Iot-Based Smart Automation System for Electric Vehicles Charging Using Solar Energy

Mr. Divakar Dipak Nale[1], Mr. Awadhut Bapu Chougale[2], Mr. Mohammadasim Asaphalli Mullani[3], Mr.Ravindra B Lohar[4], Aniket Anilkumar Prabhavalikar[5]

[1] Assistant professor, First Year Engineering Department Dr.D Y Patil College of Engineering Salokhenagar Kolhapur Maharashtra Email: nalesir.dyp@gmail.com, Orcid id: 0009-0 002-9318-7363
[2] Assistant professor, Electrical Engineering Department Dr.D Y Patil College of Engineering Salokhenagar KolhapurMaharashtra Email: awadhutchougale@gmail.com Orcid id: 0009-0007-1336-1947
[3]Assistant Professor, Mechanical Engineering Dr.D Y Patil College of Engineering Salokhenagar Kolhapur Maharashtra Email Id: asimmullani@gmail.com Orcid Id: 0009-0006-3845-0957
[4]Asst.Professor, Electrical Engineering Dr.D Y Patil College of Engineering Salokhenagar Kolhapur Maharashtra Email Id: ravi.dypsn@gmail.com Orcid Id:0009-0007-6857-7542
[5] Assistant Professor,Electrical Engineering Dr.D.Y.Patil College of Engineering SALOKHENAGAR Kolhapur 416007 Email Id: prabhavalikaraniket@gmail.com Orcid Id:0000-0001-8360-7681

Abstract

The growing popularity of electric vehicles (EVs) has established a high demand of effective and sustainable charging infrastructure. In order to overcome this problem, this paper will suggest an IoT-based smart automation system of EV charging using solar energy. The system combines the work of solar photovoltaic (PV) panels, a battery storage unit, intelligent sensors, and an IoT-enabled controller to control and track the charging process. The solar energy is generated and used to power electric vehicles directly or to charge batteries, which can be used later, or used to check the charge status of electric vehicles and whether they are under charge, relaying this information to a cloud platform to be monitored and controlled remotely via a mobile or web interface. The suggested system will maximize the use of energy, help decrease reliance on traditional grid electricity, and enhance efficiency in charging. Such a strategy helps develop sustainable and intelligent EV chargers and helps to minimize the carbon footprint and enhance the integration of renewable energy.

Keywords: Electric Vehicles, Internet of Things (IoT), Solar Energy, Smart Charging System, Renewable Energy, Automation.

1. Introduction

The high pace of transportation development and the growing importance of the environmental issues have boosted the growth of EVs worldwide. EVs are broadly believed to be a clean substitute to the traditional vehicles powered by internal combustion engines due to the low levels of greenhouse gases emissions and reliance of fossil fuels. The world governments and research centers are positively encouraging the use of EVs by means of different policies and incentives. Nonetheless, the rising prevalence of EVs has greatly augmented the need to incorporate effective and dependable charging systems, which has emerged as a crucial issue to the current power systems [1].

The majority of currently available EV charging points heavily depend on the traditional grid power, making them potentially add pressure to the power distribution systems. This increase in energy demand could cause some problems like a fluctuation in voltage, power overload, and an increase in the cost of operation by electricity providers. Moreover, when the grid electricity is produced by using non-renewable sources of energy, the positive environmental factors of EVs might be alleviated to some extent. As such, the use of renewable sources of energy in charging EVs has become a significant research field [2].

