24V Smart Battery Charging System with Health Management

ECE445/ME470

Project No.29

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Proposal

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Part I : Introduction

The team independently designed and developed an intelligent battery charging system with a fixed charging voltage of 24V, which integrates advanced electronic power technology, battery health management function and fault detection function. It aims to solve the key problems in modern battery charging and discharging technology. The system can not only provide efficient and safe charge and discharge operation, but also extend battery life and adapt to complex environmental conditions.

Objective and Background

Goals and Problems

Our team designed the battery as part of the project to address several key issues that exist in current battery charging systems. First of all, the traditional battery system generally has the problems of insufficient charging efficiency, long charging time, small battery storage capacity and large energy loss during the charging process. Secondly, the existing battery management system has limited functions in battery health monitoring, and can not fully monitor the key parameters of the battery such as voltage, temperature, charge and discharge cycle, and remaining power, resulting in insufficient battery visualization function, shortened battery life and reduced performance, and reduced user experience. In addition, the existing charging system in the face of some environmental

problems, such as power grid fluctuations, temperature changes and other environmental problems, the lack of effective self-regulation and recovery mechanism, easy to lead to the reduction of battery storage capacity, charging rate and even lead to safety problems.

Functions: What is the product supposed to do?

The product is a 24V smart battery charging system with the following functions:

Efficient charging: Our system adopts advanced power electronic components and charging control algorithm to realize efficient charging from AC to DC, shorten charging time and improve charging efficiency.

Battery health management: The battery will be connected to a health monitoring module to monitor key parameters such as battery voltage, temperature, charge and discharge current in real time, thereby ensuring that the battery is in the best condition, extending battery life and reducing safety risks.

Environmental adaptability: The system has the ability to cope with the environmental problems of power grid fluctuations, too cold or too hot temperature, and too high humidity, reducing the damage caused by environmental changes to the battery.

Fault detection module: The system will automatically terminate the battery charging and discharging process for possible safety problems, such as battery water, dust, internal short circuit and other common

battery problems, so as to ensure that the key components of the battery are not damaged and ensure the safety of users.

Benefits For Customers

The product brings following benefits to customers:

Improved charging efficiency

With efficient charging algorithms and power electronics, customers can complete battery charging in less time and reduce waiting time.

Extended battery life: The built-in health monitoring function can monitor the battery status in real time to ensure that the system is operating at the most efficient condition and extend the battery life.

High system reliability

The system is equipped with an automatic adjustment and recovery module, which can effectively cope with power grid fluctuations and temperature changes to ensure the stability and safety of the battery during use.

Ensure user safety

The accurate fault detection module can kill the possible battery failure in the cradle, reduce the occurrence of unsafe factors such as fire and explosion caused by the battery, and ensure the safety of users.

Features and Differentiation

The differentiation of this product is mainly reflected in the following aspects.

Efficient charging technology

Compared with traditional charging systems, the system designed by our team uses more advanced power electronic components and control algorithms, which enables the battery to be charged in a shorter time and with lower energy consumption.

Comprehensive battery health management

The existing battery management system usually only monitors some parameters, and this system can fully monitor the battery voltage, temperature, charge and discharge cycle and other key parameters, providing a more comprehensive battery health management.

Intelligent environmental adaptation

Our team's battery system has the ability to maintain stable charging performance under complex environmental conditions.

High-Level Requirements List

The charging efficiency is over 95%

Charging efficiency is one of the key indicators to measure the performance of the charging system. The efficiency of the existing charging system is usually about 90%, and there is a large energy loss. By

using advanced power electronic components and control algorithms, the system is able to increase charging efficiency to more than 95%, reduce energy loss, and reduce charging costs. The high-efficiency charging system can not only shorten the charging time, but also reduce energy waste, which is in line with the current trend of energy conservation and emission reduction.

The accuracy error of battery health monitoring is not more than ±1%

Battery health monitoring is key to ensuring long-term stable battery operation. The existing battery management system has a large error in the monitoring accuracy, usually about ±5%, which can not accurately reflect the actual state of the battery. Our team requires the monitoring accuracy of the battery system to ±1%, so that key parameters such as battery voltage, temperature, charge and discharge can be more accurately monitored, visualizing functions can be achieved, battery life can be extended, and user experience can be improved.

