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IMPLEMENTATION OF A MULTI PORT DIRECT DC-DC CONVERTER

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***Abstract*— Multiple-Port dc-dc converter have been identified as a cost-effective approach for energy harvesting and dispatching. This converter is applicable in hybridizing alternative energy sources, and thus the advantages of different sources are achievable. 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. Using of a multilevel inverter leads to reduction of voltage harmonics .The input energy sources consist of primary source (fuel cell) and energy storage system (battery), is built with nonisolated MIMO dc-dc boost converter to produce two different output voltages from a single converter module. The converter module avoids the use of huge transformer, and reduces the number of switching elements since existing system consist of large number of switching elements and its operation which makes the system costly and complex . By proper switching of the converter, charge and discharge of battery by means of input sources is possible. It connects different voltage levels of energy sources with different voltage dependent loads like electrical vehicles, multilevel inverter etc., The proposed system is validated through different simulation results. The proposed circuit is designed and analysed using MATLAB simulink.**

***Index Terms*—Avoids costly and complex systems, dc – dc boost converter, different voltage dependent loads, Hybrid, MIMO, Multi-port.**

INTRODUCTION

Increase in energy consumption due to population growth and necessities, and the depletion of fossil fuels are important reasons for using looking for an alternative sources of energy. Utilization of renewable energy sources on user premises has attracted a significant interest for many commercial and industrial applications owing to their merits of non-pollution and rich reserves. Due to the intermittent nature of renewable energy, storage and standby sources are usually required to function as backup. A hybrid power system may lower environmental impacts and improve security of supply. Besides, a simultaneous combination of sources is available for optimal energy/economic dispatch. At the same time, many loads and appliances used in offices, commercial facilities and residential buildings often dictate the need of power supply with different gains. Thus, the need of technology for distributing power to a variety of consumption loads whose voltage levels are different motivates the development of supply structure with multiple voltages.

Many distributed energy resources include but are not limited to solar panels and fuel cells generate DC voltages, and a growing number of consumption loads and appliances are using DC, e.g. data centers, portable devices, LED lights, etc. Thus, DC distribution systems are envisioned to interact with different energy sources, modern electronic loads and storage units for simplicity and efficiency The fuel cell (FC) stack usually used as clean energy source. The FCs are energy sources that directly convert the chemical energy reaction into the electrical energy. Currently, FCs are acknowledged as one of the promising technologies to meet the future energy generation requirements. FCs generate electric energy, rather than storing it, and continue to deliver the energy, as long as the fuel supply is maintained. However, there are some well-known technical limitations to FCs: they have slow power transfer rate in transitory situations, and a high cost per watt. This case is the reason for which FCs are not used alone in many applications like the Electrical Vehicles to satisfy the load demands, particularly during startup and transient events. So, in order to solve these problems, usually FC is used with energy storage systems (ESSs) such as batteries or supercapacitor (SC). Furthermore, the association of FC and ESSs leads to a reduction of the hydrogen consumption of the FC. FC and ESSs such as battery and SC have different voltage levels. So, to provide a specific voltage level for load and control power flow between input sources, using of a dc—dc converter for each of the input sources is need. Usage of a dc—dc converter for each of the input sources leads to increase of price, mass, and losses. Consequently, in hybrid power systems, multiinput dc—dc converters have been used. Multiinput converters have two main types, isolated multiinput dc—dc converters and non-isolated multiinput dc—dc converters.

In isolated multiinput dc—dc converters, high-frequency transformer is used in order to make electric isolation. High-frequency transformer provides electric isolation and impedance matching between two sides of converter. In general, isolated dc—dc converters use leakage inductance as energy storage for transferring power between two sides of converter. Usually isolated dc—dc converters, in addition to high-frequency transformer, have high-frequency inverter and rectifier. The power flow between input and output sides is controlled by adjusting the phase shift angle between primary and secondary voltages of transformer . Due to using of transformer, isolated dc—dc converters are heavy and massive. These converters require inverters in input sides of transformer for conversion of input dc voltage to ac and also need rectifiers in outputs of transformer for conversion of ac voltage to dc. Therefore, in all input and output terminals of these converters, several switches are applied which leads to increase of cost and losses. Furthermore, transformer has losses in its core and windings. Because of the aforementioned drawbacks of isolated multi-input dc—dc converters, usage of non-isolated multiinput dc—dc converters in most of the domestic applications seems more useful.

