Photovoltaic Based Electric Vehicle Charging Stations: A Technological Review

Mr. Amol Eknath Halde[1], Prof. Kalpesh M. Mahajan[2]
[2] Assistant Professor, Dept of Electrcal
[1, 2] K.C.E. Society's College of Engineering and Management, Jalgaon1(MH) India

Abstract- *The use of renewable energy sources like solar photovoltaic (PV) to charge electric vehicles (EVs) is an intriguing possibility with various technological and economic benefits. The challenges associated with greenhouse emissions caused by internal combustion engines can be alleviated by combining emission-free EVs with low-carbon PV power generation. EV charging utilising grid energy has been the subject of several articles, including multiple reviews, over the years. However, a review article on EV charging utilising PV as one of the energy sources appears to be missing.This paper reviews and updates some of the major elements of PV-EV charging in light of the increased interest in this area. It includes information on EV basics, batteries, and a quick introduction of PV systems for the benefit of a larger audience. The PV-grid and PV-standalone are the two forms of PV-EV charging that are explored in depth.*

Keywords- Electric Vehicle, Charging Station, Fast Charging, Photovoltaic.

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].

Advances in power conversion technologies, battery management systems, and improved installation methods and design standards have all helped to increase the use of PV to charge electric vehicles (i.e. PVEV charging). The EV is frequently parked lazily in the parking lot under direct sunlight, especially during the day.This opens up the possibility of charging the EV directly utilising the 'charging-while-parking' approach, in addition to the more regularly used 'charging-by-stopping' [10]. For example, the EV may be readily charged while the vehicle's owner engages in other activities [8] by installing a PV roof on the car park [11,12]. The PV-powered charging station has a slew of advantages, according to the authors of [13]. Because the charging is done throughout the day, when the load demand and power rate are at their highest, the savings are significant. Furthermore, it uses the least amount of fuel and emits the least amount of CO_2. Roofed parking areas give free shelter from the sun and rain from a structural standpoint, which is a desirable feature in hot temperature nations [14].

The rise in electric vehicle numbers has created a new problem: increased grid power consumption. Decentralizing power generation, such as incorporating renewable energy local sources into charging infrastructure, is one effective way to mitigate the effects. Liu et al. [15] report on the connection between renewable energy and EV charging problems in the presence of smart grid technology to address this problem.

Due to greater environmental consciousness, cost reductions, and better PV module efficiency, PV power technology is likely to undergo significant improvement in the future.The PV powered charging station in office parking has various economic and environmental benefits, according to P. J. Tulpule et al.[16]. In addition, the charging procedure takes place during the day, when the power generation is at its peak. As a result, a significant cost savings is ensured. PV modules put on the top of a running parking garage provide free cover in inclement weather [17]. PV-grid-based systems are favoured over other renewable energy-based systems because of these benefits.

All electrically assisted cars must be recharged via charging systems, and photovoltaic-charging stations are those that utilise solar modules as a source of electric energy for battery recharging (PVCS). PVCS are classified into two categories: PV-grid charging systems and PV freestanding charging systems. We will study this subject in this paper by contrasting the properties of the two designs and presenting the current technological position of the charging system. As a result, we publish every aspect of the PV charging infrastructure in order to provide engineers and researchers with up-to-date information.

II. PHOTOVOLTAIC SYSTEM

The solar panels, which create electricity by directly converting the sun's energy into electricity, are the most significant component of a photovoltaic (PV) system. The majority of solar panels are built of semiconductor materials, with Silicon (Si) being the most common. Materials with higher conversion characteristics, such as gallium (Ga) and aluminium (Al), have lately become more widely used. The electrical devices that interface the PV output with the AC or DC loads are included in the PV system's components.

Improving cell efficiency and optimising energy extraction are two important challenges in maximising the use of solar cells for power generation. The solar cell can generate maximum power at a specified operating point, which fluctuates based on air conditions. The capacity of utilities to estimate output power at a given time for a particular place is hampered by this fluctuating output, posing a scheduling difficulty. The I-V (current-to-voltage) characteristic may be used to estimate the cell's optimal operating point for maximum power generation.

