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Original Article

Grid-Connected Solar-Battery System for Multi-EV Charging Infrastructure

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Abstract *- In this paper, the real-time issues of sustainable charging stations for Electric Vehicles (EVs) are handled through the integrated grid-tied solar photovoltaic system with the backup of energy storage technology. The paper mainly focuses on the grid stability issues and the impact of the traditional charging facilities on the environment. It focuses on the growing need and reliability of renewable energy sources for developing a reliable charging infrastructure. It states about financial feasibility and advantages for the environment with the integrated approach. The grid-connected solar energy system used solar energy to generate the required power to facilitate the infrastructure for charging EVs. To make the system reliable, the power flow should be dual, i.e, PV to grid or grid to PV, based on the availability of power at the charging station. This provides an efficient, clean, and long-lasting charging infrastructure. In addition, backup battery storage technology is provided to ensure reliability during unforeseen conditions. The investigation shows the ecological charging infrastructure for EVs by utilizing various energy sources for effective implementation.*

Keywords *- Electric Vehicles (EVs), Photovoltaic (PV), Charging Infrastructure, Grid Connected System, Multi-EV Charging.*

1. Introduction

Transportation has become an essential part of modern life. Fuel-based vehicles are ruling the world by generating high pollutants, which harm society. So, it is necessary to replace them with modern transportation, i.e., Electric Vehicles (EVs). Electric Vehicles work with electrical energy by charging their batteries; these are more efficient, carbon-free, and low-cost operating vehicles. Comparison between EVs and IC-based vehicles is discussed below [1, 2]:

- Efficiency: In an efficiency perspective, EVs are 60% efficient when they draw power from the grid, whereas IC vehicles are only 20% efficient. So the losses are more for IC vehicles.
- Zero Emissions: As everyone knows, EVs are carbon-free, whereas IC vehicles will release CO2, which is the main reason for choosing EVs. The CO2 pollutant is three times higher in vehicles compared to conventional power generation.
- Operating Cost: The running cost of EVs is less than that of IC vehicles because of fuel cost. It means the cost of petrol or diesel is more than the power generated from fossil fuels.

Still, the operating cost of EVs can be reduced by choosing sustainable power generation.

So, the demand for Electric vehicles (EVs) has increased worldwide in recent years to achieve sustainable and clean transportation with the advantages mentioned earlier.

The main problem for the adoption of EV transportation is grid dependency because most of the power generated in India is from fossil fuels. So, developing a solar-based EV charging infrastructure is the solution to reduce stress on the grid, as well as an alternative method of power generation.

This renewable-based power generation not only meets the requirement of power to charge EVs but also helps the grid by providing excess energy to the grid. The Indian government has taken the challenge to lower the impact of EV charging on the grid. 40% of Electric Power should be generated from sustainable energy sources by 2030 by installing renewable plants to switch people towards EVs [3, 4].

Solar-powered EV charging systems consist of PV modules that are used to convert the sun's light into Electricity (DC) to charge EV vehicles directly or indirectly with power converter circuits. The solar system is configured in various methods, such as Grid-Connected, Standalone, and Hybrid-Connected (Solar Battery Connected) [5, 6]. The Solar Battery-Connected system is implemented in this paper because of the following reasons:

- Solar energy is available only during the daytime; to use it in its absence, a battery system will take care of the required power, which is connected to the grid.
- If the generated power from solar is in excess, then the battery system will help to store energy.
- The solar system is connected to the grid for EV charging to have continuous, regulated power.

This paper addresses the issues of a hybrid connected solar battery-powered charging station, which helps to improve stability and load balancing tasks. This system provides a reliable, long-lasting, and durable charging facility infrastructure for the electric vehicles [7, 9].

The suggested system's block diagram of multi-EV Charging with a hybrid connection is shown in Figure 1. Section II talks about the essential components of the block diagram. Section III talks about charging infrastructure with a renewable-based integrated system, and Section IV talks about simulation results.

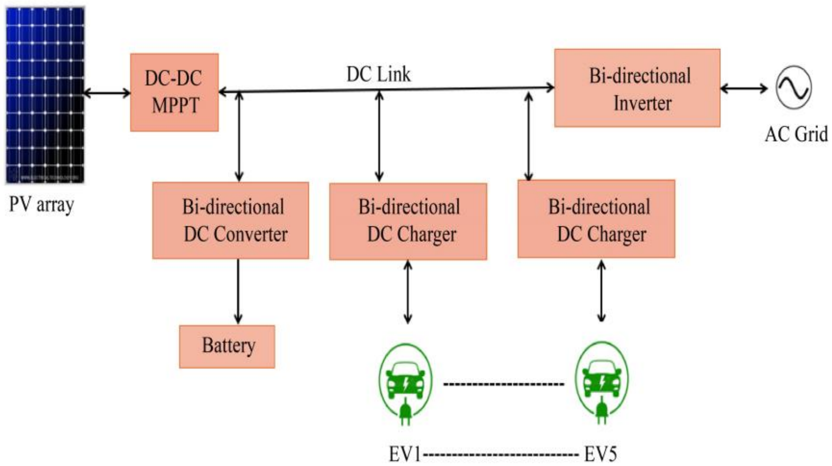

Fig. 1 Block diagram of the proposed system for multi-EV charging

2. Solar-Battery Connected System

A solar battery-connected system requires many components to generate and distribute power to various loads [10]. The detailed analysis of each component is discussed below:

2.1. PV System

2.1.1. PV Cell

A Photovoltaic (PV) Cell is a semiconductor device that uses a p-n junction to change sunlight directly into electricity through the Photovoltaic Effect. A PV cell is a replica of an Electrical Model that acts as a Current Source (IL), by considering various elements of a Diode (D), and two resistances: a Series Resistance (RS) and A Shunt Resistance (Rsh). The amount of current generated by hitting the surface of a solar panel from light is directly related to the proven equation, which is expressed in equation (1):

$$I = I_L - I_o(e^{\frac{q(V+IR_S)}{AkT}} - 1) - \frac{V+IR_S}{R_{sh}} \quad (1)$$

The notations used in the above equation are represented below as:

- Io is the current that flows through the diode when it is fully charged,
- q is the charge of an electron,
- k is the Boltzmann constant,
- 'Tis the temperature of the cell, and
- A is the ideality factor of the diode.