In [12], a nonisolated multiinput dc—dc converter which is derived from H-bridge structure has been proposed. In fact, by cascading two H-bridge with different dc-link voltages, different voltages due to addition or subtraction of H-bridges outputs are accessible. Modes in which either output voltage of the H-bridges is negative are not considered here because they are related to bidirectional double-input converters, which were beyond the scope of paper. By eliminating the aforementioned nonuseful modes. a simplified double input dc—dc converter is obtained. The advantage of this converter is its less number of passive elements and switches, and its drawback is unsuitable control on the power which is drawn from input sources. In [13]—[15], a multi-input dc—dc buck converter is introduced. In fact, this converter consists of paralleling two buck converter in their inputs. One switch is series to each input source to prevent short circuit of sources. The advantage of this converter is reducing the number of inductors and capacitors which lead to reduction in cost, volume, and weight of converter, Lack of proper power flow control between input sources with each other is a shortcoming of the proposed converter. In [16], multiinput z-source dc—dc converter is presented. The structure of proposed converter is changed such that the number of inductors and capacitors is equal to a single input z-source converter. Nevertheless, two inductor and capacitor is applied in the proposed converter.

In [17], multiphase converter is introduced. The proposed converter has four input by different voltages. In this converter, each of the energy sources can deliver or absorb energy from load and other sources. Employment of a separate inductor for each input source is the drawback of this converter. In [18], a triple input converter for hybridization of battery, photovoltaic cells, and fuel cell is introduced by the author. By proper switching of converter, charge and discharge of battery by means of other sources and load is possible, respectively. In [19], a systematic approach for derivation of nonisolated multiinput converter topologies by combination of buck, boost, cuk, and sepic is presented. According to this paper, mentioned converters are divided to two types, pulsating voltage source converters (PVSC) and pulsating current source converters (PCSC). Because PVSC is considered as a voltage source, it can put series with current buffer (inductor) branch or output of other converter to form a double input converter. Also, because PCSC is considered as a current source, it can be located in parallel with a voltage buffer (capacitor) branch or output of other converter to form a double input converter. In [20], a new converter for power and energy management between battery, SC, and electric motor in an electric vehicle is proposed. In this converter, instead of two separate inductors as energy storage element, a coupled inductor is used. It is claimed that utilization of coupled inductors lead to 22%-26% volume reduction in comparison with two separated inductors. However, volume of coupled inductors is more than one inductor. Also, regeneration of brake energy to battery and SC in this converter is possible. In [21], a multiinput converter with just one inductor is proposed which is able to distribute load power between input sources. Also, in this converter, transferring power between sources is possible.

One way to generate several dc-link is usage of multioutput dc—dc converters. In [23] and [24], a single inductor multioutput dc—dc converter is proposed which can generate several different voltage levels in its outputs. The converter is controlled to regulate the output voltages at their desired values despite the load power variation or input voltage variation. In [27], a new control method is proposed which is provided satisfactory dynamic performance for multioutput buck converter. But the shortcoming of these converters is their single input source. In other words, in applications such as electric vehicles that several input energy sources like fuel cell and battery are employed, this converter is not utilizable. One way to solve this problem is using of multiinput multioutput converters.

In [26] [27] and [28], a nonisolated multiinput multioutput converter is introduced which has just one inductor. Using of large number of switches is drawback of this converter which caused low efficiency. Impossibility of energy transferring between input sources is other disadvantage of the proposed converter.

In this paper, a new multiinput multioutput nonisolated converter based on combination of a multiinput and a multioutput converter is proposed. The proposed converter compared to similar cases has less number of elements. This converter can control power flow between sources with each other and load. Also, proposed converter has several outputs that each one can have different voltage level. This paper is organized as follows. The converter structure and operation modes are explained in Section II. Sections III and IV represents the simulations and experimental results, respectively, and Section V concludes this paper.

II. CONVERTER STRUCTURE AND OPERATION MODES

As mentioned in the Introduction, in [23], a multioutput converter is presented. The proposed converter is a single input converter. On the other hand, use of just one input energy source in electric vehicles cannot provide load requirements because the load is dynamic and its power has variation. Therfore, hybridization of different sources is essential. As mentioned in the Introduction, in [21], a nonisolated multiinput dc—dc converter for hybridization of energy sources is proposed which has just one inductor. In this paper, a nonisolated multiinput multioutput dc—dc converter based on the combination of these two converters is proposed.

A new multiinput multioutput nonisolated converter based on combination of a multiinput and a multioutput converter is proposed. The proposed converter compared to similar cases has less number of elements. This converter can control power flow between sources with each other and load. Also, proposed converter has several outputs that each one can have different voltage level.

