

Problem Statement

Solar energy systems often rely on low-cost charge controllers that operate as “black boxes,” providing limited visibility into system performance. This lack of transparency makes it difficult to understand system behavior, troubleshoot issues, and optimize performance. SolarSense was developed to address this problem by creating a low-cost solar monitoring system that provides real-time insight into voltage, current, temperature, and charging behavior. The system enhances both educational value and practical usability of small-scale solar systems.

Problems Encountered

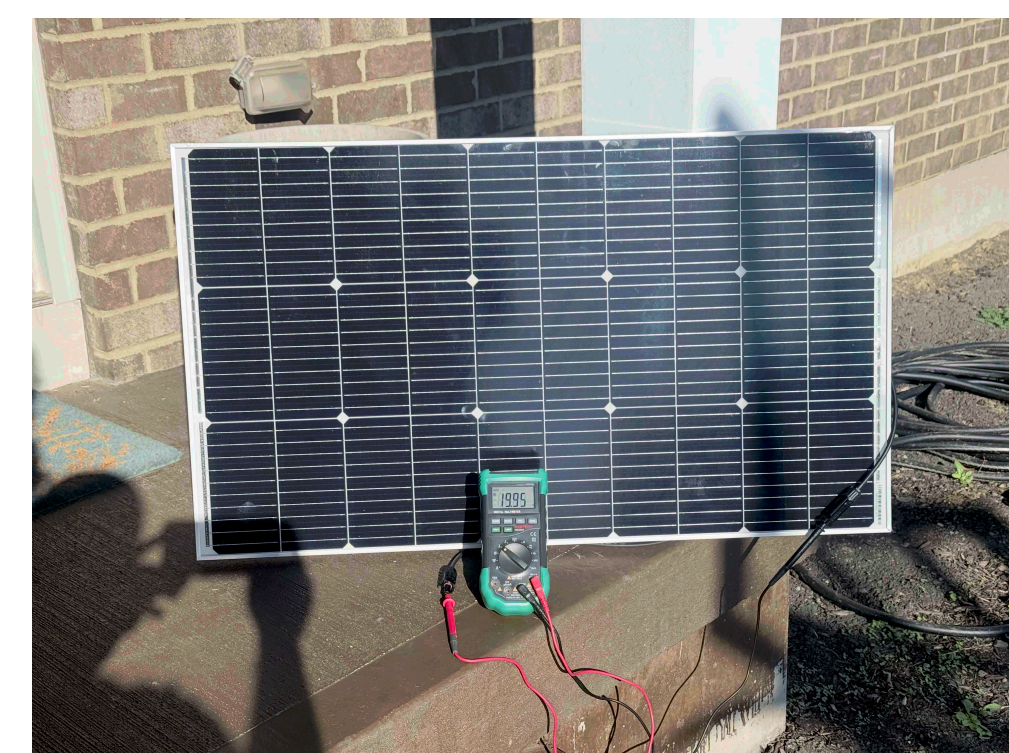
- During development, several challenges affected system performance and integration:
- MOSFET Heating:** High voltage differences caused excessive heat, requiring improved thermal management
 - Sensor Noise:** PWM switching introduced noise into current measurements
 - Current Calibration:** Bidirectional sensing required precise calibration
 - Communication Reliability:** MQTT communication between ESP32 and Raspberry Pi required debugging
 - Wiring Complexity:** Early prototypes required improved organization for reliable connections

