

A Non Isolated Dual Input Dual Output DC–DC Boost Converter for Electric Vehicle Applications

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Abstract: A new non isolated multi input multi output dc–dc boost converter is presented in this paper. This converter is applicable in hybridizing alternative energy sources in electric vehicles. By hybridization of energy sources, advantages of different sources can be achieved. In this converter, the loads power can be flexibly distributed between input sources. Also, charging or discharging of energy storages by other input sources can be controlled properly. The proposed converter has several outputs with different voltage levels which makes it suitable for interfacing to multilevel inverters. Use of a multilevel inverter leads to reduction of voltage harmonics which, consequently, reduces torque ripple of electric motor in electric vehicles. Also, electric vehicles which uses dc motor have at least two different dc voltage levels, one for ventilation system and cabin lightening and other for supplying electric motor. The converter presented here has just one inductor. Depending on charging and discharging states of the energy storage system (ESS), two different power operation modes are defined for the converter. The validity of the converter and its control performance are verified by MATLAB/SIMULINK

Keywords: DC–DC converters, electric vehicle (EV), energy storage system (ESS), fuel cell (FC), hybrid power system, super capacitor (SC).

I. INTRODUCTION

Increasing rapidly population and energy consumption in the world, increasing oil and natural gas prices, and the depletion of fossil fuels are justifiable reasons for using electrical vehicles (EVs) instead of fossil-fuel vehicles. The interest in developing the EVs with clean and renewable energy sources as a replacement for fossil-fuel vehicles has therefore steadily increased. The EVs are introduced as a potential and attractive solution for transportation applications to provide environmentally friendly operation with the usage of clean and renewable energy sources. . In this paper, a new multi input multi output non isolated converter based on combination of a multi input and a multi output converter is presented. This converter compared to similar cases has lesser number of elements and it can control power flow between sources with each other and load. Also, presented converter has several outputs that each one can have different voltage level.

II. DUAL-INPUT DUAL-OUTPUT DC-DC BOOST CONVERTER

A non isolated dual input dual output DC–DC converter is presented. The structure of the converter with two-input two-output is shown in Fig.1 . In this figure, R_1 and R_2 are the model of load resistances that can represent the equivalent power feeding to a multilevel inverter. Four power switches S_1 , S_2 , S_3 , and S_4 in the converter structure are the main controllable elements that control the power flow and output voltages of the converter. In this converter, source V_{in1} can deliver power to source V_{in2} but not vice versa. So, in EV applications, FC which cannot be charged is located where V_{in1}

is placed in circuit. Also, usually where V_{in2} is placed, ESSs such as battery or SC which are chargeable are located. In this paper, FC is used as a generating power source and the battery is used as an ESS. Depending on the utilization state of the battery, two power operation modes are defined for this converter. In each mode, just three of the four switches are active, while one switch is inactive. When load power is high, both input sources deliver power to load, in such a condition, S_2 is inactive and switches S_1 , S_3 , and S_4 are active. Also, when load power is low and V_{in2} is needed to be charged, V_{in1} not only supplies loads but also can charge V_{in2} . In this condition, switches S_1 , S_2 and S_4 are active and S_3 is inactive