A single PV cell only provides roughly 0.6 V of voltage in real time. To get higher voltages and currents, all the PV cells can be connected in series and parallel combinations to meet the required power. The relation of current with series and parallel combination of cells is expressed in equation (2):

$$I = N_p I_L - N_p I_o(e^{\frac{q(\frac{V}{N_S}+\frac{IR_S}{N_p})}{AkT}} - 1) \quad (2)$$

N_s and $N_p$are the numbers of cells that are connected in series and parallel, respectively.

2.1.2. MPPT Controller

As everyone knows, a solar system is a dynamic system; the power generated from the system is also a dynamically variable because it depends on solar irradiance, temperature, and load variations. The paramount importance of an MPPT is to operate the system at maximum voltage and current to achieve the maximum power. The inputs of the solar system are changing continuously, so the controller should adjust the operating conditions to obtain the maximum power from solar panels. The Perturb and Observe (P&O) strategy is widely used as an MPPT controller strategy due to its user-friendliness and understandability. The same controller strategy is implemented in this solar battery connected to operate the DC-DC Converter.

2.1.3. DC-DC Converter

A DC-DC converter plays a significant role in a solar system, which regulates either the output voltage or current. The output from the solar system is constantly changing because of its dynamic inputs; therefore, the output also continuously affects the load. So, to regulate the output of the converter as per the requirement of the grid/load, the operating point should be adjusted by using an MPPT controller. The relationship between the output voltage, input voltage, and duty ratio is expressed in equation (3).

$$V_o = \frac{V_{pv}}{1-D} \quad (3)$$

2.2. Battery Energy Storage System (BESS)

BESS is a type of storage technology that stores electrical energy to charge batteries. The batteries used in the solar system will work as rechargeable batteries. Bidirectional converters are used to operate the power flow through the controller in both directions, which are discussed below with two operating modes:

Mode 1: The power generated from the solar system is more than the demanded power. In such a case, the excess power is stored in the batteries after meeting the load demand. This mode is known as the charging mode of the battery.

Mode 2: If the power generated from the solar input is not sufficient to meet the demand power, then the battery acts as an input (source) power to meet the demand power. This mode of operation is known as discharging mode, where power is sent to the load [11].

2.3. Multi EV Load / Grid

Multi EV charging and Load sharing through a renewable system or the grid pose a significant challenge to the system. The system will be efficient and reliable when multiple rated EVs charge simultaneously. All multi-EV Charging will be done through a single point in the network, which will affect the system's stability, and harmonics will also be injected into the network-smart Power distribution for various loads, reducing the stress on the feeder with managerial strategies.

2.4. Controller

A controller needs to be designed effectively to operate the system smoothly to prevent the above-mentioned limitations of the solar-battery connected through the grid. The controller determines the power flow based on the availability of energy, known as power management with system balance, to improve stability and optimise the load schedule based on need and demand on both the load side and the source side. As per the block diagram of Figure 1 mentioned, the five EVs need to charge simultaneously at different ratings, either through solar battery or through the grid, which will be discussed in Section IV.

3. Optimised EV Charging System

In many small Photovoltaic (PV) systems, grid connection is not preferred to avoid direct interaction with local loads. The systems are working to allow for bidirectional connections to have power flow between the grid and Electric Vehicles (EVs). The fundamental idea is to use the PV electricity that is generated locally whenever possible and only use the grid as a backup. The reverse power flow is also allowed to give the extra energy from PV, which can be sent to the grid based on the demand. To charge EVs during the night, the power required through solar will not be possible; therefore, they should rely on the grid. So, to improve system performance with bidirectional power flow will be possible by an optimised controller [12, 13]. As discussed in the previous section, PV (solar), battery, and grid are the significant components of a sustainable EV charging system. The operation of the system depends on the design of the controller for the optimistic power balance, which is discussed in the flowchart 1. When the solar system is connected through the grid and battery, there will be three possible case studies discussed in the flowchart 1:

- If the power generated from solar is deficient, then the required energy needs to be taken from the grid or the battery.
- If the power generated is sufficient, there will not be any power flow to the grid or the battery, and vice versa.
- If the power generated from solar is in excess, then it can give the energy to the grid or to charge the battery (as backup).

The battery system plays a significant role in storing and managing the solar energy as well as driving the EV charging system. This system acts as a buffer during generation and peak demand. A battery system not only stores the generated energy but also improves the grid stability by providing additional benefits like frequency control and peak shaving. To improve the usage of renewable energy optimistically, the fast Charging of EVs is enabled so as not to burden the grid. The State of Charge (SoC) of a battery at any time t is expressed in equation (4).

$$SoC(t) = SoC(0) + \eta_c \sum_{k=0}^{t} P_{CB}(k) + \eta_d \sum_{k=0}^{t} P_{d=DP}(k) \quad (4)$$

where $SoC(0)$ is the initial battery charge, P_{CB} and P_{DB} are the charging and discharging powers, and η_c and η_d are the charging and discharging efficiencies. The battery is operated within limits: $B_{min} \leq SoC \leq B_{max}$ and $0 \leq P_{DB}(k) \leq P_{max}$, preventing overcharging or deep discharge, and extending battery life.

