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Photovoltaic Based Off-Board Electric Vehicle Charging Stations

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Abstract
With the development of electric vehicles during the past ten years, the automotive sector has flourished (EV). The development of EVs is heavily dependent on the battery charging infrastructure. The load requirement on an EV battery increases when it is charged from the grid. This prompts the suggestion in this study of an off-board photovoltaic (PV) array-based EV battery charging solution. The EV battery must always be charged regardless of solar radiation, which is accomplished by using a backup battery bank in addition to the PV array. The suggested solution can charge the EV battery during both sunny and cloudy periods thanks to the boost converter and a bidirectional DC-DC converter. The backup battery facilitates the charging of the EV battery during non-sunny hours and simultaneously charges the EV battery during peak sunlight hours. Simulink in the MATLAB software is used to simulate the suggested charging system, and the findings are provided in this paper.
Keywords: *Electric Vehicle, Charging Station, Fast Charging, Photovoltaic.*

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I. INTRODUCTION

The EV's environmental, technological, and economic potential have sparked the integration of electrical power and transportation networks in ways that were previously unthinkable [1]. The charge of the batteries—the source of power for the EV traction, control, lighting, and air-conditioning system—is the fundamental link between the two sectors. However, charging the EV via the electrical grid places an additional stress on the utility, especially during peak demand periods [2,3]. Promoting charging from renewable sources is one feasible method for reducing the grid's negative effect. The usage of this type of clean energy is expected to have a positive influence on the environment while also improving the overall charging system efficiency [4,5].

With the price of photovoltaic (PV) modules continuing to fall, solar power is becoming more widely acknowledged as a cost-effective energy source to supplement the grid [6,7]. Furthermore, both in terms of fuel and labour, the PV system is nearly maintenance-free [8].

Power converters are required to charge the EV battery because the PV array is intermittent. Due to their ability to interface power sources and energy storage components like PV arrays, ultracapacitors, super capacitors, fuel cells, and batteries with the loads in EVs like motors, lights, power windows and doors, radios, amplifiers, and mobile phone chargers, multiport converters (MPCs) are preferred among various converters in the onboard chargers of hybrid EVs. As all the sources are contained within the EV itself, the MPCs have the disadvantage of increasing the weight, cost, and maintenance of the EV. Additionally, in these converter-based EV battery charging systems, the complexity of controller implementation rises [9–11]. Therefore, an off-board charger is suggested in this study, where the PV array and backup battery bank are situated in the charging station or parking station and the EV battery is housed inside the vehicle unit. The literature [12–14] presents a number of converter topologies for off-board charging systems.

The boost converter is the most popular converter topology because it can operate in boost mode. The advantages of low input current ripple, low EMI, and the identical input and output voltage polarity are also present [15, 16]. An auxiliary storage battery bank is necessary to charge the EV battery during times of low solar irradiation and darkness. Depending on the solar irradiation, this backup battery bank needs to be charged in a forward direction and discharged in a backward manner. A bidirectional converter that can transmit power in either direction is therefore necessary [17].

Bidirectional DC-DC converter (BIDC) is a favoured non-isolated bidirectional converter topology because of its benefits including increased efficiency in discontinuous conduction mode, low inductance value, and reduced ripple current as a result of multiphase interleaving technology. By using zero voltage resonant soft switching approach, the snubber capacitor across the switches lowers the turnoff losses and the inductor current parasitic ringing effect is also decreased. These additional benefits of this bidirectional converter are listed in

[18–20]. The off-board EV battery charging system in [20] uses a bidirectional DC-DC converter to charge the EV battery from PV array electricity when the vehicle is stationary and discharges the EV battery to power the dc load when the vehicle is moving. Its limitation to solar-only charging of EV batteries is a negative. The proposed charger was created using a PV array integrated with a sepic converter, a bidirectional DC-DC converter, and a backup battery bank to get around this drawback and charge the EV battery without any interruptions.

