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Dual Input DC to DC Converter for Hybrid Electric Vehicles

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***Abstract*— A DC-to-DC converter is a crucial component in an electric vehicle (EV) charging system, as it facilitates the conversion of high-voltage DC power from the charging station to the lower-voltage DC power required by the vehicle's battery system. The DC-to-DC converter ensures that the electric vehicle's battery receives the correct voltage and current for charging. A dual-input DC-DC converter can draw power from two separate DC sources at the same time. It combines these power sources and delivers it to a single load. These converters are useful in situations where it is desired to tap two different sources. The Dual Input DC to DC converters are realised by using either of single power path approach or parallel power path approach. In this paper parallel power path approach is used to configure a dual Input DC to DC Converter which combines the power generated by PV panel and the fuel cell to charge the electric vehicle battery. The proposed converter is realised with MATLAB Similink model and simulation results are presented.**

***Keywords*— Dual input converter, duty cycle, PWM, voltage control, electric vehicle.**

I. INTRODUCTION

Power converters are crucial components in electric vehicle (EV) battery management systems. They perform the essential function of transforming electrical energy between different voltage levels and AC to DC or vice versa. Two main types of power converters used in EV battery management are DC to DC converters and DC to AC Converters [1]. DC-DC converters step up (boost) or step down (buck) the voltage from the EV battery to various voltage levels required by the vehicle's electrical systems [2]. A DC-DC converter can boost the battery voltage to power the high-voltage traction motor that drives the wheels. Conversely, it can also buck down the battery voltage to supply lower voltage power for accessories like headlights, wipers, and infotainment systems [3]. DC-AC converter also known as inverters converter the DC electricity stored in the battery into AC electricity which can be used by the electric traction motor. By controlling the frequency of the output AC voltage, the inverter regulates the speed of the motor, hence controlling the vehicle's acceleration. The AC – DC converter in the form of rectifier for EVs are refereed as on board chargers [4]. They converter AC power from the grid to DC power for charging the EV battery [5].
These converters are designed to be unidirectional or bidirectional, depending upon the specific requirements of the system [6]. The selection of appropriate power converters for an EV battery management system is influenced by several factors, including the battery voltage, power requirements of the electric motor and various electrical systems, and desired charging characteristics.

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The increased demand of onsite energy conversion of renewable sources has triggered inventions and innovations in power converters. Being a clean source of energy photovoltaic (PV) and fuel cells (FC) are popular choice in EVs and hybrid EVs [7]. The intermittent characteristics of PV systems and lower voltages of fuel cells makes it essential to include a battery in the practical system to supply the load smooth and consistent power. The renewable sources need step power conversion and integration with the DC link in such applications. A dual input DC to DC converter is hence proposed to cater these needs [8 -10].

By integrating many sources and loads with distinct terminal (voltage) characteristics, these multiport power converters increase power density, efficiency, and reliability while minimising the system's cost. These power converters can accept two separate DC inputs and deliver a single, regulated DC output [11]. It allow for combining and managing power from multiple sources, such as: Batteries with different voltage levels, Renewable energy sources (solar, wind), Mains power, Energy storage systems. The regulated DC output voltage is often adjustable to meet specific load requirements. The dual input DC to DC converter are deployed for improving flexibility, efficiency and reliability by simplifying the system design [12]. The [13] has demonstrated dual input DC – DC converter for EV application where, PV and ultra- capacitor are combined to feed the DC link. The voltage regulation of the converter is done through PWM control [14].

