

**OVERVIEW AND HARDWARE IMPLEMENTATION FOR EV CHARGING MANAGEMENT AND BATTERY MONITORING SYSTEM BASED ON IOT AND RENEWABLE ENERGY****Abhishek Singh<sup>1</sup>, Kirti Pal<sup>2</sup>, Tripti Kunj<sup>3</sup> and C. B. Vishwakarma<sup>4</sup>**<sup>1, 2, 3</sup>Electrical Engineering Department, School of Engineering Gautam Buddha University Greater Noida, U.P, India<sup>4</sup>Department of Electrical Engineering, Harcourt Butler Technical University, Kanpur, India**ABSTRACT**

*This paper presents the design, development, and experimental validation of a compact, IoT-enabled Electric Vehicle (EV) charging station prototype powered by solar energy with grid backup. The system integrates key hardware components including a lithium-ion battery, ESP32 microcontroller, voltage and current sensors, a MOSFET-based inverter, and a Blynk-powered mobile application for real-time monitoring and control. A comprehensive literature review was conducted to assess the current state of IoT-based EV battery management systems, identifying key gaps in real-time implementation, renewable integration, and mobile-based user interfaces. Addressing these gaps, the proposed model emphasizes renewable energy utilization, offering automatic switching between solar and grid power to ensure uninterrupted charging. Real-time tracking of parameters such as solar input, battery voltage, and charging current is enabled through IoT connectivity, significantly enhancing system reliability and user accessibility. Unlike many existing works that remain simulation-based, this prototype was physically implemented and tested under variable solar conditions. The system achieved seamless energy management and successful remote monitoring via a mobile dashboard, demonstrating its potential for scalable applications in semi-urban and residential EV infrastructure.*

**Key-Words:** -Electric Vehicle (EV), Charging Station, Battery Management, Internet of Things (IoT), Solar Energy, Lithium-ion battery

**1 INTRODUCTION**

The transition from internal combustion engine vehicles to electric vehicles represents a pivotal shift in the automotive and energy sectors. As the adoption of EVs accelerates globally, ensuring efficient and effective battery management and charging strategies becomes increasingly vital. The battery, often considered the heart of an EV, is central to its performance, longevity, and overall user experience. Consequently, optimizing battery management and charging processes is essential to maximizing the benefits of electric mobility, [1].

Battery management encompasses a range of tasks, from monitoring battery health and charge levels to ensuring safe and efficient charging. Traditional approaches to battery management can be limited in scope and may not fully leverage the capabilities of modern technology. This is where the Internet of Things (IoT) offers transformative potential. By integrating IoT technologies revolutionize how EV batteries are monitored, managed, and charged, [2].

IoT involves the interconnection of devices and systems through the internet, enabling them to collect, share, and act on data in real-time. In the context of EV battery management, IoT provides a platform for continuous monitoring and intelligent control. Smart sensors embedded in the battery pack can track critical parameters such as state of charge, temperature, and overall battery health. This data is transmitted to a centralized cloud-based system where it can be analyzed and utilized to make informed decisions, [3].

The integration of IoT in EV battery management and charging not only improves operational efficiency but also enhances user experience. Mobile applications connected to the IoT system provide users with real-time updates on battery status, charge levels, and maintenance needs, empowering them to make informed decisions and optimize their EV usage, [4].

The integration of the Internet of Things (IoT) in electric vehicle (EV) battery monitoring and charging station management represents a groundbreaking shift towards more efficient and intelligent transportation infrastructure, [5].

IoT technology enables real-time monitoring of EV batteries, allowing for continuous tracking of critical parameters such as voltage, temperature, and state of charge. This real-time data is instrumental in predictive maintenance, helping to anticipate battery issues before they result in failures and thus extending battery life and enhancing performance [6-7].

On the charging station front, IoT facilitates dynamic load management, optimizing energy distribution and preventing over-loads, while also improving user experience through real-time information on charger availability and automated payment systems, [8].

The ability to remotely manage and monitor charging stations, coupled with secure data handling and analysis, underscores the transformative impact of IoT, driving efficiency and reliability in EV infrastructure and supporting the broader adoption of electric vehicles, [9-10].

IoT-enabled systems facilitate real-time monitoring, predictive maintenance, and efficient management of charging stations, thus addressing critical challenges associated with EV battery management [11].

Battery health monitoring is crucial for ensuring the longevity and performance of EV batteries. Traditional methods often rely on periodic checks, which can be inefficient. IoT introduces real-time monitoring, which provides continuous data on battery status, the use of IoT sensors to measure parameters such as voltage, temperature, and state of charge (SoC) in real time, [12-13].

Predictive maintenance, powered by IoT, leverages historical and real-time data to forecast potential battery failures before they occur. Predictive models can be trained on data collected from various sensors to identify patterns that precede battery malfunctions. This approach reduces unexpected breakdowns and extends battery life by facilitating timely interventions, [14].

IoT enables dynamic load management at charging stations, optimizing the distribution of electrical load based on real-time demand and supply conditions. This dynamic approach helps in integrating renewable energy sources and managing peak loads effectively, [15].

The integration of IoT improves the user experience at charging stations by providing real-time information on charger availability, status, and estimated wait times. Mobile applications connected to IoT systems that allow users to locate and reserve charging spots, making the process more convenient and user-friendly, [16].

IoT facilitates automated payment and billing systems at charging stations. Smart charging stations equipped with IoT can handle various payment methods, including mobile payments and subscription-based models. The system can automatically calculate and process payments based on the energy consumed and provide detailed billing information to users, [17].

