

# Smart Energy Meter: Real-Time Monitoring & Control

Power management for a smarter future.

Prateek Bhardwaj(12214917)

Nikhil (12211804)

Pritam Kumar(12220892)

Palli Anil Kumar(12221200)

Submitted to : Ch. Ravi Sankar (14909)

# Introduction to the Smart Energy Meter

A smart energy meter is a digital device that measures and records electricity consumption data in real-time. It provides valuable insights into energy usage patterns, empowering users to manage their energy more efficiently.

The primary objective of this project is to develop a "device that monitors, protects, and manages energy effectively" - a crucial tool for modern energy systems that demand increased sustainability and optimization.

# Introduction to the Smart Energy Meter

- **Rising Demand for Smarter Energy Systems:** The growing need for efficient and sustainable energy management drives the development of advanced metering solutions.
- **Limitations of Traditional Meters:** Conventional energy meters lack real-time monitoring capabilities and fail to provide comprehensive fault protection, limiting their effectiveness in modern energy grids.
- **Objectives:** The project aims to deliver a smart energy meter that offers real-time energy monitoring, fault detection and alerts, and cloud-based data analytics for improved energy management.

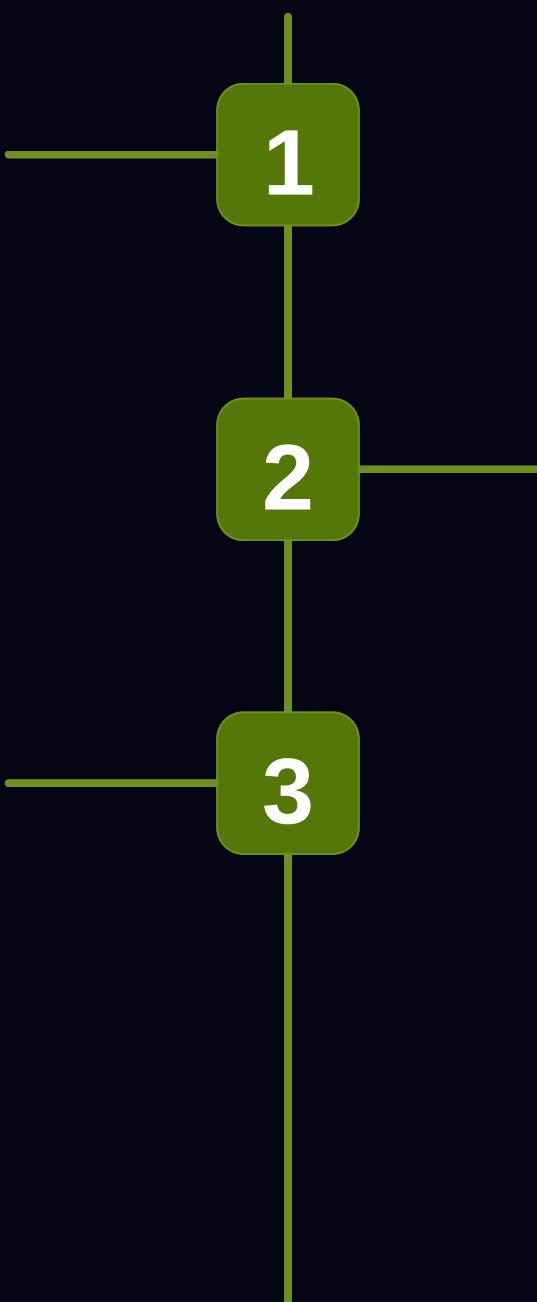
# Literature Review on Smart Energy Meters

## Traditional Meters

Traditional energy meters have limited functionality, relying on manual readings and lacking real-time data monitoring capabilities.

## Identified Gaps

Despite progress, there is still a need for more comprehensive smart meter features, including advanced fault detection and deeper data integration.



## IoT-Based Solutions

Advanced smart meter designs leverage IoT technologies, integrating various sensors and enabling cloud-based data analytics.

# Key Features of the Smart Energy Meter

## Line Switching

Automatically switches between the main power line and a backup line to ensure continuous electricity supply.

## Real-Time Monitoring

Provides accurate readings of current, voltage, and power consumption in real-time to enable better energy management.

## Protection Features

Safeguards against overloads and overvoltage to prevent damage to connected devices and ensure safety.

## Cloud Connectivity

Allows for remote data logging and analysis through seamless integration with cloud-based platforms.



# Technical Design & Coding Flow



## PZEM-004T Data

Voltage, current readings.

## ESP32 Processing

Data interpretation and control logic.