II. PROPOSED SYSTEM

A PV array, a boost converter, a bi-directional dc-dc converter, an EV battery, a backup battery bank, and a controller make up the proposed PV-EV battery charger in Fig. 1. The boost converter receives gate pulses from the controller in order to maintain a constant output voltage at the dc link. In order to operate the bidirectional dc-dc converter in boost mode, which charges the backup battery from the PV array, and in buck mode, which charges the EV battery from the backup battery, gate pulses are also created. Auxiliary switches Sa, Sb, and Sc receive gate pulses from the controller as well. All auxiliary switches are turned on during periods of high solar radiation to interface dc links with the PV array via boost converter, dc links with the backup battery via bi-directional dc-dc converter, and dc links with the EV battery. Switch Sa is switched OFF to isolate the PV array and boost converter from the dc link when solar irradiation is low. When the solar power is inadequate to charge the backup battery, the switch Sc is switched OFF to disconnect the bidirectional dc-dc converter and the backup battery from the dc connection. The three operating modes of the proposed system—mode 1, mode 2, and mode 3—are described in this section.

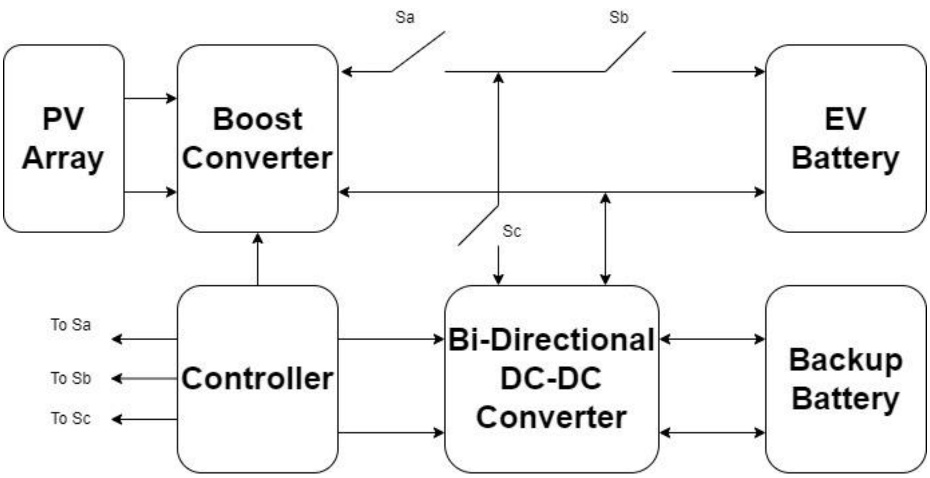

Figure 1: Block Diagram of the proposed system

2.1 Mode 1:

All auxiliary switches are turned on during peak sunlight hours, when the PV array power generated is at its highest, to charge the backup battery and EV battery from the PV array simultaneously using boost converters and bi-directional dc-dc converters, respectively. In this mode, the bi-directional dc-dc converter boosts the dc link voltage in order to charge the backup battery.

2.2 Mode 2:

PV array output is insufficient to charge an EV battery in low solar irradiation circumstances and during hours when it is not sunny. Thus, the bi-directional dc-dc converter connects the EV battery to the backup battery while switches Sb and Sc are turned ON to disconnect the PV array from the dc link. When operating in this mode, the bi-directional dc-dc converter steps down the backup battery voltage to charge the electric vehicle battery.

2.3 Mode 3:

Switches Sa and Sb are turned ON and switch Sc is turned OFF to disconnect the bi-directional dc-dc converter and backup battery bank from the dc connection when the electricity provided by the PV array is sufficient to charge only the EV battery.