II. Dual Input DC to DC Converter

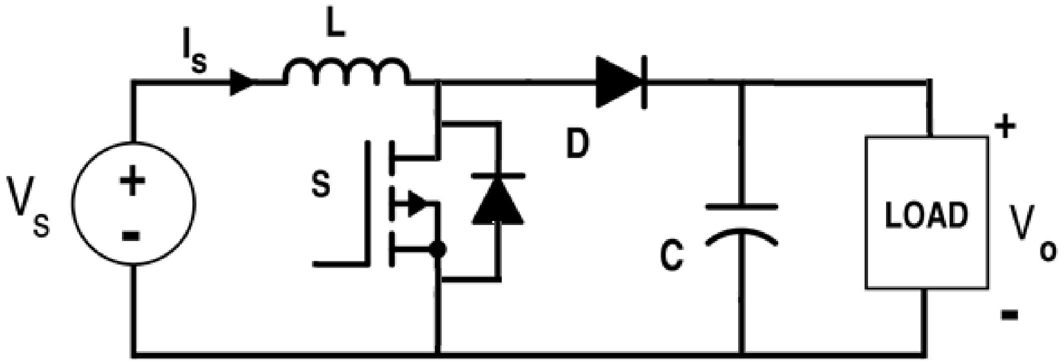

Figure 1: Conventional boost converter

The circuit topology of conventional boost converter is shown in figure 1. The voltage equation of boost converter is written as,

$$V_o = \frac{1}{1-D} V_s \quad \dots (1)$$

Where, D is duty cycle of the converter.

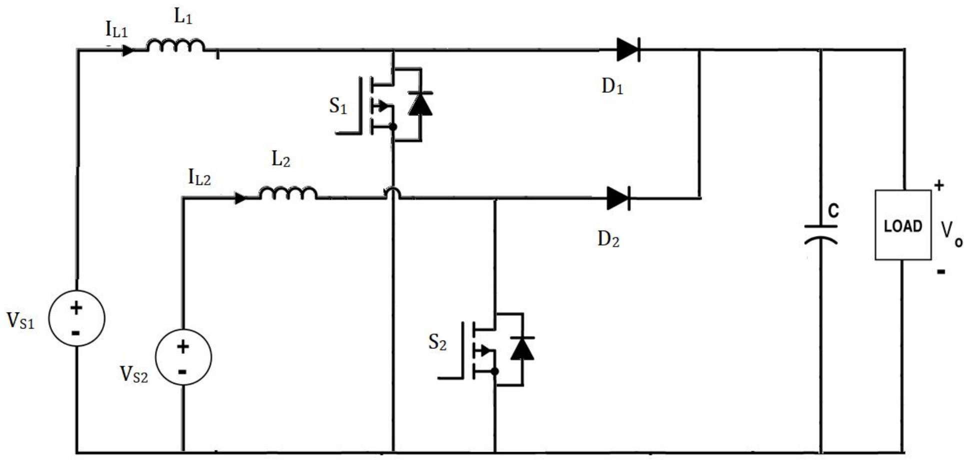

Figure 2: dual input DC to DC boost converter

The circuit topology of dual input DC to DC converter is shown in figure 2. The circuit topology consists of two boost converters feeding single load. The voltage equation of this converter is written as,

$$V_o = \frac{1}{1-D_1} V_{s1} + \frac{1}{1-D_2} V_{s2} \qquad \ldots (2)$$

Thus to regulate the output voltage to a constant value, the duty cycle of the respective converter has to be adjusted precisely.

The operation of the converter takes place in two modes. In the first mode, the power is delivered to the load from source V_{S1}. When S_1 is turned ON and S_2 is turned OFF, current flows from V_{S1} through S_1, the inductor (L_1), and then to the load. The inductor stores energy in its magnetic field during this time. Diode D_2 is reverse biased and blocks current flow from V_{S2}.

In the second mode, the power is delivered to the load from source V_{S2}. When S_1 is turned OFF and S_2 is turned ON, current flows from V_{S2} through S_2, the inductor (L_2), and then to the load. The energy stored in the inductor from the previous step helps maintain current flow during this short period when S_1 is off (important for a continuous output). Diode D_1 is reverse biased and blocks current flow from V_{S1}.