A thin layer of semiconductor is used to create a p-n junction in the solar cell. The solar cell's output power is determined by the amount of sunshine energy (photons) absorbed by the semi-conductor material. As illustrated in Fig. 1, the solar cell's output power is determined by the semiconductor material's I-V characteristic. In addition, the I-V curve may be used to identify the maximum power point (MPP) at which the solar cell produces the most output power. Calculating the product of the voltage and output current yields the power at maximum power point.To obtain maximum power, the solar cell is usually operated at or very close to its maximum power point. This point is near the voltage-current characteristic's 'bend' or 'knee,' as seen in Fig. 1 at point A.

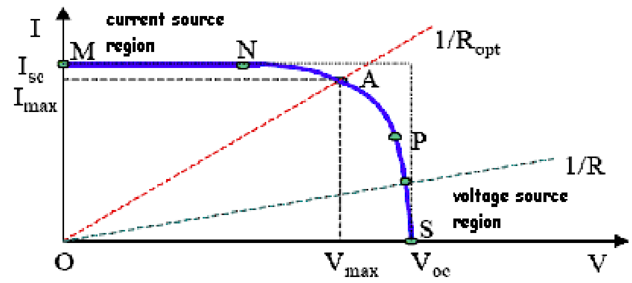

Fig. 1 Typical I-V characteristic of a solar cell

A solar cell's voltage-current characteristic is divided into two parts:

A) The region where the current source is located.
B) The area of the voltage source.

The solar cell has a high internal impedance in the first area of the I-V characteristics, and the output current remains constant as the voltage increases, but the terminal voltage remains constant throughout a wide range of output current and the internal impedance is low in the latter region.

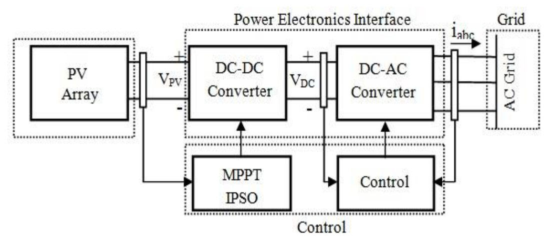

Fig. 2 Solar PV System Connected to Grid

The maximum power transfer hypothesis asserts that when the source internal impedance and the load impedance are exactly the same, maximum power is supplied to the load. In order to run the solar cell at or near its maximum power point, the output impedance of the solar cell is made equal to the input impedance of the load. The internal impedance of the solar cell is governed by the terminal voltage and output current, therefore the maximum power operating point may be maintained by regulating either the voltage or output current, or both. Because external factors like as temperature and irradiance affect the maximum operating point, maintaining it at the optimal point (MPP) becomes unpredictable, resulting in output power variance.To complete the assignment, a maximum power point tracker (MPPT) is used. The buck converter (step-down), boost converter (step-up), or buck-boost converter arrangement is used in the majority of MPPT controllers.

III. ELECTRIC VEHICLE CHARGING STANDARDS

The Society of Automotive Engineering (SAE), the CHAdeMO association, and the International Electro-technical Commission are three major organisations that seek to standardise electrical characteristics of EV charging stations across the world (IEC). Aside from these organisations, Tesla Motors, the world's leading electric vehicle manufacturer, establishes its own standards for its Model S, Model X, and Roadster electric vehicles.

Every organisation listed above offers a variety of charger standards that function with both AC and DC power. The SAE, for example, has been working on standard J1772, which divides electric vehicle chargers into three levels [5]: Level 1, Level 2, and Level 3.

i) Level 1: The charger is built-in and delivers DC voltage with a maximum current of 80 A and a power output of 40 kW.
ii) Level 2: The charger gives a DC voltage of up to 200 A with a maximum output of 90 kW.
iii) Level 3: The charger is disconnected from the board. With a maximum capacity of 240 kW, the charging station delivers DC electricity straight to the battery through a DC connection.

Level 3 chargers are all considered fast chargers. CHAdeMO and the International Electrotechnical Commission (IEC) suggested various power and current requirements for DC rapid charging. A quick summary of power and current level evaluation for electric car DC charging standards is presented in table 1 for additional information.