## ThingSpeak Integration

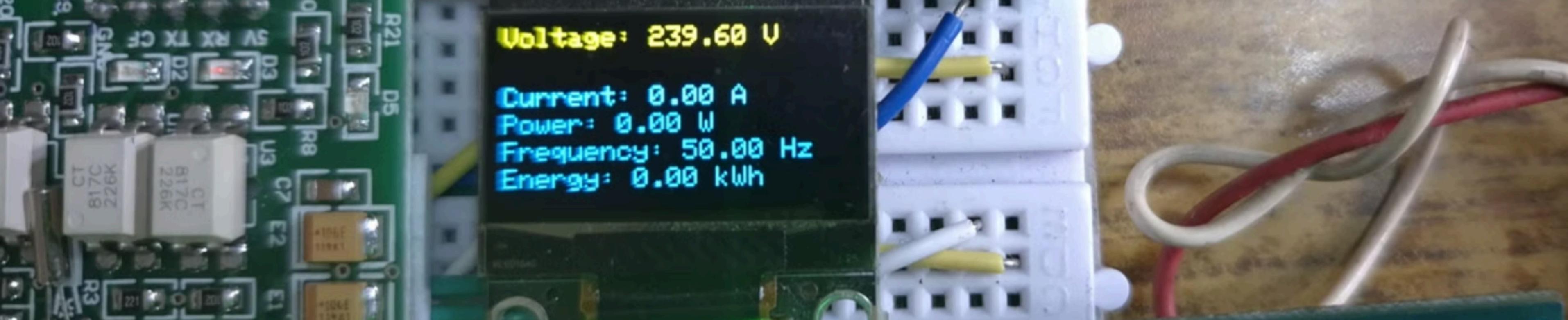
Cloud data storage and visualization.

## Relay Control

Power switching based on thresholds.

## Custom Dashboard

Data visualization and Power switching controls



# Hardware Components

PZEM-004T

Voltage & current monitoring

ESP32

WiFi connectivity & control

OLED Display

Real-time data display

Relay Modules

Power switching functionality

# Smart Energy Meter: Coding Flow



## Data Acquisition

The PZEM-004T module collects real-time data on voltage, current, and power consumption.

## Data Processing

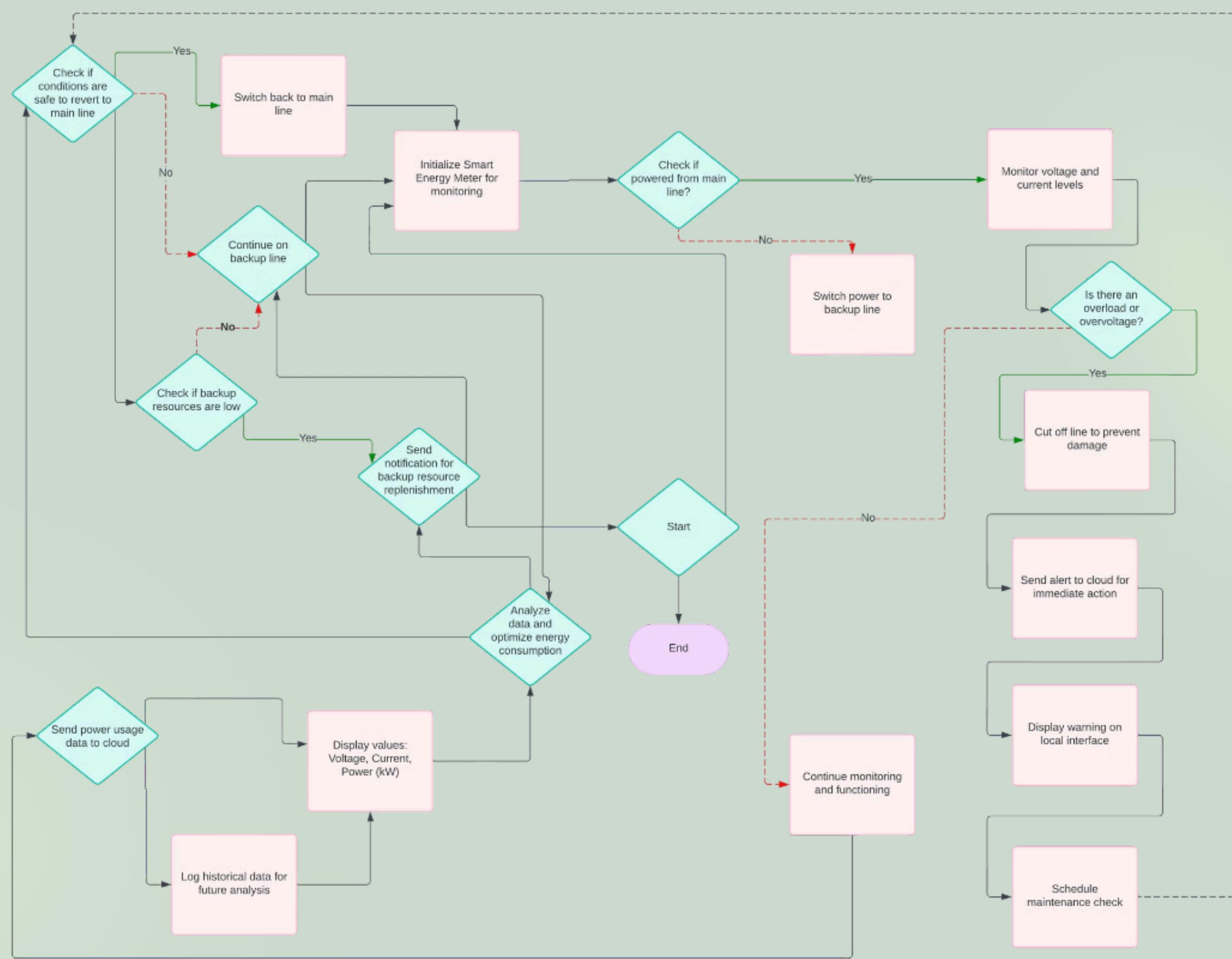
The ESP32 microcontroller interprets the sensor data and executes the control logic.

