Department of Electronic and Telecommunication Engineering

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EN2160 Engineering Design Realization

Smart Energy Meter Project Report

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200641T

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1. Abstract

This report presents the comprehensive analysis of a smart energy monitoring device project undertaken for the EN2160 - Engineering Design Realization course. The report encompasses a detailed overview of the device's functionality, specifications, the entire design process, and user instructions. Through this project, a state-of-the-art smart energy monitor has been developed to provide real-time energy consumption data and enable users to optimize power usage effectively. The report offers valuable insights into the design and implementation of the device, shedding light on its contribution towards promoting energy efficiency and sustainability.

2. Introduction

The Smart Energy Meter is a sophisticated and user-friendly device that goes beyond simple energy measurement. It serves as an indispensable tool in helping users optimize their power consumption and reduce energy wastage effectively.

Equipped with non-invasive sensing technology, the Smart Energy Meter accurately measures the electrical parameters within a residence, such as current, power, and energy consumption. Real-time data is processed and displayed on the device's screen, providing users with valuable insights into their energy usage.

Through seamless integration with a mobile application, users gain remote access to energy data from anywhere in the world. This empowers them to monitor their energy consumption even when away from home, enabling informed decision-making to manage power usage efficiently.

The Smart Energy Meter's proactive approach to energy conservation sets it apart from conventional energy monitoring devices. Upon detecting the activation of high-power consuming devices, such as air conditioners or electric heaters exceeding 700W, the device emits a distinct beeping sound. Simultaneously, an LED indicator illuminates if the total power consumption in the house surpasses 1150W. These immediate alerts draw users' attention to energy-intensive activities, encouraging them to take prompt action and make conscious choices.

Furthermore, to reinforce energy-saving efforts, the Smart Energy Meter generates mobile notifications to inform users of the high-power consumption instances. This timely reminder serves as a gentle nudge to adjust their power usage habits and adopt more energy-efficient alternatives.

3. Functionality

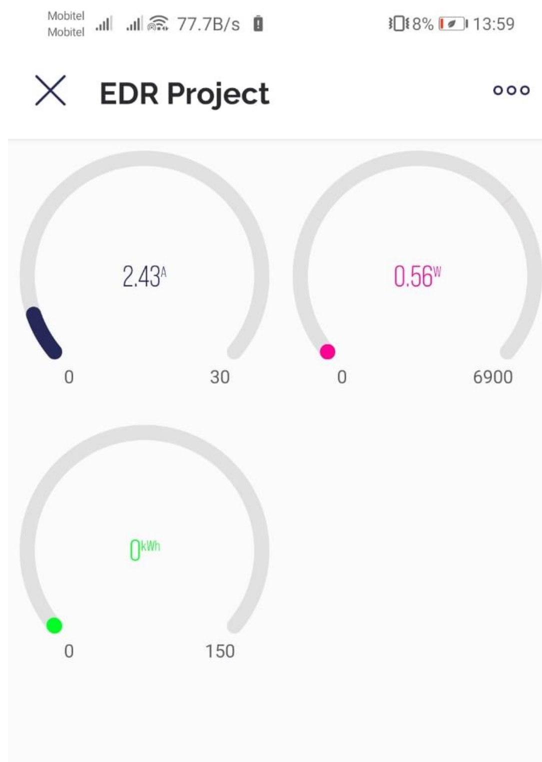
The device is designed to be easily integrated into a 230V power supply, and its non-invasive current sensor can be securely clamped to either the live or neutral wire of the main power supply in the house.

To provide user convenience, the device features a refresh button, located on the leftmost side, allowing the system to be easily refresh if needed. The device's screen displays real-time information, including Current, Power, and the number of Units being consumed.

Units can be reset by pressening reset button which is at the middle. Display can change for current , Power and unit with use of change button which is the left ost button of the device.

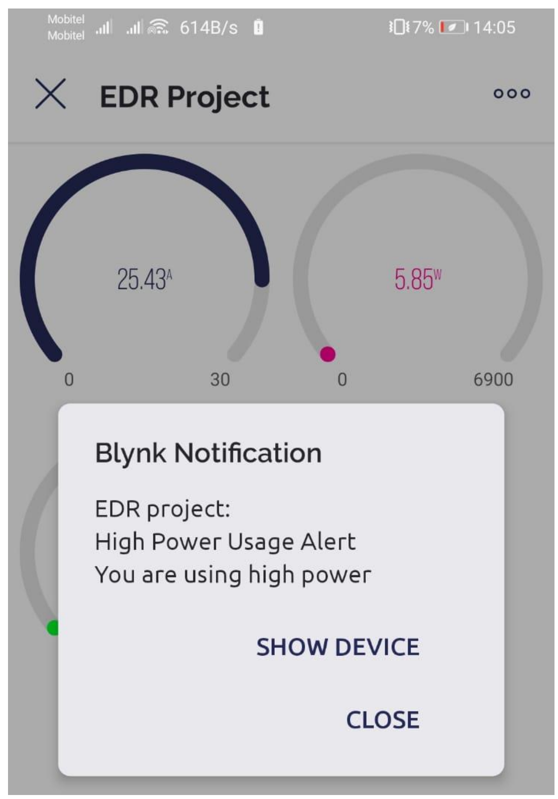
Blynk IOT mobile application can be used to connect with the device through WIFi. The Blynk IOT application can be download and install using the playstore.

The device incorporates alerting mechanisms to ensure proactive energy management. When a high-power consuming device is plugged in, the device alerts users through buzzing sounds. Moreover, if the total power consumption exceeds a predefined threshold, an LED illuminates to indicate the situation. Furthermore, a notification is sent to the user's mobile phone, notifying them of the high power consumption event.



4. Product Specifications

- Supply Voltage 230V/50Hz
- Rated Measuring Current (0-30) A
- Accuracy ±2%
- power consumption <3w
- Operating Temperature 25°C - 75°C
- Supply voltage 230V/50Hz
- Operating voltage 5V DC
- 0.96" OLED display.
- Wi-Fi 2.4 GHz support WPA/WPA2
- Mobile Application
- Real time data monitoring system.



5. Circuit Design

The design of the smart energy meter circuit involves the consideration of four primary parts to streamline the implementation process:

1. Measuring Current:

In this part, the circuit focuses on accurately measuring the electric current flowing through a electrical circuit

2. Processing Data:

Once the current measurement is achieved, the circuit proceeds to the data processing phase. Here, the raw current data is transformed into meaningful information.

