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Modeling And Simulation Of Non-Isolated Multi-Port Dc-Dc Converter For Electric Vehicle Applications

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ABSTRACT : Multi-port unidirectional/bidirectional DC-DC Converters are the significant solution for Electric Vehicle (EV) applications. This paper focuses on a non-isolated dual input dual output (four-port) DC-DC Converter that can be applied for EV applications. This topology of DC-DC converter can provide both step-up and step-down outputs simultaneously. This converter comprises of less number of components and its control method is also simple which makes this converter simple, reliable and economical. This converter also exhibits bidirectional power flow operation making it more suitable for battery charging of an electric vehicle during the regenerative braking operation. In this paper, four-port (dual-input, dual-output) DC-DC converter has been designed and simulated on MATLAB Simulink. The simulation outcomes verify the performance of the four-port DC-DC Converter.

Keywords: Bidirectional DC-DC Converter, Multi-port converter, Battery Charging, Electric Vehicle, Regenerative braking

1. INTRODUCTION

Now-a-days, the use of renewable energy resources has been augmented to protect the environment and remaining fossil fuel and the energy storage requirement is also augmented. In many applications like electric vehicles (EV) the want of interfacing of energy storage with load and source is improved for a reliable and energy efficient system. Bidirectional DC-DC converter is the main device used to interface the battery as a storage device to increase the system reliability. Moreover, as shown in Figure 1, in electric vehicle bidirectional DC-DC converters are very much useful for capturing the kinetic energy of motor and charging the battery during regenerative breaking by reverse flow of energy.

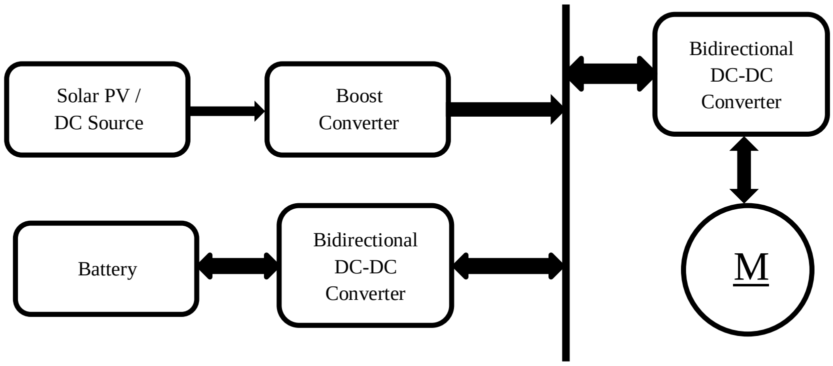


Figure 1. Solar PV powered electric vehicle

The complexity of the power transmission system increases, the traditional unidirectional converters are no longer enough for use. A bidirectional DC-DC converter can achieve bidirectional power flow in the same topology. Examples are: uninterruptible power supplies, energy storage systems, and kinetic energy recovery for electric vehicles. It can effectively reduce the total components required, increase the power density and reduce production cost. The novel bidirectional DC-DC converters which just designed for higher conversion ratio, efficiency, stability and low cost have also bounded up.

Many researchers are working on this DC-DC converter for electric vehicles with different approaches [1-13] like usage of bidirectional power flow control [1-7], effective usage of energy storage devices [8-9], renewable energy resources [9] and electric drive [10] etc. The conversion efficiency of DC-DC converter is improved by using interleaved boost converters [11-13].

In this paper, session 2 explains the structure of the four-port DC-DC converter topology. Session 3 discusses about the various modes of operation. Validation of this converter topology and its simulation outputs are presented in Session 4. Finally, conclusion is presented in session 5.

