

# Design and Analysis of Electric Vehicle Charging Infrastructure with Renewable Sources

Sylvestre Toe<sup>1</sup>, Martin Sankoh<sup>2</sup>

<sup>1</sup>Department of Electrical Engineering, Norbert Zongo University/IUT, Burkina Faso.

E-mail: sylvestretoe94@gmail.com

<sup>2</sup>Department of Mechanical and Maintenance Engineering, Fourah Bay College,

University of Sierra Leone, Sierra Leone.

E-mail: martin.sankoh@usl.edu.sl

---

## Article Info

### Article History:

Received Dec 19, 2026

Revised Jan 14, 2026

Accepted Feb 18, 2026

---

### Keywords:

Electric Vehicle Charging

Infrastructure

Renewable Energy Integration

Solar Photovoltaic System

Energy Management System

---

## ABSTRACT

In order to support the quick widespread use of this mode of transportation, a dependable infrastructure for charging electric vehicles is becoming more and more necessary. The demand for dependable and sustainable infrastructure for charging has surged due to the quick expansion of electric vehicles (EVs), creating difficulties for current power systems. A viable way to lower greenhouse gases, peak load stress, and operating expenses is to incorporate renewable energy sources (RES) like wind and solar power into EV charging stations. The planning and evaluation of a renewable energy-powered charging system for electric cars with potential grid support are presented in this paper. To guarantee effective and continuous charging under changing load and generation conditions, the suggested system combines photovoltaic generating, energy storage, power electronics converters, and a smart energy management strategy. System performance is assessed using simulation-based analysis in terms of cost-effectiveness, grid dependency reduction, renewable energy utilisation, and charging efficiency. The findings show that while preserving power quality and dependability, environmentally friendly EV charging infrastructure greatly increases energy efficiency and sustainability. The viability of implementing cost-effective and environmentally friendly EV charging options for next smart transportation systems is demonstrated by this study.

---

### Corresponding Author:

**Sylvestre Toe,**

Department of Electrical Engineering,

Norbert Zongo University/IUT, Burkina Faso.

E-mail: sylvestretoe94@gmail.com

---

## 1. INTRODUCTION

The need for electric energy has skyrocketed worldwide due to the notable rise of the use of electric cars (EVs). The market for electric vehicles has expanded dramatically worldwide. There were only a few hundred EVs on the roads in 2010; by 2017, there were about three million, and by early 2019, there were almost six million. Exciting substitutes for conventional cars (CVs) are electric automobiles [1]. Because the EV emits no carbon when in use, it can significantly

reduce emissions of pollutants and our planet's overall effect. Biofuels would become less necessary as petroleum and coal are gradually phased out. Compared to CVs, which have an effectiveness of less than 20%, electric motors are more desirable due to their 80–95% efficiency. EVs are also a crucial part of modern transportation since they employ several state-of-the-art industrial technologies (including a generator, an energy source, and a charging station). However, the adoption of electric vehicles is not going as smoothly as expected [2]. The majority of individuals concur that EVs' limited range and long recharging times are the main barriers to their promotion. Despite being more expensive to buy, electric cars require less maintenance and consume far less energy than traditional cars.

Numerous research facilities and energy suppliers started giving serious consideration to lessening the strain on regional electrical networks due to the growing number of EV charging stations in response to the sharp rise in demand for electric cars and EV charging [3]. The infrastructure for EV charging may be supported by renewable energy sources like solar and wind, which are among the best ways to close this gap in local electrical networks.

Research on renewable energy-based charging infrastructure (RCI) started with wind and solar charging infrastructure following the announcement of the EV's rapid development at the start of the new millennium. It envisaged a charging facility that could meet demand for electric automobiles using direct current (DC) and alternative energy supplies in order to alleviate the shortcomings of conventional charging infrastructure [4]. The grid's stability is impacted by conventional charging stations due to problems including harmonics, fluctuations, and current outages. The RCI, on the other hand, has a number of benefits, including high efficiency, cheap system cost, and ease of setup. Additionally, compared to facilities that rely on alternating current (AC), it requires lower power conversion levels. The RCI can make a substantial contribution to lowering carbon emissions and increasing the use of energy from renewable sources in the energy sector. Additionally, RCI may reduce the price of charging for electric cars. However, the unpredictability of sources of clean electricity (such as seasonal variations in gusts of wind and sunshine and daily fluctuations in cloud cover for rooftop solar solar panels) and EV requirements (such as battery capacity, the quantity and types of EVs, stop intervals, battery begin time, and the initial point of charge) pose serious challenges to the RCI's implementation.

