Automated Energy Metering System

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A Final Year Design Project (FYDP) submitted to the Department of Electrical and Electronics Engineering in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronics Engineering.

Department of Electrical and Electronics Engineering
Brac University
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Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is my/our own original work while completing the degree at Brac University.
2. The Final Year Design Project (FYDP) does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The Final Year Design Project (FYDP) does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

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Approval

The Final Year Design Project (FYDP) titled "Automated Energy Meter" submitted by

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Ethics Statement

We, the four members of group 2 under ATC panel 4 designed and developed a smart energy meter that will record real-time energy consumption data and send it to both customers' and distributors' ends wirelessly through a cloud server network. We hereby state that while making this project we did not utilize any sort of external aid and all the team members participated in the project equally. We kept this project and all its blueprints confidential. This project was tackled under the proper and constant supervision of our ATC panel members. We researched as far as we could to build this project and all the supporting references were provided as the panel recommended.

Abstract/ Executive Summary

Meter theft and tampering have been prevalent issues in the energy industry and civil life for decades, causing financial losses to both civilians and utility providers. Traditional energy meters require manual readings, which can be time-consuming and prone to errors, making it difficult to detect instances of energy theft or meter tampering. To address this issue, this paper proposes the development of an automated energy meter that can send real-time energy consumption data to both customers and distributors and also detect tampering with the meter. The proposed system incorporates advanced technologies such as microcontrollers, wireless communication, and physical sensors to automate the energy meter reading process and detect any potential cases of tampering. The system operates by collecting energy consumption data from the user's premises and sending it wirelessly to both the utility provider and the user for billing purposes. The physical tamper detection sensors are utilized to identify any attempts to tamper with the meter, such as opening the meter casing or breaking the sealing wires. The system is designed to provide an efficient, secure, and cost-effective solution to energy metering and tamper detection which can help civilians to reduce their financial losses and improve the overall private energy management process. The proposed system was tested in a real-world scenario, and the results demonstrated that the system can accurately detect cases of tampering and provide an effective solution to energy metering and management. The system's ability to detect tampering can help utility providers to prevent energy theft, reduce revenue loss, and enhance the overall security of their energy infrastructure besides being a useful device for civilians as well. Overall, the proposed automated energy meter with tamper detection can play a significant role in improving the energy industry's operational efficiency and financial sustainability.

Table of Contents

Chapter 1: Introduction- [CO1, CO2, CO10]

1.1 Introduction

Automated energy meter is a smart meter which operates using wireless connection such as, wi-fi or GSM sim. Unlike any traditional or manual meter, the automated energy meter provides more accurate information about energy consumption.

In the usual energy metering systems, it is difficult to keep track of the consumption of the energy or electricity of the consumers. Smart energy meters help to keep track of these information and provide an easier medium of the overall operation system. The information from the smart energy meter is transmitted to the end users through wireless connection. Therefore, no human interference is required for the regular management of the system. The wi-fi based automated energy meter is sustainable since the world is gradually changing more towards the IoT system globally. This paper deals with the embedded system and the automated process of the energy meter. Along with that a theft detection system has been added to it so that the risks of tampering can be avoided from anyone's ill intention.

1.1.1 Problem Statement

At the end of every month, an appointed person from the energy supply company goes from house to house to take the meter reading in order to make an electricity bill. Errors occur, and sometimes dishonest people try to tamper with the meter and even the bill. In order to reduce the manual work and eliminate these tampering risks, we are designing an automated energy meter with an anti-theft system. This meter will instantaneously provide accurate meter readings and actual billing costs directly to the customers and their respective energy suppliers along with some theft detection notifications.

1.1.2 Background Study

There are different kinds of designs of automated energy meters having various functionalities and parameters that have been done previously. In [1] the design has mainly 3 modules which are, the smart meter, the Android application, and the server. This server will be connected to the other two modules (smart meter and Android application). They have a system that alerts the user that if their maximum energy use is exceeded, it will restrict excessive amounts of energy usage [1]. However, there are a variety of meter designs which are costlier but at the same time have more parameters and quality components. In the design of [2] the author has used a GSM module, a Wi-Fi module, and an optocoupler. Users are always looking for an energy meter that will be inexpensive in cost, but in this case, due to too many components, the cost of the device will only increase. Along with the increased cost, the architecture of the system will also be very complicated. In design [3] the authors used some extra parameters which are; temperature and humidity measurement. The author has also used a gas sensor in his design [3]. This will increase some extra costing because extra modules are needed to add in the circuit. Moreover, the microcontroller that they used is Raspberry Pi [3] which is much

pricey than Arduino boards. Again, in [5] the author has used in his design both a GSM module and wi-fi. In order to use the GSM module in their design, the mobile phone must support an "extended AT command set" to be able to send or receive SMS. Their design has a two-way communication system between the meter and the central system. They have designed their own webpage using HTML for communication. This design controls the other household devices to maintain minimum power consumption during peak hours, if power consumption passes the threshold amount then the power supply will be turned off automatically, and if the user wants they can turn it on by increasing the threshold.
In [4], the author tried to make an automated energy metering system that will be of a meager cost. That is why they have used a low-cost microcontroller, ESP8266, as their central processing unit, which has a built-in Wi-Fi module [4]. This means operating this system via Wi-Fi, and they won't need an extra Wi-Fi module, which will reduce the cost of the meter. This system will send the information to the website via Wi-Fi after a calculation is performed in the CPU [4].

1.1.3 Literature Gap

In this era of technology, Bangladesh still uses manual procedure in terms of taking meter readings and distributing the bills. On the other hand, smart meters have been installed in homes and other premises in many countries of the world like the USA, Europe, Australia and Canada, Italy, Sweden, Finland, and Spain [6].

As in Bangladesh, there is a large deficit between energy generation and demand, and smart meters will be beneficial in this matter. First of all, all the readings will be calculated automatically, so there will be no errors in bills. Secondly, customers will be more aware of the wastage of electricity as they will have access to all the necessary data by using the provided website.

Electric Supply Company (DESCO) is taking the initiative to introduce an intelligent metering system. So, they have conducted a pilot project to introduce prepaid meters with many features for domestic customers such as the "POISA" app. [7]

Though DESCO has been working with prepaid meters, there is still a significant need to improve in the field of smart meters for better and efficient usage of electricity in Bangladesh.

1.1.4 Relevance to current and future Industry

In this era people are more inclined towards the automated system rather than manual systems. Smart energy meters play an important role in advancing the digitization process of the energy industry [8]. From the socio-political and socio-economic perspective, the use of automated energy meters is domineering in order to alter the energy system digitally and sustainably. In recent years the rollout of smart meters has been conducted in many countries. According to a report, the number of smart meters doubled in 2013 compared to 2012 [8]. The deployment has taken place in 35 countries in Europe, Africa, Latin America, Eurasia, South Africa, and

Southeast Asia [10]. In Germany, the law of implementation of smart energy meters has been set for organizations where their annual consumption of energy is more than 6000 kWh [8]. Due to the increased number of automated energy meters, it is possible for the electrical distribution system to have better control and management scope. More improvement has occurred in terms of efficient operation, energy loss reduction, and increased reliability of the distribution system. The automated energy meter has brought more transparency about the real energy consumption towards both the end users; household or organizations and energy companies. By incorporating IoT with the meter, the record of the amount of energy usage with a precise value, the field of big data is immensely benefited [9]. According to the report of Pike Research, the approximate number of global smart meter rollouts has tripled from 10.3 million units in 2011 to 29.9 million units in 2017 [10]. The rollouts are completed in Italy and Sweden and are still in a fast continuation process in Finland and Spain [12]. In Germany, within 2032 the rollout of the smart meter throughout the whole country has been set [8].

1.2 Objectives, Requirements, Specification, and Constraints

1.2.1. Objectives

Our objective of designing this meter is as follows:

- Display of instantaneous current, voltage, and power.
- Reduction of manual work.
- Increased accuracy of bill calculation.
- Theft detection alerts.

1.2.2 Functional and Nonfunctional Requirements

- Functional requirements:
  - Should be able to check instantaneous real-time energy consumption.
  - Should provide theft detection notification.
  - The number of tamper counts should be recorded.
  - Should record previous months' bills.

