

Fuzzy Logic Controlled Multi Input DC to DC Converter for EV Application

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Abstract— A DC–DC converter plays a vital role in an electric vehicle (EV) charging architecture by enabling the conversion of high-voltage DC from the charging source into a suitable lower-voltage level required by the EV battery. It ensures the battery receives appropriate voltage and current for efficient charging. A multi-input single output DC–DC converter has the ability to draw energy simultaneously from two independent DC sources, integrating them to supply a single load. Such converters are particularly advantageous when multiple power sources are available for utilization. The configuration of dual-input DC–DC converters can be achieved using either a single power-path or a parallel power-path topology. In this paper, a parallel power-path configuration is employed to design a dual-input DC–DC converter that integrates energy from a photovoltaic (PV) panel and an auxiliary lead acid storage battery for charging of EV battery. The proposed system has been simulated using MATLAB/Simulink with fuzzy logic controller, followed by hardware implementation and validation of results.

Index Terms— multi-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 convert 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 referred as on board chargers [4]. They convert 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.

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

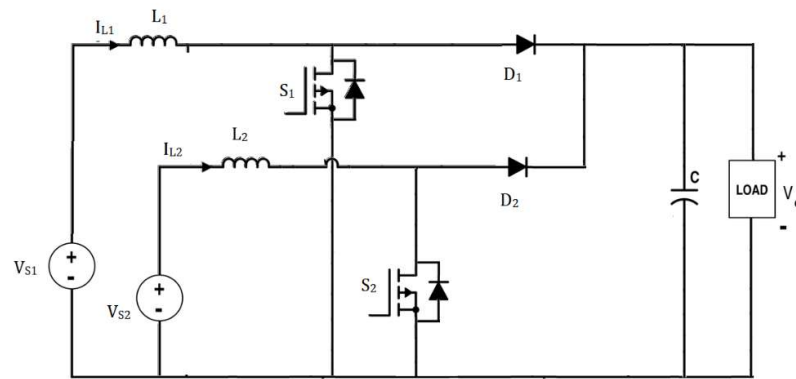


Figure 1: Dual input DC to DC boost converter

The circuit topology of dual input DC to DC converter is shown in figure 1. The circuit topology consists of two boost converters feeding single load. The voltage equation of this converter is written as,

$$V_o = \frac{1}{1-D_1} V_{S1} + \frac{1}{1-D_2} V_{S2} \quad \dots (1)$$

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} .

III. MATLAB SIMULATION AND RESULTS

The MATLAB model of dual input boost converter is shown in figure 2. The converter is fed through a PV source and lead acid battery. 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 fuzzy logic controller (FLC). The FLC is tuned to automatically adjust the duty cycle of converter so that the voltage output is maintained constant.

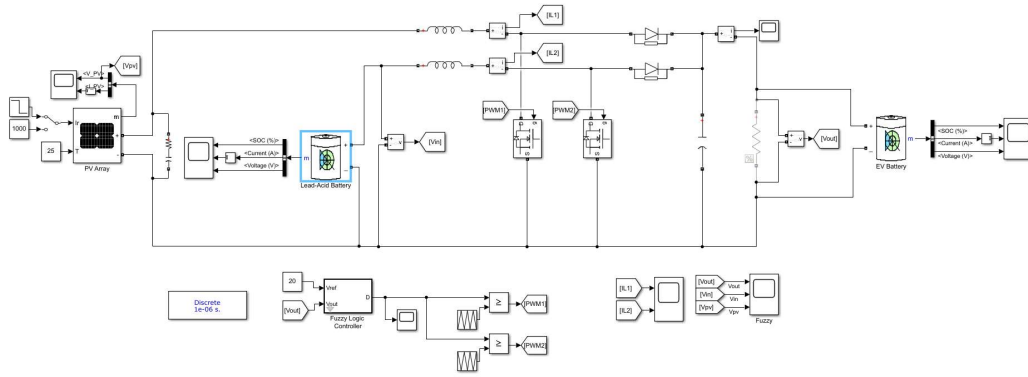


Figure 2: MATLAB Simulink Model of dual input DC – DC boost converter

TABLE I: CONVERTER PARAMETER SPECIFICATION

PV Panel	12 V, 300W
Lead Acid Battery	12V, 20Ah
Load	18V, 36Ah Battery
Inductors (L1, L2)	0.24Mh
Output capacitor	470 μ F
Switching frequency	5 kHz
Controller	FLC

The fuzzy logic controller membership functions for error, change in error and output (duty cycle) are shown in figure 3(a), 3(b) and 3(c) respectively.