III. DESIGN OF THE CONVERTERS

Now, we are going to calculate the battery side parameters.
Specifications of the converter for battery side capacitors and inductors are:
Vin = 800 V
Vout = 360 V
Fsw = 5kHz
Vripple = 0.36 V
Iripple = 3A

$$L = \frac{Vout * (Vin - Vout)}{Iripple * Fsw * Vin}$$

$$L = \frac{360*(800-360)}{3*5000*800} = 13\text{mH}$$

$$C = \frac{Iripple}{(8 * Fsw * Vripple}$$

$$C = \frac{3}{8 * 5000 * 0.36} = 20uF$$

IV. DESIGN OF CONTROLLERS

The boost converter, bi-directional dc-dc converter, and three auxiliary switches are all connected to the controller of the proposed charger through gate pulses. Fig. 2 depicts the algorithm used to toggle the auxiliary switches ON and OFF. The PV array voltage and current are sensed by the controller, which also calculates the PV array power. The controller generates gate pulses to turn ON all auxiliary switches in order to charge both the EV battery and the backup battery bank simultaneously from the PV array if the PV array power is greater than the rated power of the EV battery, PR. The PM, the switch Sc is turned OFF to disconnect the backup battery from the charging system, and switches Sa and Sb are switched ON to charge the EV battery solely from the PV array if the PV array power is less than the rated power of the EV battery but greater than the minimum required power. The switch, Sa, is switched OFF to isolate the PV array and boost converter from the charging system if the PV array power is less than the minimum needed power, PM. The backup battery may now charge the EV battery because the switches Sb and Sc are ON. In order to maintain a constant voltage at the dc link regardless of changes in the PV array voltage, the proposed charging system uses the PI voltage controller to generate gate pulses to the MOSFET in the boost converter.

Two switches make up a bidirectional dc-dc converter. The two switches in the must receive gate pulses that are 180 degrees out of phase with one another. Depending on the power of the PV array, the controller in the proposed system creates two gate pulses for the bi-directional dc-dc converter. Gate pulses are generated to the BIDC switches to operate it in boost mode, increasing the dc link voltage to charge the backup battery bank if PV array power exceeds PR. The gate pulses are generated appropriately to operate the bi-directional dc-dc converter in buck mode, creating a step down voltage at the dc link sufficient to charge the EV battery by the backup battery if the PV array power is less than PM.