3. User Inputs and Outputs:

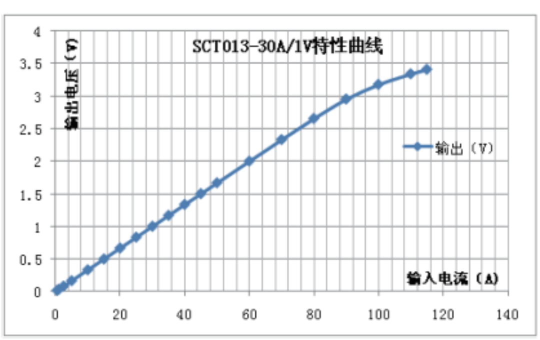
The final part considers taking some additional data entered by user and presenting the processed data to the end-user in a user-friendly manner.

4. Power Supply Unit

Consider how to convert 230V AC voltage to a stable 3.3V DC Voltage.

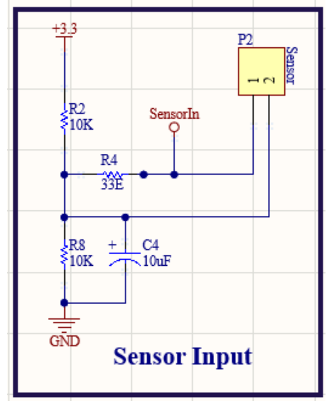
5.1 Measuring Current

The SCT013-030 Split core current transformer serves as the current sensor in the system, ensuring precise current measurement with an accuracy of ±1%. This specific model, SCT013-030, exhibits a linear characteristic for voltage(output) concerning the current(input).



The SCT013-030 has a rated input current (rms) of 30A and provides a rated output voltage (rms) of 1V. Since the product incorporates the ESP8266 microcontroller, it becomes necessary to convert that output voltage to a scale which is compatible with the esp8266 microcontroller. (More details are discussed in the calculation and calibration section of the report.)

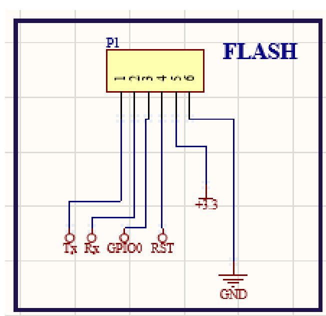
To achieve this conversion and establish a common reference ground for both the microcontroller and the sensor, a specific circuit has been designed.

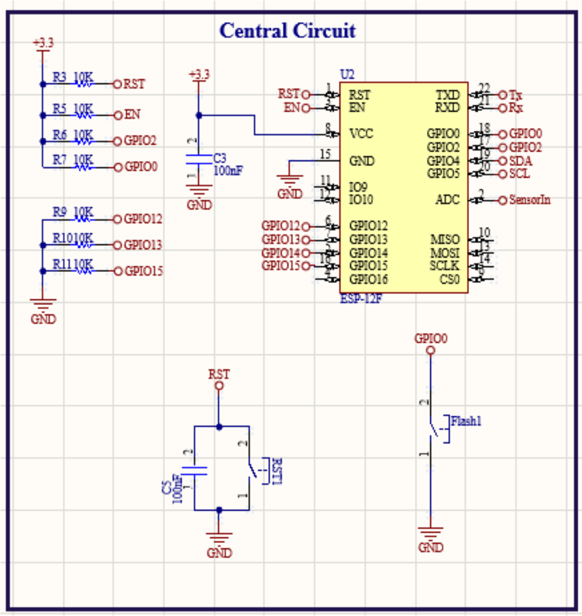


5.2 Processing Data

The ESP8266 microcontroller plays a central role in the smart energy meter system, as it processes the input data from the current sensor and performs the necessary calculations to determine the energy consumption and other relevant outputs (These calculations are discussed in detail in the calculation and calibration part).

To facilitate easy updates and enhancements to the system, a flashing mechanism has been integrated into the circuit. This mechanism allows the firmware running on the ESP8266 to be quickly modified or replaced. Also, it enables the system to adapt to evolving requirements and ensures that the smart energy meter remains up to date with the latest functionalities and optimizations.



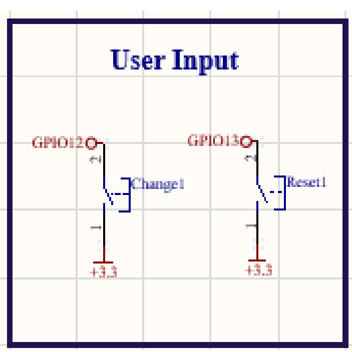


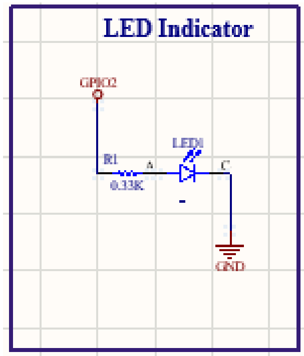
5.3 User Inputs and Outputs

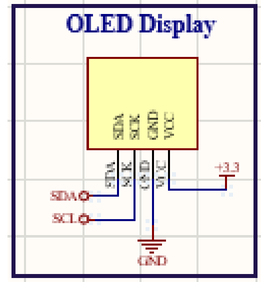
Various output methods are considered, such as digital displays, wireless communication with a mobile app and alerting systems with buzzer and LED.

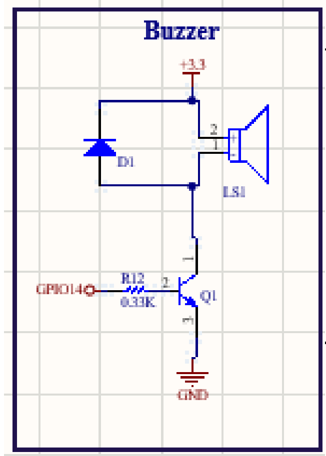
Some User Inputs are taken to control the digital display(change1) , refresh the system(RST1) and reset some readings(Reset1).

The objective is to furnish clear and comprehensive information about energy consumption, empowering users to make informed decisions to optimize their energy usage and promote energy efficiency.





