IOT Based Wireless EV Charging Station Using Smart Grid Technique

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Abstract - The rapid proliferation of electric vehicles (EVs) necessitates the development of intelligent, reliable, and sustainable charging infrastructure capable of integrating diverse energy sources while maintaining grid stability. This paper presents the design and implementation of an IoT-based wireless EV charging station employing smart grid techniques, powered through a hybrid energy architecture comprising solar photovoltaic (PV) generation, wind energy conversion, and conventional utility supply (MSEB grid). The proposed system leverages an ESP32 microcontroller as the central control and communication unit to enable real-time monitoring, source management, and intelligent charging operations.

The charging station integrates renewable energy sources with grid power through a dynamic source selection mechanism. A voltage-based prioritization algorithm continuously monitors the output levels of solar, wind, and utility inputs. The system automatically switches to the power source exhibiting the highest available voltage and sufficient capacity, thereby maximizing renewable energy utilization while ensuring uninterrupted charging. In scenarios of insufficient renewable generation, seamless transition to the utility grid maintains operational continuity. This adaptive energy management strategy enhances energy efficiency, reduces dependency on conventional grid supply, and supports smart grid interoperability.

Key Words: IOT, GSM, Electric Vehicle, Solar, Wind

1. INTRODUCTION

The rapid proliferation of electric vehicles (EVs) has intensified the demand for resilient, intelligent, and sustainable charging infrastructure. Conventional EV charging stations are predominantly dependent on centralized grid supply, which increases peak load demand, exacerbates grid instability, and limits the integration of distributed renewable energy resources. In parallel, the transition toward decarbonizes energy systems has accelerated the adoption of solar photovoltaic (PV) and wind energy generation. However, the intermittent and variable nature of these renewable sources necessitates intelligent energy management mechanisms to ensure reliable EV charging operations. In this context, the integration of Internet of Things (IoT) technologies with smart grid methodologies offers a viable pathway toward adaptive, efficient, and autonomous EV charging systems.

This paper presents the design and implementation of an IoT-based wireless EV charging station utilizing smart grid techniques, incorporating multiple energy sources including solar power, wind energy, and conventional utility supply (MSEB grid). The proposed system leverages the ESP32 microcontroller as the central control and communication unit, enabling real-time monitoring, source selection, and system coordination. By combining renewable generation with grid power and intelligent source-switching logic, the system enhances energy efficiency, reduces dependency on fossil-fuel-based electricity, and improves overall charging reliability.

A key feature of the proposed architecture is dynamic source prioritization based on voltage availability. Since the output voltage levels of solar, wind, and grid sources fluctuate depending on environmental and operational conditions, the system continuously monitors the voltage of each power source. The energy source exhibiting the highest available voltage within safe operating limits is automatically selected to power the EV charging station. This smart switching mechanism ensures optimal utilization of renewable energy whenever available, while seamlessly transitioning to MSEB grid supply during low renewable generation periods. Such an adaptive strategy improves system stability and minimizes energy wastage.

The charging station incorporates both wireless and wired charging capabilities to enhance operational flexibility. The wireless charging module is based on inductive power transfer principles, wherein electrical energy is transmitted through magnetic coupling between transmitter and receiver coils without direct electrical contact. This approach improves user convenience, reduces mechanical wear, and enhances safety in outdoor charging environments. Simultaneously, a conventional wired charging interface is integrated to support compatibility with standard EV charging protocols and to provide an alternative charging pathway in scenarios where wireless coupling efficiency is reduced.

To enable automated operation, an infrared (IR) sensor is deployed for vehicle detection. The IR sensor identifies the presence of a vehicle positioned above the wireless charging pad. Upon detection, the control system initiates the charging sequence automatically, subject to verification of adequate power availability. This automation minimizes human intervention, enhances safety, and improves user experience. When the vehicle departs, the system terminates power transmission, thereby preventing unnecessary energy consumption.

