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# Electric Vehicle Charging Station Energy Management and Grid-Connected Renewable Energy Source Simulation Design

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**Abstract:** The growing popularity of electric vehicles (EVs) has made adequate charging infrastructure necessary. Combining renewable energy sources with EV charging stations offers a viable way to reduce transportation's adverse environmental effects and reduce fossil fuel use. This study looks into different grid-connected renewable energy source energy management techniques for EV charging stations. This study aims to optimize energy utilization, lower operating costs, and improve the sustainability of EV charging infrastructure by utilizing Renewable Energy Generation (REG), such as solar and wind power, in conjunction with intelligent charging algorithms. The study examines the body of research, evaluates various energy-management strategies, and suggests creative solutions to the problems of incorporating REG into EV-CS (Electric Vehicle Charging Stations). The report also addresses the possible advantages, practical issues, and financial effects of implementing these strategies. Through in-depth analysis and simulation studies, this research expands our understanding of energy management systems for grid-connected renewable sources in the context of EV charging infrastructure.

***Keywords:*** *PV, RERs, EVs, BESS, MPPT, EMS, BMS, EV-CS, etc*

## I. Introduction

The extensive research on EV systems is driven by the impending scarcity of fossil fuels and the environmental challenges associated with reducing greenhouse gas emissions. To lessen its reliance on fossil fuels and reduce carbon emissions, the global automotive industry has made electric vehicles (EVs) an essential tool in the transition towards sustainable mobility. However, as EVs become more commonplace, a reliable infrastructure for charging them must be created to meet the increasing energy demand while reducing the adverse effects on the environment. Using clean energy to power EV charging stations and grid-connected renewable energy sources presents a promising means of achieving this goal. The automotive industry has undergone a paradigm shift with the rise in electric vehicles (EVs), primarily due to worries about air pollution, climate change, and energy security. EV adoption is being encouraged by policies being implemented by governments around the globe, which is driving an exponential increase in the market share of EVs. However, the accessibility and dependability of the infrastructure for charging electric vehicles are just as crucial to the success of EVs as the availability of these vehicles. The grid electricity that conventional EV charging stations usually use comes from non-renewable resources like coal and natural gas. This dependence on fossil fuels increases greenhouse gas emissions and undercuts the environmental advantages of electric vehicles. Furthermore, the increasing demand for electricity from EV charging stations threatens the grid's stability and dependability, particularly during peak demand periods. With the advancement of solar and wind energy technologies and large-scale storage technologies, the charging station should be able to meet net-zero carbon emission targets. This study assumes that all charging stations use the same kind of solar PV and battery storage packs to provide a fair comparison across different geographical locations. To address these issues, renewable energy sources must be integrated into EV charging infrastructure. Energy independence and carbon emissions reduction are two benefits of renewable energy, which includes hydroelectric, solar, and wind power. We can significantly lessen the environmental impact of electric vehicles while improving energy resilience and grid stability by using renewable energy for EV charging. In addition, incorporating renewable energy into EV charging stations is in line with more significant initiatives to move toward a low-carbon economy and meet targets for mitigating climate change as stated in global accords like the Paris Agreement. However, implementing efficient energy management techniques is necessary to utilize grid-connected renewable energy sources for EV charging fully. The following are the main goals:

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- Examine the body of research on energy management techniques, RES integration, and EV charging infrastructure.
- Examine the effects of incorporating renewable energy into EV-CS infrastructure for technical & non-technical parameter considerations.
- Examine different energy management strategies, such as predictive control algorithms, load balancing, demand response, battery energy storage, and peak shaving.
- Evaluate the effectiveness of various energy management techniques using simulation and case studies.
- Talk about the implementation issues, difficulties, and plans for grid-connected renewable energy sources in EV charging stations.

The primary aim of this research paper is to facilitate the widespread implementation of renewable energy sources within the automotive sector, with the ultimate goal of enhancing sustainable transportation infrastructure. Implementing innovative energy management techniques can optimize the utilization of renewable energy resources, enhance grid stability, and expedite the transition toward a cleaner and more sustainable transportation system.

## II. EV Charging Infrastructure

Infrastructure for Electric Vehicle (EV) Charging on Grid-Connected RES Energy Management Plans for EV-CS applications.

**1.** *Overview of EV Charging Facilities*

- EVs have become increasingly popular as a sustainable transportation option due to worries about the environmental effects of fossil fuel usage. The foundation of the ecosystem for electric mobility is EV charging infrastructure, which promotes the uptake and spread of EVs. Conventional EV charging stations mainly depend on grid power, which is frequently derived from non-renewable resources. On the opposite side, incorporating RES for the EV-CS infrastructure offers a chance to improve sustainability and lower transportation-related greenhouse gas emissions.