Requirements

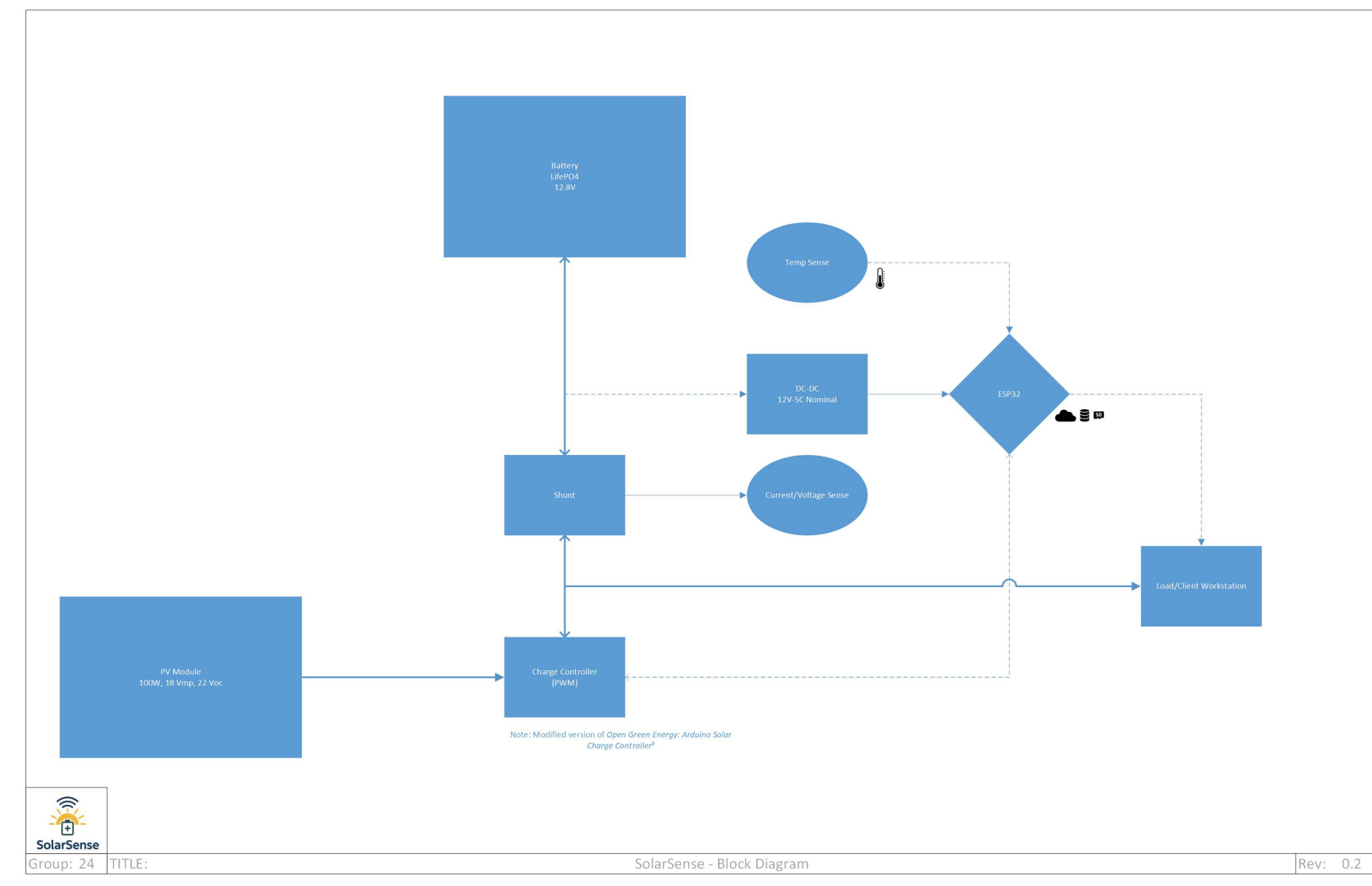
- The system was designed to meet the following requirements:
- Monitor a **12.8V LiFePO₄ battery (4S configuration)**
 - Interface with a **100W solar panel**
 - Implement a **PWM charge controller**
 - Measure **voltage, current, and temperature**
 - Provide **real-time data visualization**
 - Enable **wireless communication via Wi-Fi (MQTT)**
 - Ensure **safe battery operation through protection mechanisms**

Hardware Components

- ESP32-S3 Microcontroller
- ACS724 Current Sensors (PV + Battery)
- DS18B20 Temperature Sensors
- MOSFET switching stage
- Raspberry Pi 3B+ (dashboard)
- 1.3” OLED Display (I²C)
- 100W Solar Panel
- 12V LiFePO₄ Battery



