Step-Up Multi-input DC–DC Converter for Hybrid Electric Vehicles Application

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Abstract *- A multi input bidirectional DC-DC converter (MIBC) is proposed to integrate various DC sources with different voltage levels with bidirectional power flow capability. The structure of multi input bidirectional DC-DC converter simpler to design compare with single input converters. The FC is considered as the main power supply, and roof-top PV is employed to charge the battery, increase the efficiency, and reduce fuel economy. The converter has the capability of providing the demanded power by load in absence of one or two resources. The voltage from the photo voltaic(PV) cells is fed to the cuk converter to step up the voltage before feeding to inverter providing the power to propulsion of three phase induction motor. The multi input bidirectional converter can deal with ultra-capacitor and battery individually or simultaneously with proper control mechanism. The proposed circuit is validated through the simulation results presented in the paper.*

Keywords *- Hybrid Electric Vehicle, DC-DC Converter, ultra-capacitor etc.*

I. INTRODUCTION

Due to increasing diligence on energy crisis and environmental protection, the Hybrid Electric Vehicles (HEVS) are received lot of attention in recent years. Petroleum is used world-wide at a higher rate due to the wider requirement of transport. It plays a major role in modelling the vehicles with minimum and without consumption of petroleum. And therefore the alternate propulsion technologies have been increasingly engaged by the automobile industries and this hassled to the increased exploitation rate of HEV. One of the main advantages for the HEV drive is to improve the efficiency of the motor drive. The key components of the traction systems in hybrid electric vehicles are the multi input bidirectional DC-DC converters. Multi input bidirectional converters have combine the different sources, such as batteries, ultra capacitor, photovoltaic cells, fuel cells, and other renewable energy sources, with different voltage characteristics. The designs characteristic of the induction motor are used in HEV, the overview of HEV are discussed. By applying suitable starting frequency and voltage for the inverter fed induction motor low starting current and high starting torque can be obtained (7). Using high frequency transformer to connect different sources, where each source is connected by full-bridge cells using 12 switches for three sources(8). A current fed half-bridge topology has been proposed in [9] to reduce the ripple current in the battery using phase shift modulation. The stability analyses of multiple input isolated buck–boost and forward converters along have been presented in [10]. In these types of converters, power sharing between various sources is difficult to control. In this topology, it is not possible to transfer energy directly between dc sources, and also, a higher number of devices are being used. In this paper a new type of multi input bidirectional DC-DC converter will be proposed in order to integrate various energy sources. The proposed circuit will be analyzed, modelled, designed, controlled, and simulated.

II. CONVERTER TOPOLOGY

The structure of the three-input dc–dc boost converter is depicted in figure. The converter is formed of two conventional boost converters, substituting extra capacitor in one of the converters, and a battery to store the energy. Characteristic of the converter is suitable for hybrid systems. In this paper, behavior of the converter in terms of managing the sources is analyzed in power management and control part. Then, V_{PV} and V_{FC} are two independent power sources that output is based on characteristic of them. L1 and L2 are the inductances of input filters of PV panel and fuel cell. Using L1 and L2 as in series with input sources change PV and

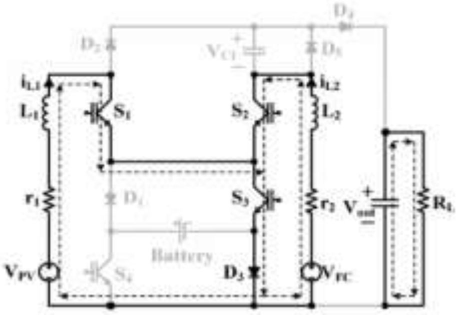
FC modules to current sources. r_1 and r_2 are V_{PV}'S and V_{FC} 'S equivalent resistance, respectively. R Load is the equivalent resistance of loads connected to the dc bus. S1, S2, S3, and S4 are power switches. Diodes D1, D2, D3, and D4 are used to establish modes, which will be described. Capacitor C1 is used to increase output gain and output capacitor, Co is performed as an output voltage filter. Operation of the converter is divided into three states:

- The load is supplied by PV and FC and battery is not used.
- The load is supplied by PV, FC, and battery, in this state, battery is in discharging mode.
- The load is supplied by PV and FC and battery is in charging mode.

a) First Operation State (the Load is supplied by PV and FC While Battery is Not Used):
In this state, there are three operation modes. During this state, the system is operating without battery charging or discharging. Therefore, there are two paths for current to flow (through S3 and D3 or D1 and S4). Also S3 and D3 is considered as common path. However, D1 and S4 could be chosen as an alternative path. During this state, switch S3 is permanently ON and switch S4 is OFF.