- Non-functional requirement:
  - It should be unaffected by extreme weather (for example: placing the meter in a secured place).
  - The IR sensor should be connected in such a way that it only sends a notification when people other than the authorized ones try to open the meter.

1.2.3 Specifications

Sub-System	Components	Properties
Power Measurement	ESP32	• Input voltage: 5-12V • Crystal oscillator :16 MHz
	Current Sensor (ACS-712)	• Input Current: 0-30A • Frequency: 50Hz-150KHZ
	Voltage Sensor (ZMPT101B)	• Input: ~230V
	Transformer (AC-DC)	• Input: ~260 • Output: 9-12 V
	Resistor	• 10K Ω • 10 Ω
	Power Source	• 220V • 50Hz

	Component	Properties
Theft Detection	IR Sensor	● Range (0.7-1000 μ m)
	Led	● Input 5V ● Red color
	Buzzer	● Input 5V

	Component	Properties
Communication	Wi-fi Module	● Input 5V ● 2.5 GHz ● 100m Range
	GSM Module	● 4G sim Supported ● Input Voltage ~5V

Table-1: System-level specification of the optimal design

1.2.4 Technical and Non-technical consideration and constraint in design process

Designing any electronic device creates multiple perspectives of analytical ability and construction pathways for the design of the device for an engineer; at the same time, it also brings forward numerous constraints that engineers must consider before proceeding with a definitive design for the betterment of the society. That being said, the project at the hand of us authors are no different. From the beginning to the end of the project, we have faced and taken care of the following constraints in a very professional manner, more of which will be discussed in detail later in this book.

Technical considerations and constraints:

In the design of all, the power calculations or value of energy consumption were to be in kWh but a kWh is equivalent to 1000 watt-hours, and displaying such a large quantity was impractical for devices being used to serve civil citizens and make their lives easier. Hence the author decided to represent a kWh in simpler terms of basic units. The theft detection system used IR sensors which have different ranges of detection for indoor and outdoor environments. For outdoor scenarios, the range of detection is between 10-15 cm practically and thus it was placed in a manner considering the technical constraint. All designs used a microcontroller, which requires a suitable power supply to function properly all within 5-12V with a maximum current of 2.1A for the raspberry pi however since the device will be connected directly to a power supply in order to calculate the energy consumption the author decided that there must be the existence of an AC to DC buck converter to regulate voltage and current for the safe operation of the system. Both design-1 and design-3 require the aid of wi-fi for data transmission from the system to customers as well as for uploading to cloud servers; the devices will thus require separate wi-fi reservations to function efficiently. However, providing a single wi-fi router for all the devices may cause inefficient functionality of all the devices in terms of data transmission hence based on the routers used, a specific number of devices must be connected to a wi-fi reservation simultaneously; this might require multiple routers to support 20+ devices' operation.

Non-technical considerations and constraints:

It is mandatory that meters be installed by authorized personnel in isolation from public interaction. Since the meters will be quite sophisticated related to random meters we see in our country at the present moment, it shall be beneficial if a set of essential backup tools and components be available where meters are installed in large quantities; such a backup will aid in immediate restoration or troubleshooting of the meter due to any technical errors that might pop up.

1.2.5 Applicable compliance, standards, and codes

IEEE standards:

- IEEE 802.21 - GSM standard
- IEEE 1625 - Rechargeable battery standard
- IEEE 830 - Software Requirements Specifications
- IEEE 802.11 - Wireless networking - "Wi-Fi"
- ISO 9000 - Quality system management standard

- ISO 9001:2000 – Quality assurance to customer end :
  It is important to note that all the mentioned standards and codes of practice are in adherence to the Electricity Distribution Code under Bangladesh Energy Regulatory Commission and also in conjunction with their own criteria in a manner consistent with good engineering practice.

- The system designed shall be developed on the basis of technical and design criteria such that the demand of all the existing consumers connected or seeking connection with it shall be met for the next 5 years minimum. All the apparatuses and circuits shall have adequate capacity to cater to their need for electricity metering in a safe, economical and reliable manners. (Section 4.10 Technical and Design Criteria, Electricity Distribution Code, Bangladesh Energy Regulatory Commission).

- Planning of the system must always keep in view the cost-effectiveness of the system and shall incorporate the latest technology for maximum sustainability and efficiency. The design of the system must ensure maximum quality of materials along with smooth operational compatibility of components used in circuits and relevant connections.

- The system shall be supervised and undergo maintenance by practiced professionals in the field of electrical engineering to avoid tampering with data. It is also the responsibility of the owners, manufacturers, and distributors of the system to make sure of non-faulty service of the system or professional coordinators to troubleshoot the system if it shall undergo a defective operation as deemed by inspection or user-based feedback. (Adapted from section 5.4 Responsibility for operational safety, Electricity, Distribution Code, Bangladesh Energy Regulatory Commission).

- All equipment shall be properly wired, earthed, and compactly enclosed so as to avoid any regular civil interactions and thereby endanger the health safeties of civilians or wildlife. The installation location of the system must be carefully planned to avoid unnecessary civil and wildlife attention and thereby break any safety protocols. (Adapted from section 5.8 Connected Plant Restrictions, Electricity, and Distribution Code).

- The designed system shall be thoroughly tested, before distribution and again before installation at the location, for malfunctions and defects that might provide any false operational reports or may cause harm to the animal or human lives. In accordance with the tests carried out that have already ensured correct operation, two operation manuals should be made available for every system, namely one for low-end usage for consumers or domestic users and one for coordinators for high-end engineering level interaction with the system.

- An inventory of spares and components must be provided with each distributed system or be readily available in the market for swift maintenance of the equipment. (Section 6.12 Tools and Spares, Electricity and Distribution Code, Bangladesh Energy Regulatory Commission).

- With the intention of troubleshooting, alteration of the equipment, checking unauthorized bypassing of meters for consumption of energy, and carrying out general inspection and testing, the Licensee or his staff authorized by him shall be entitled to enter the premises of a consumer after informing the consumer. If the consumer refuses to allow access or obstructs the licensee or his personnel from entering the premises, the license or authorized officer shall without prejudice to other modes of action available in law disconnect the usage of the equipment from the user. (Adapted from Chapter 9, ELECTRICITY SUPPLY PROCEDURES, 53, Electricity and Distribution Code, Bangladesh Energy Regulatory Commission).

1.3 Systematic Overview/summary of the proposed project

In brief, our proposed project delivers automatic calculations of the meter reading through its central processing unit and displays the information on the meter itself and the cloud server (IoT platform). All the previous information will appear as a time vs power graph, so that the consumers and the suppliers can have a clear view of the consumed energy over time. Along with it there is an added feature in our system that is if anyone tries to open the meter in order to tamper with it or for any other reasons without the permission of the authority, the automated energy meter will instantly send notification to the cloud server and a buzzer will buzz on the energy meter.

1.4 Conclusion

While coming up with a solution to the problem we have taken into consideration the factors such as delayed billing, manual billing hassles, tampering of meter to alter the bills and paperwork complications of bills. The designed product is aimed to solve all the prior mentioned problems in the most cost friendly and technologically simple yet efficient way possible.

Chapter 2: Project Design Approach [CO5, CO6]

2.1 Introduction:

Though there are different types of approaches available for Automated Energy Metering System, it is important to select some of the approaches which are most effective to complete our requirements and objectives. Therefore, to analyze and finalize our optimal design solution we selected three design approaches.

