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Design and MATLAB Simulation of a 4 kW Solar Hybrid EV Charging Station

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ABSTRACT

Electric vehicles (EVs) are proving to be a competitive alternative to cars that use internal combustion engines (ICEs) as the need to transition to a clean transportation system grows and the cost of utilizing fossil fuels decreases. However, the growing number of EVs is placing an enormous strain on the electrical system, particularly at quick charges. A 4kW solar-powered hybrid EV charging station that combines photovoltaic (PV) generating with battery energy storage is proposed in this article, along with its design and modeling. By providing a steady and sustainable charging mechanism, the hybrid system seeks to reduce carbon emissions and power grid usage.The planned station also prefers a three-phase power management scheme, which incorporates solar power, batteries, and the power grid to sustain power supply throughout. By injecting the extra solar energy into the grid, the overall amount of electricity needed can be decreased. The PV cell modeling, maximum power point tracking (MPPT), and efficiency-boosting smart charge controller algorithms are the main components of the system. The design offers a feasible and sustainable idea for the infrastructure supporting electric vehicles (EVs) in the future.

Keywords: *Hybrid Electric Vehicles, Renewable Energy Integration, P&O MPPT, Photovoltaic System Design, EV Charging Stations*

INTRODUCTION

The increasing anxieties regarding the harm to the environment, greenhouse gases, and the dwindling availability of fossil fuels have made the world shift towards more sustainable and cleaner energy sources. The adoption of electric vehicles (EVs) is one of the key solutions because they are becoming more and more popular as a cleaner alternative to traditional internal combustion engine (ICE)-powered vehicles [1]. Replacing vehicles with EVs will not only contribute to the reduction of carbon emissions but also influence energy efficiency and decrease the cost of running. Their massive deployment, however, introduces new issues with the power grid, particularly with fast and ultra-fast charging stations, where spike demand may lead to trouble with peak load issues and voltage deviation [2].

As a solution to these problems, it is important to include solar photovoltaic (PV) systems and other sustainable energy sources with energy storage and intelligent power control. EV charging stations powered by solar can put pressure on the grid hence promoting sustainable transportation [3]. One can have a hybrid charging system, which combines solar power and battery storage, and this facilitates the charging process to be more reliable and efficient even during the cloudy seasons and the peak hours. Moreover, the additional solar energy can be fed back into the power grid which will aid in load balancing and contributes to the work of smart grids [4].

1. 4. The design and modeling of a 4 kW solar-powered hybrid EV charging station are presented in this work.which was developed using MATLAB. The system uses the closed-loop control technique to hold constant the voltage but be able to provide the peak power. The system is connected to a one-phase AC grid by a bidirectional buck/boost DC-DC converter, and a DC-AC inverter. The arrangement brings the benefit of creating energy flow in both ways (charging or discharging) depending on the demand, which provides a highly efficient management of power. The design is optimized to take advantage of solar energy; a Perturb and Observe (P&O) maximum power point tracking (MPPT) algorithm is employed in the design, and the performance of the PV array is modeled and validated with the PVsyst software [5].

2. Efficiency and responsivity are enhanced by incorporating the logic of smart charge controllers and sophisticated MPPT methods. The proposed hybrid station provides a sustainable EV charging infrastructure via renewable energy and smart power electronics by enabling a reliable and scalable solution.
3. EV charging with solar energy is one of the major moves towards decreasing the use of fossil fuels around the globe. Although EVs are cleaner vehicles compared to internal combustion engine vehicles, their actual sustainability depends on the ability to be fuelled by renewable materials rather than fossil-based electricity. As EVs continue to become more and more popular, the home-based EV charging equipment will be installed by a large number of solar panel owners in the nearest future [6]. The photovoltaic (PV) system especially performs well when grid-connected, since it can generate solar power during daytime when the demand in the grid is high. At the most propitious moments when the sun is shining, excess energy could be sent to the grid, thus creating utility credits under net metering [7]. Such credits may be used later to compensate the accessed electricity used to charge EV in the evening, usually when the home, EV, and utility grid are exchanging electricity bi-directionally [8]. This will promote clean energy in transportation, lower the electricity costs, and stability in the grid, which will boost the development of smart, solar-powered EV charging solutions.

LITERATURE REVIEW

Electric vehicle (EV) charging stations and photovoltaic (PV) systems face a number of technological issues, chief among them being that solar electricity is not constant but rather depends on weather and may not always be available. Patel emphasized that the dependability of fast-charging stations may be impacted by variations in PV production. Grid-tied PV systems with battery energy storage should be integrated to provide a continuous power supply in order to ensure the steady power supply of EVs [9]. A charging infrastructure must be built to be economical, effective, and dependable in order to connect additional EVs and facilitate high charging speeds.

Tan created a DC-DC charge controller based on a buck converter and used the Perturb and Observe (P&O) maximum power point tracking (MPPT) method to get the most power possible from the PV array. It has a three-stage battery charge cycle- MPPT buck charging, constant voltage absorption charging and floating charge; with the objective of effective control of lithium-ion batteries [10]. The reason is that the P&O method is very simple and just simplistic sensing and circuitry is required. It has the notion of altering the PV voltage in a small amount and recording the power change. The algorithm propagates the perturbation in the same direction until the growing power is reaching its maximum and propagates the perturbation in the opposite direction until the decreasing power is reaching its minimum. This enables the system to operate and/or close to maximum power point (MPP) under steady conditions of the system [11].

To get around the drawbacks of conventional MPPT methods, de Oliveira proposed an approach based on particle swarm optimization (PSO). PSO performs better in actual PV systems when there is partial shade (PSC). The PSO is more successful in grid-tied inverters than the less advanced approaches because it can identify the power voltage (P 7 V) curve's strongest power point (MPP) even if the curve has many peaks [12].

Other approaches, such the fuzzy logic controllers (FLCs) of MPPT, have also been attempted by researchers. In a different study, backpropagation was used to train artificial neural networks (ANNs) using FLC data in an effort to reduce the difference between the actual and predicted numbers. The hybrid architecture allowed for rapid MPP localization under changing temperature and solar irradiation.[13].

The performance of inverters is especially important in grid-connected PV-EV charging systems. The boost converter uses a voltage source inverter (VSI) to change the DC output to AC. Synchronous pulse width modulation (PWM) with d-q frame control are used to regulate current flow into the grid. LC filters and isolation transformers reduce high-frequency harmonics and offer safe separation, while phase-locked loop (PLL) circuits keep phase and frequency synchronized with the grid [14].

More efficient conversion of power has been done with optimized MPPT circuits and bandpass filters. In other designs, a three-phase inverter can be applied to power either the grid or local loads. In this case, voltage is increased and zero-sequence currents are minimized using a delta-star transformer and then the power is added to the grid [15].

