Project Scope: ESP32-Based Smart Energy Monitoring & Control Unit

# 1. Overview

This project aims to design and implement a Smart Energy Monitoring and Relay Control Unit based on the ESP32-WROOM-32 microcontroller. It integrates real-time power/voltage monitoring using the BL0942 energy metering chip and includes one 30A high-power relay for load control, Ethernet connectivity, TFT screen display, and I/O expansion via I²C and IR interfaces. The firmware is built using ESPHome for easy Home Assistant integration and OTA support.  
  
This device is suited for smart home energy automation, industrial load control, and power diagnostics systems.

# 2. Key Objectives

* Real-time monitoring of voltage, current, power, and energy consumption
* Safe control of a high-current load (up to 30A)
* Real-time display of energy stats, device state, and network info
* Integration with ESPHome + Home Assistant
* Support for Ethernet, Wi-Fi, Bluetooth, USB-C, and I²C expansion
* IR control interface for automation triggers
* Dry contact input support
* Compact, DIN-rail or wall-mountable hardware design

# 3. Hardware Components

|  |  |
| --- | --- |
| Component | Details |
| MCU | ESP32-WROOM-32 (Dual-core, WiFi, BLE) |
| Energy Monitor | BL0942 (active power, voltage, current, energy) via UART |
| Relay | HF2150-1A-5DE, SPDT, 30A, 5V coil |
| Voltage Sensor | ZMPT107-1 (AC voltage monitor, analog) |
| Display | ILI9341 TFT, 2.8", 240x320, SPI |
| Digital Input | 1x dry contact |
| Push Buttons | S1 = Reset / S2 = Download |
| I2C Bus | 1x I²C terminal block for expansion (BME280, OLED, RTC, etc.) |
| Ethernet | LAN8720 10/100Mbps PHY (PoE optional) |
| IR Interface | IR Receiver and IR Transmitter sockets |
| Power Supply | 12–24V DC (default), or AC 100–240V (optional) |
| USB Interface | USB Type-C for power/flashing/debugging |

# 4. GPIO Pin Mapping (ESP32)

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| --- | --- | --- |
| Peripheral | Function | GPIO Pin |
| I²C SDA | I²C data | GPIO 16 |
| I²C SCL | I²C clock | GPIO 15 |
| Relay Output | Relay control | GPIO 33 |
| Digital Input | Dry contact input | GPIO 32 |
| IR Sender (TX) | IR LED | GPIO 4 |
| IR Receiver (RX) | IR photodiode | GPIO 5 |
| BL0942 UART RX | ESP32 receive from BL0942 | GPIO 13 |
| BL0942 UART TX | ESP32 transmit to BL0942 | GPIO 14 |
| Ethernet MDIO | LAN8720 | GPIO 18 |
| Ethernet MDC | LAN8720 | GPIO 23 |
| Ethernet Clock | ETH\_CLK\_OUT | GPIO 17 |
| TFT SCK | SPI Clock | GPIO 25 |
| TFT MOSI | SPI Data Out | GPIO 26 |
| TFT DC | Display Data/Command | GPIO 27 |
| TFT CS | Chip Select | GPIO 19 |
| TFT RESET | TFT Reset | GPIO 22 |
| TFT BL | TFT Backlight | GPIO 21 |

# 5. Communication & Interfaces

* WiFi (802.11 b/g/n)
* Bluetooth (Classic + BLE)
* Ethernet (LAN8720) with IPv4/IPv6
* USB Type-C – Flashing, debugging, power input
* I²C Expansion Terminal – Sensors like BME280, OLED, RTC
* IR Transmitter/Receiver
* Relay Output – SPDT 30A
* Dry Contact Input – e.g., door switch or trigger
* TFT SPI Display – Status and diagnostics

# 6. Display Capabilities (ILI9341 TFT)

Type: TFT LCD, 2.8", ILI9341, SPI interface  
Resolution: 240x320 pixels  
Functions: Show voltage, current, power, energy  
Additional Info: Network status, relay state, time, errors  
Optional: Touchscreen overlay (if touch-enabled)

# 7. Firmware Platform

ESPHome (YAML-based)  
- BL0942 UART sensor integration  
- ILI9341 display widgets via SPI  
- Relay control with automation triggers  
- OTA firmware update via WiFi or Ethernet  
- Home Assistant auto-discovery  
- Dry contact input mapping  
- IR control via remote\_transmitter and remote\_receiver  
- I²C expansion for sensors and displays

# 8. Mechanical Design

- Compact layout for DIN-rail or enclosure mounting  
- Front-facing TFT screen  
- Rear/side terminal blocks for AC/DC input, sensors, relay  
- Power: 12V–24V DC (default) or 100–240V AC (optional)  
- PoE power optional via Ethernet

# 9. Deliverables

* Complete Schematic (KiCAD / Altium)
* PCB Layout & Gerbers
* Bill of Materials (BOM)
* ESPHome YAML firmware file
* Display UI mockups
* Enclosure model (3D STEP/STL)
* Wiring Diagram & Test Manual
* GitHub Repo with full project
* Assembly & Configuration Guide

# 10. Testing & Validation

Relay Test: Load switching (manual and remote via Home Assistant)  
Energy Meter Test: BL0942 accuracy (compare to multimeter reading)  
Ethernet Test: LAN8720 speed, link check, OTA flashing  
Display Test: SPI communication, screen updates  
I/O Functionality: Button input, dry contact, I²C device recognition  
IR Test: Send/receive test via IR LED and receiver  
OTA & MQTT: ESPHome OTA and Home Assistant dashboard sync