2. STRUCTURE OF FOUR-PORT DC-DC CONVERTER

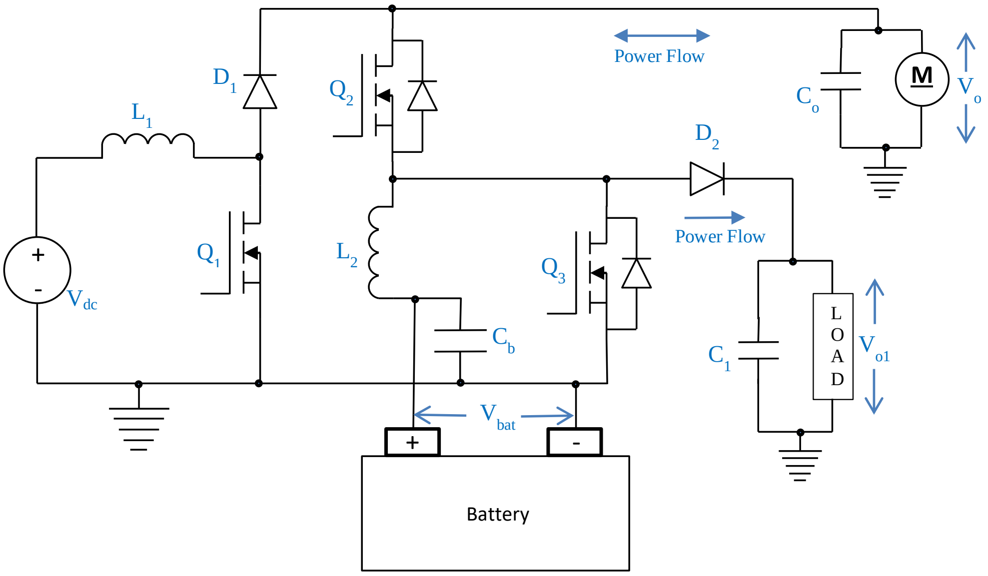


Figure 2. Circuit diagram of four-port DC-DC Converter

A non-isolated multi input multi output unidirectional/bidirectional DC-DC converter is considered as shown in Figure 2. This topology of DC-DC converter consists of an input side boost converter, an output side unidirectional boost converter and an output side bidirectional buck-boost converter. This topology of power converter interface different power resources with the traction motor of an electric vehicle. In this, we considered primary DC voltage source or Solar PV source as one input and another source is the rechargeable battery. Similarly we have considered two outputs: an electric motor which is used as traction motor, the auxiliary loads (Heater, Light, Air Conditioner, Etc.) used in the electric vehicle.

3. MODES OF OPERATION

The operation of this four-port DC-DC converter can be explained with the following five modes. Figure 3 shows the switching pulses used for various MOSFET switches in the converter circuit. Figure 4 shows the various modes of operation of the four-port DC-DC converter. The switching sequences of switches Q_1, Q_2 and Q_3 for various modes are shown in Table 1.

Mode 1: In this mode, Converter act as a single input dual output DC-DC converter. Here, input source is the primary DC source and the output is traction motor as well as the auxiliary loads. During this mode of operation switches Q_1 and Q_3 are ON, Switch Q_2 is OFF, during the time interval 0 to D_1T_s. While considering $V_{dc} > V_{bat}$, the voltage V_{dc} appears across the inductor L_1, resulting in the inductor is getting charged. During time interval, D_1T_s to T_s, switches Q_1 and Q_3 are OFF, switch Q_2 is ON. Energy stored in the previous time interval is discharged to the output through the diode D_1. The steady state output voltage during this mode is given by,

$$V_o = \frac{1}{1 - D_1} V_{dc}$$

$$V_{o1} = \frac{1}{1 - D_1} V_{dc}$$

Mode 2: In this mode, converter act as a single input three output DC-DC converter. Operation of this mode is similar to the Mode 1. Here, input source is the primary DC source and the outputs are Battery, traction motor and the auxiliary loads. When the battery needs to be charged from the input DC source, Q_2 operates with $D_2<0.5$. Q_3 and Q_1 operate with $D_1>0.5$ to produce boosted output across the load. The voltage equations for this mode is given by,

$$V_o = \frac{1}{1 - D_1} V_{dc}$$
$$V_{o1} = D_2 V_{dc}$$
$$V_{bat} = D_2 V_{dc}$$