There is a great number of MPPT techniques and their advantages and disadvantages. The method used will be determined by issues such as system complexity, cost, response time and the capabilities of the algorithm to identify local or global MPPs. P&O, Incremental Conductance (IC), Fractional Open-Circuit Voltage (FOCV), Fractional Short-Circuit Current (FSCC), Fuzzy Logic, ANN, Sliding Mode Control (SMC), Robust Unified Control Algorithm (RUCA), PSO, Fractional open-circuit voltage fuzzy logic, ANN, Sliding mode control, Robust Unified Control Algorithm, PSO, Grey Wolf Optimization, Intelligent Monkey king evolution [16]. In the case of the traditional methods, it will work well under uniform sunlight, because there is typically only a single MPP. But in cases of partial shading, the PV curve can have a number of peaks, and the simple hill-climbing algorithms such as P & O or IC can tend to fail. Thus, the selection of the correct MPPT strategy is the key to maximizing the energy harvesting and providing the stability of the work of PV systems.

Table 1. Work done by various researchers in the concerned area.

Ref. No.	Author(s)	Focus Area	Identified Drawback / Limitation
[9]	Patel	Grid-tied PV with battery storage for EV fast-charging stations	PV output is intermittent and weather-dependent
[10]	Tan	Buck converter-based MPPT using P&O for lithium-ion battery charging	P&O algorithm may fail under rapidly changing irradiance or partial shading

Ref. No.	Author(s)	Focus Area	Identified Drawback / Limitation
[11]	Singh and Sharma	P&O and hill-climbing MPPT methods	Traditional methods struggle to detect global MPP in partially shaded conditions
[12]	de Oliveira and Lima	PSO-based MPPT under partial shading	Higher computational complexity compared to conventional algorithms
[13]	Iqbal and Hussain	Hybrid FLC and ANN-based MPPT technique	Requires large training datasets; performance is data-dependent
[14]	Zhang and Kumar	Grid-tied inverter synchronization with PLL and PWM	Requires precise phase-matching; complex control and filtering setup
[15]	Xu, Zhang, and Wei	Harmonic filtering in three-phase PV systems with transformer integration	System design may become bulky and costly due to extra components
[16]	Bansal and Garg	Comparison of MPPT techniques under partial shading	Conventional techniques not suitable for dynamic or shaded environments

MODELING AND MPPT CHALLENGES

Challenges of MODELING and MPPT.

To optimize photovoltaic (PV) systems' energy production, maximum power point (MPP) tracking is required. Conventional MPPT methods such as Observe (P&O) and Perturb typically are limited in the partial shading case. When this occurs the powervoltage (PV) curve will have many peaks and the standard algorithms might converge to a local MPP, rather than the global MPP, leading to reduced energy yield [17]. In order to solve this issue, scientists have proposed Particle Swarm Optimization (PSO), Improved Monkey King Evolution (IMKE) and Grey Wolf Optimization (GWO) artificial intelligence (AI)-based methods. The global maximum is detectable even in the complicated and changing environmental conditions with these methods [18].

The PV cell has to be accurately represented in order to be controlled and simulated. A circuit with a current source, a diode, and resistance elements is typical of a PV cell equivalent circuit. The diode is the reflection of the p-n junction's activity, and the current source is the current generated by the light.

Among the electrical parameters of importance that are usually supplied by manufacturers are the short circuit current (Isc) and the open circuit voltage (Voc) [19]. Figure 1 shows a simplified equivalent circuit of a PV cell, where Rsh is the parallel resistance, which models leakage current and Rs is a series resistance, which models internal losses due to material and contact resistance [20].

Photo- Voltaic Cell Modelling

The behavior of a solar cell may be shown using a similar electrical circuit. Two essential measurements that are commonly used to describe a PV cell are the open-circuit voltage (Voc) and the short-circuit current (Isc >). Manufacturers often include these numbers in the datasheet for the PV module.

PV Cell Equivalent Circuit Representation

The equivalent circuit of a PV cell is as illustrated in figure 1. It has a current source which is the current generated by the light, a diode and a shunt resistance which is in parallel. The array resistance is referred to as Rsh.

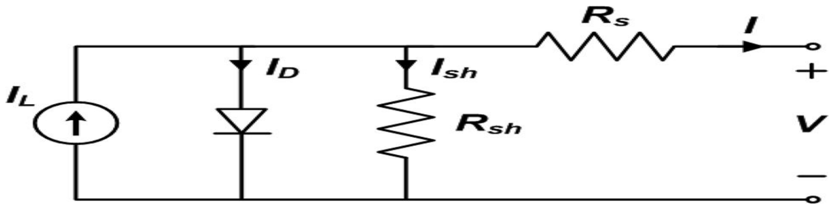


Figure 1. PV cell equivalent circuit.

By the Rsh, and Rs the array series resistance. The current generated by the incident light is called ipv and it is proportional to the irradiance of the sun. The output of the array is I and V.

Characteristics Of PV Array Under Un-Shaded Condition

Every PV module in an array produces the same voltage when exposed to the same amount of solar irradiation when it is not shaded. Because photovoltaic cells are non-linear, factors like temperature and sun irradiation have a significant impact on their performance and output power. The effects of temperature and irradiance fluctuations on PV cell output current, voltage, and power are depicted in Figures 2 and 3.

EV CHARGING TECHNIQUES

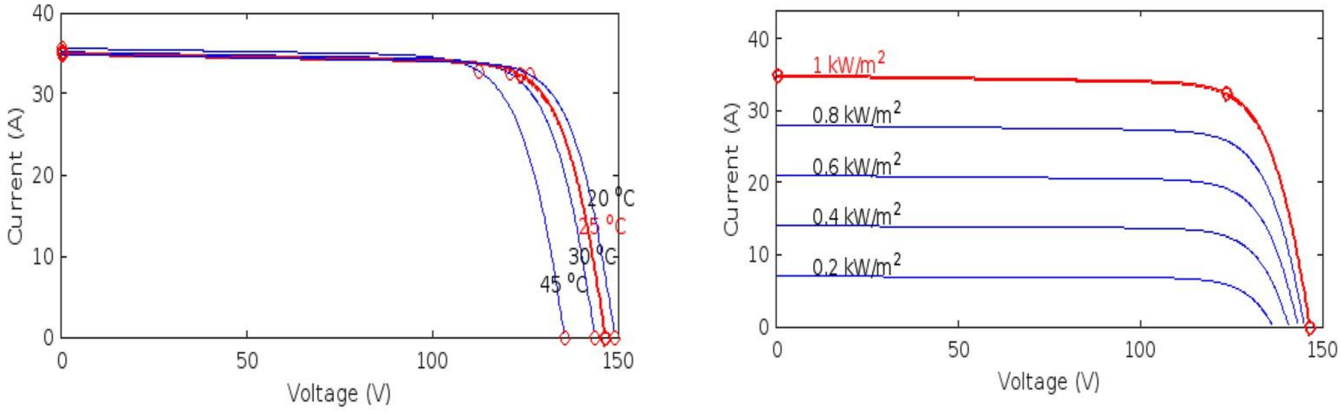
MPPT And Battery Charge Controller Technique

As seen in Figs. 2 and 3, the PV characteristics of the PGS are nonlinear and significantly impacted by changes in temperature and solar insolation. Consequently, a dependable and effective method for modifying the operational point of a solar producing system to maximize energy production—a difficult task—is discovered. The PV array can be operated with a single terminal voltage for better power delivery or increased array efficiency. MPPT tracking requires DC to DC SMPS converters with DC converters.