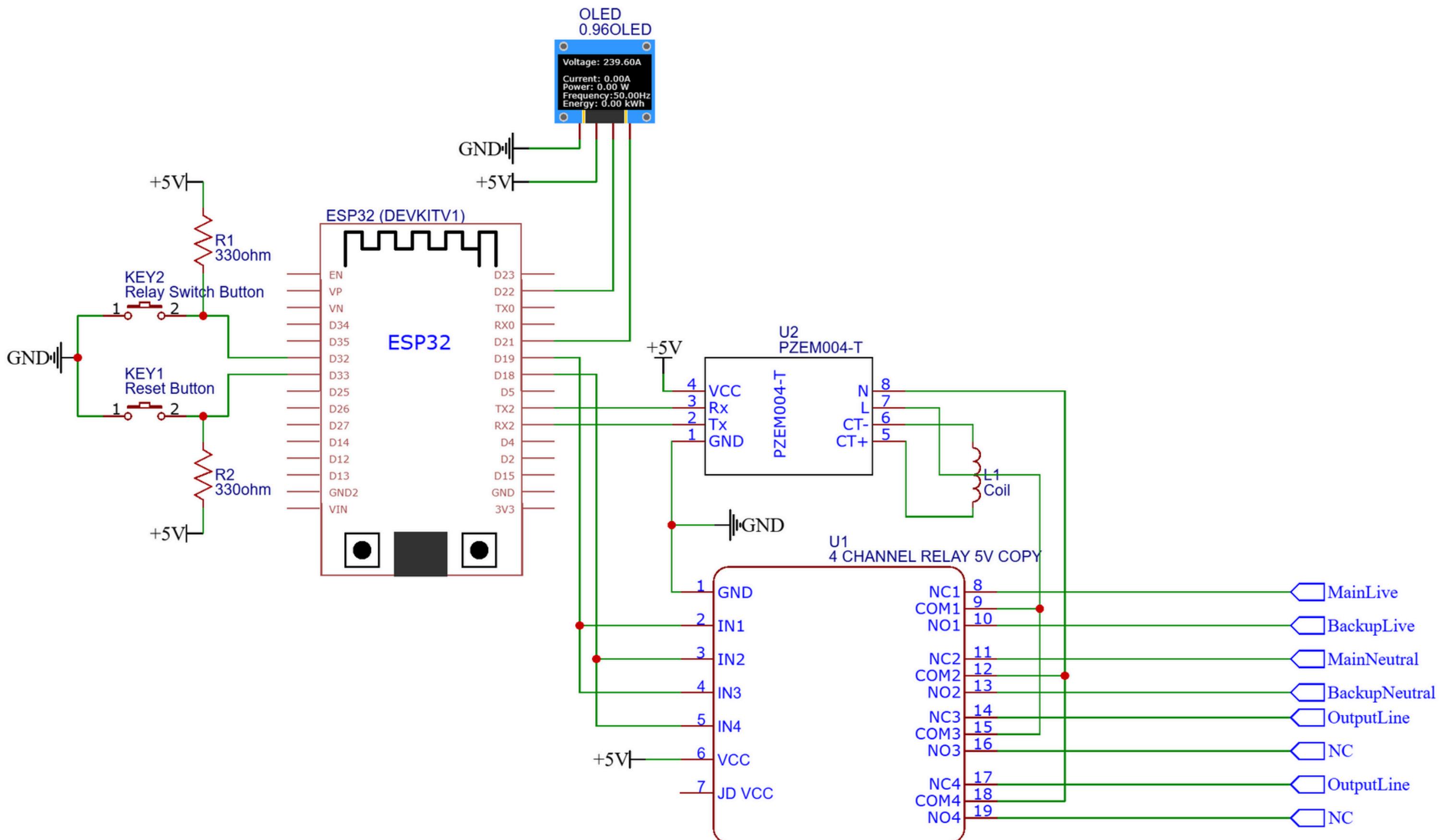
## Cloud Integration

The energy data is securely transmitted to the ThingSpeak IoT platform for storage and analysis.

