Solar PV Tied Electric Vehicle Charging System Using Bidirectional DC-DC Converter

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***Abstract*—Renewable energy-based battery charging systems for Electric Vehicles (EV) have seen surge in automotive research in last few years. Solar PV-fed EVs are thoroughly examined in this research. Among the many benefits of using batteries to store energy in ground vehicles include zero emissions, load levelling, excellent transient functioning, and ability to recover energy while braking. To meet these criteria, bidirectional DC-DC converter is needed to connect PV to battery's dc-link. A PV-powered electric vehicle must be able to operate in two distinct modes: charging and discharging. Maximum Power Point Tracking (MPPT) technique is utilized in this study to harvest most power by solar PV. In addition, DC-DC converter with bidirectional output requires closed-loop control circuit which is proposed in this paper. MATLAB simulations are used to confirm system's efficacy.**

Keywords—DC-DC Converters, Electric Vehicle, PI Controller, Renewable Energy.

I. INTRODUCTION

Growing environmental concerns, energy conservation, with global warming have caused shift toward developing industry in which renewable energy is seen as one of its strongest foundations by governments, businesses, and people alike. As an instance, EV has emerged as significant issue for both public and scholars [1]. In addition to wind and solar power, renewable energy sources also include hydel, ocean, and thermal sources [2], [3]. A power electronic converter including boost converter or DC-DC bidirectional converter may regulate flow of harvested energy and be used for wide range of applications [4], [5]. These converters are needed to harness these energies. Historically, SCRs were used to regulate all of these converters. A broad range of frequencies may now be operated by contemporary switches like MOSFETs and IGBTs [6], [7]. Inductors and capacitors may be reduced in size and cost by increasing frequency of operation [8]. Fast charging of batteries is also necessary in order to compete with petrol stations. This research demonstrates how an electric vehicle may be powered entirely by solar energy. Solar PV arrays are amongst easiest to install of renewable energy sources, and ever decreasing cost of PV modules further ads to their appeal. As a result, PV array-based EV battery charging has become preferred method of charging for many EV owners [9], [10]. There's a requirement for an intermediate DC-DC converter as well as bidirectional DC-DC converter for combining PV array with EV battery [11]–[13].

Plug-in hybrid electric vehicles (PHEVs), fuel cell vehicles, and Uninterruptible Power Supplies (UPS) all use bidirectional DC-DC converters as an essential part of their power conversion systems. Using DC-DC converter is critical when switching from low-voltage battery to high-voltage source to charge household appliances. There are two types of bidirectional DC-DC converters: isolated as well as non-isolated. Non-isolated has higher efficacy because of its basic design. There's been several topologies published recently that use soft switching approach to improve efficiency of power transfer [14]. Soft switching by hysteresis current controller required introduction of bidirectional converters with connected inductors [15]. Zero-Voltage-Switched (ZVS) and Zero-Current-Switched (ZCS) techniques were developed for bidirectional converters to reduce switching losses as well as increase reliability [16]. High power applications benefit from use of multiphase bidirectional converter. With low switching frequency, many converters may be linked in parallel or series to reach large voltage or current ratings [17]. For bidirectional converters using complimentary switching among topmost and bottom switches, unified current controller was presented [18].

Purpose of this study is to discuss usage of a bidirectional DC-DC converter in PV fed EV system. For functioning of converter in both buck (charging mode) as well as boost (discharging mode) modes, closed loop control approach is presented. Fig.1 is the schematic representation of PV-powered electric vehicle. It comprises of a PV module that is coupled to boost converter for boosting output voltage. Further DC-link is created in between boost converter and bidirectional converter for transferring the voltage. This bidirectional DC-DC converter is then connected to EV which is represented with a battery. This entire setup is made using MATLAB/Simulink to test and validate the working.

II. CIRCUIT DESCRIPTION

Fig. 2 depicts continuous conduction of DC-DC converter. Anti-parallel diode D1 serves as boost mode diode in this design, which modulates switch S2 to operate the boost converter. The anti-parallel diode D2 serves as buck mode diode when flow of power is reversed, transforming topology in buck converter by switch S1. The inductor current in two modes is going in opposing directions, as should be noticed. Fig. 3 depicts gate drivers for switches S1 as well as S2.

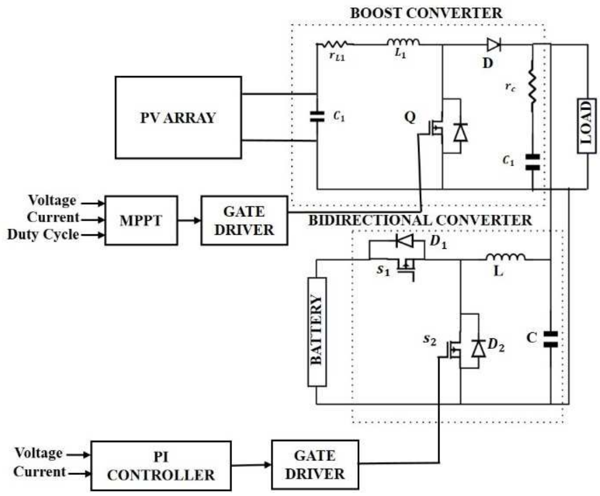


Fig. 1. Schematic diagram of solar PV fed EV.