Solar energy is one of the most promising sources of renewable energy which are quite common. The solar photovoltaic (PV) technology has the potential of converting sunlight into electrical energy without any dangerous emissions. EV charging systems are solar powered, thus offering a clean and sustainable way of offering energy to electric vehicles. With the help of solar power, the grid-

independence can be acquired and help to provide the solutions enabling the transportation that is environmentally friendly [3].
Although solar energy generation has its benefits, it is by nature intermittent since it is subject to weather conditions and the availability of sunlight. Such variability poses problems on the continuity of a steady energy supply towards charging EV systems [14]. In order to resolve this problem, batteries are frequently combined with solar PV systems. These storage facilities are in a position to accumulate surplus energy when the sun is generating power and send it whenever the sun lacks power [4].
The latest technological developments have brought the Internet of Things (IoT) as a potent instrument of enhancing the efficiency and automation of energy systems. The IoT technology has the ability to make different devices, sensors, and controllers connect to one another through the internet and provide an opportunity to monitor information in real-time and make smart decisions [15]. IoT platforms can be used in smart energy to enable constant monitoring of system parameters like the voltage levels, power generation, battery status and charging demand [5].
IoT combined with EV charging infrastructure has provided new opportunities in the field of smart management of energy [10]. The operational data of charging stations can be gathered by means of smart sensors and communication modules and sent to the cloud-based platforms. This information can then be used to maximize the use of energy, enhance the system performance, and make the charging operations reliable. They are used to minimize energy wastage and improve the efficiency of EV charging systems on the whole [6-8].
The other notable benefit of IoT based charging systems is that remote monitoring and control is possible[11,12]. The charging can be monitored with the help of mobile applications or web interfaces, which enable the user to monitor the process of charging, energy consumption, and generation of solar power in real time. These characteristics enhance user convenience as well as allow operators to operate charging infrastructure in a better way [9].
In this regard the current research has suggested an IoT-based smart automation charging of electric vehicles with the help of solar energy [13]. The suggested system will combine solar photovoltaic panels, battery storage units, IoT sensors, and cloud-based monitoring platforms to develop a sustainable and smart EV charging system. Through renewable energy production and the application of the IoT approach to automation, the system will achieve deeper energy consumption, minimize and eliminate reliance on traditional electrical facilities, and enhance the evolution of intelligent and sustainable transportation networks [8].

2. Literature Review

Bhatti et al. [16] (2016) examined the promotion of solar photovoltaic (PV) and charging electric vehicles infrastructures. The research paper has offered an in-depth discussion of EV charging methods using solar energy and has highlighted the environmental advantages of the introduction of renewable energy. The authors found that solar-based electricity charging systems would greatly decrease carbon emissions and decrease reliance on grid electricity. The study, however, also pointed out that smart energy management systems are necessary to deal with the variations in power generation through the solar energy.
Yilmaz and Krein [17] (2013) made a thorough review of battery charging topology and charging infrastructure of plug-in electric vehicles. The study looked at different charging levels, converters of power electronics, and infrastructure needs. The findings showed that the advanced charger technologies can improve the efficiency of charging, shorten charging time, yet the effective control strategies are needed to facilitate the operation of the large-scale EV charging networks.Atzori et al. [18] (2010) discussed the notion of the Internet of Things (IoT) and how it could be applied in intelligent setting. The research paper elaborated on how interdependent counterparts and apparatuses can interact using the internet based facilities to offer real time data tracking and management. The authors came to a conclusion that, with the use of IoT, automation and energy control in intelligent systems, such as EV charging infrastructure, could be greatly enhanced.

A vision and architecture of IoT based smart systems were suggested by Gubbi et al. [19] (2013). Their work pointed towards the significance of incorporating sensors, communications networks and cloud platforms in order to facilitate intelligent monitoring and decision making. The research indicated that smart transportation systems could be effected by efficient distribution of energy and real-time control with the help of IoT-based solutions.

Zhang et al. [20] (2018) created a smart charging management system of the electric vehicles with the help of IoT. The proposed system also made use of sensors and cloud-based solutions to track status and real-time energy use during charging. The outcomes of the experiment indicated that the system enhanced the efficiency of energy use and enabled the process of remote monitoring of the charging stations via mobile applications.

Ahmad et al. [21] (2020) surveyed the EV charging infrastructure evolution and had a look at the problem of massive EV adoption. Some of the problems that were pointed out by the authors include grid overloading, infrastructure constraints and location of charging stations. The paper proposed the idea that EV charging networks could be made much more sustainable through incorporating renewable sources of energy and smart management systems.