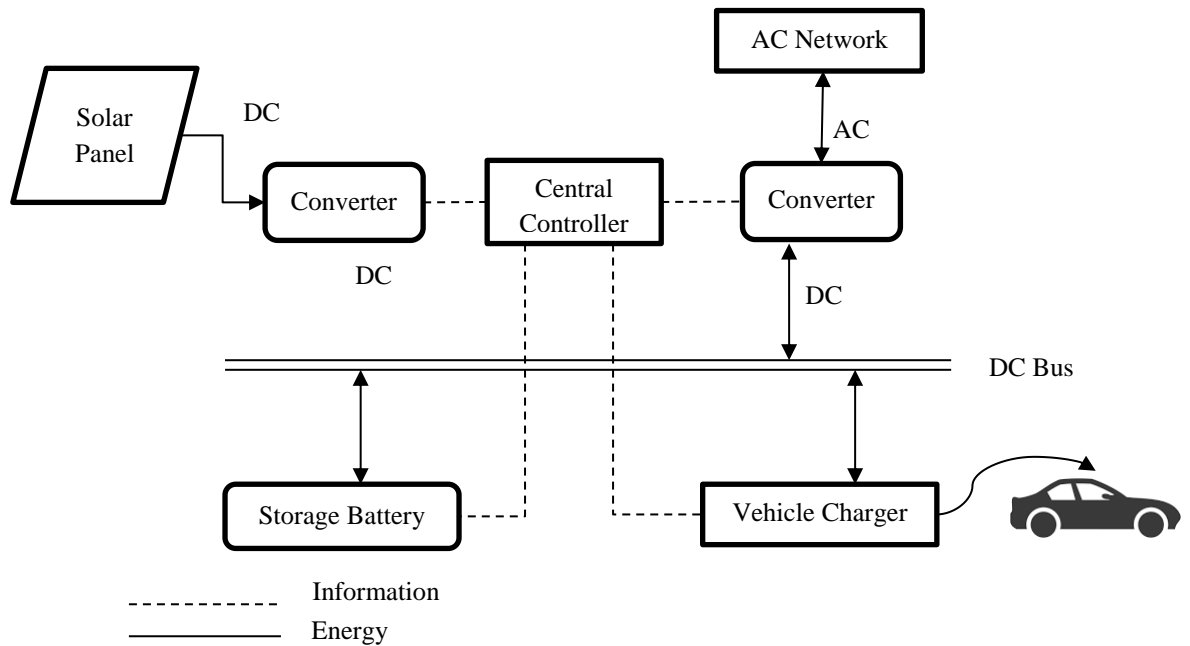


Figure 1. Infrastructure for EV Charging Using a Solar PV Adapter

To preserve the additional energy provided by photovoltaics, an organised controller is required to reroute the electricity that is produced to the battery, as illustrated in Figure [5]. The order of controllers used in photovoltaics has been studied by numerous academics. They emphasised how crucial it is to increase solar energy generating productivity using pulse width modulated (PWM) and maximum power point tracker (MPPT) technologies.

The aforementioned subjects are currently the subject of extensive ongoing research. Concurrently, other academics are focussing on different facets of RCI implementation and operation, including pricing strategies, optimal planning, controlling, and scaling, and analysis of the critical elements impacting the direct connection of EV load with the RCI. Few studies, for example, examined research on EV charging infrastructure, but they focused on general technical elements rather than energy sources that are renewable. A different study examined RCI research, but it concentrated on consumer preferences and EV interactions [6]. To the best of our knowledge, no study has studied RCI studies in-depth by covering all pertinent research issues.

### 1.1 Problem Statement

When fossil fuel-based electricity is used, the quick uptake of electric vehicles (EVs) puts a great deal of strain on traditional power systems, resulting in peak load problems and higher carbon emissions. Grid reliance, operating expenses, and environmental effect can all be decreased by incorporating energy from renewable sources (RES) like solar and wind with EV charging infrastructure. However, there are issues with these systems' cost-effectiveness, power management, intermittent handling, and ideal scale.

