BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 416 (July 2023)
Microprocessors and Embedded Systems Laboratory

Final Project Report

Section: B(G2) Group: 05

Designing a Low Noise Operational Amplifier

Course Instructors:
Nafis Sadik, Lecturer, Department of EEE, BUET.
Shafin Shadman Ahmed, Lecturer (PT), Department of EEE, BUET.

Signature of Instructor: ______________________________

Academic Honesty Statement:

IMPORTANT! Please carefully read and sign the Academic Honesty Statement, below. <u>Type the student</u> <u>ID and name, and put your signature</u>. *You will not receive credit for this project experiment unless this statement is signed in the presence of your lab instructor.*

"In signing this statement, We hereby certify that the work on this project is our own and that we have not copied the work of any other students (past or present), and cited all relevant sources while completing this project. We understand that if we fail to honor this agreement, We will each receive a score of ZERO for this project and be subject to failure of this course."

Signature: ______________ **Full Name: Mushfiquzzaman Abid** **Student ID: 1906084**	**Signature:** ______________ **Full Name: Md. Zonayed Hossain** **Student ID:1906087**
Signature: ______________ **Full Name: Arnab Kundu** **Student ID:1906089**	**Signature:** ______________ **Full Name: Dipika Rani Nath** **Student ID:1906092**

Table of Contents

1 Abstract

This report outlines the design and creation of a Low Noise Operational Amplifier (LNA), emphasizing the fulfillment of specific performance requirements. The main goals included achieving a low noise figure, high gain, and meeting critical parameters within a specified supply voltage range of 2-5V and a gain bandwidth of 1 MHz. Given the significance of LNAs in diverse applications such as wireless communication, radar systems, and medical imaging, the project holds considerable relevance.

The design process utilized Cadence Virtuoso software and GPDK45 process technology for circuit development, simulation, and optimization. A methodical approach involving trial and error was adopted, involving the adjustment of transistor parameters and component values to precisely optimize the LNA's performance.

2 Introduction

In the realm of contemporary engineering, the pursuit of innovation and resolution of intricate, real-world challenges define the field. This report delves into such complexity, detailing the design and development of a Low Noise Operational Amplifier (LNA). While amplifiers are not groundbreaking in electronics, the demanding intricacies imposed on this LNA's design elevate the project to the status of a formidable engineering problem.

Engineering Challenge: The intricacy of this engineering challenge arises from the necessity to reconcile conflicting objectives. On one side, the LNA must deliver high gain for effective amplification of weak input signals. Conversely, it must maintain an exceptionally low noise figure to uphold signal quality. This inherent requirement creates a trade-off, as increased gain often accompanies higher noise levels. Moreover, the LNA must operate within a constrained supply voltage range of 2-5V and meet specific gain bandwidth, input bias, and output voltage criteria. Achieving equilibrium amidst these conflicting demands constitutes a substantial engineering challenge.

Potential Alternative Approaches:

1. **Design Exploration:**

- Exploring diverse circuit topologies and amplifier configurations allows for a comprehensive understanding of trade-offs, aiding in the identification of the most suitable design.

2. **Component Selection:**
   - Rigorous selection of electronic components, including transistors and passive elements, becomes crucial to optimizing the amplifier's performance. This involves meticulous analysis of component datasheets and characteristics.
3. **Algorithmic Optimization:**
   - Employing advanced optimization algorithms and simulation tools enables systematic fine-tuning of the amplifier's parameters, seeking the optimal balance between gain and noise.
4. **Feedback Mechanisms:**
   - Integration of feedback mechanisms and control circuits allows for dynamic adjustments to the amplifier's parameters based on varying input conditions, enhancing its adaptability.

3 Design

3.1 Problem Formulation (PO(b))

The scope of the problem in designing a low noise operational amplifier (LNA) encompasses various technical and engineering challenges that must be addressed to achieve optimal performance. The key aspects of the scope include:

1. **Noise Figure Optimization:**
   - Designing an LNA requires minimizing the noise figure, which involves understanding and mitigating the different sources of noise within the amplifier circuit. Achieving a balance between gain and noise is a fundamental challenge.
2. **Trade-offs in Gain and Bandwidth:**
   - Balancing the conflicting requirements of high gain and sufficient bandwidth is a critical aspect of LNA design. Adjusting the transistor parameters and circuit topology to achieve the desired gain without compromising bandwidth is a challenging trade-off.
3. **Power Consumption Constraints:**
   - While optimizing for low noise and high performance, power consumption must be considered. Finding ways to achieve low noise without significantly increasing power consumption is a challenging aspect of the problem.
4. **Supply Voltage Range Compatibility:**

- Meeting the specified supply voltage range (e.g., 2-5V) adds complexity to the design. Ensuring the LNA operates within this range while delivering optimal performance is a crucial aspect of the problem scope.

5. **Stability and Reliability:**
    - Designing an LNA that is stable under varying operating conditions and reliable over time is a significant challenge. Ensuring robustness against parameter variations and environmental factors contributes to the complexity of the problem.
6. **Process Technology Selection:**
    - Choosing the appropriate process technology (e.g., TSMC18) involves considering trade-offs in terms of transistor characteristics, parasitic elements, and fabrication constraints. Selecting the right technology is crucial for achieving the desired LNA performance.
7. **Integration with System Requirements:**
    - Integrating the LNA into the overall system while meeting specific application requirements adds another layer of complexity. Ensuring compatibility with downstream components and system constraints is an integral part of the problem scope.
8. **Testing and Verification:**
    - Developing effective testing methodologies to verify the LNA's performance against design specifications is a vital aspect of the problem. Ensuring that the fabricated amplifier meets the intended criteria involves challenges in experimental validation.

3.1.1 Identification of Scope

3.1.2 Literature Review

The literature on low noise operational amplifiers (LNAs) highlights key principles, challenges, and advancements in amplifier design. Baker and Lee's seminal work in 1997 emphasized noise sources in transistors and laid the groundwork for LNA design. Riaz and Haslett (2003) explored trade-offs between gain and noise, addressing challenges in achieving optimal performance. Recent research by Li et al. (2019) delved into advanced semiconductor technologies, presenting innovative approaches for enhancing LNA performance. These studies collectively inform the current project, offering a comprehensive understanding of historical developments and contemporary strategies in the field of low noise operational amplifier design.

3.1.3 Formulation of Problem

The essence of any engineering endeavor rests upon recognizing and comprehending a complex problem. In the case of designing a Low Noise Operational Amplifier (LNA), it is crucial to articulate a precise understanding of the challenge at hand. This entails reconciling conflicting objectives such as achieving high gain while maintaining a low noise figure, all within specified parameters like a 2-5V supply voltage range. This foundational clarity forms the basis for subsequent design decisions and solution development in the LNA project.

