Design Analysis of an IOT-Based Electric Vehicle Battery Charging Control System to Improve Battery Endurance

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Abstract

The rapid development of electric vehicles (EVs) demands more efficient and intelligent battery charging systems to ensure optimal performance and prolonged battery life. This study analyzes the design of a battery charging control system based on the Internet of Things (IoT), aimed at improving the endurance and efficiency of EV batteries. The system integrates IoT technology to monitor real-time charging parameters such as voltage, current, temperature, and state of charge (SoC). By employing a microcontroller and cloud-based data processing, the system is able to optimize charging cycles and prevent overcharging or deep discharging. Experimental simulations demonstrate that the IoT-based control system can enhance battery durability by maintaining stable charging conditions and providing remote access for monitoring and control. The implementation of this smart charging system contributes to the sustainability and reliability of electric vehicle operations.

Keywords: ***Electric Vehicle, IoT, Battery Charging Control, and Battery Endurance.***

Introduction

The advancement of electric vehicle (EV) technology has become one of the strategic solutions to address the fossil energy crisis and carbon emission issues. Electric vehicles offer a more environmentally friendly, efficient, and sustainable transportation system. However, one of the main challenges in the widespread adoption of EVs lies in the management and efficiency of battery charging, which serves as the primary power source.

A crucial factor in EV performance is battery endurance (lifetime), which is highly influenced by the charging method, charging temperature, input current, and voltage stability. Irregularities during the charging process can lead to significant battery cell degradation, shortening the service life and increasing maintenance costs. Therefore, an intelligent and adaptive control system is required to manage the battery charging process effectively. With the development of Internet of Things (IoT) technology, battery charging monitoring and control can now be performed in real-time, integrated, and data-driven. This allows for the optimal regulation of power input, charging time, and battery operating temperature. IoT-based systems also enable users to remotely monitor battery status through applications or cloud dashboards.

The increasing global vehicle population has significantly contributed to higher fossil fuel consumption and carbon dioxide (CO_2) emissions into the atmosphere. This has prompted many countries to shift toward more eco-friendly vehicle technologies, such as electric vehicles. In Indonesia, the development of electric vehicles has also been encouraged as part of a clean energy program and efforts to reduce dependence on fossil fuels. One of the vital components in EVs is the battery, which functions as the main energy storage and supply source for the vehicle's propulsion motor. Battery endurance and efficiency heavily rely on the charging system used. Errors in charging methods—such as overcharging, undercharging, or charging at high temperatures—can reduce battery cell capacity, accelerate material degradation, and significantly shorten battery lifespan.

Along with technological advancement, there is great potential to integrate IoT systems into electric vehicle battery charging management. IoT allows for real-time supervision and control of the charging process, including monitoring key parameters such as temperature, voltage, current, and charging status. Through this integration, users can receive early warnings, perform automated charging, and avoid extreme conditions that can damage the battery.

However, many existing battery charging systems still lack intelligent and adaptive control that takes into account real-time load dynamics and environmental conditions. Therefore, further research is needed to design and analyze an IoT-based electric vehicle battery charging control system, focusing on enhancing battery endurance and usage efficiency. This study is expected to offer an innovative solution in the development of smart charging systems that are not only efficient but also capable of significantly extending the lifespan of electric vehicle batteries through data-driven monitoring and control.

Literature Review

The theoretical foundation serves as the scientific basis for supporting the design and analysis process of the IoT-based battery charging control system. The theories used include fundamental concepts of electric vehicles, lithium-ion batteries, control systems, and IoT technology.

2.1 Electric Vehicle (EV)

An electric vehicle is a type of vehicle powered by an electric motor, with its primary energy source coming from rechargeable batteries. EVs offer advantages such as energy efficiency, low emissions, and lower operational costs compared to fossil-fueled vehicles. The main components of an EV include an electric motor, a controller, and an energy storage system (battery pack).

2.2 Battery Charging Control System

Lithium-ion (Li-Ion) batteries are commonly used in electric vehicles due to their high energy density, long cycle life, and good charging efficiency. However, these batteries are sensitive to overcharging, overheating, and unstable charging currents. Important parameters in battery charging management include:

1. Maximum charging voltage (V)
2. Charging current (A)
3. Operating temperature (°C)
4. State of Charge (SoC) and Depth of Discharge (DoD)

A charging control system is used to regulate the input current and voltage into the battery safely and efficiently. Common charging methods include:

1. Constant Current (CC)
2. Constant Voltage (CV)
3. CC-CV Charging

Additionally, control algorithms such as PID, fuzzy logic, or threshold-based systems can be applied to maintain stability in charging parameters.