- Mode 1: ($0< t <d_1T$): In this interval, switches S_1, S_2, S_3, and diode D_3 are turned ON. Inductors L1 and L2 are charged via power sources V_{PV} and V_{FC} , respectively
- Mode 2: ($d_1T < t < d_2T$): In this interval, switch S_1 is turned OFF and D_2 is turned ON and S_2, S_3, and D_3 are still ON. Inductor L_2 is still charged and inductor L1 is being discharged via VPC − VFC

- Mode 3: ($d_2T < t < T$): In this interval, S_1 is turned ON and S_2 is turned OFF and S_3 and D_3 are still ON. Inductor L_1 is charged with V_{PV} and inductor L_2 is discharged via V_{PV} + V_{C1} – Vo



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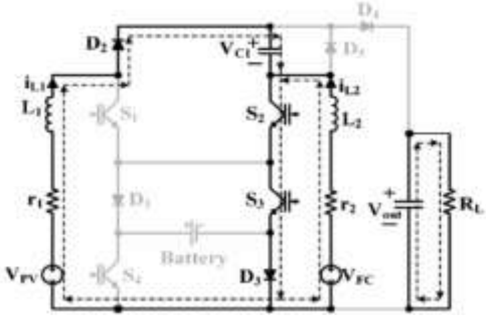

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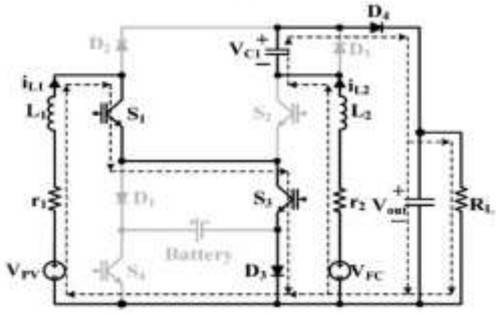

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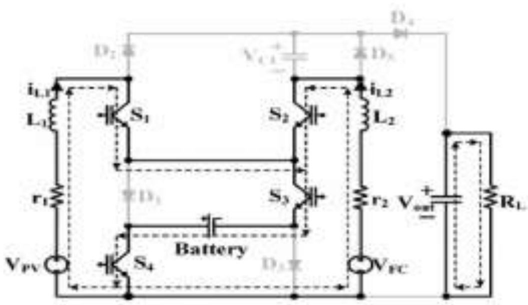
Fig.1 - Current-flow path of operating modes in first operating state. (a) Mode 1. (b) Mode 2. (c) Mode 3.

b) Second Operation State (the Load is Supplied by PV, FC, and Battery)
In this state, there are four operation modes. During this state, the load is supplied by all input sources (PV, FC, and battery). In first mode, there is only one current path. However, in other three modes, there are two current paths (through S3 and D3 or D1 and S4).

In this state, current flows through D1 and S4 . Switch S4 is permanently ON during this state.

- Mode 1: ($0 < t < d_1T$): In this interval, S_1, S_2, S_3 , and S_4 are turned ON. Inductors L1 and L2 are charged by V_{PV} + $V_{Battery}$ and V_{FC} + $V_{Battery}$, respectively



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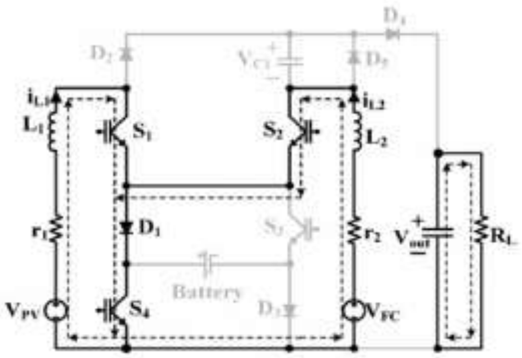

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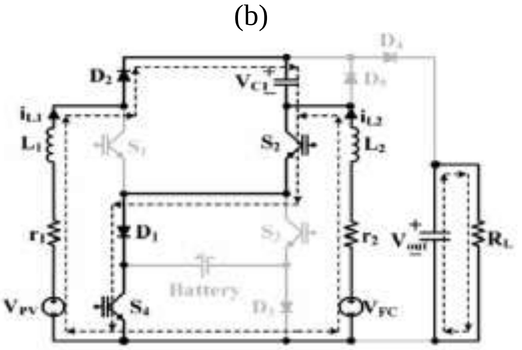

