

# Multi Input Multi Output Using Non Isolated DC-DC Boost Converter

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**ABSTRACT:** A new non isolated multi input multi output DC-DC boost converter is proposed using single magnetic field storage component (L). The proposed converter can be used for transferring energy between different energy resources such as FC, PV and ESS. In this paper, fuel cell 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 operation modes are defined for the converter based on charging and discharging states of the battery. The converter module has an advantage of using minimum number of power electronic components. It is suitable for electric vehicle applications. The validity of the proposed MIMO converter is verified with both computer simulation using software (MATLAB/ Simulink) and laboratory based prototype verified the results.

**KEYWORDS:** DC-DC converter, Boost converter, Fuel cell, Energy storage system (ESS), Electric vehicle, Multi Input Multi Output, state-space averaging.

## I. INTRODUCTION

Now a day's, renewable energy is increasingly valued and employed because of energy shortage and environmental contamination. High step up dc-dc converters are widely employed in many renewable energy applications including fuel cell, wind power, photovoltaic system etc. [1]. Energy sources like PV, and wind turbine systems are intermittent and unpredictable; therefore they are not highly reliable. In order to address this issue, renewable resources are either combined with each other or fuel cell and ESS (battery) [2]. Fuel cells are widely recognized as one of the most promising technologies to meet the future power generation requirements. The fuel cell and battery have different voltage levels, so to provide a specific voltage level for load and control power flow between input sources, using of dc-dc converter is needed.

An important point to remember about all dc-dc converters is like a transformer, they essentially change the input energy into different impedance level. So, whatever the output voltage level, the output power all comes from the input; there's no energy manufactured inside the converter [3]. Now a days, these converters provide simple circuit topologies, centralized control, high reliability, low manufacturing cost, and size [4]. The multiport converter topologies can be classified into two categories: non isolated and isolated topologies. Several bidirectional topologies, such as full-bridge [5] and half-bridge [6] topologies have been proposed. These two topologies utilize many switches with complicated drive and control circuits [7]. Non isolated multiport converters are usually used in electric vehicle based applications where it is more suitable to satisfy the required load demand rather than isolated topology, where it suffers from high frequency transformer losses. In [8] a single inductor multi output dc-dc converter is proposed which can generate several different voltage levels in its outputs, this converter is controlled to regulate the output voltages at their desired values despite the load power variation or input voltage variation. From various studies mentioned above, this paper proposes, a new non isolated multi input multi output dc-dc boost converter. Compared with the converter in [9] using four controllable switches, the proposed converter only use three controllable switches. This converter can control power flow between sources with each other and load. This paper is organized as follows. The converter structure and

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operation modes are explained in section II. The state space modeling of the proposed converter is given in section III. Section IV represents the simulation results, section V represents experimental results and section VI concludes this paper.

## II. PROPOSED MULTI INPUT MULTI OUTPUT (MIMO)

In this paper, a new non isolated multi input multi output dc-dc boost converter based on the combination of two input sources is proposed. The structure of the proposed converter is presented in fig.1. As seen from fig.1 the converter interfaces two input power sources  $V_{in1}$  and  $V_{in2}$ .

