iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** III **Month of publication:** March 2025

DOI: https://doi.org/10.22214/ijraset.2025.67919

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

Solar EV Charging Station: A Comprehensive Review

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Abstract: The growing adoption of electric vehicles (EVs) has intensified the demand for sustainable and efficient charging solutions. Solar-based EV charging stations (SEVCS) present a promising approach by integrating renewable energy sources to reduce dependency on conventional power grids and minimize carbon emissions. This review paper explores the latest advancements, challenges, and opportunities in solar-powered EV charging infrastructure. Key aspects such as photovoltaic (PV) system design, energy storage integration and smart charging technologies are analysed review concludes that while solar-based charging stations hold significant potential in promoting green mobility, overcoming efficiency limitations, intermittency issues, and high initial investment costs remains crucial for widespread adoption.
Key Words: Solar EV Charging Station (SEVCS), PV panels, DC-DC converter, Battery Management System (BMS).

I. INTRODUCTION

Solar-based EV charging stations harness solar energy through PV panels to charge vehicle batteries, thereby reducing reliance on conventional power grids and minimizing the carbon footprint associated with EV charging. This integration not only promotes the use of clean energy but also addresses the intermittency issues associated with solar power by aligning peak solar generation periods with typical EV charging times [1].
Recent data underscores the severity of air pollution in India. In November 2024, Delhi recorded a monthly average PM2.5 level of 249 micrograms per cubic meter, marking the highest pollution levels for the city since 2017. This elevated PM2.5 concentration is over four times the daily National Ambient Air Quality Standard (NAAQS) for PM2.5, set at 60 micrograms per cubic meter [2].

A. PV System

Photovoltaic System is an essential part of the SEVCS infrastructure as its generating source of power supply for the EV charging purpose and also provides grid independence for establishment of SEVCS at remote locations. In this review, we are going to study different PV arrays and models. The most widely used PV arrays/modules are based on poly– or mono– crystalline technology [3].

B. Battery Management System

The use of Li-ion batteries is done in most of the EV as well as for the energy storage unit for no radiation period [4]. Since the Li–ion cells are sensitive to charge and discharge, they can neither be overcharged nor over discharged. Thus, the use of BMS is necessary for the supervision of battery conditions.

C. Charging Technology

The battery pack is considered the heart of Electric Vehicles. Many reviews focused on EV battery charging and highlighted the relation between battery life, charging time, and cell temperature. A higher charging current leads to a rapid charge of the batteries but degrades the battery's life [5]. Thus, advanced charging technology constant current-constant voltage will be discussed in this paper.

II. SOLAR PV PANELS

Photovoltaic is the technology that uses solar cells or an array of them to convert solar light directly into electricity [6]. The most widely used PV arrays/modules are based on poly– or mono–crystalline technology [5]. However, recently, thin film is getting more popular, especially for large PV systems [7]. Despite their lower efficiency, thin film cells are easier to manufacture, more cost effective and exhibit better performance at higher temperatures. Other technologies include the Hetero–junction with Intrinsic Thin layer (HIT) [8] and multi– junction cells [9]; but they are not used for general applications owing to their much higher cost. A typical commercial module is rated between 200– 300W with an open circuit voltage of about 20–30 V.

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The modules are arranged in series strings to achieve the required working direct (dc) voltage; for EV charging applications, this voltage is in the range of 200–500 V, depending upon the type of EV. To increase the array power, several series strings are connected in parallel. The main impetus for the PV–based charging station is the consistent drop in the module price. This can be related to the fact that in a typical PV project, the module comprises approximately 60–70% of the total investment; thus, the overall cost is very vulnerable to the price of this component.