### 1.2 Major Contributions

1. **Design of a Renewable Energy-Integrated EV Charging Infrastructure:** This paper proposes comprehensive system architecture for an electric vehicle charging infrastructure that integrates solar photovoltaic generation with battery energy storage and grid support. The design enables efficient power flow management while ensuring reliable EV charging under varying demand and renewable generation conditions.

2. **Implementation of an Intelligent Energy Management Strategy:** An energy management system is developed to prioritize renewable energy utilization, minimize grid dependency, and maintain battery operation within safe limits. The proposed strategy dynamically allocates power among renewable sources, storage systems, and the utility grid, thereby improving charging efficiency and reducing operational costs.
3. **Comprehensive Performance Evaluation and Comparative Analysis:** The proposed system is validated through simulation-based implementation and experimental analysis under multiple operating scenarios. When compared to traditional grid-based EV charging systems, comparative results show notable gains in charging performance, renewable energy utilisation, electricity usage reduction, and cost savings.

## 2. LITERATURE REVIEW

A summary of electric cars and different charging station layouts is provided in this study. In order to have an ideal design, charging points are grouped according to the amount of power used using different optimisation algorithms, techniques [7], and future directions. Additionally, a summary of the grid-connected combination of off-grid mode and renewable energy is provided, along with an outlook for the future. The large load drawn from the grid, particularly during peak hours, can be decreased by integrating renewable energy and storage devices into the charging station.

This implies that the objective of encouraging EV adoption to lessen dependency on fossil fuels and prevent climate change may encounter substantial obstacles. Therefore, in order to optimise the efficiency of EV distributing in an environmentally responsible manner, renewable energy generating for EV charging stations is required [8]. This study aims to suggest the best clean energy producing system to power an electric vehicle charger, with a focus on using actual demand information for the station, accounting for emissions of carbon and financial analysis, and looking at a specific example location in Korea. A case study of an EV charging station in Korea was selected, & its renewable energy fractions (REF) of 0%, 25%, 50%, 75%, & 100% were considered for fiscal evaluation and carbon emissions comparability using HOMER software. In order to identify the best operating strategy while accounting for the climate characteristics of the instance location, the structure with 25% REF was also investigated.

To solve these problems, this paper proposes a framework that integrates vehicle-to-grid (V2G) optimisation, geographical and temporal demand estimation, and a hybrid deep neural network model. With an RMSE of 2.1 kWh and an  $R^2$  value of 0.92, the framework demonstrated strong prediction accuracy, successfully capturing daily demand trends and variances across charging stations [9]. The necessity for focused planning strategies for tackling high-demand areas and underutilised places was highlighted by the spatial analysis that showed utilisation discrepancies between city and suburban stations. Under typical circumstances, V2G optimisation raised the use of renewable energy to 68% and decreased the Peak-to-Average Ratio by 28%, improving reliability of the grid and energy utilisation. In order to ensure dependable performance and operational efficacy, the framework was evaluated under scenarios of growing EV adoption and station numbers.

This study suggests a sustainable energy-based on-road wireless charging (ORWC) network to use renewable energy within a smart city framework and shorten charging times in order to address these issues [10]. This study develops a prototype of the ORWC systems and examines its technological, financial, and benefits for the environment. Additionally, the study

assesses cost-effectiveness, energy economics, and annualised energy share. The results of the proposed study show that the ORWC structure in combination with RERs effectively reduces energy prices from \$0.112/kWh - \$0.30/kWh and emissions of carbon from 76.9 tons/year - 29.5 tons/year.

### **3. METHODS AND MATERIALS**

#### **3.1 Research Methodology**

To construct and assess an electric vehicle (EV) charging facilities integrated with renewable energy sources, this study uses a system modelling and simulation-based research technique. The methodology focusses on assessing how demand for EV charging, energy storage, renewable energy production, and grid support interact under various operating scenarios. Initially, typical user behaviour and charging patterns are used to model the demand for EV charging. The available electrical power potential is then estimated through the assessment of renewable energy resources. Mathematical models are used for system components such charging units, power electronic converters, battery storage, and renewable energy sources. Realistic input datasets are then obtained through data collecting and preprocessing [11]. To find important factors affecting system performance, the extraction of features and analysis are done. Lastly, a simulation-based performance assessment is carried out to evaluate the suggested charging infrastructure's sustainability, grid dependency, efficiency, and dependability.