A nonisolated multiinput dc—dc converter for hybridization of energy sources is proposed which has just one inductor. In this paper, a nonisolated multiinput multioutput dc—dc converter based on the combination of these two converters is proposed. The structure of the proposed converter is presented in Fig.1, As seen from the figure, the converter interfaces m input power sources $V_{in1}, V_{in2}, V_{in3}, \ldots, V_{inm}$ such that $V_{in1} < V_{in2} < V_{in3} \ldots < V_{inm}$. The proposed converter has just one inductor, n capacitors in its outputs and m + n-1 switches. The R1, R2, R3,…. Rn are the load resistances, which can represent the equivalent power feeding a multilevel inverter. By proper switching of switches, control of power flow between input sources in addition to boost up input sources voltages is possible. Outputs are capable to have different or equal voltage level which is appropriate for a connection to a multilevel inverter. The proposed converter is suitable alternative for hybridizing of FC, battery, or SC. In this paper, for convenience, the proposed converter with two-input two-output is analyzed. In Fig.2, the proposed converter with two-input two-output is shown. In this figure, R1 and R2 are the model of load resistances that can represent the equivalent power feeding a multilevel inverter. Different types of multilevel inverters can be used in connection to this converter. Multilevel inverter which is used must be with non floating de-links. Three power switches S1,S3, and S4 in the converter structure are the main controllable elements that control the power flow and low.-put voltages of the converter. In the proposed converter, source Vin1 can deliver power to source Vin2 but not vice versa. So, in EV applications, FC which cannot be charged is located where Vin1 is placed in circuit. Also, usually where Vin2 is placed, ESSs such as battery or SC which are chargeable are located.

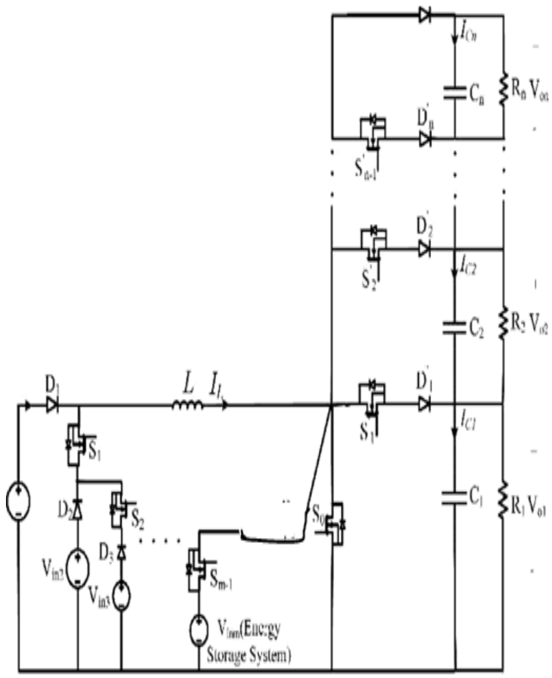


Fig.1:Proposed converter structure

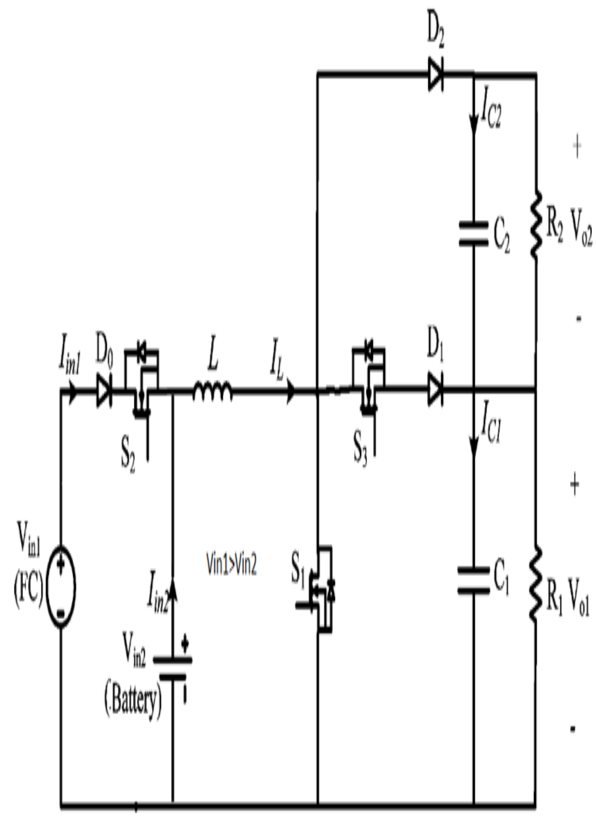


Fig.3 : Proposed converter with two-input, two-output.

