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Design of EV Charging Station Using Renewable Energy Sources

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***Abstract*—This paper presents the EV charging stations using renewable energy sources. For everyday needs, every person on earth must travel from one location to another. Conventional vehicles were created to meet this criterion. Only fossil fuels like gasoline, diesel, and other types of gas are used to power vehicles. When these fuels are consumed, CO2 is released as a byproduct, which contributes to global warming, the emission of greenhouse gases, and other negative effects. In order to overcome these problems, Electric Vehicles are increasing nowadays. This electric vehicle runs entirely on electricity and doesn't need any fuel or lubricants. Compared to our current petrol/diesel bunk, there are fewer electric vehicle charging stations. EV charging station is a smart method that is an alternative and environmental solution. To run E-vehicles we need more charging stations. By implementing the EV charging station at various places like homes, offices, colleges, and hospitals in India, there is a chance of increasing more number of E-Vehicles. In this paper, solar PV and fuel cell-based EV charging stations were introduced to satisfy the never-ending demand for the charging of electric vehicles. The battery management system using a bidirectional converter and a solar PV and fuel cell-based EV charging station is presented in this article. MATLAB/SIMULINK is used to model the suggested circuit. The results of the simulation are discussed, and the necessary output waveforms for different input conditions are presented.**

Keywords— Electric vehicles, charging station, Solar panel, fuel cell, SEPIC converter, Bidirectional converter.

I. INTRODUCTION

An electric vehicle is powered by an electric motor instead of using an internal combustion engine. It produces electricity by burning fuel and emitting hazardous gases. A replacement for reducing problems like global warming, rising pollution, greenhouse emissions and the exhaustion of natural resources, etc. is an electric vehicle. EV batteries are the future mode of transport. Compared with gasoline vehicles, EVs produce zero emissions since the EV batteries are charged from electricity from renewable energy sources. In this paper, the use of renewable energy sources, such as fuel cells and solar PV cells are used to charge EV batteries are proposed. EV charging station was designed using solar PV system. Solar energy will be available only during daytime. So, during nighttime EV battery can be charged using grid voltage [1-3]. Solar PV and wind will produce variant energy which will be available seasonally [4-6]. The bbuck converters can step down the input voltage. On the other hand, the boost converters can step up the voltage. These converters are suitable for applications where the desired output voltage is either higher or lower than the input voltage. The buck boost, Cuk, and SEPIC converters could decrease and increase the voltage, making them versatile for such applications. Buck-boost converters can be cost-effective because they require a single inductor and capacitor, simplifying the design and reducing component count compared to other converters. However, they do suffer from a higher amount of input current ripple compared to buck or boost converters. This ripple can introduce harmonics in the system, which may require additional measures to mitigate. To address the input current ripple and associated harmonics, larger capacitors or LC filters can be used in the converter design. These components help smooth out the ripple and reduce harmonics, ensuring stable and clean power delivery. The selection of a specific DC-DC converter depends on the requirements of the application, including the input and output voltage ranges, cost considerations, efficiency, and the need for input current ripple suppression [7 -9]. To overcome the above limitations, SEPIC converter is proposed.

The synchronous buck converter-based EV charging station is developed using solar PV. However, voltage boost cannot be done during low irradiance. [10,11]. More charging stations are needed to recharge the vehicles on lengthy drives. These units might receive their supply from renewable resources. The primary goal of the project is to create electric car charging stations that use renewable energy sources like solar PV and fuel cells. The main objective of this study is to develop a 24V DC bus EV charging station powered by solar PV and fuel cells using SEPIC converter. The storage battery can be charged/discharged with the help of bidirectional converter. The proposed system is simulated in MATLAB/Simulink environment.

II. PROPOSED EV CHARGING SYSTEM

The charging system consists of a solar PV array and the fuel cell with SEPIC converter, a backup battery. The bidirectional converter integrates the solar PV/fuel cell and the battery which is used for charging and discharging of battery connected to a DC bus. Fig. 1 shows the proposed EV charging station. The Solar panel generates electricity which is DC in nature. The SEPIC converter connected to the solar PV /fuel cell will buck/boost the voltage according to output from solar PV/ Fuel cell. The output of the converter forms as 24V DC bus. Whenever excess power is available, it will be stored in the battery with the help of bidirectional converter. The two modes of operation for a bidirectional converter are buck mode (for charging) and boost mode. (discharging). Fuel cells and batteries will give the power to charge e-vehicles when there is not enough irradiance. If there is no e-vehicles connected in station for charging, then fuel cell and solar PV energy will be stored in the storage battery. Batteries, fuel cells, and solar PV power are all linked to a 24V DC bus. Both an individual and society can profit from charging EVs with solar and fuel cell power because emission-free transportation can improve the quality of life