One of the primary challenges in IoT-based EV battery monitoring and charging station management is ensuring scalability and interoperability across different systems and manufacturers, [18]. As IoT systems become more prevalent, regulatory and ethical considerations related to data privacy, security, and user consent become increasingly important. The integration of IoT in EV battery monitoring and charging station management represents a significant advancement in the field, offering real-time in-sights, enhanced efficiency, and improved user experiences. While challenges such as scalability, data management, and regulatory issues remain, ongoing research and technological advancements are likely to address these concerns and drive further innovation in the sector, [19], [20].

The proposed hardware model aims to build a small-scale EV charging station prototype powered by solar energy and the grid. The system includes IoT capabilities to allow real-time monitoring of battery charge levels and energy source status via a mobile interface. The system is designed to ensure optimal energy management, switching between solar and grid power as needed.

### 1.2 Literature Review, Research gaps and contributions

In recent years, a growing body of literature has explored the role of IoT in enhancing electric vehicle (EV) charging and battery management systems. Studies such as [21] and [23] focus on integrating IoT and artificial intelligence for improved state-of-charge (SoC) estimation and battery health monitoring. However, many of these works remain confined to theoretical frameworks or simulations without full-scale hardware implementation. For instance, [22], [24], and [25] utilize sensors and microcontrollers for battery parameter tracking but lack integration with renewable sources, inverter control, or mobile-based monitoring interfaces.

Further, optimization-driven approaches in [26]–[31] investigate dynamic pricing, charging station location, fleet-level management, and machine learning-based charging strategies. While these methods contribute to improved energy efficiency and user behavior modeling, they often overlook real-time data acquisition and physical implementation challenges. Similarly, studies such as [32]–[34] address broader system-level aspects such as vehicle-to-grid (V2G) integration, energy management in microgrids, and real-time control, yet fall short of demonstrating compact, scalable prototypes suitable for real-world deployment particularly for semi-urban or residential settings.

**Table1:** Research gap and Contribution

Ref	Year	Key Findings	Research Gap Identified	Methodology	Contribution of Present Work
[21]	2023	IoT + AI for SoC monitoring, cloud-based battery tracking.	Lack of real-time physical prototype validation.	AI-enhanced SoC monitoring using sensors + cloud.	Developed a functional IoT-based prototype using Blynk and ESP32 for real-time SoC monitoring.
[22]	2021	EV battery performance tracking using IoT.	No integration with renewable sources or hardware implementation.	Conceptual IoT system, simulation-based.	Integrated solar/grid system with real-time mobile monitoring via Blynk app.
[23]	2022	IoT BMS using sensors + ThingSpeak cloud.	Lacks inverter load control and hybrid power input (solar+grid).	Sensor-based data to cloud; no system control or switching.	Added inverter, AC load control, and automatic switching between solar and grid power.
[24]	2022	IoT BMS using LR estimation and mesh topology.	Complex network model but no mobile-based implementation.	MeshNet + latency optimization focus.	Real-time monitoring using ESP32 + Wi-Fi + mobile dashboard (Blynk) for low-latency applications.
[25]	2023	Cost-effective microcontroller-based BMS with Arduino.	Arduino used, but lacks cloud/mobile app control.	Local real-time BMS with basic parameters.	Demonstrated mobile integration, remote monitoring, and user control through app.

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[26]	2019	Dynamic pricing strategies in EV charging.	No real-world prototype or renewable energy consideration.	Theoretical pricing strategy simulation.	Focus on physical prototype with basic energy management; future work can add pricing logic.
[27]	2019	Optimal charging station location models.	Focused only on planning, not on energy source management.	GIS-based and user-centric planning.	Offers hardware-based micro-station model useful in rural/small-space deployment.
[28]	2016	Optimization in EV infrastructure cost/coverage.	High-level modeling; lacks IoT integration.	Optimization algorithms.	Presents a cost-effective prototype with embedded IoT for monitoring and control.
[29]	2020	ML for demand prediction in EV charging.	Predictive analysis focus, no integration with IoT platforms.	ML algorithms for behavior prediction.	Future direction of the current system includes ML-based predictive maintenance.
[30]	2021	Grid congestion management via smart EV charging.	No integration with actual hardware.	Load optimization models.	Proposed automatic switching between solar/grid sources for decentralized congestion reduction.
[31]	2021	Smart charging for EV fleets using reinforcement learning.	Algorithmic simulation; not field-tested.	RL-based model for fleet-level optimization.	Our prototype suitable for testing in small fleet or household EV setups.
[32]	2019	V2G aggregator to reduce cost & grid support.	Limited real-world demonstrations.	Bidirectional energy control simulation.	Lays the groundwork for V2G by monitoring battery health and flow direction with inverter setup.
[33]	2022	Cooperative energy management in microgrids.	Lacks battery-level BMS focus.	Microgrid control models.	Offers modular system easily embedded in microgrid with local solar generation.
[34]	2014	Real-time data-based EMS for EVs.	No focus on mobile-based monitoring or Blynk integration.	Real-time load control in smart grids.	Real-time Blynk dashboard included with local + mobile data visualization.