*2.An Overview of Infrastructure for EV Charging*

- **Classifications of EV-CS**: EV charging stations can be categorized into several levels based on the power delivery and charging speed. While Level 2 chargers use specialized charging units to provide faster charging, Level-1 uses regular charging facilities with slow charging operations. In contrast, Level-3 type EV-CS offers a quick charging facility with DC fast chargers with an appropriate system for public & commercial charging stations.
- **Grid Connection:** Most CS are connected to the main grid for continuous power supply. Grid-connected charging stations allow EV owners to have convenient and dependable EV battery charging by drawing power from the utility grid.
- **Energy Demand and Grid Impact:** As EV adoption rises, charging stations' energy demands rise, especially during peak hours. This increase in electricity consumption threatens the grid's stability, so creative solutions are needed to manage energy demand properly.

*3.Including Renewable Energy Sources*

- **The role of renewable energy:** When powering EV charging stations, RES like PV, HPP, and Wind will provide a sustainable substitute for fossil fuels. Infrastructure for EV charging can lessen environmental impact and cut carbon emissions by utilizing REG.
- **Grid-Tie REG:** Grid-tie REG will allow electric vehicle charging stations to continue to be connected to the electrical grid while using clean energy produced from renewable sources. This integration improves the resilience of the infrastructure used for charging and permits more flexibility in energy sourcing.

*4.Strategies for Energy Management*

- **Peak shaving:** Peak shaving is a technique used to find peak load stress on the grid using less energy during high demand. EV charging stations can optimize energy consumption and minimize the impact of peak loads by employing peak-shaving techniques.
- **Load balancing:** To minimize overloading and maximize resource usage, load balancing techniques seek to disperse energy consumption among charging stations equally. Grid integration can be maximized, and efficient operation of EV charging infrastructure can be achieved through intelligent load management.
- **Demand Response:** EV charging stations can modify their energy usage in response to utility signals and grid conditions thanks to demand response programs. Charging stations can help maintain grid stability and earn incentives for load management by taking part in demand response programs.
- **Energy Storage from Batteries:** Battery energy storage systems, or BESS, can store extra renewable energy for later use or supply extra power during periods of high demand. Integrating BESS into EV charging stations makes dynamic load management and improved energy resilience possible.
- **Predictive control:** algorithms use AI (Artificial Intelligence) and ML (Machine Learning) with data

analytics to forecast energy consumption and optimize charging schedules. Charging stations can optimize the use of renewable energy by adjusting their charging profiles adaptively in advance of anticipated energy requirements.

These energy-management techniques provide practical methods for maximizing the use of RES connected to the grid in EV-CS. Charging infrastructure can support the widespread adoption of electric vehicles and achieve greater sustainability, cost-effectiveness, and grid integration by combining these strategies. Developing, modelling, and assessing EMS plans for grid tie RES in EV-CS applications which can be done methodically with the help of this methodology. By amalgamating data analysis, simulation tools, and performance evaluation techniques, scholars can appraise the efficacy of diverse tactics and guide the implementation of sustainable charging infrastructure.

## III. EV-CS WITH RES INTEGRATION

Figure-1 illustrates the architectural design of the proposed charging station. Three energy sources are photovoltaic (PV), energy storage unit (ESU), and utility grid.

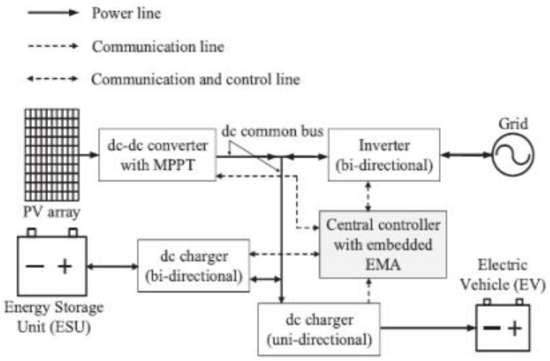



**Fig-1** EV-CS with PV & ESU [12]

They are linked to the electric vehicle (EV) via the direct current (DC) common bus. The photovoltaic (PV) source uses a DC-DC converter to control the maximum power point tracking (MPPT). The power grid connection is established through an inverter, which facilitates bidirectional power conversion between the grid and the direct current (dc) common bus. A bidirectional DC charger is used to connect an ESU. The unidirectional charger is employed on the load side to control the charging power for the connected electric vehicles (EVs). The charger facilitates the transmission of electric vehicle (EV) demand data to the central controller. To address this phenomenon in real time, a central controller is equipped with an energy management algorithm (EMA) that regulates energy flow.

