# IOT-ENABLED SMART USB CHARGER WITH PREDICTIVE THERMAL PROTECTION AND REAL-TIME MONITORING

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**Keywords**:

IoT, Smart USB Charger, Predictive Thermal Protection, NTC Thermistor, ESP32 Microcontroller, Real-time Monitoring, Energy Efficiency, Embedded Systems

**Introduction:**

1. In today’s digital era, USB charging devices have become essential for powering smartphones, tablets, and other portable electronics. With the increasing number of devices, traditional chargers often face problems such as overheating, overcurrent, and energy wastage. These issues reduce device lifespan and can even pose safety risks.
2. This project focuses on developing a Smart USB Charger with predictive thermal protection, ensuring safe, reliable, and energy-efficient charging. It integrates IoT technology, allowing real-time monitoring of parameters such as voltage, current, and temperature via a cloud dashboard. The ESP32 microcontroller serves as the central control unit, processing sensor data and managing safety mechanisms.
3. Temperature monitoring is achieved using an NTC thermistor, which changes its resistance according to temperature. The system can automatically reduce charging current or temporarily shut down when overheating is detected, providing predictive thermal protection.
4. Beyond safety, energy efficiency is a major focus. Smart algorithms optimize power delivery while maintaining optimal charging speed. The combination of IoT connectivity, embedded control, and predictive safety makes this charger a modern, practical, and sustainable solution for everyday electronics.

**Objectives:**

The primary objective of this project is to design and develop a Smart USB Charger with predictive thermal protection and real-time IoT monitoring to ensure device safety and energy-efficient charging. Specific goals include:

- **Prevent overheating and overcurrent:** Maintain USB temperature below safe limits (e.g., 60°C) and automatically cut off excess current to protect connected devices.

- **Accurate temperature sensing:** Integrate an NTC thermistor for real-time measurement and predictive thermal control.
- **IoT-based monitoring:** Implement an ESP32 microcontroller to collect data and transmit it wirelessly to a cloud dashboard.
- **Cloud visualization:** Develop a user-friendly dashboard to monitor charging status, temperature trends, and energy consumption in real-time.
- **Energy-efficient fast charging:** Optimize power management to maximize efficiency while maintaining fast and reliable charging.
- **Predictive thermal protection:** Implement an embedded algorithm analyzing the rate of temperature increase (dT/dt) to detect overheating risks and enable preemptive soft shutdowns or power throttling.

**Methodology:**

The project follows a systematic methodology that includes material selection, circuit design, mechanical design, IoT integration, system integration, and testing.\

The entire process is divided into several phases as follows:

1. **Component Selection:**

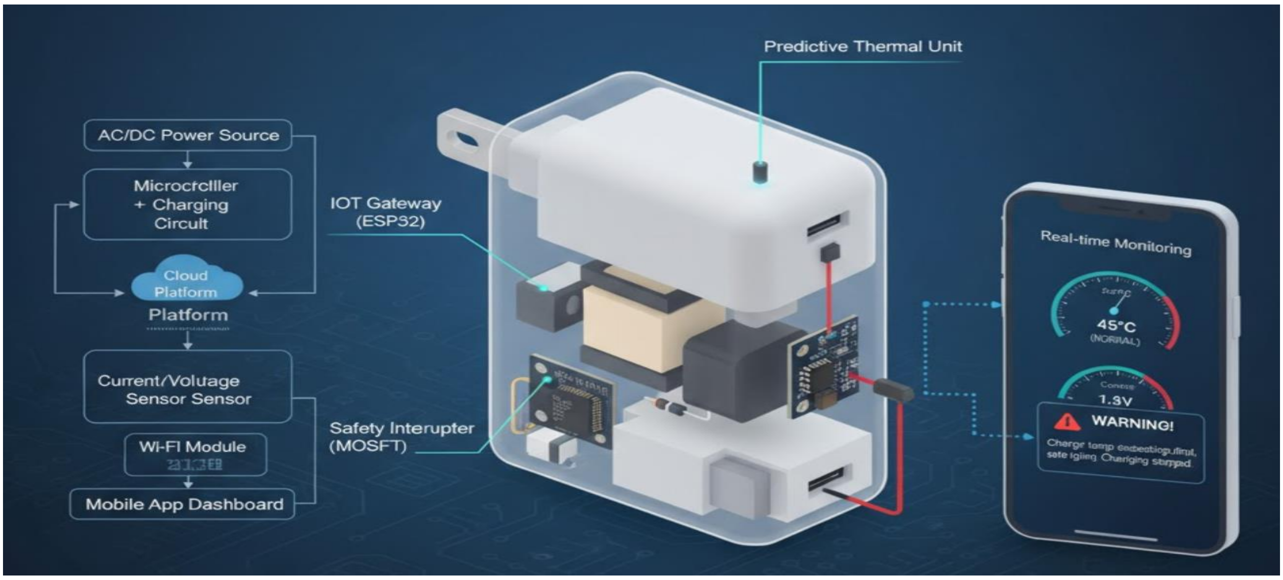
In this phase, all required electronic components were selected based on performance, reliability, and safety.

