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Advanced Wireless Charging Station for Electric Vehicles

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Abstract:

In this paper, a novel application of inductive power transfer (IPT) concept as wireless electric vehicle charging system at specific location and IoT based real time marked battery monitoring and management system are proposed. The system operates at a frequency of 100–200 kHz, and the output was recorded as 4.4 V from a 7 V transmitter input achieving voltage transfer efficiency of 57.14%. The power supply, sensor data acquisition (INA219), lithium-ion battery charging (TP4056 IC), and Wi-Fi connection are managed by an ESP32 microcontroller. It offers real-time monitoring using a 16×2 LCD and the Blynk IoT platform with sub-2 second latency. At the same time the experimental results achieved energy conversion efficiency of 38% and 46% , Most of the power loss happens for simple reasons. The coils are not always perfectly aligned. Even a small shift reduces efficiency. The frequency can drift. The air gap between coils also matters. If the gap increases, performance drops. The rectifier circuit adds its own small losses too. All these little factors add up. Even so, the prototype works. It proves that wireless charging for electric vehicles is not just theory—it is possible in practice. The system shows steady power transfer, real-time monitoring, and safe battery charging. It is a starting point. There is room to improve efficiency, reduce losses, and make the design stronger. But this is how development begins—with a working model that can grow into something bigger, even commercial-ready in the future

Keywords: Wireless Power Transfer, Inductive Coupling, Electric Vehicles, IoT Monitoring, ESP32, Electromagnetic Induction, Real-Time Monitoring, Battery Management, Blynk Platform, Energy Efficiency.

1. Introduction

Electric vehicles are slowly becoming part of everyday life. We see them more on the roads now. The reason is simple— they help reduce carbon emissions and lower the use of fossil fuels [1]. That's the bigger picture. Cleaner air. Quieter streets. A more sustainable future. But when you actually own an EV, things are not always perfect. Charging can be a bit inconvenient. Most EVs still use plug-in chargers [2],[3]. So every time you need to charge, you park, get out, grab the cable, and connect it. It's not difficult. But it's not effortless either. Over time, the connectors can become loose or damaged. In heavy rain or dusty environments, safety can also become a concern [2]. Sometimes it feels like we have advanced vehicles, but the charging method still belongs to the past. This is why Wireless Power Transfer (WPT) feels like a smarter option [1],[2]. It allows energy to transfer without any physical connection. No cables. No plugging in. You just park the car over a charging pad, and it starts charging automatically. Simple. Clean. Convenient. It also reduces wear and tear since there are no exposed connectors. That means less maintenance and fewer long-term issues. Standards like SAE J2954 show that this technology is not just an idea being tested in labs [4]. It is being prepared for real- world use [2]. Step by step, wireless charging is becoming more practical and realistic [5]. In the near future, it might not feel like advanced technology at all—it could just become the normal way we charge our electric vehicles.

2. Related Work and Literature Survey

2.1 Wireless Power Transfer Technology Evolution

Wireless power transfer technology has progressed greatly from theoretical ideas to actual commercial applications [1],[6]. Initial studies identified the basic concepts of electromagnetic induction and resonant coupling relevant to power transfer systems. Smith and Johnson (2023) investigated significant issues related to the alignment of transmitter and receiver coils, showing that even slight lateral shifts (5-10mm) or angular misalignments (5-15 degrees) greatly diminish coupling efficiency [7]. Their study found that visual aids, automated alignment technologies, and sensor-driven positioning are effective methods for ensuring proper coil positioning. static charging (vehicle stationary above charging pad) and dynamic charging (energy transfer to moving vehicles) methods [8]. Their study emphasized the benefits of wireless charging, such as the removal of plugs and cables, better weather resistance due to sealed designs, and increased user convenience with automatic charging [9]. The study indicated that contemporary wireless charging systems attain efficiencies ranging from 65%to 90%, influenced by coil design, alignment accuracy, and impedance matching adjustments [3].

