

A NOVEL ADVANCED MULTI-INPUT DC-DC CONVERTER FOR CROSS-BASED ELECTRIC VEHICLES APPLICATION

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ABSTRACT : *In this paper, a multi-input DC-DC converter is proposed and inspected for hybrid electric vehicles (HEVs). Diverged from standard works, the yield gain is made strides. Fuel cell (FC), photovoltaic (PV) board and energy storage system (ESS) are the data hotspots for proposed converter. The FC is considered as the standard control supply and housetop top PV is used to charge the battery, increase the efficiency and lessen fuel economy. The converter has the capacity of giving the asked for control by stack without two or three resources .Moreover, control organization procedure is depicted and associated in control strategy. A model of the converter is in like manner realized and endeavored to check the examination.*

Keywords: *Fuel Cell (FC), Photovoltaic (PV), Hybrid Electric Vehicles (HEVS), Energy Storage System (ESS).*

I. INTRODUCTION

A wide temperature lift and nonattendance of oil based merchandise are the main downsides of vehicles filled by oil or diesel. To vanquish the in advance said issues and regarding the limit of clean energies in producing electricity, auto fashioners have indicated interest in hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs). The general structure of hybrid electric vehicle filled by inexhaustible assets is delineated in Fig.1. Electric vehicles (EVs) have moreover been considered. EVs depend upon energy set away in energy storage system (ESS). Constrained driving degree and long battery charging time are their main drawbacks. For any situation, by using a bidirectional on/off board charger, they could have as far as possible. Sun filled helped EVs have additionally been considered. Required region and size of PV sheets have made them nonsensical at present. Employing energy section as the main power wellspring of HEVs is the possible result of different broadened lengths of innovative work on HEVs. Unadulterated water and warmth are the main outpourings of energy parts. Furthermore, FCs have distinctive great conditions like high thickness yield current point of confinement, clean electricity age, and high capacity undertaking. For any situation, surprising expense and poor transient execution are the main issues of FCs. Note that vehicles mainly filled by FCs, are hybridized by ESSs.

The main favorable circumstances of hybridizing are enhancing mileage, providing a more adaptable operating system, overcoming energy component cool begin and transient issues and reducing the expense per unit control.

A converter using coupled inductors is moderately superior to disconnection transformers since the coupled inductors have less complex winding structure and lower conduction misfortune [4]. In any case, the leakage inductors of the coupled inductors will devour critical energy for a huge winding proportion. In such case, the voltage stress and the loss of the switches will both be increased.

A lift converter with coupled inductor and active-clamp circuit is proposed in [4]. This lift converter can yield a high advance up voltage gain, diminish the voltage stress on switches, and reuse the energy in the leakage inductor.

II. PROPOSED TOPOLOGY

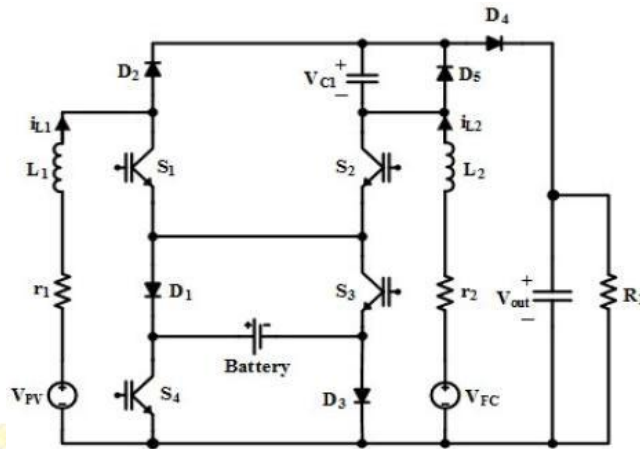


Fig. 1. Topology of the proposed converter

The structure of proposed three-input DC-DC boost converter is depicted in Fig. 2. 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. $r1$ and $r2$ 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 C_o is performed as output voltage filter. System is operating in continuous conduct mode (CCM) to produce smooth current with least possible amount of current ripple.

The purpose of continuation load-flow is to find a continuum of load-flow solutions for a given load/generation change scenario, i.e. computation direction [Ibs96]. It is capable of solving the whole PV-curve. The singularity of continuation load-flow equations is not a problem; therefore the voltage collapse point can be solved. The continuation load-flow finds the solution path of a set of load-flow equations that are reformulated to include a continuation parameter [Ajj92]. This scalar equation represents phase conditions that guarantee the non-singularity of the set of equations. The method is based on prediction-correction technique. The prediction-correction technique applied to the PV-curve solution is illustrated in Figure 1. The intermediate results of the continuation process also provide valuable insight into the voltage stability of the system and the areas prone to voltage collapse.