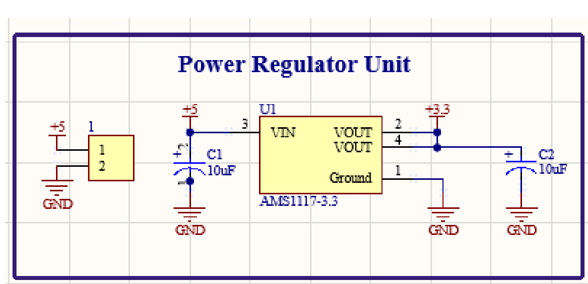




5.4 Power Supply Unit

The 5V DC power supply obtained from the Switch Mode Power Supply (SMPS) serves as the primary power source for the circuit. To provide the required 3.3V DC power supply for the ESP8266 microcontroller and other components, a voltage reduction and regulation circuit have been implemented.

The specific circuit used for reducing and regulating the voltage from 5V to 3.3V. It maintains a stable 3.3V output, ensuring the reliable operation of the microcontroller and other components within their specified voltage range.



6. Critical Component Selection

6.1 Current Sensor

The SCT013-030 Split core transformer serves as the current sensor for the smart energy meter. This sensor is capable of handling a large input range of currents. Based on statistical data, the total current (rms) typically used in a medium-level house is found to be less than 30A. As a result, the SCT012-030A variant of the sensor proves to be sufficient and cost-effective for most applications. However, when necessary, the SCT013-100A can be used without any modification, providing a higher current handling capability.

One of the advantages of the SCT013 series current sensors is their linear relationship between input current and output voltage, which holds true for a broad range of input currents. This characteristic simplifies the handling and processing of the sensor's output data, making it straightforward to convert the current measurements into meaningful energy consumption information.

Furthermore, being a non-invasive sensor, the SCT013-030 does not require any alterations or modifications to the existing electrical circuit that the user is interested in monitoring. This feature allows for easy and hassle-free installation of the smart energy meter device without the need for invasive interventions, making it a user-friendly and convenient solution for energy consumption monitoring in various settings.

6.2 Microcontroller

The ESP8266 microcontroller is deemed the simplest and most cost-effective choice to meet the design requirements for the smart energy meter. It offers a set of features that make it ideal for this application.

The ESP8266 provides 1 analog input, which can be utilized for interfacing with the current sensor. Additionally, it offers 11 usable digital input/output pins, which can be used to connect OLED display, Buzzer, LED, and other user inputs.

The built-in Wi-Fi communication capability of the ESP8266 allows data transfer and communication with mobile applications.

While other microcontrollers in the market, like the ESP32, also meet the design requirements, the ESP8266 stands out as a more cost-effective and straightforward option.

By opting for the ESP8266 microcontroller, the design achieves a balance between cost-effectiveness, simplicity, and the necessary functionality to fulfill the requirements of the smart energy meter project.

6.3 Power Supply unit

Indeed, a Switch Mode Power Supply (SMPS) is an efficient and accurate method to convert the 230V AC supply voltage to a stable 5V DC output. SMPS technology is widely used in various electronic devices due to its higher efficiency and lower heat dissipation compared to traditional linear power supplies.

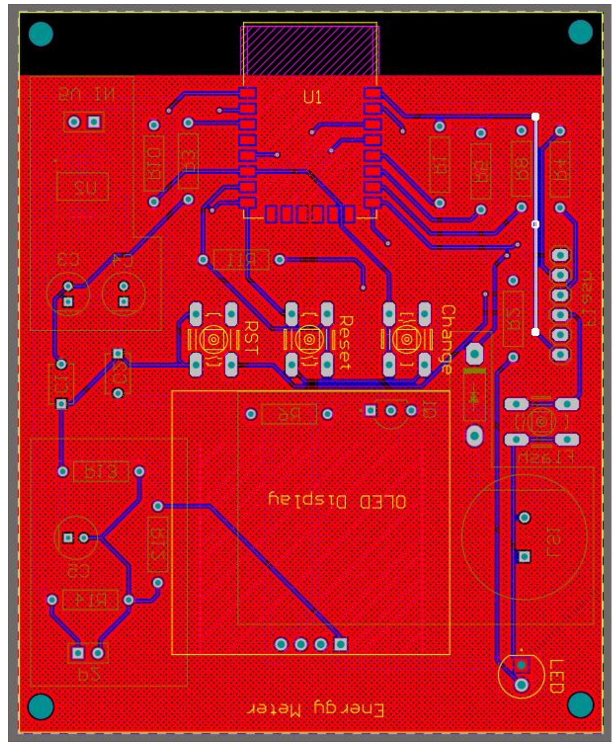
The selection of a 5W SMPS for the smart energy meter is a suitable choice because it is capable of providing a 5V output voltage with a maximum current output of 1A. Since the smart energy meter is a low-power consuming device, 5W is more than sufficient to power all the components and functionalities effectively.

By utilizing an SMPS in the design, the energy conversion process is optimized, resulting in reduced power wastage and improved overall efficiency. This, in turn, contributes to the energy efficiency of the smart energy meter, aligning with the project's goal of monitoring and promoting energy-conscious practices.

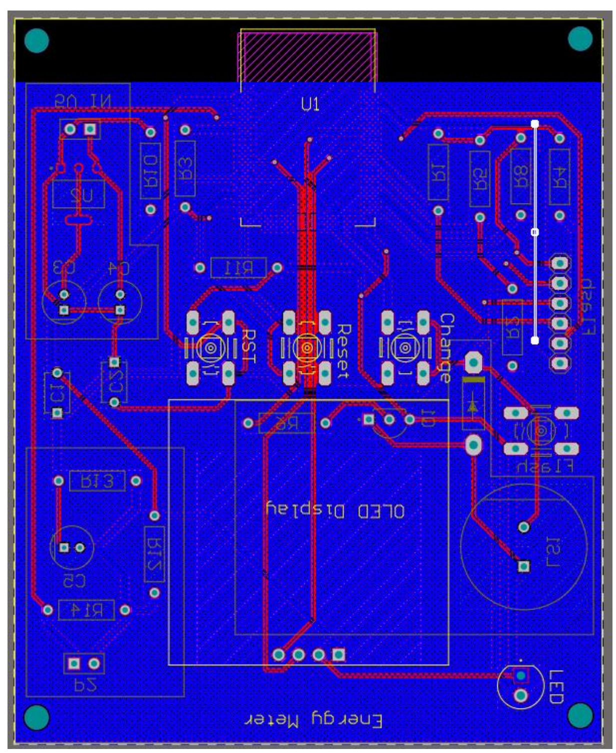
7. Schematic and PCB Design

The PCB and Schematic design for the smart energy meter were accomplished using the Altium Designer software, following the specific requirements of the manufacturer, JLCPCB. The circuit layout was designed as a double-layer PCB, which is a common and cost-effective choice for many electronic devices.