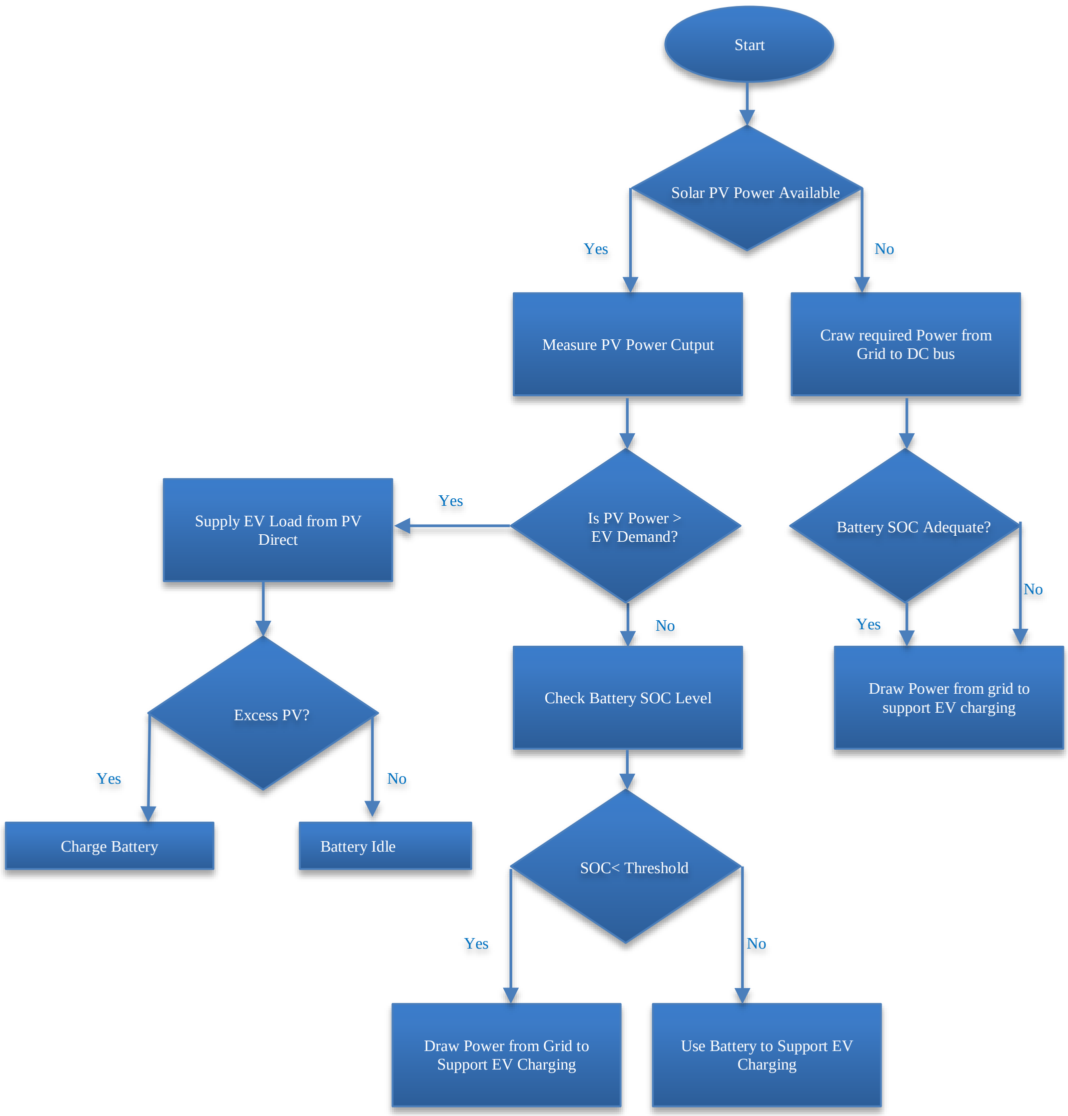

Fig. 2 Flowchart 1: PV, battery, and grid operation

As a result, the battery lasts longer, preventing overcharging or severe drain. The primary means of transferring power across the system is the DC bus. It provides a constant DC voltage to EV chargers, converters, PV arrays, and energy-storing batteries so that electricity may be transferred quickly. The DC bus regulates power between PV generation, storage, and the grid supply, permits energy to flow in both directions, and maintains the health of power electronics. Because the DC bus maintains voltage stability, downstream inverters and connected loads can operate dependably.

4. Simulation Results

The effectiveness of the grid-connected solar-battery system for multi-EV charging infrastructure was estimated and designed in two operating scenarios, with detailed simulation results discussed in this section. Solar-generated power, battery SOC, grid power, and EV charging profile of all five vehicle simulation results are shown in the figures below. The simulation results are discussed with two cases to show the dynamic power flow of the system.

4.1. Case 1: Power Profiles of Various Generations of the System

In this mode, the PV system is installed to deliver the 92.72 kW of DC power under optimum irradiation conditions. The five EVs are connected to the system for simultaneous Charging. If the total load connected to the system is 68.78 kW, the battery is maintaining 40% of its maximum SOC. The remaining power (i.e., Excess power) of 50.27 kW is supplied to the grid. All the above power profiles, along with the charging power profiles of all five EVs, are shown in Figure 3.