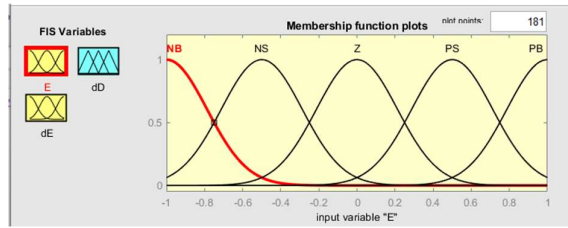


Figure 3 (a) Membership function of error signal

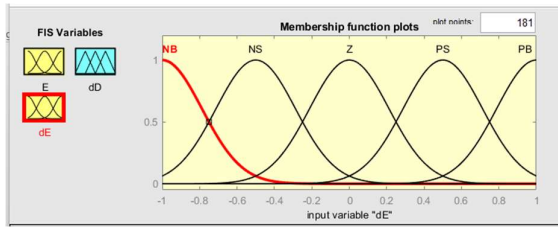


Figure 3(b) Membership function of change error signal

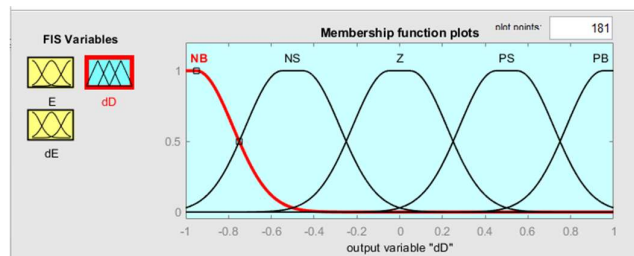


Figure 3(c) Membership function of Duty Cycle Output

The reference voltage is set at 20V for the FLC. This reference value is considered as the voltage required to charge 18V battery. The difference between this reference voltage and actual voltage of the converter is given as error to the FLC controller. In response to this error signal The FLC generates a proportional output which is referred as the duty cycle. The saturation value of due to cycle is set at 80% 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 a zoomed view of PWM gate pulses of the MOSFETs. The duty cycle of these MOSFETs is adjusted to regulate the output voltage of the converter to 20V which is suitable for charging of the EV battery.

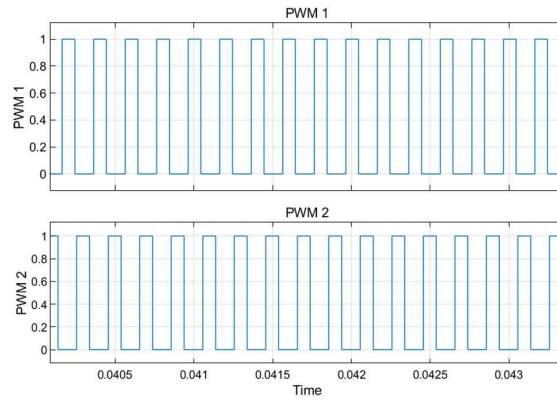


Figure 4: PWM control signals of converter switches S1 and S2

Figure 5 shows the voltages of PV panel, lead acid battery and the EV battery load. From the graph of the load voltage, it can be clearly seen that the control system is effective enough to regulate the load voltage to the reference value and charge the EV battery by using both sources in parallel.

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.

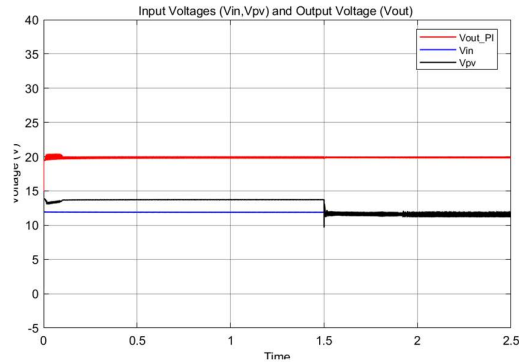


Figure 5: PV Voltage, lead acid battery voltage and output voltage

The graph of PV voltage and current vs. irradiations is shown in figure 7. The fall in irradiations at time instance 1.5s results in the drop in PV output power and thereby voltage. The controller responds to this fall in input of PV and controls the duty cycle in such a way to regulate the output voltage to a constant value of 20V.