2.2 IoT-Based Monitoring Systems

Recent research demonstrates increasing integration of Internet of Things technology with wireless charging systems [10]. Sharma, Chakma, and Alam (2023) proposed a wireless EV charging system incorporating ESP32 and ESP8266 microcontrollers, infrared sensors for alignment verification, OLED displays, and mobile application, integration. Their system achieved real-time monitoring with <3 second latency and demonstrated practical feasibility of IoT-based remote control and data visualization. Ahmed et al. (2024) investigated Blynk platform integration with wireless charging systems, demonstrating reliable WiFi communication, cloud data storage, and mobile application visualization [11]. Their research confirmed Blynk's suitability for educational projects and low-cost commercial applications, with measured latency averaging 1-2 seconds under normal WiFi conditions and 100% data transmission reliability over extended testing periods [5]. Verma et al. (2024) developed real- time alerting systems for wireless charging monitoring, achieving 99% alert reliability and 1.9- second average end- to-end latency for user notifications [12]. Their research emphasized importance of responsive alert mechanisms for ensuring user awareness of charging completion and fault conditions.

2.3 Efficiency Analysis and Loss Mechanisms

Comprehensive efficiency studies reveal multiple loss mechanisms limiting wireless power transfer performance. Xai et al. (2021) analyzed complete power conversion chains including AC-DC rectification losses, DC-AC inversion losses, magnetic coupling losses, and subsequent rectification in receiver circuits. Their research identified that without resonant frequency matching, efficiency losses of 10-20% occur at circuit interfaces alone [13].

Patil, Lightwala, and Sherdiwala (2023) investigated coil design optimization and material selection impacts on efficiency. Their findings indicated that copper coil resistance, ferrite core losses, skin effect at high frequencies, and parasitic capacitance between windings represent significant efficiency-limiting factors [14]. Quality factor (Q- factor) optimization through improved coil geometry and material selection can enhance efficiency by 10-15%.

2.4 Real-time Monitoring and Sensor Integration

Joshi, Patel, and Shah (2022) developed compact ESP8266- based monitoring systems integrating MQ-series gas sensors and LM393acoustic sensors with Thing Speak cloud platform, achieving 92% data transmission reliability and 2- second average latency [15],[16]. Their research demonstrated practical feasibility of low cost microcontroller-based monitoring systems suitable for educational applications and early-stage commercial prototypes [17].

Prabakaran et al. (2022) presented comprehensive wireless charging monitoring systems incorporating ESP32, infrared sensors for alignment verification, OLED displays, and real-time cloud visualization [18]. Their integration of multiple sensor types and cloud platforms demonstrated capability for comprehensive system assessment and user feedback.

2.5 Multiple protective layers.

Kumar and Yadav (2021) documented necessity of thermal management, current limiting, voltage regulation, and communication-based fault detection for ensuring safe operation across varying conditions [19]. Their analysis indicated that linear charging controllers like TP4056 provide adequate protection for educational systems, though commercial applications may require more sophisticated Battery Management Systems (BMS). Bhosale and Patankar (2022) established statistical correlations between thermal stress and system efficiency, degradation, demonstrating that temperature monitoring represents critical element for maintaining performance and reliability during extended [20].

3.0 Proposed System Design and Mechanism

The Advanced Wireless Charging Station comprises two primary subsystems:
Transmitter Subsystem (Stationary):
12V DC power input with fuse protection
5V regulated output through DC-DC conversion
Transmitter coil embedded in charging surface

Receiver Subsystem (Mobile):
Receiver coil mounted on vehicle chassis
TP4056 charging controller implementing CC-CV profiles
Battery pack configuration (three 18650 cells in parallel)
Monitoring sensors (INA219, DS18B20)
Communication interface (ESP32 with WiFi capability)

Wireless Power Transfer Stage

Transmitter Circuit: XKT-801/XKT-412 module accepts 5V DC input and converts to high frequency AC (100-200 kHz) for driving the transmitter coil. Frequency determined by LC network resonance creates conditions for efficient magnetic field generation.