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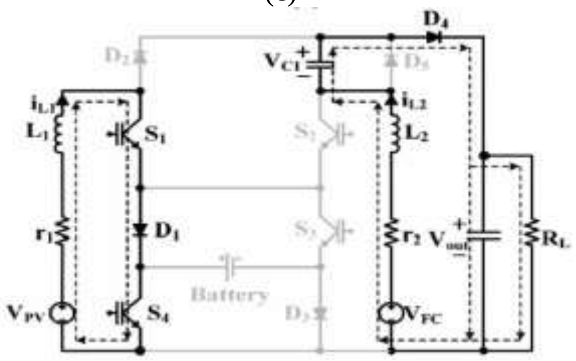

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Fig.2- Current-flow paths in operation modes of second state: (a) Mode 1. (b) Mode 2. (c) Mode 3. (d) Mode 4.

- Mode 2: ($d_1T < t < d_2T$): In this interval, S1, S2, S4 , and D1 are turned ON. Inductors L1 and L2 are charged by V_{PV} and V_{FC} ,
- Mode 3: ($d_2 T < t < d_3T$): In this interval, S2, S_4,D_1, and D_2 are turned ON. Inductor L1 is discharged to capacitor C1 and L2 is charged by V_{FC}.
- Mode 4: (d3T < t < d4T): In this interval, S1, S4,D1, and D4 are turned ON. Inductor L1 is charged by V_{PV} and inductor L2 discharges C1 to the output capacitor

c) Third Operation State (the Load is supplied by PV and FC While Battery is in Charging Mode)

In this state, there are four modes. During this state, PV and FC charges the battery and supply the energy of load. In the first- and second-operation modes, there are two possible current paths through S3 and D3 or D1 and S4). The path D1 and S4 is chosen to flow the current in this state. During this state, switch S3 is permanently OFF and diode D1 conducts.

- Mode 1: ($0 < t < d_1T$): In this interval, S1, S2, S4 and D1 are turned ON. Inductors L1 and L2 are charged by V_{PV} and V_{FC}, respectively].
- Mode 2: ($d_1T < t < d_2T$): In this interval, S2, S4, and D1 are turned ON. Inductor L1 is discharged to capacitor C1 and inductor L2 is charged by V_{FC}
- Mode 3: ($d_2 T < t < d_3T$): In this interval, S1, S2,D1, and D3 are turned ON. Inductors L1 and L2 are charged by $V_{PV} - V_{Battery}$ and $V_{FC} - V_{Battery}$, respectively
- Mode 4: ($d_3 T < t < d_4T$): In this interval, S1, S4, D1, and D4 are turned ON. Inductor L1 is charged by $V_{PV} - V_{Battery}$ and inductor L2 is discharged by $V_{FC} - V_{C1} - Vo$

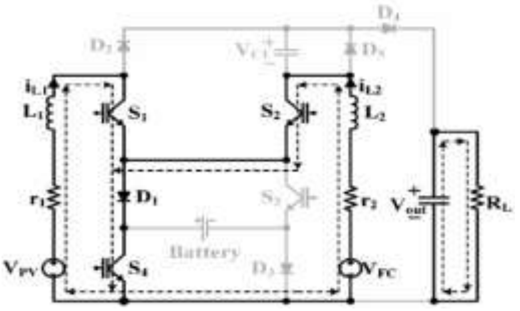
To fulfil switching operation, a saw-tooth wave as a carrier is compared with signals d1, d2, d3 , and d4 , which can independently control on state of power switches. Without considering output voltage utilized power of each sources PV, FC, and battery can be controlled using d1, d2, d3 , and d4 signals.

d) The power management procedure is as follows:

- Control signals, acceleration, and brake, identify the command power.
- In case command power is less than maximum PV power and battery energy level is less than minimum energy level, PV work at MPP and extra energy will be stored in battery. If command power is less than maximum PV power but battery energy level is more than minimum energy level, PV will generate the command power and the battery remains off. In both conditions, FC is off.
- If command power is more than maximum PV power, PV panel will operate in MPP and new command power will be defined as:

$$P_{new\ command} = P_{command} - P_{PV}$$

- New command power is compared with FC's rated power. Given that the new command power is greater than rated power of FC, the FC will works at its rated power and battery will provide the rest of demanded power.