*1.Solar photovoltaic (PV) system design calculation for a charging station.*

- The PV panel system has a total connected load of 300 kWh/day.
- The system's total kilowatt-hour (KWh) rating can be calculated by multiplying the total connected load (KW) by the number of operating hours, which is 156.
- The chosen module determines the power output of a PV panel.
- The power factor of Wp is 305 x 0.75, which equals 228.75 watts.
- The operating factor is employed to infer the precise output of a photovoltaic (PV) module.
- In normal operating conditions, the operating factor ranges from 0.60 to 0.90, indicating that the output power is 60 to 80% lower than the rated output power. This range is influenced by temperature and dust accumulation on the module. The power consumption at the final stage is reduced due to the system's lower efficiency.

*2.The power output of the panel*

- The combined efficiency is calculated as 228.75 ± 0.81 = 184.68 ± 185 W.
- The energy generated by a single 305 Wp panel within 24 hours can be calculated as follows:

1. Actual power output 8 hours/day (peak equivalent)
2. 185 8 = 1480 = 1.48 KWh/module

*3.To determine the number of solar modules needed to meet the estimated daily load*

- One must divide the total KWh rating (daily load) by the daily energy a panel produces.
- In this case, the ratio is 1800/1.48, resulting in a value of 1216.21 x 1217.

*4.Calculation of Battery Energy Storage System (BESS) for Charging Station Design*

The state-of-charge (SOC) estimation of the energy storage unit is derived from:-

$$SOC(t) = SOC(t-1).(1-\delta_{bat}(t)) + \left(\frac{p_B(t)}{V_{bus}}\right)\eta_{bat}\Delta t ----(1)$$

The required BESS power refers to the minimum load in kilowatts that increases the state of charge (SOC) from its initial value. The available ESU power refers to the highest amount of power in kilowatts that the BESS can provide in a specific time step **Dt** before its state of charge (SOC) reaches the minimum limit. It is commonly known as;

$$\text{Req\_P}_{\text{ESU}}(\text{t}) = \frac{SOC_{max} - SOC(t) \times C_b N_b}{\Delta t} \quad ----(2)$$

$$\text{Avl\_P}_{\text{ESU}}(\text{t}) = \frac{(\text{SOC(t)-SOC}_{\text{min}}) \times \text{C}_\text{b}.\text{N}_\text{b}}{\Delta \text{t}} \quad ----(3)$$

The SOC established a minimum threshold of 10% and a maximum threshold of 90%. The battery model comprises a nonlinear voltage source, accounting for the open circuit voltage and series resistance. Therefore, the output voltage is influenced by both the current and the state of charge (SoC), which is a nonlinear function of time. In the proposed system, SOC & battery voltage can be defined as such:

$$\text{V}_b = \text{V}_0 - R_b I_b - K \frac{Q}{Q - \int I_b dt} + A \exp(-B \int i_b dt \quad ----(1)$$

The battery possesses an internal resistance denoted as Rb, an open circuit voltage potential (Vo), a charging and discharging current represented as ib, a polarization voltage denoted as K, an exponential voltage denoted as A, and an exponential capacity denoted as B.

$$SOC(\%) = SOC_0(\%) - 100 \left[ \frac{\int I_{bat}.dt}{Q} \right] ----(2)$$

*6.EV Load Demand Calculation for Charging Station*

In modelling electric vehicle (EV) power demand, three primary parameters are considered.

1. Battery capacity (in kilowatt-hours)
2. Enter the time in hours.
3. SOC level for starting & ending

The proposed electric vehicle (EV) charging model assumes that the EV batteries' state of charge (SOC) should be 80% of their total load capacity at departure. To prevent over-discharge, the charging process should be halted when the SOC reaches 10% of the rated capacity. Hence, the upper demand limit for an individual electric vehicle (EV) is equivalent to 70% of its rated battery capacity. The power demand of a single electric vehicle (EV) at a specific time t is determined by referencing the research conducted in [10, 11].

$$P_{EV.t} = P_{EVreq.} \times S_t \times w_t \times C_t$$

The EV power that is necessary can be determined as;

$$P_{EV.req.} = \left( SOC_{max} - SOC_{min} \right) \times C_{bat}$$

The total power demand for multi-connected electric vehicles (EVs) can be mathematically represented as

$$EV_S\_demand_{\text{total}} = \left\{ \sum_{n=1}^{N} \text{p}^{\text{n}}_{\text{EV.t},(\text{t}=9,10,...22)} \right.$$