3.1.4 Analysis

The central issue in this project revolves around crafting a Low Noise Operational Amplifier that seamlessly combines high gain and a low noise figure. To unravel the intricacy of this challenge, it is crucial to dissect the problem into its essential components.

Intricate Engineering Challenge: Devising a Low Noise Operational Amplifier poses a multifaceted engineering challenge. Several factors contribute to the intricacy of this task:

Divergent Goals: The primary complexity arises from the inherent conflict between achieving high gain and maintaining a low noise figure. Striving for elevated gain often brings about higher noise levels, leading to intricate trade-offs between these two critical parameters.

Component Interplay: The LNA design involves intricate interactions among various electronic components, such as transistors, passive elements, and feedback networks. Subtle variations in component values can exert significant influence on the overall performance.

Power Limitations: Operating within a constrained supply voltage range of 2-5V introduces an additional layer of complexity to the design process.

3.2 Design Method (PO(a))

The primary processor employed in this project was the Arduino UNO, renowned for its open-source nature and equipped with an ATmega328p microcontroller. Facilitating the monitoring of current, the project utilized the ACS712-20A Current Sensor, known for its Hall Effect technology and commendable current-handling capabilities. For voltage measurement, the active Single Phase Voltage Transformer ZMPT101B was chosen, offering a lowered supply voltage and enhanced handling capacity. The control of load elements within the circuit was managed through relays and sockets, with 60W incandescent light bulbs and table fans serving as initial loads. To ensure seamless communication with the server, an ESP 8266 NodeMCU device was integrated into the system. Operationally, the sensors independently gauged current and voltage, with the collected data transmitted to the microcontroller. Subsequent calculations involving angle and Power Factor were executed, followed by the transfer of processed data to the server via the ESP-8266 module. Access to the server was facilitated through our dedicated website, featuring password protection for enhanced security.

.

Figure: *ESP-8266 Wi-Fi module*

Figure: Arduino UNO

Figure : *ZMPT101B*

Figure: ACS712-20A 4

Figure: 1_channel relay module 5V

3.3 Circuit Diagram

Here is the circuit design of the project as in Proteus 8:

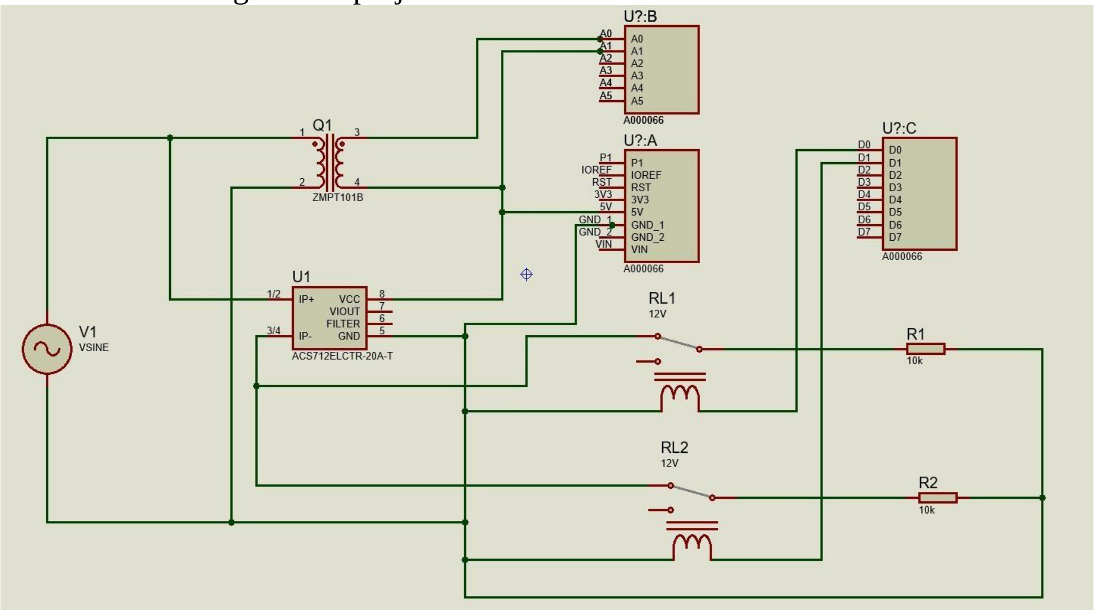

Figure: Proteus Diagram of the Circuit

3.4 Simulation Model

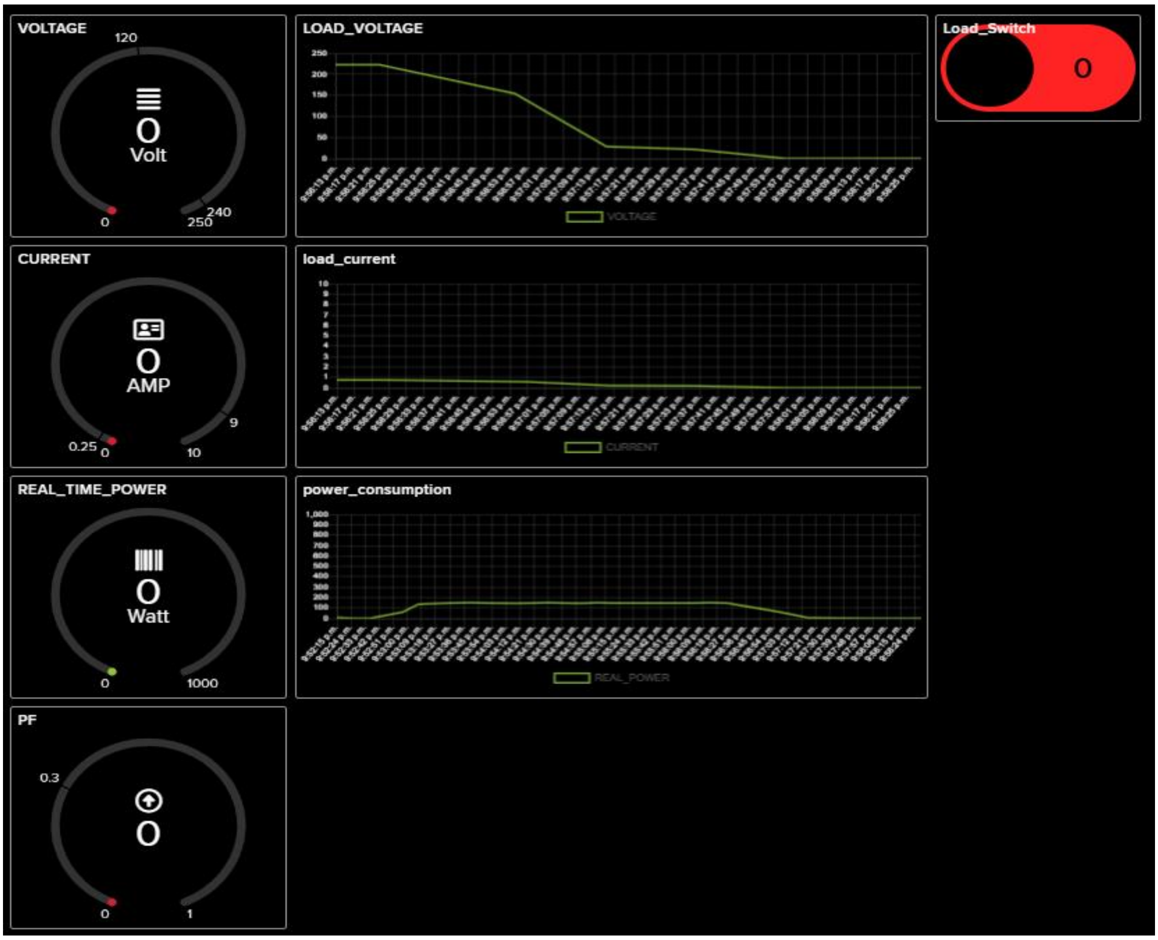

Figure: The Simulation of measurement data in User Interface accessed from our Website

3.5 CAD/Hardware Design

Here is the hardware design of our project:

