# Off-Board Electric Vehicle Battery Charger Using PV Array

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***Abstract-*** *The demand for efficient and environmentally friendly battery charging solutions has been heightened by the quick advancements in the automotive sector, which have sped up the acceptance of electric vehicles (EVs). Electric vehicle charging on the conventional grid results in non-renewable energy use and peak load stress. This study presents a grid-independent method of charging electric vehicle (EV) batteries that is based on photovoltaic (PV) arrays and may be used off-board. To ensure that electric vehicle batteries can be charged regardless of fluctuations in solar irradiation, it is advised to have a backup battery bank and PV array. To prevent the PV output voltage from fluctuating, a Single-Ended Primary Inductor Converter is used. The Perturb and Observe (P&O) algorithm used in the ATmega328 microcontroller guarantees the most efficient energy extraction from PV arrays in a wide range of environmental circumstances using Maximum Power Point Tracking (MPPT). You may regulate the charging and draining of the EV battery and backup battery using a bidirectional DC-DC converter. During times of maximum sunlight, the PV array charges the primary and secondary batteries of the electric car. In cloudy or low-light conditions, the electric vehicle may still be powered by the backup battery. The complete system, including power electronic converters, sensors, gate drivers, and the ATmega328 controller, is modeled and simulated using Proteus Design Suite. Unlike conventional MATLAB/Simulink-based system-level simulations, Proteus enables real-time hardware-oriented validation with embedded C code execution, PWM signal generation, ADC-based sensing, and LCD interfacing. Experimental validation through laboratory prototype testing confirms stable voltage regulation, efficient MPPT performance, smooth bidirectional power flow control, and reliable EV battery charging. With better energy management and increased dependability, the suggested system proves to be an efficient, affordable, and scalable answer for autonomous solar-powered electric vehicle charging applications.*

## 1. INTRODUCTION

The automotive business has changed due to the rise of electric cars (EVs) in the recent decade. The future of EV technology depends on the reliability and efficiency of battery charging infrastructure. Traditional EV charging methods use utility grid electricity, which increases during peak charging periods. The authors of this work set out to solve this issue and advance sustainable energy by suggesting an off-board method of charging electric vehicle (EV) batteries using solar (PV) arrays.

The suggested setup relies on photovoltaic (PV) array-generated solar energy as its principal power source for charging electric vehicle (EV) batteries. Solar irradiance and weather fluctuations are two environmental factors that significantly impact solar power output. There is a backup battery bank built into the system so that charging may continue continuously even when sunlight isn't available. The electric vehicle's battery may be successfully charged in both sunny and overcast weather with this backup energy storage.

To optimize power transfer between the PV array, backup battery, and EV battery, a three-phase bidirectional DC-DC converter and a Single-Ended Primary Inductor Converter (SEPIC) are used. During the solar energy peak hours, the electric vehicle's main battery and backup battery bank are charged at the same time. However, even in low-light conditions, the electric vehicle's backup battery continues to charge the battery, ensuring reliable and continuous charging.

We use MATLAB/Simulink to model and simulate the system in order to verify that the suggested charging architecture works. In addition, a working model of the charging system is created and evaluated in a controlled environment. The modelling and experimental findings show that the charging performance is enhanced, energy is used efficiently, and the reliance on the traditional power grid is minimized. In sum, the planned PV-based EV charging system helps with green mobility and backs the incorporation of renewable energy into current electric car infrastructure.

## II. OVER ALL SYSTEM ARCHITECTURE

- Solar PV Array
- SEPIC Converter (MPPT Controlled)
- Bidirectional DC–DC Converter
- Backup Battery (24V)
- EV Battery
- ATmega328 Microcontroller Control Unit
- Voltage and Current Sensors
- Gate Driver Circuit (TC4420)
- LCD Display Module

## III. PHOTOVOLTAIC EFFECT

Photovoltaic (PV) technology uses semiconductors that exhibit the photovoltaic effect to transform solar energy into direct current power. Electricity is produced by photovoltaic cells found in solar panels. Some examples of photovoltaic materials include cadmium telluride, polycrystalline silicon, amorphous silicon, copper indium selenide/sulphide, and polycrystalline silicon. The growing need for environmentally friendly energy has spurred recent advancements in solar cells and photovoltaic arrays. Although solar photovoltaics only account for a tiny percentage of the world's capacity (4800 GW), they have been the fastest-growing power-generating technology since 2010. This technique is used by more than 100 countries.