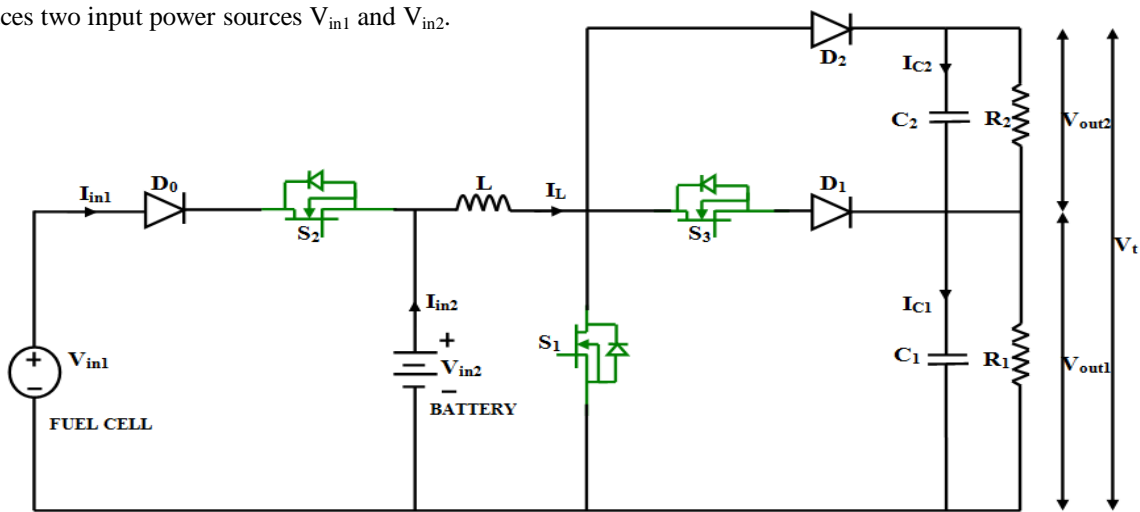


Fig.1 Proposed converter structure.

The outputs from this proposed converter are capable to have different or equal output voltage magnitudes which can also be used for connecting to a multilevel inverter. The proposed converter has two input sources such as a generating power source FC and energy storage system (battery) combination. The input source  $V_{in1}$  can deliver power to the source  $V_{in2}$  not vice versa. In this system, FC which cannot be charged is located in  $V_{in1}$ , also in  $V_{in2}$  such as ESS can be charged is placed. Depending on the utilization state of the battery, two power operation modes are defined for the proposed converter, which are the charging and discharging modes of operation which has been investigated as follows.

### DIFFERENT OPERATING MODES OF MIMO

#### A. BATTERY CHARGING MODE

In this mode of operation,  $V_{in1}$  not only supply to the load but also delivers power to  $V_{in2}$ . This condition occurs when load power is low and battery requires to be charged. For each switch, a specific duty is considered. Three independent duty ratios of the converter facilitate power flow among input sources and the load.  $S_1$  is switched to regulate the total output voltage  $V_t = V_{out1} + V_{out2}$  to a desired value. It is clear that by regulation of  $V_t$  and  $V_{out1}$  the output voltage  $V_{out2}$  is regulated too. According to different switching states, three different operation modes in one switching period is given as follows;

#### 1. SWITCHING STATE 1 ( $0 < T < DT_1$ )

In this state, switch  $S_1$  and  $S_2$  is 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, so inductor current increases. Equivalent circuit of proposed converter for this state is shown in fig. (2). Also in this mode, capacitors  $C_1$  and  $C_2$  gets discharged and deliver their stored energy to load resistance  $R_1$  and  $R_2$ . The inductor and capacitors equations in this mode are as follows;

$$L \frac{di_L}{dt} = V_{in1}$$

$$C_1 \frac{dv_{out1}}{dt} = -\frac{V_{out1}}{R_1} \quad (1)$$

$$C_2 \frac{dv_{out2}}{dt} = -\frac{V_{out2}}{R_2}$$

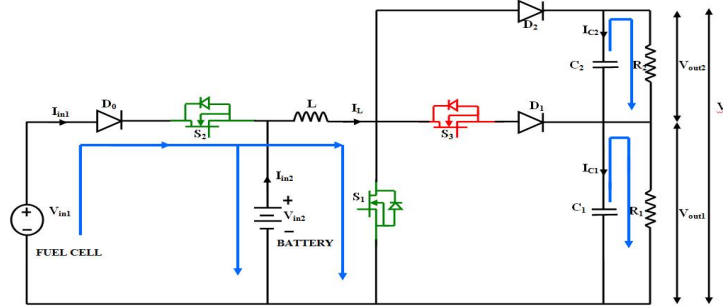


Fig.2. Equivalent circuit for switching state 1.