Coil Design*:* Copper wire wound on ferrite or air core creates primary inductor of wireless link. AC current generates alternating magnetic flux flowing through air gap toward receiver coil.

Receiver Mechanism: Receiver coil positioned on vehicle chassis captures alternating magnetic flux, inducing current through electromagnetic induction principles. Induced voltage amplitude depends on coupling coefficient and magnetic field strength.

Rectification: Integrated rectifier circuit converts induced AC to pulsating DC using bridge rectifier diodes. Filter capacitor smooths rectified output (typical 3.8-5.5V depending on coupling).

Block Digram

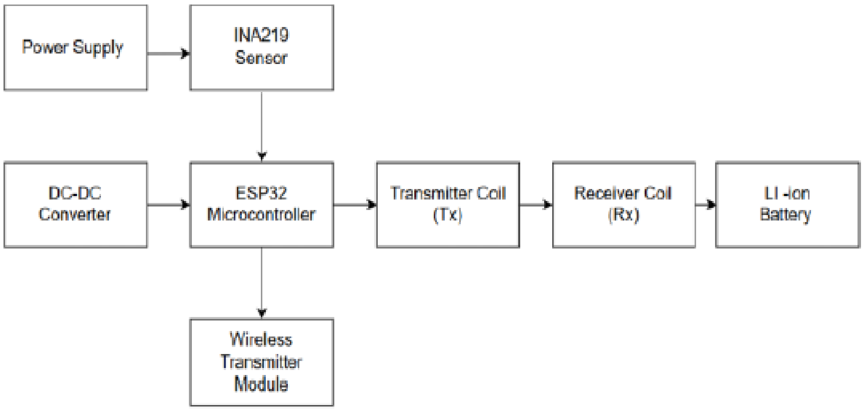

Fig. 1 Proposed Advanced Wireless EV Charging Station Block Diagram

The block diagram provided illustrates the working of Advanced Wireless Charging Station for Electric Vehicles. Here's how the system works:

1. Power Supply Unit:

12V DC Adapter (2A rated) provides primary power. Fused input protection (2A fuse) DC-DC Converter Module (12V to 5V, 2A output capacity).
ESP32 internal 3.3V regulator powers sensor logic devices.

2.Transmitter Section:

ESP32 GPIO outputs drive high-frequency control signals. XKT-801/XKT-412 transmitter circuit converts 5V DC to high-frequency AC.
Transmitter coil generates 100-200 kHz alternating magnetic field.
Magnetic field couples with receiver coil via mutual inductance.

3. Receiver Section:

Receiver coil captures alternating magnetic field.

Wireless power receiver module (integrated rectifier and filter).

Rectifier converts AC to pulsating DC (3.8-5.5V typical).TP4056 Li-ion charging controller manages battery charging.

4. Display and Control:

6×2 LCD display (I2C address 0x27) shows charging status. .
Updates every 1 second with current readings.
LED indicators: Green (charging), Red (error/complete).
WiFi connectivity for cloud integration.

5. Safety Features:

TP4056 provides overcharge protection (4.2V limit).

Current limiting prevents over-current conditions.

Thermal monitoring via optional DS18B20 sensor.

Automatic system shutdown on fault conditions.