#### **3.2 System Materials and Components**

Several interconnected parts make up the suggested EV charging infrastructure, which is intended to provide dependable and effective charging [12]. Because solar photovoltaic (PV) systems are readily available and suitable for charging stations, they are regarded as the main renewable energy source. To store extra renewable energy and provide power during times of low production or high demand, a bank of lithium-ion batteries is used as a form of energy storage. Power electronic interfaces, such as DC–DC converters, DC–AC transformers, and EV charging devices, are used to control voltage levels and guarantee that energy sources and EV loads are compatible. When green energy and battery capacity are insufficient, a grid connector is integrated to maintain continuous charging and offer backup support [13]. To regulate the flow of electricity among all components, a system for energy management (EMS) is put in place. System performance is modelled, analysed, and validated using simulation tools like MATLAB/Simulink and HOMER Pro.

#### **3.3 Data Collection**

To guarantee accuracy and dependability [14], actual additional sources and computational datasets provide the data needed for system modelling and analysis. The total number of electric automobiles served daily, the start and end times of charging, the state of charge upon arrival, the power for charging levels, and the daily energy use are all included in the EV charging statistics. Standardised EV charging rates and common urban consumption patterns are used to represent these characteristics. Data on renewable energy includes daily and seasonal variation patterns as well as solar irradiation, outside temperature, and gusts of wind when relevant. These data are used for modelling realistic energy production from renewable sources and are derived from conventional meteorological datasets. To facilitate precise system modelling and economic analysis, grid and batter-related data are also gathered, including power tariffs, peak and off-peak load times, capacity of batteries, charging and discharge efficiency, and state-of-charge limits.

### **3.4 Data Extraction and Preprocessing**

To extract relevant and practical information for system modelling and simulation, the raw data gathered from multiple sources is processed. To guarantee data trustworthiness, data preparation entails locating and eliminating missing, inconsistent, or incorrect values. To ensure uniformity between datasets, solar radiation and EV load histories are normalised. Hourly data on renewable energy generation and EV charging demand are synchronised using time-series alignment. Additionally, information for daily and hourly energy consumption are combined to examine patterns of generation and fluctuations in demand. In order to accurately simulate charging behaviour and renewable energy generation under various operational situations, the processed data are arranged into structured time-based datasets.

### **3.5 Feature Identification and Selection**

Key features are found and chosen from the processed datasets to facilitate effective energy administration and system optimisation [15]. These characteristics include peak demand periods, grid power imported and exported levels, battery state of charge, hourly EV charging demand for renewable energy generation capacity, and renewable energy utilisation ratio. These features were chosen because they directly affect charging efficiency, system dependability, grid dependency, and overall performance. The system for managing energy can make well-informed decisions about power distribution and resource utilisation by concentrating on these crucial factors.

### **3.6 Energy Management Strategy**

To optimise power flow between renewable energy sources, storage of batteries, the utility network, and EV charging loads, a system for energy management (EMS) is put in place. In order to optimise the use of clean energy, the EMS is built to give priority to the usage of solar power for EV charging. The excess energy is kept in the battery system when renewable generating surpasses the requirement for charging. Grid electricity is used to maintain continuous charging when stored battery power and renewable energy sources are insufficient. In order to improve battery longevity and system dependability, the EMS also makes sure that the battery's level of charge stays within predetermined safe operating limits.

### **3.7 Performance Evaluation**

Through simulation, the suggested EV charging infrastructure's performance is assessed under various operating conditions. These scenarios cover both islanded and grid-connected ways of operation, peak sunlight production with an average charging load, and times with elevated EV charging needs with low clean energy supply. Metrics like charging efficiency, the use of renewable energy, the decrease in grid power usage, and total cost savings are used to evaluate system performance. The evaluation's findings shed light on the renewable energy-integrated EV charging infrastructure's efficiency, sustainability, and viability from an economic standpoint.

The four layers of an IoT system's architecture—physical, cloud, communication, and service—are depicted in Figure 2. The hardware, firmware, network, and integration elements necessary for any IoT strategy are included in these four layers.