**2. SWITCHING STATE 2 ( $D_{T1} < t < D_{T2}$ )**

In this state, switch  $S_1$  is OFF, and switch  $S_2$  and  $S_3$  is turned ON. The diode  $D_2$  is reverse biased and does not conduct. For this state, inductor  $L$  is discharged and delivers its stored energy to  $C_1$  and  $R_1$ , so inductor current decreases. Equivalent circuit of proposed converter for this state is shown in fig. (3). Also in this mode capacitor  $C_1$  is charged and capacitor  $C_2$  is discharged and deliver their stored energy to load resistance  $R_2$ .

$$L \frac{di_L}{dt} = V_{in1} - V_{out1}$$

$$C_1 \frac{dv_{out1}}{dt} = i_L - \frac{V_{out1}}{R_1}$$

$$C_2 \frac{dv_{out2}}{dt} = -\frac{V_{out2}}{R_2}$$

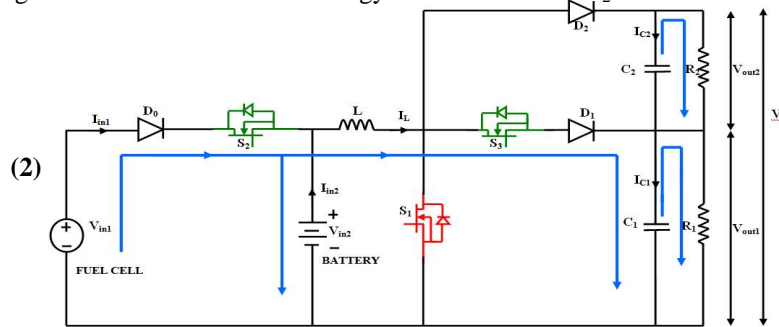


Fig.3 Equivalent circuit for switching state 2.

**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 (4). 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;

$$L \frac{di_L}{dt} = V_{in1} - V_t$$

$$C_1 \frac{dv_{out1}}{dt} = i_L - \frac{V_{out1}}{R_1}$$

$$C_2 \frac{dv_{out2}}{dt} = i_L - \frac{V_{out2}}{R_2}$$

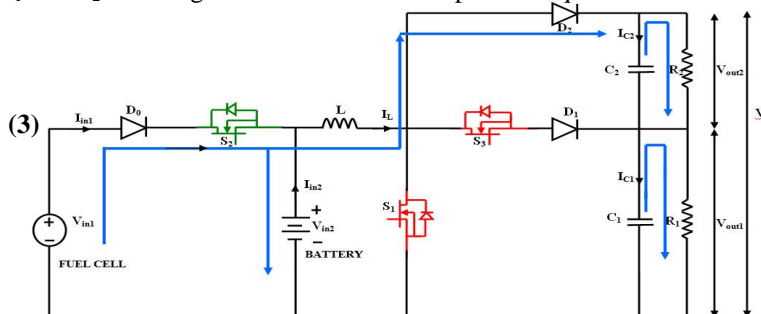


Fig.4. Equivalent circuit for switching state 3.

**B. 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.

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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. The total output voltage  $V_t$  is regulated as  $V_t = V_{out1} + V_{out2}$ .

### 1. SWITCHING STATE 1 ( $0 < T < D_{T1}$ )

In this state, switch  $S_1$  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  $V_{in2}$  charges inductor  $L$ , so inductor current 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 equation for this mode are as follows;

$$L \frac{di_L}{dt} = V_{in2}$$

$$C_1 \frac{dv_{out1}}{dt} = -\frac{V_{out1}}{R_1}$$

$$C_2 \frac{dv_{out2}}{dt} = -\frac{V_{out2}}{R_2}$$

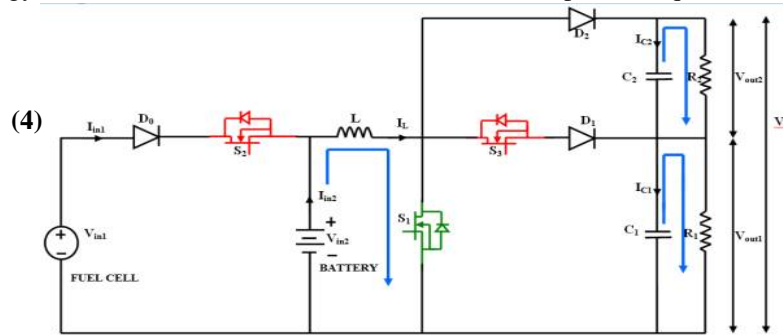


Fig.5 Equivalent circuit for switching state 1.