A. SOLAR PV PANEL

The 165 Watt Aavid Solar ASMS PV array module is used in the Simulink. This source's current and voltage are 35V and 4.71A. For the chosen charging station, a total of 10 parallel strings with 2 series-connected modules per string are used. The system uses SEPIC converter to achieve a bus voltage of 24V by increasing or decreasing the voltage from PV array. Table 1 presents the parameters of PV panel. Voltage, current and Power at maximum power point is 27V, 4.71A and 164.85W.

Table 1 Parameters of PV Panel

No. of Cells in a module	72
Voc -Open Circuit Voltage of the array,	23.5 V
Isc -Short circuit Current,	5.25 A

B. Fuel cell

A fuel cell is an electrochemical device that produces electricity during a chemical reaction between hydrogen and oxygen. A fuel cell operates like a battery but differs in that it requires a continuous supply of fuel and oxidizer to sustain the reaction.

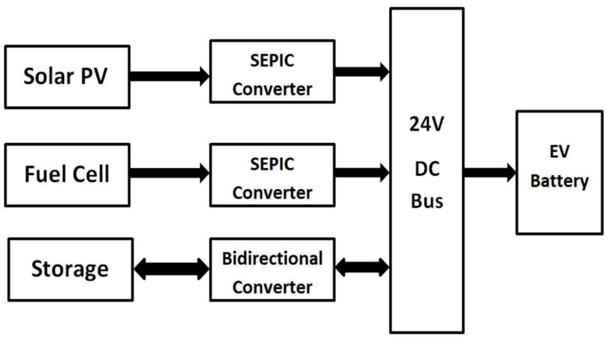

Fig. 1 Block diagram proposed charging station.

The fuel produces electricity through electrochemical conversion without any harmful emissions and scalability. Based on the substance used, own operating principles, characteristics, and applications, they are categorized as Polymer Electrolyte Membrane Fuel Cell (PEMFC), Molten Carbonate Fuel Cell (MCFC), Solid Oxide Fuel Cell (SOFC), Phosphoric Acid Fuel Cell (PAFC), Alkaline Fuel Cell (AFC) and Direct Methanol Fuel Cell (DMFC) [12,13]. The best choice among these for power sourcing is SOFC and is highly efficient, has long lifespans, and is suitable for stationary power generation in applications like residential, commercial, and distributed power systems.

Table 2 Electrical characteristics of fuel cell

Voltage at 0A and 1A	14.34, 13.3
Nominal operating point	[30, 106.5]
Maximum operating point	[33.2, 104.86]
No. of cells	119
Operating temperature (*Celsius*)	600
Nominal Air flow rate (*Ipm*)	635

The power generated by the fuel cell is DC nature and can be applied where the DC supply is required as input. The excellent utility might be EV and the batteries require DC for charging. In case of low irradiance, the battery is charged from a fuel cell. For Simulating the model, a SOFC of 3KW, 100V DC with a nominal stack efficiency of 60% is taken into consideration. Electrical characteristics of this fuel cell is depicted in table 2.

C. SEPIC converter

The DC-DC SEPIC converter regulates the voltage generated by the solar PV/ Fuel cell. It includes the inductor, a diode, a MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) as a power switch, coupling capacitor, and capacitor for the DC connection (DC Bus Voltage). By altering the MOSFET's duty cycle, voltage can be controlled or changed based on the incoming voltage. Basically, SEPIC converter is a buck-boost converter that is a combination of boost converter and an inverted buck-boost converter. However, it has significant advantages over other converters, including high efficiency, low output ripple, and positive output voltage. The SEPIC converter is better because a converter operates with high switching frequency pulses. The SEPIC converter circuit diagram is shown in Fig. 2.