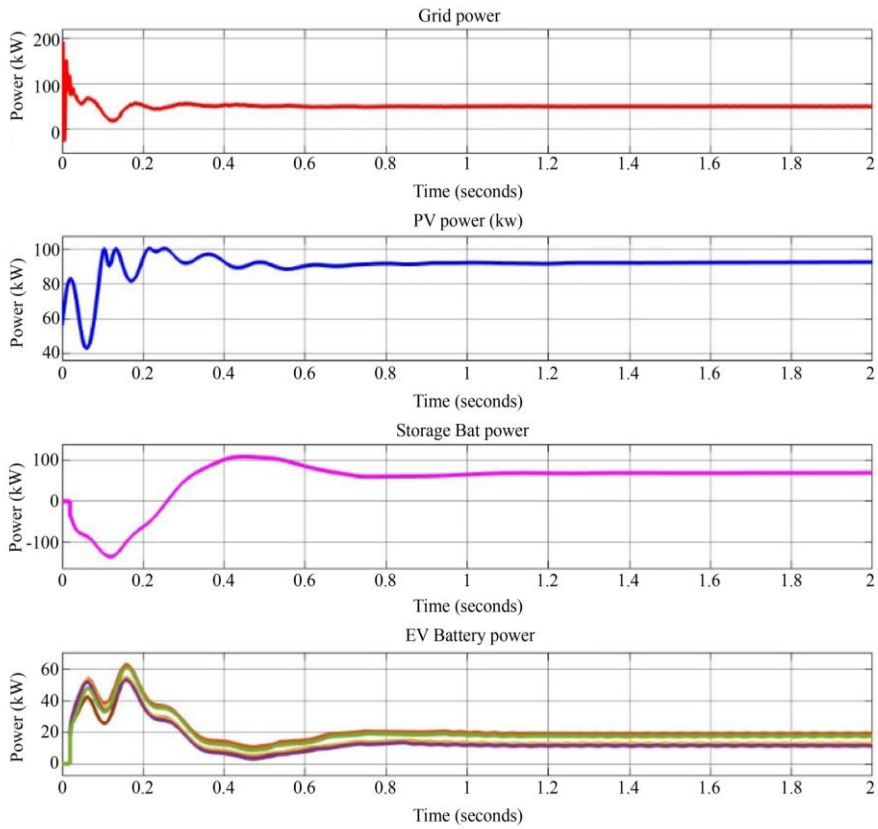

Fig. 3 Power profiles of grid, PV, storage battery, multi EVs Battery power

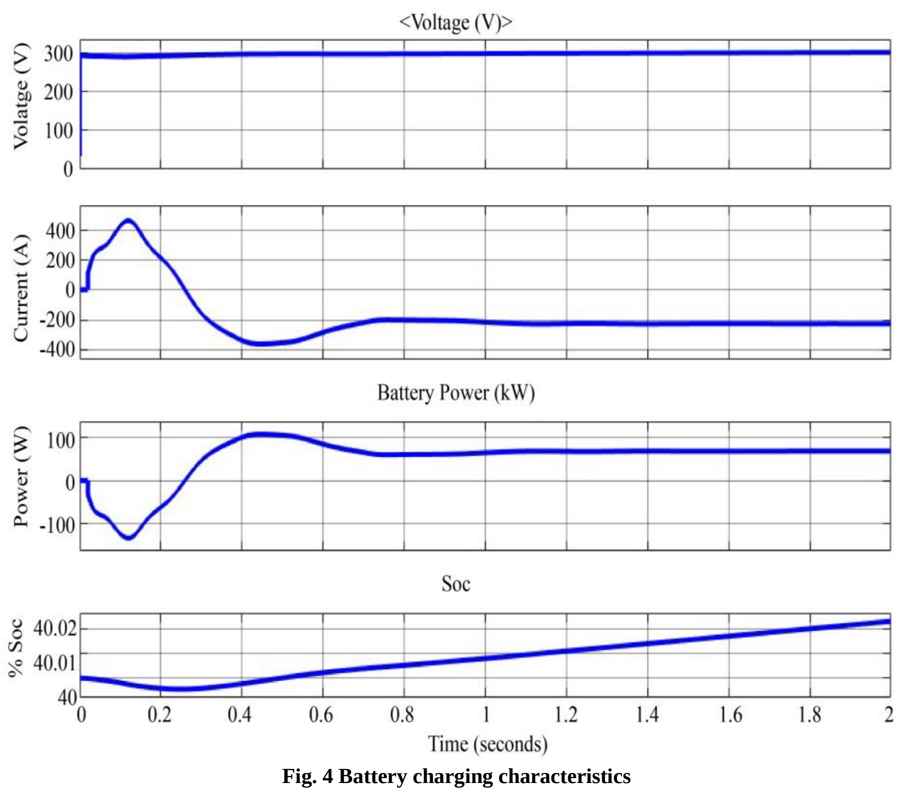

Fig. 4 Battery charging characteristics

Figure 3 shows the simulation results of the various system power profiles mentioned. As per flow chart 1, the power generated from solar is more than required. The controller will decide the power flow from the source to the grid. Therefore, the excess power of 50.27 kW is supplied to the utility grid, demonstrating partial reliance on grid supplies in addition to local sources.

Furthermore, 68.78 kW of power is connected as an EV load from a solar and storage battery system. The measured power values show that the hybrid energy system is well-balanced and can intelligently coordinate its sources to suit changing load needs. The storage battery parameters of voltage, current, power, and SOC of the simulation results are 302 V and -227.6 A, respectively, as shown in Figure 4. The charging profile of the battery SOC is displayed in Figure 4.

4.2. Case 2: Charging Mode of Multiple Electric Vehicles

The simulation results aim to analyse dynamic power flow, storage control schemes, and grid interaction, while ensuring effective and sustainable energy use. The total power generation from the solar battery has to provide about 153.64 kW. The multiple EVs of different ratings are connected to the solar-battery system.

The total load of five electric vehicles is 84.90 kW (EV1: 22.5 kW; EV2: 15.0 kW; EV3: 16.2 kW; EV4: 13.0 kW; EV5: 18.2 kW). The total load connected to the system will be charged simultaneously. The EVs each have a current of 74.50 A, 49.67 A, 53.64 A, 43.05 A, and 60.26 A. All five EVs charging profile characteristics are discussed below:

4.2.1. EV1

The voltage range of the EV-1 is 260-300 V, and the current required to charge the vehicle is in the range of 70-75 A. The power rating of the EV-1 is 22.5kW; it is supplied with 302 V, so the EV-1 is charging through 74.5A, which is in the recommended range to charge the vehicle. Figure 5 shows the charging voltage, current, and power with battery SOC for optimal Charging effectively within permissible limits.