To ensure proper grounding and minimize interference, both PCB layers were grounded by creating polygon pours.



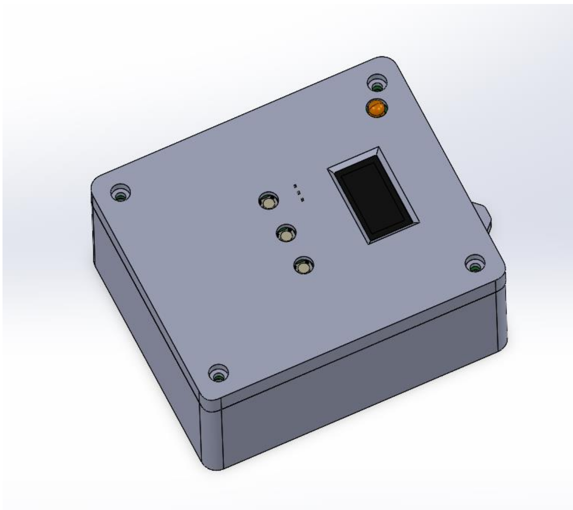
Top Layer



Bottom Layer

8. Enclosure Design

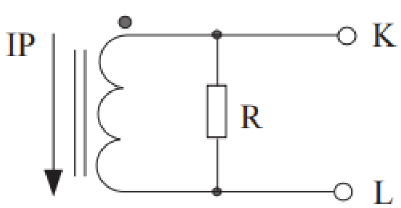
The Enclosure of the Smart Energy Monitor was designed using the SOLIDWORKS software.



9. Calculations and Calibrations

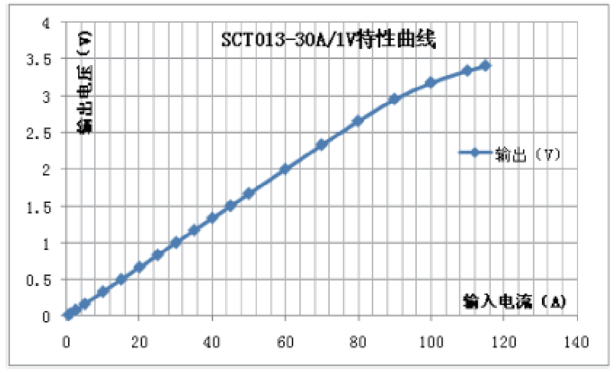
9.1 Current measurement

SCT013-30A split core transformer is used as the current sensor in the smart energy monitor circuit. And it has an internal circuit like below.



Built-in with sampling resistance voltage output type

So, it has a linear relationship between input current and the output voltage as below.



Therefore, the resulting sensor output voltage is an AC signal which alternate between $\pm V_{pp}$.

We know,

$$V_{pp} = \sqrt{2}\, V_{rms}$$

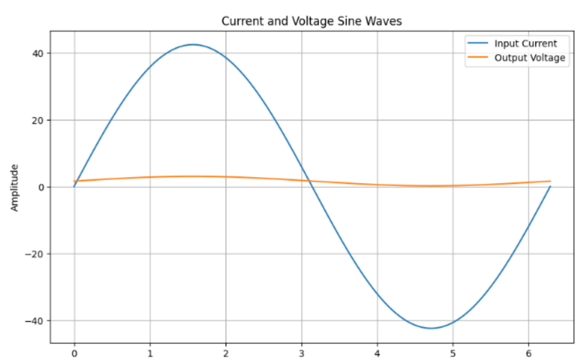
In this case for 30A rated rms input current $\pm V_{rms} = 1V$.

Therefore,

$\pm V_{pp} = \sqrt{2} = \pm 1.414V.$

To process the input data from the SCT013-30A current sensor, it needs to be provided as an analog input to the ESP8266 microcontroller, which operates within a voltage range of 0 to 3.3V. To achieve this voltage range, a bias voltage of 1.6V is added using a simple voltage adder circuit (described in circuit design section) . As a result, the input to the ESP8266 varies between 0.2 - 3V.

Then the final relationship between input and output can be illustrated as below.



In the calibration process (In Arduino Code) ensures that the current readings obtained from the

SCT013-30A current sensor are accurately facilitating precise and reliable current and energy consumption calculations in the smart energy monitor.

9.2 Power Calculation

The smart energy monitor project involves certain assumptions to simplify the calculations and design. These assumptions are as follows:

1. Constant Power Line Voltage: The power line voltage is assumed to remain constant at 230V throughout the operation of the smart energy monitor. This assumption allows for simplified calculations and ensures consistent measurement and analysis of energy consumption.

2. Negligible Difference between Apparent Power and Real Power: It is assumed that the difference between apparent power (P=VI) and real power is negligible, implying that the power factor is approximately equal to 1. In practical scenarios, loads with a power factor close to 1, such as resistive loads, are considered to minimize the impact of reactive power.

3. Linear Relationship between Voltage and Current for Passive Loads: It is assumed that the loads connected to the smart energy monitor are passive and have a linear relationship between voltage and current. This assumption is valid for many common household appliances and devices, making it easier to determine real power consumption based on voltage and current measurements.

By making these assumptions, the design and calculations for the smart energy monitor become more straightforward and enable the accurate assessment of energy usage in various household scenarios. However, it is essential to acknowledge these assumptions and consider their potential limitations when interpreting the results and applying the smart energy monitor in real-world situations.

$$power = V_{rms} * I_{rms}$$

$$power = 230 * I_{rms}$$

$$I_{rms} = \frac{I_{pp}}{\sqrt{2}}$$

I_{pp} can be found continuously reading the analogue input to the esp8266.

9.3 Energy Units Calculation

When calculating energy units, a 1Hz sampling rate is assumed, meaning that power is considered constant for 1 second intervals. This simplifies the energy calculation process, but it may not be entirely accurate for rapidly changing loads.