2.3 Internet of Things (IoT)

The Internet of Things (IoT) is a concept of interconnected devices that can communicate with each other over the internet. In the context of a battery charging system, IoT is used for:

1. Real-time monitoring of temperature, voltage, and current
2. Data storage and visualization via cloud platforms (such as Firebase, ThingSpeak)
3. Remote control via dashboards or web/mobile-based applications

The main IoT device used in this research is the NodeMCU ESP8266, a Wi-Fi-based microcontroller capable of reading sensor data and transmitting it to the internet.

2.4 Buzzer

A buzzer is an electronic component that converts electrical vibrations into sound vibrations. Its working principle is similar to that of a loudspeaker. It consists of a coil mounted on a diaphragm; when current flows through the coil, it becomes an electromagnet. The coil is pulled inward or outward depending on the direction of the current and the polarity of the magnet. Since the coil is attached to the diaphragm, every movement of the coil causes the diaphragm to vibrate back and forth, which then vibrates the air to produce sound.

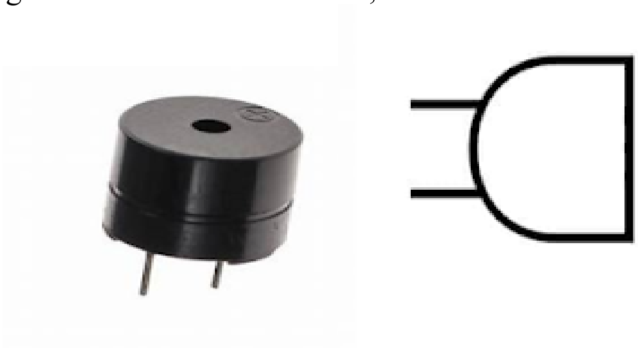

Figure 1. Physical Form and Symbol of a Buzzer

In the design, the buzzer is used as an indicator that activates when the predefined settings are not met or exceed the set thresholds, causing the alarm to sound.

2.5 Relay

A relay is an electromagnetic switch that uses a low DC voltage to turn on or off a device or system connected to a high DC or AC voltage. The simplest configuration of a relay consists of a coil of conductive wire wound around an iron core. The relay contact configuration generally consists of:

1. Normally Open (NO): The switch is in an open position when the relay is not energized.
2. Normally Closed (NC): The switch is in a closed position when the relay is not energized.

The figure below shows the condition of a relay in a normally open state.

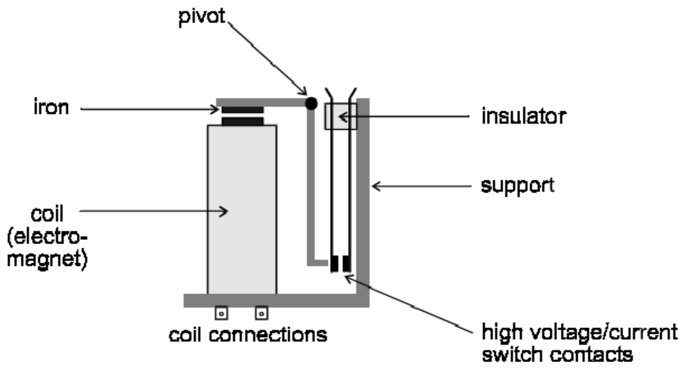

Figure 2. Relay Condition in Normally Open State

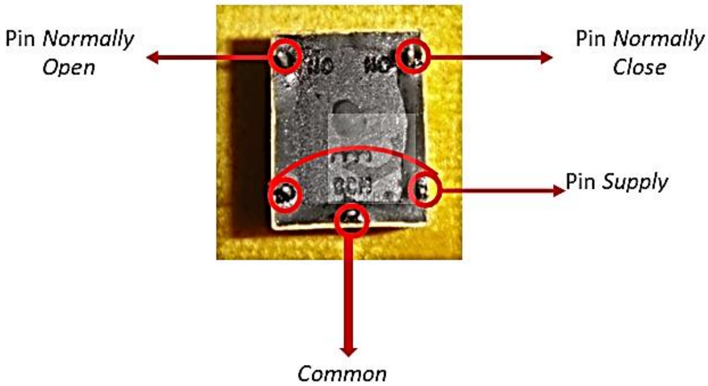

Figure 3. Relay Pin Configuration

Based on its basic working principle, a relay operates due to the presence of a magnetic field used to move the switch. When the coil is supplied with a voltage equal to the relay's operating voltage, a magnetic field is generated in the coil as current flows through the wire winding. This coil, acting as an electromagnet, then pulls the switch from the NC (Normally Closed) contact to the NO (Normally Open) contact. When the voltage to the coil is turned off, the magnetic field disappears, allowing the spring to pull the switch back to the NC contact.