Hannan et al. [22] (2017) conducted a literature review of battery management systems in electric cars. The research targeted the lithium-ion battery technologies and state-of-charge estimation techniques. The findings suggested that effective battery management systems are needed to secure battery safety, increase battery life, and increase the reliability of EV charging systems.

Shaaban and Ismail [23] (2019) examined how the optimization and planning of EV charging stations in smart grids are conducted. Their study suggested optimization methods of finding charging stations and charging loads control. The paper has shown that smart grids may greatly enhance charging efficiency and mitigate the effects of EV charging in power distribution systems.

Rahman and Oo [24] (2016) suggested a distributed energy management approach to microgrids which have renewable energy sources. The paper presented a coordinated control strategy that enables several energy sources such as solar power to collaborate effectively. Results of simulations demonstrated a better power distribution and system stability in microgrid-based charging settings.

The article by Khan and Rehman [25] (2019) suggested an EV charging station smart energy management system based on IoT. The system used real-time data which is measured by sensors to check on the energy consumption and which optimized the charging activities. The experimental outcomes proved to have a higher charging efficiency and energy distribution as compared to the conventional EV charging systems.

The use of internet of things (IoT) enabling technologies and communication protocols and uses has been thoroughly surveyed by Al-Fuqaha et al. [26] (2015). The paper has presented the need of IoT in the development of smart cities as well as its use in energy management, transportation, and monitoring the environment. The authors came to the conclusion that the IoT technologies are necessary to construct intelligent and sustainable infrastructure.

Liu et al. [27] (2013) examined the best approaches of planning EV charging stations of power distribution network. The study suggested mathematical optimization methods to identify optimal points where charging stations will be installed at minimal power losses and costs of infrastructure. The findings showed that charging accessibility and grid stress could be improved through effective planning.

Table 1: Comparison of Existing EV Charging and IoT-Based Energy Management Systems

Ref	Author & Year	Method / Technology	Advantages	Limitations
[16]	Bhatti et al., 2016	Solar PV integrated EV charging	Reduces carbon emissions and grid dependency	Solar power fluctuation affects charging reliability
[17]	Yilmaz & Krein, 2013	Battery charger topology analysis	Improves charging efficiency and infrastructure design	Limited focus on renewable integration

[18]	Atzori et al., 2010	IoT architecture for smart systems	Enables real-time monitoring and automation	Security and privacy challenges
[19]	Gubbi et al., 2013	IoT smart system framework	Supports intelligent energy management	Requires reliable communication networks
[20]	Zhang et al., 2018	IoT-based EV charging monitoring system	Real-time charging control and remote monitoring	Higher implementation cost
[21]	Ahmad et al., 2020	EV charging infrastructure review	Identifies infrastructure challenges and solutions	Mostly conceptual analysis
[22]	Hannan et al., 2017	Battery management systems for EV	Improves battery life and charging safety	Complex system design
[23]	Shaaban & Ismail, 2019	Smart grid-based charging station planning	Optimizes charging station placement	Requires advanced grid infrastructure
[24]	Rahman & Oo, 2016	Microgrid energy management	Improves distributed energy utilization	Integration complexity
[25]	Khan & Rehman, 2019	IoT-based smart EV charging system	Efficient energy monitoring and automation	Network latency issues
[26]	Al-Fuqaha et al., 2015	IoT communication technologies	Supports smart city applications	Data security concerns
[27]	Liu et al., 2013	Optimal charging station planning	Reduces power loss and improves accessibility	Requires complex optimization models

3. Proposed Methodology

This section will introduce the suggested IoT-based smart automation system on the electric vehicle (EV) charging with the usage of solar energy. The design combines renewable energy production, smart monitoring, and automated control systems to design an efficient and sustainable EV charging system. The presented model prioritizes the usage of solar power to the most extent and makes sure that the energy can be charged in the cases of energy storage and the IoT-based monitoring.