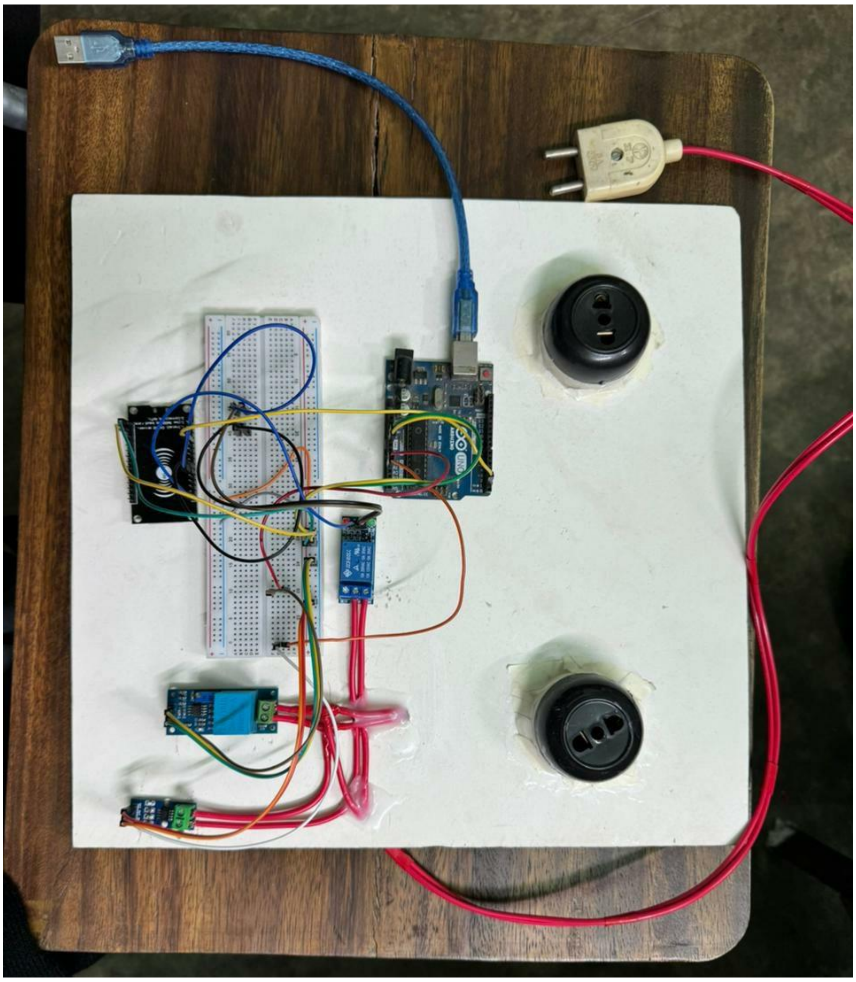

Figure: Hardware Design for a Smart Meter system

3.6 Full Source Code of Firmware

Arduino Code for processing sensor data:

```
#include <math.h>
#define led1 13
#define led2 12
int blinkFlag = 0;
int decimalPrecision = 2;
int loop_i = 100;
int analogInputPin1PA = A0;
int analogInputPin2PA = A1;
float voltageAnalogOffset = 0;
float currentAnalogOffset = 0;
unsigned long startMicrosPA;
unsigned long vCurrentMicrosPA;
unsigned long iCurrentMicrosPA;
unsigned long periodMicrosPA;
double vAnalogValue = 0;
double iAnalogValue = 0;
double previousValueV = 0;
double previousValueI = 0;
double previousphaseAngleSample = 0;
double phaseAngleSample = 0;
double phaseAngleAccumulate = 0;
double periodSample = 0;
double periodSampleAccumulate = 0;
double phaseDifference = 0;
double phaseAngle = 0;
double frequency = 0;
double voltagePhaseAngle = 0;
double currentPhaseAngle = 0;
double averagePeriod = 0;
int sampleCount = 0;
int a = 3;
double powerFactor;
unsigned long current_time;
unsigned long last_time;
float voltageSqSum = 0;
float voltageRMS = 0;
float currentSqSum = 0;
float currentRMS = 0;
float power = 0;
float energy = 0;
float sum_current;
float sample_num;
float sum_voltage;
int load1;
int load2;


void offset_calibrate()
{
  sum_current = 0;
  sample_num = 0;
  sum_voltage = 0;
  int q = 0;
  for (q = 0; q <= 1000; q = q + 1)
  {
    vAnalogValue = 
analogRead(analogInputPin1PA) - 512;
    iAnalogValue = 
analogRead(analogInputPin2PA) - 512;
    sample_num = sample_num + 1;
    sum_current = sum_current + iAnalogValue;
    sum_voltage = sum_voltage + vAnalogValue;
  }
  currentAnalogOffset = sum_current / 
sample_num;
  voltageAnalogOffset = sum_voltage / 
sample_num;
}

//SoftwareSerial ESerial(0, 1);

void setup()
{
  Serial.begin(9600);
  //ESerial.begin(9600);
  offset_calibrate();
  pinMode(led1, OUTPUT);
  pinMode(led2, OUTPUT);
  last_time = micros();
}


void loop()
{
  if (load1 == 0)
  {
    digitalWrite(led1, HIGH);
  }
  else
  {
    digitalWrite(led1, LOW);
  }
  if (load2 == 0)
  {
    digitalWrite(led2, HIGH);
  }
  else
  {
    digitalWrite(led2, LOW);
  }
  vAnalogValue = analogRead(analogInputPin1PA) 
- 512 - voltageAnalogOffset;
  iAnalogValue = analogRead(analogInputPin2PA) 
- 512 - currentAnalogOffset;
  current_time = micros();
  voltageSqSum = voltageSqSum + 
```

```
sq(vAnalogValue);
  currentSqSum = currentSqSum +
sq(iAnalogValue);
  if ((vAnalogValue < 0) && a == 3)
  {
    a = 0;
  }
  if ((vAnalogValue >= 0) && a == 0)
  {
    startMicrosPA = current_time;
    a = 1;
    previousValueV = 0;
    previousValueI = 0;
  }
  if ((vAnalogValue > previousValueV) && a == 1)
  {
    previousValueV = vAnalogValue;
    vCurrentMicrosPA = current_time;
  }
  if ((iAnalogValue <= previousValueI) && (a == 1
|| (a == 2 && (vAnalogValue <= 0))))
  {
    previousValueI = iAnalogValue;
    iCurrentMicrosPA = current_time;
  }
  if ((vAnalogValue < 0) && a == 1)
  {
    a = 2;
  }
  if ((vAnalogValue >= 0) && a == 2)
  {
    periodMicrosPA = current_time;
    periodSample = periodMicrosPA -
startMicrosPA;
    periodSampleAccumulate =
periodSampleAccumulate + periodSample;
    voltagePhaseAngle = vCurrentMicrosPA;
    currentPhaseAngle = iCurrentMicrosPA;
    phaseAngleSample = currentPhaseAngle -
voltagePhaseAngle;
    iCurrentMicrosPA = 0;
    vCurrentMicrosPA = 0;
    if (phaseAngleSample >= 100)
    {
      previousphaseAngleSample =
phaseAngleSample;
    }
    if (phaseAngleSample < 100)
    {
      phaseAngleSample =
previousphaseAngleSample;
    }
    phaseAngleAccumulate =
phaseAngleAccumulate + phaseAngleSample;
    sampleCount = sampleCount + 1;
    a = 3;
  }
  delay(5);
  if (sampleCount == loop_i)
  {
    averagePeriod = periodSampleAccumulate /
sampleCount;
    frequency = 1000000 / averagePeriod;
    phaseDifference = phaseAngleAccumulate /
sampleCount;
    phaseAngle = ((phaseDifference * 360) /
averagePeriod) - 90;
    ;
    powerFactor = sin(phaseAngle * 0.017453292);
    if (powerFactor < 0)
    {
      powerFactor = 0;
    }
    voltageRMS = sqrt(voltageSqSum /
sampleCount);
    currentRMS = (sqrt(currentSqSum /
sampleCount)) / 100;
    if (voltageRMS < 20)
    {
      voltageRMS = 0;
      powerFactor = 0;
      currentRMS = 0;
      phaseAngle = 0;
      frequency = 0;
    }
    if (currentRMS < 0.09)
    {
      currentRMS = 0;
      powerFactor = 0;
      phaseAngle = 0;
    }
    power = voltageRMS * currentRMS *
powerFactor;
    // Serial.print("Voltage :");
    // Serial.print(voltageRMS, decimalPrecision);
    // //ESerial.print(voltageRMS,
decimalPrecision);
    // Serial.print(" V ");
    // Serial.print("Current :");
    // Serial.print(currentRMS, decimalPrecision);
    // //ESerial.print(currentRMS, decimalPrecision);
    // Serial.print(" A ");
    // Serial.print("Power :");
    // Serial.print(power, decimalPrecision);
    // //ESerial.print(power, decimalPrecision);
    // Serial.print(" W ");
    // Serial.print("Phase Angle :");
    // Serial.print(phaseAngle, decimalPrecision);
    // //ESerial.print(phaseAngle, decimalPrecision);
    // Serial.print("° ");
```

```
    // Serial.print("Frequency :");
    // Serial.print(frequency, decimalPrecision);
    // //ESerial.print(frequency, decimalPrecision);
    // Serial.print(" Hz ");
    // Serial.print("Power Factor :");
    // Serial.println(powerFactor, decimalPrecision);
    //ESerial.println(powerFactor,
decimalPrecision);
    sampleCount = 0;
    periodSampleAccumulate = 0;
    phaseAngleAccumulate = 0;
    previousphaseAngleSample = 0;
    voltageSqSum = 0;
    currentSqSum = 0;
    energy = power * ((current_time - last_time) /
1000000);
    last_time = current_time;
    sending_values(currentRMS, voltageRMS,
power, powerFactor, frequency);
    // if (Serial.available())
    // {
    //   extract_and_send_data();
    // }
    offset_calibrate();
  }
}


void sending_values(float I, float V, float P, float
theta, float E)
{
  String dataToSend =
"ABAABBAABAABAABBAAABD" + String(I)
+ "," + String(V) + "," + String(P) + "," +
String(theta) + "," + String(E);
  Serial.println(dataToSend);
  delay(10000);
}
```

ESP8266 Code:

```
#include <ESP8266WiFi.h>
#include "Adafruit_MQTT.h"
#include "Adafruit_MQTT_Client.h"
#include "config.h"

/************************* Example Starts
Here *********************************/

// digital pin 5
#define LED_PIN1 D0
// WiFi parameters
#define WLAN_SSID       "MME_CDI"
#define WLAN_PASS       "406191919"

// Adafruit IO
#define AIO_SERVER      "io.adafruit.com"
#define AIO_SERVERPORT  1883
#define AIO_USERNAME    "ECE_hellbent"
#define AIO_KEY
"aio_NHPi02f9CQdGDtmNjI49WZzCP8ay"

WiFiClient client;
Adafruit_MQTT_Client mqtt(&client,
AIO_SERVER, AIO_SERVERPORT,
AIO_USERNAME, AIO_KEY);

// Adafruit IO feeds
Adafruit_MQTT_Publish VOLTAGE =
Adafruit_MQTT_Publish(&mqtt,
AIO_USERNAME "/feeds/Voltage");
Adafruit_MQTT_Publish CURRENT =
Adafruit_MQTT_Publish(&mqtt,
AIO_USERNAME "/feeds/Current");
Adafruit_MQTT_Publish POWER =
Adafruit_MQTT_Publish(&mqtt,
AIO_USERNAME "/feeds/real-power");
Adafruit_MQTT_Publish PHASE_ANGLE =
Adafruit_MQTT_Publish(&mqtt,
AIO_USERNAME "/feeds/Phase_Angle");
Adafruit_MQTT_Publish FREQUENCY =
Adafruit_MQTT_Publish(&mqtt,
AIO_USERNAME "/feeds/Frequency");
Adafruit_MQTT_Publish POWER_FACTOR =
Adafruit_MQTT_Publish(&mqtt,
AIO_USERNAME "/feeds/Power_Factor");

// set up the 'digital' feed
AdafruitIO_Feed *testfeed1 = io.feed("testfeed1");

void setup() {

  pinMode(LED_PIN1, OUTPUT);
  // start the serial connection
  Serial.begin(9600);
  WiFi.begin(WLAN_SSID, WLAN_PASS);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
  }

  // wait for serial monitor to open
  while(! Serial);

  // connect to io.adafruit.com
  Serial.print("Connecting to Adafruit IO");
  io.connect();

  // set up a message handler for the 'digital' feed.
  // the handleMessage function (defined below)
  // will be called whenever a message is
  // received from adafruit io.
  testfeed1->onMessage(handleMessage);

  // wait for a connection
  while(io.status() < AIO_CONNECTED) {
    Serial.print(".");
    delay(500);
  }

  // we are connected
  Serial.println();
  Serial.println(io.statusText());
  testfeed1->get();

}

void loop() {

  io.run();
  if (Serial.available()) {
    // Read data from serial
    String data = Serial.readStringUntil('\n');
    Serial.println(data);
    while (data.charAt(0) == 'A' || data.charAt(0) ==
'B') {
      data.remove(0, 1); // Remove "DATA," from
the beginning
    }
    if (data.startsWith("D")) {
      Serial.print(data);
        float I, V, P, PF, f;
        sscanf(data.c_str(), "D%f,%f,%f,%f,%f", &I,
&V, &P, &PF, &f);

        // Publish data to Adafruit IO feeds
        VOLTAGE.publish(V);
        CURRENT.publish(I);
```

```
    POWER.publish(P);
    //FREQUENCY.publish(f); ## TO BE
CREATED
    POWER_FACTOR.publish(PF);
    Serial.println("Done");
  }
 }

 // Maintain MQTT connection
 if (!mqtt.connected()) {
  connect();
 }
 mqtt.processPackets(10000);
}


void handleMessage(AdafruitIO_Data *data) {

 Serial.print("received <- ");

 if(data->toPinLevel() == HIGH)
  Serial.println("HIGH");
 else
  Serial.println("LOW");


 digitalWrite(LED_PIN1, data->toPinLevel());
}

void connect() {
 int8_t ret;
 while ((ret = mqtt.connect()) != 0) {
  delay(5000);
 }
}
```