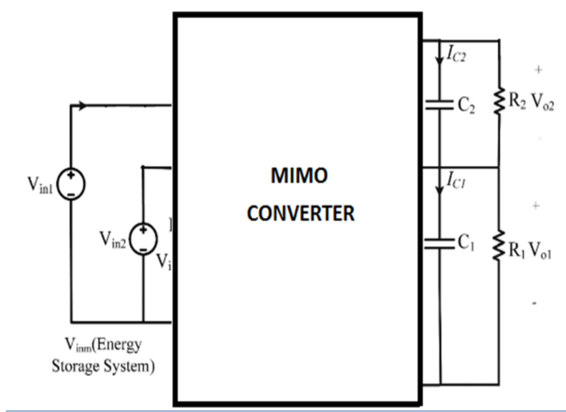


Fig.2; Block diagram

OPERATION PRINCIPLE

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 proposed converter. In each mode, just two of the three switches are active, while one switch is inactive. When load power is high, both input sources deliver power to load, in such a condition, all the switches S1, S3, and s4 are active. Also, when load power is low and Vin2 is needed to be charged, Vin1 not only supplies loads but also can charge Vin2. In this condition, switches S1, and S4 are active and S3 is inactive. In FCs, because of output voltage dependence to drawn current and also to make an exact power balance among the input powers and the load, ripple of drawn current should be minimized. in battery charging mode when the loads power and battery charging current have low values, it is possible that the converter works in discontinuous conduction mode (DCM). It should be noted that each of input sources can be used separately. In other words, the converter can work as a single input dc—dc. Two main operation modes of the converter have been investigated as follows:

A. First Operation Mode (Battery Discharging Mode)

In this operation mode, two input power sources vn1 and vn2 (battery) are responsible for supplying the loads. In this mode, S1, S3, and S4 are active. For each switch, a specific duty is considered. Here S1 is active to regulate source 2 (battery) current to desired value. In fact, S1 regulates battery current to desired value by controlling inductor current. Regulation of total output voltage VT = VO1 + V02 to desired value is duty of the switch S3. Also, output voltage Vo is controlled by S4. It is obvious that by regulation of VT and V01, the output voltage V02 is regulated too. Gate signals of switches and also voltage and current waveforms of inductor are shown in Fig. 4. According to switches states, there are four different operation modes in one switching period as follows:

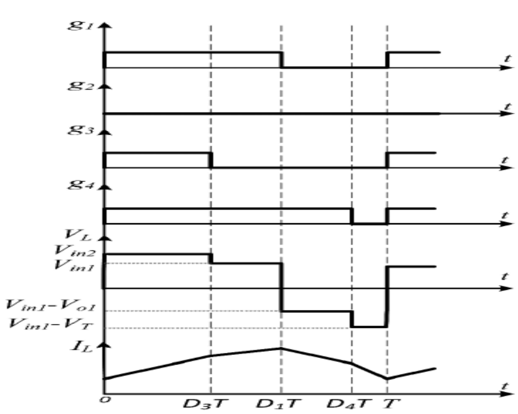


Fig.4: steady state waveforms of battery in discharging mode

1) Switching State 1 (0 < t < D3T): In this state, switches S1 and S3 are turned ON. Because S1 is ON, diodes D1 and D2 are reversely biased, so switch S4 is turned OFF. Since S3 is ON and Vin1 < Vin2, diode Do is reversely biased. Equivalent circuit of proposed converter in this state is shown in Fig. 5(a). In this state, Vin2 charges inductor L, so inductor current increases. Also, in this mode, capacitors C1 and C2 are discharged and deliver their stored energy to load resistances R1 and R2 , respectively.

The inductor and capacitors equations in this mode are as follows:

$$\begin{cases} L\dfrac{di_L}{dt} = v_{\text{in}2} \\ C_1\dfrac{dv_{O1}}{dt} = -\dfrac{v_{O1}}{R_1} \\ C_2\dfrac{dv_{O2}}{dt} = -\dfrac{v_{O2}}{R_2} \end{cases}$$

2) Switching State 2 (D3 T < t < Dl T): In this state, switch S1 is still ON and S3 is turned OFF. Because S1 is ON, diodes D1 and D2 is reversely biased, so switch S4 is still OFF. Equivalent circuit of proposed converter in this state is shown in Fig. 5(b). In this state, Vin1 charges inductor L, so inductor current increases. In addition, capacitors Cl and C2 are discharged and deliver their stored energy to load resistances R1 and R2 respectively. The inductor and capacitors equations in this mode are as follows:

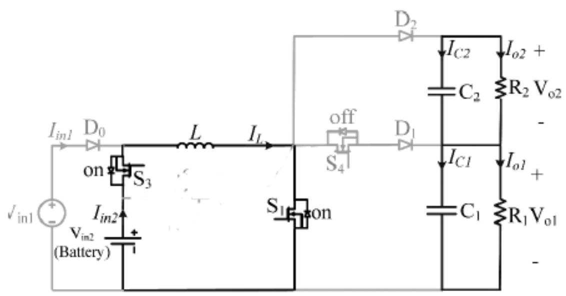
$$\begin{cases} L\dfrac{di_L}{dt} = v_{\text{in}1} \\ C_1\dfrac{dv_{O1}}{dt} = -\dfrac{v_{O1}}{R_1} \\ C_2\dfrac{dv_{O2}}{dt} = -\dfrac{v_{O2}}{R_2}. \end{cases}$$

3) Switching State 3 (D1T < t < D4T): In this mode, switch Si is turned OFF and switch S3 is still OFF. Also, switch S4 is turned ON. Diode D2 is reversely biased. Equivalent circuit of proposed converter in this state is shown in Fig. 5(c). In this state, inductor L is discharged and delivers its stored energy to C1 and R1, so inductor current is decreased. In this state, Cl is charged and C2 is discharged and delivers its stored energy to load resistance R2 . The energy storage elements L, and C2 equations in this mode are as follows:

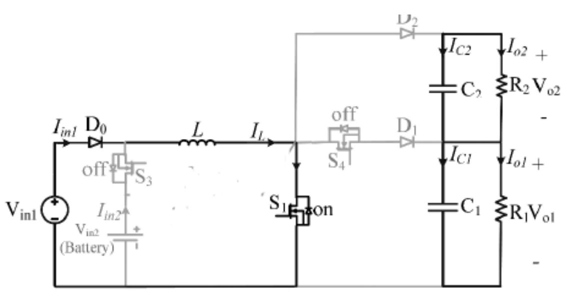
$$\begin{cases} L\dfrac{di_L}{dt} = v_{in1} - v_{O1} \\ C_1\dfrac{dv_{O1}}{dt} = i_L - \dfrac{v_{O1}}{R_1} \\ C_2\dfrac{dv_{O2}}{dt} = -\dfrac{v_{O2}}{R_2}. \end{cases}$$

4) Switching State 4 (D4T < t < T): In this mode, all of three switches are OFF. So, diode D2 is forward biased. In this state, inductor L is discharged and delivers its stored energy to capacitors Cl , C2 , and load resistances R1 and R2 . Also, in this mode, capacitors C1 and C2 are charged. Equivalent circuit of proposed converter in this state is shown in Fig. 5(d). The inductor and capacitors equations in this mode are as follows:

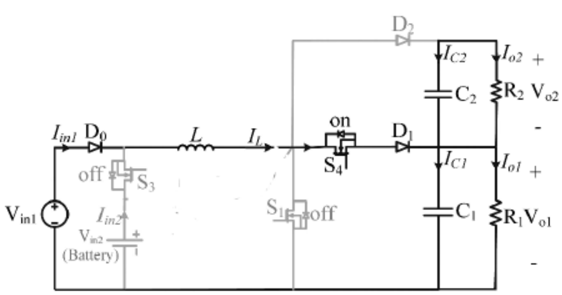
$$\begin{cases} L\dfrac{di_L}{dt} = v_{\text{in}1} - (v_{O1} + v_{O2}) \\ C_1\dfrac{dv_{O1}}{dt} = i_L - \dfrac{v_{O1}}{R_1} \\ C_2\dfrac{dv_{O2}}{dt} = i_L - \dfrac{v_{O2}}{R_2}. \end{cases}$$



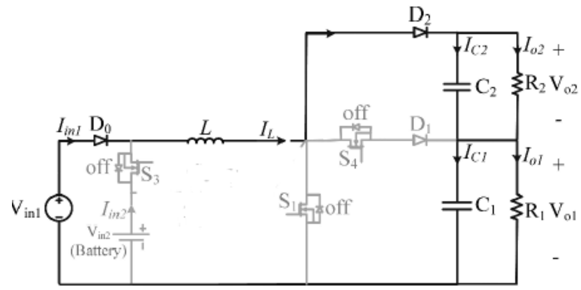
(a)



(b)



(c)



(d)

Fig.5. Equivalent circuit of battery discharging mode, (a) switching state 1, (b) switching state 2, (c) switching state 3, (d) switching state 4.