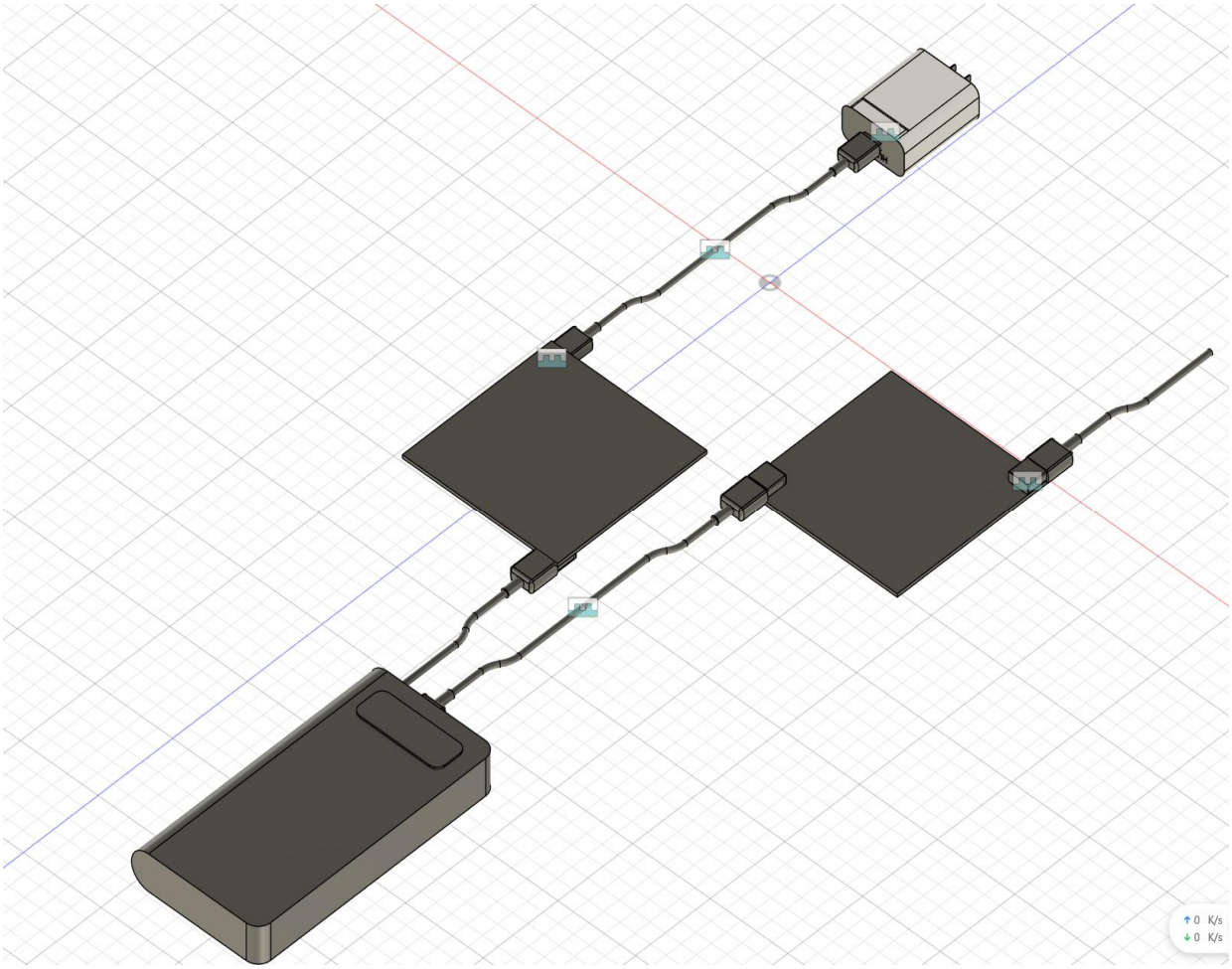
The system can automatically adjust and maintain stable charging within the range of ±10% of the grid fluctuation