[35]	2023	User behavior effects on charging optimization.	No integration with IoT hardware or mobile alerts.	Modeling user behavior patterns.	Real-time mobile alert feature added using Blynk app notifications.
[36]	2018	Robust model for uncertain supply.	No IoT or mobile monitoring; purely algorithmic.	Probabilistic and interval optimization.	System validates resilience via dual power (solar + grid) integration in real time.
[37]	2018	Multi-objective optimization of home energy systems.	Focus on household energy—not EV-specific hardware.	MOO strategies.	Real hardware designed for EVs; can integrate with future optimization schemes.
[38]	2018	Game theory for energy pricing and user optimization.	Theory only; no working prototype.	Hierarchical game models.	Future direction: Dynamic charging based on energy pricing can be added on top of our model.
[39]	2020	Charging station sharing optimization.	No sensor-based monitoring, no renewable sources.	Station-level charging allocation.	Demonstrated shared infrastructure at micro scale with solar/grid hybrid.
[40]	2021	Comprehensive review of EV standards and architecture.	No low-scale hardware system proposed for rural/small use.	Standards and protocols review.	Used IEC 61851-compliant design logic, ESP32 integration, and inverter control for compliance-ready system.

To bridge these gaps, a detailed mapping of key literature review as presented in Table 1 was conducted, identifying prevailing research gaps in sensor-based monitoring, hybrid energy source management, user interface design, and cost-effective prototyping. The current paper directly addresses these gaps by developing a fully functional prototype that integrates solar and grid energy sources, utilizes the ESP32 microcontroller, and employs the Blynk IoT platform for real-time mobile monitoring. Unlike many of the referenced works, this study validates its methodology through physical implementation, demonstrating energy source switching, inverter control, sensor-based voltage and current measurement, and user-friendly data visualization. The proposed system thus offers a robust foundation for scalable, sustainable, and user-centric EV charging infrastructure.

### 1.3 Organization of the Paper

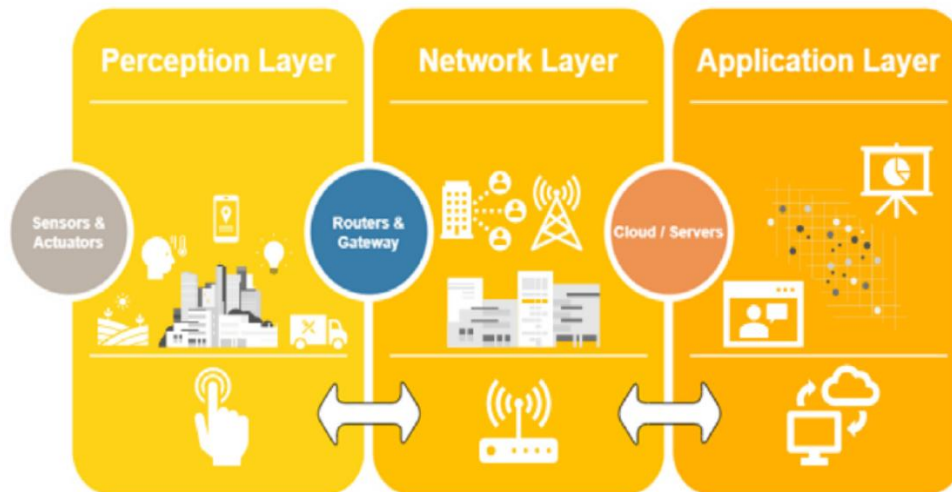
This paper is organized into six main sections. Following the introduction and literature review, Section 2 describes the proposed EV battery charging management system, detailing its architecture, components, and the integration of IoT technology. Section 3 outlines the methodology for prototype development, including hardware integration, solar and grid energy management, and real-time monitoring using the Blynk platform. Section 4 presents the experimental setup, component specifications, and results, demonstrating the system's performance

under real-time operating conditions. Section 5 discusses the future scope of this work, identifying potential advancements such as predictive maintenance, smart grid integration, and standardization. Finally, Section 6 concludes the paper by summarizing the key findings and reaffirming the system's contribution to sustainable and scalable EV charging infrastructure.

## 2. EV Battery Charging Management System using IoT

An EV Charging Management and Battery Monitoring System based on the IoT can provide effective control and monitoring of EV charging stations and battery performance. Such a system enables seamless communication between charging stations, electric vehicles, and a central management platform as shown in figure 1. Here's a high-level overview of how such a system can be structured:

- **Charging Stations:** Each charging station is equipped with IoT devices, such as sensors, communication modules, and control units. These devices enable real-time monitoring and control of the charging process [41].
- **Electric Vehicles:** Electric vehicles are equipped with IoT devices, typically embedded within the vehicle's charging port. These devices facilitate communication with the charging stations and transmit relevant information, such as battery status, charging requirements, and vehicle identification [42-45].
- **IoT Gateway:** An IoT entryway acts as a tie between the charging stations and the central management platform. It collects data from multiple charging stations and securely transmits it to the central server [46-48].