Table 1: EV Charger categories

Standard	**Level**	**Max Current Rating (A)**	**Max Power Rating (kW)**
SAE	DC Level 1	80	40
	DC Level 2	200	90
	DC Level 3	400	240
CHAdeMO	DC Fast Charging	125	62.5
IEC	DC Fast Charging	400	100-200
Tesla	DC Super Charger	340	136

IV. PHOTOVOLTAIC CHARGING STATION TECHNOLOGIES

PV-grid and PV-standalone are two methods for charging an electric vehicle using solar energy. PV-grid charging provides the benefit of being able to charge utilising the grid when there is inadequate solar irradiation [18]. It's also more adaptable since PV electricity may be pumped into the grid in the absence of the EV (to be charged). PV-standalone, on the other hand, is more advantageous in distant places where utility supply is unavailable or prohibitively expensive [19, 20]. Because there are fewer power conversion steps, it has a simpler configuration.

4.1 PV-Grid Charging System:

Figure 3 shows a charging architecture that is defined by two conversion phases produced by AC/DC and DC/DC converters, which has been investigated from diverse perspectives in numerous published papers[21], [22]. Furthermore, the dc bus is critical since it is intended to connect the PV array, ESU, and EV battery pack, as well as other dc-powered equipment. Because the station is directly linked to the grid, batteries or an energy storage unit (ESU) may be unnecessary in this layout. Nonetheless, it would play a significant role if people were ready to minimise their reliance on the grid. The authors of [23] look towards friendly topologies for integrated PV-grid chargers.

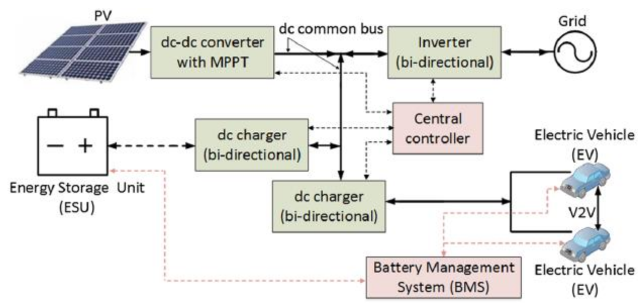

Figure 3: Block Diagram of a General PV-Grid CS

The SOC of an EV when it is first plugged in is usually less than 100 percent. The charging priority in the most generic PV-grid system (without the ESU, V2G, and V2V activities) are as follows [21]:

- Case 1: If the PV generates more electricity than the EV requires, the PV will be utilised to charge the EV entirely. The power from the grid is not used for charging. If there is any residual extra electricity, it will be put into the grid.
- Case 2: If PV power is unavailable due to inclement weather or at night, the charging will be carried out only by the grid. In addition, if the PV system develops a problem, the same procedure will be followed.
- Case 3: If the available PV power is insufficient to charge the EV due to low irradiance, the EV will be charged using whatever power is available from the PV. The rest (balancing) will be provided by the grid.

• Case 4: If the charging station does not have a commitment to charge (i.e. there is no EV to be charged), the PV energy will be immediately sent into the utility grid, usually with a monetary advantage to the owner.

The first mode (PV charging mode)

If the PV energy is adequate to charge the EV, the PV will handle the full charging process. Figure 4 [24] shows how it's done using a dc–dc converter and a dc charger. The PV will charge on its own in this situation, and the system will be electrically separated from the grid. The dc charger adjusts the dc voltage to match the charging profile of a specific EV.

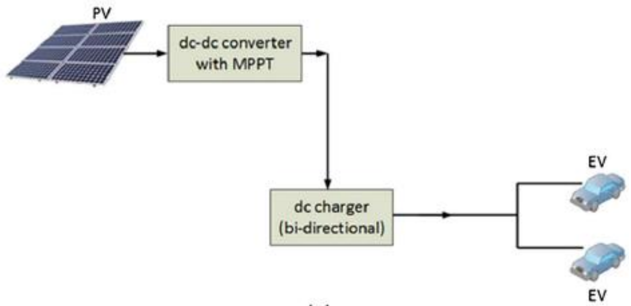

Figure 4: PV Charging Mode

2nd Mode (Grid-connected rectification mode)

On the other hand, if the PV system is completely unable to provide any power (due to zero or extremely low irradiance), the EV will be charged straight from the grid. The grid ac power is initially transformed to dc using a rectification mode bidirectional inverter. The dc charger then further conditions the dc voltage. Figure 5 [24] depicts this condition.