Figure 4. Physical Form of Relay

Research Methodology

This research applies an experimental method to design, simulate, and analyze an IoT-based battery charging control system aimed at improving battery endurance in electric vehicles. The methodology involves several key stages: literature study, system design, component selection, software and hardware integration, testing, and data analysis. The research is structured using a descriptive-experimental approach**,** which involves the systematic observation, construction, and testing of a prototype charging system. The performance is evaluated based on real-time measurements of critical battery parameters such as voltage, current, temperature, and state of charge (SoC).

Key tools and components used include:

1. NodeMCU ESP8266 (as the main IoT microcontroller)
2. Voltage and current sensors (INA219 or ACS712)
3. Temperature sensor (DS18B20 or DHT22)
4. Lithium-ion battery module (for simulation)
5. Relay module (for charge control)
6. Buzzer (as an over-temperature warning)
7. Charging adapter (DC power supply)
8. Breadboard, jumper wires, and supporting circuit components
9. Firebase or Thingspeak (as cloud IoT platforms)
10. Mobile/web dashboard (for monitoring battery parameters remotely)

Data Collection Techniques

1. Literature Review**:** Collecting theoretical and technical references related to electric vehicles, lithium-ion battery management, IoT systems, and control algorithms.
2. Observation**:** Direct observation of sensor behavior and system performance under varying input conditions.
3. Simulation**:** Software simulation (if applicable) using tools such as Proteus, MATLAB/Simulink, or Tinkercad.
4. Prototyping**:** Constructing the physical circuit and integrating IoT components.
5. Testing**:** Measuring voltage, current, temperature, and battery status in real-time during the charging process.

Data Analysis Techniques

1. Calculating the variations in sensor data during charging cycles.
2. Comparing measurement results with standard values using a digital multimeter and thermometer.
3. Analyzing the effect of controlled charging on battery temperature and performance.
4. Evaluating system response to threshold limits (e.g., over-temperature or over-voltage) through buzzer alerts and relay control.

Operational Definitions of Variables

1. Independent Variable**:** Control system based on IoT (NodeMCU + sensors)

2. Dependent Variables**:** Battery parameters — voltage, current, temperature, and state of charge
3. Control Variable: Charging voltage and environmental temperature

This method is expected to result in a smart, efficient, and safe charging system that enhances battery longevity by preventing overcharging and excessive heat through intelligent real-time monitoring and control.

Results

4.1 Power Supply Electric Vehicle.

In Accordance With The Main Objective Of This Research, Which Is To Develop A Battery Security System Circuit For Electric Vehicles Via SMS Based On Atmega328 Microcontroller**,** There Are Several Steps Taken In Building The Device Before Conducting Tests. The Purpose Of The Power Supply Testing Is To Determine The Output Voltage Of The Power Supply That Will Be Used As The Working Input Voltage For The Microcontroller Circuit. This Test Is Carried Out To Prevent Unexpected Or Incorrect Voltage Levels. The Testing Of The Power Supply Circuit Is Performed By Measuring The Output Voltage Using A Voltmeter. The Voltage Source Used As The Working Voltage In The Battery Security System Circuit For Electric Vehicles Via SMS Based On Atmega328 Microcontroller Comes From A 12V DC Source. In This Study, Testing Will Be Conducted On The Power Supply Circuit By Measuring The Output Voltage Produced By Each Voltage Source Supplied To The Microcontroller Circuit. The Following Table Shows The Results Of The Power Supply Circuit Measurements To The Microcontroller.