III. MODELING OF CASE STUDY:

PRINCIPLE OF OPERATION

In this section, principles of the proposed converter are discussed. Operation of the converter is divided into three states: 1- The load is supplied by PV and FC and battery is not used. 2- The load is supplied by PV, FC and battery, in this state battery is in discharging mode. 3- The load is supplied by PV and FC and battery is in charging mode.

TOPOLOGICAL MODES AND ANALYSIS:

A. First operation state (The load is supplied by PV and FC while battery is not used)

In this state, as it is illustrated in Fig. 2, 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 S_3 and D_3 or D_1 and S_4). In this paper S_3 and D_3 is considered as common path. However, D_1 and S_4 could be chosen as an alternative path. During this state, switch S_3 is permanently ON and switch S_4 is OFF.

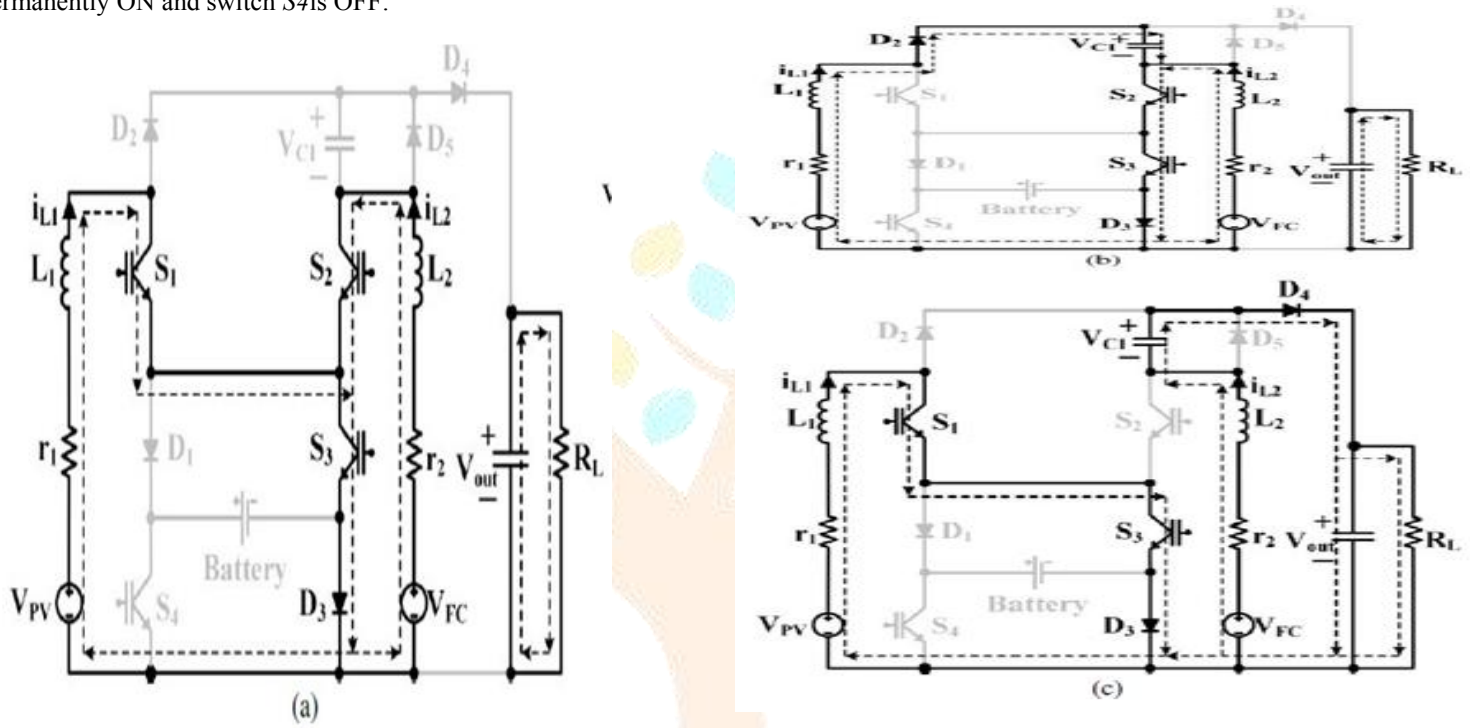


Fig. 2. Current-flow path of operating modes in first operating state. (a) Mode 1. (b) Mode 2. (c) Mode 3.

Mode 1 ($0 < t < d1T$): In this interval, switches S_1 , S_2 , S_3 and diode D_3 are turned ON. Inductors L_1 and L_2 are charged via power sources v_{PV} and v_{FC} , respectively [see Fig. 2(a)].

Mode 2 ($d1T < t < d2T$): 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 L_1 is being discharged via $v_{PV}-v_{C1}$ [see Fig. 2(b)].