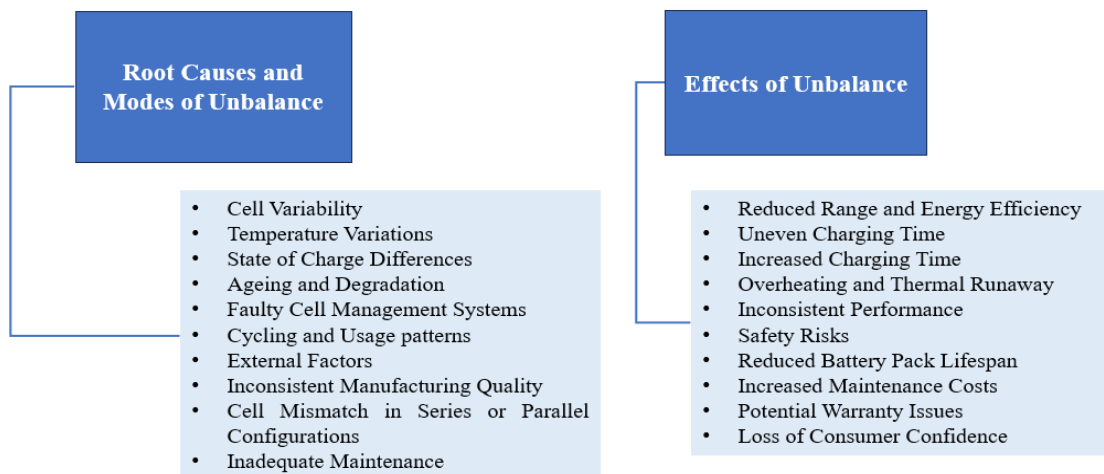
**Fig. 1.** IoT architecture [49].

- **Central Management Platform:** This platform serves as the central control and monitoring system for the charging infrastructure. It receives data from the charging stations, processes it, and provides necessary insights and control functionalities. The platform may be cloud-based or on-premises, depending on the specific implementation [50-52].

This article synthesizes insights from diverse research efforts, providing a comprehensive understanding of the advancements in Battery Management Systems (BMS), the complexities of unbalancing in battery packs, the capabilities of LPWAN technologies, and the transformative impact of IoT on Electric Vehicle battery monitoring. As the electrification of transportation continues to reshape the automotive landscape, these studies collectively contribute to the knowledge base guiding the development of sustainable and efficient electric mobility solutions.

### 2.1 Root Causes, Modes, and Effects of Unbalance in Battery Management Systems

One root cause of unbalance is cell degradation, where individual cells within a battery pack experience varying levels of capacity loss or internal resistance over time, resulting in uneven charge/discharge characteristics[53]. Another cause could be manufacturing inconsistencies or differences in cell aging due to operating conditions. These factors can manifest in modes such as voltage imbalance, where some cells reach higher voltage levels than others during charging, or SoC imbalance, where certain cells discharge faster than others, leading to premature capacity exhaustion. The effects of unbalance in BMS include reduced energy capacity, diminished power output, and increased risk of overcharging or overdischarging certain cells, which can accelerate degradation and compromise overall battery performance and safety [54]. Additionally, unbalance can lead to uneven thermal distribution within the battery pack, exacerbating temperature-related issues and potentially causing thermal runaway or catastrophic failure. Therefore, effective BMS strategies such as cell balancing algorithms, periodic calibration, and thermal management are essential to mitigate unbalance and ensure the optimal operation and longevity of battery systems as shown in figure.2.



**Fig.2:** Root causes, modes, and effects of unbalance in Battery Management System

Throughout the battery value chain, several significant challenges persist, impacting production, performance, and sustainability. One major challenge is the availability and cost of raw materials, such as lithium, cobalt, and nickel, which are essential components in lithium-ion batteries. Fluctuating demand and geopolitical factors can lead to supply chain disruptions and price volatility, affecting battery manufacturing costs and overall market competitiveness. Another critical issue is battery performance and safety, particularly in high-demand applications like EVs [55]. Ensuring consistent energy density, cycle life, and thermal stability while minimizing risks of overheating or thermal runaway remains a complex engineering challenge. Additionally, the lack of standardized recycling infrastructure presents a sustainability challenge, as end-of-life batteries often end up in landfills or incinerators, posing environmental and health hazards as shown in figure 3. Addressing these challenges requires collaboration across industries to advance battery technology, improve supply chain resilience, and develop robust recycling solutions to support the transition towards a more sustainable energy future.



**Fig.3:** Major Battery challenges throughout the value chain

## 2.2 IoT Blynk Application

The Blynk Application is a popular Internet of Things platform that allows developers to build and control IoT projects easily, without needing to write complex backend code [56-57]. Blynk provides a user-friendly mobile app (available for Android and iOS) that connects to various hardware devices, such as ESP32, Arduino, Raspberry Pi, and others, enabling real-time interaction with these devices over the internet.

### 2.2.1 Key Features of the Blynk Application:

- **Easy-to-Use Interface:** The Blynk app features a drag-and-drop interface where users can design custom dashboards by adding widgets like buttons, sliders, graphs, and displays. These widgets are linked to various functions of the connected hardware [58].
- **Hardware Compatibility:** Blynk supports a wide range of microcontrollers, including ESP32, ESP8266, Arduino, and Raspberry Pi. Developers can easily program these devices and connect them to the Blynk server.
- **Cloud-Based Platform:** Blynk operates on a cloud-based platform, which allows users to control their IoT devices remotely from anywhere in the world, as long as they have internet access. Data is sent to and from the Blynk cloud servers, enabling real-time monitoring and control.
- **Customizable Dashboards:** Users can customize the app's dashboard to suit their specific needs by adding various elements like LEDs, buttons, and virtual displays to monitor sensor data or control connected devices.
- **Real-Time Data Monitoring:** The Blynk app displays real-time data from the connected hardware, allowing users to track sensor values such as temperature, humidity, voltage, and more. Users can also visualize this data using graphs and charts [58].