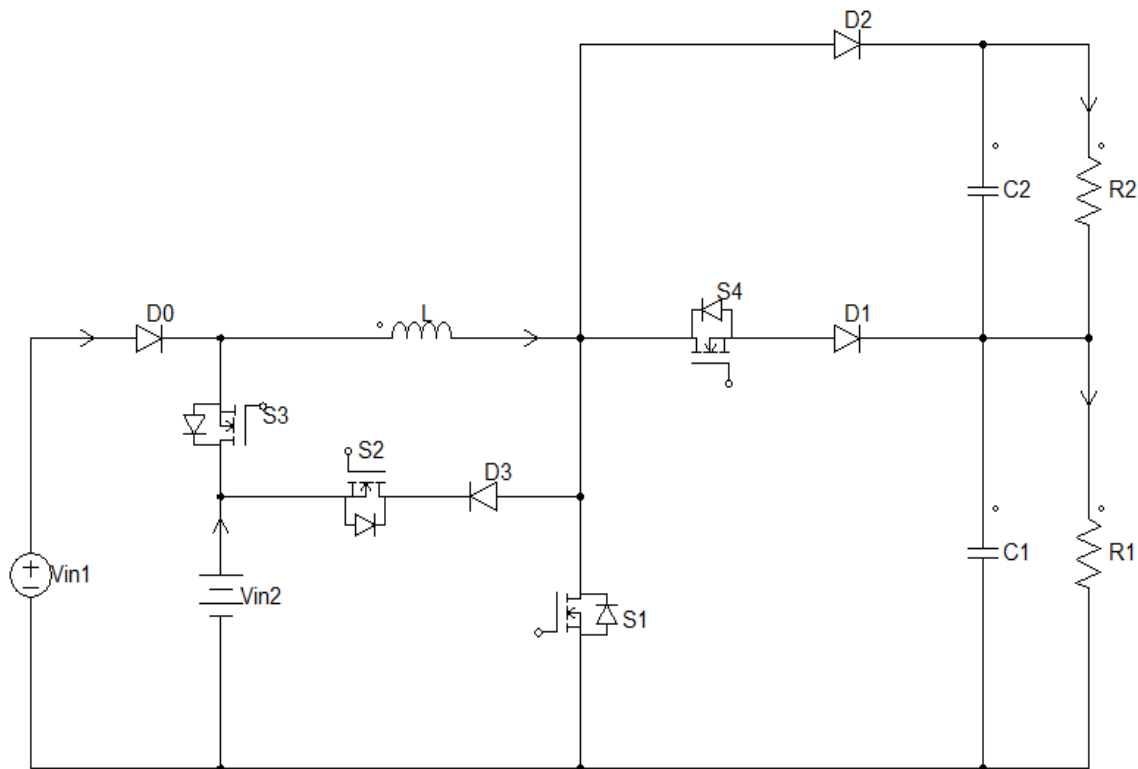


Fig.1. Circuit diagram

A. Modes of Operation:

Depending on the utilization state of the battery, two power operation modes are defined for this converter. First is battery discharging mode and second is battery charging mode.

Battery Discharging Mode:

In this operation mode, two input power sources V_{in1} and V_{in2} (battery) are responsible for supplying the loads. In this mode, S_2 is OFF entirely and S_1 , S_3 and S_4 are active. For each switch, a specific duty is considered. Here, S_1 is active to regulate source 2 (battery) current to desired value. In fact, S_1 regulates battery current to desired value by controlling inductor current. Regulation of total output voltage $V_T = V_{O1} + V_{O2}$ to desired value is duty of the switch S_3 . Also, output voltage V_{O1} is controlled by S_4 . It is obvious that by regulation of V_T and V_{O1} , the output voltage V_{O2} is regulated too. Gate signals of switches and also voltage and current waveforms of inductor are shown in Fig. 3. According to switches states, there are four different operation modes in one switching period as follows:

(a). Switching State 1 [$0 - D_3 T$]:

During this state, switches S_1 and S_3 are turned ON. Because S_1 is ON, diodes D_1 and D_2 are reversely biased, so switch S_4 is turned OFF. Since S_3 is ON and $V_{in1} < V_{in2}$, diode D_0 is reversely biased. In this state, V_{in2} charges inductor L , so inductor current increases. Also, in this mode, capacitors C_1 and C_2 are discharged and deliver their stored energy to load resistances R_1 and R_2 respectively.