**IV.EV-CS Operating Modes**

*1.Mode-1 Initial operational mode (i.e., photovoltaic to electric vehicle)*

The process of transferring energy from a photovoltaic (PV) array to electric vehicles (EVs), referred to as PV2EV, is executed in mode 1. This operation is achieved using a direct current-to-direct current converter (with maximum power point tracking) and a one-way charger, as depicted in Figure-2. Solar energy is prioritized for utilization to reduce the utility grid's charging demand. The photovoltaic (PV) energy is procured from PV_Pr to sell to all interconnected vehicles at a predetermined price, denoted as Chrg_Pr. The transfer of photovoltaic (PV) energy to electric vehicles (EVs) (PV2EV_ENR) exhibits variability across different scenarios. [12]

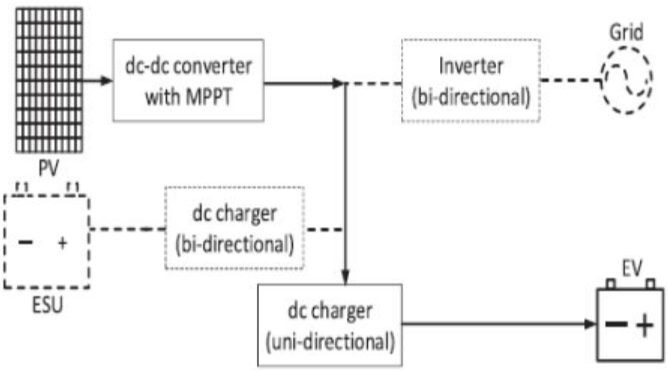



**Fig-2** Operating Mode-1 for PV to EV [12]

*2. Mode-2 Transitioning from ESU to EV as the second operational mode*

Mode 2 (ESU to EV) occurs when the photovoltaic (PV) array is unable to meet the electric vehicle (EV) demand, and the grid is experiencing overload (GE_Pr ≦ ESU_Pr). The energy flow in this mode is depicted in Figure 3.

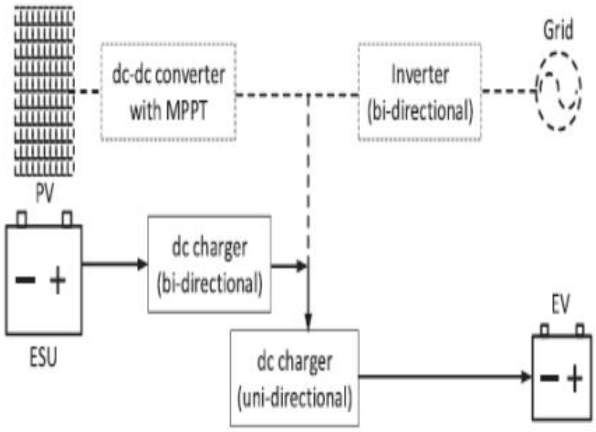



**Fig-3** Operating Mode-2 for ESU to EV [12]

*3.Mode-3 Grid to electric vehicle (EV) is the third operational mode*

In mode 3 (Gd2EV) operation, as depicted in Figure-4, the grid energy is acquired at the current GE_Pr and sold to the connected vehicles at a predetermined price.

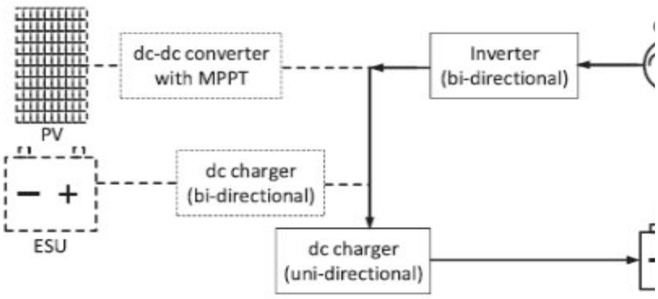



**Fig 4** Operating Mode-3 for Grid to EV [12]

*4.Mode-4 Fourth mode of operation for PV to ESU*

Figure-5 illustrates the functioning of mode 4 (PV2ESU). This mode is activated when the photovoltaic (PV) output power exceeds the power demand of the vehicle and the state of charge (SOC) of the energy storage unit (ESU) is lower than the state of charge unit (SOCU). In this scenario, the prices associated with acquiring and selling energy are equivalent to PV_Pr.

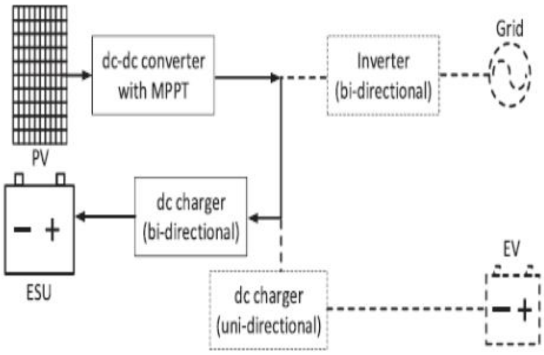



**Fig-5** Operating Mode-4 for PV to ESU [12]

*5.Mode-5 PV to the grid is the fifth operational mode*

The operation of mode 5 (PV2Gd) is depicted in Figure 6. This mode's energy flow occurs when the photovoltaic power (PV_Pwr) exceeds the combined power demand of the vehicles and the energy storage unit (ESU).

