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Design And Simulation Of A Smart Automatic Ev Charging System Using Iot

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Abstract—The global transition towards electric mobility has created an urgent need for intelligent and efficient electric vehicle (EV) charging infrastructure. Conventional charging systems lack automation, remote monitoring capabilities, and the ability to interact with the power grid, leading to potential grid strain and inefficient energy consumption. This paper presents the design and simulation of a smart, automatic EV charging system leveraging the Internet of Things (IoT). The proposed system utilizes a NodeMCU (ESP8266) microcontroller as its core, integrated with voltage and current sensors to monitor the battery's state of charge (SoC). A relay module is employed to automatically control the charging process, preventing overcharging and enhancing battery longevity. The system communicates with an IoT cloud platform via the MQTT protocol, enabling users to remotely monitor real-time charging parameters and control the charging operation through a web-based dashboard. The complete system architecture, hardware, software logic, and simulation approach are detailed, demonstrating a cost-effective, reliable, and user-friendly solution for modern EV charging.

Keywords—Electric Vehicles (EVs), Internet of Things (IoT), Smart Charging, Energy Management System (EMS), NodeMCU, MQTT.

I. INTRODUCTION

The global push towards decarbonization has spurred the rapid adoption of electric vehicles (EVs), with projections showing significant growth in the coming decade [1]. This transition, however, presents substantial challenges to existing power grids. Conventional EV chargers lack the intelligence for efficient energy management, often leading to grid strain from uncoordinated charging and potential battery damage from overcharging [2]. This creates a critical need for smarter charging solutions.

In contrast, smart charging systems, enabled by the Internet of Things (IoT), offer a solution by providing real-time monitoring, remote control, and automated operation [3]. By connecting charging hardware to the internet, these systems can optimize energy consumption based on battery status, user preferences, and even grid conditions. This not only improves user convenience and battery health but also allows EVs to function as flexible loads, supporting overall grid stability.

This paper presents the design and simulation of a low-cost, IoT-based smart EV charging system to address these limitations. The proposed system focuses on automation, user accessibility, and safety, utilizing a NodeMCU microcontroller for its core logic and connectivity. The goal is to provide a practical and accessible solution that automates the charging cycle while empowering users with remote oversight and control.

II. LITERATURE REVIEW

The application of IoT in EV charging has been explored in several studies. Sharma et al. [4] demonstrated an IoT-based monitoring system using a Raspberry Pi, but it lacked automatic control functionalities and remote user intervention. Similarly, Singh et al. [5] developed a system with a fuzzy logic controller for optimizing charging speed, yet it did not feature a comprehensive remote control interface for the user. These systems provided monitoring but lacked complete automation and user interactivity.

More complex, grid-integrated solutions like that of Hannan et al. [6] focus on large-scale building energy management, using advanced algorithms to coordinate EV charging with other loads and renewable sources. While effective, such systems are not easily adaptable for standalone residential use. The importance of security in any connected system was highlighted by Al-Ali et al. [7], who proposed a secure IoT framework to protect against data breaches and unauthorized access, a critical aspect for future commercialization.

This review reveals a need for a solution that integrates automatic control, remote monitoring, and user accessibility into a single, low-cost device. The existing literature often focuses on either high-level grid optimization or partial device-level monitoring, leaving a gap for an all-in-one, user-centric smart charger. This paper aims to address this gap.

III. SYSTEM DESIGN AND METHODOLOGY

The proposed system is architected in three layers: hardware (sensing and control), processing (microcontroller firmware), and cloud (IoT platform and user interface). The design prioritizes simplicity, low cost, and functionality.

A. System Architecture

The core of the system is a NodeMCU (ESP8266) microcontroller. It is connected to the EV charging circuit, which consists of an AC-to-DC charger and the EV battery. A relay module is inserted between the charger and the battery to act as an electronically controlled switch. An INA219 voltage and current sensor is placed in series with the charging line to measure the real-time electrical parameters.

The NodeMCU reads data from the INA219 sensor, processes it, and uses its built-in Wi-Fi to communicate with an IoT cloud platform via the MQTT protocol. It publishes the sensor data for user monitoring and subscribes to a command topic to receive instructions (e.g., "START," "STOP") from the user's dashboard. Based on the sensor readings (specifically, the battery voltage reaching a full-charge threshold) or a user command, the NodeMCU controls the relay to start or stop the flow of power to the battery.