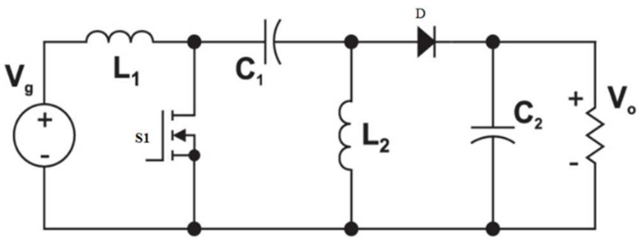

Fig. 2 SEPIC converter circuit

Assume that the operation of SEPIC converter is in continuous-current mode. During on state of the power switch, current flows through inductor L1 and is charged from the input sources. Also, the inductor (L2) charges the capacitor (C1) where the diode will be reverse biased, and the output voltage will be equal to voltage across the capacitor (C2). The power switch is switched off, the diode is to be in forward bias and charges the capacitors. MOSFET is utilized as a switch which permits current to flow in both direction using controlled switching action. The DC bus voltage is compared with the input voltage ie from either solar panel/ fuel cell. The error signal is processed using PI controller. The PI controller output determining the duty cycle of the MOSFET which in turn regulates DC bus voltage.

D. Battery

When solar power production is inadequate, a battery bank stores the energy produced by the fuel cells and deliver it for charging EVs. When sunlight is present, the photovoltaic system provides the load immediately and stores any excess energy in batteries. While the battery storage and the fuel cell can meet the consumer load requirement during the day or when sunlight is not present. A lithium-ion battery is used to create the battery bank due to its superior efficiency at high temperatures and power-to-weight ratio is high [14]. The characteristics of a lithium-ion battery are shown in Table III. The bidirectional converter controls the battery's charge and discharge.

Table 3 Specifications of Lithium-ion battery

Type	Lithium-ion battery
Nominal voltage (V)	12
capacity (Ah)	10
SOC (%)	85
Response time (secs)	25

E. Bidirectional Converter

A bi-directional DC-DC converter is a dual-quadrant DC-DC converter. The polarity of the input voltage and output voltage is fixed but the current path of the input and output are variable. The switch's converter input and output ports continue to be able to perform voltage shifting functions. The power flows from the 24V DC bus to battery is bidirectional. Two switches, two capacitors, and an inductor make up a bidirectional converter. MOSFET is utilized as a switch which permits current to flow in both directions using controlled switching action. The output of the PI controller, which determines the duty cycle for controlling the MOSFET based on the DC bus voltage and power from the renewable energy sources. Bidirectional charging allows for the efficient use of more reliable and renewable energy sources. Fig. 3 shows the circuit of a bidirectional DC-DC converter.

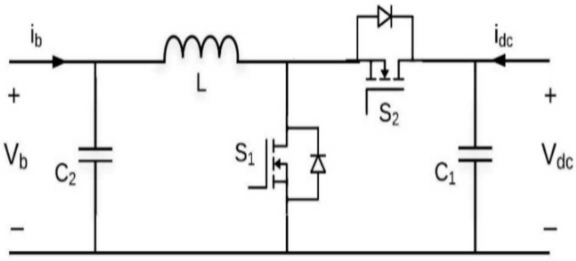

Fig. 3 Bidirectional DC-DC Converter Circuit

The DC-DC Bidirectional converter operates in two modes:
Buck mode: The switch S1 and the antiparallel diode in switch S2 are in on state and switch S2 and the antiparallel diode in switch S1 are reverse biased, hence the converter operates in buck mode.

Boost mode: The switch S2 and the diode in switch S1 are in state and switch S1 and the diode in switch S2 are reverse biased condition, hence it operates in boost mode.

When the solar irradiance is available and fuel flow rate are adequate to produce the load voltage then the power flows from PV array and fuel cell to batteries and the batteries can be charged simultaneously and the bidirectional converter operates in buck mode. When the solar irradiance is available and fuel flow rate are not capable of producing adequate load voltage for charging the batteries then the power flows from storage batteries to load and the bidirectional converter operates in boost mode.

F. PI Controller

PI controller performs both operation of proportional and integral. It is used to control the MOSFET switch in converters. It is used to provide duty cycle to switch. PI controller is a combination of P and I. Fig. 4 shows the block diagram of PI controller. The mathematical equation of PI controller is

$$e(t) = Kp\, e(t) + Ki \int e(t)$$

$$Ti = Kp/Ki$$

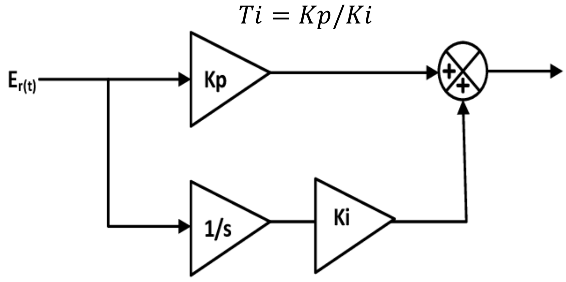

Fig. 4 PI controller

G. Design Calculations

<u>SEPIC CONVERTER</u>

Duty Cycle:

$$V_0 = D * \frac{Vin}{1-D}$$

Inductance:

In the SEPIC converter, L_1 is equal to L_2.

$$L_1 = L_2 = Vin * \frac{D}{fs * \Delta IL1}$$

Capacitance:

$$C_1 = \frac{Io * D}{0.5 * f * \Delta Vc1}$$

$$C_2 \geq \frac{Io * D}{0.5 * fs * \Delta Vo}$$

Load Resistance:

$$R = \frac{Vo^2}{P}$$

where *Vin* - input voltage (V), *Vo* - output voltage (V), L_1 and L_2 – inductances (H), C_1 and C_2 - capacitance values of capacitors (F), $\Delta IL1$ - ripple current of L_1 (A), ΔIL_2 – ripple current of L_2 (A), ΔVC_1 - ripple voltage (V), ΔVo - output ripple voltage (V), Iin - input current (A), R_L - load resistance (Ohms), P – Output power (W).

The design values are provided in TABLE 4 and 5, where the parameters of the SEPIC converter for solar PV and fuel cells are developed. When the temperature is 30°C and the solar radiation is 1000 W/m2, the SEPIC converter is integrated with solar panel and for supplying input power. For a fuel flow rate of 1 Ipm, the output of the fuel cell serves as the input voltage for the SEPIC converter attached to the fuel cell. Due to the 24V DC bus, fuel cell and solar PV converter's output voltage is 24V.

Table 4 SEPIC CONVERTER FOR SOLAR PV

Parameter	Value	Parameter	Value
Vin	12 V	L	0.09e-3 H
Vo	24 V	C1	5.3392e-6 F
P	20 W	C2	5.52e-5 F
fs	50kHz	R	40 Ω

Table 5 *SEPIC CONVERTER FOR FUEL CELL*

Parameter	Value	Parameter	Value
Vin	12 V	L	0.0412e-3 H
Vo	24 V	C1	5.04 e-6 F
P	12 W	C2	2.1 e-5 F
fs	50k Hz	R	53.3 Ω

BIDIRECTIONAL DC-DC CONVERTER

The DC output voltage of the converter will be $v_0 = dV_s$.

The average output current or the inductor current is

$$I_L = \frac{Vo - Vb}{R}$$

When Vo> Vb, The power flows from the source Vs to the battery. A buck mode is created by the switch S1, the lower diode, and the inductor. The battery is charging from the source voltage.
At steady state condition when Vo=Vb, the current is zero. There would not power exchange between the source and the battery.
When Vo<Vb, current flows from the battery to the source Vs. The battery power flows into the source and the converter operates in boost mode.

$$V_s = \frac{Vo}{1 - d_2}$$

where d_2 - duty cycle of the bottom switch. The switches are switched in a complementary manner, $d+d_2=1$.
Table 6 shows the Calculation parameters of Bidirectional converter for battery connected to Solar PV and fuel cell.

Table 6 *Bidirectional DC-DC Converter*

Parameter	Value	Parameter	Value
Vin	12 V	L	0.02e-3 H
Vo	24 V	C	2.5e-8 F
Io	0.3 A	fs	25k Hz

H. Implementation Algorithm

The algorithm for implementing the proposed system is given below.
Step 1: If Solar PV voltage > 24V and fuel cell voltage > 24V, additional power from both fuel cell and Solar PV will be stored into battery.
Step 2: If Solar PV voltage < 24V and fuel cell voltage < 24V, power from storage battery will supply to the EV battery.
Step 3: If Solar PV voltage < 1 and fuel cell voltage >= 24V, then fuel cell will supply power to the EV battery.
Step 4: If solar PV voltage >= 24 and fuel cell voltage <1, then Solar PV will supply power to the EV battery.

III. RESULTS AND DISCUSSION

The designed charging station is simulated using MATLAB/Simulink environment. The input to the PV array is temperature and irradiance as assumed as varying. Fig. 5 shows the overall simulation diagram.