Mode 3: In this mode, converter act as a single input dual output DC-DC converter. Here, the input source is the battery and the outputs are traction motor and the auxiliary loads. During the time interval 0 to D_3T_s, the current in the inductor L_2 is increases because of the energy from the battery. During the interval D_3T_s to T_s, the current in the inductor L_2 decreases. The ON-OFF state of Q_3 provides a boosted output to the traction motor. Since the switch Q_1 is not involved in the energy transfer during this mode, it is kept in OFF throughout the entire mode. The output voltage equations are given by,

$$V_o = \frac{1}{1 - D_3} V_{bat}$$
$$V_{o1} = \frac{1}{1 - D_3} V_{bat}$$

Mode 4: In this mode, converter act as a dual input dual output DC-DC converter. Here, both the primary DC source and the battery are act as input source and the outputs are traction motor and the auxiliary loads. During the time interval 0 to D_1T_s, the switches Q_1 and Q_3 are ON. It causes the inductor currents i_{L1} and i_{L2} increases linearly. Complimentary gate signal is applied to the switch Q_2. During the OFF period of switches Q_1 and Q_3, the inductor currents i_{L1} and i_{L2} are decreases. Thus boosted power is transferred from both DC source and the battery to the loads via diodes D_1 and D_2. Output equations during this mode are given by,

$$V_o = \frac{1}{1 - D_1} V_{dc}\ (or)\ V_o = \frac{1}{1 - D_3} V_{bat}$$
$$V_{o1} = \frac{1}{1 - D_1} V_{dc}\ (or)\ V_{o1} = \frac{1}{1 - D_3} V_{bat}$$

Mode 5: In this mode, converter act as a single input dual output DC-DC converter. Here, the power is transferred from the load to the battery and the auxiliary loads. During this regenerative braking, the kinetic energy stored in the traction motor is fed back to the battery. During this mode, the switch Q_1 is permanently in OFF condition. The switch Q_3 is permanently in ON condition and the switch Q_2 is in ON – OFF state, which enables the charging of battery. The battery voltage is given by,

$$V_{bat} = D_2 V_o$$

And the voltage across the auxiliary load is given by,

$$V_{o1} = D_3 V_o$$

Table 1. Switching sequence for different modes of operation

Mode	Input	Status of the Switches			Outputs	
		Q_1	**Q_2**	**Q_3**	**V_o**	**V_{o1}**
1 (V_{dc}>V_{bat})	V_{dc}	1	0	1	Boost	Boost
		0	1	0		
2 (V_{dc}>V_{bat})	V_{dc}	1	0	1	Boost	Boost
		0	1	0		
3 (V_{dc}<V_{bat})	V_{bat}	-	0	1	Boost	Boost
		-	1	0		
4 (V_{dc}=V_{bat})	V_{dc} & V_{bat}	1	0	1	Boost	Boost
		0	1	0		
5 (V_{bat}<V_{load})	Regenerative braking	-	1	0	Buck	Buck
		-	0	1		

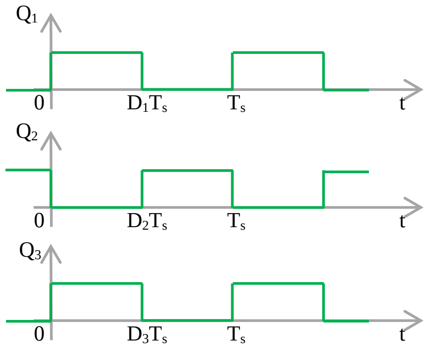


Figure 3. Switching waveforms for various switches

4. RESULTS AND DISCUSSIONS

In order to study the performance of four port bidirectional DC-DC converter, simulation was carried out using MATLAB Simulink. The developed simulation model of this topology of DC-DC converter is shown in Figure 5. The various parameters used for this simulation are listed in the Table 2.

The simulation outputs for various modes of operation are shown in Figure 6. It shows that the simulated bidirectional non-isolated DC-DC converter works in all possible operations like, Buck mode, Boost mode, battery charging mode and regeneration mode. Figure 6(a) shows the voltage and current across the auxiliary load and the traction motor. Figure 6(b) shows battery current and the load voltages. As the battery current is negative, it means battery is charging from the power supply. Figure 6(c) shows source current, battery current and load voltages. Here the source current is zero and the battery current is positive. It means that the entire power to the load is taken from the battery. Figure 6(d) shows battery current and the load voltages, during this mode of operation both input source and the battery supplies power to the load.