II. MATLAB Simulation and Results

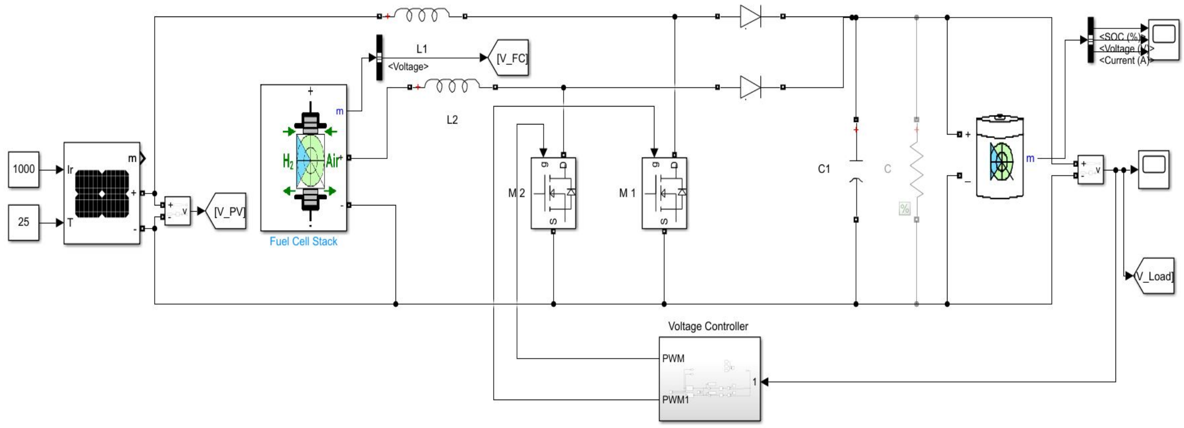

Figure 3: MATLAB Simulink Model of dual input DC – DC boost converter

The MATLAB model of dual input boost converter is shown in figure 3. The converter is fed through a PV source and fuel cell. These two sources are combined together with dual input DC to DC boost converter to charge the EV battery. The specifications of the simulation model are mentioned in table 1. A closed loop voltage control is achieved with PI controller. The PI controller is tuned to automatically adjust the duty cycle of converter so that the voltage output is maintained constant.

TABLE I: CONVERTER PARAMETERS SPECIFICATIONS

Source (V1)	14 V, 250W
Source (V2)	12V, 250W
Load	250 W Resistive 36 V, 20Ah battery
Inductors (L1, L2)	600mH
Output capacitor	1000 µF
Switching frequency	10 kHz

The reference voltage is set at 39V for the PI controller. This reference value is considered as the voltage required to charge 36V battery. The difference between this reference voltage and actual voltage of the converter is given as error to the PI controller. In response to this error signal The Pi controller generates a proportional output which is referred as the duty cycle. The saturation value of due to cycle is set at 95% on upper threshold limit and 0% on lower threshold limit. This duty cycle value is given as input to the PWM generator. The PWM generator provides the required gate pulses for MOSFET. The figure 4 shows graph of PWM gate pulses of the MOSFETs. The duty cycle of these MOSFETs is adjusted to regulate the output voltage of the converter to 39V.