### 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.

$$L \frac{di_L}{dt} = V_{in1} - V_t$$

$$C_1 \frac{dv_{out1}}{dt} = i_L - \frac{V_{out1}}{R_1}$$

$$C_2 \frac{dv_{out2}}{dt} = i_L - \frac{V_{out2}}{R_2}$$

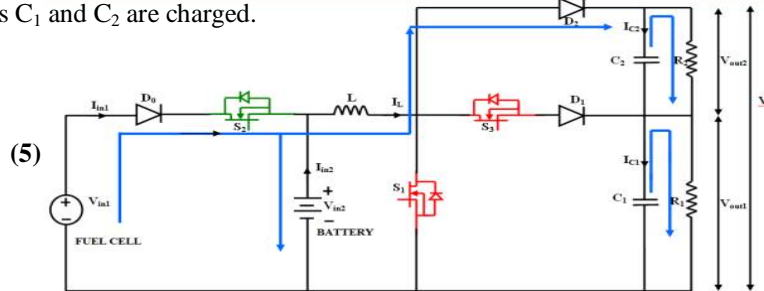


Fig.6 Equivalent circuit for switching state 2.

### 3. SWITCHING STATE 3 ( $D_{T2}, D_{T3} < t < T$ )

In this state, switch  $S_1$  and  $S_2$  is 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  $R_2$ .

$$L \frac{di_L}{dt} = V_{in2} - V_{out1}$$

$$C_1 \frac{dv_{out1}}{dt} = i_L - \frac{V_{out1}}{R_1}$$

$$C_2 \frac{dv_{out2}}{dt} = -\frac{V_{out2}}{R_2}$$

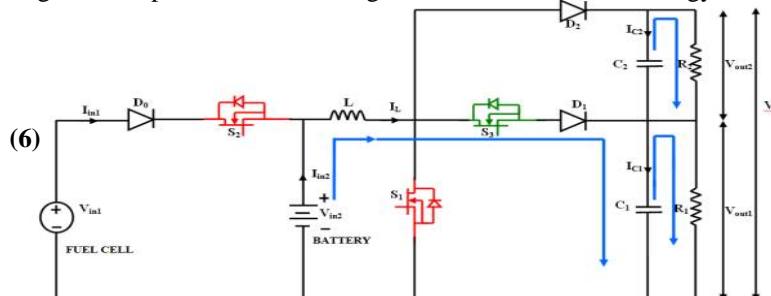


Fig.7 Equivalent circuit for switching state 3

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### III. STATE SPACE MODELING

The state space model is the mathematical model that provides a dynamic model of a physical system, including switching converters by a set of first-order differential equations. Using this state space average model of DC–DC converter, one can obtain the small signal model and transfer function of DC–DC converters, which will be very useful in the design of closed-loop controller using various control techniques. In this paper, the converter module has three controllable switches  $S_1$ ,  $S_2$  and  $S_3$ . For each switch, a specific duty will be considered. A different state space average model's is obtained for both charging and discharging modes of operation.