The PV array output is linked to the input terminal of the DC-DC converters, and the voltage of the array is controlled by the duty-cycle fluctuation between the various voltages that the converter maintains at maximum power (Fig.4).

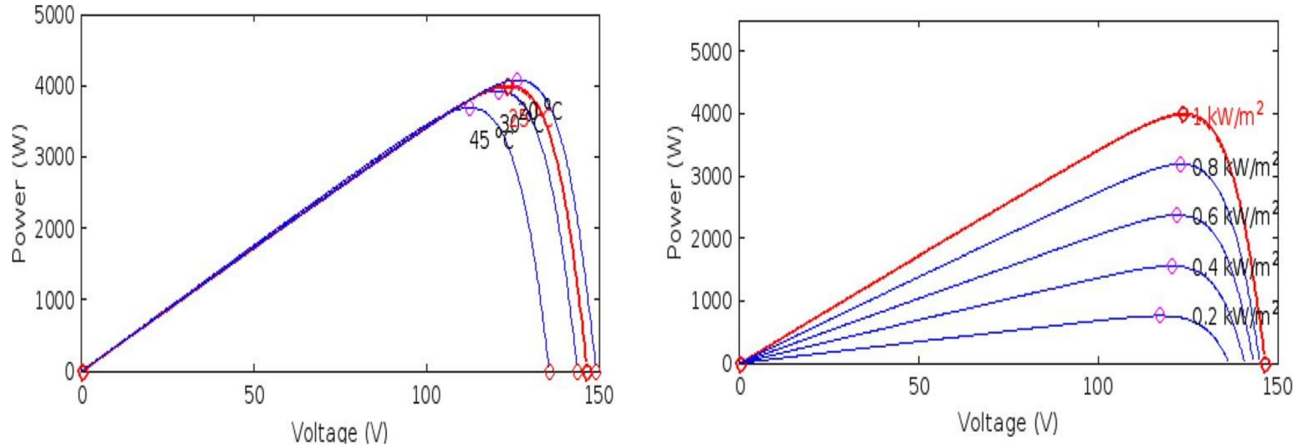
P&O (Perturb & Observe)

The Perturb and Observe (P&O) technique is considered to be one of the simplest methods of monitoring Maximum Power Points. This is because the processing time is rather minimal. Another term used to describe it is the hill-climbing. Since the peaks and the troughs in the PV curve relative to the maximum power point define the operation of the PV curve.



(a) (b)

Figure 2. (**a**) Effect of temperature, (**b**) solar irradiance on I–V curves.



(a) (b)

Figure 3. (**a**) Effect of temperature, (**b**) solar irradiance on P–V curves

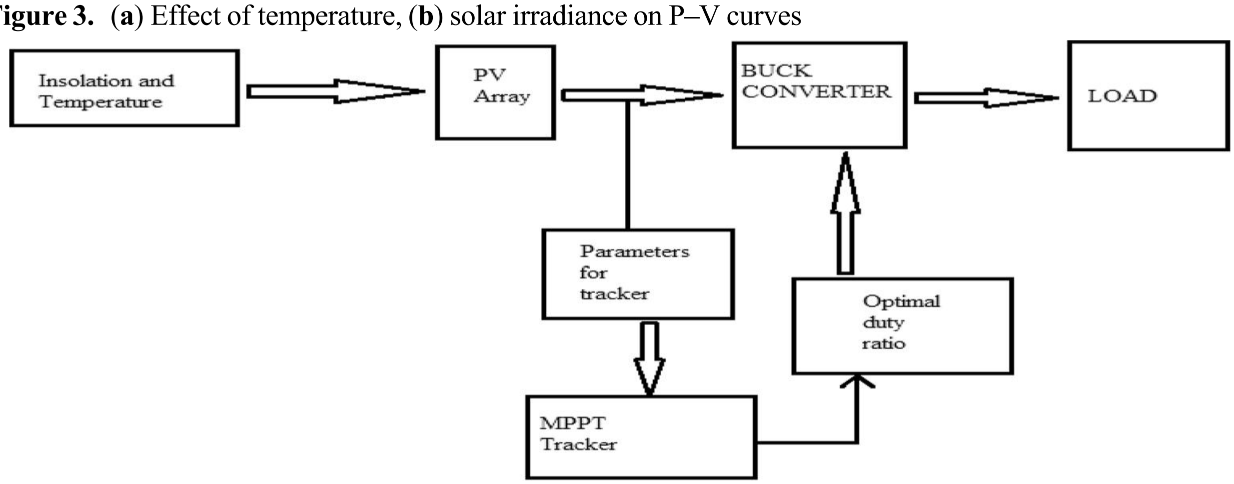


Figure 4. Block diagram of MPPT.

Perturb and Observe (P&O) method uses sensors to measure the current and voltage of solar PV array as shown in Fig. 5. Based on these readings, the algorithm determines how to alter the duty cycle of converter to generate the most power by increasing or reducing it. This will be established by comparing the present power, to the previously measured power. When the input voltage is bigger than in the previous instance, the duty cycle (D) of a boost converter is reduced to move on the maximum power point (MPP). On the other hand, the duty cycle is also increased to track the MPP when the input voltage is reduced, however, power increases. However, with too large a perturbation step (Delta D), continuous oscillations may occur, and the system will never reach the actual MPP. The constraint notwithstanding, P&O method simplifies the design and calculations of solar PV modules, but does not affect their physical properties.