From 2004 to 2009, the capacity of grid-connected PV systems increased at a rate of 60% per year, reaching 21 GW. Both ground-based systems, often used in agriculture and grazing, and building-integrated photovoltaics (BIPV) are possible. 3–4 GW are generated by PV systems that are not connected to the grid. Photovoltaic costs have dropped since the invention of solar cells due to technical advancements, greater production runs, and increased manufacturing experience. Net metering and financial incentives, such as solar feed-in tariffs, have been advantageous to PV solar projects in a number of countries.

## IV. COMPARABLE CIRCUIT

It is possible to use the same electrical circuit to depict the complex physics of PV cells. Listed below are the circuit specs. Light current (IL) is equal to the output terminal current (I) minus the currents through the diode (Id) and the shunt-leakage (Ish). A number of factors, including series resistance, contact resistance, the depth of the PN junction, the concentration of impurities, and the current flow, contribute to the internal resistance [Rs]. The shunt resistance Rsh is impacted by the leakage current to ground in the opposite way. It is expected that PV cells would not experience any ground leakage (Rsh = □) or series loss (Rs = 0□). For a solid one inch, the resistance levels vary.The median value of 2 silicon cells is 200-300 ;, and it often falls between 0.05 and 0.10 ;. The efficiency of PV conversion is unaffected by Rsh, while Rs is sensitive to variations in Rs. Solar photovoltaic output may be drastically altered by a rise in Rs.

When the diode current Id and shunt leakage current Ish are removed from the same circuit, the external load gets the same current as the illumination, IL. When the load current is zero, or I = 0, get the open-circuit voltage (Voc) of a cell. To get VOc, add IRsh to V. The resistances in a shunt and a series are distinct. Eliminating these resistances allows many to simplify their models of solar cells.

## V. WORKING

Solar panels use the photovoltaic effect to transform sunlight into power. Both the top and bottom layers may have module structures, which are components that carry weight. Most modules contain crystalline silicon wafer cells, cadmium telluride cells, or silicon thin films. Crystalline silicon is widely utilized. Electrically linked to each other and the system, and mechanically shielded against wind, snow, and hail throughout production, transport, installation, and operation, cells are helpful.

Since moisture corrodes the metal contacts and interconnections, it is especially important to shield the delicate silicon cells produced on wafers from it. Due to the performance and longevity reduction caused by their transparent conductive oxide layer, thin-film cells are likewise affected by this issue. While the majority of solar panels lack flexibility, recent advancements in thin-film cell technology have opened the door to semi-flexible panels. Connecting electrical components in series produces a fixed voltage while connecting them in parallel produces a fixed current. To avoid reverse currents, operate in full or partial shade, or keep the lights on all night long, you may need to use individual diodes. If mono-crystalline silicon cells' p-n junctions display enough reverse current properties, they may not be necessary.

## VI. OPERATION MODES

**Mode 1: Buck Mode (Charging Backup Battery)**

Power Flow:

- DC Bus → Converter → Backup Battery
- High side MOSFET switches.
- Voltage is stepped down.
- Controlled charging current.

**Mode 2: Boost Mode (Discharging Backup Battery)**

Power Flow:

- Backup Battery → Converter → EV Battery
- Inductor stores energy.
- Output voltage boosted.
- EV battery charging continues.

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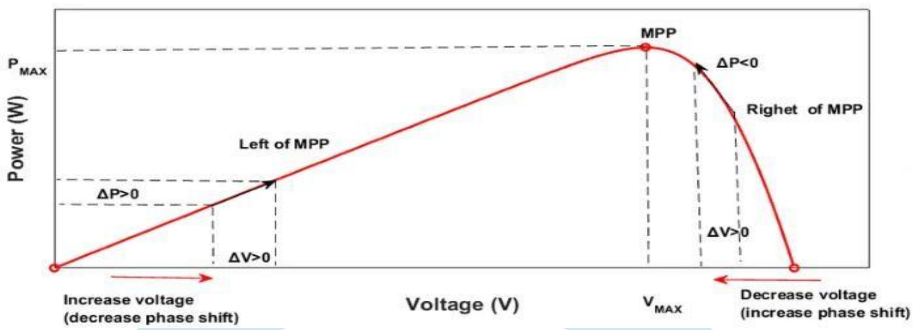



**An attribute of photovoltaic modules is their power-voltage (PV)**

## VIII. PV ARRAY OPERATIONAL ELEMENTS

Light exposure: Photocurrent is highest at 1.0 sun. As light brightens on a half sunny day, photocurrent decreases. The I-V characteristic diminishes with solar intensity. When clouds roll in, short-circuit current drops considerably. However, open-circuit voltage remains almost unchanged.