"Config.h"

```
#define IO_USERNAME "ECE_hellbent"
#define IO_KEY
"aio_NHPi02f9CQdGDtmNjI49WZzCP8ay"


#define WIFI_SSID "xxxxxxxx"
#define WIFI_PASS "406191919"

// #define USE_AIRLIFT

// #define USE_WINC1500

//#define ARDUINO_SAMD_MKR1010

#include "AdafruitIO_WiFi.h"

#if defined(USE_AIRLIFT) ||
defined(ADAFRUIT_METRO_M4_AIRLIFT_LIT
E) ||         \
   defined(ADAFRUIT_PYPORTAL)
// Configure the pins used for the ESP32
connection
#if !defined(SPIWIFI_SS) // if the wifi definition
isnt in the board variant
#define SPIWIFI SPI
#define SPIWIFI_SS 10 // Chip select pin
#define NINA_ACK 9
#define NINA_RESETN 6 // Reset pin
#define NINA_GPIO0 -1 // Not connected
#endif
AdafruitIO_WiFi io(IO_USERNAME, IO_KEY,
WIFI_SSID, WIFI_PASS, SPIWIFI_SS,
              NINA_ACK, NINA_RESETN,
NINA_GPIO0, &SPIWIFI);
#else
AdafruitIO_WiFi io(IO_USERNAME, IO_KEY,
WIFI_SSID, WIFI_PASS);
#endif
```

4 Implementation

4.1 Description

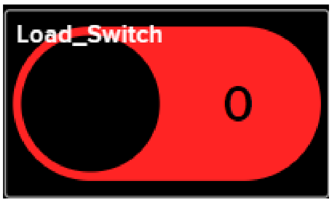

Figure: The user interface for controlling the appliances(More can be added next)

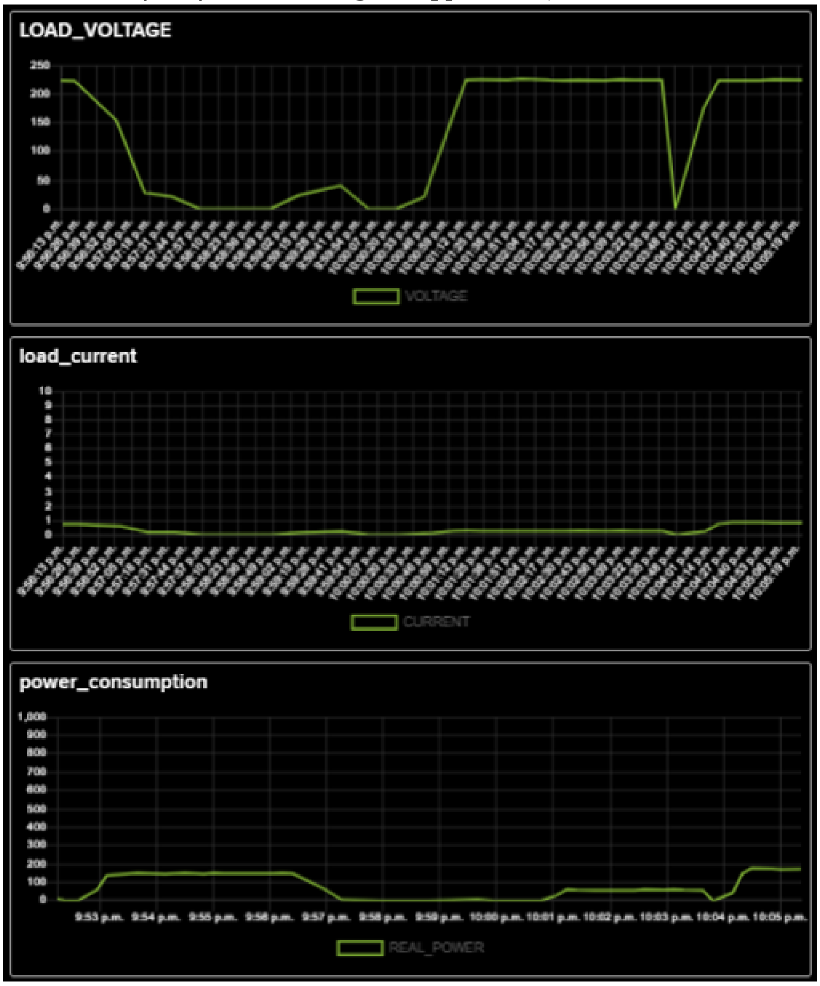

Figure: List of data from the sensors showing in the dashboard. The change in angle signifies the addition of a fan, which is an inductive load and so the power consumption increases

5 Design Analysis and Evaluation

5.1 Novelty

In the project, there are some unique features. Firstly, The User will get real-time consumption data from the Interface. The Interface will have features like Load Controlling and Alarm for Overload or Short Circuit. The user can manually or automatically control loads based on preset priority from a distance through the website. The provider can also view users' Real-time consumption data and can cut power off. The provider can also perform remote diagnosis of faults.