Then, units $= \frac{Power\ in\ Kilowatt*1}{3600}$

9.4 Other Assumptions

High Power Consuming devices are devices which use more than 700W. Assuming that device is being used 10 hrs per day 700W * 10hrs = 7kwh per day 7 * 30 = 210Units. High Current Means More than 5A. A buzzer beeps when a device which uses more than 700W is plugged in. And LED will light up when current limit exceeds 5A.

9.5 Libraries used for processing data

When practically calculating the Irms, an efficient library known as 'EmonLib' is utilized to calculate Irms. This library simplifies the process by taking the analog input from the current sensing part of the circuit and providing the necessary calculations for Irms determination.

The 'EmonLib' library efficiently processes the analog input data, performs necessary mathematical computations, and outputs the accurate Irms value. This enables the smart energy monitor to precisely measure and analyze the current consumption, which is crucial for calculating energy usage.

By incorporating the 'EmonLib' library into the implementation, the complexity of the energy calculation process is reduced, resulting in a more streamlined and efficient solution for monitoring and analyzing energy consumption data in real-time.

[Arduino Reference for EmonLib]

10. Bill of Materials

Item	Description	Quantity	Price (Rs.)
Current Sensor	SCT013-030	1	2100
Power Supply Unit	5W Switch Mode Power Supply	1	2700
Display	I2C 0.96" OLED 128x64- Blue	1	1600
Microcontroller	ESP 8266 12F	1	1100
Buzzer	3V Piezo Buzzer 85dB	1	430
100nF Capacitors	Ceramic Capacitors 0.1uF 50V 10%	2	150
10uF Capacitors	Electrolytic Capacitors 10uF 16V	3	150
Voltage Regulater	AMS 1117 3.3V	1	200
10K Resistors	1/4 watt axial resistors	9	50
330E Resistors	1/4 watt axial resistors	2	50
470K Resistors	1/2 watt axial resistors	2	50
Transistors	BC 547	1	20
Shotkey Diode	1N4007	1	20
Push Buttons	Small Tac Switch 4 Bases	4	40
LED Bulb	RED 5mm	1	10
PCB Manufacturing	Imported from china (JLCPCB)		3000
Enclosure Manufacturing	3D Printed enclosure		3500
Other Expenses			3000
		Total	18170

11. Instruction for Assembly

To assemble the parts of the smart energy monitor, follow these steps:

Connect the power supply cable to the SMPS.

Securely mount the SMPS to the bottom part of the enclosure.

Establish the connection between the SMPS output and the power input of the main circuit board (PCB).

Connect the current sensor to the designated sensor input on the main circuit board.

Align the mounting holes of the main PCB with the screw bases on the bottom part of the enclosure.

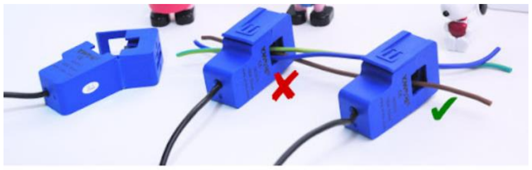
Gently position the top part of the enclosure over the assembly and carefully tighten the screws.

By meticulously following these steps, all components will be properly integrated within the enclosure, ensuring the efficient functioning, and safeguarding of the smart energy monitor.

12. Test for functionality

Step 1: Plug the Smart Energy meter into the 230V power supply.

Step2: Properly clamp the current sensor to either the neutral or live wire of the main power supply.



Step3: Press the refresh button once to initiate current measurement.

Step4: The device will start measuring the current and display the reading on its screen.

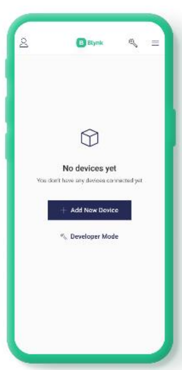
Step5: Turn off all home appliances and ensure that the device displays zero current.

Step6: Press the Change button to toggle between displaying current, power, and units.

Step7: For further verification, switch on a known power-consuming appliance (e.g., a 100W bulb) and confirm that the device shows the correct values.

Step8: Reset the units to zero by pressing the reset button if necessary.

Step9: To establish Wi-Fi connectivity, open the Blynk IoT application and search for the device.



Step10: If the device is not visible, press the refresh button again, and the Smart Energy Meter should appear.

Step11: Connect to the device through the application to remotely monitor all electrical parameters.

Step12: Verify that the parameters displayed on the device's screen and the mobile application are consistent.

Step12: Gradually switch on other devices one by one and confirm whether the alerting system functions effectively.

13. Conclusion and Future Improvements

This Smart Energy meter is designed based on several assumptions, which may impact the accuracy of the readings to some extent. Despite this, it remains a cost-effective solution for identifying high power-consuming devices and promoting energy conservation.