When converter is operating in continuous conduction mode, state space representation is represented in (1),

$$A.\begin{bmatrix} I_L \\ V_1 \\ V_2 \end{bmatrix} + B.\begin{bmatrix} V_L \\ V_H \end{bmatrix} = 0 \quad (1)$$

Where $A = \begin{bmatrix} \frac{-r_l}{L} & \frac{D}{L} & \frac{-1}{L} \\ \frac{-D}{C} & \frac{-1}{R_1 C} & 0 \\ 1 & 0 & \frac{-1}{R_2} \end{bmatrix}$

$$B = \begin{bmatrix} 0 & 0 \\ 0 & \frac{1}{R_1 C} \\ \frac{1}{R_2} & 0 \end{bmatrix}$$

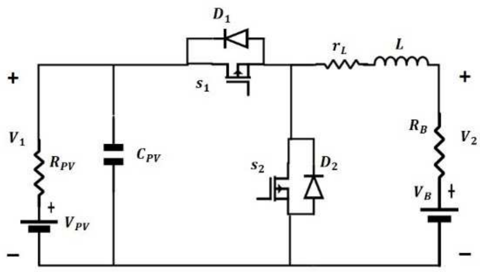


Fig. 2. Bidirectional DC-DC converter.

A. Comparison with Previous Converters

Table I shows the comparison result of proposed converter with available bidirectional DC-DC converters. The parameters like switch count, inductor count, capacitor count, coupled inductor and common ground are the basic components that has dynamic role into designing converter circuit. Less number of components less will be the complexity of circuit. By table it could be observed that suggested converter requires very less number of switch

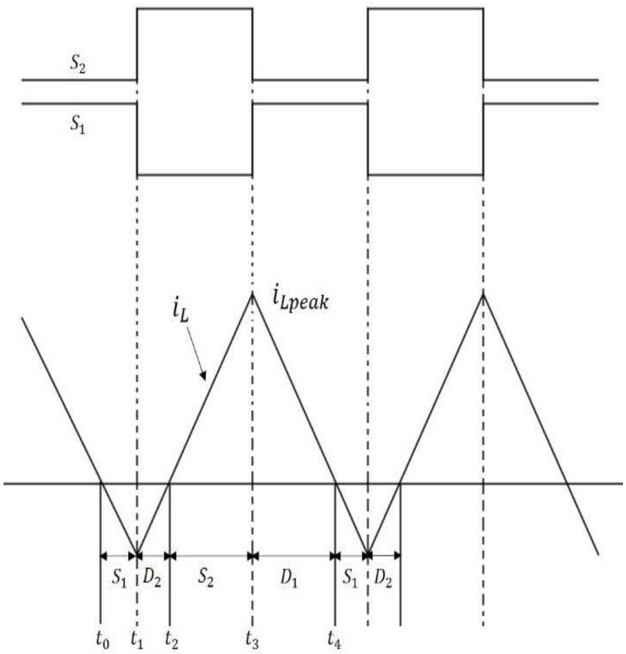


Fig. 3. Gate drivers for switches and diodes.

count as compared with [19]–[23]. The converter in [21] and [23] requires equal number of switch count. The converter [22] requires highest number of switch count. Another parameter is inductor count. The proposed converter, [19] and [20] require equal number of inductors. The converter [21] and [22] does not require any inductor. The converter [23] requires highest number of inductor count. Similarly for capacitor count, [23] and [21] require highest number of capacitor. Proposed converter requires only one capacitor count which makes it simpler. As the proposed converter is of non-isolated type, there is not any requirement of coupled inductor. Converter [22] uses coupled inductor in its circuit.

III. Control Technique

In this study, two types of control were used. In solar PV, most often utilized algorithms is Maximum Power Point Tracking (MPPT) method. Even though certain modules may be affected by shadowing, MPPT algorithm plays an important role in extracting optimum power from solar PV panel throughout all times. Although certain modules have been obscured, remainder of battery pack will be energized to guarantee that EV functions properly. MPPT adjusts the value of solar PV power in line with the load or battery charger need. Another control method is for converter circuit.