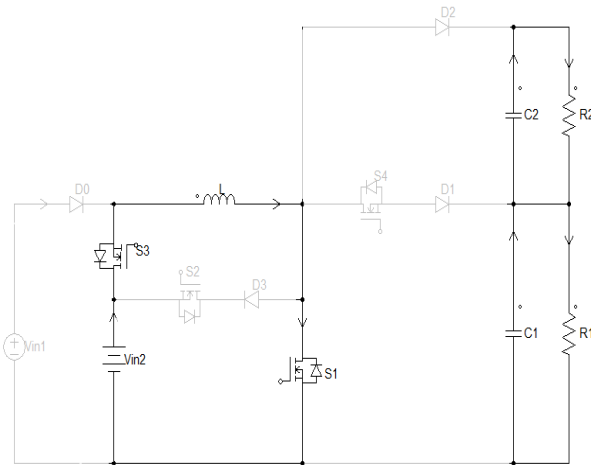


Fig. 2. Switching state 1 operation

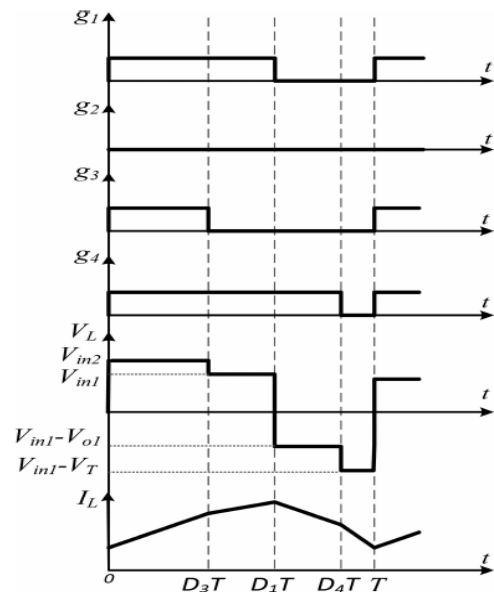


Fig. 3. Steady state waveforms in Battery discharging mode

(b). Switching State2[$D_3T < t < D_1T$]:

During this state, switch S_1 is still ON and S_3 is turned OFF. Because S_1 is ON, diodes D_1 and D_2 is reversely biased, so switch S_4 is still OFF. In this state, V_{in1} charges inductor L, so inductor current increases. In addition, capacitors C_1 and C_2 are discharged and deliver their stored energy to load resistances R_1 and R_2 respectively.

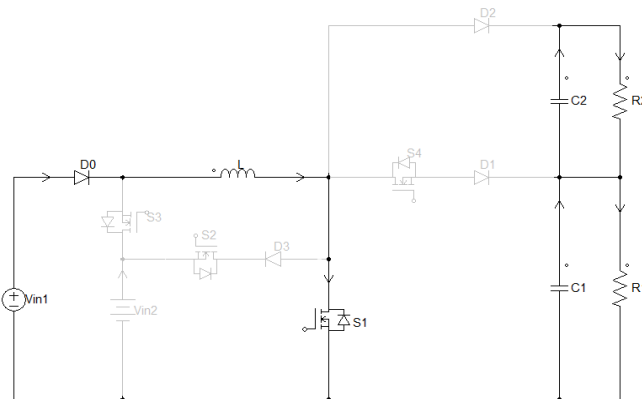


Fig. 4. Switching state 2 operation

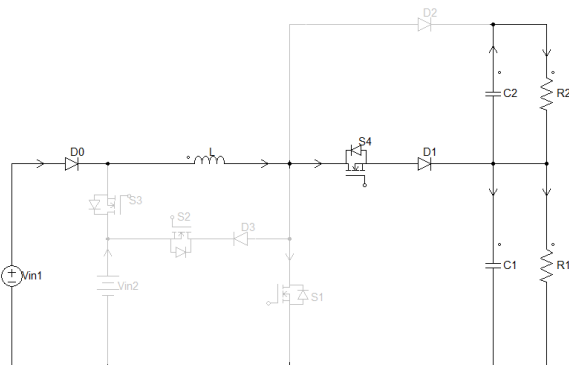


Fig. 5. Switching state 3 operation

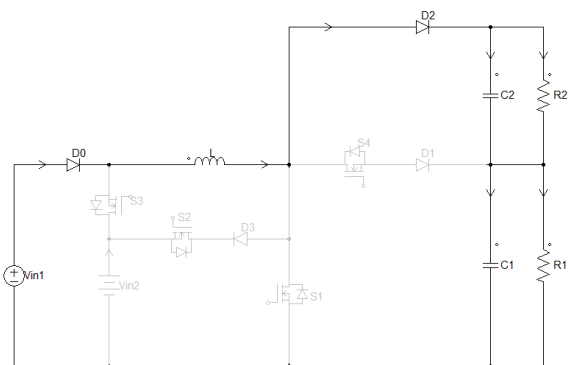


Fig. 6. Switching state 4 operation

(c). Switching State 3 [$D_1T < t < D_4T$]:

During this state, switch S_1 is turned OFF and switch S_3 is still OFF. Also, switch S_4 is turned ON. Diode D_2 is reversely biased. Equivalent circuit of proposed converter in this state is shown in Fig. 5. In this state, inductor L is discharged and delivers its stored energy to C_1 and R_1 , so inductor current is decreased. In this state, C_1 is charged and C_2 is discharged and delivers its stored energy to load resistance R_2 .