5.2 Design Considerations (PO(c))

5.2.1 Considerations to public health and safety

Electromagnetic Radiation Exposure: we ensure that the smart energy meters emit minimal electromagnetic radiation, adhering to safety standards to prevent health risks associated with prolonged exposure.

Fire Hazards: Implement safety features to mitigate the risk of fire hazards, such as overheating or electrical malfunctioning in the energy metering system.

Data Security: Protect personal data collected by the energy monitoring system to prevent unauthorized access, ensuring that sensitive information related to energy consumption patterns is secure from potential breaches.

Remote Monitoring and Maintenance: Enable remote monitoring and maintenance of the energy metering infrastructure to reduce the need for physical interventions, thus minimizing occupational hazards for maintenance personnel.

Integration with Emergency Response Systems: Integrate the energy monitoring system with emergency response mechanisms to enable timely responses in case of accidents or emergencies related to energy consumption. The Smart Meter system will give the consumers protection from Short Circuit, Fault, and other power system-related problems by giving prior warning to them. The consumers will get notifications even when they are not at home from the application website. The consumers will also preset priorities for the appliances for automatic control. The data fed from the sensors is transparent to the consumer. And it is protected by password encryption.

5.2.2 Considerations of the Environment

Energy Efficiency: we design energy meters with high energy efficiency to minimize the overall energy consumption of the monitoring system, thus reducing environmental impact and carbon footprint.

Materials and Manufacturing: Use environmentally sustainable materials and manufacturing processes for the production of smart energy meters, ensuring that the entire lifecycle of the product is environmentally friendly.

End-of-Life Disposal: Implement recycling and disposal programs for smart energy meters to properly manage electronic waste, reducing environmental pollution and promoting circular economy principles.

Reducing Resource Consumption: Optimize resource consumption during the operation of energy monitoring systems, such as minimizing the use of water or other resources required for system maintenance and data transmission.

Environmental Impact Assessment: Conduct thorough environmental impact assessments during the deployment phase of smart energy metering projects to identify and mitigate potential negative effects on ecosystems and natural habitats.In this project design, Wi-Fi was chosen as the communication medium. Wi-Fi from ESP 8266 has a short range. So, the radiation is not harmful to the environment. Again, the System does not consume so much power. So, additional Power generation is not necessary. The required power can be provided through Li-ion rechargeable batteries which are relatively less harmful to the environment.

5.2.3 Considerations to cultural and societal needs

Accessibility: we have to ensure that the energy monitoring system is accessible to all members of society, including individuals with disabilities or those from diverse cultural backgrounds, by incorporating user-friendly interfaces and multi-language support.

Privacy and Data Ownership: Respect cultural norms and societal values regarding privacy and data ownership, providing transparent policies and mechanisms for individuals to control their personal information collected by the energy metering system.

Community Engagement: Foster community engagement and participation in energy monitoring initiatives through educational programs, outreach activities, and stakeholder consultations to promote awareness and collective action toward sustainable energy practices.

Equity and Social Justice: Address equity and social justice considerations in the deployment of smart energy metering systems, particularly in marginalized or underserved communities, to ensure fair access to benefits such as energy savings and cost reductions. The Smart Meter may be difficult to operate in a large region when LPWAN technologies which have better performance will be implemented because of their rareness and sophisticated operating protocols. So, we used Wi-Fi, which is relatively familiar to the people. The device can be superimposed with a traditional Meter which makes the operation easier. The device will not consume much electricity.