- **Notifications and Alerts:** The app can be programmed to send notifications or alerts to the user's smartphone when specific conditions are met. For instance, if a sensor detects a threshold value (e.g., high temperature), the app can notify the user instantly.
- **API and Webhooks:** Blynk provides APIs and webhooks, allowing users to integrate their IoT projects with third-party services and cloud platforms, creating a more interconnected system.

### 2.2.2 Applications of Blynk in IoT:

- **Smart Home Automation:** Blynk can be used to control lights, appliances, and security systems remotely through a mobile app, turning any home into a smart home.
- **Industrial Automation:** Blynk provides real-time monitoring of industrial sensors and machinery, enabling predictive maintenance and improved operational efficiency.
- **Wearables and Health Monitoring:** It is often used in IoT projects involving health monitoring systems, where data from sensors is sent to the Blynk app for real-time health tracking.
- **Agriculture:** Blynk can be utilized in precision agriculture to monitor soil moisture, control irrigation systems, and optimize resource usage.

## 3. METHODOLOGY FOR PROPOSED HARDWARE MODEL

The proposed model description is divided in two parts. First describes the charging station management and second section describes application of IoT for EV charging monitoring.

### 3.1 EV Charging Station Management

Effective EV charging station management is crucial for optimizing the use of resources, enhancing user experience, and ensuring operational efficiency. It involves overseeing the deployment, maintenance, and utilization of charging stations, including monitoring the performance and availability of chargers in real time. Additionally, incorporating IoT technologies allows for remote monitoring and diagnostics, enabling proactive maintenance and reducing downtime. By leveraging renewable energy sources, such as solar power, and integrating with the grid, charging station management can also contribute to sustainability efforts, making EV charging more efficient and environmentally friendly. Ultimately, a well-managed EV charging network plays a vital role in promoting electric vehicle adoption and supporting the transition to greener transportation.

Figure 4 represents a solar-powered IoT-based energy management system. It consists of key components such as a solar photovoltaic (PV) panel, a battery, sensors, a microcontroller, and an inverter. The solar PV panel (16V, 5W) captures solar energy, which is then used to charge a 12V, 6.8Ah battery through a diode that prevents reverse current flow. Voltage sensors are placed across the solar panel and battery to monitor their respective voltages. The microcontroller, equipped with a Wi-Fi module (ESP32), collects data from the voltage and current sensors and communicates this data to an IoT device for remote monitoring.

The stored energy in the battery is converted from DC to AC through a MOSFET-based inverter, providing AC output. A current sensor monitors the AC output to measure the load's power consumption. This AC output is delivered to the connected load, such as a household appliance. The LCD display shows real-time data, such as voltage levels and power consumption, and the IoT device enables remote access and control of the system.

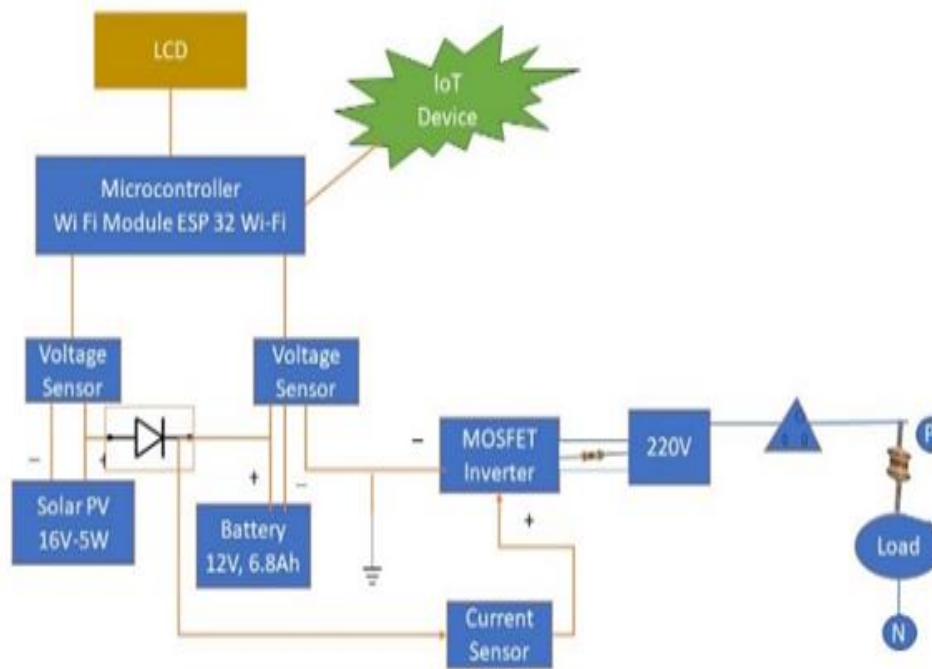


Fig. 4: Block diagram of proposed model for EV charging

### 3.2 Prototype Development Process

The development of the prototype followed a step-by-step approach, focusing on the integration of solar energy, grid backup, and IoT-based monitoring. The key stages of the development process are shown in figure.5.