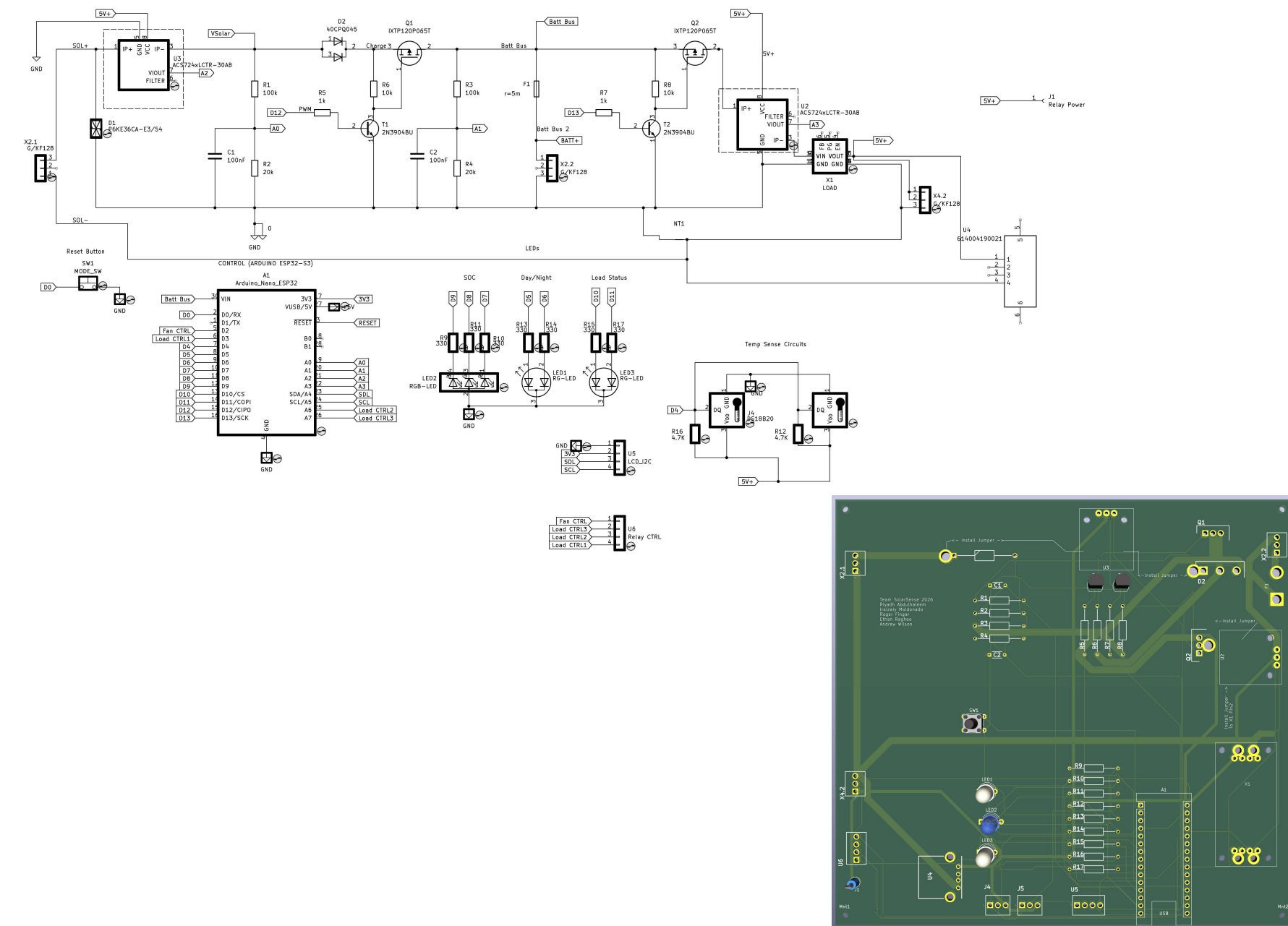
System Design



SolarSense system architecture showing power flow, sensing, and data processing through the ESP32.

Simulation / Implementation

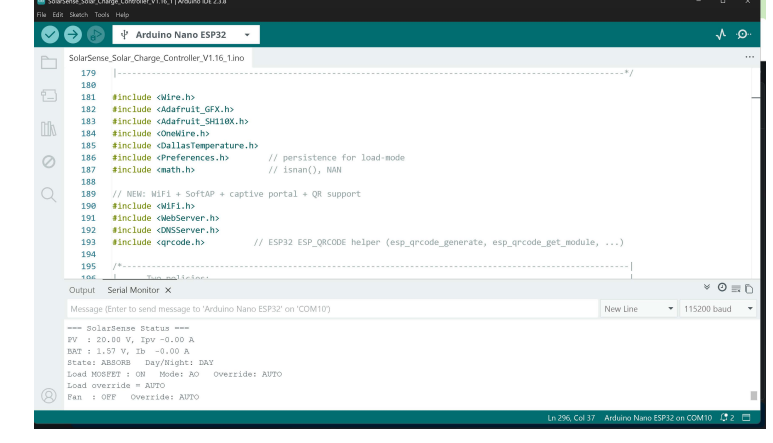
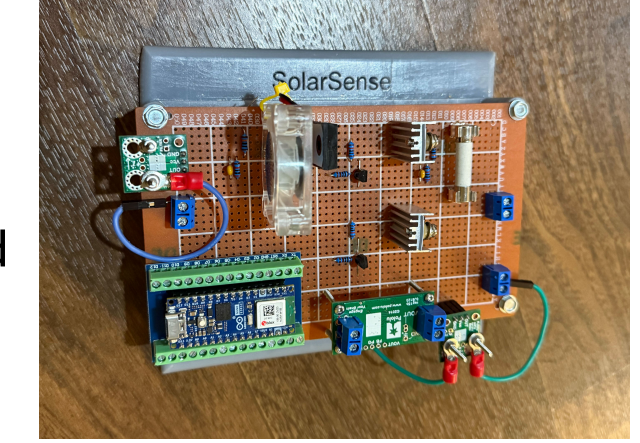
- Control system implemented using PWM charging (Bulk → Absorption → Float)
- Circuit designed and validated using **KiCad** and **PSpice**
- Firmware developed on **ESP32 (Arduino IDE)**
- PCB designed for improved integration and reliability