Bidirectional DC-DC converters may operate in both buck - boost converter modes, hence control circuit has been built as illustrated in Fig. 4. PI controller and PWM generator comprise responses closed loop control circuit block diagram, which detects and controls error signal in relation to reference signal. Inner current loop as well as outer voltage loop are part of control circuit. In the outer voltage loop, we calculate V_b (battery's voltage) as well as contrast it to V_{ref}. PI controller receives difference among two values. Using PI controller, steady state error among battery current being measured as well as reference battery current being monitored may be reduced or eliminated.

TABLE I. COMPARISON WITH VARIOUS PARAMETERS OF CONVERTERS

Converters	Proposed Converter	Converter [19]	Converter [20]	Converter [21]	Converter [22]	Converter [23]
Inductor Count	1	1	1	0	0	2
Capacitor Count	1	3	3	4	3	4
Coupled-Inductor	0	0	0	0	2	0
Common Ground	Yes	Yes	Yes	Yes	Yes	No

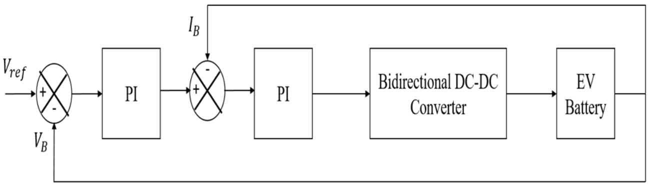


Fig. 4. Closed loop control circuit for bidirectional DC-DC converter.

PI controller's transfer function is specified by

$$G(s) = K_P + \frac{K_I}{s}$$

Proportional as well as integral gains are denoted by notation K_P and K_I , respectively. Then return to current iteration of loop. Lastly, when compared to I_b (battery's current), difference is sent to PWM modulation via other PI controller. Stable PV voltage as well as steady EV current may be obtained via controller

IV. SIMULATION RESULTS

In this section, the performance of the proposed model of Bidirectional DC-DC converter is analyzed utilizing the MATLAB Simulink platform. Figures below showing various parameters including the PV module voltage, current and corresponding power, DC link voltage, EV battery voltage, battery's State of Charge (SoC) at different level of irradiations on the PV side. It's not regarded inductor parasitic resistance or MOSFET turn-on resistance. To determine if suggested topology works, following converter parameter values are taken into account throughout testing process.

Principal Parameters of the Bidirectional converter are: L = 500μH, C = 1000μF, f_{SW} = 5kHz.

Battery capacity = 50 Ah, initial SoC = 45%, Battery nominal voltage = 24 V.

Fig. 5(a) and 5(b) shows the battery voltage and battery current respectively with increase or decrease of the irradiation of the solar energy available to the PV module, that different irradiation levels of 0 W/m^2 and 500 W/m^2. In Fig.5(a) it can be seen that the battery voltage is increasing slowly with time that shows the charging mode of EV battery and same charging nature can be seen in terms of current in Fig.5(b), the decreasing nature of battery current. The Fig.6(a), 6(b) and 6(c) showing the voltage, current and power levels of a PV module at 500 W/m^2 of irradiation and cell temperature of 25℃. Fig. 7 represents the irradiation level of 500W/m^2. After passing this output voltage of a PV module to the battery side through a common point i.e. a DC link, with using Bidirectional DC-DC converter corresponding battery charging voltage as well as charge state of the battery can be observed into Fig. 8 that depicts the rising nature, showing the charging mode of the EV battery.