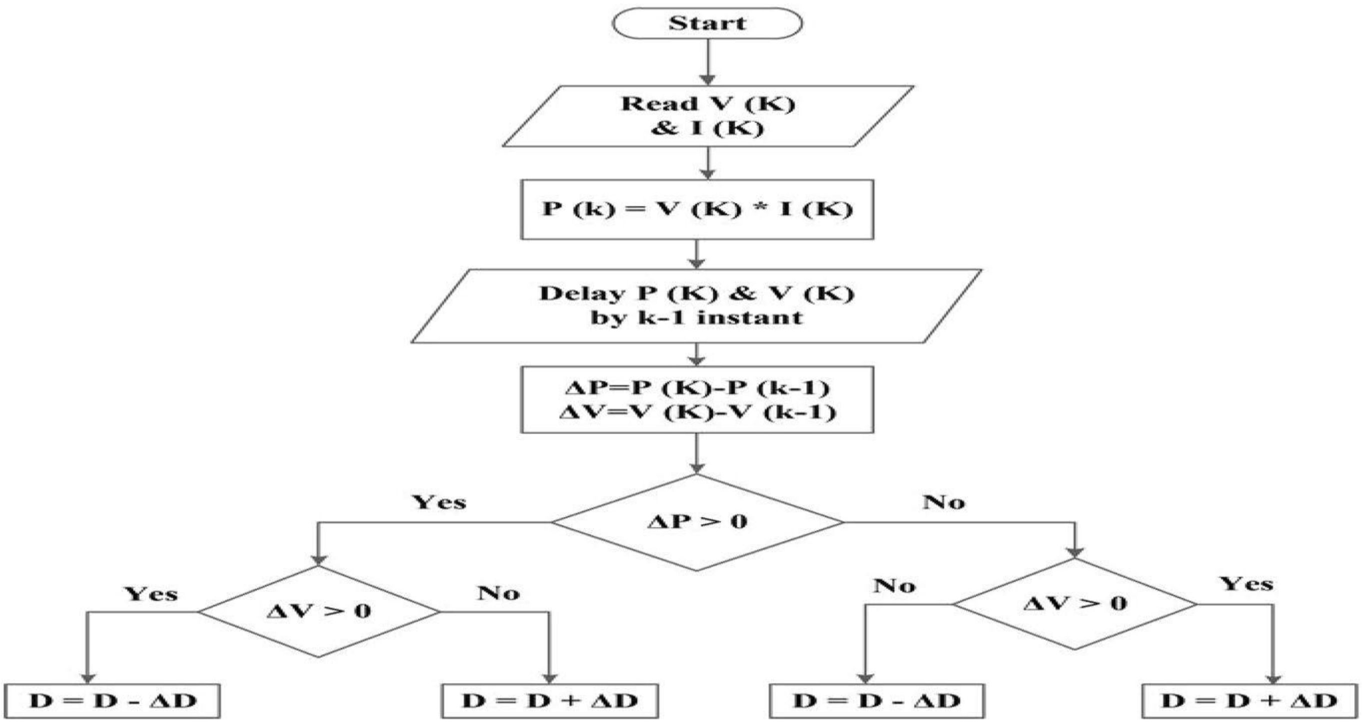


Figure 5. Flow chart of P&O algorithm.

Battery Charge Controller

Three distinct charging modes—trickle charging, constant current charging, and constant voltage charging—are included within the lithium-ion battery charge controller. To charge the battery to its maximum rated capacity, a steady current is delivered at maximum power point tracking (MPPT) in the first stage, referred to as the bulk charging stage. Until the battery is fully charged, the second phase—also referred to as the absorption phase—provides a steady voltage without MPPT. To prevent overcharging, gassing, and overheating, the final stage, float charging, maintains the state of charge (SoC) at 100V.

Three charging modes—constant voltage, constant current, and trickle charging—will also be enabled by the lithium-ion battery charge controller. The first step, called the bulk charging stage, involves applying a continuous current at maximum power point tracking (MPPT) to fully charge the battery to its rated capacity. The second step, also referred to as the absorption phase, maintains a steady voltage without MPPT until the battery is fully charged. "Float charging," the final phase, keeps the state of charge (SoC) at 100V to prevent overcharging, gassing, and overheating.

SYSTEM MODELING

MATLAB was used in line with the recommended approach to develop a 4 kW PV-Powered charging station for EVs after a thorough research, measurements, and data analysis of the solar system using PVsyst. Average annual temperature: 25.3 °C. Latitude/longitude: 28.37° N/77.32° E.

Following a thorough investigation, measurements, and data analysis of the solar system using PVsyst, MATLAB was used in line with the recommended methodology to construct a 4 kW PV-Powered EV charging station. Temperature: 25.3 °C annually on average. The coordinates are 77.32° E/28.37° N.

The preceding picture displays temperature variations with the seasons, wind speed, global radiation, and solar radiation dispersion. The graphic below shows that the greatest prices in each column occur in May, June, July, and August. The annual global radiation is either 3264.4 kW/m 2 or 250.7 kW/m 2. The term "month" is used at a temperature of 25.3 °C.

Figure 6. Battery charge controller flow chart.

Table 2. Monthly meter data[16].

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Horizontal globe (/kWh/m^2)	88.9	112.0	158.3	174.7	183.6	170.8	148.0	144.2	141.0	124.1	93.8	87.5	1626.9
Horizontal diffuse (/kWh/m^2)	50.9	56.3	71.5	83.9	101.6	101.9	96.7	92.6	84.5	73.3	57.8	51.9	922.9
Exteraterrestia (/kWh/m^2)	192.6	210.7	278.0	309.4	344.0	341.1	348.1	329.5	284.9	248.7	197.0	180.3	3264.4
Cleanness index (ratio)	0.462	0.532	0.569	0.565	0.534	0.501	0.425	0.438	0.495	0.499	0.476	0.485	0.498
Ambient temp (°C)	13.3	17.6	23.7	29.7	33.5	33.1	31.4	30.4	29.2	26.5	20.2	15.0	25.3
Wind velocity (m/s)	1.8	2.1	2.2	2.4	2.6	2.6	2.4	2.1	1.9	1.3	1.2	1.4	2.0

MATLAB IMPLEMENTATION OF THE BLOCK

The primary components used in the design that was shown were photovoltaic modules, electric vehicle charging stations (EVCS), battery banks, controllers, converters, connections, cables, and mounting structures. The flow chart for the hybrid charging station and the Matlab simulation block diagram are displayed in Figures 7 and 8, respectively.

Mathematical Computations To generate power.

Requirement for load power consumption: Yulu Bikes, the vehicle to be charged, = 48V, 30 Ah, or 1440 Wh/day

= Total daily watt-hours of appliances / 1.3.
In this instance, the system's factor loss is 1.3, which is equal to 1440 × 1.3 = 1872 Wh/day.
Consequently, we assume that we charge ten cars per day.
= 18720 Wh/day (1872 × 10).
PV panel size:
In this instance, we'll presume that the panel generation factor will be taken into account at five hours every day.
Thus, panel power rating is equal to power consumption divided by panel generation, which equals 18,720/5 = 3744 Watt.