## User Interface

The OLED display presents real-time energy metrics and allows for remote power switching.





# Library Used

```
#include <WiFi.h>

#include "ThingSpeak.h"

#include <Wire.h>

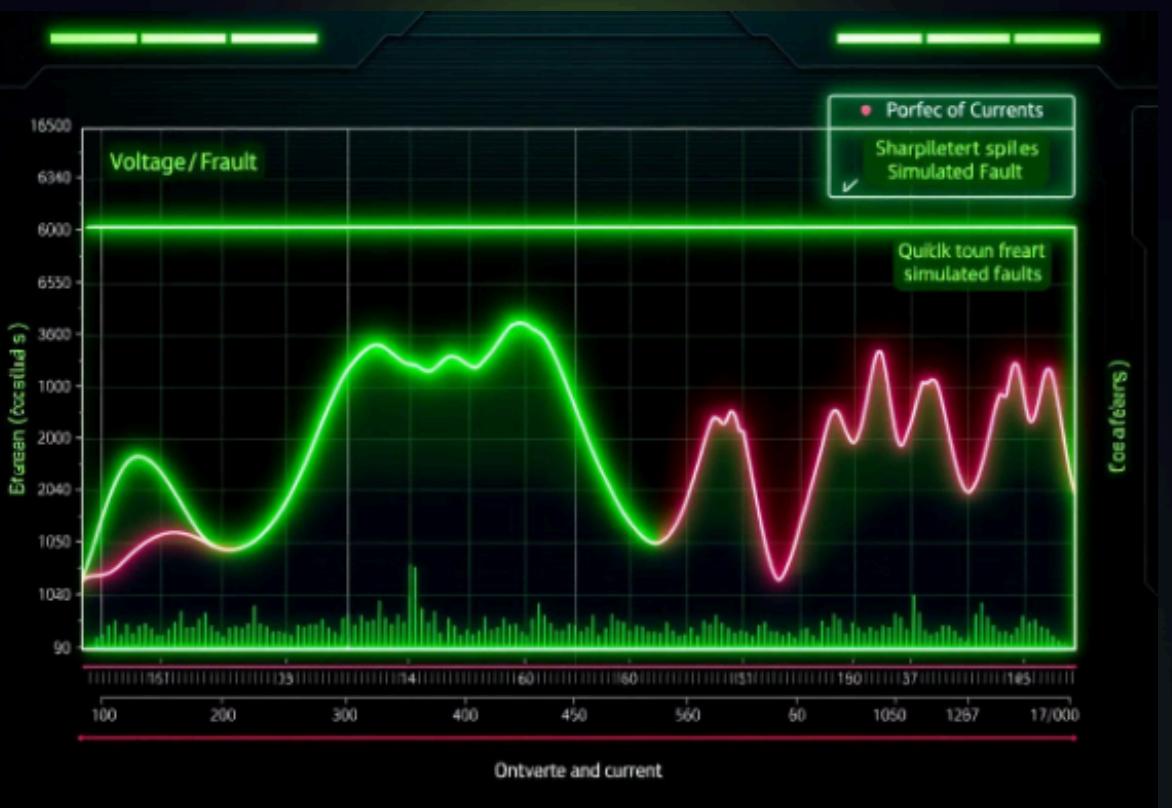
#include "DHT.h"

#include <Adafruit_GFX.h>

#include <Adafruit_SSD1306.h>

#include <PZEM004Tv30.h>
```

# Testing and Performance Evaluation



## Accurate Readings

The smart energy meter demonstrated highly accurate voltage, current, and power consumption readings, with an error of less than  $\pm 2\%$ .

## Reliable Fault Detection

The meter successfully identified and alerted users to various fault conditions, including overloads and overvoltage, ensuring the safety of connected devices.

## Responsive Performance

The system exhibited a rapid response time of under 1 second, enabling real-time monitoring and control capabilities.