Mode 3 ($d2T < t < T$): 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 $v_{PV}+v_{C1}-v_o$ [see Fig. 2(c)]

B. Second operation state (The load is supplied by PV, FC and battery):

In this state, as it is illustrated in Fig. 4, 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 S_3 and D_3 or D_1 and S_4). In this state, current flows through D_1 and S_4 . Switch S_4 is permanently ON during this state.

Mode 1 ($0 < t < d1T$): In this interval, S_1, S_2, S_3 and S_4 are turned ON. Inductors L_1 and L_2 are charged by $v_{PV} + v_{Battery}$ and $v_{FC} + v_{Battery}$ respectively .

Mode 2 ($d1T < t < d2T$): In this interval, S_1, S_2, S_4 and D_1 are turned ON. Inductors L_1 and L_2 are charged by v_{PV} and v_{FC} respectively

Mode 3 ($d2T < t < d3T$): In this interval, S_2, S_4, D_1 and D_2 are turned ON. Inductor L_1 is discharged to capacitor C_1 and L_2 is charged by v_{FC}

Mode 4 ($d3T < t < d4T$): In this interval, S_1, S_4, D_1 and D_4 are turned ON. Inductor L_1 is charged by v_{PV} and inductor L_2 discharges C_1 to the output capacitor.

C. Third operation state (The load is supplied by PV and FC while battery is in charging mode)

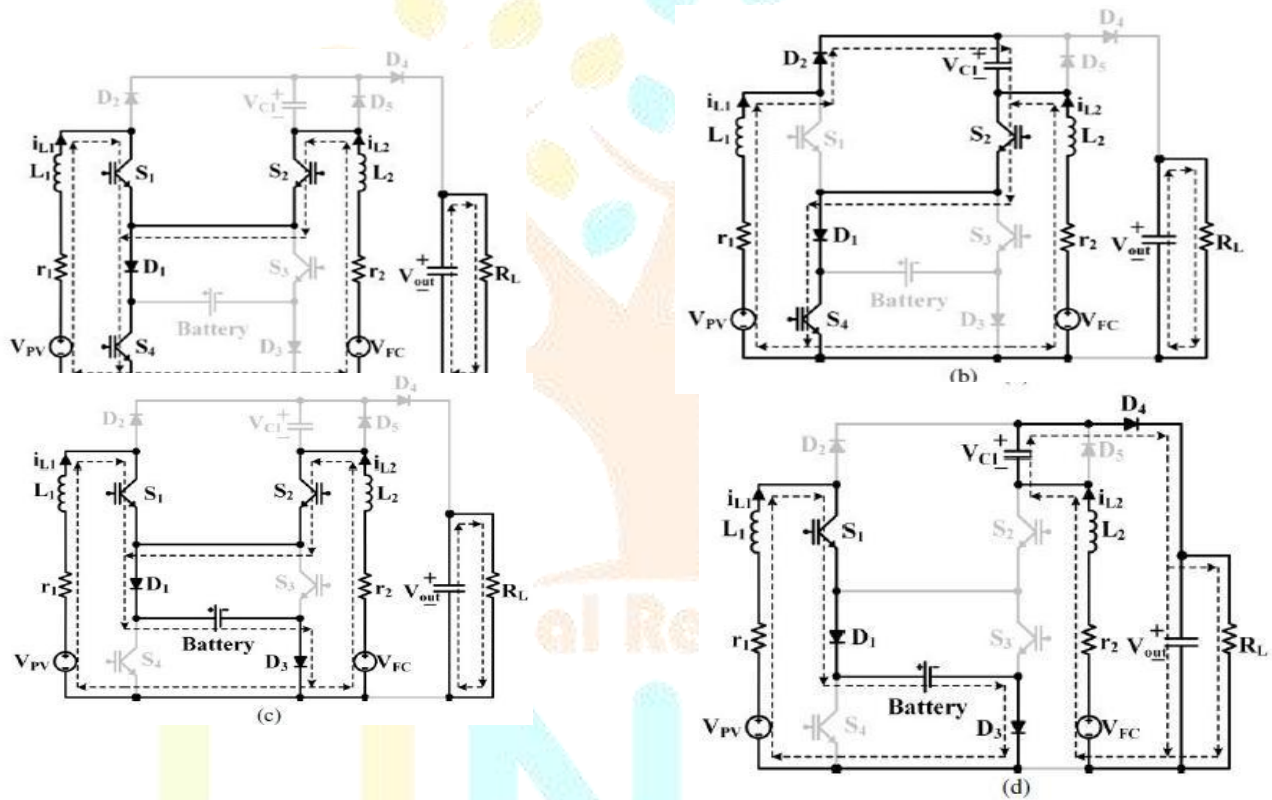


Fig. 3. Current-flow path of operating modes in third operating state. (a) Mode 1. (b) Mode 2. (c) Mode 3. (d) Mode 4.