5.3 Investigations (PO(d))

5.3.1 Design of Experiment

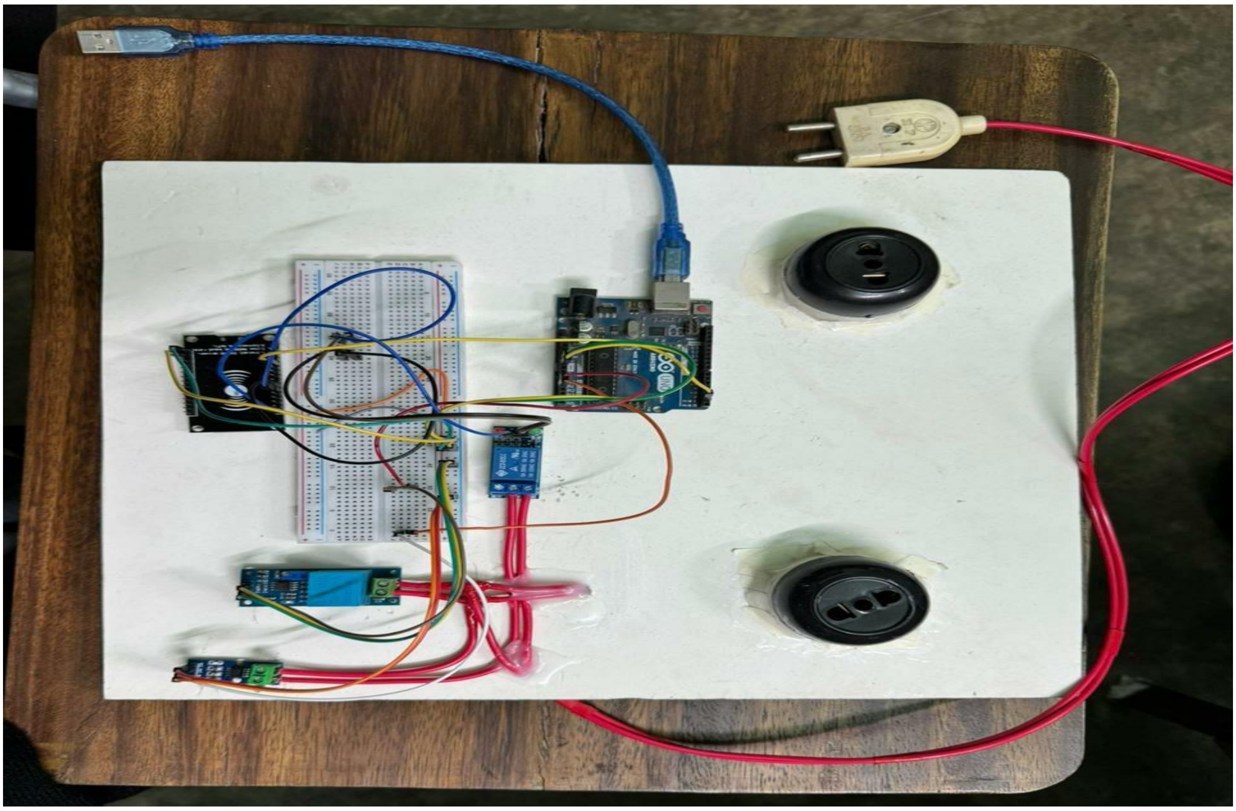

Figure: Hardware Design of the device experimental setup

5.3.2 Data Collection

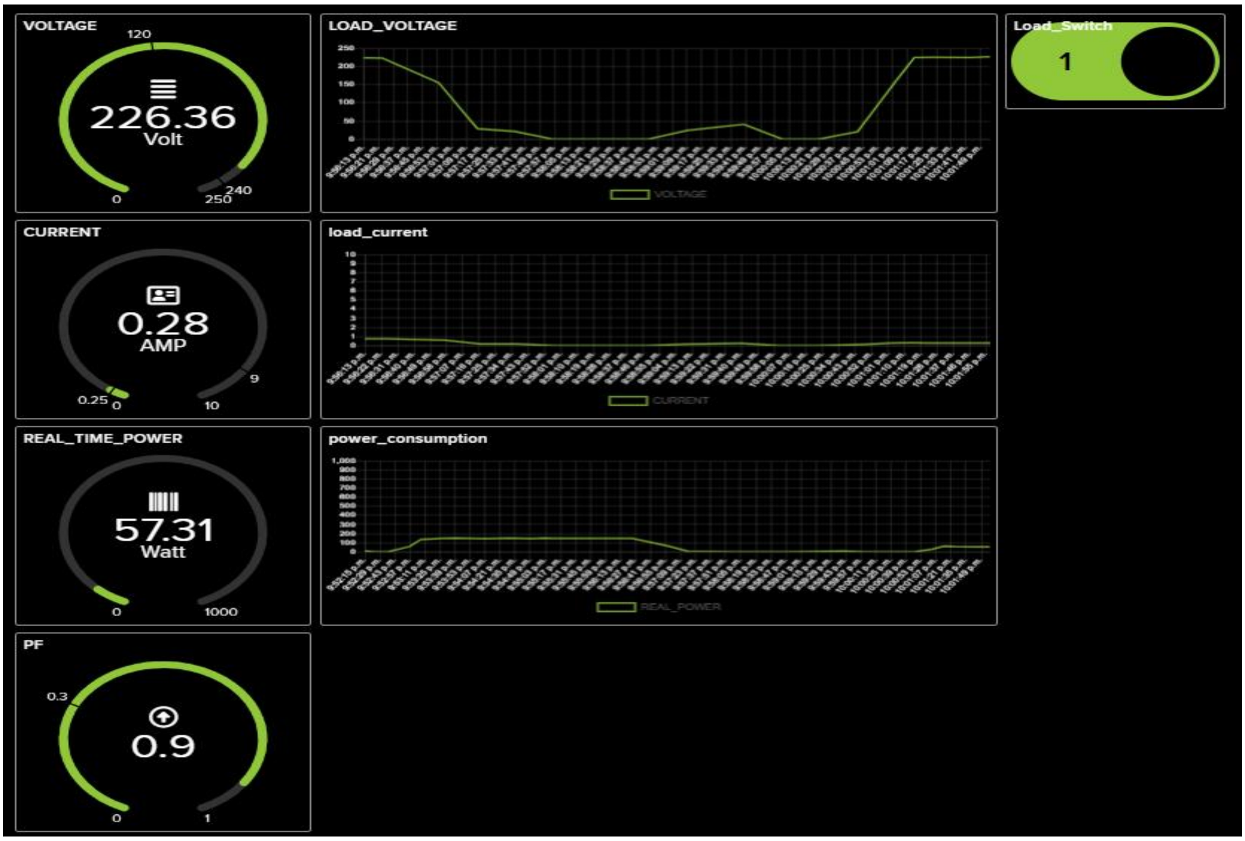

Figure: Data collection for a single load(light)

Figure: Data collection for two loads (light+fan)

5.3.3 Results and Analysis

We demonstrated the Current, Voltage , Power, power factor, power angle of the total load in our system. When only a single load is ON, the current value is 0.28 A and consumed power is 57.31 W. And when two loads are ON, the current increases to 0.85 A and consumed power increases to 172.61 W which is satisfactory for our demonstration.

5.3.4 Interpretation and Conclusions on Data

The most sophisticated part of our project was to determine the correct power factor angle and value.

```
ABAD0.30,239.44,65.02,0.91,15.43,1.93
```

Figure: Data for a light load

```
ABAD0.75,239.84,153.39,0.86,15.18,6.05
ABAD0.91,239.27,196.06,0.90,15.25,6.31
```

Figure: Data for a light+fan load

```
ABAD0.62,239.29,132.29,0.89,15.29,4.51
ABAD0.62,238.59,130.12,0.87,15.29,4.76
```

Figure: Data for a fan load

The data here signifies the main mathematical concern of our project, the determination of power factor and power angle. When the load is purely resistive, the power angle is 0 and the power factor is 1.

When the load is inductive, the power angle increases to around 14.60° and the power factor now is 0.97. When both loads are ON, the power angle decreases to 5.77° and the power factor is 0.99. The data is in consistency with the expected values.

5.4 Limitations of Tools (PO(e))

The Wi-Fi based connection to the server only covers a range of a few meters. Again ,The online Google Firebase Cloud Server may not be able to handle such big data. So, later we may need to implement our own dedicated Server. There is a lag between giving a command and implementation.

5.5 Impact Assessment (PO(f))

5.5.1 Assessment of Societal and Cultural Issues

Cultural Acceptance: we have to evaluate the cultural acceptance of smart energy metering technology within the target community. Consider conducting surveys or focus groups to understand cultural attitudes towards technology adoption and privacy concerns.

Community Engagement: Assess the level of community engagement and participation in the planning and implementation of the energy monitoring system. Identify key stakeholders, including community leaders and cultural influencers, to involve them in decision-making processes.

Cultural Sensitivity: analyze the design and deployment of the energy monitoring system to ensure cultural sensitivity, considering factors such as language preferences, religious practices, and cultural norms related to data privacy and property rights.

Impact on Social Dynamics: Consider the potential impact of the energy monitoring system on social dynamics within the community, such as changes in household behavior or social interactions related to energy consumption patterns. Anticipate and address any potential social disruptions or conflicts that may arise.

Inclusivity: Assess the inclusivity of the energy monitoring system to ensure that it serves the needs of diverse population groups within the community, including marginalized or vulnerable communities who may have limited access to technology or resources.

The consumers will be safe from Short Circuit and other Power System related faults. This system is economical to all because of the ability to control consumption. Consumers can monitor their consumption data and make better decisions. This transparency also increases economic well being. Vulnerable consumers like government offices, hospitals, schools will have uninterrupted Power Supply. Again, due to dynamic billing, it is possible to give subsidies to the agriculture and SME sector. Renewable energy producers may also get incentives.

5.5.2 Assessment of Health and Safety Issues

Electromagnetic Radiation Exposure: Conduct a thorough assessment of the electromagnetic radiation emitted by the smart energy meters to ensure compliance with safety standards and regulations. Measure and monitor radiation levels to mitigate potential health risks associated with prolonged exposure.