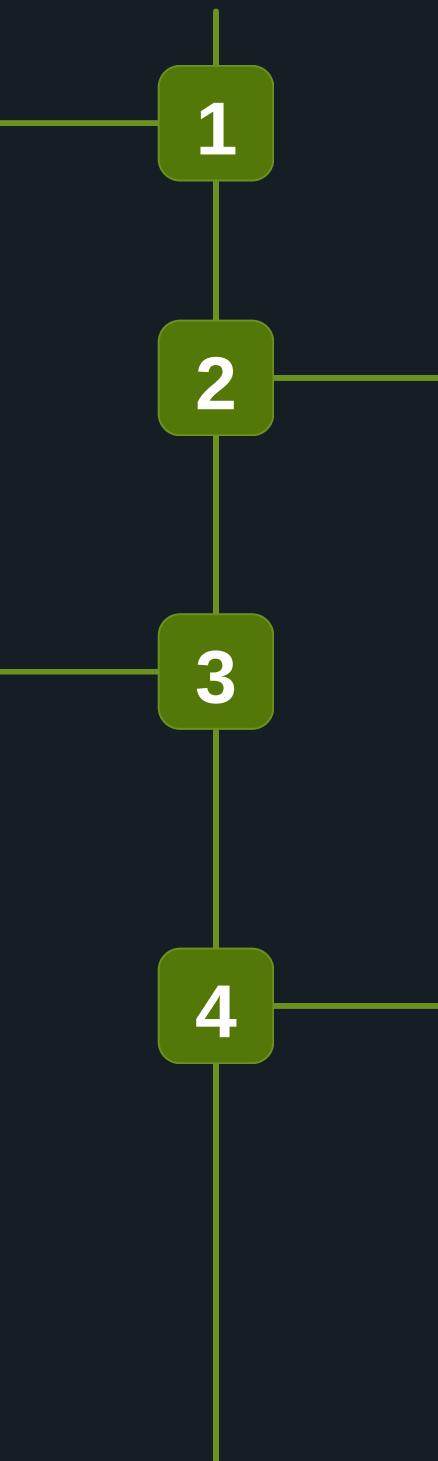
# Advantages of Using the Smart Energy Meter

## Improved Energy Efficiency

The real-time monitoring capabilities of the smart meter allow users to identify and address energy waste, leading to significant savings on utility bills.

## Enhanced Safety from Overloads

The smart meter's integrated overload protection automatically disconnects the power supply when usage exceeds safe thresholds, preventing damage to appliances and electrical systems.