#### 1. THE MATHEMATICAL MODEL FOR BATTERY CHARGING MODE:

The state space averaged model performs the following equations;

$$\begin{aligned} \dot{X} &= AX + BU \\ Y &= CX + DU \end{aligned} \quad (7)$$

Based on small-signal modeling method [10], the state variables, duty ratios, and input voltages contain two components, dc values ( $X, D, V$ ) and perturbations ( $\hat{x}, \hat{d}, \hat{v}$ ). It is assumed that the perturbations are small and do not vary significantly during one switching period. So, there are following equations for the proposed converter;

$$\begin{aligned} \Delta \hat{i}_L &= I_L + \Delta \hat{i}_L \\ \Delta v_{out1} &= V_{out1} + \Delta \hat{v}_{out1} \\ \Delta v_{out2} &= V_{out2} + \Delta \hat{v}_{out2} \\ \Delta d_1 &= D_1 + \Delta \hat{d}_1 \\ \Delta d_2 &= D_2 + \Delta \hat{d}_2 \\ \Delta d_3 &= D_3 + \Delta \hat{d}_3 \end{aligned} \quad (8)$$

In this operation mode of proposed converter,  $V_{in1}$  delivers energy to loads and  $V_{in2}$ . The inductor current  $\Delta \hat{i}_L$ , capacitor voltages  $\Delta V_{out1}$  and  $\Delta V_{out2}$  are state variables. If we substitute (8) into (1)–(3), apply the averaging to three state equations multiplied with corresponding duty cycle value, and then, neglect second-order terms, we obtain small-signal equations that are demonstrated as follows;

$$\begin{aligned} L \frac{d\Delta \hat{i}_L}{dt} &= \Delta \hat{v}_{in1} + V_{in1} \cdot \Delta \hat{d}_3 + D_3 \cdot \Delta \hat{v}_{in1} + V_{out1} \cdot \Delta \hat{d}_1 + V_{out2} \cdot \Delta \hat{d}_2 + (D_1 - 1) \cdot \Delta \hat{v}_{out1} \\ &\quad - (1 - D_2) \cdot \hat{v}_{out2} \\ C_1 \frac{d\Delta \hat{v}_{out1}}{dt} &= -I_L \Delta \hat{d}_1 + (1 - D_1) \Delta \hat{i}_L - \frac{\Delta \hat{v}_{out1}}{R_1} \\ C_2 \frac{d\Delta \hat{v}_{out2}}{dt} &= -I_L \Delta \hat{d}_2 + (1 - D_2) \Delta \hat{i}_L - \frac{\Delta \hat{v}_{out2}}{R_1} \end{aligned} \quad (9)$$

Where  $X$  is a matrix containing the state variables,  $U$  is a matrix containing the control inputs  $\Delta \hat{d}_1$ ,  $\Delta \hat{d}_2$  and  $\Delta \hat{d}_3$ ,  $Y$  is a matrix containing the system outputs  $\Delta V_{out1}$ ,  $\Delta V_t$ ,  $\Delta i_b$  So, matrixes  $X, Y, U$  takes the following form:

$$X = \begin{bmatrix} \Delta \hat{i}_L \\ \Delta \hat{v}_{out1} \\ \Delta \hat{v}_{out2} \end{bmatrix}, Y = \begin{bmatrix} \Delta \hat{v}_{out1} \\ \Delta \hat{v}_t \\ \Delta \hat{i}_b \end{bmatrix}, U = \begin{bmatrix} \Delta \hat{d}_2 \\ \Delta \hat{d}_3 \\ \Delta \hat{d}_1 \end{bmatrix} \quad (10)$$

Filling matrices  $A, B, C$  and  $D$  using (9) and state equations (7), gives the following result;

$$A = \begin{bmatrix} 0 & \frac{(D_1-1)}{L} & \frac{(D_2-1)}{L} \\ \frac{(1-D_1)}{C_1} & -\frac{1}{R_1 C_1} & 0 \\ \frac{(1-D_2)}{C_2} & 0 & -\frac{1}{R_2 C_2} \end{bmatrix}, B = \begin{bmatrix} \frac{V_{in1}}{L} & \frac{V_{out1}}{L} & \frac{V_{out2}}{L} \\ 0 & -\frac{I_L}{C_1} & 0 \\ 0 & 0 & -\frac{I_L}{C_2} \end{bmatrix}, C = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 1 \\ D_1 - D_3 & 0 & 0 \end{bmatrix}, D = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ -I_L & I_L & 0 \end{bmatrix} \quad (11)$$