Lithium-ion battery: Battery size:

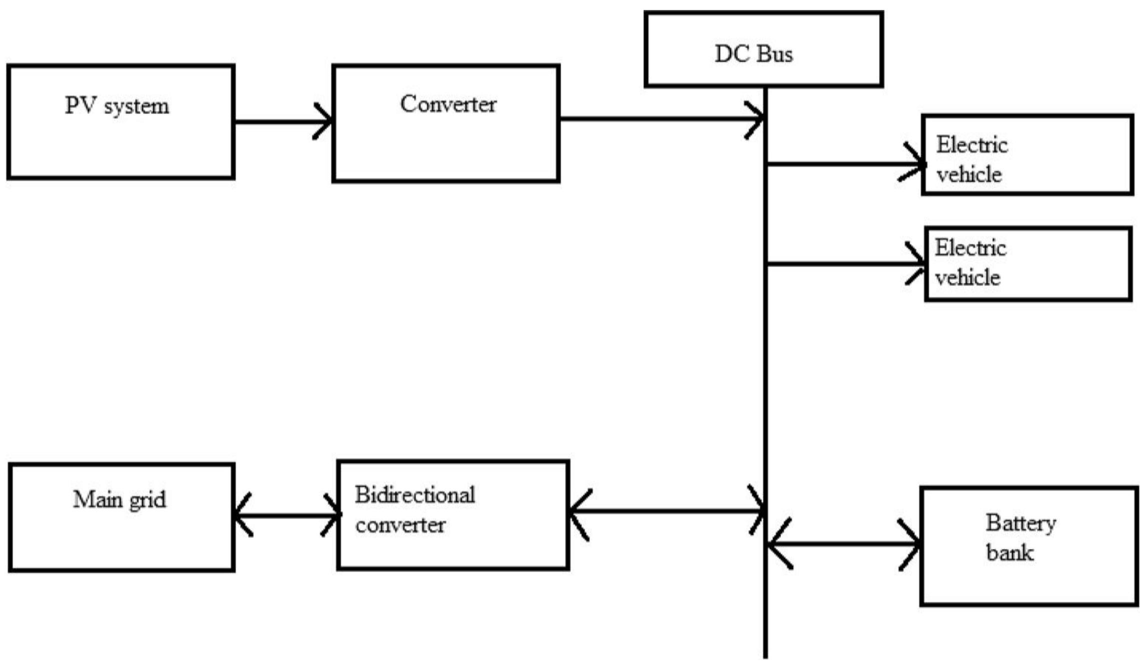


Figure 7. MATLAB implementation block of hybrid charging station.

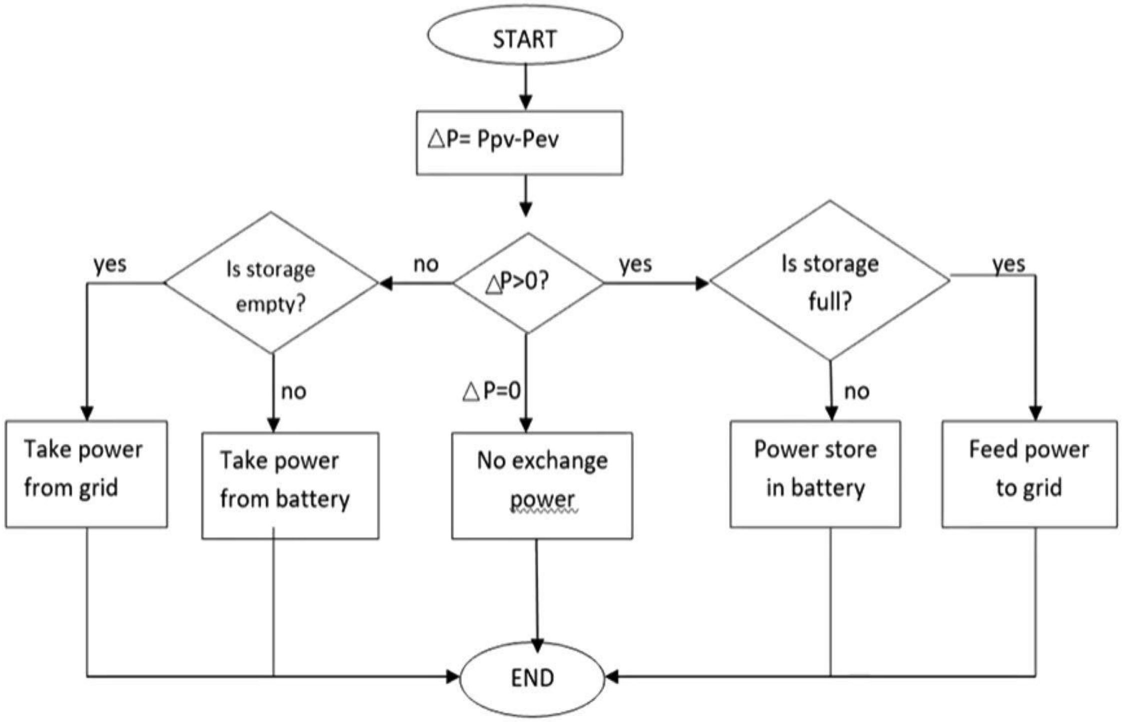


Figure 8. Flow chart of hybrid charging station.

Here vehicle want tot be charge = 1440 × 10 = 14, 400 Wh.

6 Battery loss = 0.85, DoD = 0.80, nominal voltage = 48 V, and total battery amp-hours = [14400/0.85 × 0.8 × 48] = 441.176 = 450 Ah around 48 V are all taken into account.

PVsyst Report Result With Yearly Generation And Losses

For the given parameters and geographic location, the PVsyst simulation report has been examined (Fig. 9). With a generation factor of 3.96 and an overall annual energy production of 7.6 MWh, the PVsyst output shows an annual performance ratio based on the input data.
Taking site-specific factors and system losses into consideration, the anticipated yearly output for the planned 4 kW solar PV system at the specified location is 7,635.3 kWh.