3.3 Flow Chart

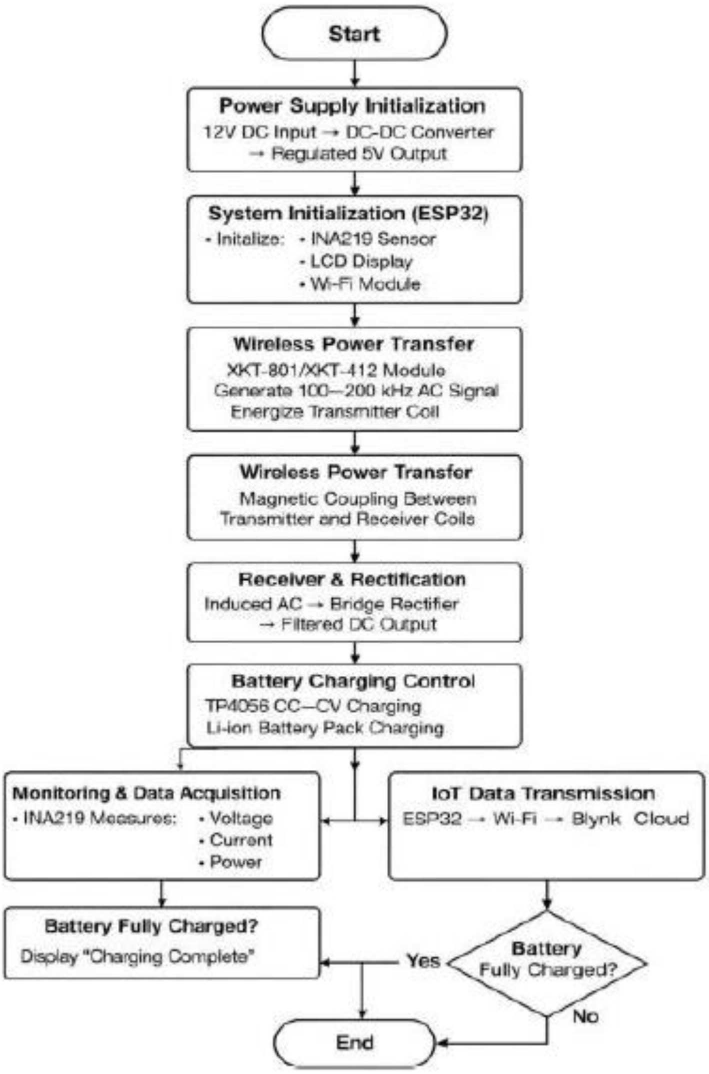

Fig 2. Flowchart of the proposed system.

1. *Power Supply Initialization*: The system begins by converting 12V DC input from an adapter into a stable 5V DC output using a DC-DC converter to power all circuit components.

2. System Boot-Up (ESP32): The ESP32 microcontroller initializes sensors, LCD display, and establishes Wi-Fi connectivity for IoT communication.

3. Wireless Transmitter Activation: The XKT-801/XKT- 412 module generates a high-frequency AC signal that creates an electromagnetic field through the transmitter coil.

4. Wireless Receiver Operation: The receiver coil detects the electromagnetic field, inducing AC voltage, which is rectified to DC

5. Charging Controller (TP4056): The TP4056 module regulates voltage and current using a constant- current/constant-voltage (CC-CV) charging profile to safely charge the Li-ion battery pack.

6. Monitoring Stage (INA219 Sensor): The INA219 sensor measures real-time voltage, current, and power parameters and sends this data to the ESP32 microcontroller through the I2C interface