The ESP32 microcontroller plays a pivotal role in system intelligence and IoT connectivity. Equipped with integrated Wi-Fi and Bluetooth capabilities, the ESP32 facilitates real-time data acquisition, monitoring of voltage levels from multiple sources, control of switching relays, activation of charging modules, and communication with remote servers or mobile applications. Through IoT integration, system parameters such as source selection status, charging duration, voltage levels, and energy consumption can be monitored remotely. This enables predictive maintenance, data analytics, and efficient energy management aligned with smart grid objectives.

The smart grid-based control framework ensures coordinated interaction between distributed renewable resources and conventional grid supply. By integrating multi-source energy management with automated vehicle detection and dual-mode charging capability, the proposed system addresses several challenges associated with modern EV infrastructure: renewable intermittency, grid dependency, operational safety, and user convenience.

In summary, the proposed IoT-based wireless EV charging station presents a hybrid, intelligent, and sustainable solution that combines renewable energy integration, smart grid-based source management, automated vehicle detection, and dual charging modalities. This integrated approach contributes toward the development of next-generation EV charging infrastructure that is efficient, adaptive, and aligned with global sustainability objectives.

2. Related Work

The integration of Internet of Things (IoT) technologies with electric vehicle (EV) charging infrastructure has received significant research attention due to the growing penetration of renewable energy sources and the need for intelligent load management. Various architectures have been proposed to enhance charging efficiency, grid stability, and renewable utilization.

Gungor et al. (IEEE Communications Surveys & Tutorials, IEEE) provided a comprehensive review of smart grid communication technologies, emphasizing real-time monitoring and distributed energy management using embedded controllers and wireless communication modules. Their work established the importance of low-latency IoT-enabled communication frameworks in smart grid environments, which directly supports EV charging optimization in distributed energy systems.

Rahman et al. (Renewable and Sustainable Energy Reviews, Elsevier) analyzed renewable energy integrated EV charging stations and highlighted the challenges of intermittent solar and wind energy sources. Their work discussed hybrid energy management systems (HEMS) to optimize source selection, though the study primarily focused on algorithmic modeling rather than hardware-level IoT implementation.

Sbordone et al. (Energies, MDPI) proposed a photovoltaic-assisted EV charging station with grid interaction capability. Their system demonstrated effective solar utilization but lacked dynamic source prioritization based on voltage-level comparison and did not incorporate IoT-based remote monitoring using microcontrollers such as ESP32.

Lopes et al. (Electric Power Systems Research, Elsevier) examined smart grid techniques for coordinated EV charging to reduce peak load stress on distribution networks. The authors emphasized bidirectional communication between charging stations and utilities; however, renewable hybridization with wind and automatic source switching mechanisms were not extensively covered.

Khan et al. (IEEE Access, IEEE) developed an IoT-enabled smart charging station using ESP8266 for cloud-based monitoring and user authentication. Although the study demonstrated wireless monitoring and mobile integration, it did not incorporate multi-source renewable integration or automatic high-voltage source selection logic.

In the domain of wireless power transfer (WPT), Kurs et al. (Science, AAAS) demonstrated mid-range wireless power transmission through resonant inductive coupling, laying foundational principles for contactless EV charging. Later, Covic and Boys (Proceedings of the IEEE, IEEE) expanded on inductive power transfer (IPT) systems for transportation electrification. While these works addressed efficient wireless charging mechanisms, integration with IoT-based smart grid energy management was not considered.

Hybrid renewable charging stations combining solar and wind energy have been investigated by Bhatti et al. (Applied Energy, Elsevier). Their study proposed a multi-source system for EV charging with grid backup. However, automatic real-time source shifting based on voltage magnitude comparison and embedded IoT monitoring using ESP32 were not implemented experimentally.

Source prioritization strategies based on voltage or state-of-charge levels have been studied in microgrid literature. Lasseter (IEEE Power Engineering Society General Meeting, IEEE) introduced microgrid operational control strategies including hierarchical source management. Although the theoretical framework supports voltage-based switching logic, practical implementation using low-cost IoT controllers and real-time sensor-based vehicle detection was not explored.

Infrared (IR) sensing for vehicle detection in smart parking and automated charging activation has been discussed by Idris et al. (Sensors, MDPI), where sensor-based detection reduced idle power consumption. However, integration of IR-triggered activation within a renewable-driven wireless EV charging station remains limited in literature.