## 2. THE MATHEMATICAL MODEL FOR BATTERY DISCHARGING MODE:

In this mode of operation, both  $V_{in1}$  and  $V_{in2}$  are responsible for supplying the load. Like battery charging mode, first small signal model should be obtained by substituting (8) into (4)–(6), apply the averaging to four state equations multiplied with corresponding duty cycle value, and then, neglect second-order terms, we obtain small-signal equations that are demonstrated as follows;

$$L \frac{d\Delta\hat{i}_L}{dt} = V_{in2}\Delta\hat{d}_1 + D_1\Delta\hat{v}_{in2} - (1-D_3)\Delta\hat{v}_{out1} + (D_2-1)\Delta\hat{v}_{out2} + V_{out1}\Delta\hat{d}_3 + V_{out2}\Delta\hat{d}_2 \quad (12)$$

$$C_1 \frac{d\Delta\hat{v}_{out1}}{dt} = -I_L\Delta\hat{d}_3 + (1-D_3)\Delta\hat{i}_L - \frac{\Delta\hat{v}_{out1}}{R_1}$$

$$C_2 \frac{d\Delta\hat{v}_{out2}}{dt} = -I_L\Delta\hat{d}_2 + (1-D_2)\Delta\hat{i}_L - \frac{\Delta\hat{v}_{out2}}{R_1}$$

Here,

$$X = \begin{bmatrix} \Delta\hat{i}_L \\ \Delta\hat{v}_{out1} \\ \Delta\hat{v}_{out2} \end{bmatrix}, Y = \begin{bmatrix} \Delta\hat{v}_{out1} \\ \Delta\hat{v}_t \\ \Delta\hat{i}_b \end{bmatrix}, U = \begin{bmatrix} \Delta\hat{d}_2 \\ \Delta\hat{d}_3 \\ \Delta\hat{d}_1 \end{bmatrix} \quad (13)$$

Like previous mode of operation, matrices A,B,C and D is given as;

$$A = \begin{bmatrix} 0 & \frac{(1-D_3)}{L} & \frac{(D_2-1)}{L} \\ \frac{(1-D_3)}{C_1} & -\frac{1}{R_1 C_1} & 0 \\ \frac{(1-D_2)}{C_2} & 0 & -\frac{1}{R_2 C_2} \end{bmatrix}, B = \begin{bmatrix} \frac{V_{out2}}{L} & \frac{V_{out1}}{L} & \frac{V_{in2}}{L} \\ 0 & -\frac{I_L}{C_1} & 0 \\ -\frac{I_L}{C_2} & 0 & 0 \end{bmatrix}, C = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 1 \\ D_1 & 0 & 0 \end{bmatrix}, D = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & I_L & 0 \end{bmatrix} \quad (14)$$

## IV. SIMULATION RESULTS

Simulations are done for both charging and discharging modes of battery, 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 PI controller act as an error minimizer, 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  $V_{out1} = 30$  V and  $V_{out2} = 10$ V respectively. So the total output voltage  $V_t$  is regulated as  $V_t = V_{out1} + V_{out2}$ , therefore  $V_t = 40$  V. Fig.(8) shows,(a) the total output voltage  $V_t$ , (b) the output voltage  $V_{out1}$  (c) the output voltage  $V_{out2}$  (d) shows, the simulation results for battery charging mode current (e) shows, the simulation results for battery discharging current (f) shows, the voltage across the switch.

S.NO	VALUES	PARAMETERS
1.	3.3 mH	Inductance (L)
2.	220 $\mu$ F	Capacitors( $C_1, C_2$ )
3.	10 kHz	Switching frequency ( $f_s$ )
4.	18 V	Input voltage ( $V_{in1}$ )
5.	12 V, 1.2 Ah	Input voltage( $V_{in2}$ ) $V_{battery}$
6.	70 $\Omega$	Resistance( $R_1, R_2$ )

Table1. The simulation parameters for the proposed converter.