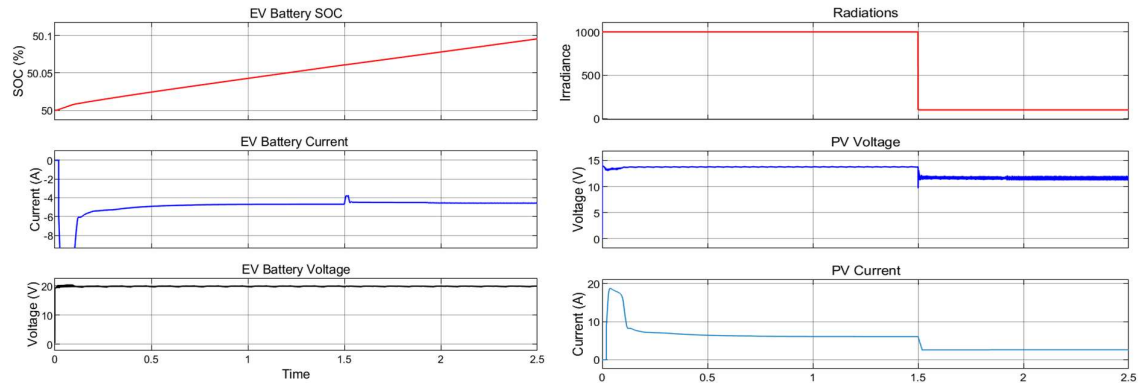


Figure 6: EV battery state of charge, voltage and current

Figure 7: radiations vs. PV output

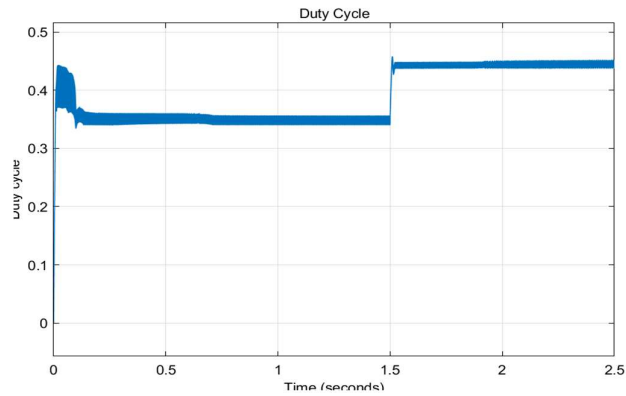


Figure 8: converter duty cycle vs. time

The figure 8 shows the graph of the duty cycle of the converter vs. time. Corresponding to the change in input voltage caused by variations in radiations, the FLC controls the duty cycle of the converter from 0.35 to 0.45 to ensure that the output voltage is regulated to 20V.

IV. EXPERIMENTAL SETUP

The experimental setup of the EV charging system with dual input DC-DC converter is shown in figure 9. The experimental model is developed for same specifications as mentioned in table 1. The fuzzy logic rule table is implemented by using switch-case based programming with Arduino Uno. The building blocks of the experimental setup are highlighted. The SoC measurement of the EV battery is carried out with coulomb counting technique. The battery state of charge and battery voltage are indicated on the LCD display. The hardware results confirms that the developed system is effective for charging the EV battery with both sources acting simultaneously or individually

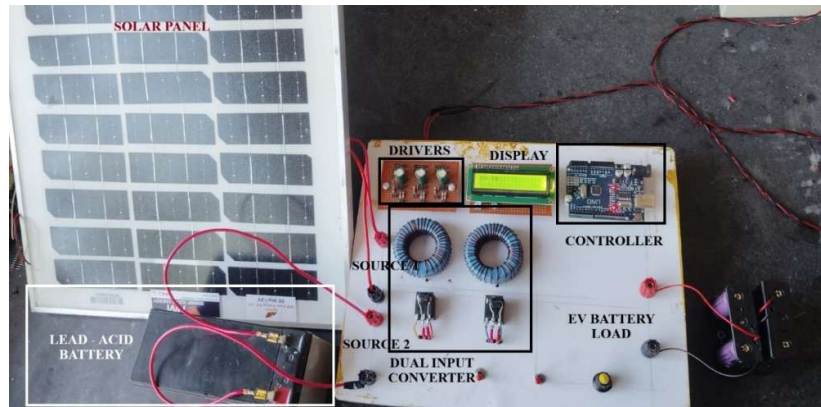


Figure 9: Experimental Setup

V. CONCLUSIONS

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 PV panels and auxiliary storage system. 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. The fuzzy logic controller is observed to respond to the variations in source characteristics with updating of the duty cycle for regulating the voltage and ensuring smooth charging of the EV battery.

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