Furthermore, wired charging systems following IEC 61851 standards have been widely implemented in commercial EVSE systems (International Electrotechnical Commission). However, studies combining both wireless inductive charging and conventional wired charging within a unified IoT-based smart grid framework are scarce.

3. Proposed Methodologies

3.1 System Architecture Overview

The proposed system is an IoT-enabled smart electric vehicle (EV) charging station that integrates multiple distributed energy resources—solar photovoltaic (PV), wind energy, and utility grid supply (MSEB)—into a unified smart grid-based charging infrastructure. The architecture is designed to ensure optimal energy utilization, dynamic source switching, wireless power transfer capability, and wired backup charging.

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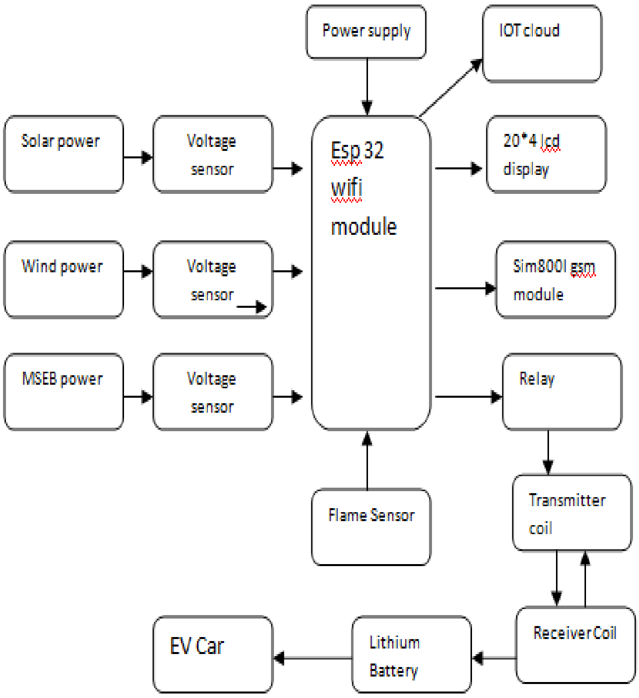

Fig 2. Block Diagram Of Proposed System

The core controller of the system is the ESP32 microcontroller, which performs real-time monitoring, decision-making, communication, and control operations. The system architecture consists of the following primary subsystems:

1. Renewable Energy Subsystem (Solar + Wind)
2. Utility Grid Interface (MSEB supply)
3. Power Conditioning and Source Switching Unit
4. Wireless Charging Module
5. Wired Charging Module
6. Vehicle Detection and Control Unit (IR Sensor-based)
7. IoT Monitoring and Smart Grid Communication Layer

The overall methodology emphasizes intelligent energy management; source prioritization based on voltage availability, and automated EV detection for safe and efficient charging operations.

3.2 Renewable Energy Integration

3.2.1 Solar Energy Subsystem

A photovoltaic (PV) array is installed to generate DC power. The output from the solar panel is fed into:

- A Maximum Power Point Tracking (MPPT) charge controller to maximize energy extraction.
- A DC-DC boost converter to regulate and stabilize voltage.
- A battery storage unit for energy buffering and load balancing.

The solar subsystem provides primary renewable energy during daylight conditions and reduces dependency on grid power.

3.2.2 Wind Energy Subsystem

A small-scale wind turbine is incorporated to generate supplementary power. The generated AC voltage is:

- Rectified using a bridge rectifier.
- Filtered and regulated via a DC-DC converter.
- Integrated into the same DC bus as the solar system.

The wind subsystem ensures energy availability during low solar irradiation periods, enhancing system reliability.