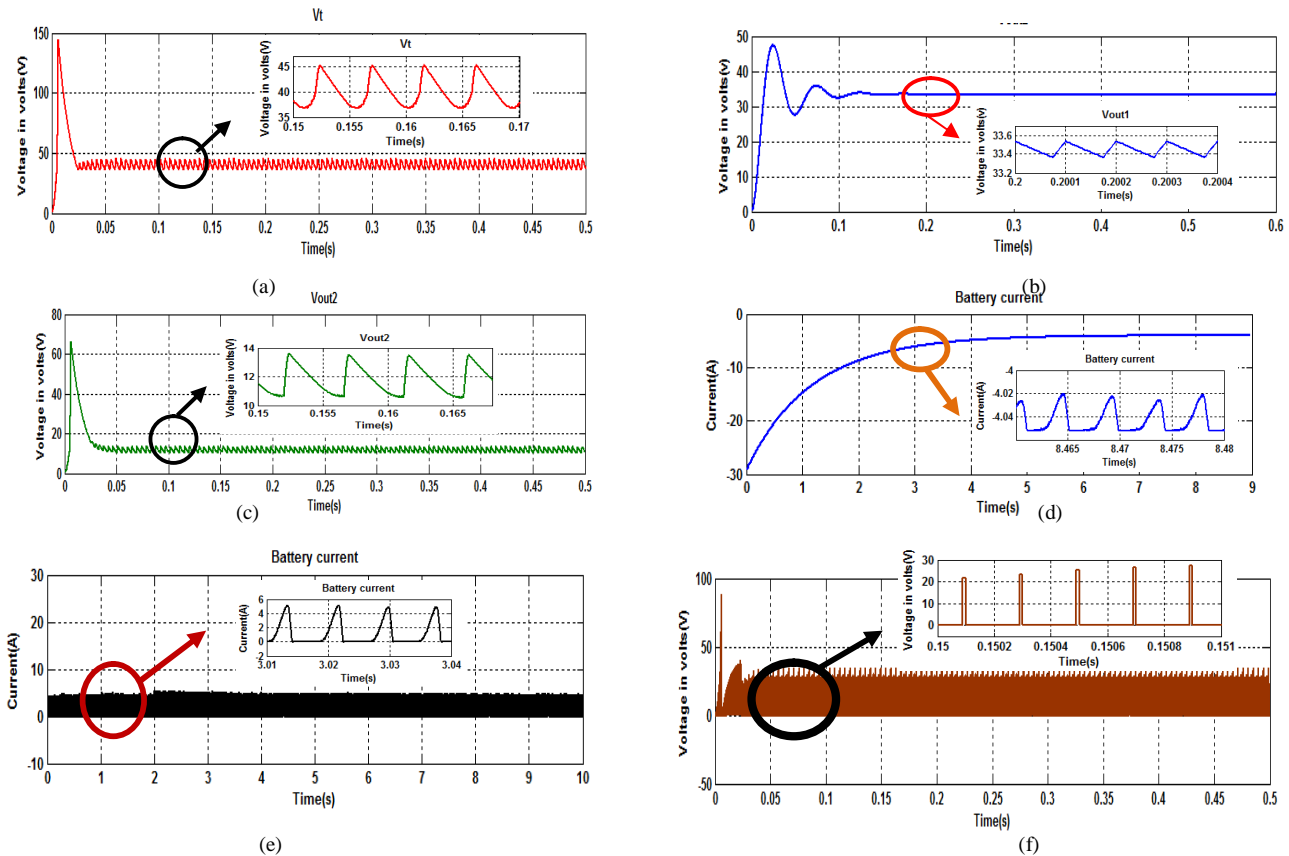


Fig.8. shows simulation results (a) the total output voltage  $V_t$  (b) the output voltage  $V_{out1}$  (c) the output voltage  $V_{out2}$  (d) shows the simulation results for battery charging mode current (e) shows the simulation results for battery discharging current (f) shows the voltage across the switch.