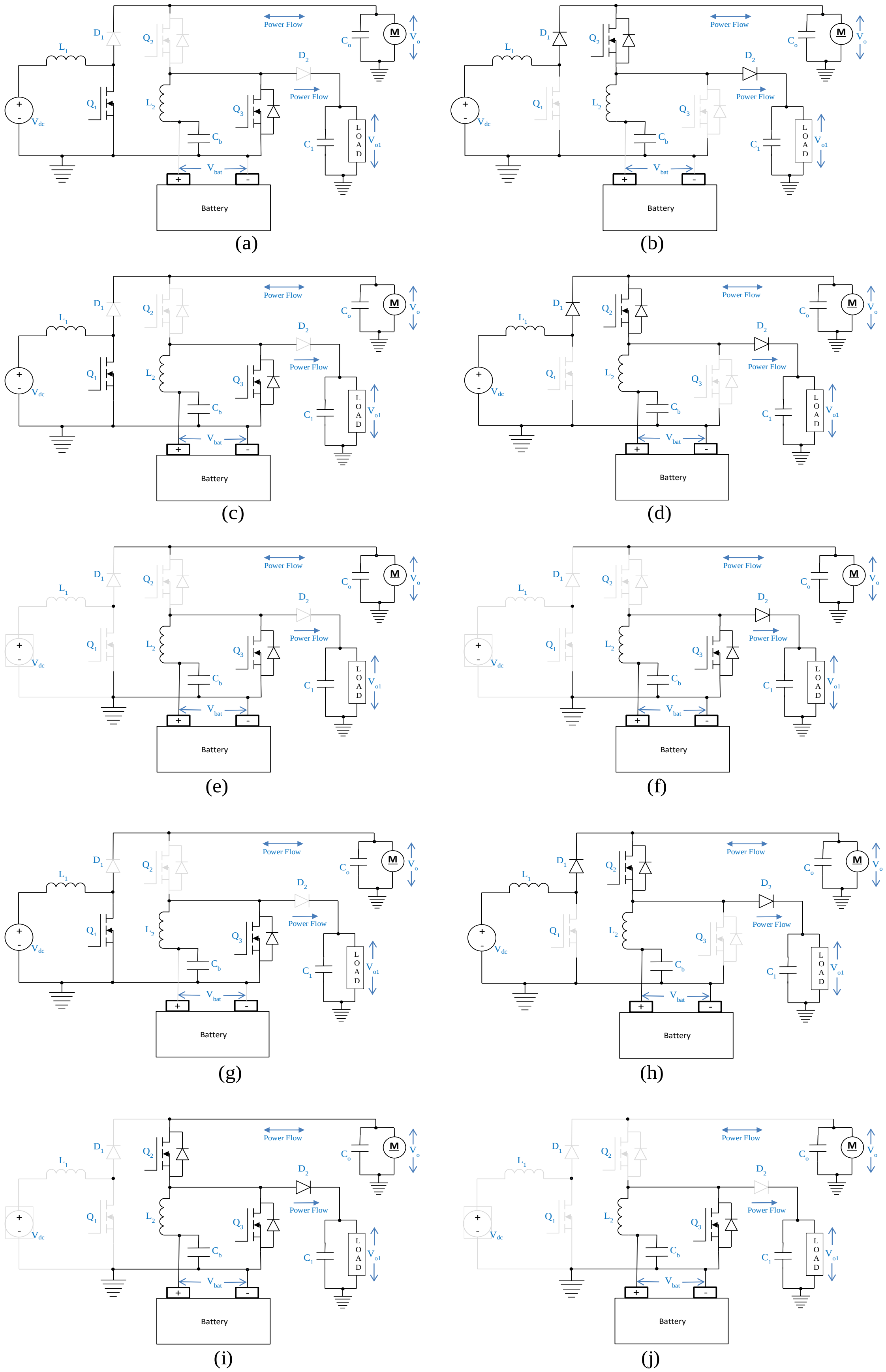

(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
Power Flow
Battery
LOAD
M

Figure 4. Various modes of operation of four-port DC-DC converter (a) & (b) Mode 1, (c) & (d) Mode 2, (e) & (f) Mode 3, (g) & (h) Mode 4, (i) & (j) Mode 5