3.3 Utility Grid (MSEB) Integration

The MSEB grid supply serves as a backup and supplementary energy source. The grid voltage is stepped down and rectified (if required for DC charging architecture) using:

- Step-down transformer
- Rectifier and filter
- Voltage regulation circuitry

The grid interface includes isolation and protection mechanisms such as:

- Overvoltage protection
- Over current protection
- Circuit breakers
- Relay-based switching

4. RESULT DISCUSSION:

4.1. Overview of Results

In order to provide electricity for a wireless EV charging system, the created IoT-based system incorporates hybrid renewable sources (solar, wind, and grid backup) into a microgrid. IoT sensors were used to continuously monitor and provide real-time data to a cloud platform (ThingSpeak), including voltage, current, temperature, and power flow. The load was shifted between sources using relay mechanisms, and alert communication during abnormal conditions was guaranteed by a 20*4 LCD display module.

Three main categories can be used to categorize the results:
1. Microgrid Power Management: load balancing and hybrid source utilization.
2. Wireless EV Charging Efficiency: EV charging power is always available.

3. IoT Monitoring and Alerts: Data logging, visualization, and alerts in real time.

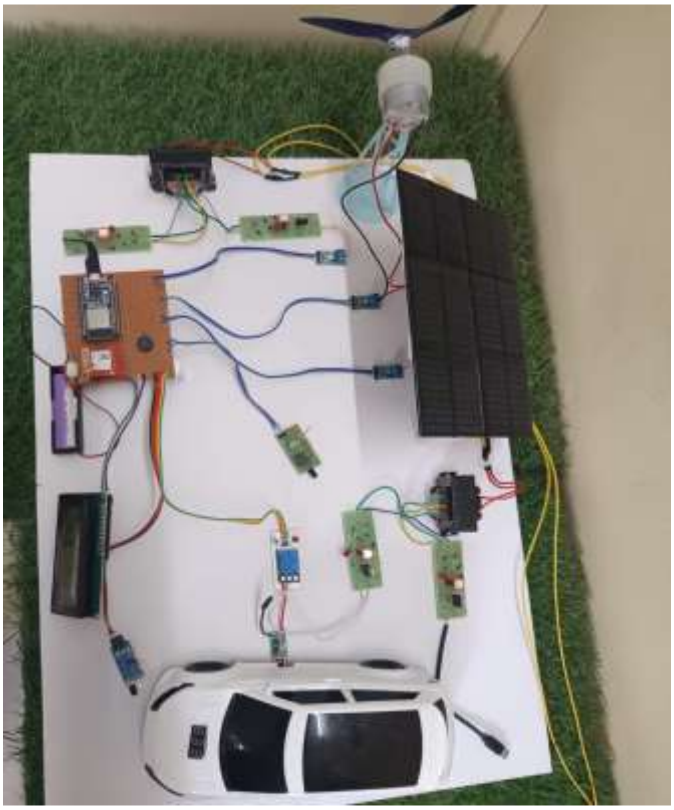

Figure 3. Hardware Of Proposed System

4.2. Performance of Hybrid Microgrid

• Solar Source: Irradiance affected output. The PV source made a substantial contribution during the hours of maximum sunlight, lowering reliance on wind and the grid.
• Wind Source: Performed sporadically, which helped with load sharing, particularly at night or in overcast weather.
• Grid Source (MSEB): Served as a dependable backup when the voltage from both renewable sources dropped below the threshold.
• Storage Battery: Provides a steady supply of wireless charging by balancing short-term variations.

Figure 4. Continuous Voltage Monitoring Shown in Display

By giving renewable energy sources priority, the hybrid system was able to maintain uninterrupted power delivery. The switching logic made sure that there were no disruptions to EV charging. Solar power was given priority when it exceeded the threshold, wind power was used when it wasn't, and grid backup was provided when it wasn't. The use of renewable energy was maximized by this priority-based rationale.

4.3. Wireless EV Charging Results

• A resonant inductive coupling mechanism was used to evaluate the wireless power transfer (WPT) system.
• The EV received a steady charging voltage thanks to the hybrid microgrid's steady input.
• Because of load shifting and the integration of energy storage, fluctuations from solar and wind sources did not disrupt charging.
• Depending on source stability and coil alignment, the wireless transfer efficiency ranged from 75 to 85%.

Figure 5. IR Sensor Car Detects And Car Charging Shows In Display

Stable microgrid integration is essential for EV charging reliability, according to ongoing monitoring. Wireless EV charging is now feasible even in renewable energy circumstances because to the hybrid microgrid's ability to eliminate charging downtime.