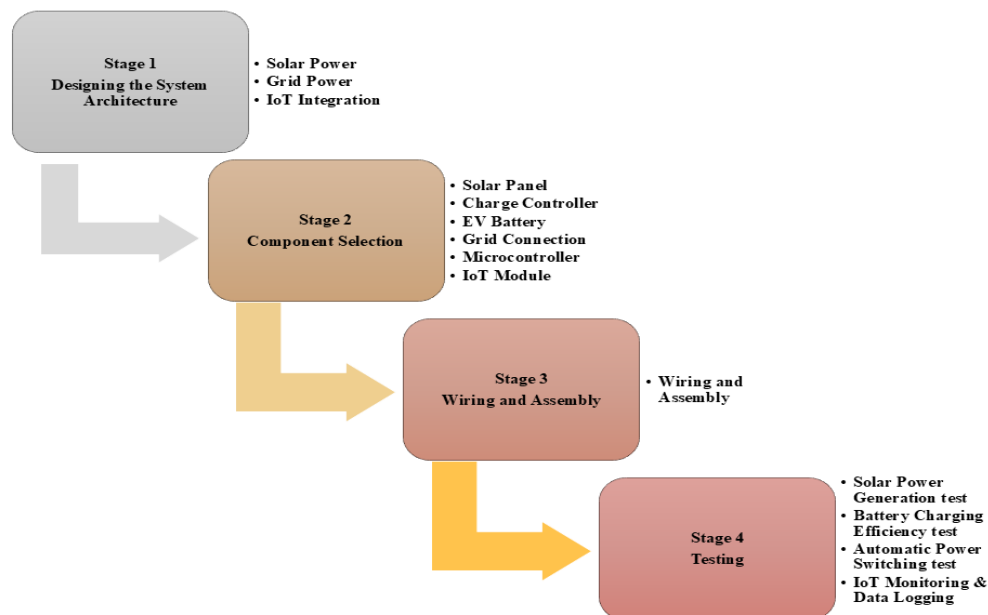


Fig 5: Prototype Model Development Stages

The diagram outlines a structured development process for a solar-powered EV charging station integrated with IoT technology. The process begins with Stage 1, where the system's architecture is designed.

This stage includes defining the integration of solar power, grid power, and IoT modules for remote monitoring and control. In Stage 2, the necessary components are selected, such as solar panels for energy generation, a charge controller to manage the power flow, an EV battery for energy storage, a grid connection as a backup power source, a microcontroller for system management, and an IoT module for monitoring.

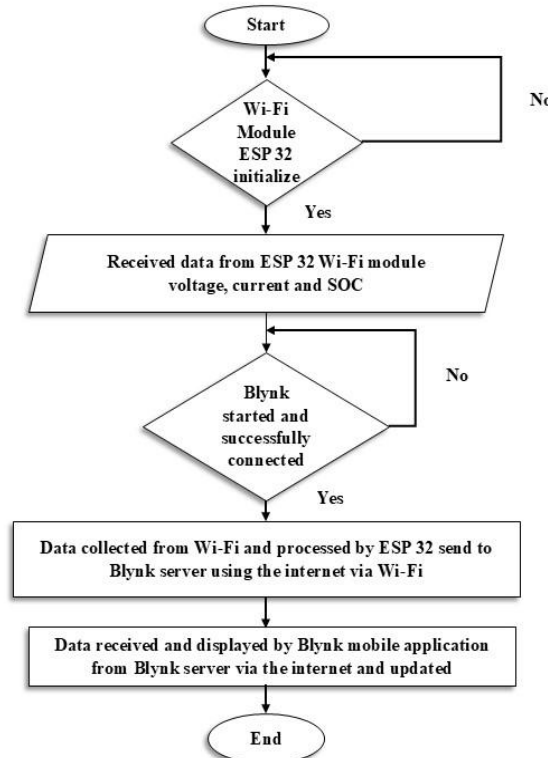
Stage 3 focuses on the wiring and assembly of these components. The solar panel, charge controller, battery, grid connection, microcontroller, and IoT module are physically connected to form a cohesive system. Finally, in Stage 4, the assembled system undergoes various tests. These tests include verifying solar power generation, checking the efficiency of battery charging, ensuring automatic switching between solar and grid power, and testing the IoT system for monitoring and data logging. This approach ensures the system is both functional and efficient, while also providing real-time monitoring capabilities.

**3.3 IoT Integration and Mobile Monitoring:**

The Blynk IoT platform was configured to collect real-time data from the system. The microcontroller interfaced with sensors to measure solar voltage, battery charge status, and current flow. The data was transmitted to the Blynk server and displayed on a custom-built dashboard, accessible through a mobile application. The dashboard allowed users to monitor key parameters, such as:

- Solar panel voltage (to ensure the solar array was generating enough power).
- Battery voltage (to track the charge level of the EV battery).
- Current flow (to monitor the charging rate).

The user interface on the mobile app provided a simple and intuitive way to remotely monitor and control the system.



**Fig. 6:** Proposed system flowchart

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This flowchart shown in fig.6 describes the process of data collection and transmission using an ESP32 microcontroller and the Blynk IoT platform. The steps for the system's operation are as follows:

- **Wi-Fi Module Initialization:** The process starts with the initialization of the ESP32 microcontroller's Wi-Fi module. If the module fails to initialize, the process loops back to the start; otherwise, it proceeds.
- **Data Collection:** Once the ESP32 Wi-Fi module is initialized, it collects data such as voltage, current, and the state of charge (SOC) from connected sensors.
- **Blynk Connection:** The system checks whether the Blynk platform has started and is successfully connected. If the connection fails, the system keeps retrying until a successful connection is established.
- **Data Transmission:** After a successful connection, the ESP32 microcontroller sends the collected data to the Blynk server using the internet via Wi-Fi.
- **Data Display:** The data is then received by the Blynk mobile application from the Blynk server. It is displayed and updated in real-time on the mobile app, allowing users to monitor system metrics remotely.
- **End:** The process concludes once the data has been successfully displayed on the mobile application.