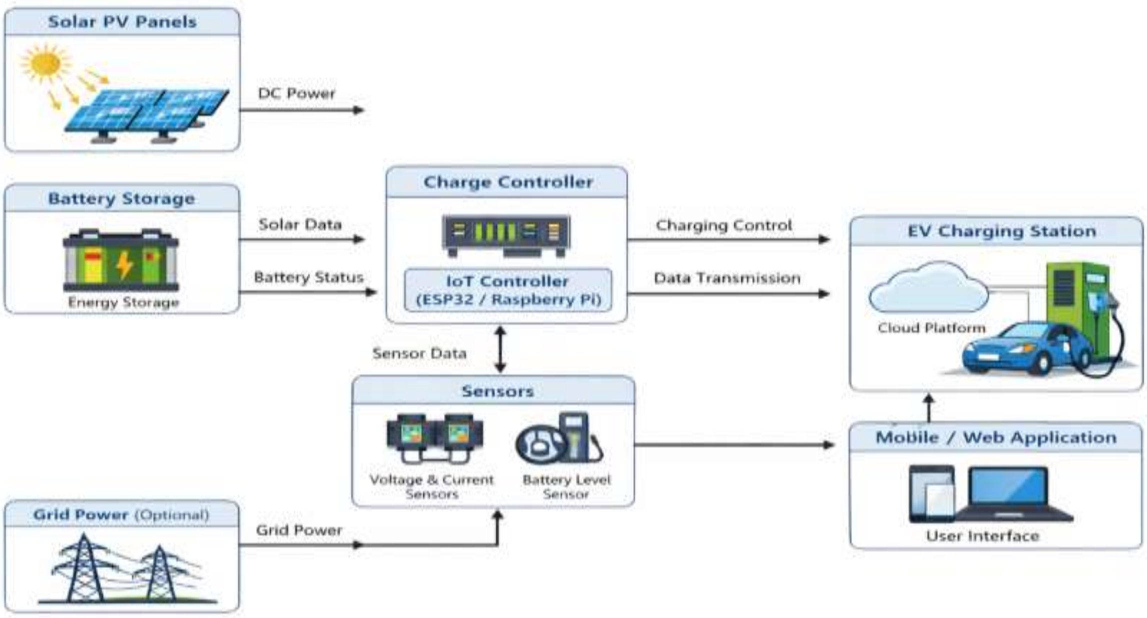

Figure 1: Proposed Model

3.1 System Architecture
The suggested system architecture will be composed of a number of interrelated devices such as solar photovoltaic (PV) panels, battery storage, internet of things (IoT) controller, sensors, EV charging station, and cloud-based monitoring platform. The solar PV panels generate electrical energy, which is the main source of power of the EV charging station.
As the production of solar power is dependent on the environmental conditions, a battery storage facility is incorporated to store redundant energy during bright sunshine. This stored energy is then utilized at the time of low fertility of the sun like when it is cloudy or at night. This interplay of solar power and battery storage is a guarantee of constant and dependable power provision to charge EV.

3.2 IoT-Based Monitoring System
The IoT monitoring system will be significant in the proposed framework. A controller with IoT capability, like ESP32 or Raspberry Pi, gathers real-time data of different sensors that can be in the charging station. Such sensors track solar power output, voltage, current, battery state of charge and EV charging.
The gathered information is relayed via the wireless communication technologies like Wi-Fi or the GSM networks to a cloud server. The data is stored and processed by the cloud and the users and the system administrators can monitor the charging station remotely by a mobile application or web interface. This characteristic enhances transparency of the system and allows the management of energy effectively.

3.3 Smart Energy Management
The smart energy management approach has been integrated into the proposed system to maximize the use of the resources of energy that is available. As far as an electric car is attached to the charging station, the system will automatically check the amount of solar energy and battery storage rate.
In case there is enough solar power, the system will provide electricity to charge the EV directly using solar panels. The insufficiency in the generation of the solar energy prompts the system to turn to the battery storage so as to sustain the charging process. Where both battery energy and solar energy are not sufficient the system can also use grid electricity as a backup source provided it is available.