Fire Hazards: Evaluate the risk of fire hazards associated with the energy monitoring system, including overheating of equipment or electrical malfunctions. Implement safety measures such as temperature monitoring and automatic shut-off systems to prevent accidents.

Data Security: Assess the security protocols and encryption mechanisms used to protect personal data collected by the energy monitoring system. Conduct regular audits and vulnerability assessments to identify and address potential security vulnerabilities that could compromise data privacy and integrity.

Occupational Health and Safety: Evaluate the occupational health and safety risks for personnel involved in the installation, maintenance, and operation of the energy monitoring system. Provide appropriate training, protective equipment, and safety guidelines to mitigate potential hazards and ensure compliance with occupational safety regulations.

Emergency Response Preparedness: Assess the readiness of emergency response mechanisms to address potential health and safety incidents related to the energy monitoring system, such as equipment failures or environmental hazards. Establish protocols for timely response and coordination with relevant authorities and emergency services. There will be no effect of the Smart Meter System regarding the health and safety of the consumers. The consumption data will be well protected. However, caution should be maintained about hacking. Some methods, specifically Blockchain technology can increase data security.

5.5.3 Assessment of Legal Issues

Regulatory Compliance: Evaluate compliance with local, national, and international regulations governing energy monitoring systems, including data privacy laws, electromagnetic radiation standards, and product safety regulations. Ensure that the project adheres to relevant legal requirements and obtains necessary permits and approvals.

Liability and Insurance: Assess liability issues related to the operation of the energy monitoring system, including potential risks of property damage, data breaches, or personal injury. Obtain appropriate insurance coverage and legal protections to mitigate liability risks and ensure financial accountability.

Contractual Agreements: Review contractual agreements with vendors, contractors, and stakeholders involved in the project to clarify roles, responsibilities, and legal obligations. Ensure that contracts include provisions for dispute resolution, indemnification, and intellectual property rights protection.

Privacy and Data Protection: Evaluate the project's compliance with privacy laws and regulations governing the collection, storage, and use of personal data obtained through the energy monitoring system. Implement privacy policies, consent mechanisms, and data anonymization techniques to protect individuals' privacy rights and mitigate legal risks related to data misuse or unauthorized access.

Intellectual Property Rights: Assess intellectual property issues related to the development and deployment of the energy monitoring system, including patents, trademarks, and copyrights. Ensure that appropriate legal protections are in place to safeguard proprietary technology and prevent infringement claims from third parties. Smart Metering System will increase the transparency in power consumption. The utility provider company can monitor if anyone is tempering the meters and using electricity illegally. The consumers can also use the utility provider company in case of any discrepancy in billing. There may be legal issues concerning data security which can be addressed as earlier.

5.6 Sustainability Evaluation (PO(g))

Wi-Fi is a reliable method of Communication. The Wi-Fi module consumes a very low amount of Power. So, the device will be sustainable. Again, the sensors have very high current and voltage operating range. So, there will not be any issues with the device except for extremely high levels of sustained fault that will be automatically addressed by stopping power supply from the provider end.

5.7 Ethical Issues (PO(h))

The main ethical challenge was the delivery of consumption data to the server and vulnerability of the server data to any cyber criminals and terrorists. Another issue may be the monopoly of current Electricity Utility providers and the extra cost for new meter. In our system, data is protected by password encryption. But we used an external cloud server. When the amount of data is big, we need our own dedicated server which will again enhance the security of data and alleviate any concerns. We did not make any significant change to meter topology; devices can be easily connected to existing meters and these are simpler and cheaper to operate.

6 Reflection on Individual and Team work (PO(i))

6.1 Individual Contribution of Each Member

Musfiquzzaman Abid (Student ID: 1906084) did the theoretical works and specifications. Md. Zonayed Hossain (Student ID: 1906087) did the hardware circuit connection and simulation of data from Smart Meter sensors. Dipika Rani Nath (Student ID: 1906092) did the codes on the server end and developed the communication protocol. Arnab Kundu (Student ID: 1906089) made the user-interface part.

6.2 Mode of TeamWork

Though each of the members in our team had individual tasks, we coordinated with one another and made the project operational. We discussed many times about the implementation online or offline where all members were present and cooperated with one another.

6.3 Diversity Statement of the Team

We form a diverse team. We all have different expertise, some in theories, some in hardware connection and others in software coding. We all are from different majors and different social and cultural backgrounds.

7 Communication to External Stakeholders (PO(j))

7.1 Executive Summary

This project is an application of IoT (Internet of things) technology in the Power System. IoT refers to networking between any possible devices or appliances. A Smart Electric Meter is such a device that can communicate with the service provider and consumer. Currently, the power system has problems in efficiency and transparency. The consumer or producer can not monitor and control the consumption data. So, the consumers cannot make intelligent and economical choices about their consumption patterns. Whereas, the provider also does not get enough consumption data for making intelligent designs about future load forecasting, dynamic billing. Illegal users and billing discrepancy cannot be addressed in the current scenario. So, there is a significant amount of system loss, both in terms of energy and economic incentives. Our device will facilitate the communication using Wi-Fi and improve the benefits for both consumers and producers of Power System.

8 Project Management and Cost Analysis (PO(k))

8.1 Bill of Materials

Name	Cost
EPS-8266	400 TK
Arduino UNO	800 Tk
ZMPT101B	270 TK
ACS712-30A	200 Tk
Relay	75 Tk
Breadboard	180 TK
Cables	140 Tk
Total	**2065 Tk**

8.2 Calculation of Per Unit Cost of Prototype

Total cost per unit prototype is 2065 Taka.

8.3 Calculation of Per Unit Cost of Mass-Produced Unit

When we will be able to produce the prototype in a large quantity, the cost will decrease. The cumulative cost per mass-produced unit will be around 1600 Tk.

8.4 Timeline of Project Implementation

Date	Contribution
3 February	Circuit Simulation and Connection
5 February	Hardware Preparation
10 February	Interface Building
17 February	Server Preparation
24 February	Final Integration of Hardware and Software parts

9 Future Work (PO(l))

In future, we want to use and compare between other communication protocols and implement this meter effectively for a large number of loads. We want to introduce an automated dynamic billing feature. We want to implement softwares for determination of faults in circuits. We want to introduce our own dedicated server for better security and data handling capacity.

10 References

[1] The Backbone of Social Economy - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Benefits-of-advanced-metering-infrastructure-AMI_fig4_306930274 [accessed 96 Sep, 2023]

[2] Vejlgaard, Benny, et al. "Coverage and capacity analysis of sigfox, lora, gprs, and nb-iot." 2017 IEEE 85th vehicular technology conference (VTC Spring). IEEE, 2017.

[3] Mohassel, Ramyar Rashed, et al. "A survey on advanced metering infrastructure and its application in smart grids." 2014 IEEE 27th Canadian conference on electrical and computer engineering (CCECE). IEEE, 2014.