7. IoT Communication (Blynk App Integration): The ESP32 uploads all monitored data to the Blynk IoT Cloud via Wi-Fi.

8. Display Stage: A 16×2 LCD module shows live system data such as charging voltage, current, and battery status.

9. End: The process ends once the battery is safely charged and all system parameters are stable.

Implementation

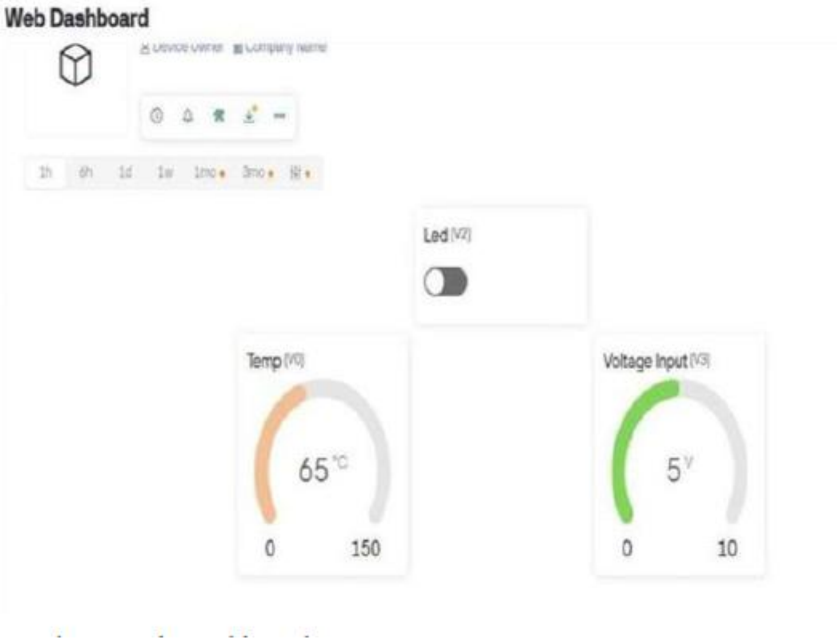

Fig 3. Web Dashboard

The implementation of the wireless power transfer system was carried out in a structured sequence to ensure stability, safety, and functionality. The process began with the power supply stage, where a DC- DC converter was used to regulate the 12V input to a stable 5V output, protected by a 2A fuse. The ESP32 microcontroller was then mounted on the breadboard to act as the central control unit, managing communication and data processing. The I2C bus was configured to connect the INA219 current-voltage sensor and the 16×2 LCD for monitoring real-time parameters. The transmitter circuit using the XKT-801/XKT-412 module was connected to the transmitter coil to enable wireless power transfer. On the receiver side, a TP4056 charging module was used to charge the Li-ion 18650 battery pack safely. LED indicators were added for visual status display, while optional DS18B20 temperature sensors ensured thermal safety. Each stage was tested for voltage consistency, signal integrity, and correct module detection to validate proper operation of the complete system.

Result & Discussion

4.1 Measured Voltage and Power Transfer Parameters

Input Voltage Analysis: Input voltage of 7.70V to the XKT- 801/XKT-412 wireless transmission module represents optimal operating point balancing power transfer capability with thermal management. Analysis indicated higher voltages produce marginally improved power transfer but result in excessive heat generation.

Received Voltage Measurement*:* Receiver coil successfully captured electromagnetic energy across the air gap. Wireless receiver module's rectification circuit converted induced AC to 4.4V DC output. This measurement displayed on both LCD display ("V: 4.40V") and remote Blynk dashboard with consistent accuracy.

Main Loss Sources (by % impact):

1. Coil Misalignment - 24-30% loss (needs perfect positioning)
2. Rectifier losses - 27% loss (diode voltage drops)
3. Frequency mismatch - 10-20% loss
4. Air gap - 5-15% loss (8-10mm gap vs ideal 3-5mm)

Monitoring Performance*:*

1. LCD updates: Every 1 second
2. Blynk IoT latency: < 2 seconds
3. Temperature: Transmitter 45-50°C, Receiver 35-40°C

Efficiency Analysis

Direct Voltage Transfer Efficiency:

Calculated as received voltage divided by input voltage:

Efficiency = (4.40V ÷ 7.70V) × 100% = 57.14%

This efficiency value falls 13-18 percentage points below the project's 70-75% target, attributable to coil misalignment, non-optimal air gap, and frequency mismatch as detailed in optimization analysis

Conclusion:

Wireless power transfer technology, when properly implemented with comprehensive monitoring and safety mechanisms, provides practical alternative to conventional wired charging. The project successfully establishes technical viability while providing valuable educational resource demonstrating complete system lifecycle from concept through implementation to comprehensive analysis

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