3.4 Automated Charging Control
The electronic control system of charging guarantees effective and secure charging of electricity automobiles. The system has sensors to monitor the EV battery status and charging conditions continuously. According to the gathered information, the controller controls the charging current and voltage to avoid battery destruction.
There are also safety measures that are taken to prevent overcharging, overheating and high power consumption. The system is also capable of prioritizing the basis of charging based on the state-of-charge of the battery and the availability of the energy so that the renewable energy resources can be used optimally.

4. System Model and Implementation.
This part explains how the suggested IoT-based solar-powered EV system would be implemented. The system combines the renewable energy production, the IoT, energy storage, and control over charging intelligibility to provide efficient yet sustainable EV charging processes.
A Five-day study will be conducted to determine the electrical power output in kilowatts and the electricity usage or energy that can be saved through solar power generation as opposed to electricity usage or energy expenditure incurred through electricity generation (Brown, 2003).

4.1 Solar Power Generation Model
The proposed system has solar photovoltaic (PV) panels as the main source of energy. These panels transform sunlight into electric power by photovoltaic effect. This produced energy comes out as direct current (DC) which is later fed to the charge controller.

The power output of the solar panel will be determined by the irradiance of the sun, the efficiency of the panel, and the environmental factors. The energy that is produced due to the presence of the sun can be utilized to directly charge the electric vehicle or it can be stored in the battery system to be utilized later. The strategy will help in effective use of renewable energy and minimize dependence on electricity generated on conventional grids.

4.2 Battery Storage System

This is because solar is intermittent and thus a battery storage system is included in the proposed architecture. The battery accumulates surplus solar energy that is generated at the optimal sunlight period and provides at times when the solar production is not enough.

The battery management system constantly measures the parameters of battery voltage, temperature and state of charge (SOC). Correct monitoring can keep the batteries in good condition and make charging safe. The energy stored gives the EV a consistent reserve of energy to charge it, particularly at night or when it is cloudy.

4.3 IoT-Based Data Monitoring

It is proposed to use an IoT controller like ESP32 or Raspberry Pi to monitor and control the charging process. The system use sensors to check the vital electrical parameters such as voltage, current, battery level and charging status.

The sensor measurements are relayed to a cloud server via wireless communication devices like Wi-Fi or GSM modules. The data is stored and processed on the cloud platform where the system administrators and users can get access to real-time data concerning the charging system.

Such real-time monitoring enhances efficiency in the system and enables to detect faults or abnormal conditions in the charging infrastructure in time.

4.4 EV Charging Control Mechanism.

The Smart charge controller links the EV charging station with the IoT controller. When an electric car is plugged in the charging point, the system initially analyzes the sources of energy available.

In case there is enough solar energy, the vehicle would be charged directly using solar energy. In case of low production of solar energy, the system will turn to battery storage. The system may also be provided to pull grid power in the event of an emergency when the solar and battery energy is not enough.

This combined energy management solution guarantees that the power is charged at all times but with as much utilization as possible of renewable energy.

4.5 Monitoring and User Interface

This is a cloud-based monitoring and user interface.

Monitoring The remote monitoring of a charging station is made possible by the cloud-based monitoring system that enables users to remotely check the charging station using a mobile application or web-based dashboard. The users can verify the following information:

- Solar power generation
- Battery charge level
- EV charging status
- Energy consumption

Such a remote control feature enhances the convenience of the users and enables the flexibility in managing the charging infrastructure.

Algorithm for Smart Charging Control

Step 1: Start the system and initialize IoT sensors.
Step 2: Measure solar power generation from PV panels.
Step 3: Monitor battery state of charge (SOC).
Step 4: Detect EV connection to charging station.
Step 5: If solar power is sufficient → charge EV using solar energy.

Step 6: Else if battery charge is sufficient → charge EV using battery storage.
Step 7: Else → switch to grid power (optional).
Step 8: Continuously update system data to the cloud platform.
Step 9: Display real-time system status on the user interface.
Step 10: Stop charging when EV battery is fully charged.