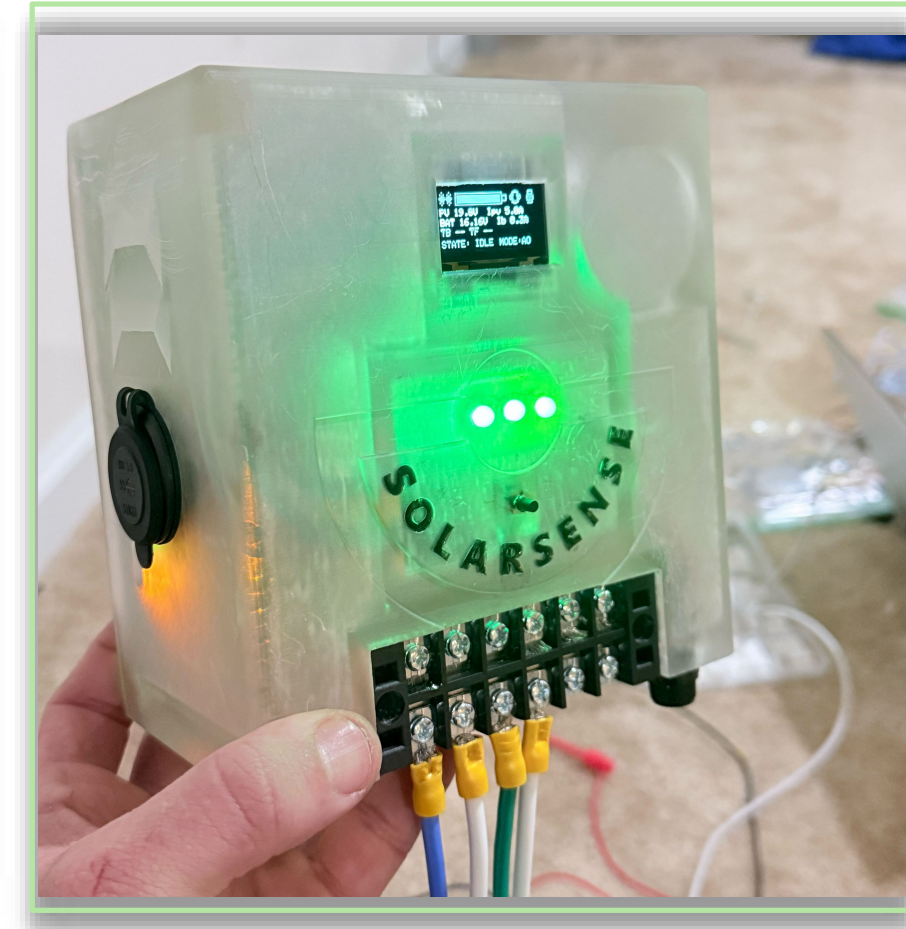
Testing

The system was tested through multiple stages, including subsystem validation and full system integration:

- Real-time monitoring verified through OLED and touchscreen interface
- Sensor accuracy validated under varying load conditions
- PWM charging behavior successfully controlled across all charging stages
- MQTT communication confirmed reliable data transmission



Final Prototype



Conclusion

The SolarSense system was successfully designed, built, and tested as a fully functional solar monitoring and control solution. The project demonstrates effective integration of hardware and software components, including sensing, control, and real-time data visualization. The system provides valuable insight into solar energy behavior while maintaining safe and reliable battery operation. SolarSense fulfills its goal of delivering a low-cost, transparent, and educational solar monitoring platform.