( $D_X$ ) is considered. A resistive load  $R_1$  and  $R_2$  is taken such that from the simulation results, the output voltages are obtained as  $V_{out1} = 85$  V and  $V_{out2} = 37$  V, respectively. So the total output voltage  $V_t$  is regulated as  $V_t = V_{out1} + V_{out2}$ , therefore  $V_t = 122$  V. Figure 9 shows, (a) the total output voltage  $V_t$ , (b) the output voltage  $V_{out1}$  and (c) the output voltage  $V_{out2}$ .

For battery discharging mode, two input power sources  $V_{in1}$  and  $V_{in2}$  are responsible for supplying the loads. Figure 10 shows the simulation results for battery discharging mode current. For battery charging mode, the input source  $V_{in1}$  not only supplies to the load but also delivers power to  $V_{in2}$  (battery). This condition occurs when load power is low and battery requires to be charged. Figure 11 shows the simulation results for battery charging current.

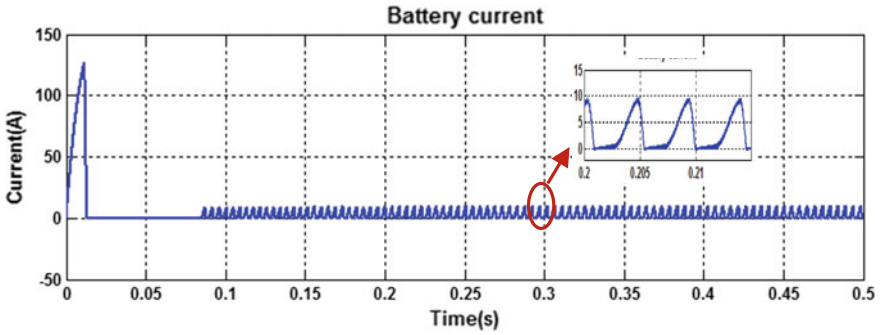


Fig. 10 Battery discharging current

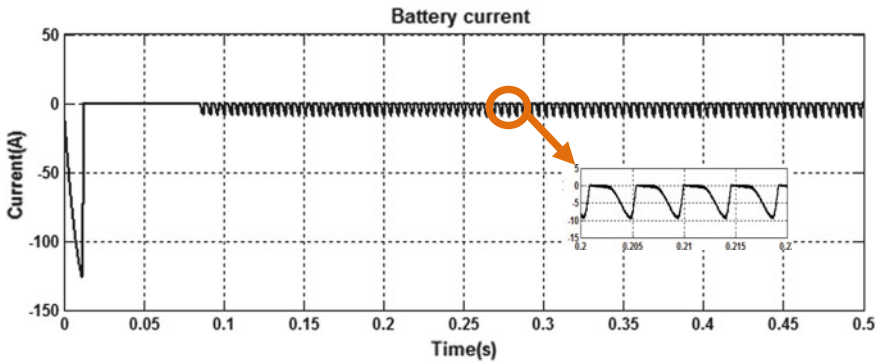


Fig. 11 Battery charging current

## 4 Conclusion

A non-cloistered dual-input multioutput DC–DC boost converter with less number of power electronics components is proposed using generating power source solar cell (PV) and energy storage system (battery). Also, the converter can be utilized as single input multioutput converter. Based on the utilization state of the battery two power operation mods are defined. For each mode, transfer functions matrices/small signal average methods are obtained separately. The proposed converter produces two different voltage magnitudes in its output which is suitable for electric vehicle-based applications.

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