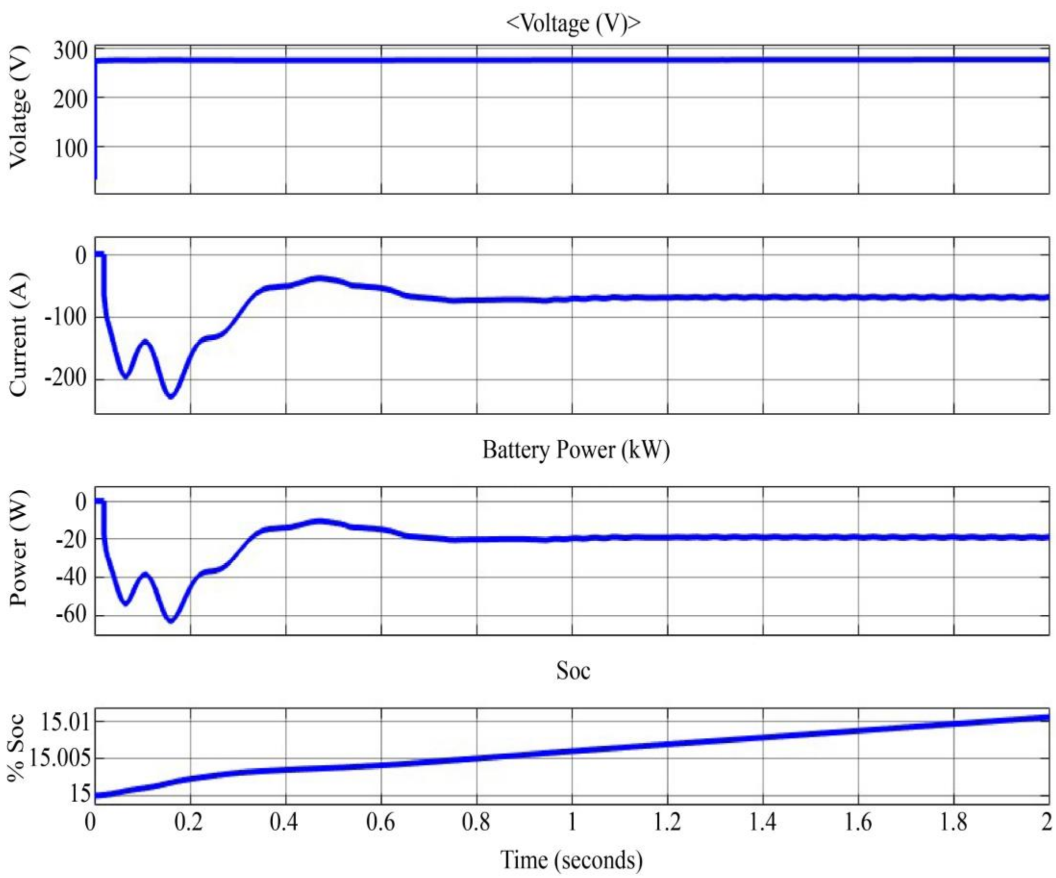

Fig. 5 EV-1 charging characteristics

4.2.2. EV2

The EV-2 specifications are power is 15kW, voltage range is 290-300V and current charging range is 45-50A. The EV-2 is supplied with 295 V DC, which is charged with a current of 49.67A. These simulation outputs are presented in Figure 6. The voltage level at the upper limit makes sure that the charging profile is stable and efficient, which leads to a smooth rise in battery SOC during the simulation period.

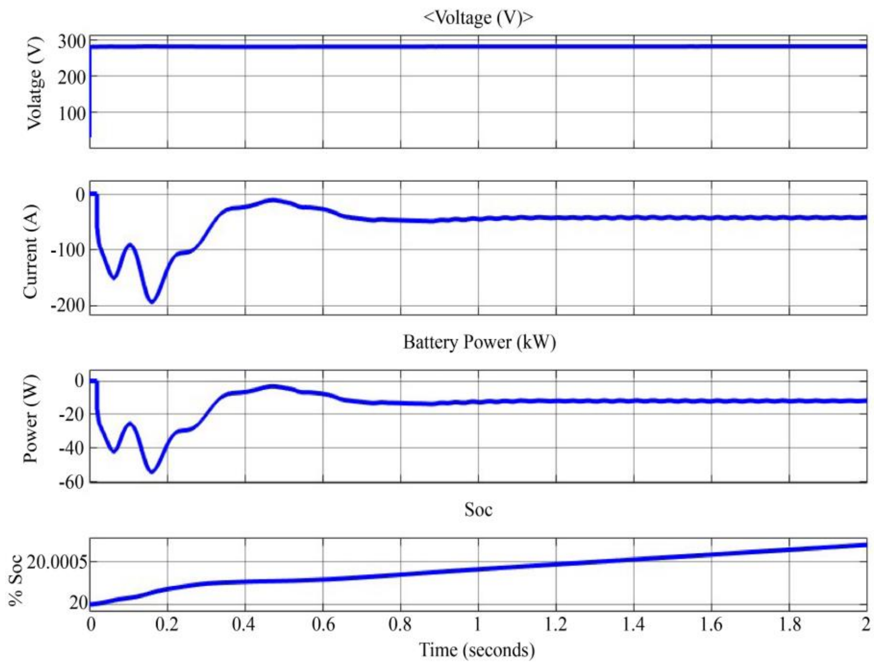

Fig. 6 EV-2 charging characteristics

4.2.3. EV3

The EV-3 has an operating voltage and current range of 260-270 V and 55-60 A. The capacity of the EV-3 is 16.2kW. The supplied voltage of this EV is 270 V, so the charging current is 53.64 A, which is just below the bottom limit of the range of currents that are allowed in Figure 7.