Table 1. IC Regulator Test Results

Test	It is expected	Measurement results	Presentation Error
1st	5 V	4.96V	0.8%
2nd	5 V	4.96 V	0.8%
The 3rd	5 V	4.96V	0.8%
4th	5 V	4.96V	0.8%
5th	5 V	4.96V	0.8%
Average value	**5 V**	**4.96 V**	**0.8%**

$$\% \, Eror = \frac{\text{Current} - \text{Read}}{\text{Current}}$$

$$\% \, Average \; DC \; 12V \; Error \; = \frac{12\text{V} - 11.98\text{V}}{12\text{V}} x \; 100\%$$

$$= \frac{0.02\text{V}}{12\text{V}} x \; 100\% = 0.17\%$$

Figure 5. Power Supply Testing

4.2 Voltage Regulator Output Results

The use of a regulator in the Battery Security System Circuit in the Bts Shelter Via SMS Based on the Atmega328 Microcontroller is used to provide a constant voltage to the minimum system circuit of the tool. Based on the datasheet, there are several types of regulator ICs that indicate the output voltage produced. In the Battery Security System Circuit in the Bts Shelter Via SMS Based on the Atmega328 Microcontroller which is made using the 7805 regulator IC, according to the data sheet, the 7805 regulator IC produces a voltage of 5 volts DC which is stated in the two digits from the back on the regulator body. The testing system on the 7805 regulator IC was carried out to determine the output voltage produced by the 7805 regulator IC. The reason for selecting the use of the 7805 regulator IC is because each component in the device works on average based on a voltage of 5V DC. The results of the regulator IC test can be seen in the table.

$$\% \, Eror \; of \; IC \; 7805 \;\; = \frac{5\text{V} - 4.96}{5\text{V}} \; x \; 100\%$$

$$= \frac{0.04\text{V}}{5\text{V}} x \; 100\% = 0.8\%$$

In designing this tool, the voltage for the system's operation is 5V and the power used is around 2.5 Ampere x 5V = 12.5 Watt. Because the current consumption of the SIM800L is around 2A (when sending SMS), while the Atmega 328 uses a current of around 0.5A, the source of which is taken from the battery.

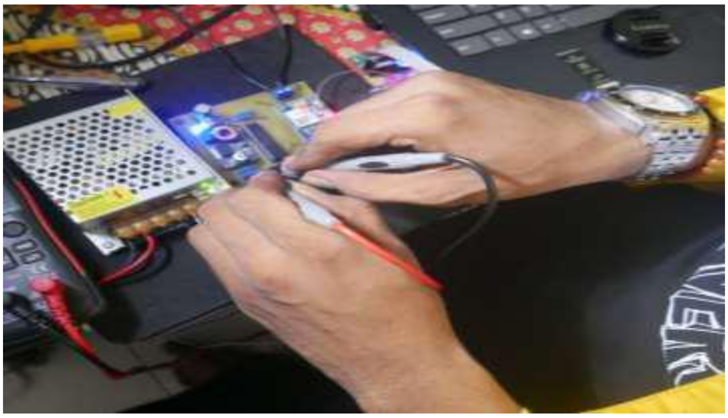

Figure 6. Voltage Regulator Testing

4.3 Sensor Testing on Cable

In this experiment, the author tested the sensor on the cable using logic 0 and I. If the measuring instrument has logic I, then the cable that connected to the sensor is disconnected, if the measuring instrument has logic 0 then the cable installed is in good condition.

Table 2. Sensor Logic Testing

No	Cable Condition	Logic
1	Disconnected	I
2	Installed	0

This sensor consists of a cable wrapped around the battery. This coil is given a signal. If the output of this sensor is connected to the ADC, then process the data to the Arduino microcontroller, then it is able to measure signals with a small resolution. If the cable is disconnected, the signal will also be automatically disconnected and the data is detected by the microcontroller so that the microcontroller sends information using SIM800L to give a message to the operator via SMS media.

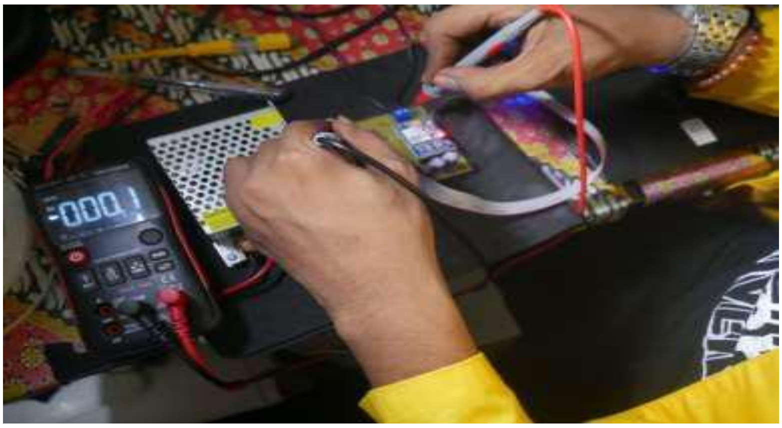

Figure 7. Cable Testing in good condition

In the image above, the author explains that if the sensor cable is in good condition, the voltage on the measuring instrument will show 0V, indicating that the sensor cable as a battery safety device is in a safe condition.