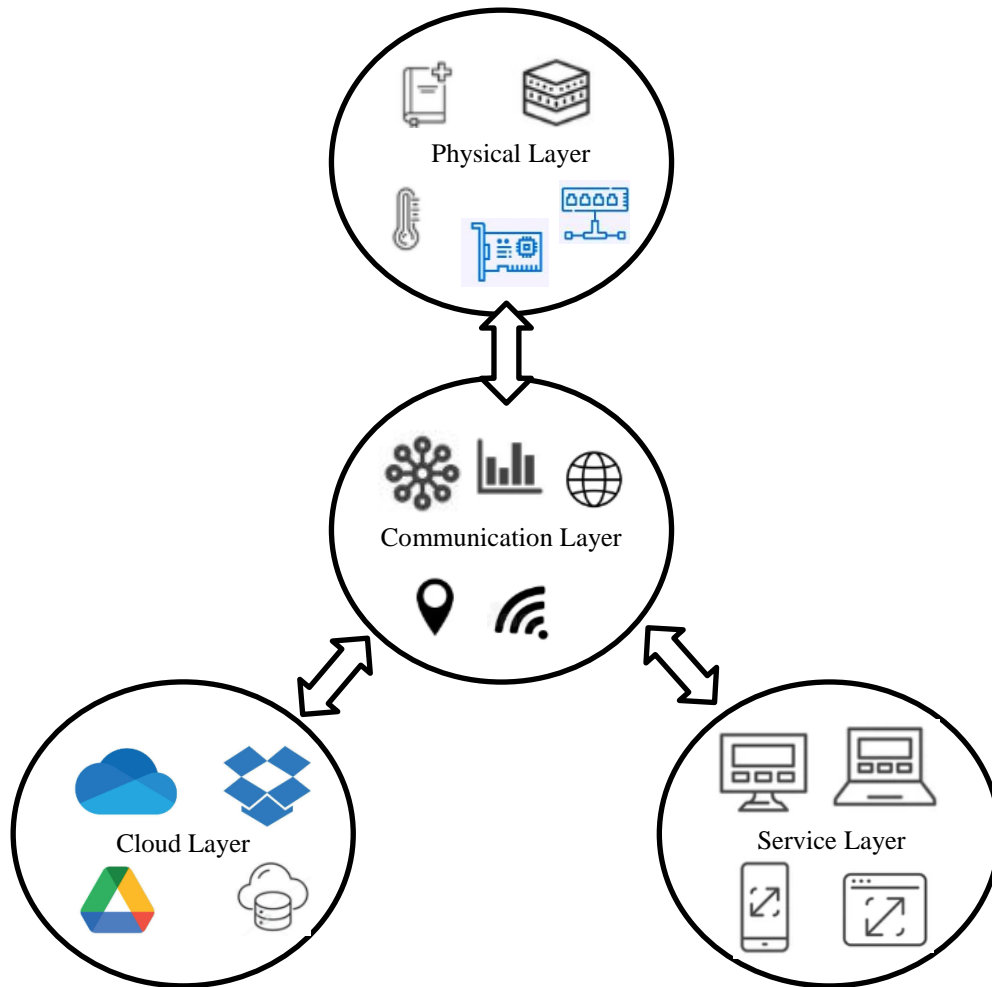


Figure 2. The architecture of an IoT system

The physical layer consists of the different sensors, actuators, chips, and other tangible components that are smartly coupled to each other to interact with the building environment.

## 4. IMPLEMENTATION AND EXPERIMENTAL RESULTS

### 4.1 System Implementation

A simulation-based method in MATLAB/Simulink and HOMER Pro is used to create the suggested renewable energy-powered electric vehicle (EV) charging infrastructure. A solar photovoltaic (PV) source, the energy storage battery system, power electronic converters, an EV charging load, grid interaction, & an energy management system (EMS) make up the system model. Based on current EV demand, the availability of renewable energy sources, and the battery's level of charge, the EMS regulates power flow. Realistic operational circumstances are simulated using hourly EV charging demands and renewable generation profiles. To assess the system's efficacy in lowering grid dependency and increasing the use of renewable energy, various scenarios are examined.