1. The main components used are ESP32 microcontroller, NTC thermistors, relays, BC547 transistors, and PC817 optocouplers for temperature sensing, switching, and protection.
2. Additional components such as 10 kΩ resistors, capacitors, AMS1117 voltage regulator, USB breakout boards, and connecting wires were used for stable circuit operation.
3. These components were selected to ensure safe and efficient USB power delivery and charging performance.

2. **Mechanical Design:**

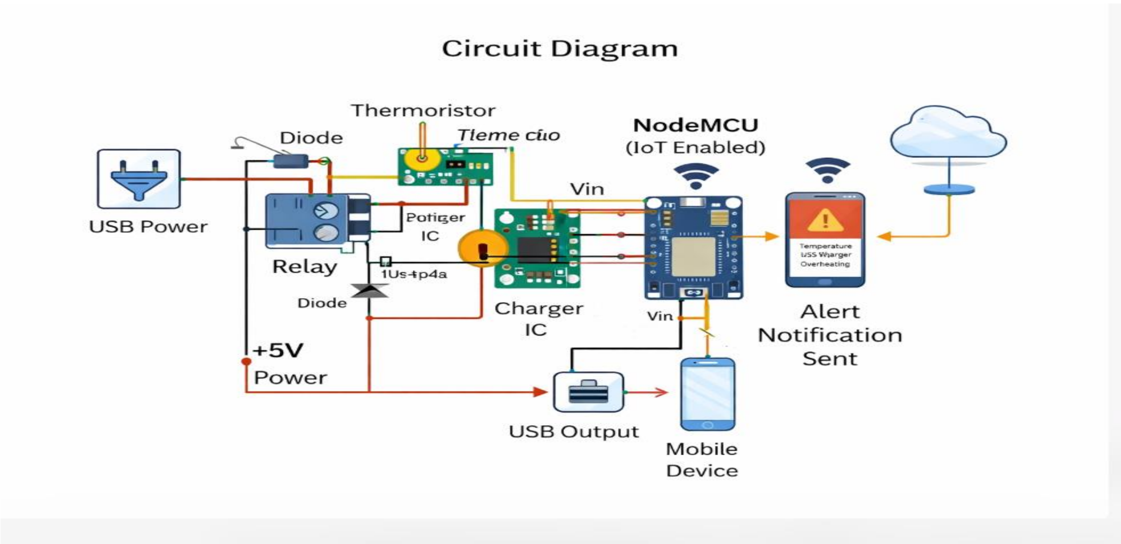
    1. A compact PCB layout was designed to integrate ESP32, sensors, relays, optocouplers, and voltage regulators in a structured manner.
    2. A temperature-based control system was implemented where NTC thermistor readings control the relay operation for enabling or disabling USB charging.
    3. The system is also designed for IoT-based monitoring to track temperature and system status in real time.

3. **Integration of IoT System:**
    1. Integrated a Wi-Fi enabled microcontroller for IoT-based real-time monitoring of voltage, current, and temperature.
    2. Enabled remote monitoring through a mobile or web interface with alert notifications for abnormal conditions.
4. **Electrical Circuit Design:**
    1. Designed a regulated power supply circuit to provide stable 5V DC output for reliable USB charging.
    2. Implemented voltage and current sensing circuits to ensure safe power delivery and overload protection.
    3. Integrated high-efficiency voltage regulation to maintain constant output under varying load conditions.
    4. Added filtering and thermal protection components to reduce noise, prevent overheating, and improve system reliability.
5. **Testing and Evaluation:**
    1. **Hardware Testing** – The charger circuit and temperature sensors were tested to ensure stable operation and accurate performance
    2. **Thermal Protection Testing** – Overheating conditions were simulated to verify automatic predictive shutdown and safe functioning.
    3. **IoT Monitoring Evaluation** – Real-time data transmission and remote monitoring were tested for reliability and quick response.
6. **Documentation and Analysis:**
    1. Analyzed temperature and charging data to evaluate system safety, performance, and improvement scope.
    2. Documented circuit design, IoT monitoring setup, and experimental results for reporting and presentation.