5. Results and Performance Evaluation

This part will provide an in-depth analysis of the conceived IoT based smart automation system of charging electric vehicle (EV) with the help of solar energy. Experimental measurements of the system, such as solar energy generation, charging efficiency, monitoring accuracy, communication latency and information throughput, were used to analyze the system performance. These parameters were applied to determine the capacity of the system to handle the process of EV charging and at the same time use renewable energy and IoT-based monitoring technologies.

The proposed model was implemented using solar photovoltaic panels, battery storage system, IoT sensors and cloud monitoring platform to perform the experimental study. The data obtained during the experiment were processed to estimate the performance of the system in different operating conditions.

5.1 Experimental Setup

The experimental system consists of solar photovoltaic panels, battery storage devices, IoT controller (ESP32), voltage and current sensors, EV charging module, and a cloud based monitoring system. The solar panels transform the sun rays into electrical power, which is the major power source used in charging EV.

The system is installed with a battery storage facility to store the surplus solar energy generated when the sun is at its highest point. This energy reserve is used later when there is a decrease in the solar power production. The IoT controller constantly gathers real-time data of the sensors like voltage sensors, current sensors, and battery monitoring sensors.

The sensor data collected are sent via Wi-Fi network to a cloud server where remote monitoring of the system performance is possible. The time frame was adjusted to five seconds to make sure that the system was monitored all the time. Table 2 indicates the key experimental parameters during the evaluation.

Table 2. Experimental System Parameters

Parameter	**Value**
Solar Panel Capacity	500 W
Battery Capacity	48 V, 100 Ah
IoT Controller	ESP32
Communication Network	Wi-Fi
EV Charging Power	3.3 kW
Monitoring Interval	5 seconds

The control parameters used were chosen to represent a typical small-scale solar EV charging station.

5.2 Solar Power Generation Results

The amount of power that was produced by the photovoltaic panels at various times of the day was measured to analyze the output. The findings indicate that there is a change in the production of solar energy with the intensity of sunlight and environmental factors.

Table 3 shows the solar power that is produced at various timings.

Table 3. Solar Power Generation at Different Time Intervals

Time	**Solar Power Generated**
09:00 AM	210 W
11:00 AM	380 W
01:00 PM	470 W

03:00 PM	350 W
05:00 PM	180 W

The findings show that maximum solar power production is in the afternoon at approximately 1:00 PM when the solar radiation is at its maximum. Throughout this time, solar power has the ability to provide or meet most of the EV charging needs. The surplus energy produced in the process is stored in the battery storage system to be used later.
A solar power generation slowly diminishes as the day approaches the evening. The battery storage facility can make EV charging operations consistent during such times in the year when the sun is not very active.

5.3 Charging Efficiency Results

Charging efficiency is the efficiency of energy conversion in the solar system to the electric vehicle battery. The efficiency was determined by dividing the input energy of the sun by the energy supplied to the EV battery.
Table 4 presents the efficient results of charging obtained in the process of the experiment.

Table 4. EV Charging Efficiency Analysis

Test Case	Input Energy (kWh)	Energy Delivered (kWh)	Efficiency
Test 1	3.2	2.95	92.1%
Test 2	3.5	3.22	92.0%
Test 3	3.0	2.76	92.0%

The experimental findings show that average efficiency in the proposed system was about 92 percent in terms of charging. It is very efficient and this shows that the system is able to convert and transfer solar energy to the EV battery with little power losses.
Efficient energy transfer will also guarantee ideal exploitation of renewable energy resource and enhance sustainability of the charging infrastructure as whole.

5.4 Monitoring Accuracy Results

Monitoring accuracy of the IoT-based system was assessed by comparing the sensor values with the reference values recorded using calibrated measuring tools.Figure 2 depicts the monitoring accuracy of the various sensors that were used in the proposed system. Voltage sensor had the most accuracy of 99.1% and current sensor had a high accuracy of 98.0%. The battery level sensor had an accuracy of 97.5% accuracy. According to these findings, the IoT-based monitoring system is highly reliable in terms of accuracy in the measurements of EV charging processes. The sensor accuracy is high, and this guarantees an accurate tracking of system parameters which is critical in the safe and effective management of energy in solar-charged EV charging stations.