2.2 Identify multiple design approach

In order to achieve our desired goals for this project, we came up with three design strategies. The design flowcharts are as follows:

<u>Design 1 (wi-fi based)</u>:

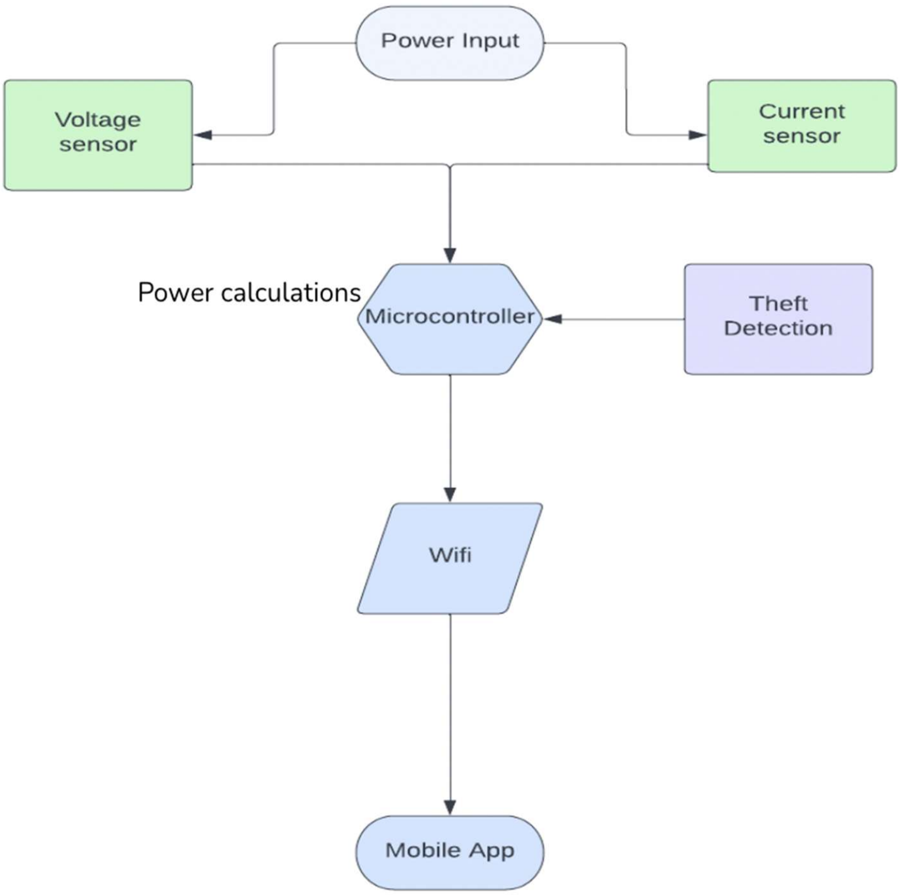


Figure-1: Wi-fi based flowchart

Design -2 (GSM sim based):

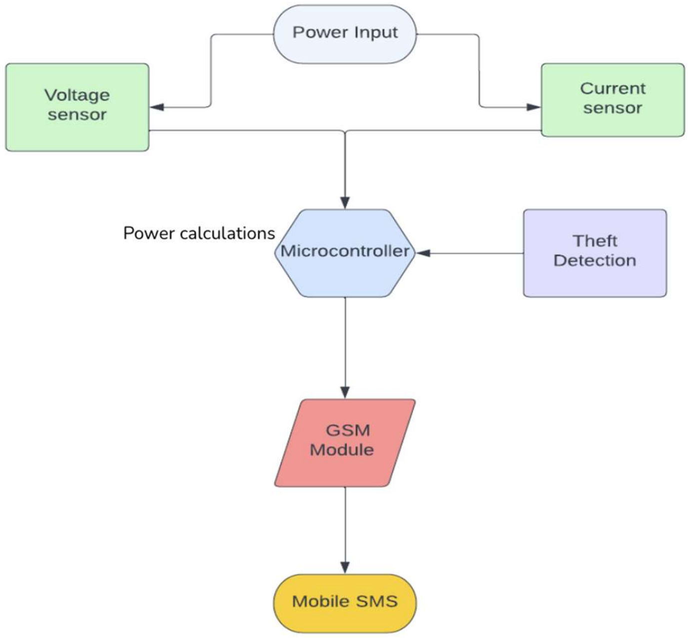


Figure-2: GSM based flowchart

Design-3 (optocoupler based):

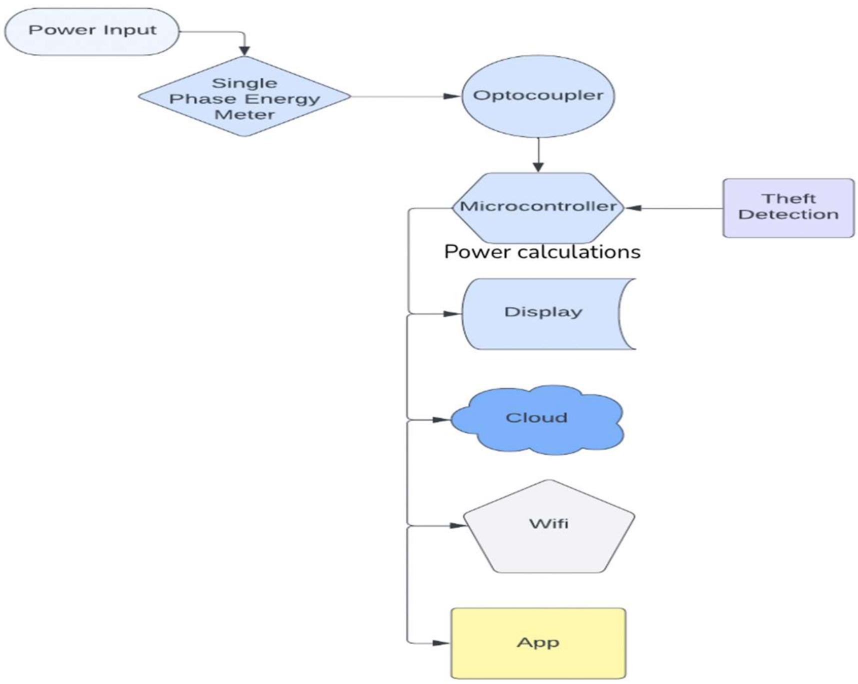


Figure-3: Optocoupler based flowchart

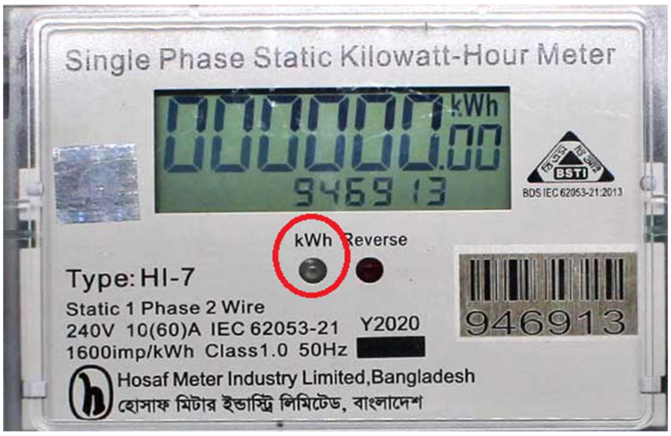


Figure-4: Energy meter with Cal Led

2.3 Describe multiple design approach:

<u>Design-1 (wi-fi based)</u>:

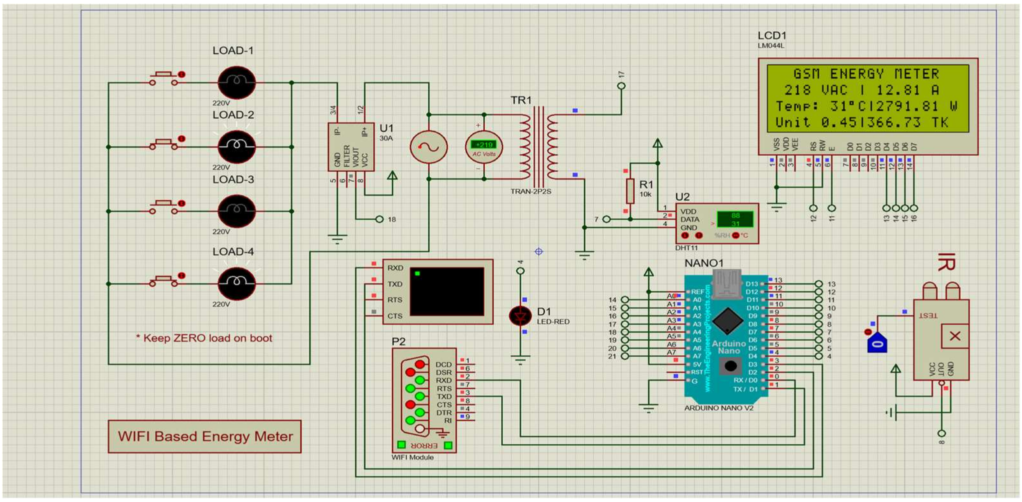


Figure-5: Simulation of design-1 in Proteus

In this design, we are using voltage and current sensors to measure the power being used. As we know (**P=VI cos θ**) and we can calculate power from the value of **I** and **V,** here we assume the unity power factor. So, by calculating power from the microcontroller's sensor values, we can get the value in units (**1 kWh=1 Unit**). After that, we will multiply the current energy rate and send the bill via wi-fi to our customers. Here we store the continuous data from our meter in the server, and a user can access it using an authorized application from their phone. Then, we also added a safety feature for our meter to avoid being tempered. We are using an IR sensor placed underneath a safety cover with a distance of 10mm. If it gets a value over 10mm, it means someone near the meter opened the meter box, and it will immediately notify the customer about the activity.