This little difference could be caused by changes in voltage at the charging port or losses in the converter. Even though there is a slight difference, the EV still charges well, and the SOC of the vehicle battery is going up, which means that energy is being transferred from the supply to the EV battery system.

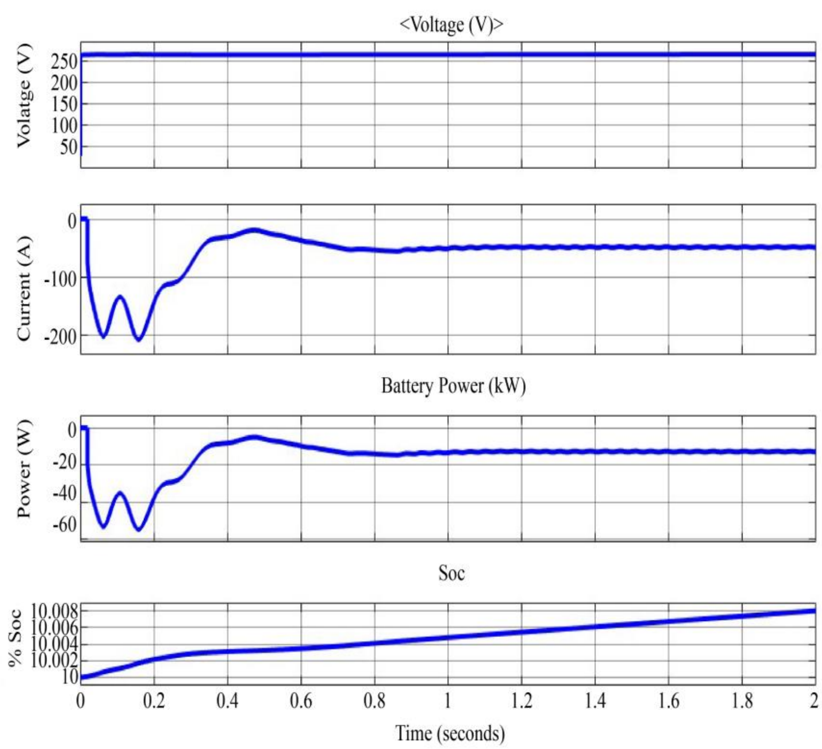

Fig. 7 EV-3 charging characteristics

4.2.4. EV4

The EV-4 is meant to work with a voltage range of 250 to 260 V and a current range of 45 to 50 A. The simulation gave us a charging power of 13 kW, which is equal to a current of 43.05 A at 302 V, as seen in Figure 8.

The current value is just below the limit that was set. This could be because the higher voltage is supplied by the vehicle battery. The vehicle is still charging, and its SOC is steadily going up, which shows that the charging mechanism is working well.

4.2.5. EV5

The rated power of EV-5 is 18.2 kW, and it works with voltages between 240 and 280 V and currents between 60 and 65 A. The current is about 60.26 A, and the voltage is 302V, as illustrated in Figure 9, which is well in the middle of the range that was given. This means that the charging circuit works well, with good voltage regulation and current management. The simulation results demonstrate that the SOC of EV-5 keeps going up while it is charging, which shows that the power transfer process is steady and reliable.