B. Second Operation Mode (Battery Charging Mode)

In this mode, Vin1 not only supplies loads but also delivers power to Vin2 (battery). This condition occurs when load power is low and battery requires to be charged. In this operation mode, switches S1 and S4 are active and switch S3 is entirely OFF. Like previous operation mode of the converter in this mode, for each switch, a specific duty is considered. S1 is switched to regulate total output voltage VT = V01 + V02 to desired value. Output voltage V01 is controlled by switch S4 . It is clear that by regulation of VT and V01, the output voltage V02 is regulated too. In Fig.6, 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:

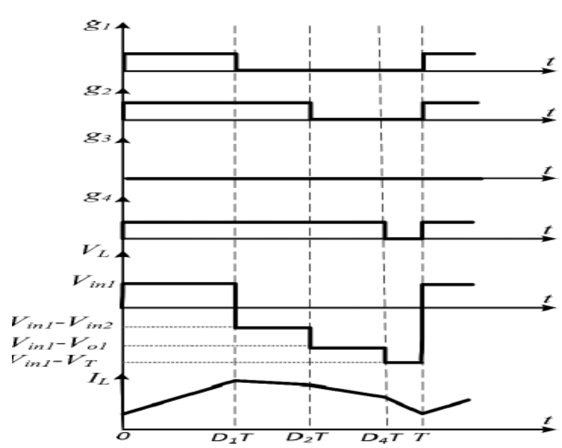


Fig.6. Steady-state waveforms of proposed converter in battery charging mode

1) Switching State 1 (0 < t < D1 T): In this state, switch S1 is turned ON, so S4 is reverse biased and cannot be turned ON. Also, diode D2 is reversely biased and does not conduct. Equivalent circuit of proposed converter in this state is shown in Fig. 7(a). In this state, Vinl charges inductor L, so inductor current is increased. Also, in this mode, capacitors C1 and C2 are discharged and deliver their stored energy to load resistances R1 and R2 respectively. The inductor and capacitors equations in this mode are as follows:

$$\begin{cases} L\dfrac{di_L}{dt} = v_{\mathbf{in1}} \\ C_1\dfrac{dv_{O1}}{dt} = -\dfrac{v_{O1}}{R_1} \\ C_2\dfrac{dv_{O2}}{dt} = -\dfrac{v_{O2}}{R_2} \end{cases}$$

2) Switching State 2 (D1 T < t < D2 T): In this mode, switch S1 is turned OFF . Diode D1 and D2 are reversely biased, consequently, S4 is still OFF. Equivalent circuit of proposed converter in this state is shown in Fig.7(b). Since Vn1 < - therefore, in this period of time, inductor current decreases and inductor delivers its stored energy to battery (Vin2). Also, in this mode, capacitors C1 and C2 are discharged and deliver their stored energy to load resistances R1 and R2 respectively. The inductor and capacitors equations:

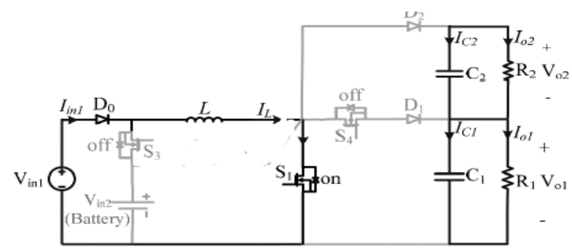
$$\begin{cases} L\dfrac{di_L}{dt} = v_{\mathbf{in1}} - v_{\mathbf{in2}} \\ C_1\dfrac{dv_{O1}}{dt} = -\dfrac{v_{O1}}{R_1} \\ C_2\dfrac{dv_{O2}}{dt} = -\dfrac{v_{O2}}{R_2} \end{cases}$$

3) Switching State 3 (D2T < t < D4T): In this mode, switch S1 is still OFF and switch S4 is turned ON. Also, diode D2 is reversely biased. In Fig.7(c), equivalent circuit of proposed converter in this state is shown. In this state, inductor L is discharged and delivers its stored energy to C1 and R1, so inductor current is decreased. In this state, capacitors Cl is charged and capacitor C2 is discharged and delivers its stored energy to load resistance R2. The energy storage elements L, and C2 equations in this mode are as follow.

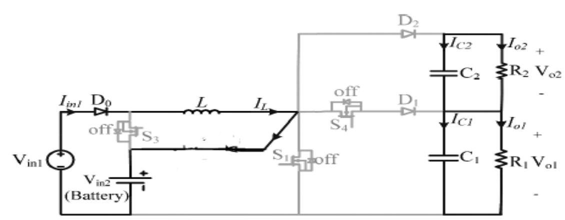
$$\begin{cases} L\dfrac{di_L}{dt} = v_{\mathbf{in1}} - v_{O1} \\ C_1\dfrac{dv_{O1}}{dt} = i_L - \dfrac{v_{O1}}{R_1} \\ C_2\dfrac{dv_{O2}}{dt} = -\dfrac{v_{O2}}{R_2} \end{cases}$$