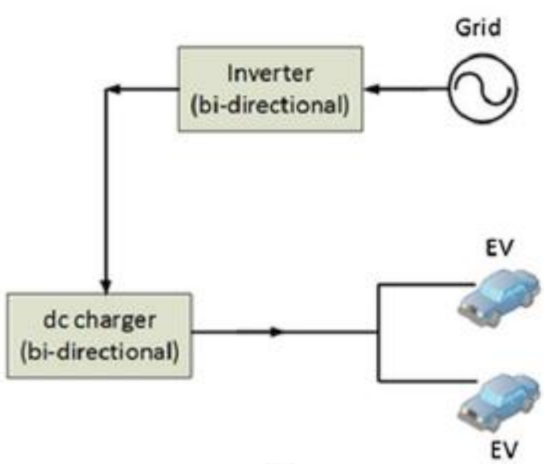

Figure 5: Grid Charging Mode

Mode 3 (grid-connected rectification and PV charging)

When the PV can give a portion of the energy (but not enough for complete independent charging), both the PV and the grid help to charge the battery, as illustrated in Figure 6 [24]. The quantity of energy taken from the grid is often determined by how much energy the PV can supply. The grid will make up the difference. Because the irradiance conditions are always changing, the controller must constantly check the power produced by the PV and adjust the grid intake correspondingly to guarantee that the needed power to the EV is maintained.

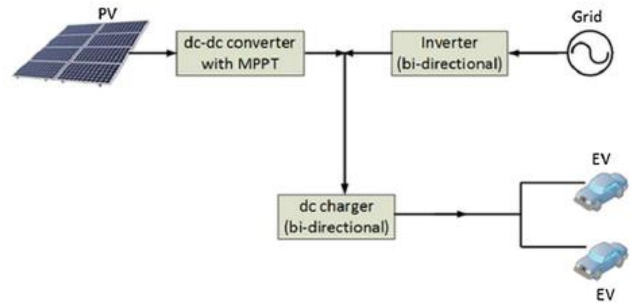

Figure 6: Hybrid Charging Mode

4th Mode (Grid inversion mode)

When no EVs are available for charging and the PV system is producing electricity, all of the energy is sold to the grid using two-step conversion operations, namely the dc–dc converter and the bidirectional inverter. Figure7 [24] depicts this operation. Even though the EV is charging, it may be more cost-effective to run in this mode in some circumstances. When the feed-in-tariff rate is significantly higher, such a concept becomes practical.

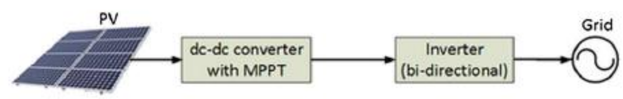

Figure 7: Grid Inversion Mode

4.2 Standalone PV Charging System

PV-standalone charging, as depicted in Figure 8 [25], refers to charging an EV purely using PV electricity, i.e. without the need of a utility (grid). Because there are fewer power conversion steps, it is more efficient [26, 27]. The PV array, on the other hand, must be large enough to meet the charging requirements for the specified number of cars [28]. Figure 8(a) [29] shows a direct PV to EV connection, while Figure 8(b) or 8(c) [30] shows a charging target achieved with an intermediary ESU. Furthermore, there are a number of ways that use hybrid solutions.

The primary problem of the direct charging technique is that the PV power is insufficient and intermittent to charge the EV continually. The ESU, on the other hand, allows surplus energy to be stored and used later when PV power is unavailable [23]. Although this is preferable, the ESU's initial investment cost may be prohibitive [31]. The charge controller is a critical component in both scenarios. It's essentially a dc–dc converter with MPPT capabilities, with the added function of regulating the PV voltage to guarantee that the charging current is optimal.