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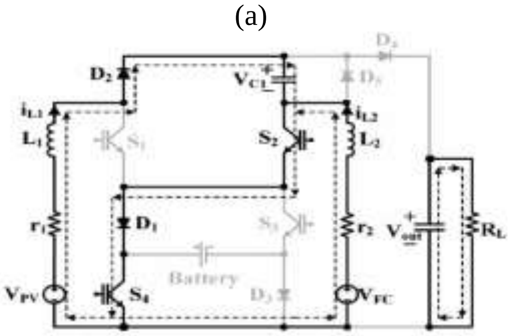

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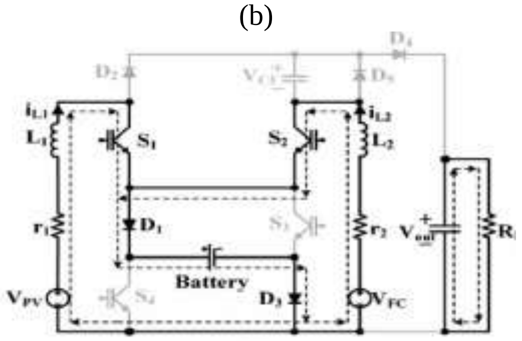

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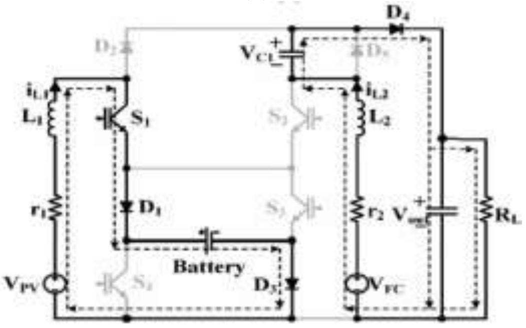

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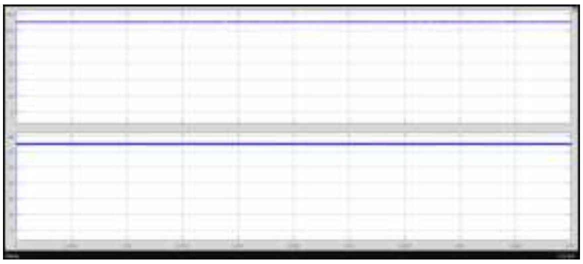
Fig.3 - Current-flow path of operating modes in third operating state. (a) Mode 1. (b) Mode 2. (c) Mode 3. (d) Mode 4.

SIMULATION STUDY

In order to verify the performance of the converter, an 80-W prototype version of the circuit is built and tested in MATLAB at Switching frequency is considered about 30 KHz. Power sources are mainly PV arrays, fuel cells, etc. Ignoring the transient time of the power sources, they could be replaced by dc power supplies to obtain experimental results. Both of the input sources are set on 20 V. A 12-V 7-Ah battery is used as an energy storage element. Due to high switching frequency, ferrite cores are chosen for the both inductors. The value of the inductor L1 is 550(μH) and the inductor L2 is 650 μH. Capacitors utilized in the converter are 470 μF. Considering 20 V for each input-source voltage properly boosted to about 110 V. Inductors current, diodes and power switches current are shown in figure below' In the experimental results of first operation mode, the inductor currents are about 2 A. The currents of diode D1 and switch S4 are zero while diode D3 and switch S3 are always on which cause the voltage across them to be about zero. The other components are being switched with the frequency of 30 kHz.



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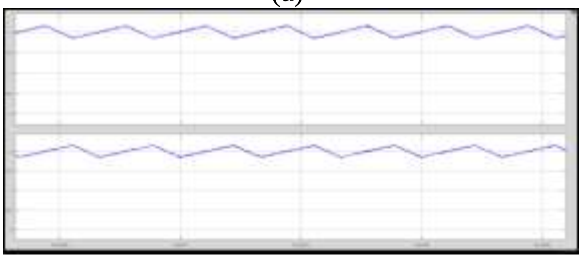

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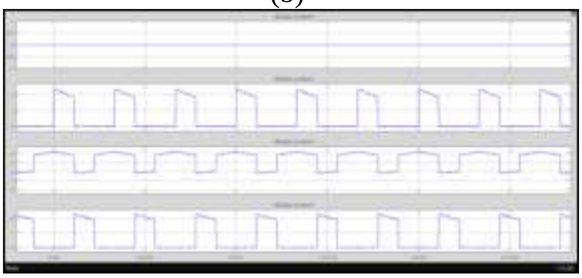

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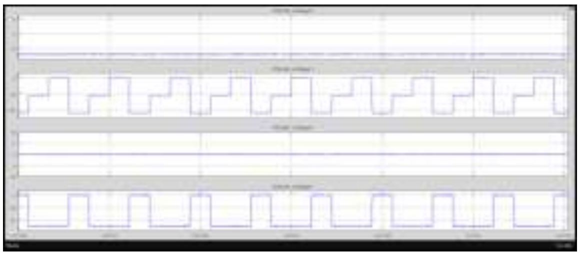