Mode 1 ($0 < t < d1T$): In this interval, S_1, S_2, S_4 and D_1 are turned ON. Inductors L_1 and L_2 are charged by v_{PV} and v_{FC} , respectively [see Fig. 3(a)].

Mode 2 ($d1T < t < d2T$): In this interval, S_2, S_4 and D_1 are turned ON. Inductor L_1 is discharged to capacitor C_1 and inductor L_2 is charged by v_{FC} [see Fig. 3(b)].

Mode 3 ($d2T < t < d3T$): In this interval, S_1, S_2, D_1 and D_3 are turned ON. Inductors L_1 and L_2 are charged by $v_{PV} - v_{Battery}$ and $v_{FC} - v_{Battery}$, respectively [see Fig. 3(c)].

Mode 4 ($d3T < t < d4T$): In this interval, S_1, S_4, D_1 and D_4 are turned ON. Inductor L_1 is charged by $v_{PV} - v_{Battery}$ and inductor L_2 is discharged by $v_{FC} - v_{C1} - v_o$ [see Fig. 3(d)].

IV DYNAMIC MODELING AND CONTROL:

Fig. 4 illustrates switching pattern for each state and each mode. To fulfill 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. The voltage gain of the proposed converter is compared with the converter proposed in [24] in fig. 7. As shown in this figure, the voltage gain of the proposed converter is higher than the converter proposed in [24]. Benefiting from high voltage gain, the proposed converter achieve the specific output voltage VO with less duty cycles in comparison with the converter proposed in [24] which increase the efficiency of the proposed converter. It is worth noting that in this figure, the inductor resistances are ignored and the voltage gain is compared in the first operation mode. Input voltages are also considered the same.

In order to control and analyze dynamic performance of the proposed converter, it should be modeled. As it has been mentioned, the presented converter operates in three states that first state is made of three modes and second and third states are contained of four modes. Each state operates to provide particular goals, which will be explained. In first state, output voltage and only one of the input power sources can be controlled.

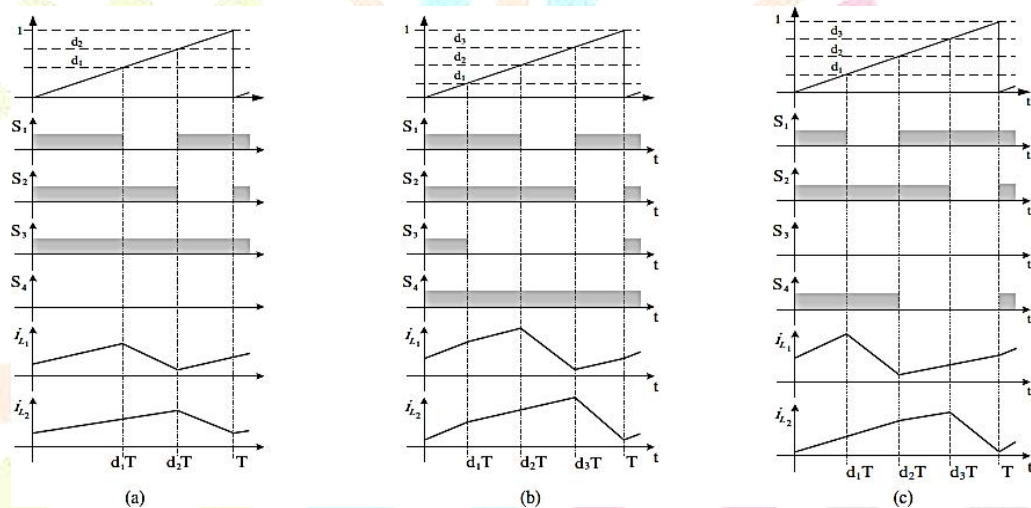


Fig. 4. Switching pattern for three states. (a) First state. (b) Second state. (c) Third state.

Due to this fact in this paper, we decide to control PV power source, which can be replaced by FC source as well. In second state because of interference the battery, output voltages and input sources power rate can be controlled. Third states' control parameters due to interference the battery is same as second state.

As mentioned previously interference the battery consists of two states, which in one of them battery will be charged and in one of them battery will be discharged. Selection of proper state (without battery, battery charging, battery discharging) is depends on power managing algorithm. Dynamic model of the proposed converter for each state is as follow: First state: In this state, $d1$ and $d2$ as control variables, control output voltage and power rate of one of the input sources that is consider PV in this paper.