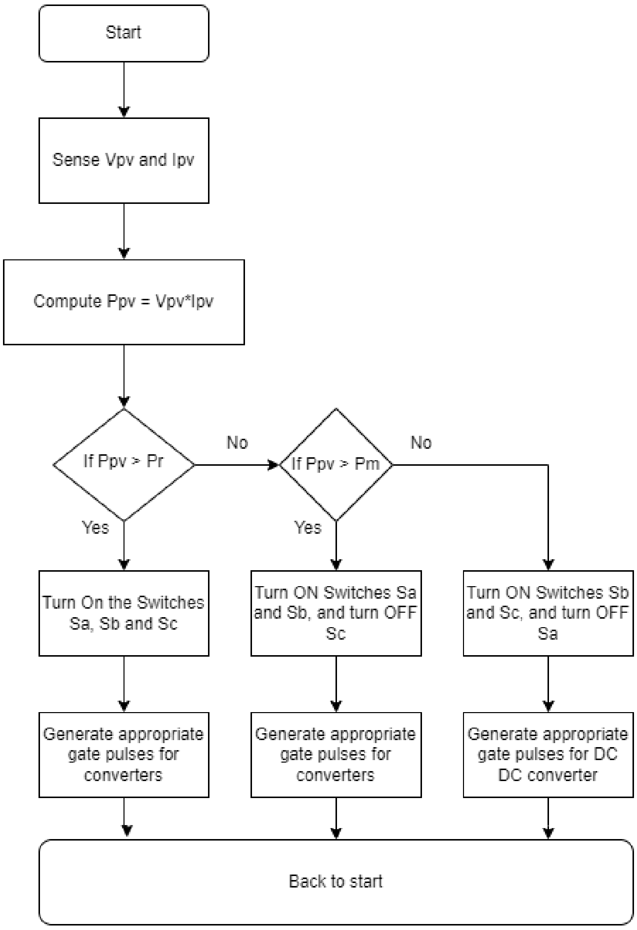

Figure 2: Flow chart of the control system

V. SIMULATION AND RESULTS

For the simulation studies of the suggested system, Simulink in the MATLAB software is employed. The classical equation for the PV array is used to model it [21, 22]. Power MOSFETs, inductors, and capacitors from the SimPowerSystems Blockset in the Simulink library are used to mimic the boost and bi-directional dc-dc converter converter. The Simulink library's PWM generator, pulse generator, logic gates, comparator, multiplier, and PI controller are used to create the controller. For the purpose of creating the suggested charging system seen in Figure 3, the battery models already included in the Simulink library are integrated with the boost converter and bidirectional dc-dc converter that have been constructed.

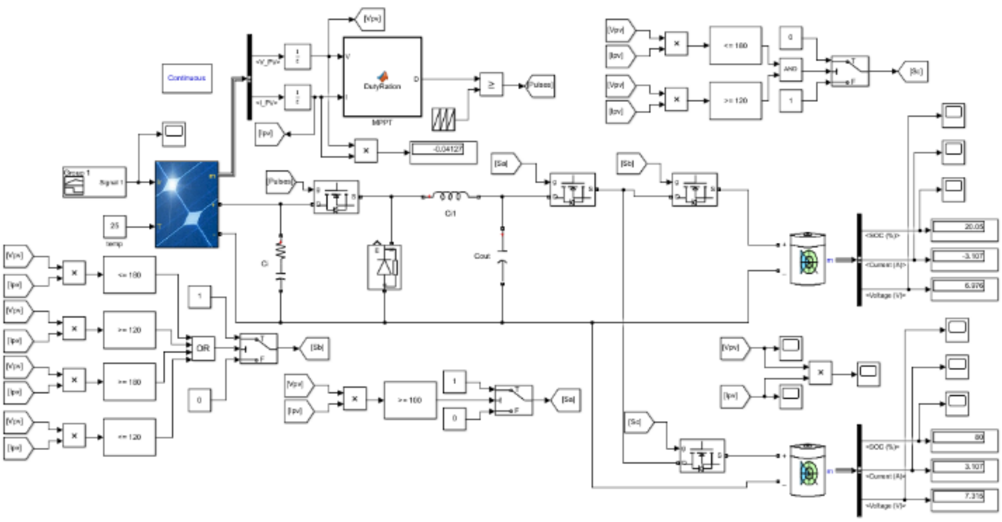

Figure 3: Mathematical Model of the simulated system

Using the created simulation model for PV array irradiation of 1000, 750, and 100 W/m2 in modes 1, 2, and 3, respectively, the dynamic response of the system was explored. Fig. 5-13 depicts the simulation results, which illustrate the voltage and current waveforms of the PV arrays in addition to the gate pulses to the auxiliary switches. Figure 4 displays the radiation waveform. In the full irradiance mode, the EV battery and the backup battery are charged simultaneously. As PV power is insufficient to charge the EV battery at low irradiation of 100 W/m2, the gate pulses of the auxiliary switches Vb and Vc are high and the gate pulse of Va is low. In order to charge the EV battery in this mode, the backup battery bank discharges using a dc-dc converter.