### 4. RESULT AND DISCUSSION

#### 4.1 Component Details

In the experimental setup of the prototype EV charging station, several key components were integrated to ensure efficient energy management and real-time monitoring. All main components are described in the table 2. Table 2 outlines the core components integrated within the prototype EV charging station and their respective roles, specifications, and system interfaces. The Voltage Sensor plays a pivotal role in continuously monitoring the voltage levels of both the battery and solar panel, feeding analog data to the ESP32 microcontroller, which serves as the central controller. The ESP32 is a dual-core, Wi-Fi-enabled unit with a 12-bit ADC, acting as the brain of the system, interfacing with all sensors and enabling real-time data acquisition and IoT-based monitoring. The INA219 current sensor is employed for precise current and power measurements, interfacing via the I2C protocol to monitor load current and energy flow. To visually display system parameters such as voltage, current, SOC (state of charge), and operational messages, an LCD display (typically 16x2 or 20x4 with an I2C adapter) is connected to the ESP32. A 12V, 6.8Ah lithium-ion battery is used for energy storage, supplying power to the EV load and storing energy from both solar and grid inputs. A MOSFET-based inverter converts the stored 12V DC battery output to 220V AC for AC loads, ensuring compatibility with household appliances. The solar panel, rated at 16V and 5W, acts as the primary renewable energy source, connected via a charge controller. To prevent backflow of current, a 1N5819 diode is placed in series with the panel output. Each component works in unison to achieve an efficient, smart, and real-time EV charging prototype with energy management and IoT integration.

**Table2:** Component Descriptions

Component	Function	Specifications	Interface with System	Measured/Controlled Parameter
<b>Voltage Sensor</b>	Monitors battery & solar panel voltage	Operating range: 0–25V DC	Connected to analog input of ESP32	Battery voltage, Panel voltage
<b>ESP32 Microcontroller</b>	Central controller with IoT connectivity	Dual-core, 240MHz, Wi-Fi, 12-bit ADC	Interfaces with all sensors and Wi-Fi	System control, Monitoring, IoT

<b>INA219 Current Sensor</b>	Measures DC current across shunt resistor	Imax: $\pm 3.2A$ , Voltage: 0–26V, Resolution: 0.1mA	I2C interface with ESP32	Load current, Power
<b>LCD Display</b>	Displays real-time system data	16x2 or 20x4 LCD (with I2C adapter)	I2C/SPI with ESP32	Voltage, Current, SOC, Status messages
<b>Lithium-ion Battery</b>	Energy storage and EV load source	12V, 6.8Ah	Charged via solar/grid, Discharges to load	SOC, Charge/Discharge cycles
<b>MOSFET Inverter</b>	Converts DC from battery to usable AC	Output: 220V AC, Input: 12V DC, MOSFET based	Connected between battery and AC load	Output voltage, Efficiency
<b>Solar Panel</b>	Primary energy source via solar irradiance	16V, 5W, Poly/Mono-crystalline	Connected to charge controller/input side	Output voltage, Current, Power generation
<b>Diode</b>	Prevents reverse current flow	1N5819 or equivalent, Forward drop: $\sim 0.6V$	Series with solar panel output	Directional current control

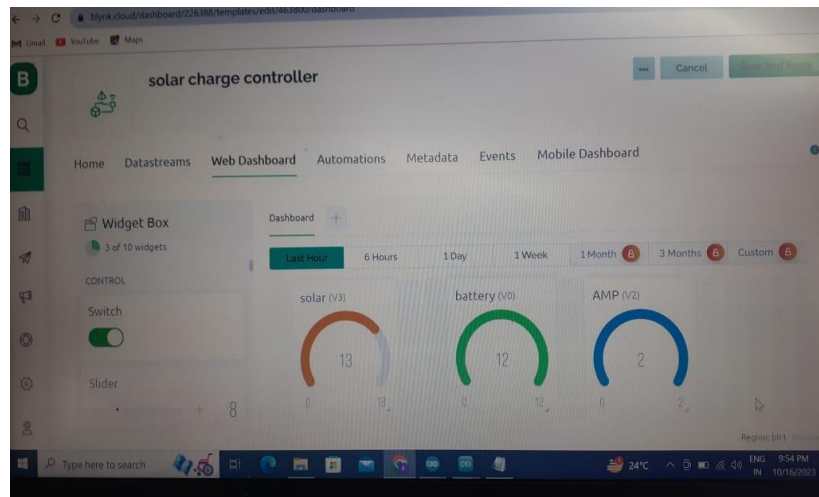
#### 4.2 Experimental observation

The prototype of the solar-powered EV charging station was successfully built and tested under real-time conditions. Figure 7 shows the complete hardware setup, which includes the solar panel, charge controller, lithium-ion battery, and IoT module for data monitoring. The solar panel is connected to the system through a charge controller, which manages the power flow between the solar panel and the battery. The setup demonstrated the seamless charging of the EV battery using solar energy, with provisions for grid power to act as a secondary source during low sunlight conditions. The system's compact design allows for efficient space usage, making it feasible for small-scale implementation in urban areas.