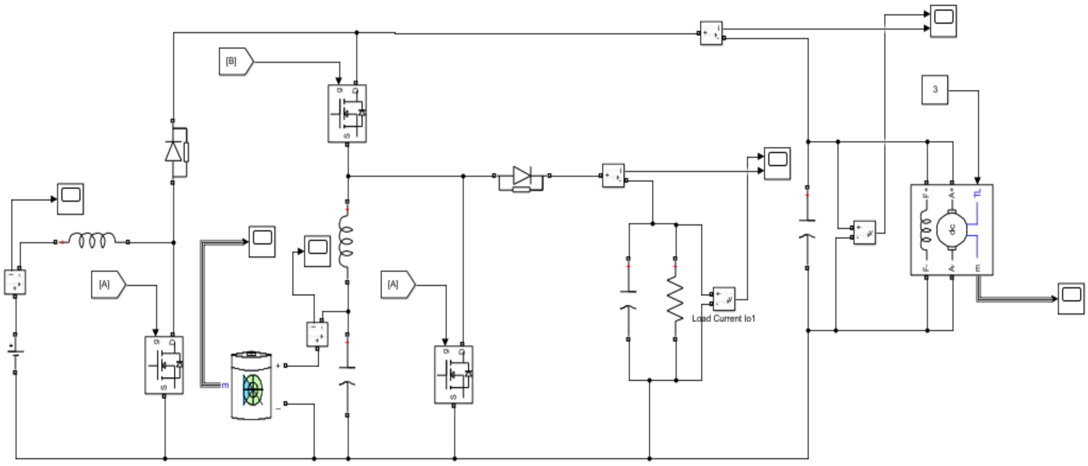
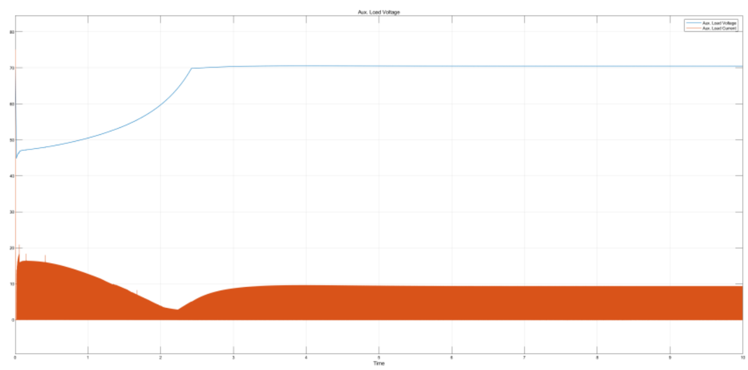
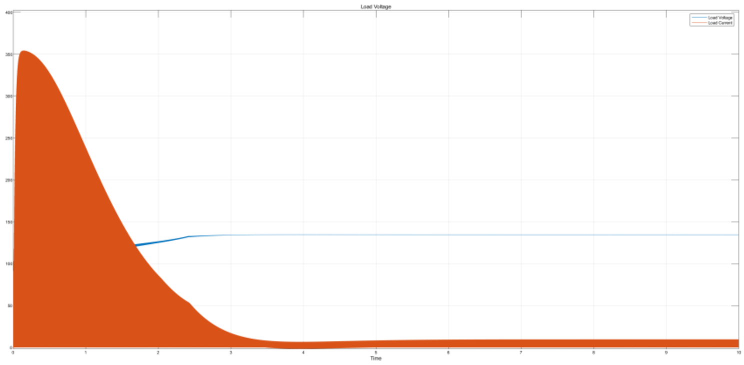