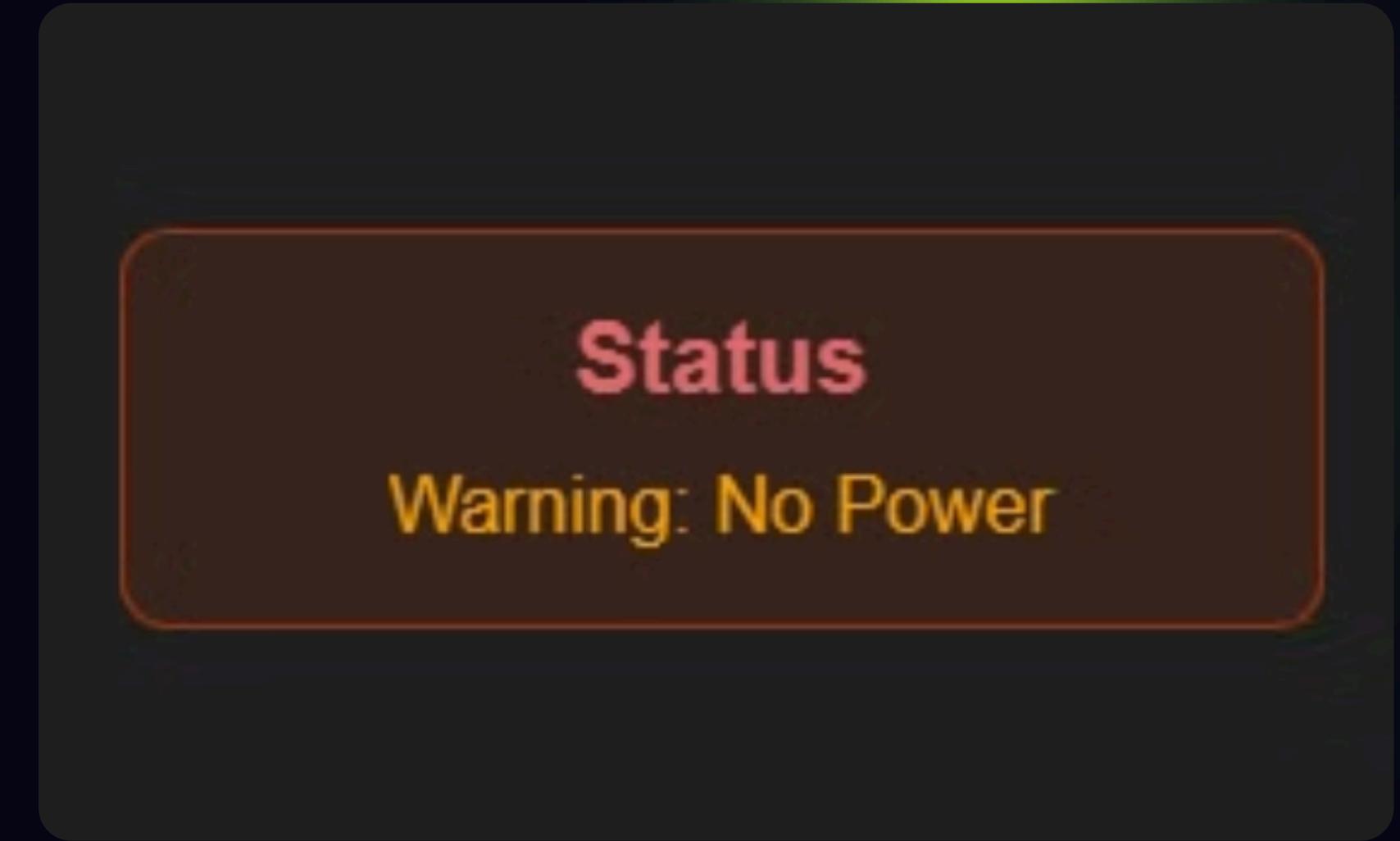
## Real-Time Monitoring and Alerts

The meter constantly tracks power usage and can instantly notify users of spikes or irregularities, enabling quick intervention to prevent issues.

## Cloud-Based Analytics for Insights

By integrating the smart meter with a cloud platform, users can access sophisticated data analysis and visualizations to gain deeper insights into their energy consumption patterns.

# User Interface on OLED Display



## Data Display

Voltage, current, power, frequency, and energy usage.

## Error Messages

Warning notifications during error conditions.

## ThingSpeak Data Visualization

Time Range: Today Chart Type: Line Number of Data Points: 60 Apply



# ThingSpeak Integration



## Real-Time Data

Voltage, current, power, and error codes.



## Remote Monitoring

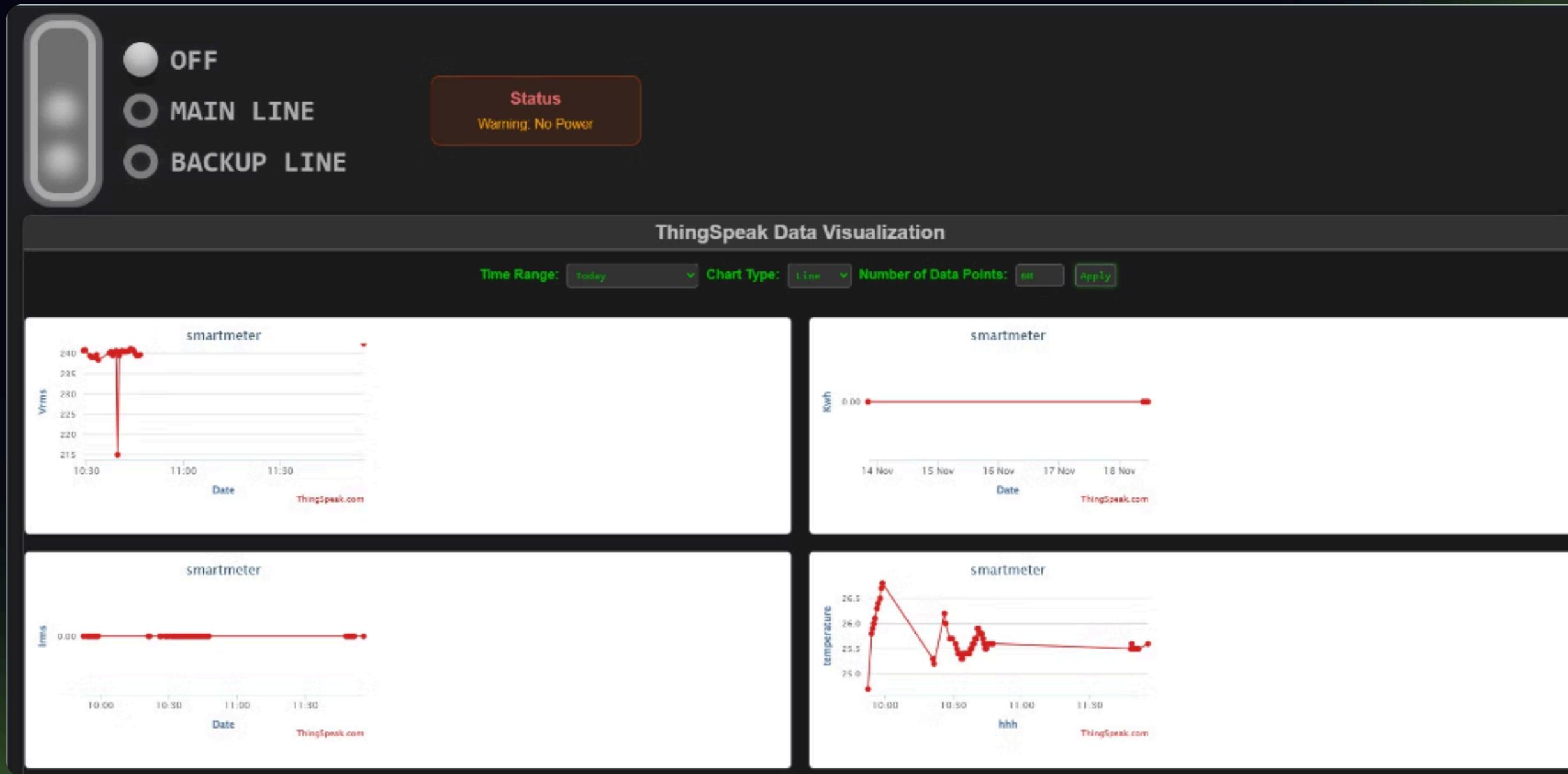
Access data and visualize trends over time.