Design -2 (GSM sim based):

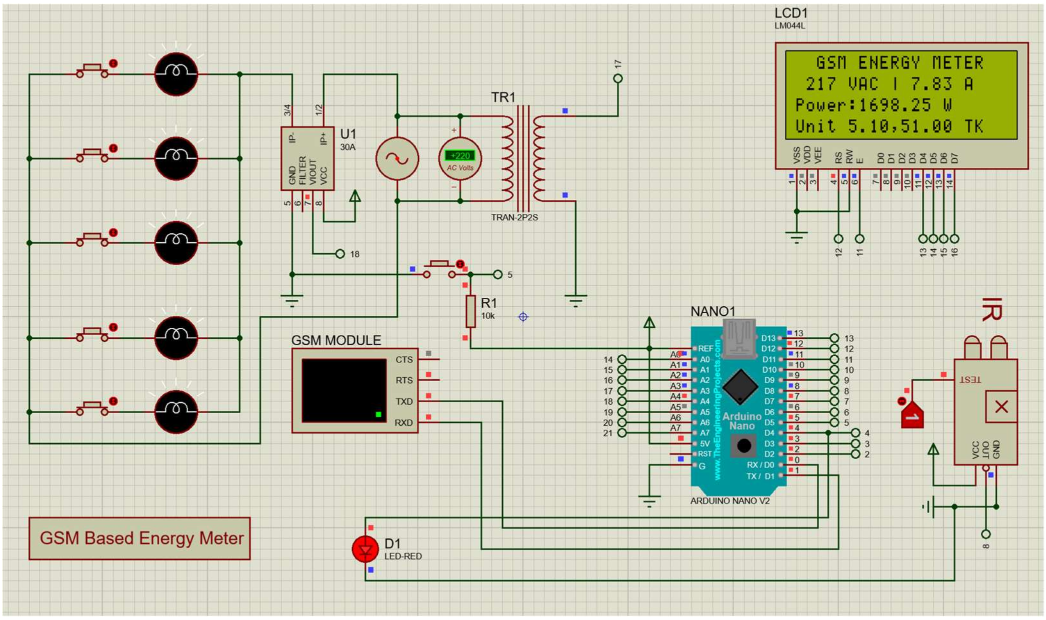


Figure-6: Simulation of design-2 in Proteus

For design-2, we use the same methods as design-1 to calculate the power used. Here we are changing the way of data transfer. We are using the GSM module to send the billing details via SMS. Here, customer needs to send a Code (for example: ***222#**) to the registered meter number via SMS, and our system will send a feedback message with current information to our customer. Here we are using a button to replace the Code option for simulation purposes. Anti-theft detection alarms will also be sent via SMS.

Design -3 (optocoupler based):

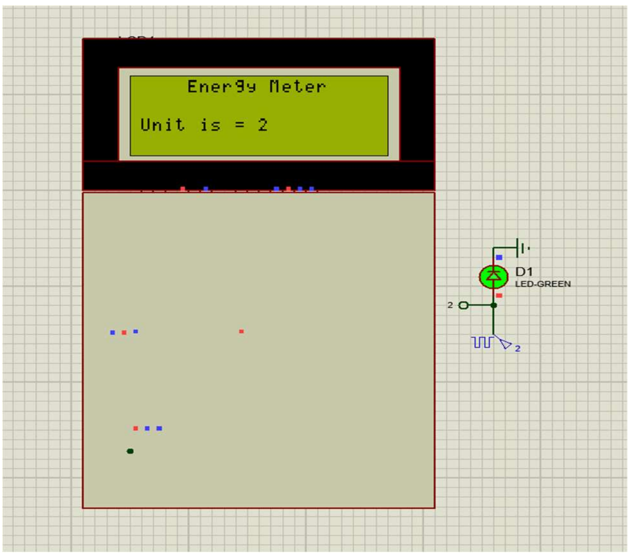


Figure-7: Simulation of design-3 in Proteus

Here in design-3, we use another different method to send consumption data to the customer. We can use this system as a sub-device with an existing meter. Currently, existing meters distributed by power supply authorities (PBD, DESCO, DPDC) have a Cal Led, which blinks when energy is used. We can count the blinks with an optocoupler and calculate the energy used (for example: 1600 blinks= 1 kWh). So, for our design3, we can calculate the bill by sensing Led blinks from an existing meter and send the data to the customer via Wi-Fi.

2.4 Analysis of multiple design approach:

Wi-fi Based energy meter:

The design approach-1 is based on Wi-Fi and it has multiple advantages in comparison with the other two designs. First of all, in design-1, we will be using the microcontroller ESP32 while actually making the prototype. ESP32 has an in-built Wi-Fi module so we do not need to add an extra component in our design. Since the communication medium is Wi-Fi, it will ensure a more stable connection with the accessibility of the user and energy supplier. Due to the Wi-Fi connection, there are no added charges to receive the meter reading from the internet. Also, this meter will display six parameters which are voltage, current, power, unit, cost, and theft alert. Again, from the IoT platform (Blynk), the users can see their previous months' energy consumption because a graph of energy consumption is displayed on the server. So, the users will get a quality projection of their energy usage from the past months/years and accordingly limit their energy use if needed. Since this meter is able to show this information and successfully convey it to the users, it has good efficiency. In addition to that it is more sustainable for being wi-fi based, low in cost, and being able to provide a stable connection. This approach will also provide us with a theft detection alarm which is sending emails to users.

GSM sim Based Energy meter:

Design-2 is set up on GSM sim. To make this model, we need to connect a GSM module to the circuit because in the microprocessor there is no in-built GSM module. Also, it will cost an extra charge for sending messages about the meter reading to the users via GSM sim. Therefore, this design is costlier than the design approach-1 in terms of the circuit structure as well as the service process. However, it can also display the six parameters (voltage, current, power, unit, cost, theft alert) and is efficient as there are no errors, and works perfectly fine. One of the main problems is the connectivity issue. Since mobile network connections vary from place to place in our country, users might face hindrance in receiving meter readings. That is why, even if there are no errors in the system, due to the cost and connectivity risk, it is less sustainable than that of design-1.

Optocoupler based:

Design approach-3 is also based on wi-fi, it is of very low cost since it has a few components, and no added charges are needed. Its connectivity is also stable due to the wi-fi connection. However, the problem is that it only shows the unit, and no other information is displayed to the users. As in the other two designs the user gets an idea about their energy consumption, in this design there is no such thing. It only gives vague information about how many units are used. Many people may not know the billing calculation using the units, even if they know it is much of a hassle to calculate the bill manually every time. Again, design-2 requires a mobile phone with a sim card for billing notifications, but Design-1 can use any smart device with internet access to observe energy usage data. That is why, we can say that this design is not that efficient and sustainable.

2.5 Conclusion:

We were able to choose the most optimal design that is more ideal, user-friendly, and closely connected to our goal because of the many analyses of each of our designs which helps us to create an effective automatic energy metering system. After considering various aspects, we can conclude, that our design approach-1 which is based on Wi-Fi, will be the optimal solution for the automated energy meter design. It is low in cost, has good connectivity, provides several meter reading information, and is more efficient and sustainable in comparison with the other two designs.