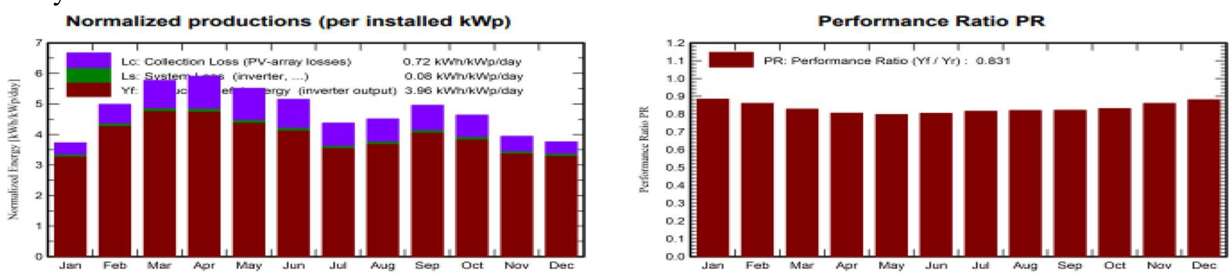
Simulation Results

It is replicated with 250W Eldora solar panels. The electrical data sheet for the SPR-E20-250, which has four strings connected in parallel with four panels per string, is shown in Table 3. Figure 10 illustrates how the simulation model is made up of several components, such as the grid-tied inverter, EV stand, battery bank, bidirectional buck/boost converter, and MPPT.
The simulation block has five modes, which are as follows.

Mode 1 (the PV system charging the battery bank).
Mode 2: PV-powered EV charging.
Mode 3: When PV power is insufficient, EVs can be charged via the grid.
Mode 4: When the grid and photovoltaic system are not available, EVs are charged by a battery bank.
Mode 5 (feeding the PV system's grid with power).

4 kw PV System MPPT/Charge Controller Waveforms 6.4

Fig. 11a
depicts the power generation of PV grid at 1000 W/m2 and 25 o C. The first ripple will be a start of PV-panels and PI -controller. Fig. 11b depicts The PV current which reaches maximum power output after 0.5 s at constant value of 70 A. Figure 11c displays the fixed voltage across DC bus of 54 V to charge the battery of EV of 48 V.



Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	88.9	50.9	13.26	115.5	113.1	550.9	539.2	0.884
February	112.0	56.3	17.61	139.6	136.6	647.6	634.6	0.861
March	158.3	71.5	23.74	179.0	174.8	798.1	782.5	0.828
April	174.7	83.9	29.65	177.3	172.8	770.0	754.4	0.806
May	183.6	101.6	33.52	170.9	165.8	735.0	720.3	0.798
June	170.8	101.9	33.14	154.5	149.9	670.5	657.0	0.805
July	148.0	96.7	31.43	135.5	131.2	596.6	584.0	0.816
August	144.2	92.6	30.42	139.8	135.8	619.3	606.2	0.821
September	141.0	84.5	29.18	148.8	144.7	659.1	645.6	0.822
October	124.1	73.3	26.52	143.7	140.4	644.1	631.0	0.832
November	93.8	57.8	20.23	118.3	115.5	548.8	537.8	0.861
December	87.5	51.9	15.01	116.6	114.1	554.2	542.7	0.882
Year	1627.0	922.9	25.34	1739.6	1694.9	7794.1	7635.3	0.831

Figure 9. PVsyst report result. (PVsyst 7.3 is a PC software package for the study, sizing and data analysis of complete PV systems).

Table 3. Electrical data sheet of SPR-E20-250 (PV panel).

Battery bank type and rating	Lithium-ion, 48 V, 450 Ah
EV battery rating	48 V, 30 Ah
Nominal power (P_{nom}) of PV panel	250 W
Total nos. of PV panels	16
PV panel configuration	4 × 4 (4 panels in one string and 4 strings)
Power tolerance	+ 5–0%
Average panel efficiency	20.4%
Rated voltage (V_{mpp})	30.2 V
Rated current (I_{mpp})	8.27 V
Open-circuit voltage (V_{oc})	36.6 V

Short-circuit current (I_{sc})	8.75 A
Maximum system voltage	1000 V IEC and 60 V UL
Maximum series fuse	15A
Power temperature coefficient	– 0.35%/°C
Voltage temperature coefficient	– 176.6 mV/°C
Current temperature coefficient	2.6 mA/°C

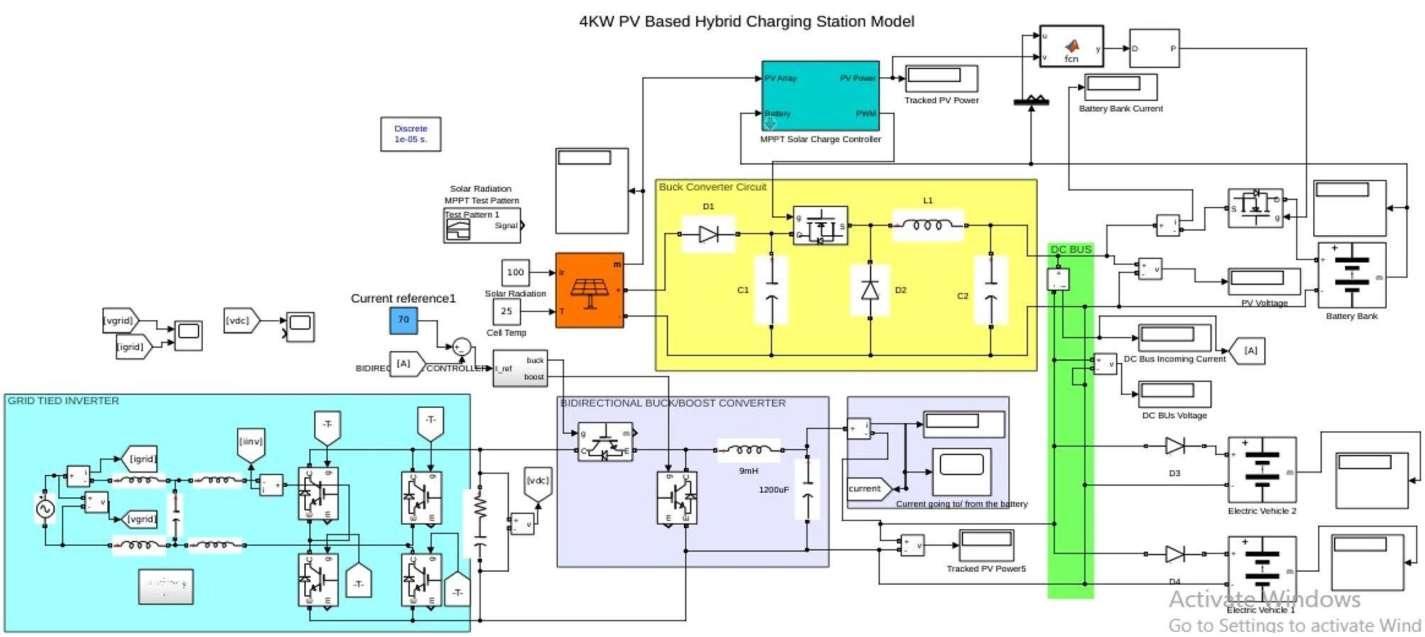
Figure 10. Hybrid charging station simulink model.