## V. EXPERIMENTAL RESULTS

The proposed parameters are listed in table 1. ATMEL 8-bit microcontroller with 16 KBYTES is used. IRF540 is taken as a switching device (Power Mosfet). A PC817X Series (DIP 4pin General Purpose Photo coupler) contains an IRED optically coupled to a phototransistor. The charging and discharging modes are defined based on the utilization state of the battery. In order to verify the effectiveness of the proposed converter, a low power range laboratory prototype was built as shown in Fig. 9 (a) proposed hardware structure. The DSO output for this prototype is shown in, fig.9 (b) the output voltage ( $V_{out1}$ ) is obtained as 30 V, (c)  $V_{out2} = 10$  V, therefore the total output voltage is regulated as,  $V_t = V_{out1} + V_{out2}$ , which is obtained as 40 V is shown in (d).

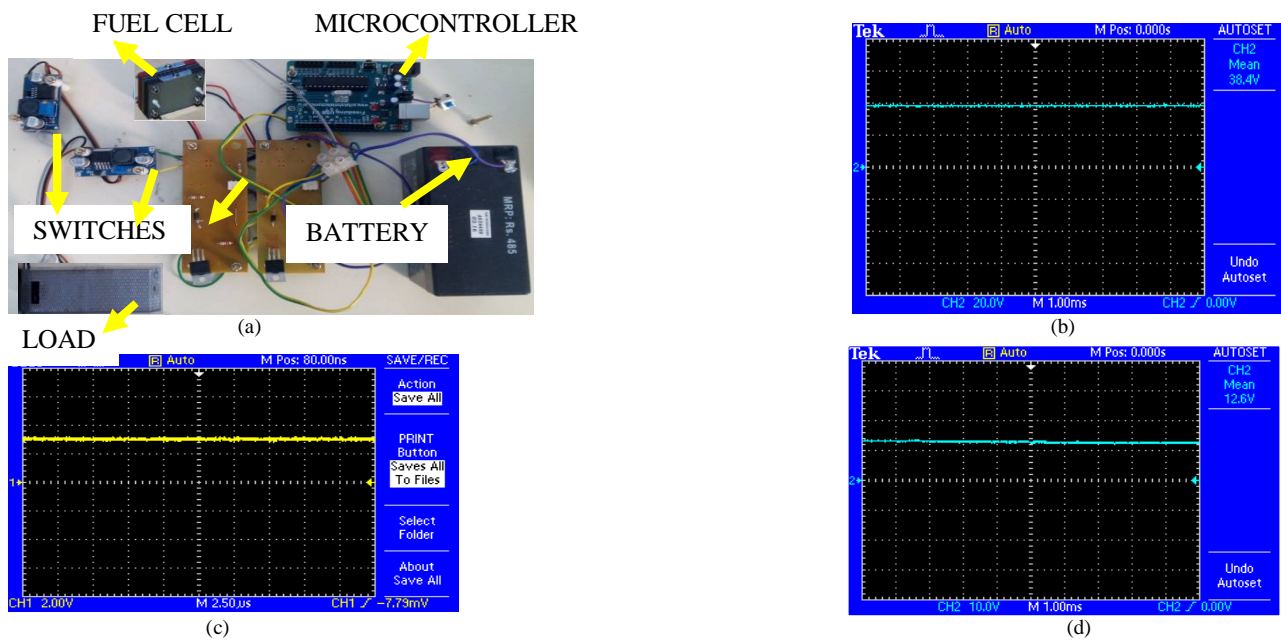


Fig.9 experimental results (a) proposed hardware structure (b) total output voltage  $V_t$  (c) output voltage  $V_{out1}$  (d) output voltage  $V_{out2}$

## VI. CONCLUSION

A nonisolated multiinput multioutput dc-dc boost converter with less number of power electronics components is proposed using generating power source (FC) and energy storage system (battery). Also, the converter can be utilized as single input multi output converter. For each mode, small signal average methods are obtained separately. The proposed converter produce two different voltage magnitudes in its output which is suitable for electric vehicle based applications.

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