Chapter 3: Use of Modern Engineering and IT Tool. [CO9]

3.1 Introduction

Day-by-day simulation, modeling and analysis are gaining popularity in terms of research-related work. In this era of modern technology, simulation has a wide range of applications, starting from the fields of logistics, scheduling, and military operations to the field of material handling, manufacturing, communication system, and computer industries. Before building the hardware model, software models can be built and tested, which is more efficient and cost-friendly. Because of these crucial contributions to the modeling and analysis field, the simulation field is advancing rapidly and emerged as one of the most widely used and acknowledged tools in system analysis and operation research. As a result, there is more and more simulation software availability with more affordable and easy-to-learn languages, and technical developments are happening. Also, there are a variety of microcontrollers to realize the designs and research. Starting from simple to complex and cheaper to costly, plenty of microcontrollers are available in the market. Before designing our project, we have compared the IT tools with several other tools. In our design, we have used those IT tools which are most suitable for our project after comparing them with several other tools and at the same time cost-effective for the consumers.

3.2 Select appropriate engineering and IT tool

IoT platforms:

ThingSpeak	Blynk	Things boards	Ubidots	Kaa IoT platform
1. API 2. Activity tracking. 3. Configuration management. 4. Data collection. 5. Connectivity management.	1. Easy widget. 2. Direct pin manipulation, no codes are needed. 3. Easy integration of new features using virtual pins. 4. History of data monitoring	1. Scalable. 2. Robust and efficient. 3. Fault tolerant. 4. Customizable. 5. Durable.	1. Easy to connect. 2. Device-friendly API and SDKs. 3. Point and click cloud application development. 4. User management.	1. Modern microservice. 2. Freedom of technology. 3. Scalable and elastic. 4. Open IoT protocols. 5. Security. 6. Blueprints.

	by super chart widget. 5. Device to device communication using bridge widget. 6. Able to send email, push notifications and so on.			

Table-2: Comparison of the key features of different IoT platforms.

Microcontrollers:

Arduino UNO	ESP32	ESP8266	Raspberry pi
1. It has 14 digital I/O pins, 6 analog input pins and 6 PWM pins. 2. 16 MHz ceramic resonator. 3. 6 PWM outputs. 4. It has UART. 5. 13 built-in LEDs. 6. 2 KB SRAM, 32KB Flash and 1 KB EEPROM. 7. 5V I/O voltage. 8. Low cost.	1. Has built-in Wi-fi 2. Xtensa dual-core 32-bit MCU. 3. Bluetooth 4.2 and BLE. 4. 160 MHz typical frequency. 5. Has SRAM and Flash. 6. 34 GPIO 7. 12-bit ADC 8. It has a touch sensor.	1. No Bluetooth 2. Xtensa single-core 32-bit MCU. 3. 80 MHz typical frequency. 4. No SRAM and Flash. 5. 17 GPIO. 6. 10-bit ADC 7. No touch sensor. 8. No hall effect sensor. 9. 8 channels of	1. 40 GPIO pins 2. Micro SD-card slot for loading operating systems and data storage. 3. 2 USB 3.0 ports and 2 USB 2.0 ports. 4. 2.4 GHz and 5.0 GHz IEEE 802.11 ac wireless LAN 5. Bluetooth 5.0 and BLE Gigabit Ethernet. 6. 1GB/ 2GB/ 4GB/ 8GB SDRAM.

	9. Has hall effect sensor 10. 16 channels of hardware/software PWM. 11. Very low cost.	hardware/software PWM. 10. Lower cost.	7. It has 2 micro-HDMI ports supporting two 4k displays. 8. High cost

Table-3: Comparison of different microcontrollers

Simulation software:

Autodesk Eagle	LTspice	EasyEDA	Proteus	kiCad
1. Free version with limited capability. 2. Easy to use and lots of resources. 3. Capable of 3-D modeling. 4. No signal and power integrity solutions. 5. Creating custom component is challenging. 6. Difficulty of library navigation. 7. Lacks	1. Free software with no usage limitations. 2. Gives accurate results. 3. Has fast simulations. 4. Does not have a PCB editor.	1. Unlimited private projects. 2. No need to install any software. 3. No non-commercial licensing needed. 4. Internet connection is required. 5. Limited components. 6. Has limited features.	1. More than 15 million components in the library. 2. Availability of microcontrollers like Raspberry pi, Arduino, PIC. 3. Great variety of analysis tools. 4. Easy to interface. 5. Very easy to use tools for professional PCB design and schematic capture.	1. Free software with no limitations. 2. Powerful 3-D viewer. 3. No limitation to board size or number of layers. 4. Does not have an auto-routing feature. 5. Complex component library.

components.			6. Packages are expensive.	

Table-4: Comparison of the features of different simulation software.

Coding software:

Arduino IDE	TextMate	Codevision AVR	Sublime Text
1. Open source software. 2. Works on Windows OS, Mac OS, Linux OS. 3. Compatible with any Arduino boards. 4. Has a simple syntax. 5. Has a large library of pre-written codes. 6. Has cross platform compatibility. 7. Versatility, easy to learn and use.	1. Supports a lot of languages. 2. Only works on Mac operating systems. 3. Auto-pairing for brackets. 4. Can record Macros without programming. 5. TextMate is a free software.	1. Integration of the code wizard to help beginners to quickly master the procedures of AVR microcontrollers. 2.Easy to use an integrated development environment. 3. Possibility to insert inline assembler code directly in the C source file.	1. The software is not free. 2. Supports many languages. 3. Works on windows, Linux, mac OS. 4. Provides instant switching between projects. 5. Has cross platform support.

Table-5: Comparison on various coding software.

3.3 Use of modern engineering and IT tools

Blynk

There are several IoT platforms to access microcontrollers, such as Blynk, ThingSpeak, and so on. We chose Blynk because it is one of the best apps to control IOT-based hardware devices (Arduino, Raspberry-pi, ESP32, ESP8266, etc.). It can display sensor data, store data, and visualize and control hardware remotely. The three main components of this platform are the Blynk app, Blynk server, and Blynk libraries. By using various widgets, interfaces are created with the project through the Blynk app. Blynk server is open-source, and it can easily communicate between smartphones and many hardware devices. Lastly, the Blynk library is able to process incoming and outgoing commands and enables communications with the hardware. Blynk connects the hardware to the cloud using various mediums such as wi-fi, ethernet, GSM, Bluetooth, etc. In our project, we are using wi-fi and GSM as the mediums. Blynk app can be downloaded from the IOS app store or Play store.

ESP32

We choose ESP32 because it is a featured microcontroller with integrated Wi-Fi and Bluetooth connectivity for a wide-range of applications. It is highly-integrated with in-built antenna switches, low-noise receive amplifier, RF balun, filters, power amplifier, and power management modules. The operating temperature of ESP32 is ranging from –40°C to +125°C. Which allows it to function reliably in industrial environments and can remove external circuit imperfections by adapting to the changes in external conditions. Moreover, ESP32 consumes ultra-low power and can work for mobile devices, wearable electronics and IoT applications. Furthermore, ESP32 is also able to interface with other mediums to provide Wi-Fi and Bluetooth functionality through its SPI / SDIO or I2C / UART interfaces.

Arduino IDE

For coding software, we have Arduino IDE, CodeVision AVR, etc. We are using the Arduino IDE for coding purposes in our project. It is an open-source tool, so it is possible to upload the code to the cloud. It offers full compatibility with Arduino software boards. Also, a good side is that it can easily be deployed in Linux, MacBook, or Windows operating systems. Again, this coding software is accessible in pricing and easy to use. After coding, the code will be uploaded as a hex file to our Proteus simulation project.

3.4 Conclusion

For functional verification, we took the help of Modern engineering and its tools. By using the Blynk app, we can access all the needed values calculated by the microcontroller, which shows more accurate results than the manual procedure of taking readings. Thus, it is easier for us to compare the designs for selecting the most efficient and optimal solution.

Chapter 4: Optimization of Multiple Design and Finding the Optimal

4.1 Introduction:

Finding the optimal design among a set of alternatives is important because it ensures that the design meets all of the required objectives and criteria, and performs at its best. Without optimization, it is possible that a suboptimal design could be selected, which may not perform as well or be as cost-effective as it could be. Optimization of multiple designs is important for several reasons such as cost reduction, customization, innovation. Optimization can help to improve the performance of a product, such as its speed, accuracy, or efficiency, which can enhance the user experience and increase the value of the product. Moreover, optimization can help to tailor a product to meet specific customer needs or requirements, which can increase customer satisfaction and loyalty. Overall, optimization of multiple designs and finding the optimal design is critical for creating high-quality products that meet customer needs and expectations, while also minimizing costs and maximizing performance. For our final design, we need to evaluate our proposed multiple designs to achieve the goal we want in an efficient way.