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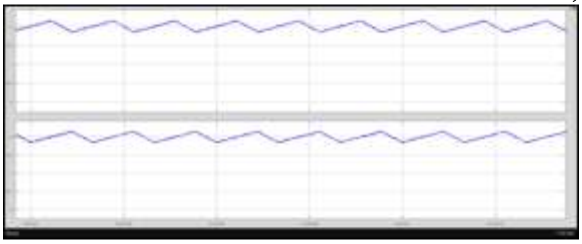
Fig.4 - Results of the first operation state.

Second state's operation results are shows in fig below. The output and capacitor C1 's voltage. Inductors L1 and L2 current also illustrated;



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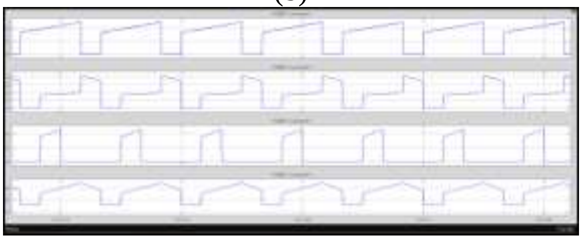

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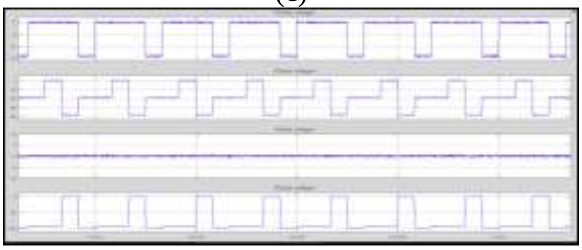

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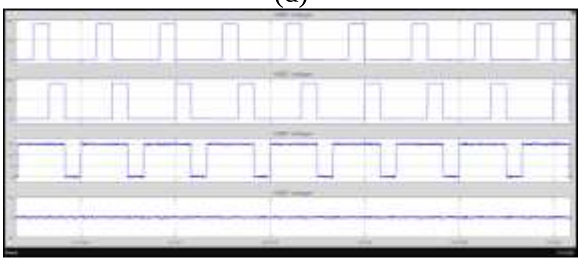

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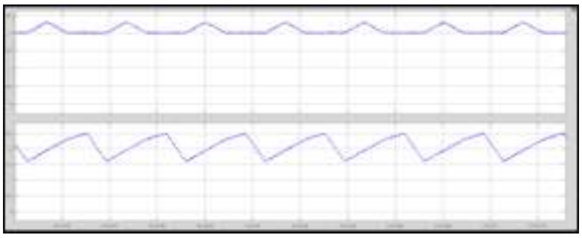
Fig.5 - Results of the second operation state.

In this operation mode, the inductor currents are about 2 A with a ripple of 1 A. Besides, the battery is discharged by the current of 3 A flows through it. In this operation mode, all switches are being switched and just diode D3 is always OFF. This caused the efficiency of the converter in this mode to be less than the others.



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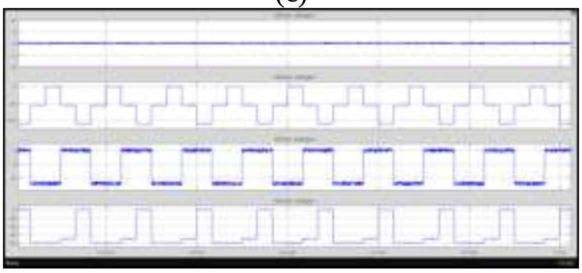

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Fig.6 - Results of the third operation state.

Third state's experimental results are shown in Fig. Voltage of capacitor C1 and output voltage, inductor currents of the proposed converter is shown. Current of diodes and power switches is below. In this operation mode, the inductor currents are about 2 A too. The battery is charged in this mode. Despite discharging mode, the current flows through the battery has three amounts, 0, 5, and 2 A. Switch S3 is OFF in this mode and the voltage across it is always equals to V_{Bat} .

CONCLUSION

The converter efficiency in first operation state is more than the others. The least efficiency of the proposed converter is about 85% which occur in discharging mode. Because the switches used in this mode are more than the others. Therefore, the switching loss in this mode is more than other modes. In this experiment, in the first state, output desired voltage is considered to be about 120 V and PV desired current is about 2 A. As mentioned, in this state, battery's power is zero. In the second part of the experiment, PV's reference current increases.

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