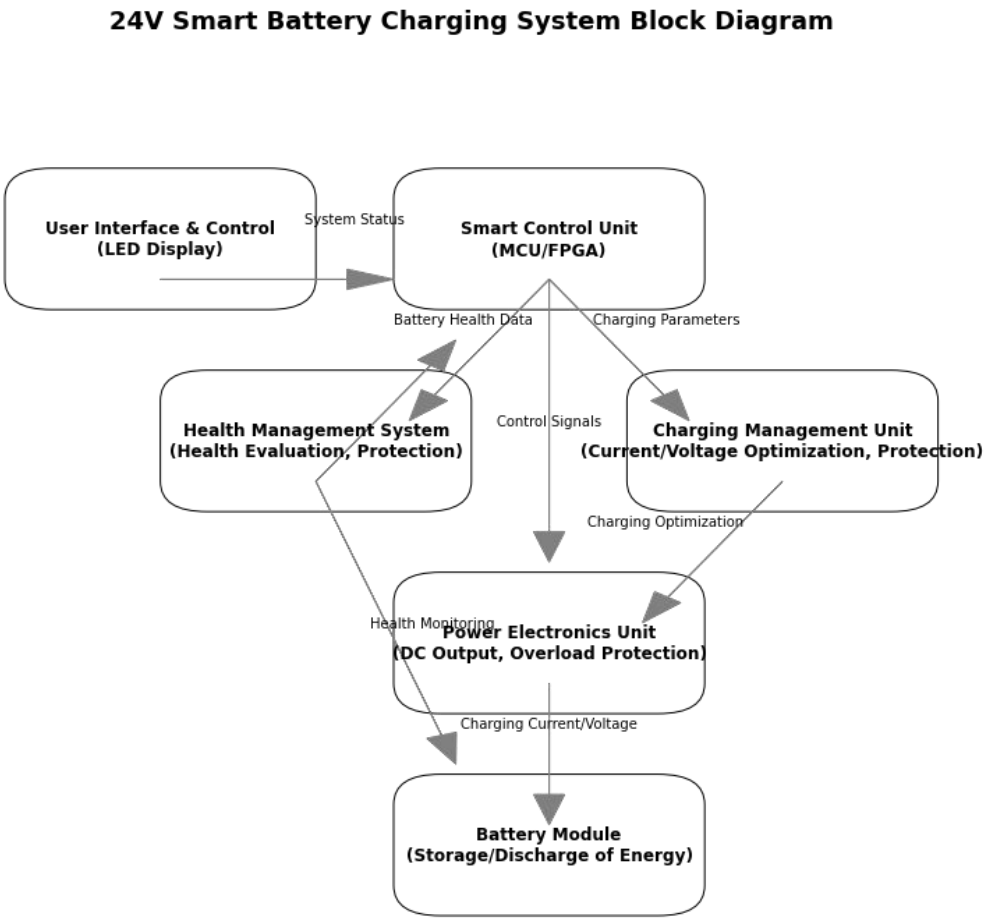
Power grid fluctuation is one of the main factors affecting the stability of charging system. In the process of user use, especially in the process of household electricity use, there will inevitably be power grid fluctuations in the case of peak and valley, resulting in unstable charging

voltage. Through the introduction of automatic adjustment mechanism, the system can automatically adjust the charging parameters within the range of the grid fluctuation of ±10% to ensure stable DC voltage and current input. This function not only improves the environmental adaptability of the system, but also enhances the reliability and security of the system

Part II : Design & Requirements

Physical Design Diagrams





The following is a detailed description of the various functional modules of the 24V smart battery charging system, combining their functions, connection methods, information transmission content, response and performance requirements in specific cases:

User Interface & Control

The user interface and control module is responsible for providing the basic indication of the battery charging status, usually through the LED display to provide real-time feedback on the battery level and status information. For example, when the battery is successfully charged, the LED shows green; When the battery is too low, the red indicator flashes. The module is connected to an intelligent control unit (MCU) to receive

system status information and provide feedback to the user. When the system is running, the LED shows green, indicating normal charging; In the event of a failure, the LED will display red or flash, indicating that the user needs attention.

Requirements:

Requirement 1: The LED display should work properly under the input voltage range of 24V ±10%.

Requirement 2: LED brightness should be consistent without significant attenuation within the ambient temperature range of -10°C to 50°C.

Smart Control Unit (MCU/FPGA)

The intelligent control unit is the brain of the battery system designed by our team and is responsible for monitoring, controlling and optimizing the charging process. It uses intelligent charging algorithms during operation to dynamically adjust charging current and voltage according to the state of the battery. This unit is also responsible for fault detection and executes protection or recovery policies in the event of abnormal conditions such as over temperature, over voltage or under voltage. For example, if the battery temperature is detected to be too high, the MCU will prevent overheating by reducing the charging power or suspending the charging; When the voltage is abnormal, the system automatically

adjusts the charging voltage to ensure that the battery works within the safe voltage range. The intelligent control unit is connected to the user interface, health management system (HMS), charge management unit (CMS) and power electronics Unit (PES) to ensure information transfer and collaboration between modules.

Requirements:

Requirement 1: MCU should support the CAN bus communication protocol with a transfer rate of up to 1 Mbps.

Requirement 2: MCU processing speed should meet real-time control requirements within the operating temperature range 0°C to 70°C.

Requirement 3: MCU input voltage should be within 3.3V ±5% and power consumption should not exceed 500mW.