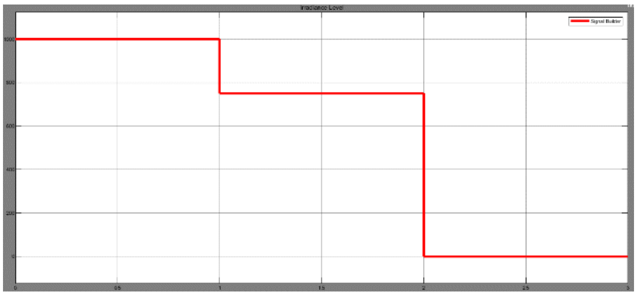
Figure 4: Irradiance level of PV array

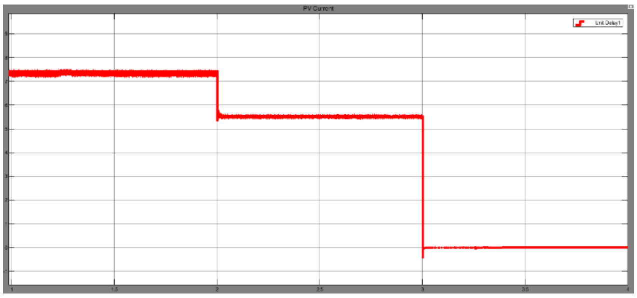
Figure 5: PV Current

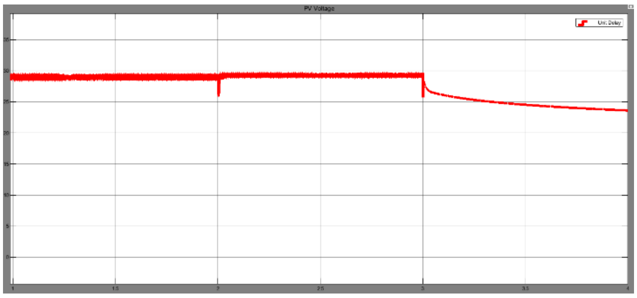
Figure 6: PV Voltage

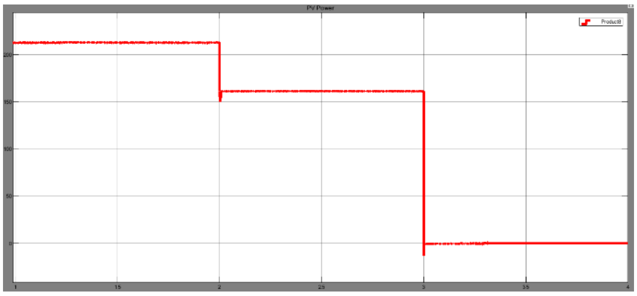
Figure 7: PV Power

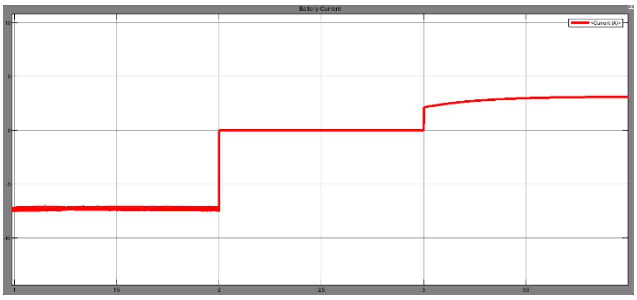

Figure 8: Current waveform for Backup Battery

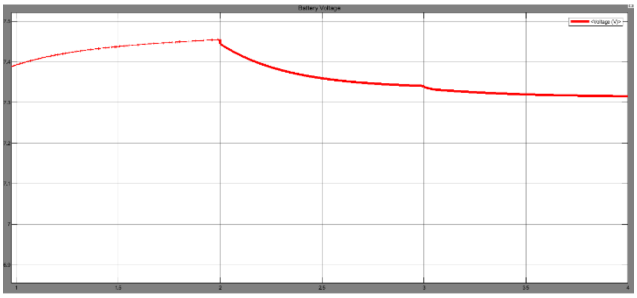

Figure 9: Voltage waveform for Backup Battery

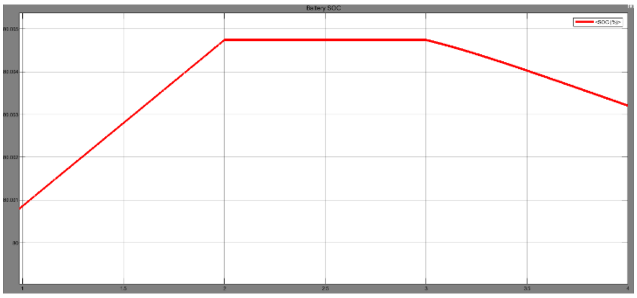

Figure 10: State of Charge for Backup Battery

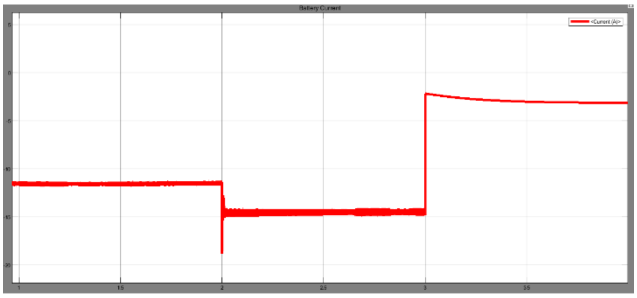

Figure 11: Current waveform for EV Battery

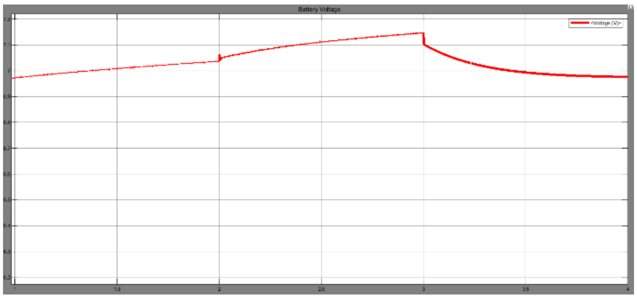

Figure 12: Voltage waveform for EV Battery

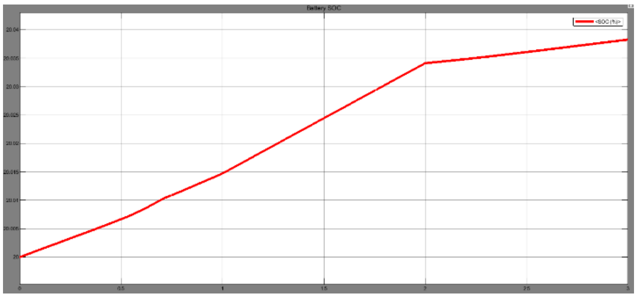

Figure 13: State of Charge for EV Battery

The auxiliary switches Sa and Sb are ON during irradiation of 750 W/m2, while switch Sc is OFF, isolating the backup battery from the system. Backup battery is segregated and not charged in this mode since PV array power is only adequate for charging EV batteries. As the EV battery is continuously charged in all three modes, the gate pulses to the switch Sb are always high. In order to prevent trickle charging of the EV battery after it is fully charged, the EV battery is separated from the charging system by activating OFF Switch, Sb.

The simulated dynamic waveforms of the PV array, EV battery, and backup battery are shown in the above figures for the respective irradiation values. The EV battery is charging in this mode, as evidenced by the rising state of charge (SOC) of the battery in Figure 14.

PV array voltage charges the EV battery in mode 2. Additionally, in this mode, the SOC of the EV battery is rising and the current is negative, signifying that the EV battery is charging. Backup battery voltage is kept at its prior value and current is decreased to zero in mode 2 as the backup battery is isolated from the charging system, as shown in Fig. 8 and 10. The EV battery's SOC is growing and its current is negative in all three modes, as shown in Fig. 11, indicating that it receives constant charging from either a PV array or a backup battery.

The PV array voltage and current waveforms displayed in Fig. 5-7 correspond to mode 3 (during non-sunny hours and low irradiation circumstances), which isolates the PV array and raises the voltage and current to their respective open circuit voltages of 37.25 V and 0 A, respectively. During this time, the bi-directional dc-dc converter steps down the backup battery voltage to charge the EV battery while operating in reverse direction in buck mode. The backup battery's positive current and declining SOC are depicted in Figure 8. It means that when in this mode, the backup battery is depleted.

VI. CONCLUSION

In this work, a PV-powered off-board EV battery charging system is suggested. This study examines the system's adaptability to continuously charge the EV battery regardless of the irradiation circumstances. The Simulink environment of the MATLAB software is used to develop and simulate the system. The simulation's outcomes highlight the viability of the suggested charger.

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