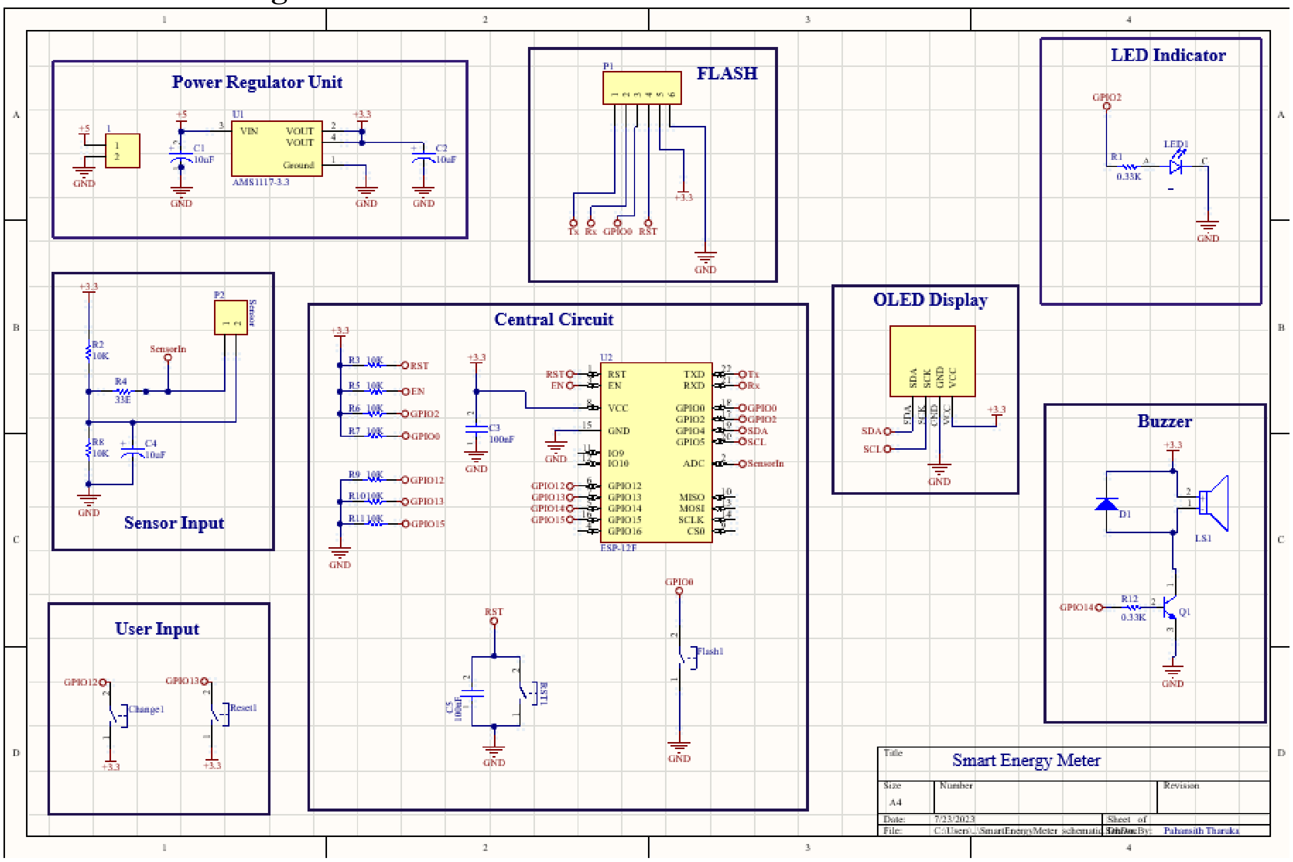
For enhanced precision, improvements can be made to the circuit and the code. By incorporating a voltage measuring feature, the need for assuming 230V rms voltage is eliminated, resulting in more accurate readings. Furthermore, utilizing a higher sampling rate allows for the determination of the power factor without assuming unity power factors.

To achieve these advancements, an upgrade from ESP8266 to ESP32 is necessary. The ESP32 provides enhanced capabilities, enabling more precise measurements and improved data processing.

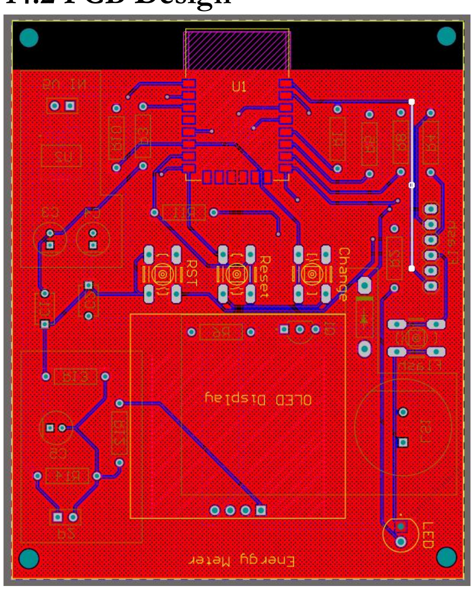
By implementing these enhancements, the Smart Energy meter can deliver more accurate and detailed energy consumption data, empowering users to make informed decisions and maximize energy efficiency in their households.

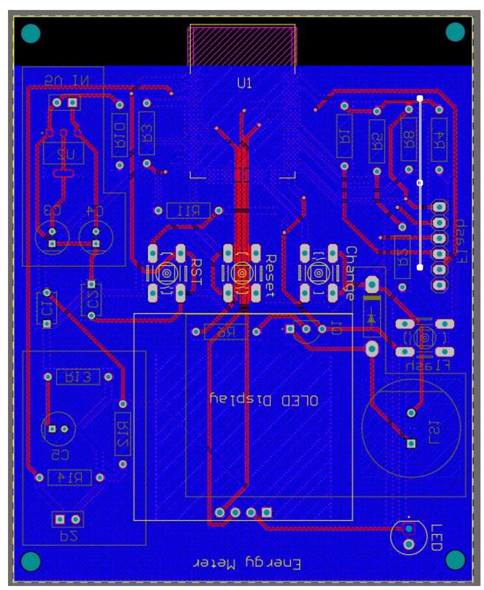
14. Appendices

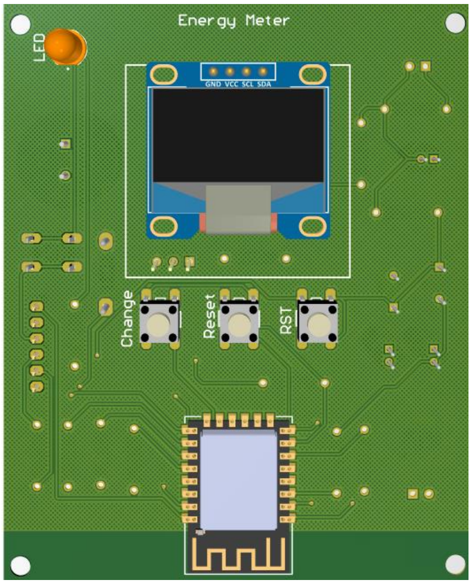
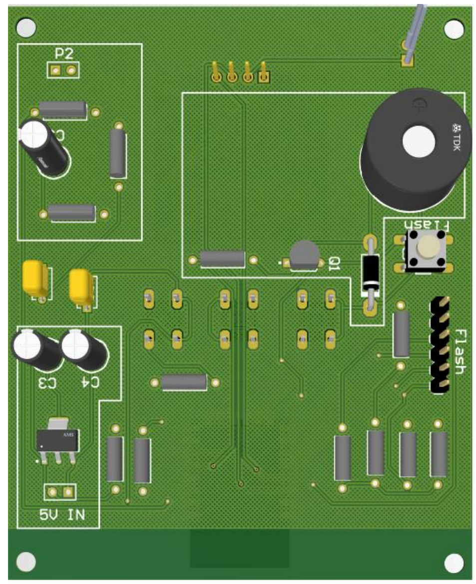
14.1 Schematic Design