(d). Switching State 4 [$D_4T < t < T$]:

During this state, all of three switches are OFF. So, diode D_2 is forward biased. In this state, inductor L is discharged and delivers its stored energy to capacitors C_1 , C_2 , and load resistances R_1 and R_2 . Also, in this mode, capacitors C_1 and C_2 are charged. Equivalent circuit of proposed converter in this state is shown in Fig.6.

Battery charging Mode:

In this mode, V_{in1} not only supplies loads but also delivers power to V_{in2} (battery). This condition occurs when load power is low and battery requires to be charged. In this operation mode, switches S_1 , S_2 and S_4 are active and switch S_3 is entirely OFF. Like previous operation mode of the converter in this mode, for each switch, a specific duty is considered. S_1 is switched to regulate total output voltage $V_T = V_{O1} + V_{O2}$ to desired value. Regulation of the battery charging current (I_b) to desired value is the duty of switch S_2 . Also, output voltage V_{O1} is controlled by switch S_4 . It is clear that by regulation of V_T and V_{O1} , the output voltage V_{O2} is regulated too. In Fig. 8, gate signals of switches and voltage and current waveforms of inductor are shown. According to different switches states, there are four different operation modes in one switching period which is discussed as follows:

(a). Switching State 1 [$0 < t < D_1T$]:

In this state, switch S_1 is turned ON, so S_2 and S_4 are reverse biased and cannot be turned ON. Also, diode D_2 is reversely biased and does not conduct. Equivalent circuit of the converter in this state is shown in Fig.7. In this state, V_{in1} charges inductor L , so inductor current is increased. Also, in this mode, capacitors C_1 and C_2 are discharged and deliver their stored energy to load resistances R_1 and R_2 , respectively.