### 4.2 Experimental Setup

Time-series data reflecting solar power generation and EV charging demand over a typical operational period are used for the experimental study. Several vehicles charging at different times are used to create the EV demand profile, and irradiance data is used to predict solar power

generation. Safe operating limits are maintained by applying restrictions on battery charging and draining. Only in situations where battery power and renewable energy are insufficient is grid support activated. Parameters including cost per unit of energy, grid power consumption, renewable utilisation, and charging efficiency are used to assess the system's performance.

### 4.3 Experimental Results and Analysis

A comparison of solar power generation and hourly charging for electric vehicles demand is shown in Table 1. It is evident that renewable energy can supply a sizable amount of the demand for EV charging during peak solar hours. Because solar output is lower in the early and late periods, grid or batteries support is needed.

Table 1. EV Charging Demand and Solar Power Generation

Hour	EV Charging Demand (kWh)	Solar Power Generation (kWh)
1	45	30
2	60	50
3	75	80
4	90	95
5	70	65
6	55	40

The effect of renewable energy generation on grid power consumption and renewable energy utilisation is displayed in Table 2. Grid power demand sharply declines as renewable penetration rises, while renewable utilisation improves. This illustrates how well renewable energy sources may be incorporated into EV recharge infrastructure.

Table 2. Grid Power Usage and Renewable Energy Utilization

Operating Scenario	Grid Power Usage (kWh)	Renewable Energy Utilization (%)
Low RES	120	35
Moderate RES	80	60
High RES	40	85

Table 3 contrasts energy costs and charge efficiency for various operating modes. The maximum charging efficiency and cheapest price per unit of energy are achieved by the green energy potential with storage configuration, demonstrating the technical and financial advantages of the suggested system.

Table 3. Performance Comparison of Operating Modes

Operating Mode	Charging Efficiency (%)	Cost (₹/kWh)
Grid Only	88	8.5
Hybrid (Grid + RES)	92	6.2
Renewable + Storage	96	4.8

#### 4.4 Comparative Discussion

The performance indicators for the three different EV charging infrastructure operating modes—Grid Only, Mixed (Grid + Renewables Sources), & Renewable + Storage—are compiled in Table 3.

The charging system is totally dependent on traditional grid power while it is in the Socket Only mode. While this guarantees constant energy availability, the price per unit of power is the greatest (₹8.5/kWh) and the charging performance is comparatively lower at 88%. Transmission losses and increased tariff rates during times of peak demand are the main causes of this.

The hybrid mode combines grid assistance with renewable energy sources, such as solar PV. The charging efficiency rises to 92% when clean energy is partially substituted for grid power, and the cost is drastically reduced to ₹6.2/kWh. This mode is appropriate for practical problems charging stations when demand might not be entirely satisfied by renewable power alone since it exhibits a sensible balance between performance and dependability.

The system optimises the usage of renewable power backed by battery storage when operating within the Renewable + Storing mode. Because sustainable energy is used to meet the majority of EV charging demand with little conversion and grid losses, this arrangement achieves the greatest efficiency of 96%. It also has the lowest cost for each of energy (₹4.8/kWh), which is a result of better use of inexpensive solar energy and less reliance on the grid. However, substantial battery capacity and renewable generation are needed for this mode to function.

#### 4.5 Graphical Analysis

The link between the demand for EV charging and the production of solar power over time is depicted in Figure 3. The graph demonstrates how solar energy reduces dependency on grid electricity during high solar hours by aligning nicely with daytime charging needs.