B. Hardware Components

1. **NodeMCU (ESP8266):** A low-cost microcontroller with integrated Wi-Fi, ideal for IoT applications due to its connectivity and GPIO availability [8].
2. **INA219 DC Current/Voltage Sensor:** A high-precision I2C sensor module for monitoring the DC charging parameters.
3. **5V Single-Channel Relay Module:** An electromechanical switch used to control the high-power charging circuit with a low-power signal from the NodeMCU.
4. **EV Charger and Battery:** For prototyping, a standard lithium-ion battery pack and a compatible charger are used.
5. **Power Supply:** A 5V DC source to power the control circuitry, keeping it isolated from the charging line.

C. Software Design and Logic

6. **Firmware (Arduino IDE):** The NodeMCU is programmed using C++ in the Arduino IDE. The firmware utilizes libraries for Wi-Fi connectivity, MQTT communication, and sensor interfacing. The main control loop continuously performs several tasks: it reads voltage and current from the sensor, calculates power, estimates the State of Charge (SoC) based on voltage, and publishes this data to the cloud. Concurrently, it listens for incoming commands from the user. The core logic automatically opens the relay (stopping the charge) if the battery voltage surpasses a predefined safety threshold. It also executes user commands to start or stop the charging process manually.
7. **Communication Protocol (MQTT):** MQTT is a lightweight publish-subscribe protocol chosen for its efficiency in IoT environments [9]. It decouples the device from the user application, allowing for scalable and reliable communication. The NodeMCU publishes data to an `ev/data` topic and subscribes to an `ev/control` topic.
8. **IoT Cloud Platform:** A platform such as Blynk or ThingSpeak is used to create a user dashboard. This dashboard is configured with widgets (gauges, charts, buttons) to visualize the data from the `ev/data` topic and publish commands to the `ev/control` topic.

D. Simulation Approach

To validate the design before physical implementation, a Proteus-based simulation is proposed. This involves a virtual NodeMCU model, a variable DC voltage source to emulate the battery's rising voltage during charging, and virtual outputs like an LED to represent the relay's state. The simulation allows for testing the control logic, particularly the automatic voltage threshold cut-off, in a safe and controlled environment without risk to physical hardware [10]. This step is crucial for debugging the firmware and verifying the circuit design.

IV. RESULTS AND DISCUSSION

As this paper focuses on the design and simulation phases, the results are the expected outcomes of a successful implementation. The system is designed to deliver tangible improvements over conventional chargers.

The primary expected outcome is a functional IoT system providing a user-friendly dashboard for real-time data visualization. This dashboard will display key metrics like voltage, current, power, and estimated SoC, along with historical data charts. This empowers the user with complete visibility into the charging process.

The system's core automation feature, the automatic charging cut-off, will be validated in the simulation. When the simulated battery voltage reaches the set threshold, the relay is expected to disengage, stopping the power flow. This feature is crucial for preventing overcharging, which is a leading cause of battery degradation, thus enhancing battery longevity and safety. Remote control functionality via the dashboard buttons will provide users the flexibility to manually manage charging sessions from anywhere.

From an efficiency standpoint, the control system itself consumes negligible power. The main efficiency gain lies in improved battery management, leading to long-term cost savings. Furthermore, the total prototype hardware cost is estimated to be under $20, demonstrating that this smart technology can be highly accessible and cost-effective compared to expensive commercial smart chargers.

V. CONCLUSION AND FUTURE WORK

This paper has presented the design of a smart, automatic EV charging system using IoT. The proposed solution offers a low-cost, effective, and user-centric approach to modern EV charging by integrating real-time monitoring, remote control, and automated safety features. By leveraging a NodeMCU microcontroller and the MQTT protocol, the system successfully addresses the key shortcomings of conventional chargers. The design, ready for simulation and prototyping, provides a practical blueprint for making EV charging safer, more efficient, and more convenient for the end-user.

Future work can extend this platform in several promising directions. Key enhancements include: integrating renewable energy sources like solar PV for greener charging; employing machine learning for predictive charging schedules based on user habits and grid pricing; implementing robust security protocols like TLS/SSL encryption for secure communication [7]; and adapting the control module for various charger types (e.g., Level 2) and for integration into commercial payment systems. Through such advancements, this foundational design can evolve into a comprehensive smart energy management solution.

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