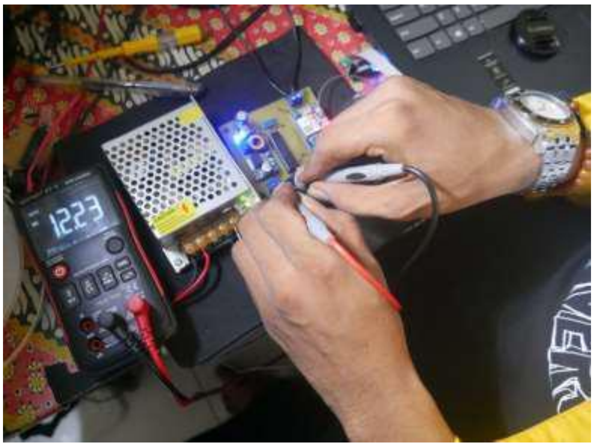

Figure 8. Testing a Disconnected Cable

In the image above, the author explains that if the sensor cable is disconnected, the voltage on the measuring instrument will return to normal at 12 V, indicating that the sensor cable as a battery safety device is disconnected, the buzzer turns on and the microcontroller automatically sends an SMS message to the registered operator to carry out an inspection.

4.4 Testing SMS messages using a GSM modem

The implementation of sending and receiving SMS using a GSM (General service for mobile) modem was carried out to determine whether the GSM modem could send and receive SMS properly. The SMS sending and receiving test was simulated using Arduino software. Arduino software is a program for programming various types of microcontrollers and microcontrollers used ATMEGA 328 terminals used for remote control by connecting using ports or other means. The results of the implementation of sending SMS from the GSM SIM800L module are shown in the following figure:

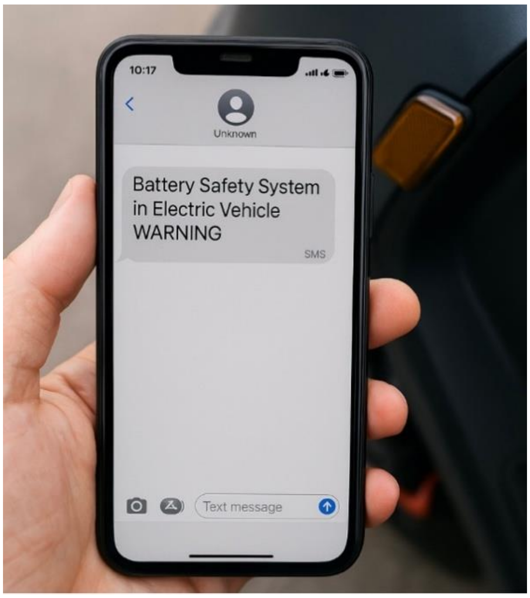

Figure 9. Testing Notification

From the SMS notification of the active alarm in the image above, the user knows there is an abnormal condition at the site. This active alarm notification prompts the mobile phone user, in this case the field cluster team, to reconfirm the alarm activation by visiting the site to ensure it is truly safe. A quick user response to the active alarm is essential to anticipate the loss of tower equipment.

Conclusion.

Based on the design and analysis conducted, the IoT-based electric vehicle battery charging control system successfully demonstrates the ability to monitor and manage charging parameters such as voltage, current, temperature, and state of charge (SoC) in real-time. The integration of sensors and the NodeMCU microcontroller with cloud-based platforms allows for efficient data acquisition, remote monitoring, and preventive control mechanisms that protect the battery from overcharging, overheating, and unstable currents. The implementation of intelligent control through IoT not only improves user awareness and system responsiveness but also contributes significantly to enhancing battery endurance. By maintaining stable charging conditions and providing alerts when operational thresholds are exceeded, the system helps reduce battery degradation, thereby extending its lifespan and reducing maintenance costs. This smart charging system prototype provides a practical, scalable solution for future applications in electric vehicle charging infrastructure, aligning with sustainable energy and transportation goals.

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