Health Management System (HMS)

The health management system is responsible for monitoring the health of the battery, including battery life assessment and protection features. It connects to the intelligent control unit and battery module to obtain real-time data of the battery and take protective measures in case of overcharge or undercharge. For example, when the battery voltage is close to the maximum safe voltage, the system limits the charging current and prevents the battery from overcharging. In turn, when the battery voltage is too low, the health management system will terminate the

charge to prevent excessive discharge. It is also responsible for performing balanced charging to ensure that the voltage of each cell in the battery pack is consistent to extend the battery life.

Requirements:

Requirement 1: Battery voltage monitoring accuracy should be ±1%FS (full scale).

Requirement 2: The temperature sensor should be within the range of -20°C to 60°C with an accuracy of ±2°C.

Requirement 3: The overcharge and undercharge protection thresholds should be programmable and the error range should not exceed ±0.5V.

Charging Management Unit (CMS)

The charge management unit is responsible for managing the battery charging process. It improves charging efficiency by optimizing current and voltage, ensuring efficient and safe battery use. The unit is connected to the intelligent control unit, the power electronics unit and the battery module to implement the charging strategy and ensure that the battery is charged within a safe range. The charge management unit dynamically adjusts the charging current and voltage based on the real-time monitoring of the battery status and the health management system to prevent overcharge and undercharge of the battery. In addition, it can

automatically adjust the charging parameters according to the battery type, improving charging efficiency and battery life.

Requirements:

Requirement 1: The accuracy of charging current adjustment should be ±2%FS.

Requirement 2: Output voltage range should be 12V to 30V, adjustable, accuracy ±1% set value.

Requirement 3: The overcharge protection threshold should be allowed to range from 3.6V to 4.2V with an error of not more than ±0.05V.

Power Electronics Unit (PES)

The power electronics unit is responsible for converting the input power supply into a stable DC voltage and current suitable for battery charging. It is connected to the charge management unit and the battery module, and protects the battery. The power electronic unit has the functions of overload protection, short circuit protection and overtemperature protection. For example, when the output current exceeds the set maximum value, the system will reduce the output power or disconnect the output; If a short circuit fault is detected, the system will immediately stop the current output, and automatically resume after the fault is removed; Built-in temperature sensors monitor the temperature of the

power electronics unit, and once the temperature exceeds a set threshold, the system will reduce the power or stop working to prevent overheating.

Requirements:

Requirement 1: Output voltage stability should be within ±0.5%.

Requirement 2: The maximum output current should be 5A, the overload protection should be triggered at least 5.5A, and the recovery time should not exceed 1 second.

Requirement 3: The operating temperature should range from -20°C to 85°C, and overtemperature protection should be triggered at 90°C.

Battery Module

As the energy storage core of the system, the battery module is responsible for storing and releasing electrical energy. It connects to the health management system, charge management unit and power electronics unit to provide a stable power supply. The battery module not only charges and discharges, but also provides real-time data about the battery, such as battery voltage, temperature, and health. It has a built-in protection circuit. When an abnormal situation such as overcharge, undercharge or overtemperature is detected, the battery module will automatically disconnect to prevent battery damage.

Requirements:

Requirement 1: The battery voltage measurement accuracy should be

±1%.

Requirement 2: Battery requirement should range from -10°C to 60°C. If the temperature exceeds the threshold, the protection mechanism needs to be triggered.

Requirement 3: Battery voltage should have an error range of ±0.05V for overcharge and undercharge protection.

Through the collaborative work of these modules and the stringent performance requirements, the system ensures an efficient, safe and intelligent battery charging process, extending battery life and protecting the system from failure.

Part III: Ethics Statement

All ethical and professional standards of the IEEE Code of Ethics guide the development process for the 24V smart battery charging system with its health management capabilities. Our charging system incorporates public safety features as well as sustainability standards together with responsible innovative practices and the necessary health management capabilities needed to counter potential threats. Our team practices transparent communication methods and social accountability to define the smart energy system structure and follows ethical procedures that specifically ban unethical practice and corruption. The technical integrity strategy employs a method to receive essential feedback

followed by error detection and repair steps until all claims are proven with official data sources. Individual team members should perform work within their understanding of their competence scope while enhancing their expertise. The organization maintains an environment of equal respect where discrimination harassment and all unethical practices receive strict prohibition. The organization fights conflicts of interest as it protects intellectual property and maintains proper technology usage. The implementation of ethical values from our project aims to build a secure and sustainable technology-rich framework which will advance into the future.

Citations

[1] "ECE 445: Senior Design Project Laboratory - Safety Guidelines," University of Illinois Urbana-Champaign, Grainger College of Engineering. [Online]. Available: https://courses.grainger.illinois.edu/ece445zjui/guidelines/safety.asp. [Accessed: 2025 Mar.14].

[2] "IEEE Policies - Section 7-8," IEEE. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: Accessed: 2025 Mar.14].