III. BATTERY MANAGEMENT SYSTEM OPERATION

When an EV is plugged–in for charging, its battery's SOC is checked and continuously monitored to avoid overcharging. This is carried out by the battery management system (BMS). If the charging system has V2G capability [10,11], then over–discharging is also monitored using BMS. In addition, the SOC data can be used to forecast the remaining battery capacity; the results are used to predict the distance that can be covered by the EV. In the PV– grid charging system, the BMS controls the switching between the grid and the battery bank for charging the EV when the PV has insufficient power as demonstrated by [12]. In the PV– standalone charging, the BMS can be used to regulate the battery voltage and to disconnect the battery from the PV when the latter produces more than allowable maximum charging current [13]. Obviously, the energy capacity of a single battery cell is inadequate to drive the traction motor. The EV battery commonly needs thousands of single cells, packed in series/parallel connections, to form a battery module [14]. Since the Li–ion cells are sensitive to charge and discharge, they can neither be overcharged nor over discharged. Overcharging of batteries causes the temperature of different cells to rise unevenly which leads to the difference of voltage among each cell (cell imbalance). This increases its temperature. If not controlled, the available capacity of the battery is decreased, and its lifetime is shortened. Figure 1 shows the location of the BMS in the EV system and its key operational parameters. The voltage, the current and the temperature are the key operational parameters that are continuously monitored to protect the cells [15]. The BMS comprises sensors, switches and controllers.

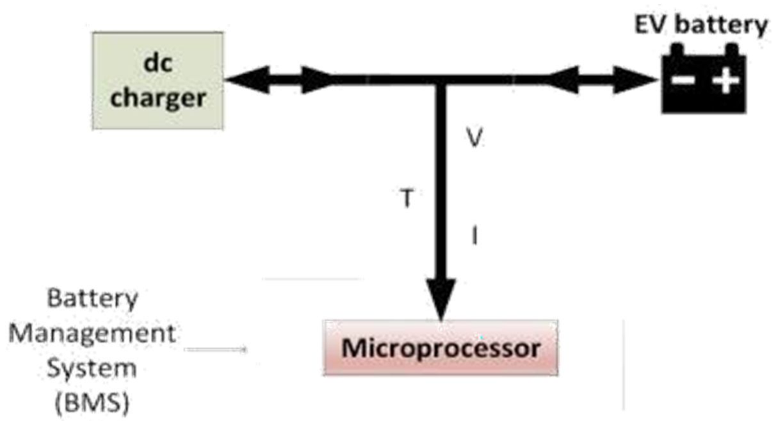

Figure 1. Key operational parameters in BMS

The microcontroller algorithm executes various functions, namely (1) to determine the battery's SOC, (2) to perform cell balancing and (3) thermal management. An accurate estimation of SOC is very important to prevent from unintentional depletion. The extremely high or low SOC may lead to permanent damage in the battery. Since no direct method is available to measure SOC, it is estimated from the current, the voltage and the temperature measurements [16].

IV. CHARGING TECHNIQUE

A. Constant Current

The constant current is maintained throughout the charging process. The predefined value is set here, whenever the charging reaches the value, it stops as shown in Fig. 3. The fast charging of the battery can be done by maintaining a high constant current, but it affects the life of the battery, whereas the low charging current can improve the battery life, but it provides a slow charge [17]. Thus, the state of battery health depends on the charging current. Choosing the suitable charging current value to balance battery life and charging time is a big challenge of CC charging.

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B. Constant Voltage

The pre-defined constant voltage is maintained throughout the charging process. Once the voltage is reached, the charger will only provide enough current to maintain the battery's voltage as shown in Fig. 3 and the flow process of both CC-CV charging is outlined in Fig. 4. If the setpoint voltage is too high, battery life gets affected, whereas the low voltage will not charge the battery completely. When the battery voltage is below the setpoint, a constant current charge is maintained. The standard setpoint voltage of lithium-ion cells is 4.2 V [18].

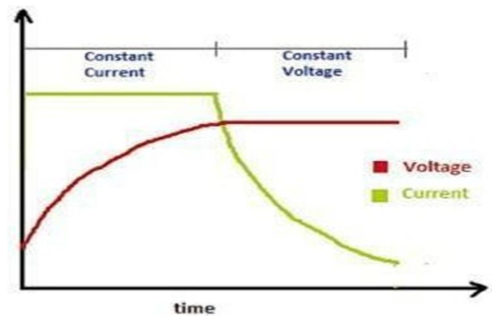

Figure 2. VI characteristics of charging techniques.