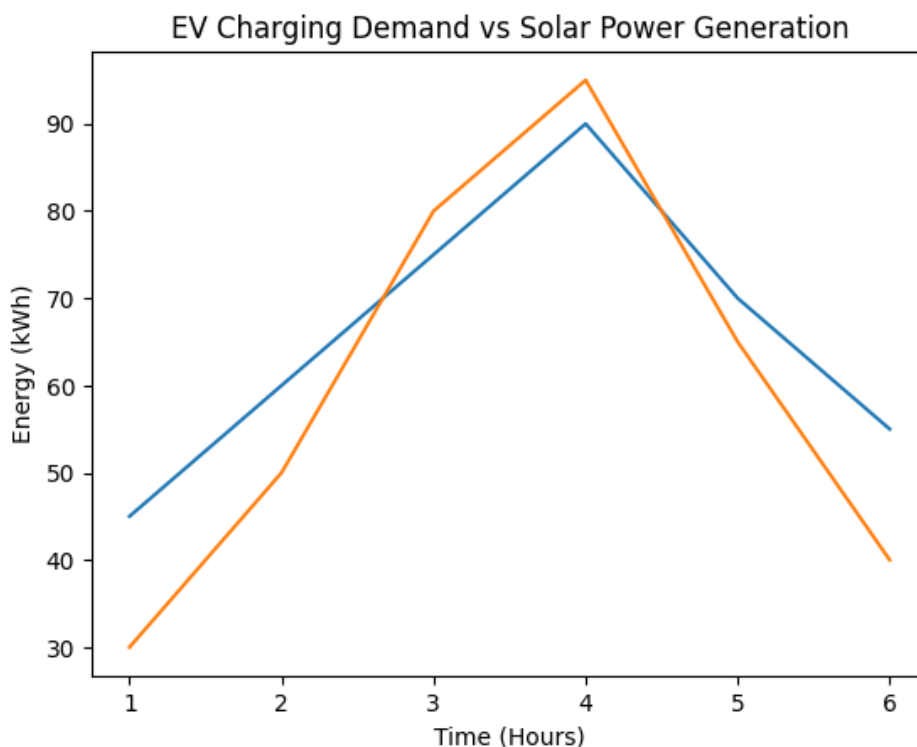


Figure 3. EV Charging Demand vs Solar Power Generation

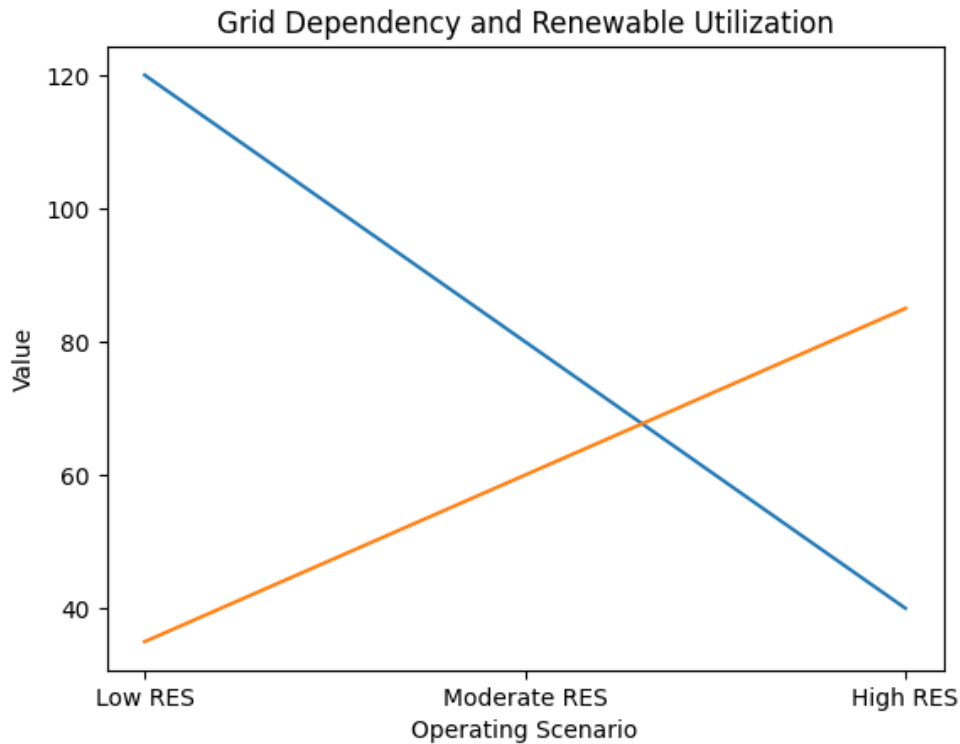


Figure 4. Grid Dependency and Renewable Energy Utilization

Figure 4 illustrates how the use of renewable energy and grid electricity varies under various operating conditions. Higher penetration of renewable energy sources is clearly correlated with less reliance on the grid.

#### 4.5 Discussion

The experimental findings verify that system performance is much enhanced when renewable energy sources are integrated with EV charging infrastructure. Utilising a system to manage energy minimises reliance on the grid, lowers operating costs, and allows for the optimal use of renewable energy. By enabling charging during times of low renewable energy, the use of storage for batteries further improves reliability.