$$L_1 \frac{di_{L1}}{dt} = V_{PV} + (d_1 - d_2)V_{C1} - r_1 i_{L1} \quad (1)$$

$$L_2 \frac{di_{L2}}{dt} = V_{FC} + (1 - d_2)V_{C1} + (d_2 - 1)V_o - r_2 i_{L2} \quad (2)$$

$$C_o \frac{dV_o}{dt} = (1 - d_2)i_{L2} - \frac{V_o}{R_{Load}} \quad (3)$$

$$C_1 \frac{dV_{C1}}{dt} = (d_2 - d_1)i_{L1} - (1 - d_2)i_{L2} \quad (4)$$

Second state: In this state, three control variables d_1 , d_2 and d_3 are used for controlling three state variables. In this state, state-space model of converter is:

$$L_1 \frac{di_{L1}}{dt} = V_{PV} + d_1 V_{bat} + (d_2 - d_3)V_{C1} - r_1 i_{L1} \quad (5)$$

$$A = \begin{bmatrix} -r_1 & 0 & 0 & \bar{d}_1 - \bar{d}_2 \\ 0 & -r_2 & \bar{d}_2 - 1 & 1 - \bar{d}_2 \\ 0 & 1 - \bar{d}_2 & -\frac{1}{R_{Load}} & 0 \\ \bar{d}_2 - \bar{d}_1 & \bar{d}_2 - 1 & 0 & 0 \end{bmatrix}, B = \begin{bmatrix} \bar{V}_{C1} & -\bar{V}_{C1} \\ 0 & \bar{V}_o - \bar{V}_{C1} \\ 0 & -\bar{i}_{L2} \\ -\bar{i}_{L1} & \bar{i}_{L1} + \bar{i}_{L2} \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \bar{x} = \begin{bmatrix} \bar{i}_{L1} \\ \bar{i}_{L2} \\ \bar{V}_o \\ \bar{V}_{C1} \end{bmatrix}, \bar{u} = \begin{bmatrix} \bar{d}_1 \\ \bar{d}_2 \end{bmatrix}$$

(14)

Second state:

$$L_2 \frac{di_{L2}}{dt} = V_{FC} + d_1 V_{bat} + (1 - d_3)V_{C1} + (d_3 - 1)V_o - r_2 i_{L2} \quad (6)$$

$$C_o \frac{dV_o}{dt} = (1 - d_3)i_{L2} - \frac{V_o}{R_{Load}} \quad (7)$$

$$C_1 \frac{dV_{C1}}{dt} = (d_3 - d_2)i_{L1} - (1 - d_3)i_{L2} \quad (8)$$

Third state: In this state, same as second state, three state variables are controlled by three control variables d_1 , d_2 and d_3 , controlling. State-space model of converter in this state can be written as follows:

$$L_1 \frac{di_{L1}}{dt} = V_{PV} + (d_2 - 1)V_{bat} + (d_1 - d_2)V_{C1} - r_1 i_{L1} \quad (9)$$

$$L_2 \frac{di_{L2}}{dt} = V_{FC} + (d_2 - d_3)V_{bat} + (1 - d_3)V_{C1} + (d_3 - 1)V_o - r_2 i_{L2} \quad (10)$$

$$C_o \frac{dV_o}{dt} = (1 - d_3)i_{L2} - \frac{V_o}{R_{Load}} \quad (11)$$

$$C_1 \frac{dV_{C1}}{dt} = (d_2 - d_1)i_{L1} - (1 - d_3)i_{L2} \quad (12)$$

Assuming small signal method [25], input voltage, state variables and duty ratios consist of two parts: steady values (\bar{V} , \bar{X} , \bar{D}) and perturbations (\tilde{v} , \tilde{x} , \tilde{d}) that are:

$$v = \bar{V} + \tilde{v}, x = \bar{X} + \tilde{x}, d = \bar{D} + \tilde{d} \quad (13)$$

As mentioned, the first state comprises two control variables as well second and third states consist of three control variables. Due to aforementioned facts, the rank of transfer function matrix represents the number of control variables.

$$G_{2 \times 2}^* = \begin{bmatrix} 1 & -\frac{s_{12}}{s_{11}} \\ -\frac{s_{21}}{s_{22}} & 1 \end{bmatrix}$$

$$G_{3 \times 3}^* = \begin{bmatrix} 1 & \frac{s_{12} \cdot s_{22} - s_{12} \cdot s_{22}}{s_{11} \cdot s_{22} - s_{12} \cdot s_{21}} & \frac{s_{12} \cdot s_{22} - s_{12} \cdot s_{22}}{s_{11} \cdot s_{22} - s_{12} \cdot s_{21}} \\ \frac{s_{22} \cdot s_{21} - s_{21} \cdot s_{22}}{s_{11} \cdot s_{22} - s_{12} \cdot s_{21}} & 1 & \frac{s_{12} \cdot s_{21} - s_{11} \cdot s_{22}}{s_{11} \cdot s_{22} - s_{12} \cdot s_{21}} \\ \frac{s_{21} \cdot s_{22} - s_{22} \cdot s_{21}}{s_{11} \cdot s_{22} - s_{12} \cdot s_{21}} & \frac{s_{12} \cdot s_{21} - s_{11} \cdot s_{22}}{s_{11} \cdot s_{22} - s_{12} \cdot s_{21}} & 1 \end{bmatrix}$$