Figure 5. Simulation model of four-port DC-DC converter

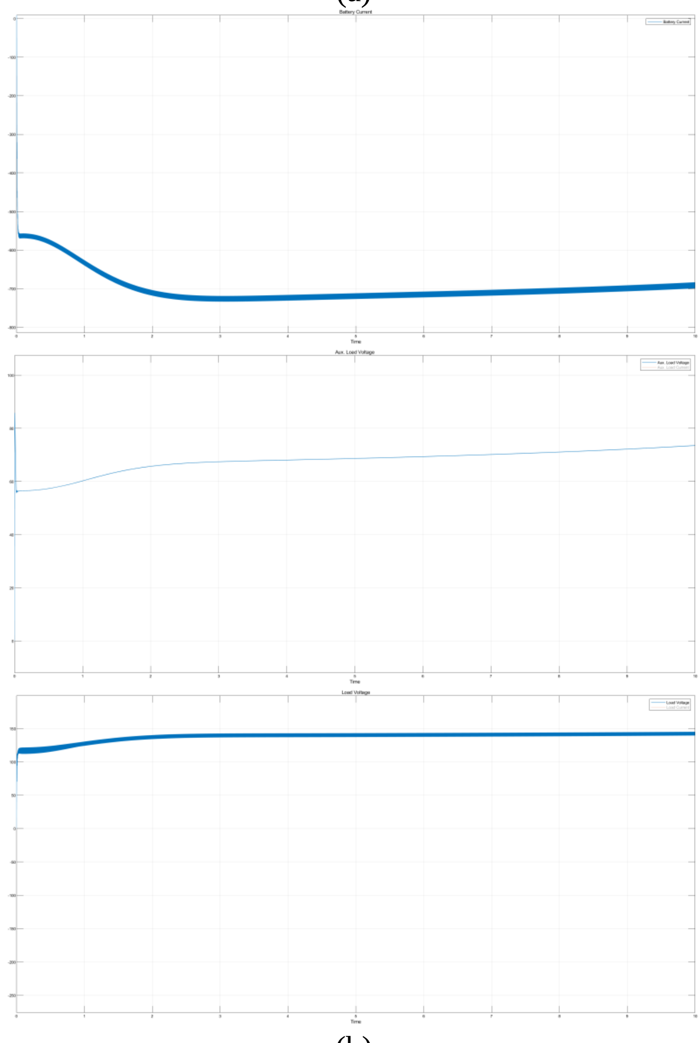
Table 2. Simulation parameters

Components	Specifications
Capacitor (C_1)	1000µF
Capacitor (C_o)	1000µF
Capacitor (C_{bat})	1µF
Inductor (L_1)	1mH
Inductor (L_2)	120µH
Battery	12V, 7Ah