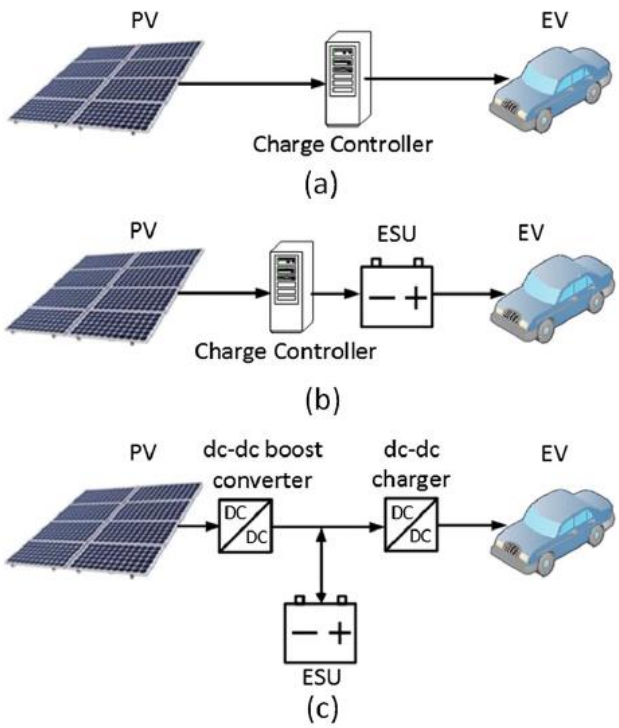

Figure 8: PV standalone CS

In [32], the authors presented a hybrid solution for the PV standalone charger that combines an electric vehicle battery with a hydrogen fuel cell system. Figure 8 depicts the conceptual diagram. The PV is split into two tracks: one to charge the EV's lead acid battery (ESU) and another to power a fuel cell vehicle. PV electricity is utilised to charge the ESU and keep it fully charged. The energy from the ESU is transferred to the EV battery through a battery charger if EV charging is necessary. On a separate track, PV electricity is used to electrolyze water to make hydrogen (to replenish the fuel cell).The system can charge the EV both during the day and at night thanks to this configuration. Another paper [23] describes an innovative hybrid standalone charging system that uses different energy storages, including ESU, super-capacitors, and fuel cells. The system's dependability may be increased by using more energy sources [22, 32]. The authors employ two control algorithms: one interfaces between batteries and fuel cells, while the other regulates power between supercapacitors and batteries. Authors in [32] propose a novel PV charging technique based on the flexible ac transmission system (FACTS) topology. FACTS is often used to improve the electrical network's control and power transmission capabilities [33].A PV-EV charging station with a dc common bus is used in this study, and a novel green plug-filter compensator and dual-action regulator are used. To provide a speedy removal of the dc side inrush and transient variations, each regulator employs a tri-loop error controlled by a modified PID controller. The FACTS devices are utilised to stabilise the dc common bus, which makes this work unique.

In [34], a mathematical model of a PV-standalone charging station is provided employing solar energy at the household level, as illustrated in Figure 8(c). The house ESU is charged by the PV current until it achieves full SOC, which is also suggested.Model parameters of the PV panel and the lead acid ESU are discovered using fitting methods for this purpose, and their models are experimentally confirmed. The MPPT control is used to achieve the greatest PV power. Because of the low solar irradiation, this type of system is not totally trustworthy to meet EV demand during the winter or in inclement weather. In Section 5.1 of this work, the failure of this type of system is demonstrated.

Another ingenious approach proposed by the authors in [35] is charging utilising the PV cells implanted in the EV body. The vehicle-integrated PV idea is the name for this concept (VIPV).Thin film cells are often installed on the EV's roof, and the batteries are charged using an on-board dc–dc converter [8]. A VIPV employing a brushless permanent magnetic dc motor is presented in a separate paper [36]. The authors, however, believe that the technique is unworkable due to the PV cells' restricted area. The amount of energy extracted is inadequate to power the propulsion system. Despite this, the VIPV idea may be used as a secondary charger, increasing efficiency by 10–20% [35]. During parked, the integrated PV cells can be used as an extra power source to drive the air conditioning system [37].The VIPV system is at the very least capable of powering auxiliary equipment such as fans, music players, and igniters [38, 39]. The silicon crystal with set quantum spots is blended with unique paints that may be painted on the automobile body in a more advanced effort [8]. Despite the solution's questionable dependability, this is an intriguing advance. Although the system's efficiency is poor (less than 2%), the technology's future potential is intriguing.

V. CONCLUSION

This paper provides a brief overview of recent work in the field of photovoltaic DC charging stations for electric vehicles. There is a comparison and explanation of the many components of the charging stations. To summarise, the advantages of PV-EV chargers that use V2G technology will gain greater attention and investment in the future from grid operators and carmakers. To summarise, the photovoltaic charging structure is growing increasingly complicated as additional functions are added into the system, necessitating sophisticated controls in each block as well as real-time station management.

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