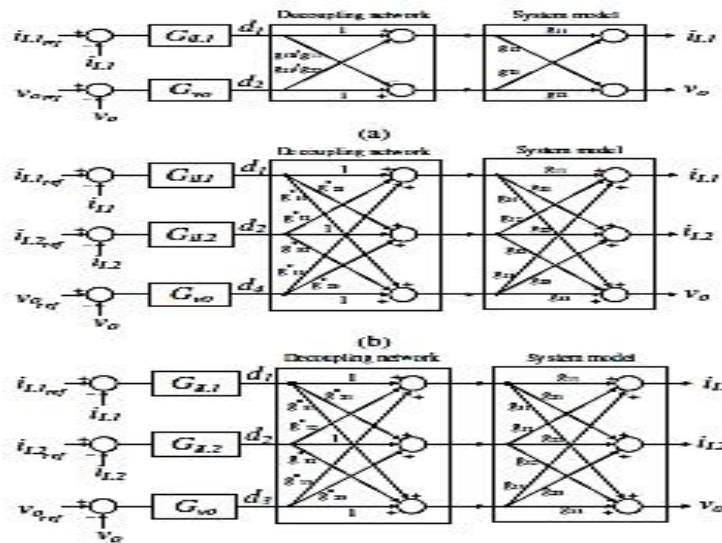


Fig. 5. Decoupling network for three states. (a) First state. (b) Second state. (c) Third state.

Where y and u are the output and input vectors, respectively, and g_{ij} is transfer function between y_i and u_j . In order to control proposed converter's desired state variables independently, decoupling the transfer function is needed [24]. Fig. 8 represent decoupling network for three operation states. Considering Decoupling Network G^* [24], [25] and $x = Gu^*$ that u^* is the modified input consist of duty ratios $u^* = G^*u$. As a result, $x = GG^*u$. Base on modern control theory [2], to provide each output of the matrixes be determined by each singular input, the matrix should be in diagonal arrange. Decoupling matrix $G^* = G^{-1}xu^{-1}$ for two controls and three control variables are given as above.

V POWER MANAGEMENT AND MPPT ALGORITHM

The multi-powered hybrid electric vehicle has a construction as depicted in Fig.1. In the drive system, the FC is the main power supply. Roof-top PV panel is employed to reduce the fuel consumption and charging the battery. The battery is utilized as storage device. With a proper design, there will be no need for an external electrical supply to charge the battery [26]. The battery can be charged via PV, FC. In order to have the system operated in optimum region, the following criteria have to be ensured:

1. Electrical motor always supplies the demand power.
2. PV panel and FC operate in their optimal region.
3. The battery energy level should be always within the optimum region.

The power management procedure is described below and the flow chart of the strategy is depicted

- I. Control signals, acceleration and brake, identify the command power.
- II. In case command power is less than maximum PV power and battery energy level is less than minimum energy level, PV will 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.
- III. If command power is more than maximum PV power, PV panel will operate in MPP and new command power will be defined.
- IV. 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 work at its rated power and battery will provide the rest of demanded power.
- V. In next step, if new command power is less than minimum power of the FC and battery energy level is less than minimum energy level, the FC will work at its rated power and extra energy will be stored in battery.
- VI. If new command power is less than minimum power of the FC but battery energy level is greater than minimum energy level, the FC will be turned off and the battery will provide the demanded power.
- VII. If new command power is greater than minimum power of the FC and battery energy level is greater than maximum energy level, the FC will provide the demanded power and the battery will be turned off.
- VIII. If new command power is greater than minimum power of the FC but battery energy level is greater than maximum energy level, the FC will work at its rated power and extra energy will be stored in battery. Different MPPT methods including perturb and observe (P&O) algorithm [27], incremental conductance algorithm [28] and slide control [29] have been studied and presented in recent reports. Simple programming and low computation have made the P&O method a practical and widely used scheme among other schemes.

VI .ADDITIONAL ADVANTAGES OF THE CONVERTER, MAKING IT SUITABLE FOR HEVS:

The proposed converter has the advantage of utilizing only one resource in case the other power sources can't provide energy.

This capability enhances the safety and reliability of the proposed converter.

Different possible states are described as follow: PV ON and FC OFF:

Due to the long start-up time of fuel cell, this state happens mostly at the starting the car or when the car is run out of fuel cell gas. In this state, battery can be charged or discharged by PV. Because of the facts that FC is the main power supply and energy storage system (ESS) has a limited capacity, this state cannot be so long. In order to let the PV operate individually, switch S_2 is turned off and instead of capacitor C_1 , the power of PV is transferred to the output capacitor C_o . According to the presented topology, battery can be charged and discharged via PV and by controlling switches S_1 , S_3 and S_4 .