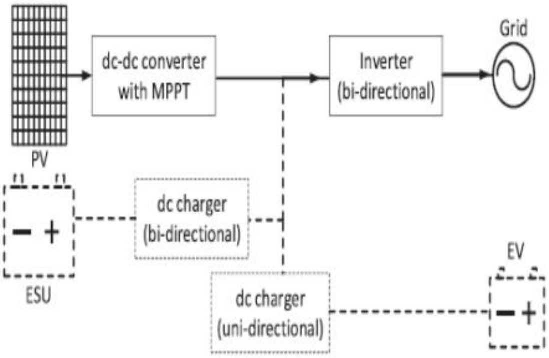


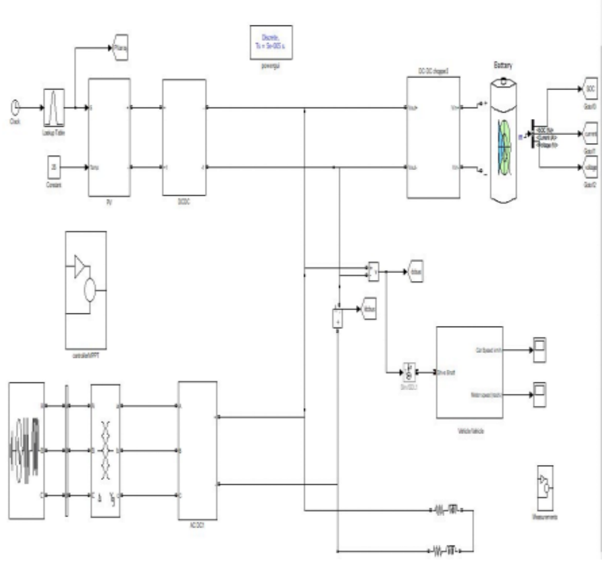

**Fig 6** Operating Mode-3 for PV to Grid [12]

## V.SIMULATION ANALYSIS

Two electric vehicle (EV) requirements cases are examined for simulation study. For scenario 1, five electric vehicles (EVs) are linked to charge from 20% to 95% state of charge (SOC) for 2 hours. The second case elucidates the necessity of employing two electric vehicles (EVs) to charge from 50% state of charge (SOC) to 95% SOC, one EV to charge from 80% to 95% SOC, and two EVs to charge from 30% to 95% SOC.

*1.Case-I*

The PV panel block in MATLAB/Simulink is provided with a lookup table containing irradiance and temperature data for a given day. Figure 7 displays the maximum power achieved by the MPPT algorithm on the PV array for the given data. The selected PV array consists of 24 parallel connected solar panels, which can generate a maximum power output of 4500W at peak time.