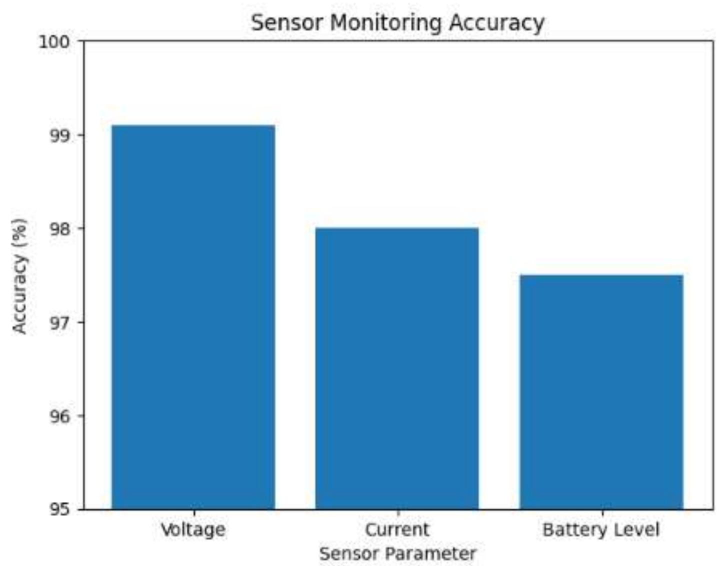

Figure 2. Sensor Monitoring Accuracy

The findings indicate that the IoT monitoring system was maximized to 98.2% on average. Proper charging is another issue that involves proper monitoring in order to keep the system safe.
The system has high monitoring accuracy to detect any abnormal condition in terms of voltage fluctuations, overheating, or high current flow.

5.5 Communication Latency Results

Communication latency is the time interval between the sensor data collection and the transfer of such data to the cloud platform. Reduced latency means faster reaction of the system and real-time monitoring.
Table 5 represents the communication latency realized in the course of the experimental examination.

Table 5. Communication Latency Measurement

Test	Latency (ms)
Test 1	115 ms
Test 2	123 ms
Test 3	118 ms
Test 4	121 ms

Averages of communication latency were 119 milliseconds, which is low enough to monitor and control the EV charging station in real-time.

5.6 Data Throughput Results

Throughput is the speed with which information flows between the IoT controller and the cloud server. Any good throughput is one that can sustain the constant monitoring data without any delays. The result of the throughput in the experiment was presented in Table 6.

Table 6. IoT Data Throughput Performance

Test	Throughput
Test 1	820 kbps
Test 2	870 kbps
Test 3	860 kbps
Test 4	845 kbps

The throughput of the proposed system was 848 kbps on average, which guarantees the stability in communication between sensors and the IoT controllers and the cloud platform.

5.7 Discussion

The results of the experiments prove the effectiveness and stability of the given IoT-based solar EV charging system. The system effectively employs solar energy when it is in the peak sun rays and makes constant charge through a battery storage.
The IoT monitoring system can be integrated to provide real-time monitoring of the system parameters making it possible to remotely control the charging activities by the users and operators. The system also reported a high monitoring accuracy, low communication latency and dependable data transmission throughput.
These findings prove that the proposed model would be able to offer a sustainable, smart, and energy efficient EV charging solution applicable to smart cities and renewable energy based transportation infrastructure.

6. Conclusion

The paper presented an IoT-based smart system of automation in charging electric vehicles (EV) with solar power. The system incorporates solar photovoltaic panels, battery storage, IoT sensors, and cloud-based monitoring to deliver an efficient and sustainable EV charging system. The test outcomes indicated that the experimental system had a 92 percent charge efficiency, 98.2 percent monitoring precision, 119 ms communication delay, and 848 kbps data transmission which shows that the system is reliable. The suggested system will enhance the use of renewable energy, decrease grid use, and allow monitoring of charging activities in EV in real-time. Artificial intelligence-based energy management and smart grid integration can be applied in the future to increase the efficiency and scalability of the system even more.

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