4.2 Optimization of multiple design approach:

Design 1:

Here, we set the fully loaded status for 5 minutes to visualize the escalation of the cost with respect to time. Also, to verify the theft detection system, we have kept the IR sensor activated to show that notification is sent to the Blynk app. In the physical model of this automated energy meter, the theft detection signal will be sent as soon as anyone tries to tamper with it. To show this signal in simulation we have used a button in our simulation.

Efficiency: Fully functional in any environment and under wi-fi range.

Component Level Cost: 2720 taka

Usability: It can measure any single-phase connection and deliver appropriate data.

Manufacturability: All components are available in the market.

Impact: Along with proper power usage calculation it will serve theft detection.

Sustainability: The system can operate under any harsh environmental situation and slight outside impact.

Maintainability: Without any component level damage it required zero maintenance.

Simulation Design:

Design-1 (wi-fi based):

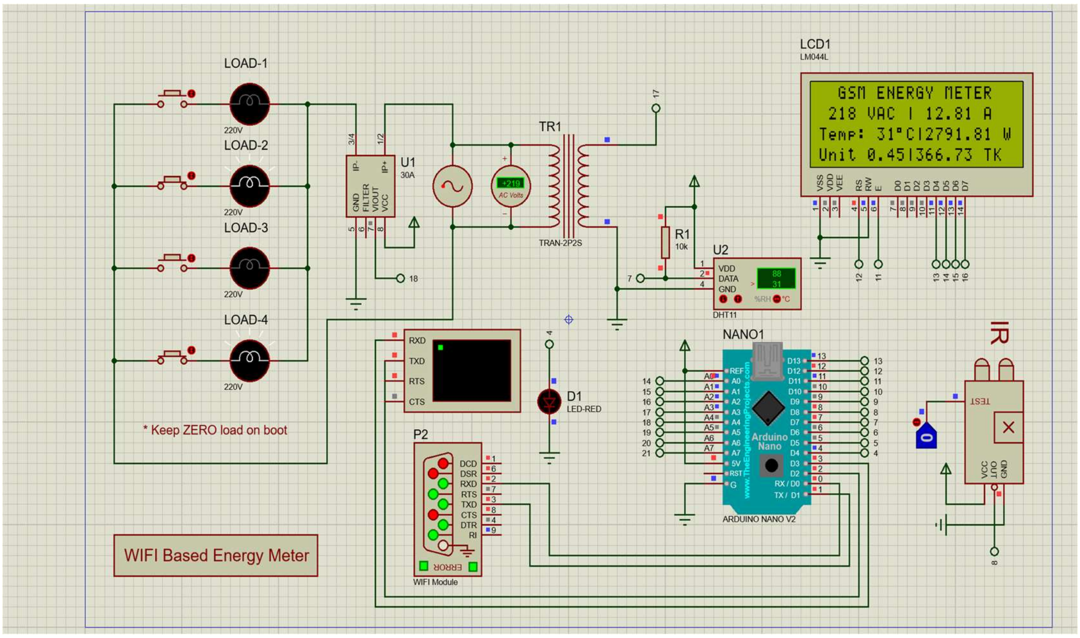


Figure-8: Simulation of Design 1

Test cases of design-1:

Case-1: Keeping 2 Loads ON

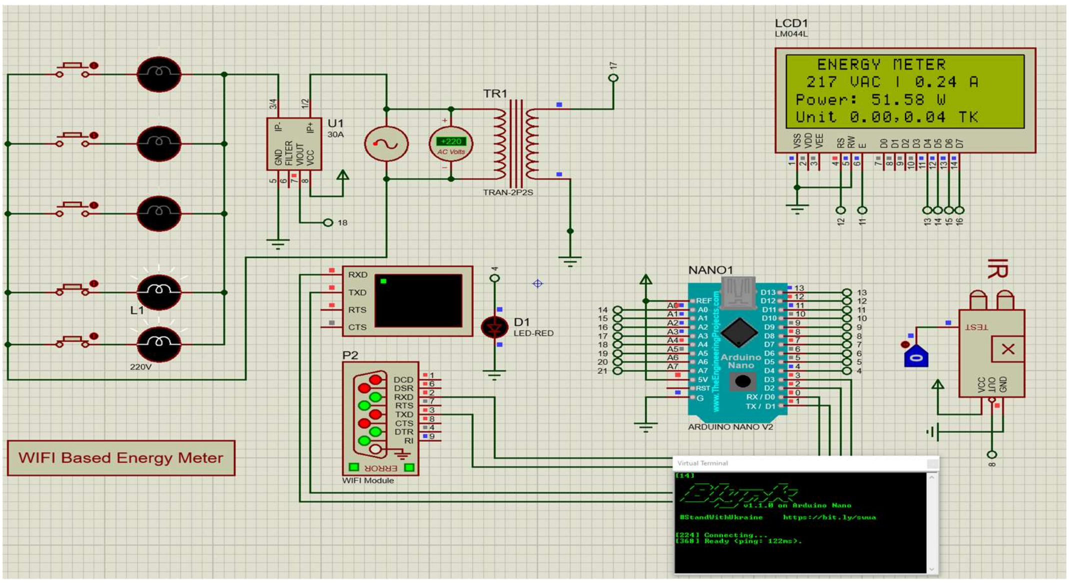


Figure-9: Simulation of 2 activated loads

Case-2: Keeping 4 Loads ON

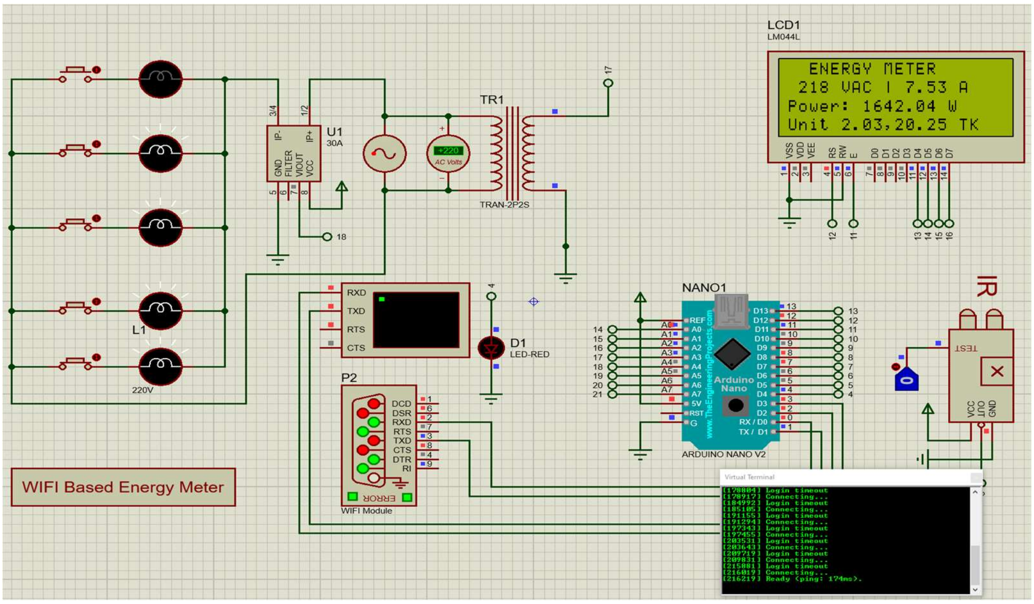


Figure-10: Simulation of 4 activated loads

Case-3: Keeping all loads activated

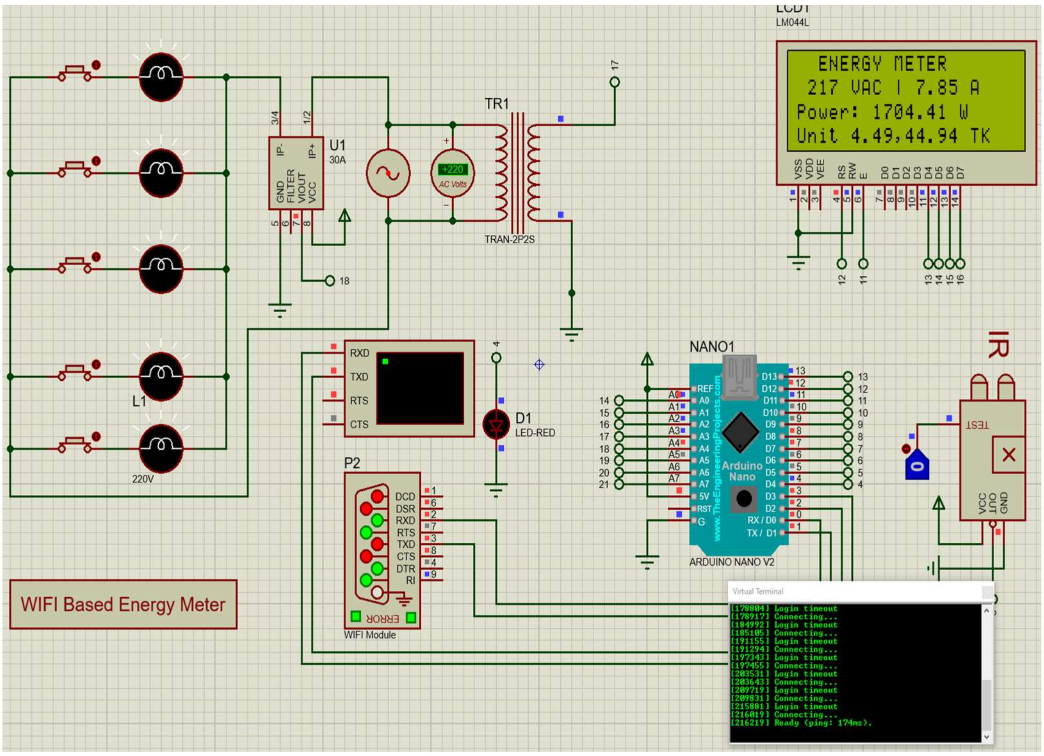


Figure-11: Simulation of fully activated loads

Result:

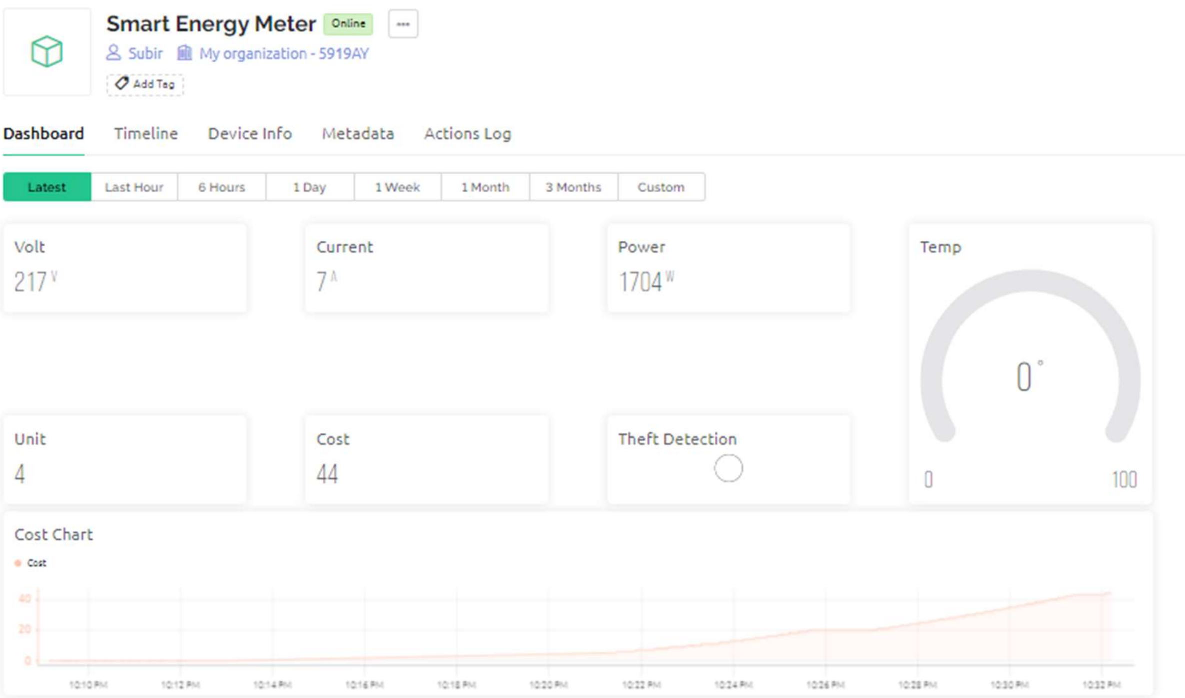


Figure-12: Overall result of different loads

Case-4: Full load with theft detection

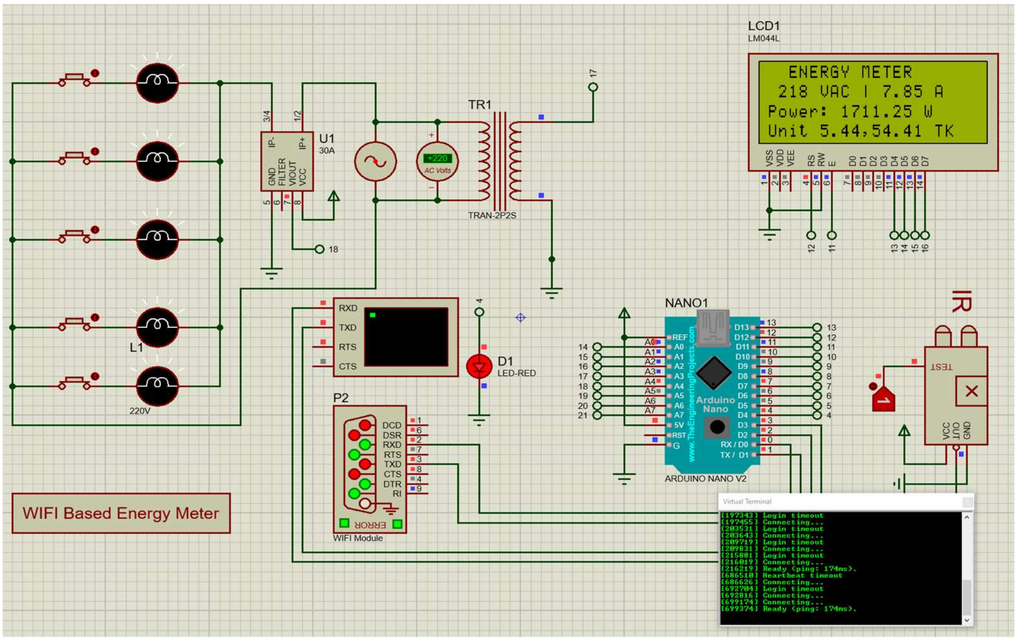


Figure-13: Simulation of fully activated loads and IR

Result:

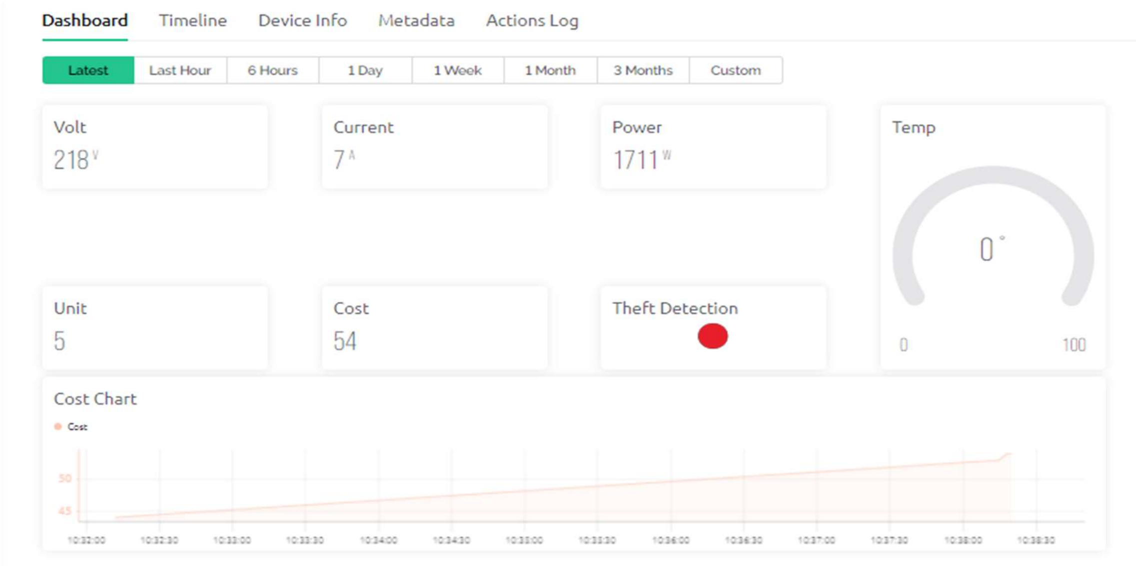


Figure-14: Overall result of different loads with activated IR

Design 2 (GSM sim based):