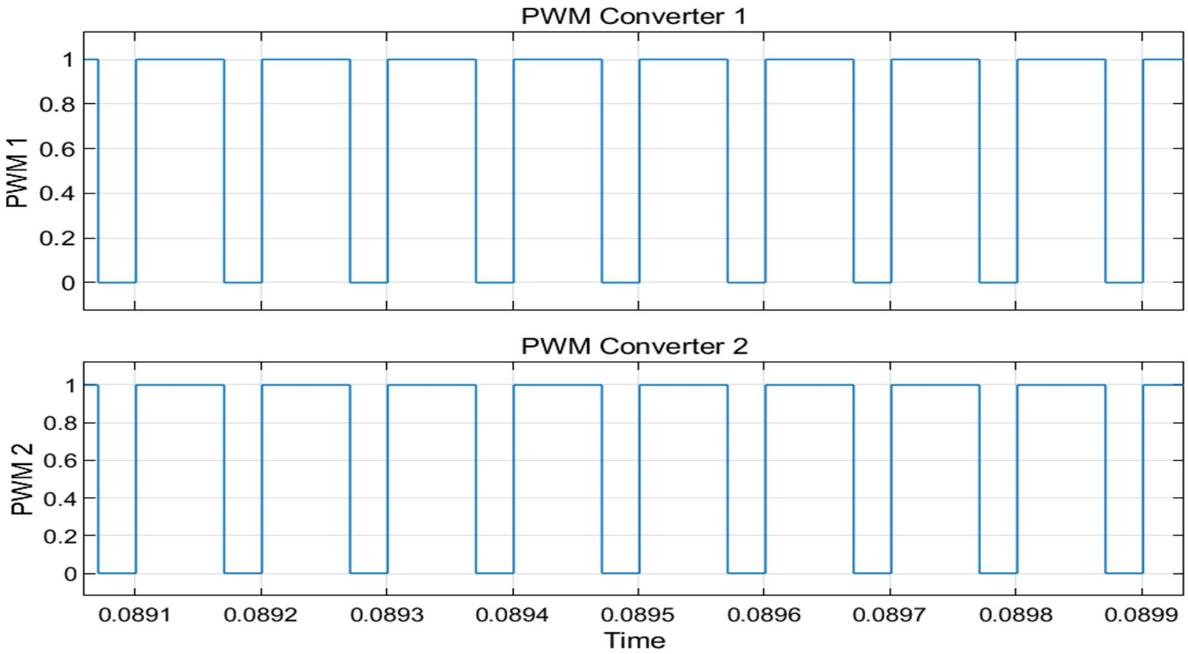

Figure 4: PWM control signals of converter switches S1 and S2

Figure 5 shows the voltages of PV panel, fuel cell and load. Note that in this case a resistive load of 200 Watt is connected at the load terminals of the converter. From the graph of the load voltage, is can be clearly seen that the control system is effective enough to regulate the load voltage to the reference value. The role of the closed loop controller is to reduce the error computed as difference between reference voltage and actual converter output voltage to zero.