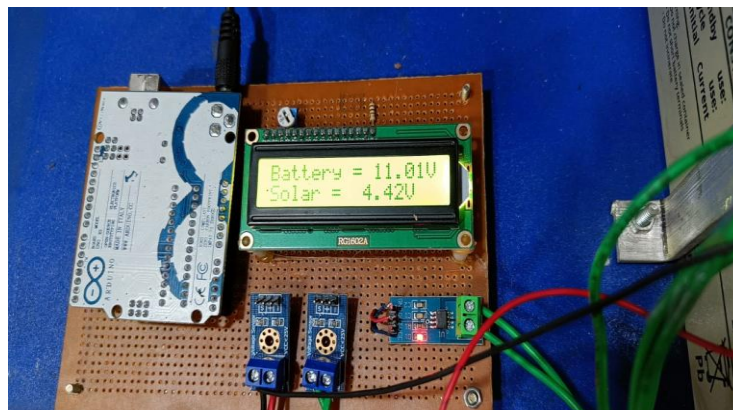
Fig.7: Hardware model for the developed battery monitoring system

Figure 8 illustrates the web-based dashboard for monitoring the charging process in real-time via IoT integration. The dashboard displays essential parameters such as solar power input, battery voltage, and current. In this particular test, the solar input was recorded at 13V, while the battery voltage was measured at 12V, indicating effective charging. The current flow through the system was 2A, confirming the system's ability to handle power distribution efficiently. The dashboard also includes additional features such as time-based analysis, where users can monitor the energy flow over different periods, from hourly to monthly data, enabling long-term performance tracking.



**Fig.8:** System information displayed by mobile application (Blynk Soft-ware)

The prototype model of the small EV charging station demonstrated effective integration of both solar and grid power to charge an EV battery. The system was tested under various conditions, and it successfully switched between solar power and grid power depending on solar availability as shown in figure 9. During periods of adequate sunlight, the solar panel efficiently charged the EV battery, and when sunlight was insufficient, such as during cloudy weather or nighttime, the system automatically transitioned to grid power. This ensured continuous charging without any interruptions, showcasing the reliability of the system in managing energy sources.



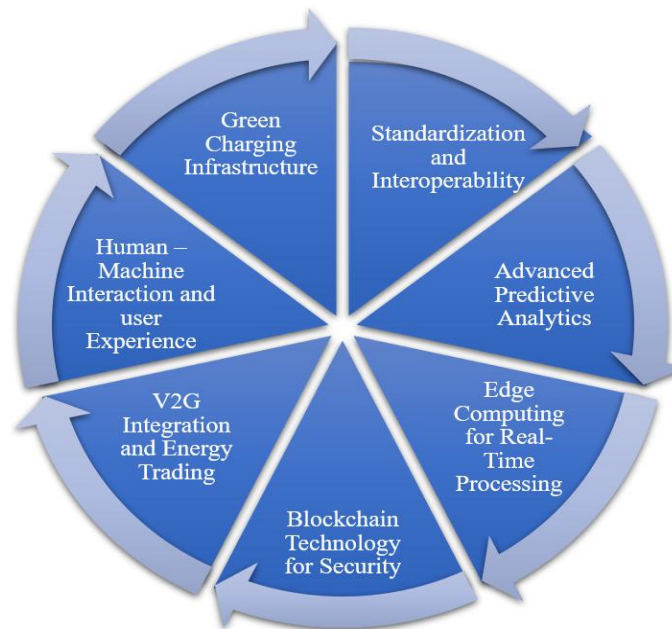
**Fig.9:** Display unit

The IoT-based monitoring system proved to be a valuable feature, offering an intuitive and user-friendly interface that allows users to manage the charging station remotely. It provides real-time alerts, performance metrics, and control options, making the system highly adaptable to user needs. The successful integration of renewable energy with smart monitoring tools confirms the system's potential for practical deployment in real-world applications,

particularly for small-scale EV charging stations. These results validate not only the technical feasibility but also the scalability of the design for broader usage in sustainable energy solutions.

### 5. FUTURE DIRECTIONS

The future scope of this paper encompasses several key areas ripe for advancement in the field of IoT-enabled EV charging management and Battery Monitoring Systems. These include the integration of more advanced sensor technologies to enhance battery monitoring capabilities, further integration with smart grid systems for optimized energy distribution, and the development of predictive maintenance techniques through advanced data analytics. Additionally, efforts towards standardization and interoperability, alongside the development of supportive policy and regulatory frameworks, are essential for the widespread adoption of IoT-enabled infrastructure. Furthermore, exploring user-centric solutions to optimize charging schedules and enhance user experience represents a promising avenue for future research and development. Overall, these areas of focus present significant opportunities for advancing the efficiency, reliability, and sustainability of EV infrastructure in the IoT era as shown in figure10.



**Fig.10:** Key Directions outline potential areas for future research and developments

### 5 CONCLUSION

The successful development and real-time testing of the solar and grid-integrated EV charging station prototype underscore its practical viability for future smart energy systems. The system demonstrated automatic switching between solar and grid sources, ensuring uninterrupted charging while optimizing renewable energy use. Integration with the ESP32 and Blynk IoT platform enabled remote, real-time monitoring of critical parameters, improving transparency, user engagement, and system diagnostics. The literature review presented in this work highlighted that many existing solutions lack practical hardware implementation, solar integration, or mobile app connectivity gaps this study directly addressed. This compact and cost-effective solution validates sensor-based monitoring, mobile interfacing, and dual-source power integration in a physical setup. Looking ahead, future advancements may include predictive maintenance algorithms, interoperability with smart grid infrastructures, advanced data analytics, and dynamic pricing models. Such improvements would enhance operational intelligence and support the broader adoption of sustainable and decentralized EV charging infrastructures, especially in energy-constrained or rural settings.

**Conflict of Interest**

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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