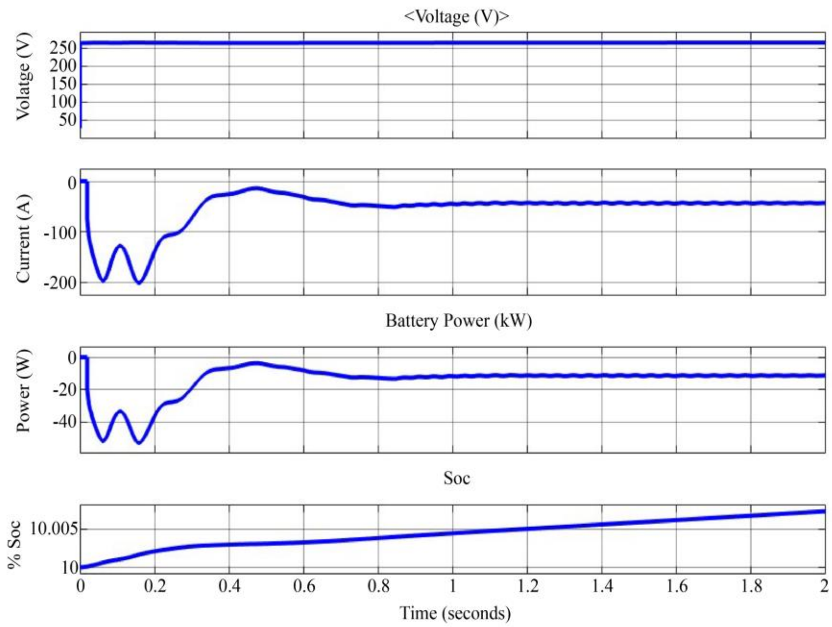

Fig. 8 EV-4 charging characteristics

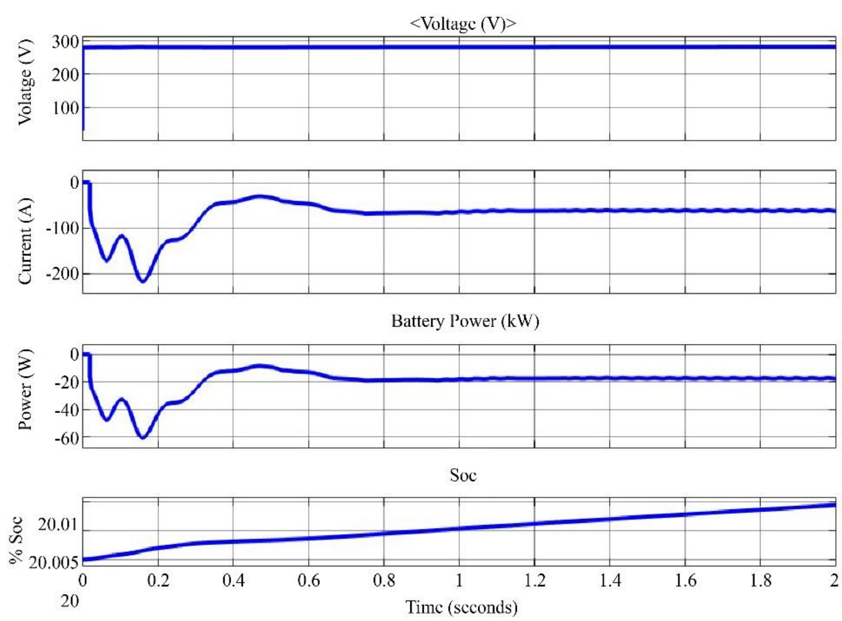

Fig. 9 EV-5 charging characteristics

All five electric vehicles are in charging condition, and their respective States of Charge increase over time. The total power drawn by the EVs is 84.9 kW, which is supplied through the grid-connected PV and storage battery system.

The slight variations in current among some EVs are acceptable and can be attributed to system losses or voltage fluctuations. Overall, the results indicate that the multi-EV charging system operates efficiently under the simulated conditions, as tabulated in Table 1.

Table 1. Multi-EV charging specifications

EV	Voltage range (V)	Current spec (A)	Power (kW)	Calculated current @302 V (A)	Within spec?
EV1	260-300	70-75	22.5	74.50	Yes
EV2	290-300	45-50	15.0	49.67	Yes
EV3	260-270	55-60	16.2	53.64	No - slightly below
EV4	250-260	45-50	13.0	43.05	No slightly below
EV5	240-280	60-65	18.2	60.26	Yes

4.3. Case 2: Excess PV Power Export to Grid

In the second scenario, the simulation looks at what happens when all five EVs are either fully charged or utilising very little power, and the storage battery is at a State Of Charge (SOC) above 90%. In this case, the PV system continues to generate significant power, and any additional power that the EVs or storage do not utilise is transmitted to the utility grid, as shown in Figure 10. A grid-tied inverter handles this change. It makes sure that the power export is compatible with voltage and frequency standards. This mode shows off the system's advanced energy management functions, like being able to communicate with the grid, giving precedence to specific loads, and getting the most out of renewable energy.

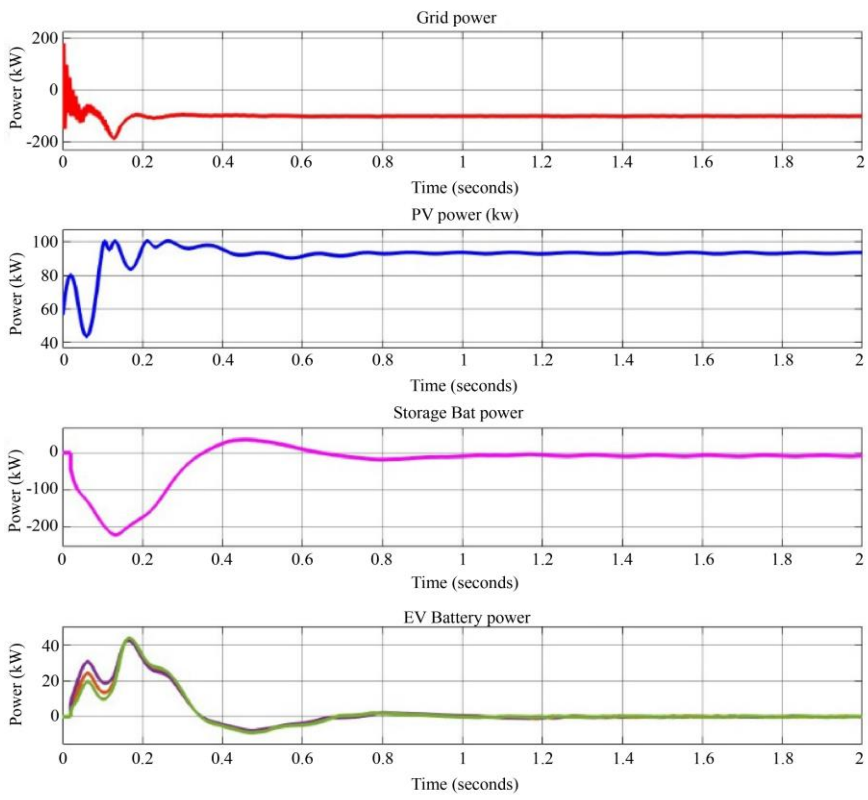

Fig. 10 Grid, PV, storage battery & EV battery power energy

In this working scenario, there are no Electric Vehicles (EVs) connected to the DC bus; hence, EV batteries are not utilising any power. However, in the best case, the Photovoltaic (PV) system keeps making electricity. When the State Of Charge (SOC) of the storage battery is at the maximum level of 90%, it is considered fully charged. No further charges are authorised to avoid overcharging. As a result, a grid-tied inverter sends all the power that the PV system makes to the utility grid. This stops energy curtailment, keeps the local system running, and makes sure that extra renewable energy is used well. Without a vehicle load, the control system maximises renewable penetration and makes sure that energy is sent to the right place by changing the power routing based on how many EVs are available and how charged the storage unit is. Simulation Results Storage battery parameters: The storage battery voltage and current are 306 V and -7.6 A, respectively. The battery's SOC stays around 95%, as illustrated in Figure 11.