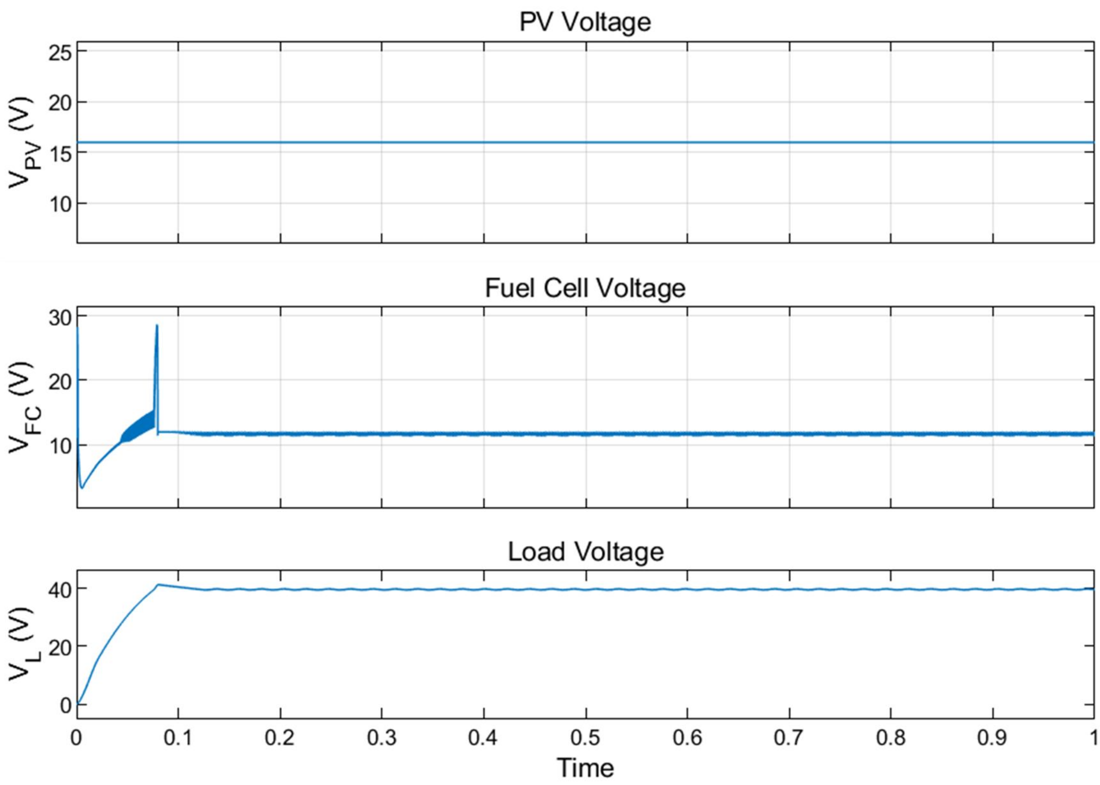

Figure 5: PV Voltage, fuel cell voltage and load voltage

The proposed converter is also loaded with EV battery. The figure 6 shows the graph of state of the charge of battery, battery voltage and battery current. The increasing value of the graph of the state of charge of the battery indicates that the battery is getting charged from the converter. The current is input to the battery and hence it is observed with negative value. With battery load, the terminal voltage at the battery is seen to be sufficient enough to charge the EV battery.