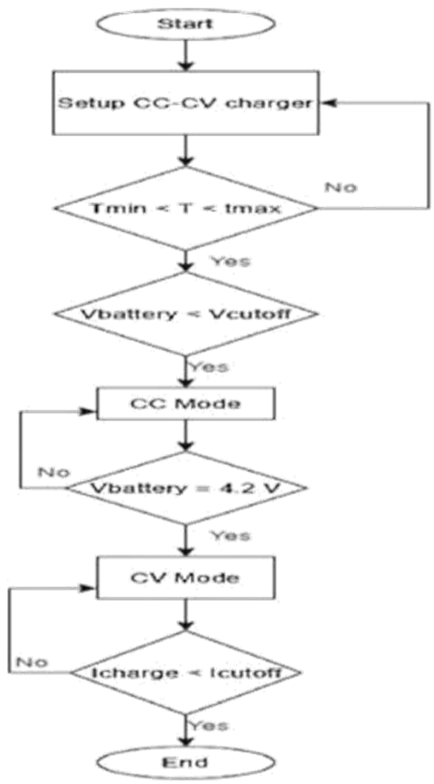

Fig 3. Flowchart of charging techniques.

C. Charging Operation

The proposed off-grid EV charging station consists of three subsections, they are PV generation, EV charger and ESS. The first section is PV generation system which includes a PV array, maximum power point (MPPT) and a boost converter. The PV array converts solar energy into clean electrical energy and provides voltage VPV and current IPV. The VPV and IPV are given to the boost converter which fluctuates due to change in irradiance. Therefore, an MPPT technique is proposed to manage the fluctuations in VPV and IPV.

The MPPT extracts maximum power PPV from the PV array and provides corresponding operating voltage and current to the boost converter. The boost converter regulates the output voltage according to the desired DC-link voltage by generating the PWM signals from the MPPT. This DC-link voltage at the DC bus is connected to the EV charger and ESS as shown in Fig. 4.

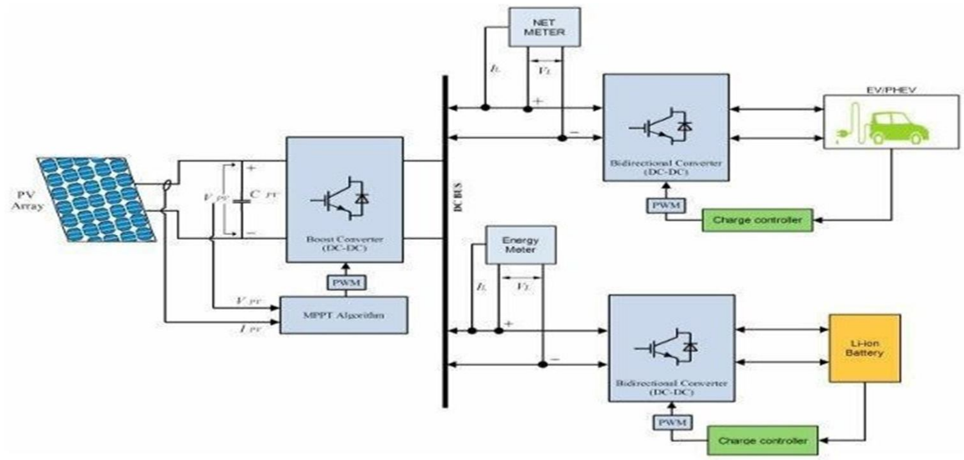

Fig 4. Solar Ev charging operation Block Diagram

The EV charger consists of a DC-DC bi-directional converter (BDC)and EVs. The operation of BDC depends on the charging and discharging of the EV battery. During charging mode, BDC acts as a buck converter. On other hand, it works as a boost converter during discharging mode. Similarly, the ESS also consists of a BDC and a battery bank. This battery bank is used as the energy saver during excess energy generation and is utilized at the maximum extent. The power that is stored in the ESS is fed back to the DC-link through BDC which is operated in boost mode. The mode of conversion is carried out with the help of constant current (CC) control strategy. This control strategy generates PWM signals to switch on the BDS. The mode (boost or buck) of converter changes according to the control signal generated by the control strategy. In this way, the operation of an off-grid EV charging is carriedout,[19].