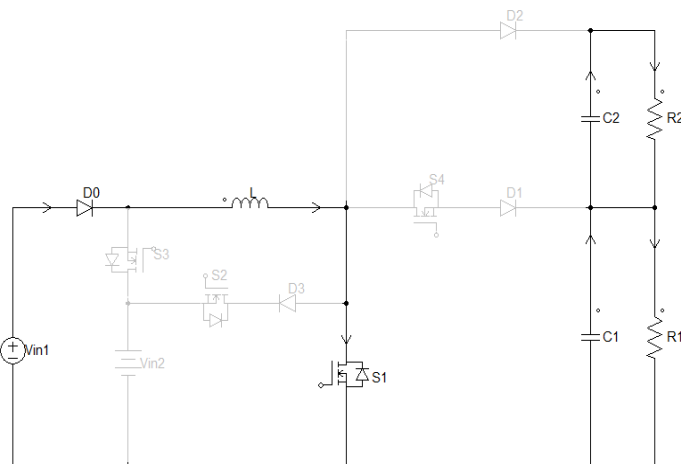


Fig. 7. Switching state 1 operation

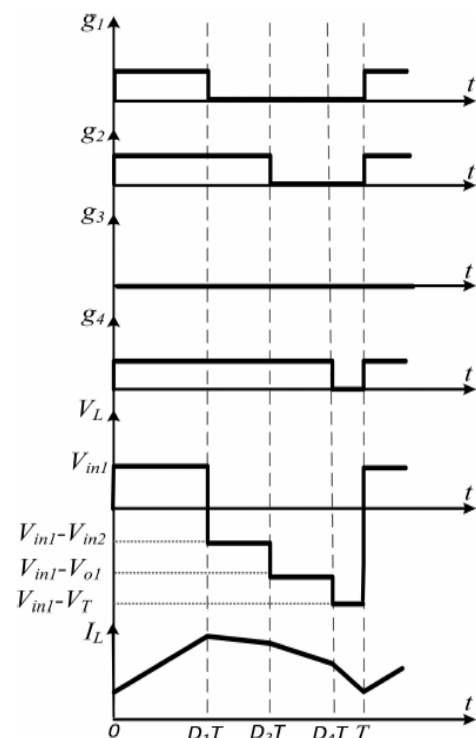
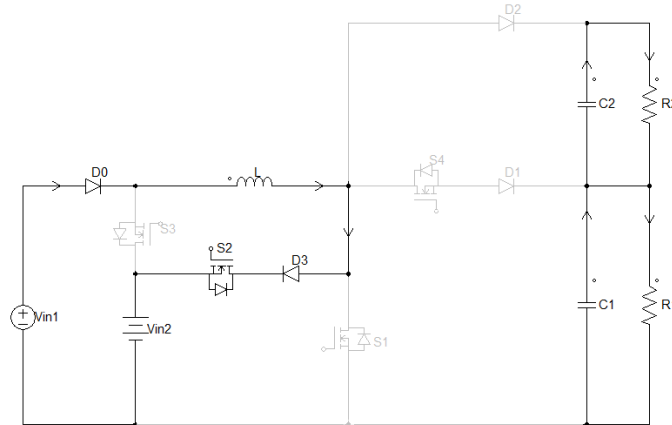
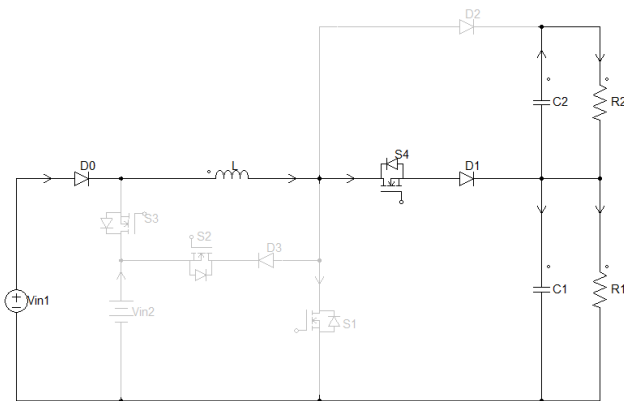
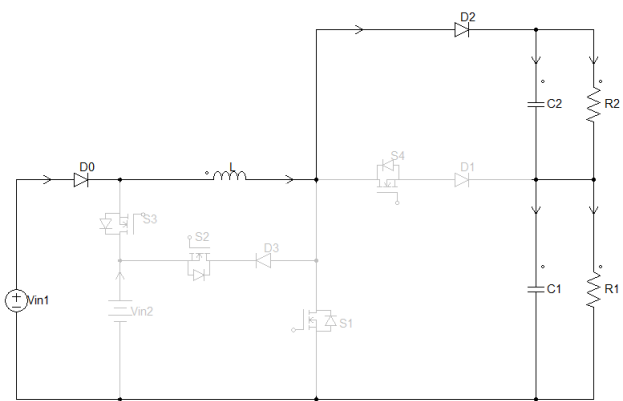


Fig. 8. Steady state waveforms in Battery charging mode

(b). Switching State 2 [$D_1T < t < D_2 T$]:

In this mode, switch S_1 is turned OFF and switch S_2 is turned ON. Diode D_1 and D_2 are reversely biased, consequently, S_4 is still OFF. Equivalent circuit of proposed converter in this state is shown in Fig. 9. Since $V_{in1} < V_{in2}$, therefore, in this period of time, inductor current decreases and inductor delivers its stored energy battery to battery (V_{in2}). Also capacitors C_1 and C_2 are discharged and deliver their stored energy to load resistances R_1 and R_2 respectively.

**Fig. 9. Switching state 2 operation****Fig. 10. Switching state 3 operation****Fig. 11. Switching state 4 operation****(c). Switching State 3 [$D_2T < t < D_4T$]:**

During this state, switch S_1 is still OFF and switch S_2 is turned OFF. Also, switch S_4 is turned ON. Diode D_2 is reversely biased. Equivalent circuit of proposed converter in this state is shown in Fig. 10. In this state, inductor L is discharged and delivers its stored energy to C_1 and R_1 , so inductor current is decreased. In this state, C_1 is charged and C_2 is discharged and delivers its stored energy to load resistance R_2 .

(d). Switching State 4 [$D_4T < t < T$]:

During this state, all of three switches are OFF. So, diode D_2 is forward biased. In this state, inductor L is discharged and delivers its stored energy to capacitors C_1 , C_2 , and load resistances R_1 and R_2 . Also, in this mode, capacitors C_1 and C_2 are charged. Equivalent circuit of proposed converter in this state is shown in Fig. 11.