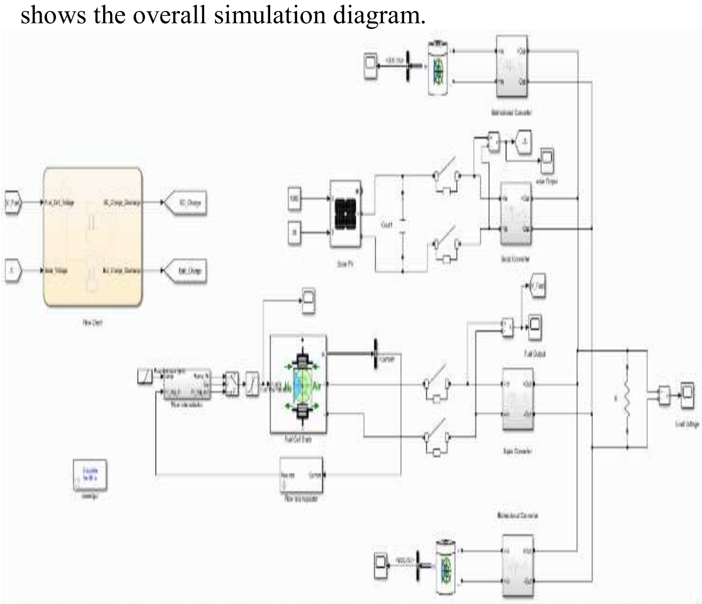

Fig. 5 Simulation circuit

The irradiance of solar panel for 1000W/m^2 and temperature of 30°C is shown in Fig. 6. The corresponding output voltage, output current, output power and duty cycle of the converter is shown in Fig. 6a – 6d.