V. CONCLUSION

Solar EV Charging Stations with Battery Backup represent a forward-thinking solution that addresses the dual challenges of sustainable transportation and renewable energy integration. These systems provide a reliable, cost-effective, and environmentally friendly way to meet the demands of electric vehicle owners while contributing to a cleaner, more sustainable energy future at any remote location.

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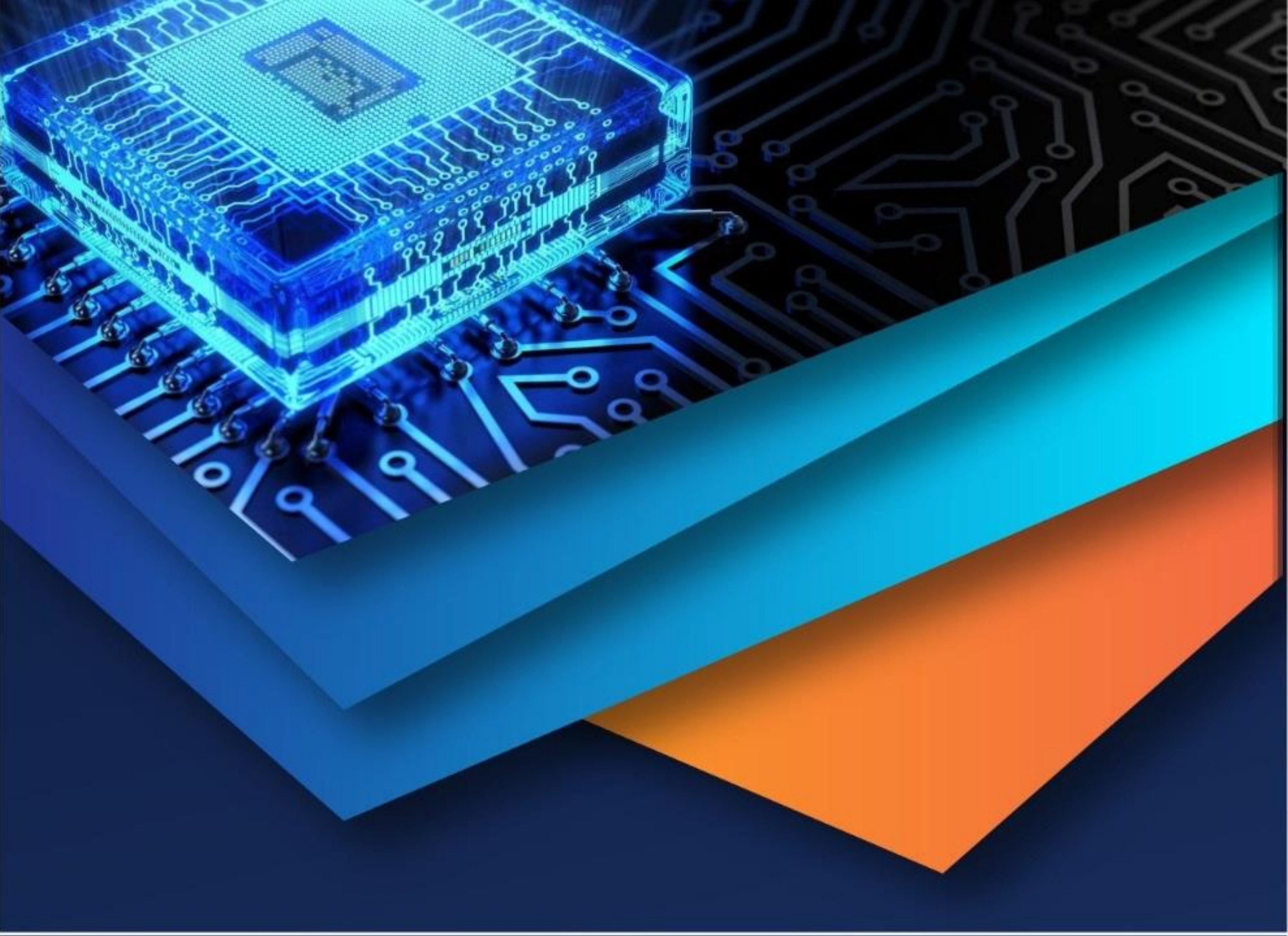

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