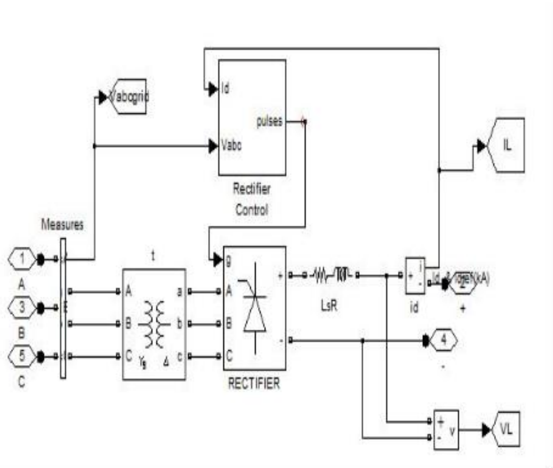



**Fig-7** Simulink model RES integrated with EV-CS

**Fig-8** Rectifier circuit for EV-CS model

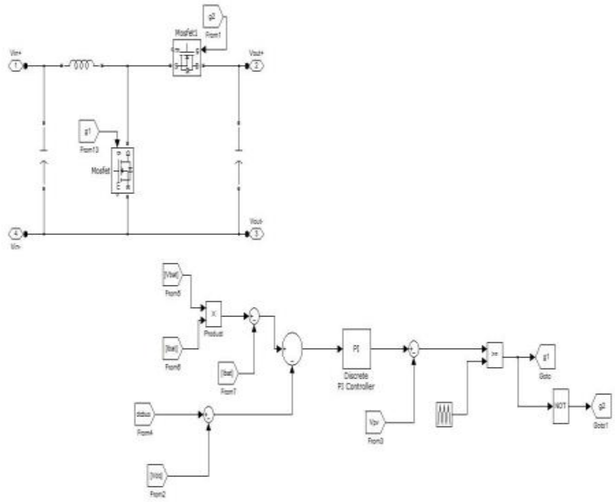


**Fig 9** Bidirectional converter & chopper circuit model

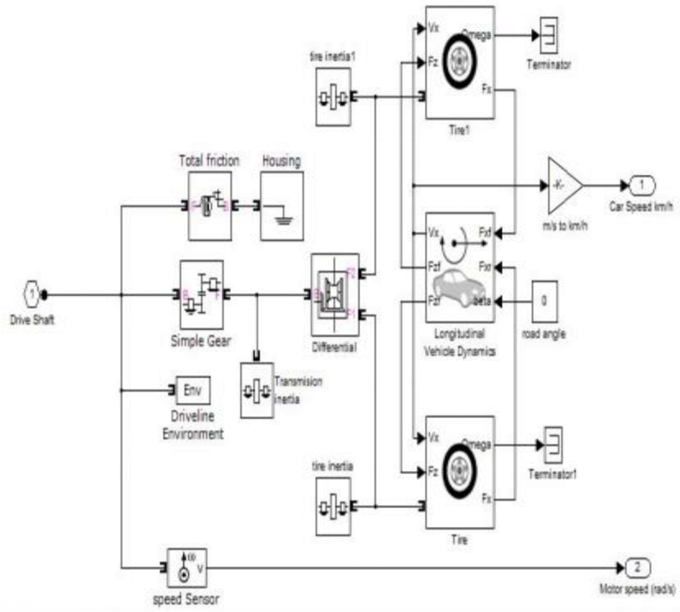



**Fig 10** Simulink model of Electric Vehicle

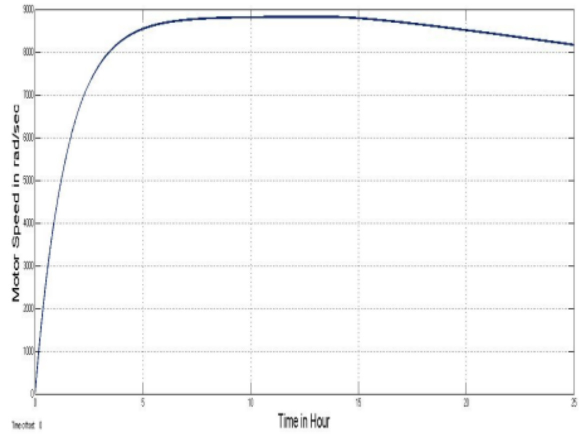



**Fig-11** Motor speed simulation results in Rad/Sec

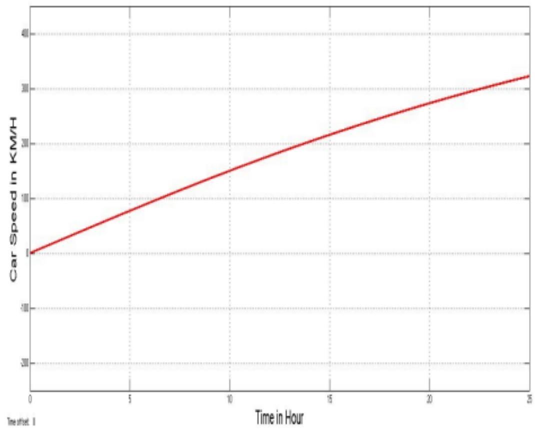



**Fig-12** Simulation outcome of Car Speed in KM per Hour

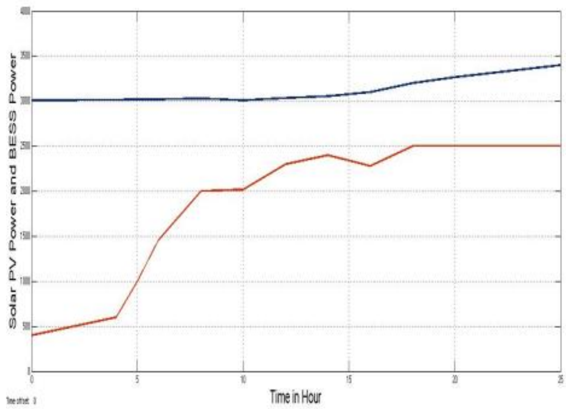



**Fig-13** Solar PV and BESS Power simulation outcome

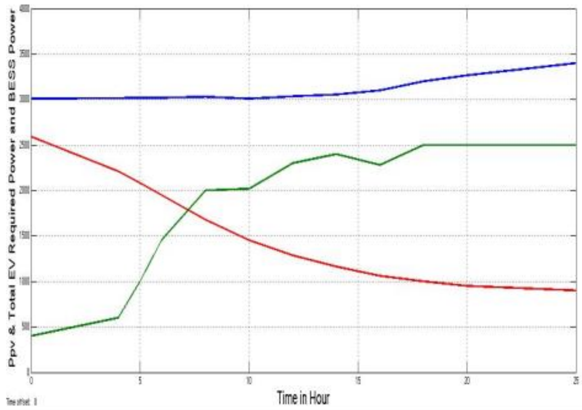