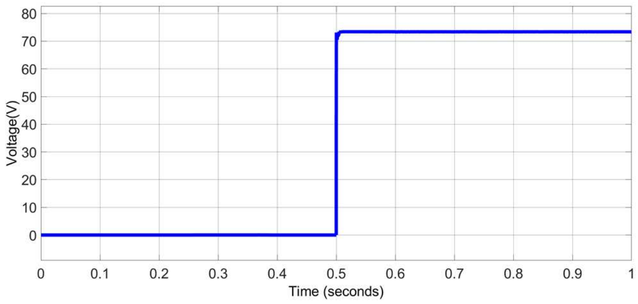

Fig. 6 Solar PV voltage for irradiance of 1000W/m2 and temperature of 30˚C

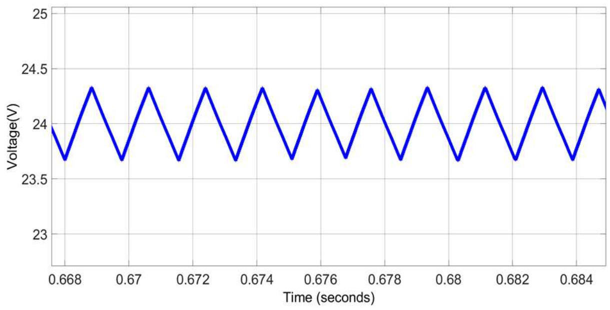

Fig. 6a. SEPIC Converter output voltage of solar PV

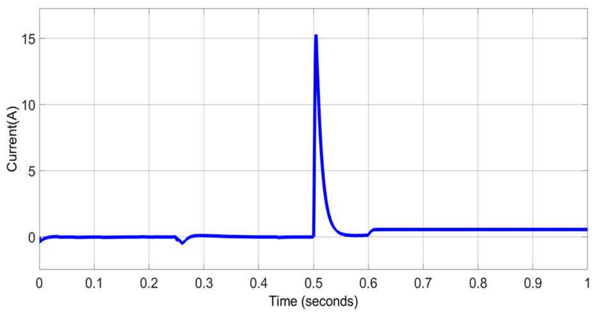

Fig. 6b SEPIC Converter output current of solar PV

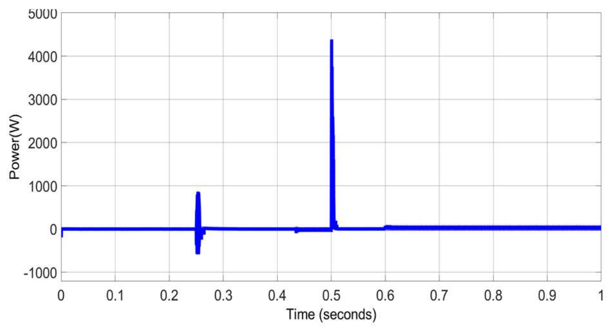

Fig. 6c SEPIC Converter output power of solar PV

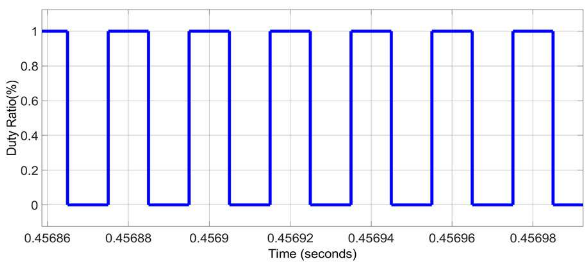

Fig. 6d Duty cycle of SEPIC converter for solar PV

At time t=0.5 sec solar panel is exposed to light of 1000w/m$^{2.}$ The panel produces maximum voltage of 14V and stepped up to 24V with ripple of 0.6 and power of 8W.

The fuel flow rate of 1lpm is given to fuel cell and produces an output voltage of 14.7V and the SEPIC produces output voltage of 24V and power of 8w approximately. The relevant waveforms are presented in Fig.7a – 7d.

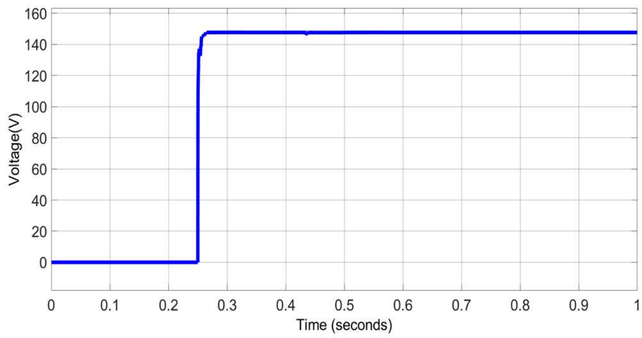

Fig. 7a Fuel cell output voltage

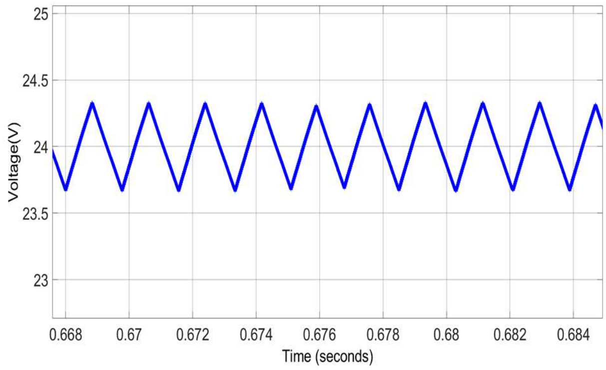

Fig. 7b SEPIC Converter output voltage of fuel cell

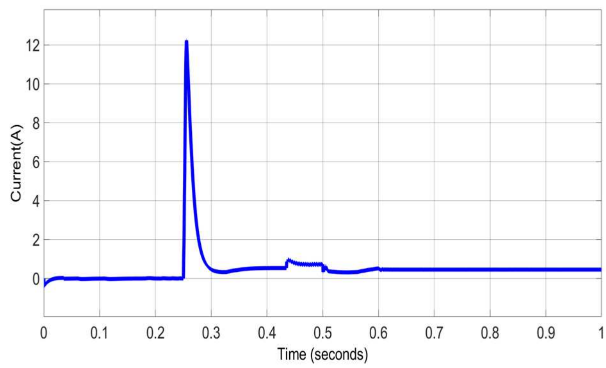

Fig. 7c SEPIC Converter output current of fuel cell

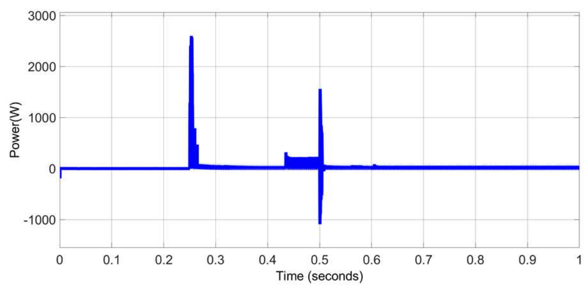

Fig. 7d SEPIC Converter output power of fuel cell

Fig. 8 shows the state of battery charge. Always SOC is maintained at 80%. At 80% of SOC, battery's nominal voltage is 12V, which is boosted using bidirectional dc dc converter. Thus, 24V dc bus is successfully obtained. In case of insufficiency of power from solar PV, battery is charged using fuel cell and storage battery.