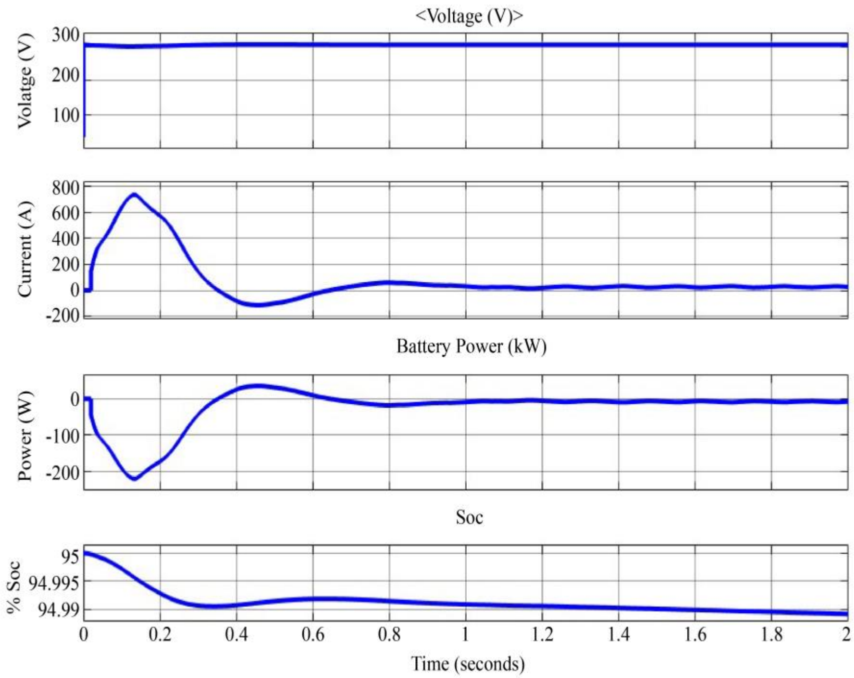

Fig. 11 Battery SOC characteristics

5. Conclusion

In conclusion, a viable and sustainable solution is provided by combining an Electric Vehicle (EV) charging station's grid-connected Photovoltaic (PV) system with batteries for energy storage. In addition to offering a sustainable and clean source of energy for EV charging, solar energy generation and energy storage also support grid resilience and stability. By using solar energy to charge EVs, the PV system lessens reliance on traditional grid electricity. By enabling energy storage during times of surplus generation and discharge at times of high demand or low sunshine, battery storage improves the charging station's dependability. This integrated strategy supports grid efficiency, environmental sustainability, and more robust infrastructure, all of which are in line with the rapidly changing clean and intelligent energy solutions for electric vehicles.

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References

[1] Vasja Omahne, Matjaz Knez, and Matevz Obrecht, “Social Aspects of Electric Vehicles Research-Trends and Relations to Sustainable Development Goals,” *World Electric Vehicle Journal*, vol. 12, no. 1, pp. 1-13, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[2] Zhenhai Gao et al., “Electric Vehicle Lifecycle Carbon Emission Reduction: A Review,” *Carbon Neutralization*, vol. 2, no. 5, pp. 528-550, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[3] Kavuri Poornesh, Kuzhivila Pannickottu Nivya, and K. Sireesha, “A Comparative Study on Electric Vehicle and Internal Combustion Engine Vehicles,” *2020 International Conference on Smart Electronics and Communication (ICOSEC)*, Trichy, India, pp. 1179-1183, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[4] Prakhar Prakhar et al., “Electric Vehicles in Transition: Opportunities, Challenges, and Research Agenda-A Systematic Literature Review,” *Journal of Environmental Management*, vol. 372, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[5] Alok Jain, and Suman Bhullar, “Operating Modes of Grid Integrated PV-Solar based Electric Vehicle Charging System- A Comprehensive Review,” *E-Prime-Advances in Electrical Engineering, Electronics and Energy*, vol. 8, pp. 1-11, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[6] Lu Wang et al., "Grid Impact of Electric Vehicle Fast Charging Stations: Trends, Standards, Issues, and Mitigation Measures-An Overview," *IEEE Open Journal of Power Electronics*, vol. 2, pp. 56-74, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[7] Md Hasan Maruf et al., "Grid-Connected Solar PV System for EV Charging Station with Battery Storage," *2024 6th International Conference on Sustainable Technologies for Industry 5.0 (STI)*, Narayanganj, Bangladesh, pp. 1-5, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[8] Chong Chiat Tan et al., "Performance Characteristics of Electric Vehicle Battery using Charging Station System with Grid Connected Configuration via Matlab Simulation," *Journal of Electronic Voltage and Application*, vol. 2, no. 2, pp. 13-22, 2021. [Google Scholar] [Publisher Link]

[9] Abhishek Kumar Tripathi et al., "Integration of Solar PV Panels in Electric Vehicle Charging Infrastructure: Benefits, Challenges, and Environmental Implications," *Energy Science & Engineering*, vol. 13, no. 4, pp. 2135-2152, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[10] Mayuri Upasani, and Sangita Patil, "Grid Connected Solar Photovoltaic System with Battery Storage for Energy Management," *2018 2nd International Conference on Inventive Systems and Control (ICISC)*, Coimbatore, India, pp. 438-443, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[11] Solmaz Nazaralizadeh et al., "Battery Energy Storage Systems: A Review of Energy Management Systems and Health Metrics," *Energies*, vol. 17, no. 5, pp. 1-21, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[12] Shahab Sabzi, and László Vajta, "Optimizing Electric Vehicle Charging Considering Driver Satisfaction through Machine Learning," *IEEE Access*, vol. 12, pp. 102167-102177, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[13] Priyadarshan Patil, Khashayar Kazemzadeh, and Prateek Bansal, "Integration of Charging Behavior into Infrastructure Planning and Management of Electric Vehicles: A Systematic Review and Framework," *Sustainable Cities and Society*, vol. 88, 2023. [CrossRef] [Google Scholar] [Publisher Link]