4) Switching State 4 (D4 T < t < T): In this mode, all the three switches are OFF. Therefore, diode D2 is forward biased. In Fig.7(d), an equivalent circuit of the proposed converter in this state is shown. In this state, inductor L is discharged and delivers its stored energy to capacitors C1 , C2 , and load resistances and R2. Also, in this mode, capacitors and C2 are charged. The inductor and capacitors equations in this mode are as follows:

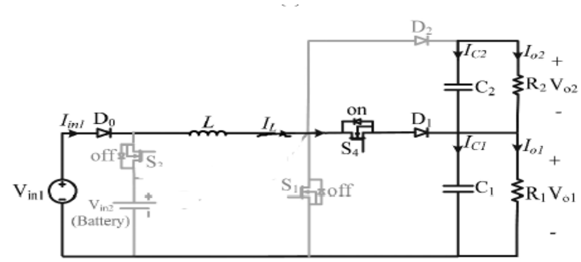
$$\begin{cases} L\dfrac{di_L}{dt} = v_{\mathbf{in1}} - (v_{O1} + v_{O2}) \\ C_1\dfrac{dv_{O1}}{dt} = i_L - \dfrac{v_{O1}}{R_1} \\ C_2\dfrac{dv_{O2}}{dt} = i_L - \dfrac{v_{O2}}{R_2} \end{cases}$$



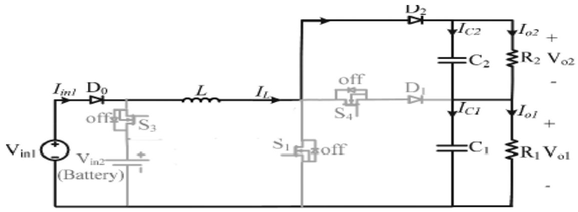
(a)



(b)



(c)



(d)

Fig.7. Battery charging mode, (a) switching state 1, (b) switching state 2, (c) switching state 3, (d) switching state 4

Thus, the operation of the proposed converter can be explained. It can be used as multiinput multioutput converter or even as single input multioutput inverter which can be applicable for various operations.

V. SIMULATION RESULTS

In order to verify the performance of the proposed converter, simulations have been done in battery discharging and charging modes by MATLAB/SIMULINK software.