In practice, sunlight doesn't alter the cell's photo conversion. The findings demonstrate that 500 W/m2 and 1000 W/m2 efficiency is similar. Thus, weather does not effect conversion efficiency. Clouds reduce solar power due to less sunlight reaching the cell.

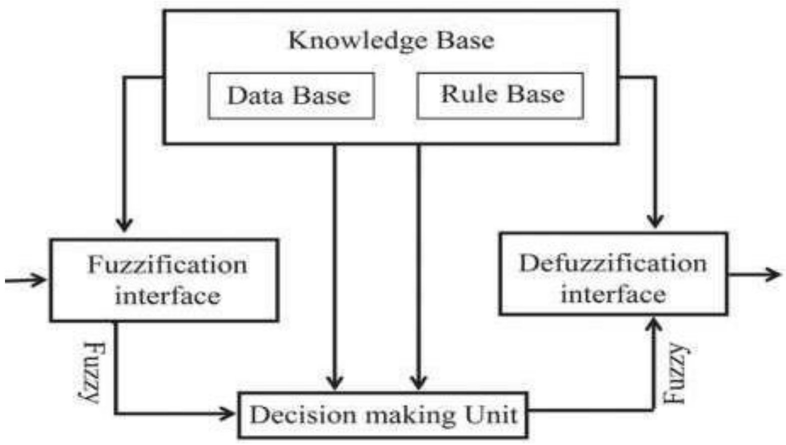
The equation I = Iocos□ may be used to get the cell current, where Io is the reference current under normal solar conditions and □ is the angle, measured in degrees, between the sun line and the normal. This cosine rule is applicable for sun angles ranging from zero to about five hundred. The electrical output deviates significantly from 500 and terminates around 850, contrary to the 7.5% power production predicted by the mathematical cosine rule.

Impact of Shadows: Multiple strings of cells linked in series could make up the array. The illustration shows two of these strings. When a building blocks the sun's path, it might cast a partial shadow over a broad array. Even while operating in direct sunlight, individual cells in a long series string will no longer form a series with one another; the photovoltaic voltage is still required to conduct the current through the string. Without an internal voltage generator, the shadowing cell is unable to produce power. On the contrary, it generates heat and localized I2R loss by acting as a load. The other cells in the string must operate at a higher voltage to compensate for a shadowed cell that loses voltage.

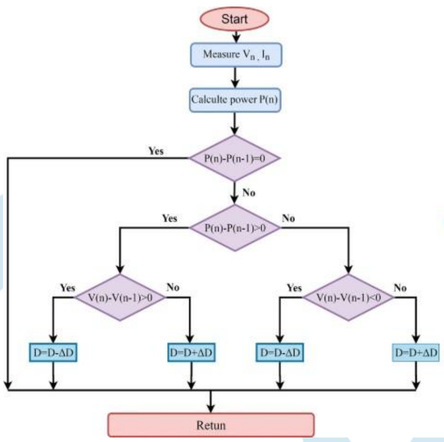
Changes in Temperature: As the temperature of the cell rises, the open-circuit voltage drops and the short-circuit current rises. To evaluate PV power precisely, it is possible to look at the voltage and current impacts of temperature separately. Using reference temperature T and the given temperature coefficients, we may assume ~ and □ for the open-circuit voltage (Vo) and short-circuit current (Io), respectively. The following equations describe the new current and voltage when the working temperature increases by □α. Comparatively, the volume formula for Voc is Vo(1-β.⊔T), whereas the integral equation for Isc is Io(1+α.ΔT).

## IX. Variable Inductor MPPT Method

A maximum power point tracking (MPPT) controller architecture for variable inductance versus current solar power applications is shown below. This approach is still dependable even when insolation levels fluctuate. The total inductor measurement is reduced by 75% when using variable inductance in the DC-DC converter. Scientifically employing the inductor to determine the MPPT shows a relationship between the minimal inductor value and PV current. Figure simplifies this procedure.