III. SIMULATION MODEL AND RESULTS

In order to verify the operation principle and the theoretical analysis, converter is simulated with MATLAB/SIMULINK simulation software and the simulation parameters are listed in TABLE.1. All switches using in simulation are ideal switches. Switching frequency f_s is taken as 10kHz. The converter can operate both in battery discharging and charging modes.

TABLE 1: Simulation parameters

Input voltage V_{in1} , V_{in2}	3 V, 8 V
Output voltage V_{o1} , V_{o2}	3.9V, 8.5V
inductance L	2.5 mH
capacitance C_1 , C_2	1000 μ F
Load Resistances R_1 , R_2	100 Ω

A. Simulink Model:

Simulink model of a dual input dual output DC-DC Boost converter with PID controller is shown in fig.12. MOSFET's are used as switches. Output voltage and output currents are analyzed from the simulation results.

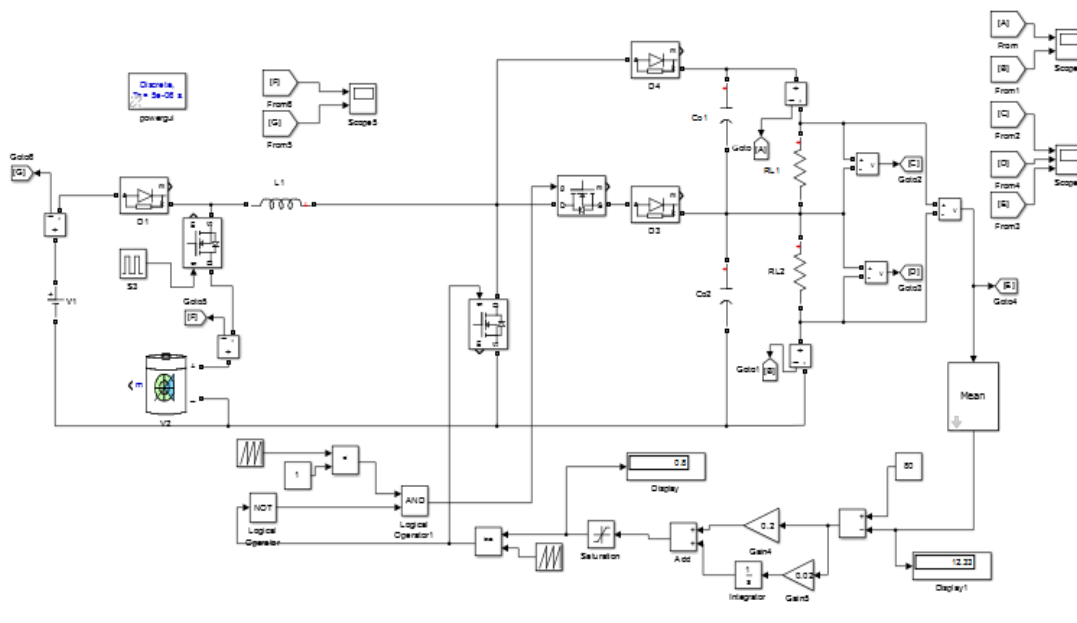


Fig. 12. Simulink model

B. Simulation Results:

Fig. 13(a, b) shows the simulation results at the input voltages $V_{in1} = 3$ V and V_{in2} (Battery) = 8 V . output voltages thus obtained are $V_{O1} = 3.9$ V and $V_{O2} = 8.5$ V . Total Voltage $V_T = 12.4$ V