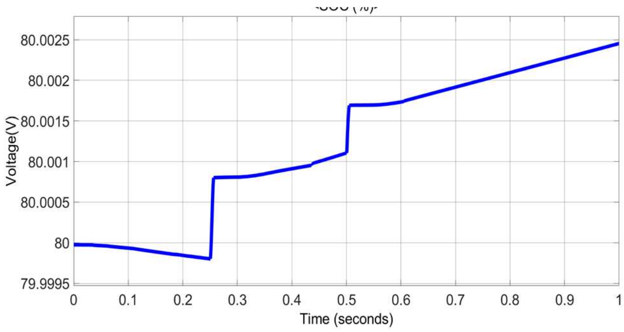

Fig. 8 Battery SOC

At time t=0.5 Sec, both the sources are feeding power to the load. Hence, the bidirectional converter charges the battery and is shown in Fig. 9. Ie power flows from load to battery. Energy from the solar PV is less, the battery discharges with the help of bidirectional dc dc converter. The battery performs both charging and discharging. In all cases the output voltage is maintained at 24 with ripple voltage of 0.8V is given in Fig. 10.

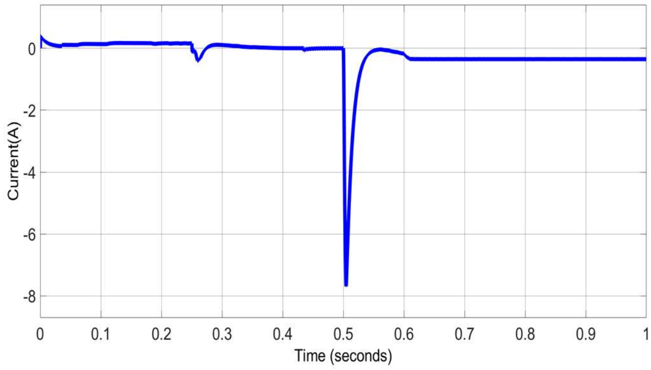

Fig. 9 Bidirectional DC-DC Converter output current

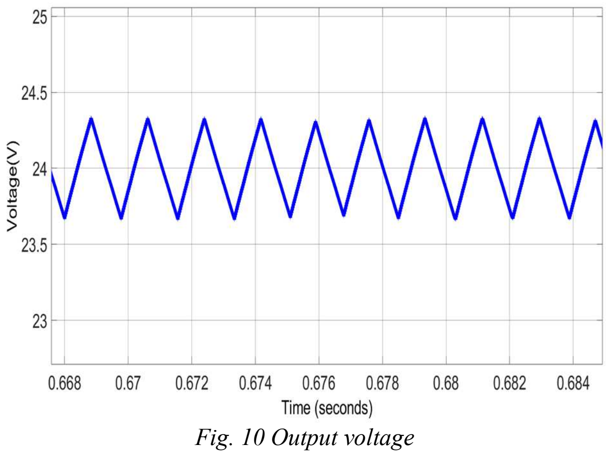

Fig. 10 Output voltage

Table7 presents the results obtained for irradiance of 1000W/m2 and temperature of 30˚C. The output DC voltage is always maintained at 24V.

IV. CONCLUSION

Solar PV and fuel cell-based EV charging station is designed and implemented with lithium-ion battery. DC bus voltage of 24V is maintained for varying irradiance, fuel flow rate and for various load. Battery charging and discharging is controlled using bidirectional converter. These converters are controlled using PI controller which provides dynamic response. EV charging stations powered by renewable energy requires very less maintenance and no external power source. Thus, lowering grid power fluctuations, which enhances the quality of the electricity. The control algorithm guarantees that the system operation more efficient and stable. The design criteria can be modified to accommodate the unique requirements of various EV models and points.

Table 7 Results for irradiance of $1000W/m^2$

Parameters	Vin(V)	Vo(V)	Io(A)	Po(W)
Solar PV SEPIC Converter	30	23.7931	0.3235	7.697
Fuel cell SEPIC Converter	14.7	23.7931	0.3231	7.687
Storage Battery	12	23.7931	0.1644	3.9115

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