## Remote Control

Manage power line switching from anywhere.

# User Dashboard Based on ThingSpeak

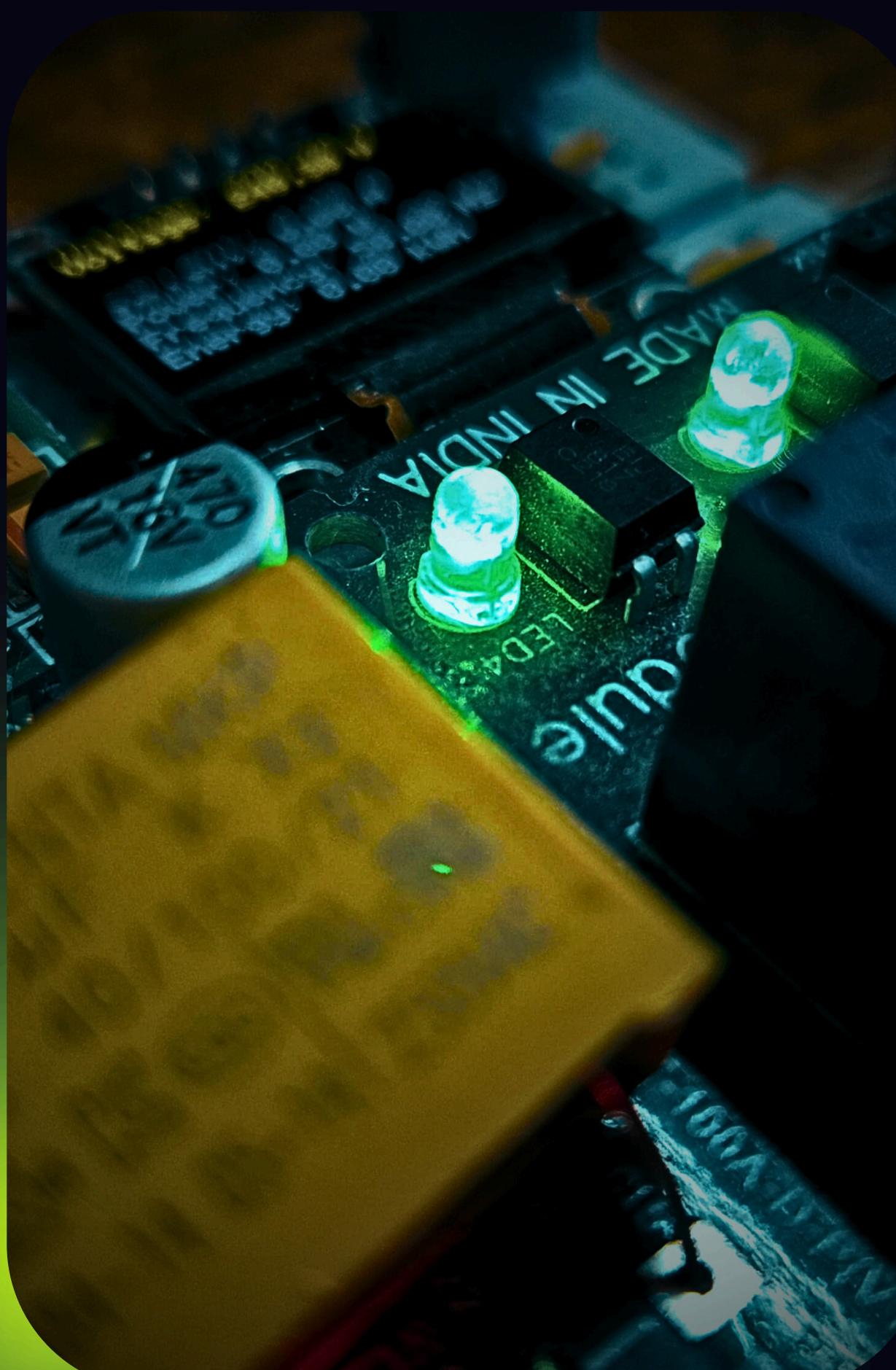


## Comprehensive Energy Analytics

The user dashboard on ThingSpeak provides real-time insights into energy consumption patterns, allowing homeowners to monitor and optimize their usage.

## Remote Power Management

Users can remotely control and switch on/off power lines through the cloud-connected dashboard, enabling convenient energy management from anywhere.