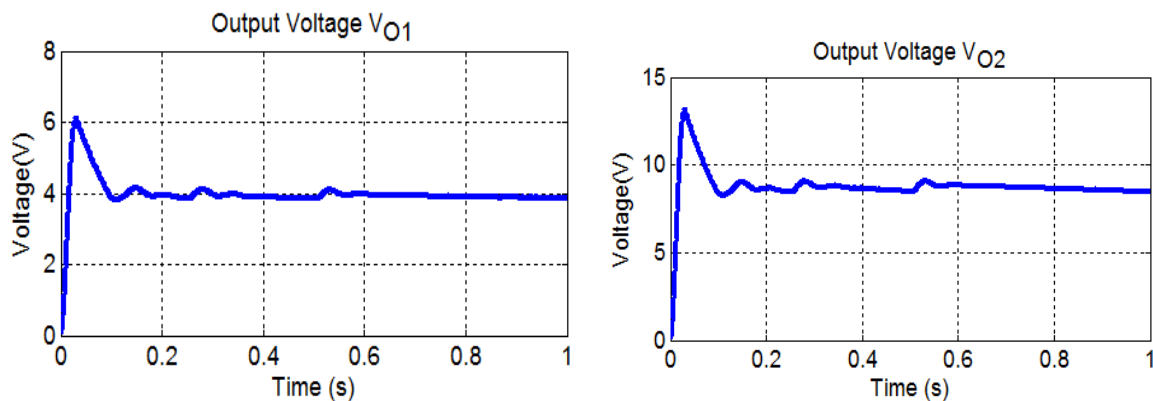


Fig.13. Output voltages (a) V_{O1} (b) V_{O2}

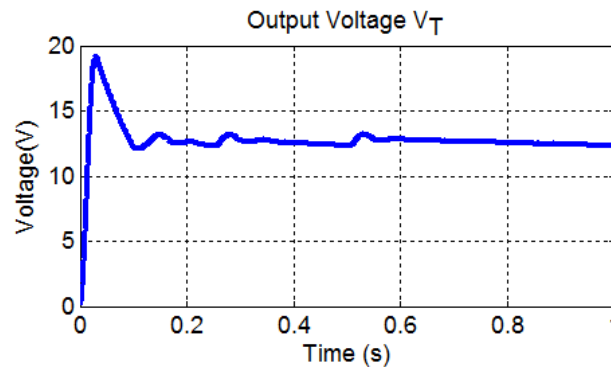


Fig. 14. Total Output voltage (V_T)

As shown in fig. 15 and fig. 16, the output currents obtained for 100Ω loads are $I_{O1} = .039$ A and $I_{O2} = .085$ A.

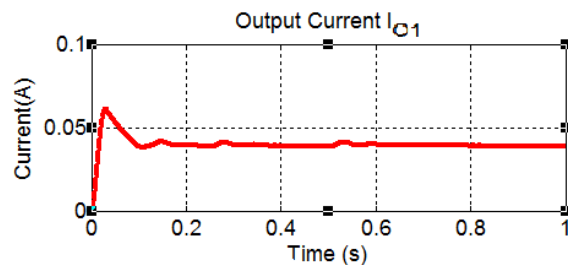


Fig. 15. Output Current (I_{O1})

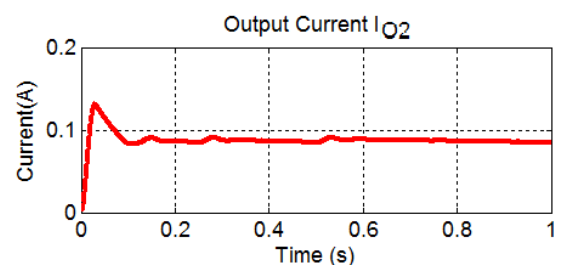


Fig. 16. Output Current (I_{O2})

IV. CONCLUSIONS

A new dual input dual output dc - dc boost converter with unified structure for hybridizing of power sources in electric vehicles is presented in this paper. The presented converter has just one inductor. This can be used for transferring energy between different energy resources such as FC, PV, and ESSs like battery and SC. In this paper, FC and battery are considered as power source and ESS, respectively. The converter has two main operation modes in which battery discharging mode both of input sources deliver power to output and in battery charging mode one of the input sources not only supplies loads but also delivers power to the other source (battery). It is seen that under various conditions such as rapid rise of the loads power and sudden change of the battery reference current, output voltages and battery current are regulated to desired values with PID controller. Outputs with different dc voltage levels are appropriate for connection to multilevel inverters. In electric vehicles, using of multilevel inverters leads to torque ripple reduction of induction motors. Also, electric vehicles which use dc motors have at least two different dc voltage levels, one for ventilation system and cabin lightening and other for supplying electric motor. Simulation results verify the operation principle of this converter.

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