Mode 1 (PV system charging battery bank): When a battery bank is powered by a PV system, this mode is accessible.
As seen in Figure 12, the PV system is charging the EVs while the load across the DC bus remains constant at 54 V. The EV is charging SoC, current, and voltage in mode 1. Changes in SoC, battery voltage, and charging current are displayed on the graph.

EVS charging via PV systems (MODE 2)
In Fig. 13, the charging SoC, voltage, and current of the EV are all in mode 2.
Mode 3 (when PV is insufficient, EVs are charged from the grid)

Mode 3 occurs when PV electricity is unavailable because of rain or when EV batteries need to be charged at night, as shown in Fig. 14. In this case, EVs are charged via the AC grid utilizing a birectional inverter and a bidirectional buck-boost converter.

Mode 4: (charging battery bank without PV system or grid).
Fig. 15 shows the EV's charging state by battery bank using mode 4 operating graphs. A protracted power loss is the premise of the operation. EVs are charged using battery banks with power backup because the



AC PV and the grid are not accessible at the same time.

.**Figure 11.** (**a**) Variation of MPPT track power (**b**) MPPT current and (**c**) MPPT voltage w.r.t time at 25 °C, 1000 Wb IR.

Figure 12. (**a**) Variation of battery SoC, (**b**) current and (**c**) voltage w.r.t time at 25 °C, 1000 Wb IR.

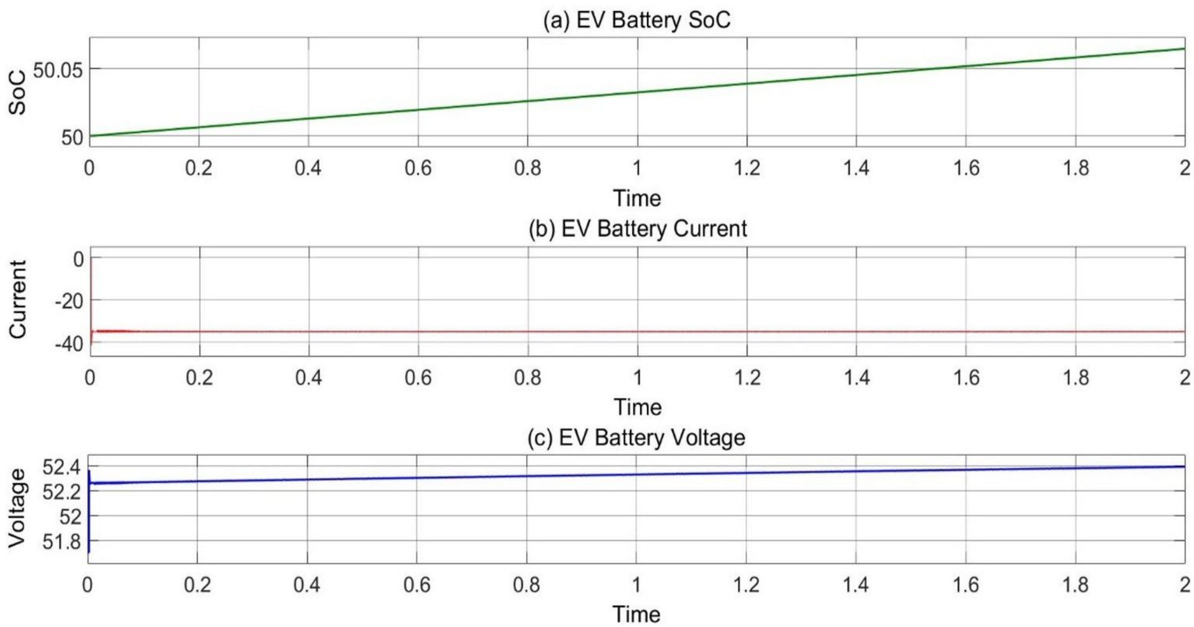


Figure 13. (**a**) Variation of EV's battery SoC, (**b**) current and (**c**) voltage w.r.t time at 25 °C, 1000 Wb IR.

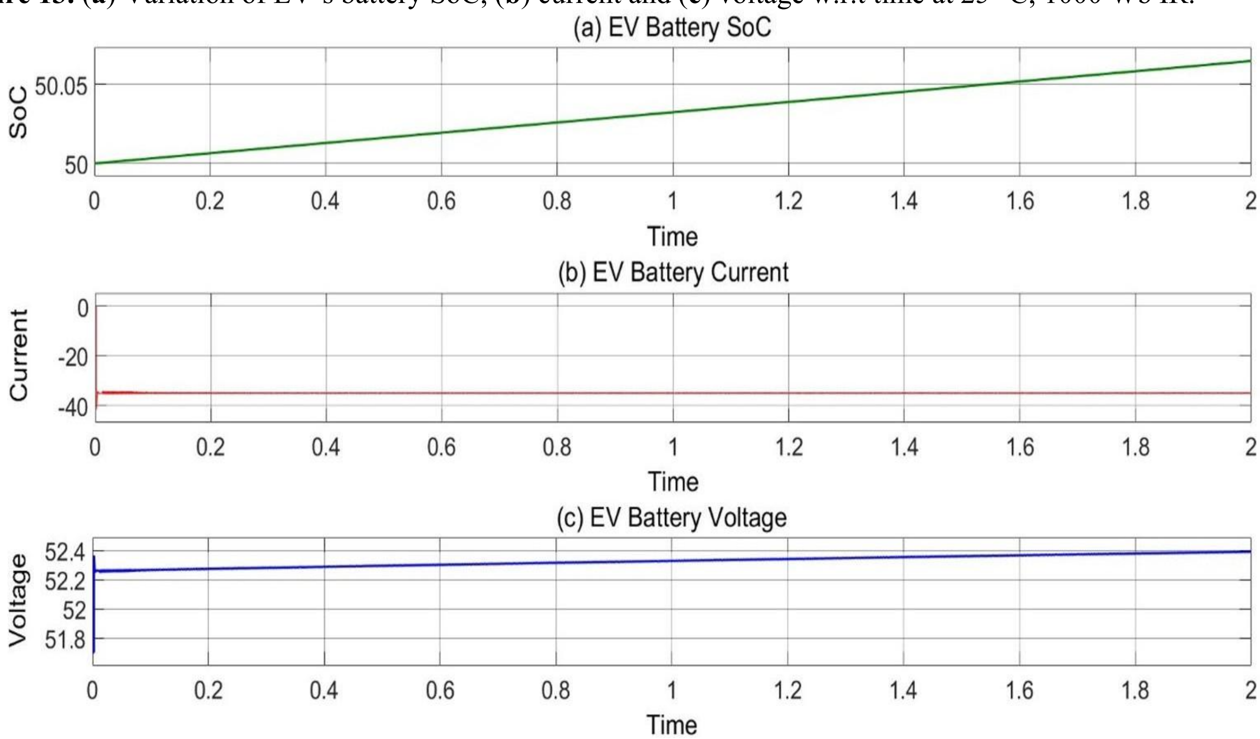


Figure 14. (**a**) Variation of EV's battery SoC, (**b**) current and (**c**) voltage w.r.t time at 25 °C, 1000 Wb IR.