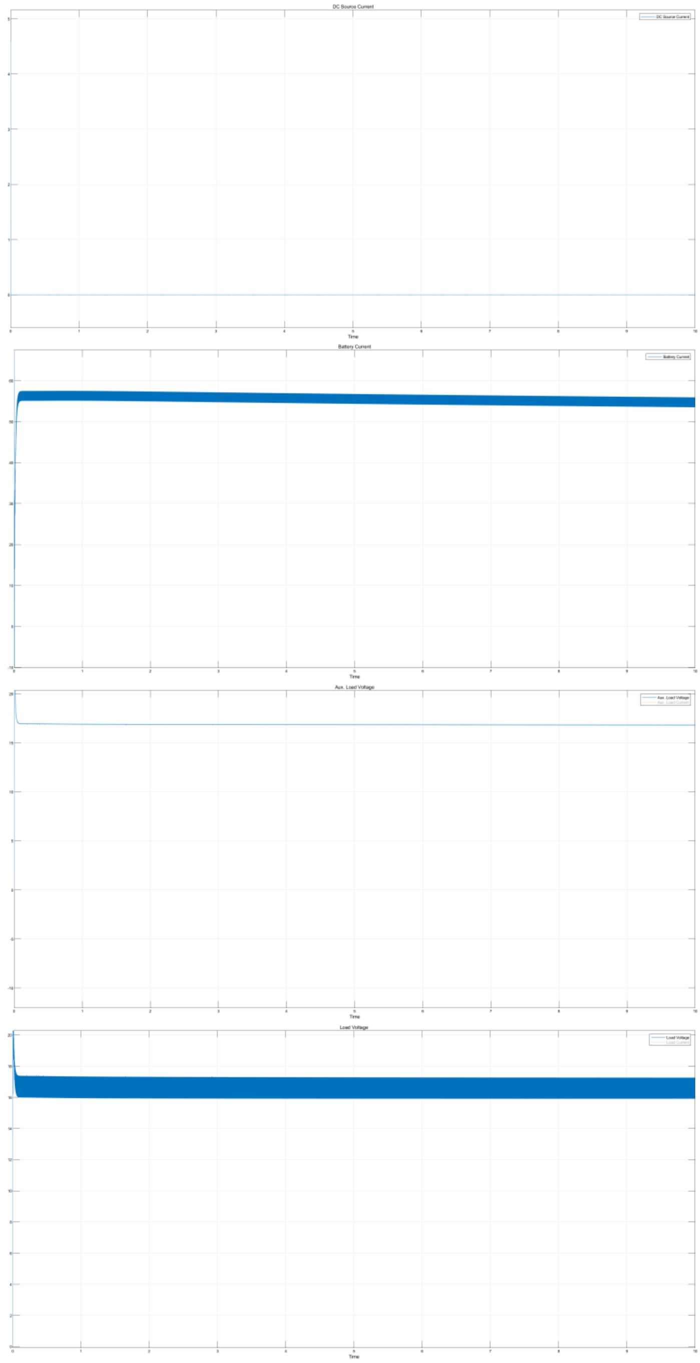




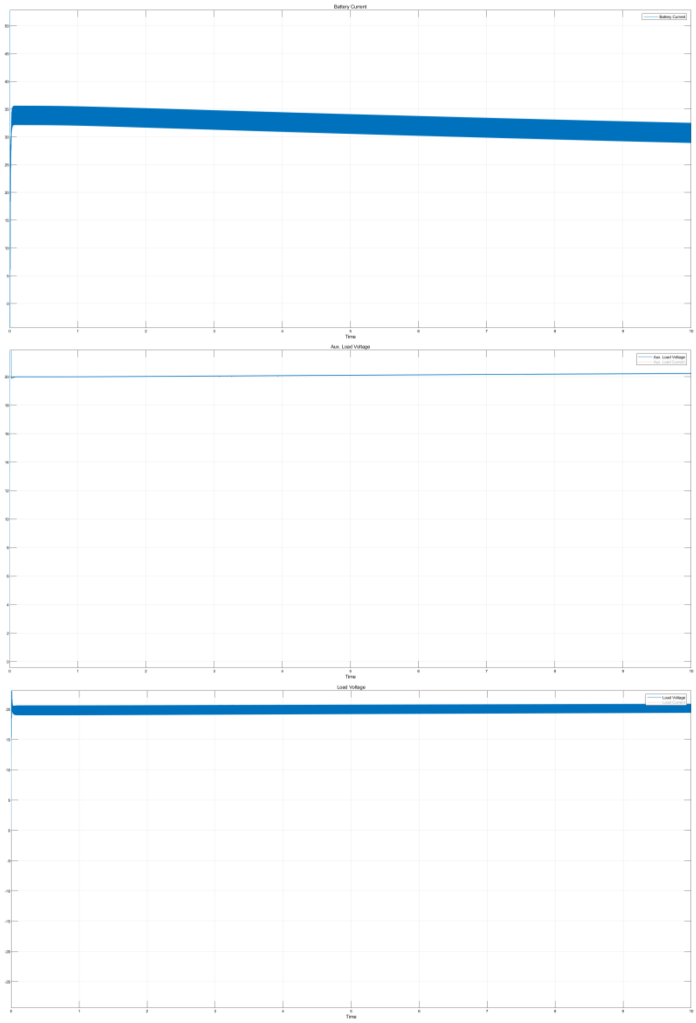
(a)



(b)


DC Source Current
Time
Battery Current
Time
Ave. Load Voltage
Time
Load Voltage
Time

(c)



(d)

Figure 6. Simulation outputs (a) Mode 1 (b) Mode 2 (c) Mode 3 and (d) Mode 4

5. CONCLUSION

A non-isolated multiport unidirectional/bidirectional DC-DC converter for electric vehicle application has been presented. The various modes of operation were discussed. This converter has the special feature of producing the outputs of buck, boost, and buck-boost mode of operations. The performance was studied using MATLAB/Simulink simulation. The simulation results validate the operation of the presented converter. This converter performance can be enhanced by applying a closed loop control.

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