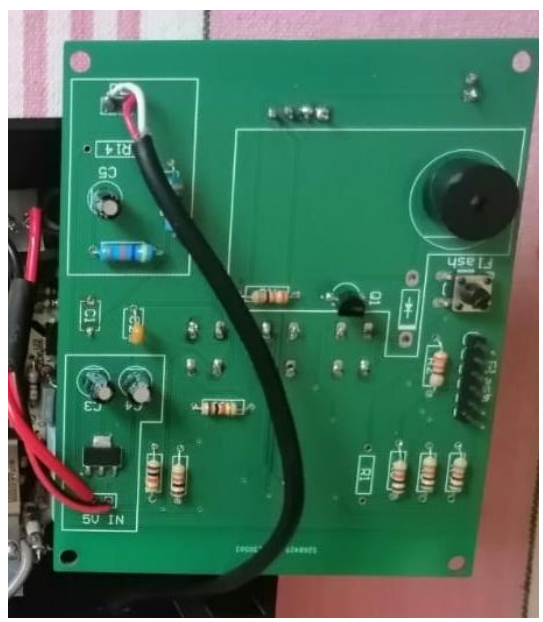


14.2 PCB Design

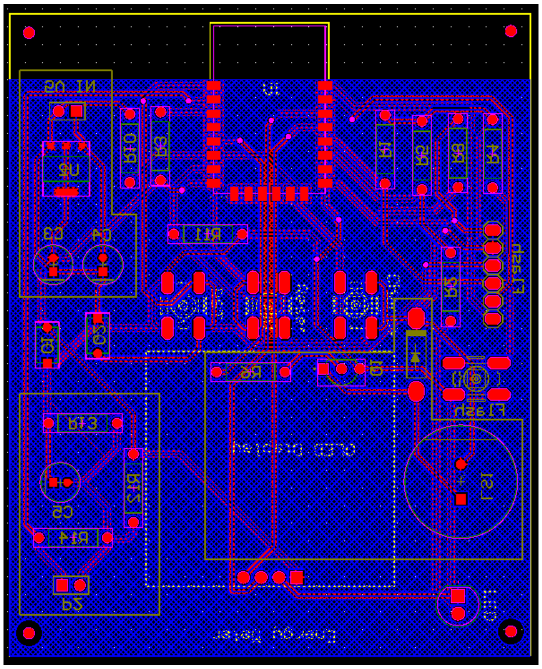


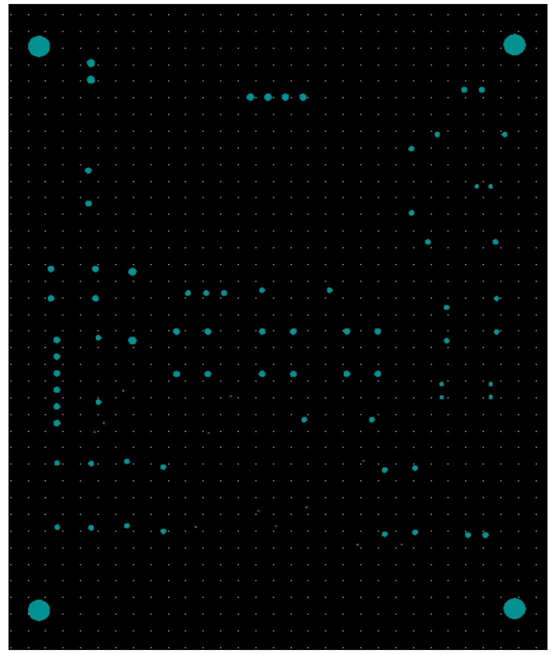



Energy Meter
LED
GND VCC SCL SDA
Change
Reset
RST

P2
Q1
Flash
C3
C4
5V IN

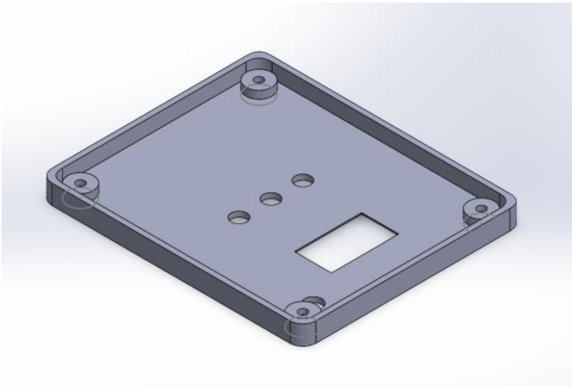
Energy Meter
LED
Change
Reset
RST

C5
C3
C4
5V IN
Flash

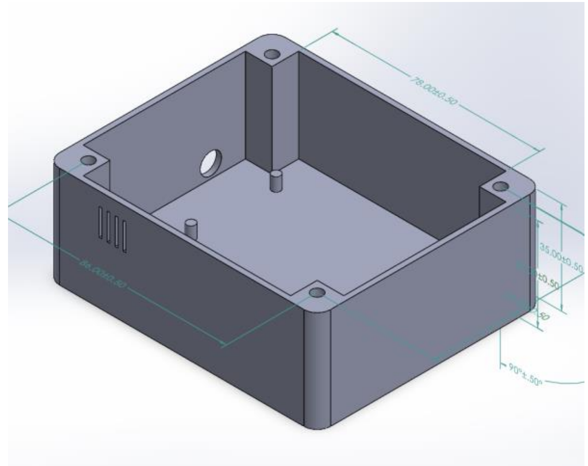
Gerber Files

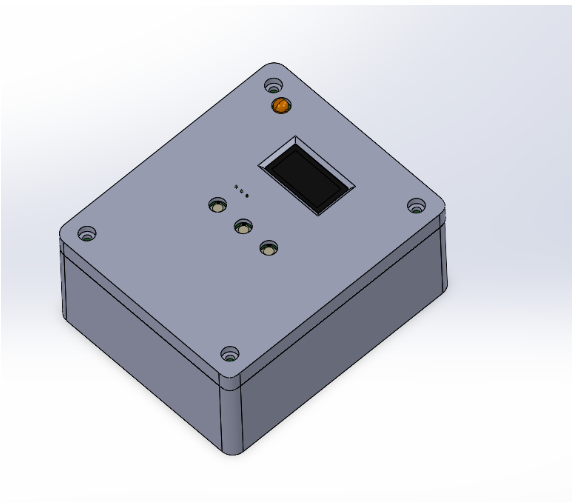


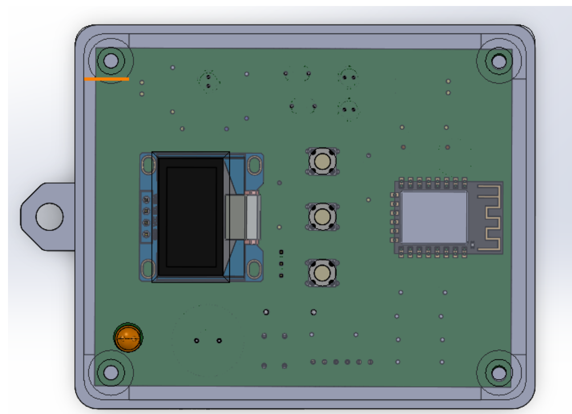


14.3 Enclosure Design









14.4 Arduino Codes

```
#include <Arduino.h>
#include "EmonLib.h"
#include <Wire.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>
#include <EEPROM.h>

#define SCREEN_WIDTH 128 // OLED display width, in pixels
#define SCREEN_HEIGHT 64 // OLED display height, in pixels


#define BLYNK_TEMPLATE_ID "TMPL6SQLECX9E"
#define BLYNK_TEMPLATE_NAME "EDR project"
#define BLYNK_AUTH_TOKEN "67kDYXxpwMEiQOIsAKz1K2jYE5z3NWrW"
#define BLYNK_PRINT Serial

#include <BlynkSimpleEsp8266.h>

char auth[] = BLYNK_AUTH_TOKEN ; //Auth Token

#include <ESP8266WiFi.h>

char ssid[] = "HUAWEI Y9 Prime 2019"; // wifi ssid
char password[] = "12345670"; // wifi password

#define ADC_INPUT A0
#define change 12
#define reset 13
#define LED_PIN 2

#define HOME_VOLTAGE 230

#define ADC BITS    10

#define ADC_COUNTS  (1<<ADC_BITS)

float units;
float watts;
float amps;
int x=0;
unsigned long lastMeasurement = 0;
unsigned long LEDlastmillis = 0;

BlynkTimer timer;
EnergyMonitor emon1;

Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire,

void sendData(){
  float current = emon1.calcIrms(1480); // Calculate Irms
  float power = current * HOME_VOLTAGE;
  Blynk.virtualWrite(V0, current); // max30
  Blynk.virtualWrite(V1, power); // max6900
  Blynk.virtualWrite(V2, units); // max150
}

void WriteToDisplay(){
  if(x==0){
  display.clearDisplay();
  display.setTextSize(2);
  display.setTextColor(WHITE);
  display.setCursor(34, 5);
  display.println("Units");
  display.setCursor(40, 40);
  display.println(units);
  display.display();
  }
```

```
  else if (x==1) {
  display.clearDisplay();
  display.setTextSize(2);
  display.setTextColor(WHITE);
  display.setCursor(25, 5);
  display.println("Current");
  display.setCursor(40, 40);
  display.println(amps);
  display.display();
  }

  else if (x==2) {