# Safety Features & Error Detection

- 1 **High Short-Circuit Detection**  
Error code 9 for short circuit events.
- 2 **Relay Shutoff**  
Disconnects power to prevent damage.
- 3 **Manual Reset Button**  
Allows user to reset the system after an error.
- 4 **OLED Display Warning**  
Displays error code and prompts user to reset.

# Applications of the Smart Energy Meter

- **Home Energy Optimization:** Track and manage energy usage in real-time to optimize household consumption and reduce utility bills.
- **Commercial Building Management:** Provide detailed insights on energy use patterns to identify inefficiencies and opportunities for savings.
- **Utility Grid Monitoring:** Collect granular data to help utilities better forecast demand, identify outages, and manage the grid more efficiently.
- **Electric Vehicle Charging:** Monitor and control the charging process to avoid overloads and optimize the use of renewable energy sources.
- **Renewable Energy Integration:** Seamlessly integrate with solar panels, wind turbines, and other distributed energy resources to enable smart energy management.

# Project Challenges

- **Voltage Fluctuations:** Addressed by incorporating dynamic voltage regulation to ensure stable power supply.
- **Cloud Connectivity:** Implemented redundant WiFi and Ethernet options to maintain reliable ThingSpeak integration.
- **Error Reset:** Integrated a manual reset button and automatic error detection to quickly recover from issues.
- **Safety Hazards:** Designed robust overload protection and automatic power shutoff to prevent device damage.
- **User Experience:** Optimized the OLED display interface for intuitive monitoring and control.

# Testing and Performance Evaluation

**Load Testing:** The system was subjected to overload conditions by simulating high-power consumption scenarios. The overload protection mechanism successfully triggered the power shutoff, preventing potential device damage.

**Energy Monitoring:** Comprehensive power consumption tracking allowed the identification of inefficient usage patterns. The data displayed on the OLED and uploaded to ThingSpeak enabled informed decisions for optimizing energy usage.

# Future Prospects and Innovations



## AI-Based Energy Usage Predictions

Advanced machine learning models analyze historical data to forecast energy consumption patterns, enabling proactive management and optimization.



## Renewable Energy Integration

The smart energy meter will integrate with a variety of renewable energy sources, allowing for dynamic load balancing and increased reliance on clean power.



## Enhanced User Interface

An improved user interface with personalized dashboards and advanced control options will empower consumers to take a more active role in managing their energy usage.

# Conclusion and Key Takeaways

## 1 Smarter Energy Management

The smart energy meter enables real-time monitoring and control, empowering users to make data-driven decisions to optimize energy consumption.

## 2 Enhanced Safety and Reliability

Robust overload protection, automatic power shutoff, and error detection features ensure the safe and reliable operation of the system.

## 3 Sustainable Energy Integration

Seamless integration with renewable energy sources like solar and wind power promotes the adoption of clean energy solutions.

## 4 Scalable and Versatile

The smart energy meter's modular design and cloud connectivity make it adaptable to a wide range of residential and commercial applications.

# References

- **PZEM-004T Datasheet** - Technical specifications and operating parameters for the PZEM-004T energy monitoring module used in the smart meter design.
- **ThingSpeak IoT Analytics Platform** - Documentation for setting up IoT data storage and visualization with ThingSpeak.
- **Chatgpt** - Used for generating project documentation, technical guidance, and refining content related to the smart energy meter, including hardware/software integration and IoT implementation.
- **YOUTUBE** - [https://www.youtube.com/watch?v=h3\\_sOcrZwYw](https://www.youtube.com/watch?v=h3_sOcrZwYw) , <https://www.youtube.com/watch?v=ca6copwwg8w>,  
[https://www.youtube.com/watch?v=j0\\_y8dPfpKc](https://www.youtube.com/watch?v=j0_y8dPfpKc) , [https://www.youtube.com/watch?v=nS\\_h2XI8iSY](https://www.youtube.com/watch?v=nS_h2XI8iSY)
- **ESP32 Documentation** - Comprehensive reference for programming and integrating ESP32 microcontrollers in IoT systems.

# References

- **Connecting ESP32 to ThingSpeak** - How to publish data from ESP32 to ThingSpeak for monitoring and analytics.
- **ESP32 and PZEM Energy Monitoring System** - A practical guide to building energy monitoring systems with PZEM and ESP32.
- **ThingSpeak IoT Data Visualization Tutorial** - How to use ThingSpeak for collecting and visualizing IoT data.
- **0.96-inch OLED Display Guide** - A detailed guide for wiring and coding OLED displays with microcontrollers.
- **Using Relays with ESP32** - A detailed explanation on relay operation and how to control them using ESP32.

# Questions and Feedback

We welcome your questions and feedback about the smart energy meter project. Please share your thoughts, concerns, or ideas for improvement. Your input is invaluable as we continue to refine and enhance this innovative energy management solution.