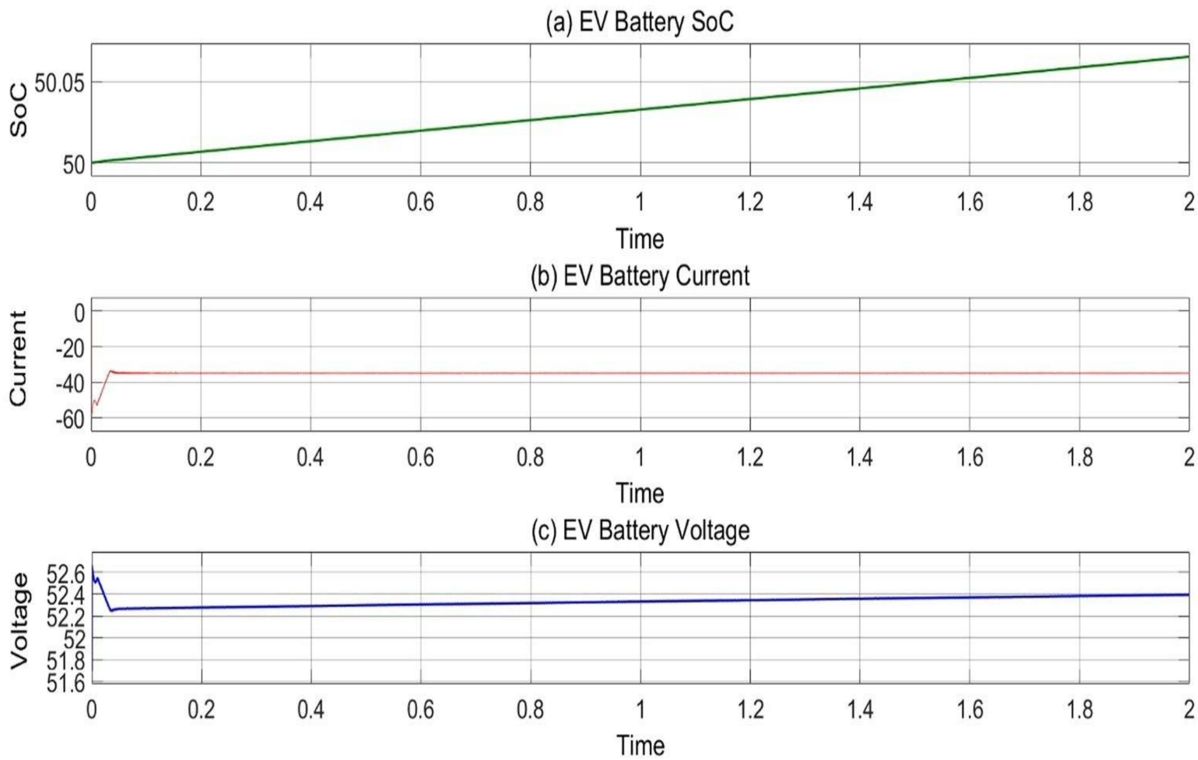


Figure 15. (**a**)Variation of EV's battery SoC, (**b**) current and (**c**) voltage in mode 4 operation

PV system in mode 5 (feed power to the grid).
The PV system generated electricity and fed it to the grid, which also helps to earn and balance the grid load during peak hours. In this scenario, the charging station is not loaded, no EV is being charged, and the battery bank is being charged. The plot of the voltage and current supplied to the AC grid is shown in Fig. 16.

The findings of simulating the five distinct EV charging station modes of operation have been verified using MATLAB and PVsyst. Among the modes are

\\ Mode 1: The battery bank is charged by the PV system.
Mode 2: PV-powered electric vehicles.
Mode 3: When PV energy is insufficient, EVs use the grid to charge their batteries.
Mode 4: When there is no grid or photovoltaic system, EVs charge their battery banks.
Mode 5: Power the grid photovoltaic system

The results of the simulation confirm that EVs can be powered sustainably by the hybrid charging station. Complete reproducibility has been demonstrated for the three-stage charge controller, buck converter, grid-tied inverter circuit, and MPPT P and O tracking algorithm. 1012 EVs may be charged with this setup using 48 V 30 Ah lithium-ion batteries. In order to reduce load demand, it may also be utilized to export excess solar energy to the grid. Furthermore, the simulation results demonstrate how the charging station would operate under different conditions, such as in the rain or at night, when PV power is insufficient, or during prolonged power outages when neither the PV system nor the grid are operational.

The results of the simulation confirm the hybrid charging station's ability to provide EVs with sustainable electricity. The entire reproducibility of the three-stage charge controller, buck converter, grid-tied inverter circuit, and MPPT P and O tracking algorithm has been demonstrated. This system has the capacity to charge 1012 EVs using 48 V 30 Ah lithium-ion batteries. Additionally, it may be utilized to export excess solar energy to the grid, reducing the demand for loads. The simulation's outcomes also demonstrate how the charging station would operate in a variety of scenarios, including when PV power is inadequate, at night or in the rain, or during prolonged power outages when neither the grid nor the PV system are operational.

Figure 16. (**a**) Variation of voltage and (**b**) current graph w.r.t time at 25 °C, 1000 Wb IR.

A large step in the direction of eliminating fossil fuel combustion and grid overloading is the use of battery storage to provide EVs with constant power.

CONCLUSION

Both a hybrid charging station and a charging controller with Simulink modeling are offered. The MPPT P & O tracking algorithm, buck converter, grid-tied inverter circuit, and three-stage charge controller have all been fully described and are easily reproducible. By recording the maximum output of the 4 kW PV-based energy source as the field and managing the charge using a three-stage charging plan, the 4 kW PV-based charging station can charge 10–12 EVs with 48 V 30AH lithium-ion batteries.

The first system constructed was PVsyst. Following the selection of the software and devices with PVsyst characteristics in Simulink, the output in the form of voltage, power, current, and state of charge, among other things, has been shown as a graph of all the significant devices. The filtering process may be optimized to get good results. The study helps construct sustainable transportation infrastructure and integrate renewable energy to address grid stability and EV charging challenges.

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