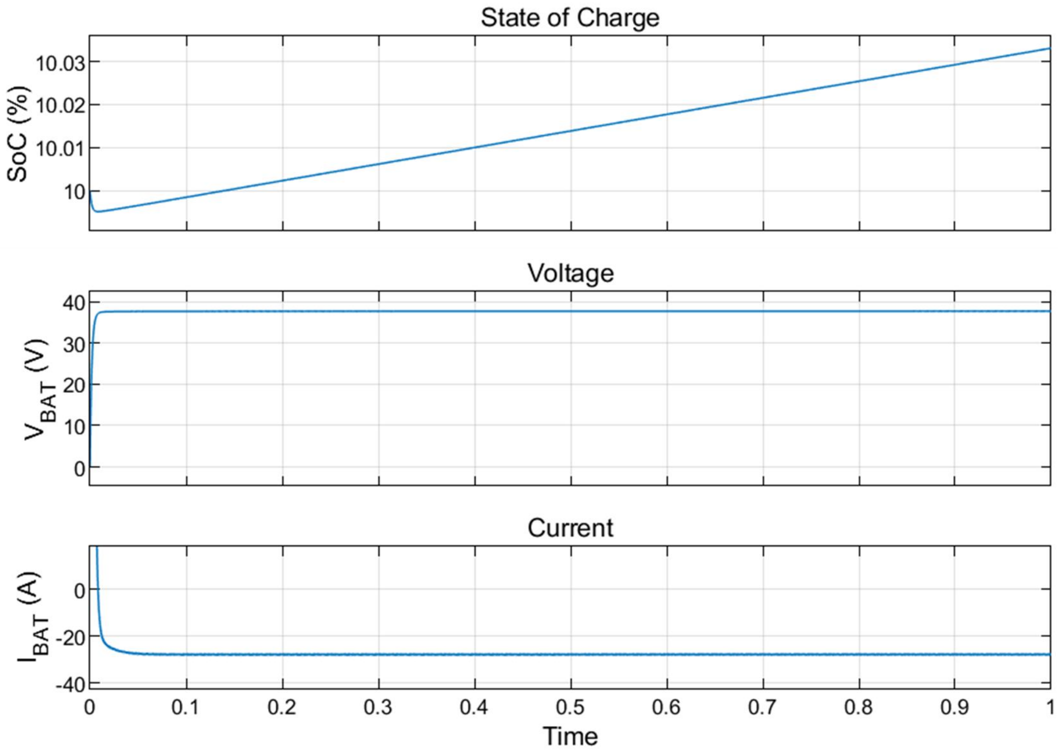

Figure 6: battery state of charge, voltage and current

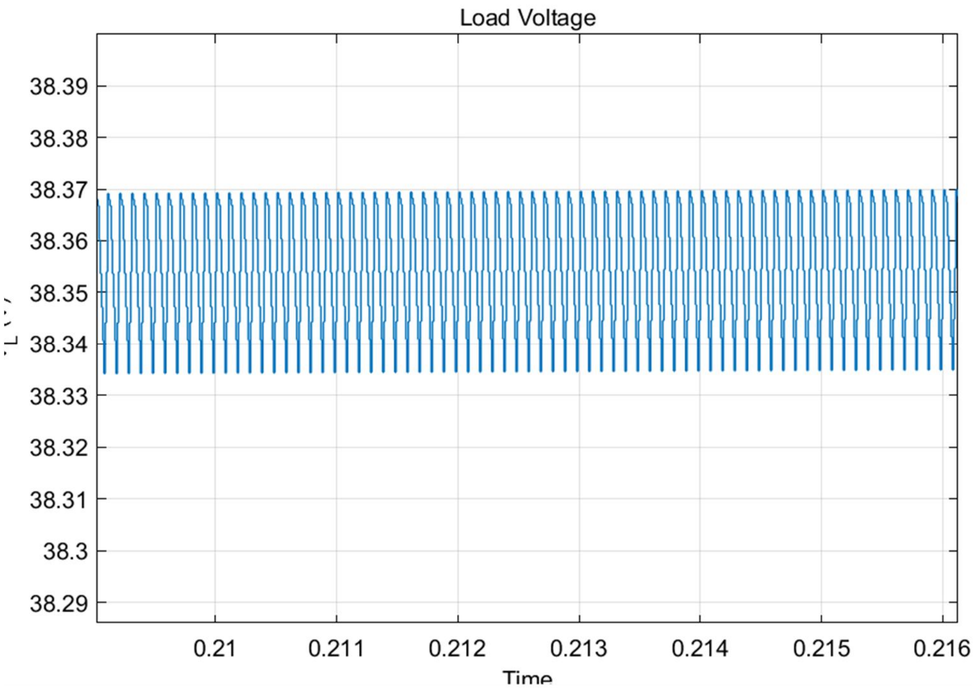

Figure 7: load voltage ripples

The figure 7 shows the graph of load voltage ripples. The ripples can have several detrimental effects on battery health if not properly managed. Ripple currents can result in energy losses within the battery system. Ripple currents can lead to increased heat generation within the battery cells due to the internal resistance. This additional heating can accelerate the chemical reactions inside the battery, leading to faster degradation of the electrode materials and electrolyte. Continuous exposure to ripple currents can shorten the battery's lifespan. As seen in figure 7, the ripples are limited to 0.035V which is 0.0875%.

IV. CONCLUSION

The voltage regulation of dual input DC-DC converters is important for the effective and efficient operation of electric vehicle charging systems. As the adoption of EVs continues to grow, the demand for reliable, efficient and flexible charging infrastructure becomes increasingly critical. Dual input DC-DC converters, with their ability to manage multiple power sources, offer significant advantages for EV applications. The dual input DC – DC boost converter is proposed here to combine the electrical energy generated from solar panels and fuel cell. The proposed system is simulated with MATLAB Simulink and is seen to be effective in charging EV battery from two sources which offer distinct voltage characteristics over their operating range.

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