PV OFF and FC ON:

As mentioned above, FC is the main power source to provide the demanded power by HEV individually because the energy of PV is less than FC and depends on climate situation. Therefore, an extra diode (D_5) is paralleled with capacitor C_1 . The diode D_5 is

off when capacitor CI is charged. When the FC is utilized individually, the capacitor CI discharges until its voltage is zero. When the voltage across capacitor CI is going to be negative, diode $D5$ will be turned on and clamps the voltage of capacitor CI .

VII. SIMULATION RESULTS :

PROPOSED CIRCUIT:

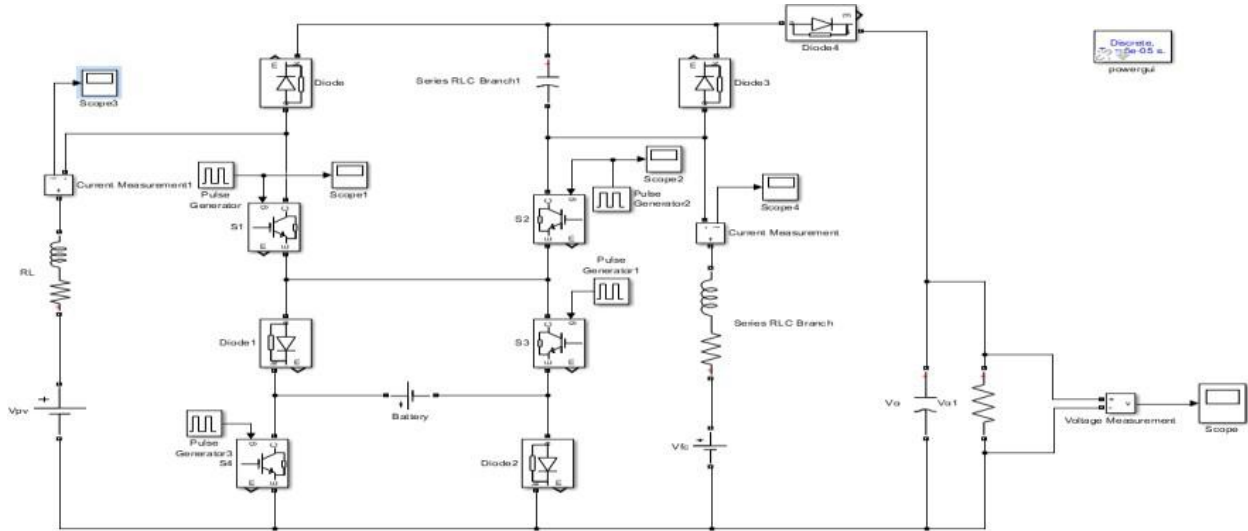


Fig. 6 Matlab Simulink for proposed converter

Here the Input given to the circuit is 100V DC and the multiple outputs got as 150V and 300VDC.