  display.clearDisplay();
  display.setTextSize(2);
  display.setTextColor(WHITE);
  display.setCursor(33, 5);
  display.println("Power");
    display.setCursor(40, 40);
  display.println(watts);
  display.display();
  }
  delay(300);


}

void setup() {
  Serial.begin(115200);
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED)
  {

    delay(500);
    Serial.print("*");
  }

  Serial.println("");
  Serial.println("WiFi connection Successful");


  pinMode(change,INPUT);
  pinMode(reset,INPUT);
  pinMode(LED_PIN, OUTPUT);

  if(!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) { // Address 0x3D for 128x64
    Serial.println(F("SSD1306 allocation failed"));
    for(;;);
  }


  emon1.current(ADC_INPUT, 20);
  Blynk.begin(auth, ssid, password);
  timer.setInterval(1000, sendData);

  units = EEPROM.read(0);
}

void loop() {
  unsigned long currentMillis = millis();

  if (currentMillis - lastMeasurement > 2000) {
    amps = emon1.calcIrms(1480); // Calculate Irms
    watts = amps * HOME_VOLTAGE;
    units = watts / 3600000;
```

```
    lastMeasurement = millis();
  }

  Blynk.run();
  timer.run();

  if (digitalRead(change) == HIGH) {
    x++;
    if (x > 2) {
      x = 0;
    }
  }

  if (digitalRead(reset) ==HIGH) {
    units = 0;
    EEPROM.write(0, 0);
  }

  if (watts > 15) {
    digitalWrite(LED_PIN, HIGH);
    unsigned long LEDcurrentMillis = millis();
    if (LEDcurrentMillis - LEDlastmillis > 1000) {
      digitalWrite(LED_PIN, LOW);
      LEDlastmillis = millis();
    }
  }
  else {
    digitalWrite(LED_PIN, LOW);
  }
  WriteToDisplay();
}
```

14.5 Data Related for Some Calculations

Item	Power Consumption
Rice Cooker(4.5L)	1500W
Rice Cooker(2.8L)	900W-1000W
Rice Cooker(1.8L)	700W
Rice Cooker(1L)	450W
Refrigerator	300-800W
Iron	800-2000W
Air Conditioner(27000BTU)	2080w
Air Conditioner(24000BTU)	1845W
Air Conditioner(18000BTU)	1645W
Air Conditioner(12000BTU)	915W
Air Conditioner(10000BTU)	700W
Water Heater (Hot water Shower)	3500W
Microwave Oven	600W-1500W
Blender	400W-1500W
Washing Machine	400W-1400W
LED TV	10W-117W
LCD TV	70-200W
Water Pump 0.5hp	~370W
Water Pump 1hp	~746W
Water Pump 1.5hp	1500W-2000W
Ceilin fan	~75W
Vacuum Cleaner	~1400W
Pressure cooker	850W-1000W
Toastetr	~1000W

15. References

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