**Block diagram of FLC**




## X. MPPT CONTROLLERS

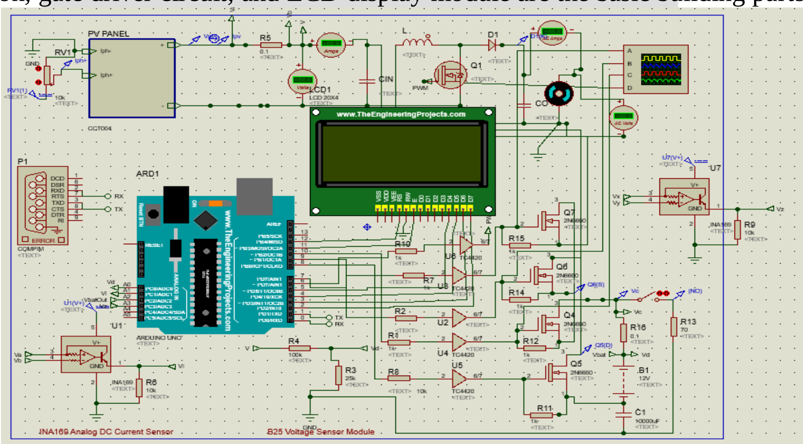
The MPPT controller optimizes PV power harvesting. The controller may purposely operate at MPP to boost PV system efficiency in any conditions. PV source and load coordination should provide maximum power output in any weather. Photovoltaic array output may be maximized by electrical or mechanical tracking.

While electrical tracking makes use of the curve to determine the optimal power point, mechanical tracking adapts the orientation of PV panels to seasonal changes. When operating off-grid, maximum power point tracking (MPPT) distributes power efficiently to the load, batteries, and motors. When operating on-grid, it redirects that power to the power grid. Due to the unpredictable and often inefficient conversion of solar irradiation, photovoltaic (PV) facilities use the maximum power point tracking (MPPT) controller. Please provide a brief description of the MPPT controller.

## XI. PROPOSED SYSTEM DESIGN AND HARDWARE DESCRIPTION

The suggested bidirectional DC-DC converter and MPPT-controlled SEPIC based on the ATmega328 are explained in this chapter for use in electric vehicle charging applications. Using a photovoltaic (PV) array and a backup battery bank, the system is meant to guarantee that electric vehicle (EV) battery charging continues uninterrupted. Modules for display, embedded control unit, sensor circuits, and power electronic converters are all part of the hardware design.

The suggested design is not based just on simulations, but rather on real-time embedded code execution and circuit-level validation made possible by the Proteus program. The PV array, bidirectional DC-DC converter, SEPIC converter, sensor unit, microcontroller control section, gate driver circuit, and LCD display module are the basic building parts of the whole system.



## XII. DESIGN OF PHOTOVOLTAIC INPUT STAGE

This system's DC voltage is modulated by a photovoltaic array that responds to temperature and sun radiation. Electric vehicle battery charging needs dictate the PV module's usual operational range.

The PV output is not suitable for direct connection to the EV battery due to its continual fluctuation. Consequently, a step for power conditioning is necessary. Before feeding it into the SEPIC converter, the input power is stabilized and rippled with the help of appropriate input filtering capacitors.

The photovoltaic system's current may be detected using the INA169 current sensor module, while the voltage divider circuits are used for voltage detection. The ADC channels on the ATmega328 receive these signals, which are used to control the MPPT.

## XIII. CONCLUSIONS

As electric automobiles proliferate, a sustainable and efficient charging infrastructure is needed. Connecting renewable energy sources to electric car charging infrastructure reduces dependency on fossil fuels. A solar EV charging system including bidirectional DC-DC conversion, MPPT, and a SEPIC converter was built and installed in this research.

The proposed system charges electric vehicles using solar power and a backup battery. The step-up and step-down SEPIC converter controls photovoltaic output voltage without inverting polarity. Thus, the SEPIC converter is appropriate for photovoltaic systems, where solar radiation affects input voltage.

The ATmega328 implements a Perturb and Observe MPPT algorithm to enhance the power collecting capabilities of solar panels. At all times, the controller keeps the converter within a safe operating range of its maximum power point by monitoring the current, voltage, and duty cycle. Consequently, solar power is put to better use.

Between the solar panel array and the backup battery, a single bidirectional DC-DC converter controls the flow of electricity. When solar output is high, the backup battery can store the excess energy. When sunlight is scarce, electric cars may be charged by feeding stored energy back into the DC bus. As a result, the system can run reliably and without interruption.

An first step in validating the suggested system was to run simulations in Proteus Design Suite. Voltage control, converter switching, and the MPPT algorithm all worked as expected according to the simulation findings. To ensure the concept was feasible in practice, a hardware prototype was created after the simulation had been validated.

Experimental results show that the system monitors the solar panel's peak power point and maintains EV battery charging voltage. The bidirectional converter enables reliable power management between the solar source and backup battery, while the SEPIC converter effectively adjusts voltage under changing input conditions..

In sum, the created system provides a green, dependable, and effective way to charge electric vehicles using renewable energy. The efficacy of the suggested design is confirmed by the results obtained from both experimental testing and modeling.

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