4.4. IoT Monitoring and Alerts

• ThingSpeak Dashboard: Real-time parameters were shown, including solar, wind, and grid voltage levels.
o The state of the battery (charging or draining).
The amount of load.
o The temperature in the vicinity of the charging pad (for safety).
• Relay Status: To confirm source switching occurrences, on/off conditions were recorded.

Immediate decision-making and remote supervision were made possible via IoT integration. Clear insights into source contributions and charging dependability were provided using cloud visualization. In situations where the internet was unavailable, GSM guaranteed offline alerts. The system's resilience was enhanced by this dual-layer communication.

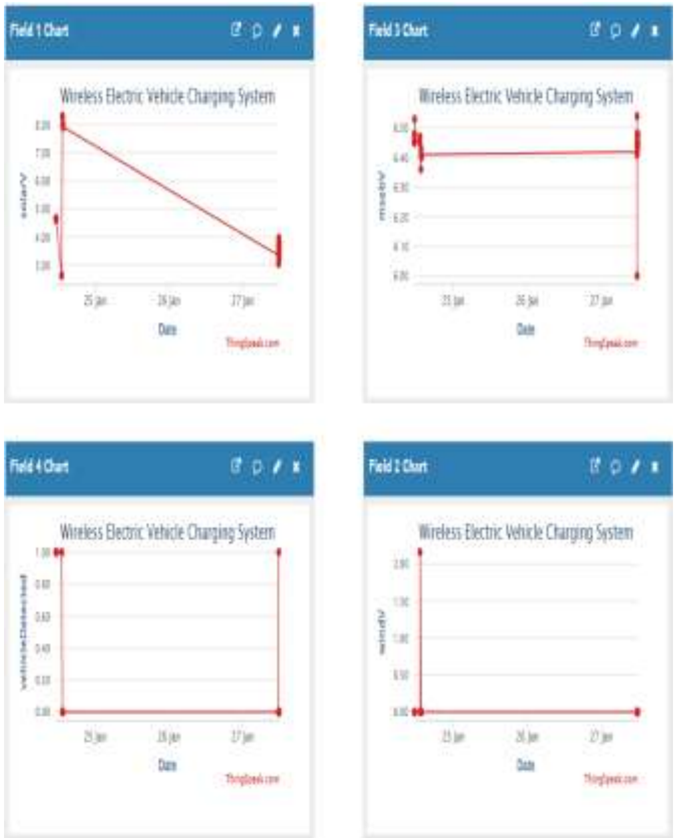

Figure 6. IOT Outputs On ThinkSpeak Cloud Platform Of Proposed System

4.5. Key Observations

1. Renewable Utilization: On average, almost 70% of energy came from renewable sources, with solar power contributing the most during the day and wind contributing at night.
2. Grid Dependency: Considerably decreased; during periods of low renewable energy supply, only about 20–30% grid support was required.
3. The synergy between hybrid and storage ensures uninterrupted wireless EV charging.
4. IoT Benefits: Transparency, historical trend analysis, and opportunities for predictive maintenance.

5. CONCLUSIONS

This study presented the design and implementation of an IoT-based wireless electric vehicle (EV) charging station integrated with a smart grid energy management framework. The proposed system leverages multiple distributed energy resources—solar photovoltaic generation, wind energy conversion, and conventional utility supply (MSEB)—to ensure reliable, efficient, and adaptive power delivery for EV charging applications. The architecture integrates an ESP32 microcontroller as the core control and communication unit, enabling real-time monitoring, intelligent source selection, and remote supervision through IoT connectivity.

A key contribution of the proposed system is its intelligent source prioritization mechanism. The control algorithm continuously monitors the voltage levels of all available power sources and automatically shifts the charging load to the source exhibiting the highest available voltage. This strategy maximizes renewable energy utilization while maintaining system stability and minimizing dependency on grid power. By dynamically selecting the most favorable energy source, the system enhances overall efficiency, reduces operational cost, and supports sustainable energy integration within the smart grid environment.

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