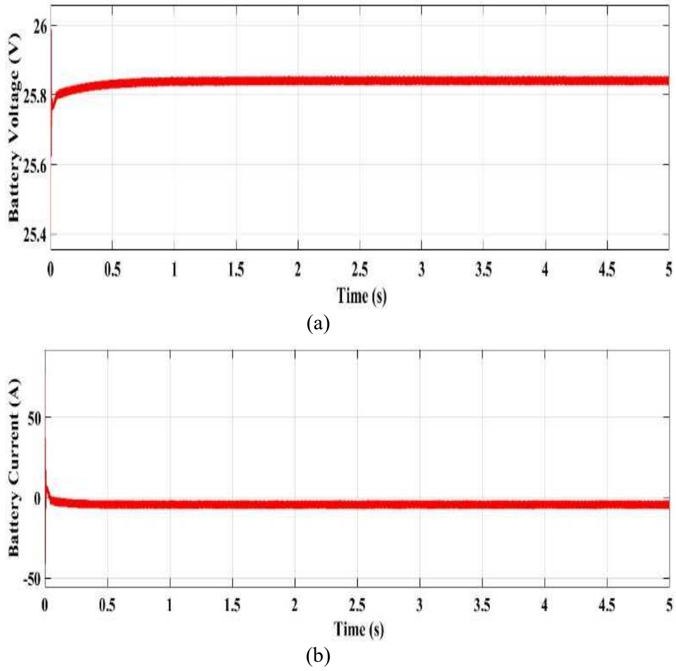
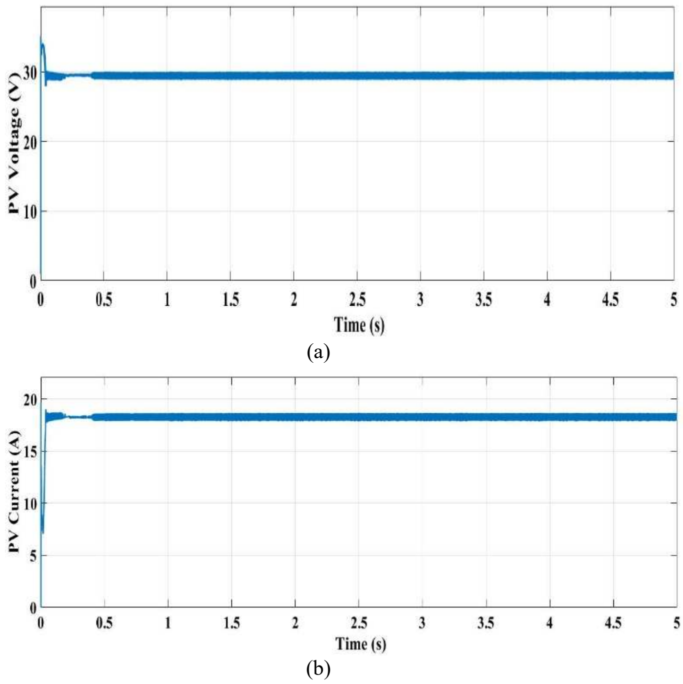
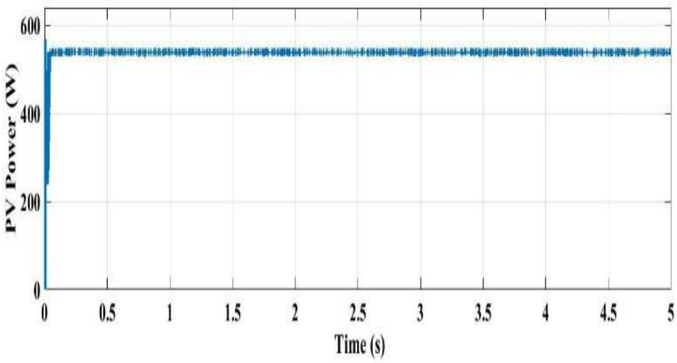


Fig. 5. Battery (a) Voltage (b) Current with respect to irradiation of solar energy.





(c)

Fig. 6. Solar PV (a) Voltage (b) Current (c) Power at irradiation of 500 W/m^2.

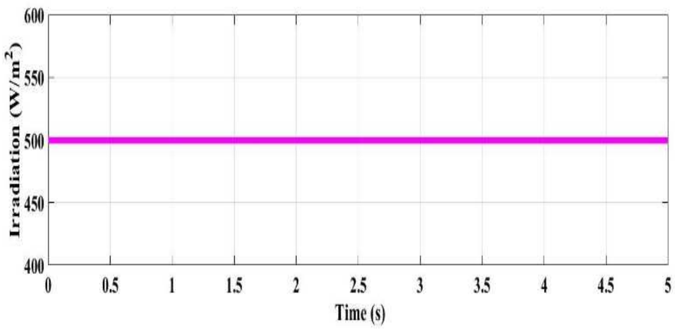


Fig. 7. Solar PV irradiation at 500 W/m^2.

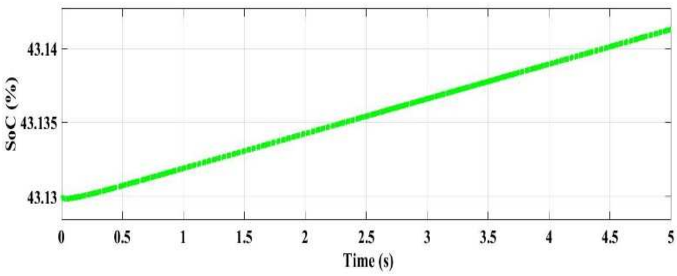


Fig. 8. Battery SoC showing its charging mode.

V. Conclusion

Hybridized electric solar cars have become more popular in contemporary period because of their solar PV panels. An effective battery charging system and cost-effective EVs have resulted from recent technological developments in this field. This paper proposes the integration of PV panel with EV battery charging system through a bidirectional DC-DC converter. The converter circuit is compared by various topologies. The converter used in this paper does not require coupled inductor which makes the circuit more simplified. Also, the number of inductor and capacitor used are very less compared to these topologies. This converter operation is controlled through PI controller and switching of charging and discharging modes can be done. This battery charging is well-suited to PI controller control strategy that has been suggested. Additionally, MPPT algorithm is employed to harvest optimum power by solar PV under all different irradiation situations. EV's operation will not be disrupted in this way. DC-DC converter as well as control circuit have been shown to work as described in previous section.

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