Charging mode-
Output voltages, Currents

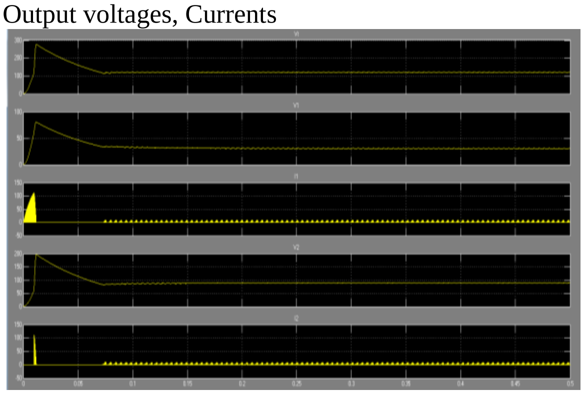


Fig 8 (a)simulation result of proposed converter in charging mode : output

Input currents

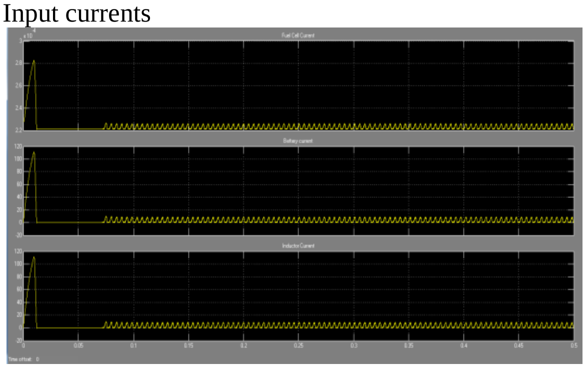


Fig.8(b)simulation result of proposed converter in charging mode : input

Discharge mode:
Output voltages, Currents

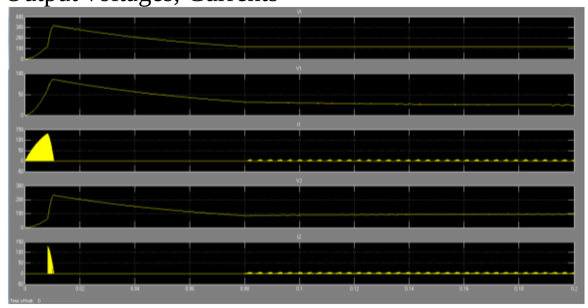


Fig.8 (c)simulation result of proposed converter in dischaging mode : output

Input currents

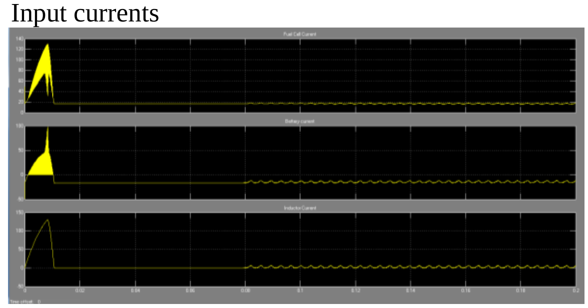


Fig.8 (d)simulation result of proposed converter in dischaging mode : input

VI. EXPERIMENTAL RESULTS

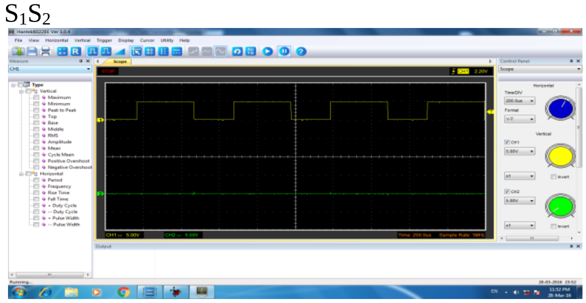
In order to verify the effectiveness of the proposed converter, a low power range laboratory prototype was built. Two different input power sources utilized. We are using a rectifier of 18 V and a battery of 12V as input. Output has been boosted upto 48V which can be fed a two different outputs of 20V and 28V. The experimental setup is examined in two different operation modes of converter. The experimental results for battery discharging and charging modes are shown below.

V_b= 12V ; V_{solar} =18 V,

V_{o1}=20 V ; V_{o2}=28 V

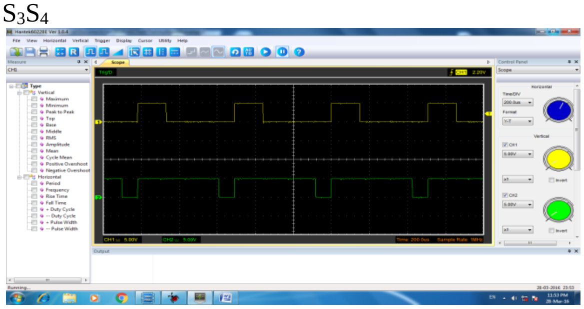
Discharging mode

S_1S_2



S_2S_3

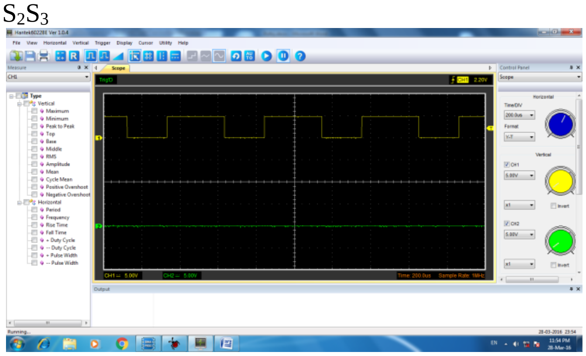
S_3S_4



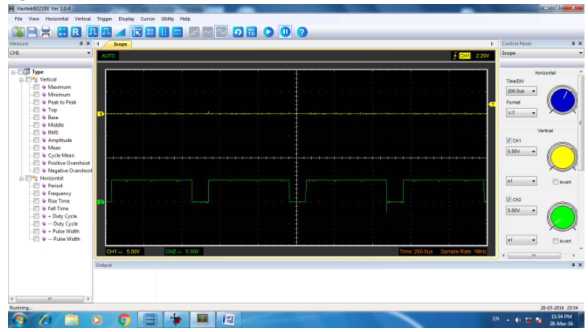
Charging

S_1S_2

S_2S_3



S_3S_4



VI. CONCLUSION

A new multiport dc-dc boost converter with unified structure for hybridizing of power sources such as electric vehicles etc is proposed in this paper. The proposed converter has just one inductor. The proposed converter 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. Also, the converter can be utilized as single input multi-output converter. It is possible to have several outputs with different voltage levels. The converter has two main operation modes which in 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 suddenly change of the battery reference current, output voltages and battery current are regulated to desired values. Outputs with different dc voltage levels are appropriate for connection to multilevel inverters. Moreover, in grid connection of renewable energy resources like PV, using of multilevel inverters is useful. Finally, operation of this converter was verified using simulation low-power range prototype.

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