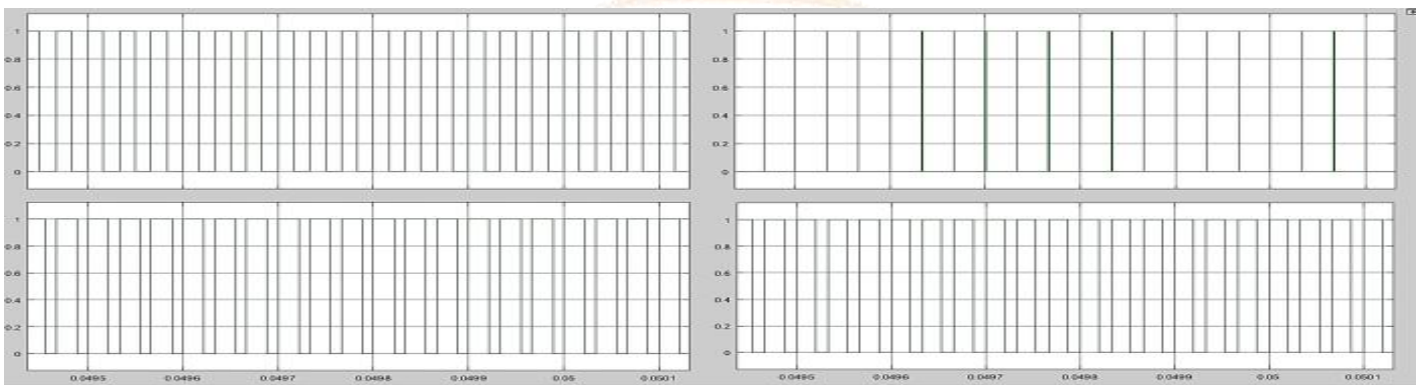


Fig .7 Pulses for the desired switches

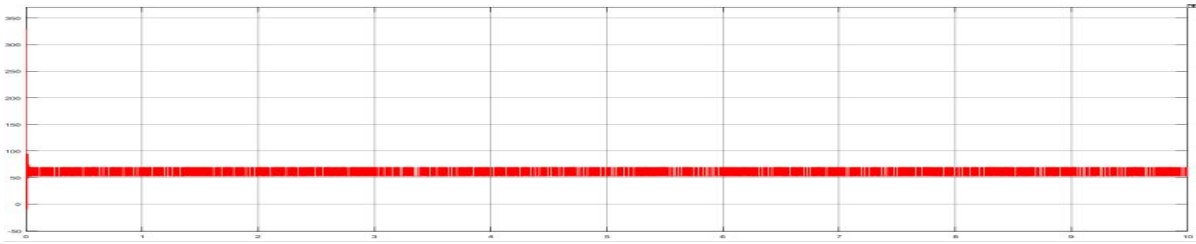


Fig. 8 Current across Inductor

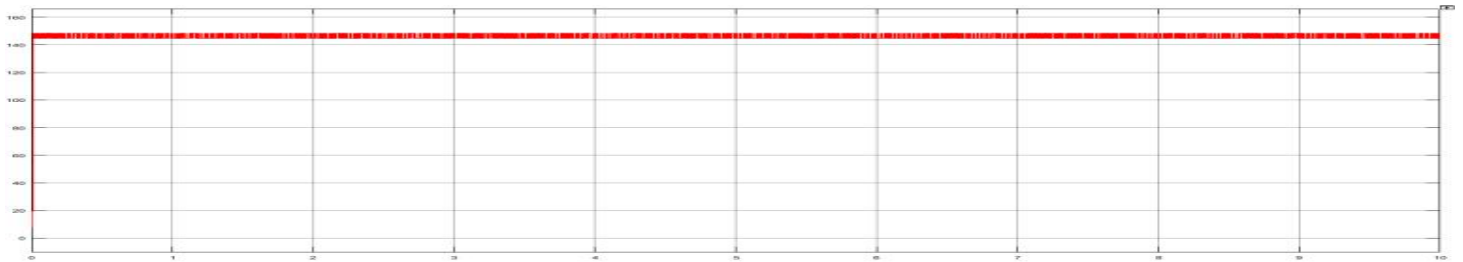


Fig.9 Current across Fuel cell

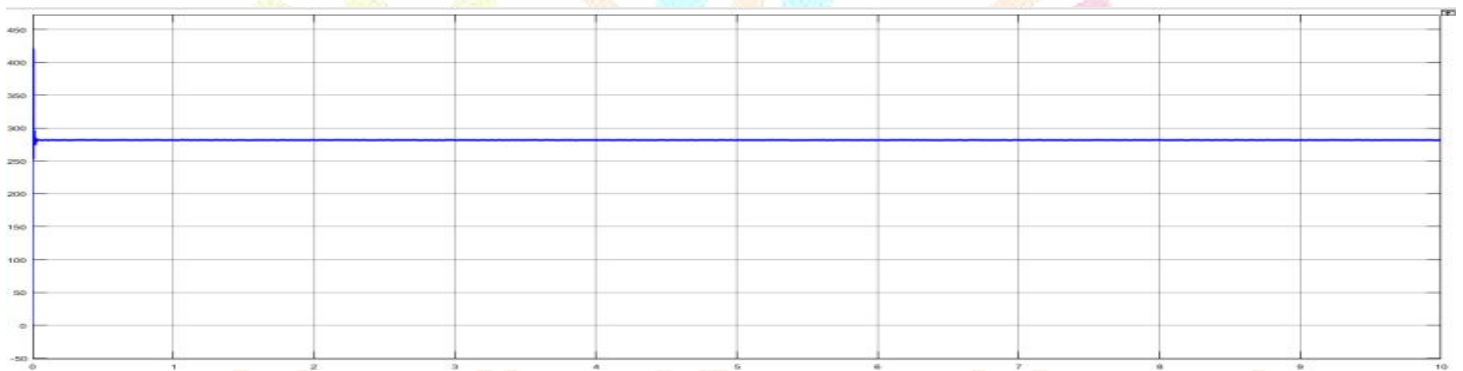


Fig .10 Output voltage Graph

VIII FUTURE SCOPE:

In this paper, a novel three-input DC/DC converter is proposed and analyzed thoroughly. The converter has the capability of providing the demanded power by load in absence of one or two resources. The promising performance of the converter and employed control method offer a high reliability for utilizing the converter in industrial and domestic applications. The converter is modeled for three different operational states and utilized to design a proper controller. MPPT algorithm is achieved and along power management is utilized to apply the commands of controller. Meanwhile, employing power management and MPPT procedure will enhance the efficiency of the converter. Finally, a laboratory prototype of the presented converted is implemented and results are taken and depicted. Results prove the analysis and performance of the converter.

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