**Fig 14** Simulation outcome of solar power and the overall power demand for Evs and BESS in case 1

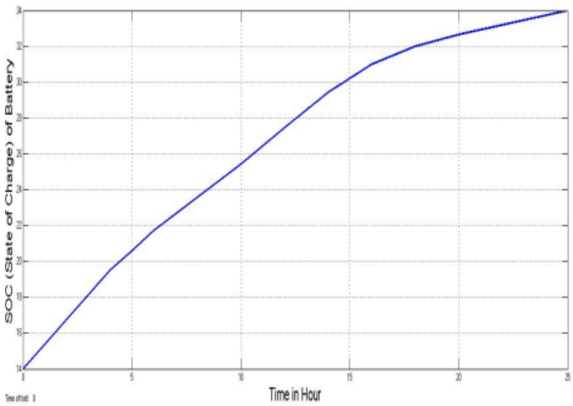



**Fig -15** simulation outcome about the charging of Electric case-1

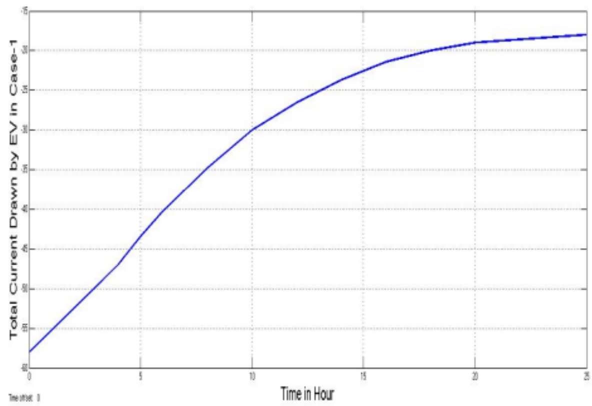



**Fig - 16** Simulation results of total current consumption in Vehicles in case 1

*2.Case II*

This study's solar output increases from 3050W to 4000W over 2 hours of operation. The simulation study reveals that the power required for simultaneously charging all five electric vehicles (EVs) ranges from 2688W to 980W for case 1, and from 1780W to 600W for case 2, as indicated in the simulation results.