**Results & Conclusions:**

1. The IoT-Enabled Smart USB Charger was successfully developed and tested to ensure safe and efficient device charging. The system continuously monitored charger temperature and maintained stable charging performance under normal operating conditions.
2. Experimental results showed that the temperature sensing module accurately detected heat rise during charging. When the temperature crossed the predefined limit, the controller automatically stopped charging, preventing overheating and ensuring device protection.
3. The IoT module enabled real-time monitoring and successfully transmitted data to the user interface. Alert notifications were generated during abnormal thermal conditions, improving user awareness and system reliability.
4. In Conclusion Overall, the project demonstrates an effective smart charging solution that integrates thermal protection and IoT monitoring. The system enhances charging safety, reduces potential hardware damage, and provides a foundation for future intelligent power management systems.



**Project Outcome & Industry Relevance:**

1. The IoT-Enabled Smart USB Charger successfully demonstrates a smart and safe charging system with real-time temperature monitoring and automatic thermal protection. The developed prototype ensures reliable power delivery by preventing overheating and improving device safety through intelligent control mechanisms.
2. The project outcome confirms effective integration of sensing, embedded control, and IoT communication for continuous monitoring and fast protective response. The system enhances charger reliability, reduces risk of hardware damage, and improves overall charging efficiency.
3. From an industry perspective, the proposed solution is highly relevant to consumer electronics, smart charging adapters, and IoT-based power management systems. The concept can be implemented in commercial chargers, smart homes, and public charging stations to improve safety standards and enable remote monitoring.
4. The project aligns with modern Industry 4.0 trends by promoting intelligent automation and connected electronic devices, offering strong potential for future scalable and commercial smart charging applications.

**Working Model vs. Simulation/Study:**

The project was implemented as a functional working prototype to validate the practical feasibility of the IoT-Enabled Smart USB Charger. Initial design verification was carried out through circuit analysis and logical simulation to ensure proper interaction between temperature sensing, control, and protection modules before hardware implementation. Simulation helped in defining safe temperature thresholds and optimizing system operation.

The developed working model enabled real-time testing under actual charging conditions. Experimental results confirmed accurate temperature monitoring and automatic activation of thermal protection during overheating scenarios. The close agreement between simulation results and hardware performance demonstrates the reliability, efficiency, and real-world applicability of the proposed smart charging system.

**Project Outcomes and Learnings:**

- Developed a functional IoT-enabled smart USB charger with real-time temperature monitoring.
- Achieved automatic thermal protection to prevent overheating and improve charging safety.
- Successfully integrated sensing, embedded control, and IoT communication in a single system.
- Enabled remote monitoring and alert notification through cloud connectivity.
- Demonstrated a scalable smart charging solution suitable for real-world applications.

**Key Learnings:**

- Gained practical experience in embedded system design and hardware integration.
- Learned IoT communication and real-time data monitoring techniques.
- Strengthened skills in hardware design, system integration, and performance testing.
- Gained understanding of thermal safety analysis and intelligent power management concepts.
- Enhanced problem-solving, technical documentation, and project execution abilities.

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**Future Scope:**

1. The proposed IoT-Enabled Smart USB Charger has strong potential to evolve into an advanced intelligent charging platform capable of adaptive power management and predictive safety control. Future development can incorporate AI-based thermal analysis to learn charging patterns and predict overheating conditions before they occur, thereby improving system efficiency and extending device lifespan.
2. With further enhancement, the system can be integrated into smart home ecosystems and centralized energy management networks. Multiple chargers can be connected through cloud infrastructure to enable remote supervision, automated power optimization, and energy usage analytics, supporting sustainable and energy-efficient environments.
3. From an industrial perspective, the technology can be adopted in commercial USB adapters, fast-charging stations, public charging kiosks, and consumer electronic products. Integration with manufacturing standards can help industries develop safer and smarter charging devices that comply with modern safety regulations while enabling remote diagnostics and preventive maintenance.
4. In the long term, the project can contribute to the development of intelligent IoT-based power ecosystems aligned with Industry 4.0 and smart infrastructure initiatives. By

combining predictive analytics, automation, and real-time monitoring, the system has the potential to transform conventional charging solutions into autonomous, reliable, and future-ready smart energy devices.

5. “This project bridges the gap between traditional power electronics and intelligent IoT systems, contributing toward safer, smarter, and sustainable charging technologies for future digital infrastructure.”