### 5. CONCLUSION

The design, installation, and performance assessment of an infrastructure for charging electric vehicles that is integrated with sources of clean energy were described in this study. In comparison to traditional grid-based charging systems, the results show that integrating solar energy & battery storage greatly reduces grid dependency, increases charging effectiveness, and lowers operating costs. While guaranteeing dependable and continuous EV charging under fluctuating demand and generation conditions, the applied energy management system successfully prioritises the use of renewable energy. The technical viability, economic viability, and environmental sustainability of renewable-integrated charging infrastructure are confirmed by simulation and experimental study. The suggested approach aids in the creation of intelligent and sustainable transportation networks and provides an affordable solution to support the expanding use of electric vehicles.

**REFERENCES**

- [1] Alkaws, G., Baashar, Y., Abbas U, D., Alkahtani, A. A., & Tiong, S. K. (2021). Review of renewable energy-based charging infrastructure for electric vehicles. *Applied Sciences*, 11(9), 3847.
- [2] Oladigbolu, J. O., Mujeeb, A., Imam, A. A., & Rushdi, A. M. (2022). Design, technical and economic optimization of renewable energy-based electric vehicle charging stations in Africa: the case of Nigeria. *Energies*, 16(1), 397.
- [3] Narasipuram, R. P., & Mopidevi, S. (2021). A technological overview & design considerations for developing electric vehicle charging stations. *Journal of Energy Storage*, 43, 103225.
- [4] Ihm, J., Amghar, B., Chun, S., & Park, H. (2023). Optimum design of an electric vehicle charging station using a renewable power generation system in South Korea. *Sustainability*, 15(13), 9931.
- [5] Li, Z., Chowdhury, M., & Bhavsar, P. (2024). Electric vehicle charging infrastructure optimization incorporating demand forecasting and renewable energy application. *World Journal of Innovation and Modern Technology*, 7(6).
- [6] Bukhari, A., Aboulola, O. I., ur Rehman, A., Alharbi, A., Alosaimi, W., & Daud, A. (2024). Renewable energy driven on-road wireless charging infrastructure for electric vehicles in smart cities: A prototype design and analysis. *Energy Reports*, 12, 5145-5154.
- [7] Karmaker, A. K., Hossain, M. A., Pota, H. R., Onen, A., & Jung, J. (2023). Energy management system for hybrid renewable energy-based electric vehicle charging station. *IEEE Access*, 11, 27793-27805.
- [8] Schmidt, M., Zmuda-Trzebiatowski, P., Kiciński, M., Sawicki, P., & Lasak, K. (2021). Multiple-criteria-based electric vehicle charging infrastructure design problem. *Energies*, 14(11), 3214.
- [9] Nawaz, M. U., Qureshi, M. S., & Umar, S. (2024). Integration of solar energy systems with electric vehicle charging infrastructure: challenges and opportunity. *Revista Espanola de Documentacion Cientifica*, 18(02), 1-18.
- [10] Boddapati, V., Kumar, A. R., Daniel, S. A., & Padmanaban, S. (2022). Design and prospective assessment of a hybrid energy-based electric vehicle charging station. *Sustainable Energy Technologies and Assessments*, 53, 102389.
- [11] Ghasemi-Marzbali, A. (2023). Electric vehicle fast charging station design by considering probabilistic model of renewable energy source and demand response. *Energy*, 267, 126545.
- [12] Al Wahedi, A., & Bicer, Y. (2022). Techno-economic optimization of novel stand-alone renewables-based electric vehicle charging stations in Qatar. *Energy*, 243, 123008.
- [13] Ray, P., Bhattacharjee, C., & Dhenuvakonda, K. R. (2022). Swarm intelligence-based energy management of electric vehicle charging station integrated with renewable energy sources. *International Journal of Energy Research*, 46(15), 21598-21618.
- [14] Abdullah, H. M., Gastli, A., Ben-Brahim, L., & Mohammed, S. O. (2022). Planning and optimizing electric-vehicle charging infrastructure through system dynamics. *IEEE Access*, 10, 17495-17514.
- [15] Pradhan, S., Ghose, D., & Shabbiruddin. (2021). Planning and design of suitable sites for electric vehicle charging station—a case study. *International Journal of Sustainable Engineering*, 14(3), 404-418.