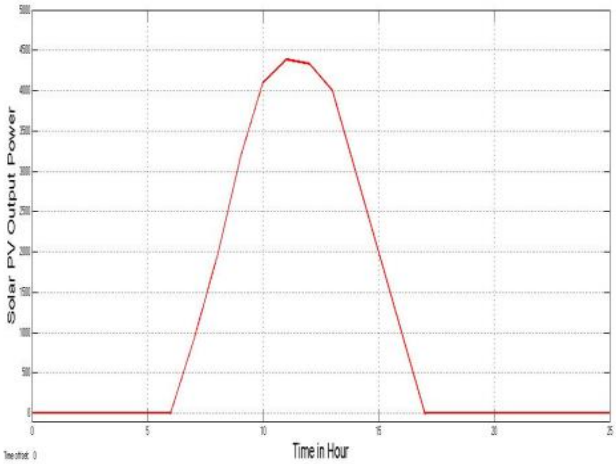



**Fig - 17** Simulation results of extracted PV power for Case-2

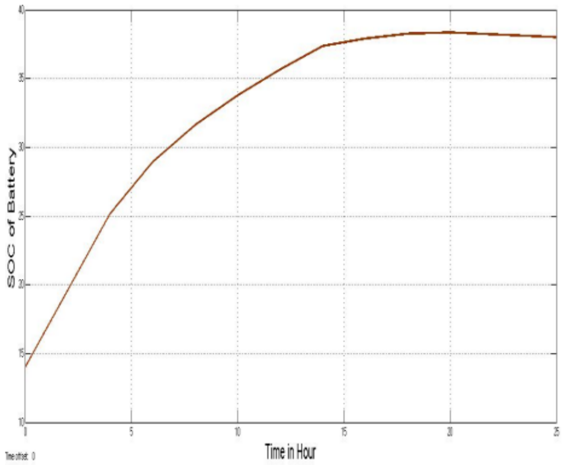



**Fig - 18** Simulation outcome of SOC level of EV for Case-2

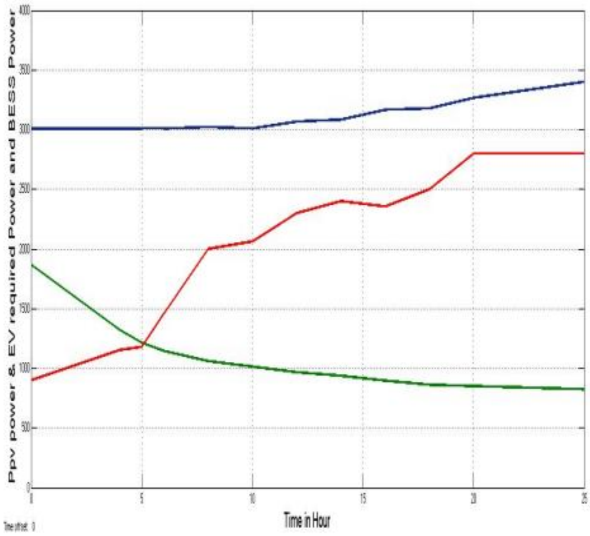



**Fig- 19** Simulation outcome of solar power and the overall power demand for Evs and BESS in case-2

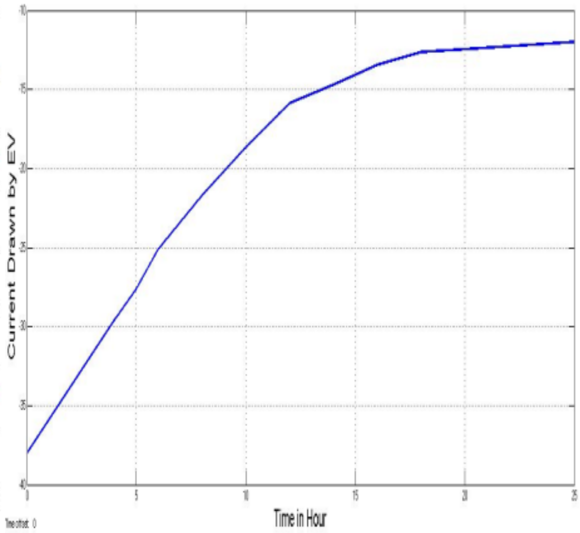



**Fig- 20** Simulation results of total current drawn in case-2

*3.Summary of Results*

The increasing prevalence of electric vehicles in circulation has rendered the issue of EV charging a pivotal concern. A solar-powered charging station with a battery storage system and additional grid support presents a viable solution for addressing the daily charging requirements of interconnected electric vehicles (EVs). PID regulates voltage and current to attain the desired power by maintaining a constant DC bus voltage at the station.

The design and power management of the suggested station are outlined and validated using MATLAB/Simulink, considering two scenarios of electric vehicle (EV) demand. This enhances the design and algorithm. This device's large power rating and capacity make it suitable for use in parking lots or workplaces as a power outlet for electric vehicles (EVs). Several design calculations utilizing RERs are provided to develop electric vehicle charging stations. The calculation determines the required energy storage capacity in Battery Energy Storage Systems (BESS) and the necessary equipment for Photovoltaic (PV) plants. Another prospective research domain involves incorporating diverse energy sources, excluding photovoltaic (PV) systems, including fuel cells, wind turbines, and standby batteries, into the smart grid infrastructure to enhance grid stability. When considering the long-term operational expenses, this integration has the potential to be economically advantageous despite the increase in capital expenditures.

## VI. Conclusion

This paper focuses on using grid power and solar PV to charge electric vehicles (EVs). A backup energy storage system, known as BESS, is also created using MATLAB Simulink. Several design calculations utilizing RERs are provided to develop electric vehicle charging stations. The calculation determines the required energy storage capacity in Battery Energy Storage Systems (BESS) and the necessary equipment for Photovoltaic (PV) plants. In addition, additional research and innovation are required to enhance the performance of grid-connected renewable sources in EV charging stations and optimize energy management strategies. In summary, integrating renewable energy sources and implementing advanced energy management techniques hold promising prospects for the future of electric vehicle (EV) charging infrastructure. The implementation of clean energy sources and the optimization of grid efficiency can contribute to the development of a transportation system that is more resilient, environmentally friendly, and sustainable. Ultimately, this will support global endeavors to address climate change and foster a more sustainable future for subsequent generations. The results validate that the charging station operates as an independent generator with excellent voltage quality. The suggested system has been successfully simulated using MATLAB, employing a range of operating modes. The results indicate that photovoltaic (PV) and battery energy storage systems (BESS) are suitable for charging electric vehicles based on effective energy management, reducing charging expenses and increasing profitability for charging stations. Furthermore, the grid encounters reduced strain during periods of high demand.

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