Energy meter (Using GSM sim):

In figure-10, figure-11, figure-12 and figure-13 we are increasing the number of loads gradually to see the changes in the parameters. Since, in figure-10 only 2 loads are kept activated for 5 minutes the unit and cost did not increase at all. However, we have increased the number of loads to 4 loads in figure-11 and 5 loads in figure-12 and keeping them ON for 5 minutes, we can see the increase in units, power consumption as well as billing cost. Since, the unit cost is set as 10 Taka, we can see the total billing cost is increasing according to this rate. Again, in figure-14 we have shown the functionality of the theft detection system. If any tampering is tried on this automated energy meter, notification will be sent to the users. All of these readings will be sent to the respective users through a SMS. In the result section the virtual terminal is acting as the SMS which will be sent to the user.

Efficiency: Fully functional in any environment

Component Level Cost: 5509 Taka

Usability: It can measure any single-phase connection and deliver appropriate data.

Manufacturability: All components are available in the market.

Impact: Along with proper power usage calculation it will serve theft detection.

Sustainability: The system can operate under any harsh environmental situation and slight outside impact.

Maintainability: Without any component level damage it required zero maintenance. Also needed to recharge the SIM to send the message.

Test cases:

Case-1: Keeping 2 Loads ON

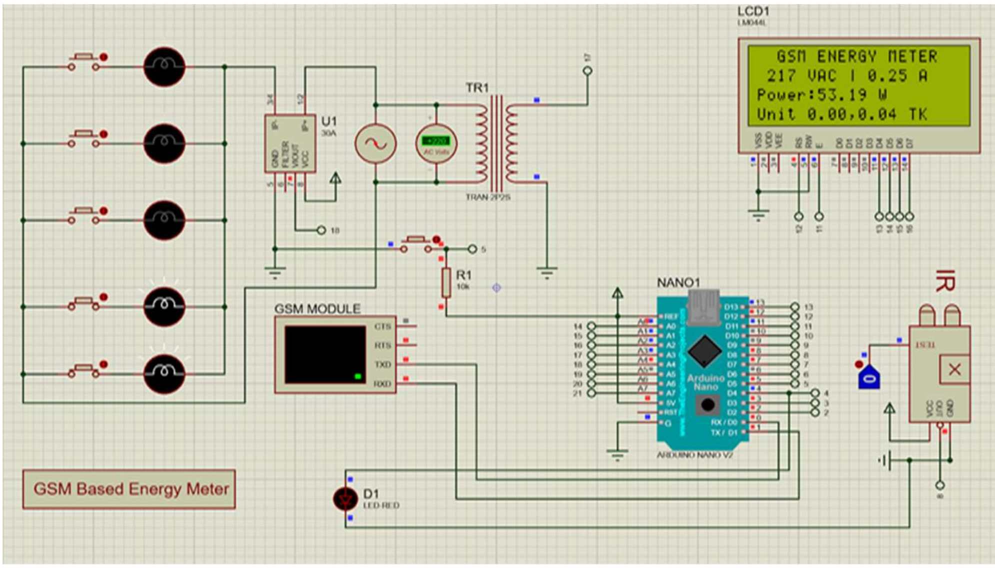


Figure-15: Simulation of 2 activated loads

Case-2: Keeping 4 Loads ON

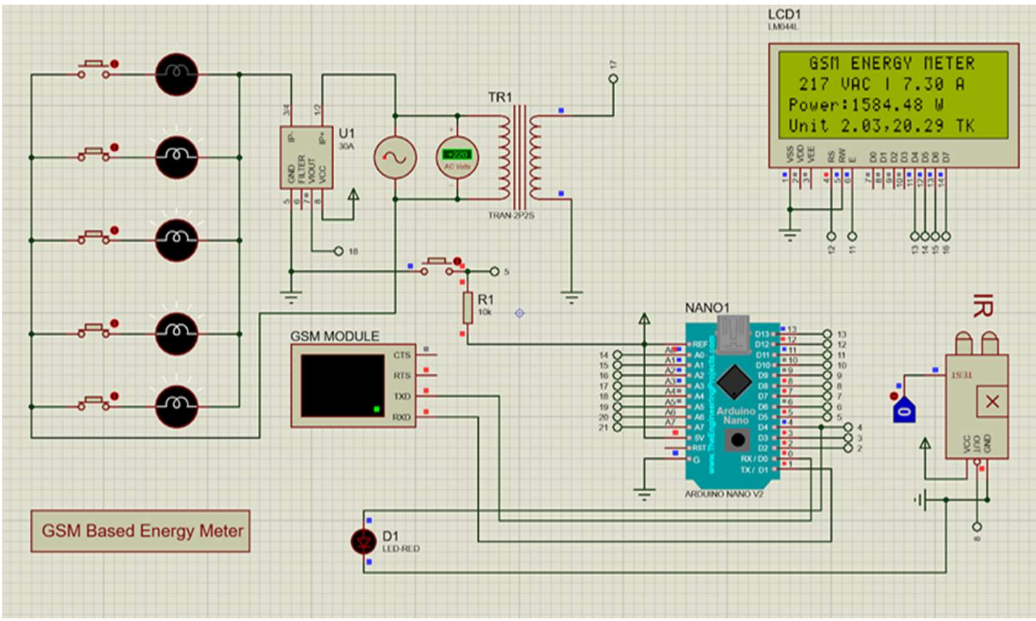


Figure-16: Simulation of 4 activated loads

Case-3: Keeping all loads activated

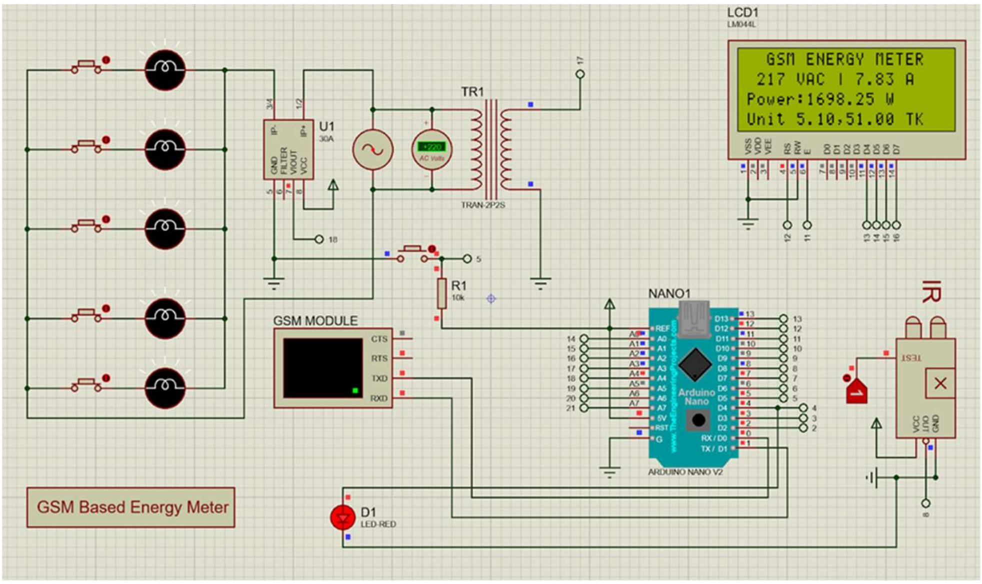


Figure-17: Simulation of fully activated loads

Case-4: Full load with theft detection

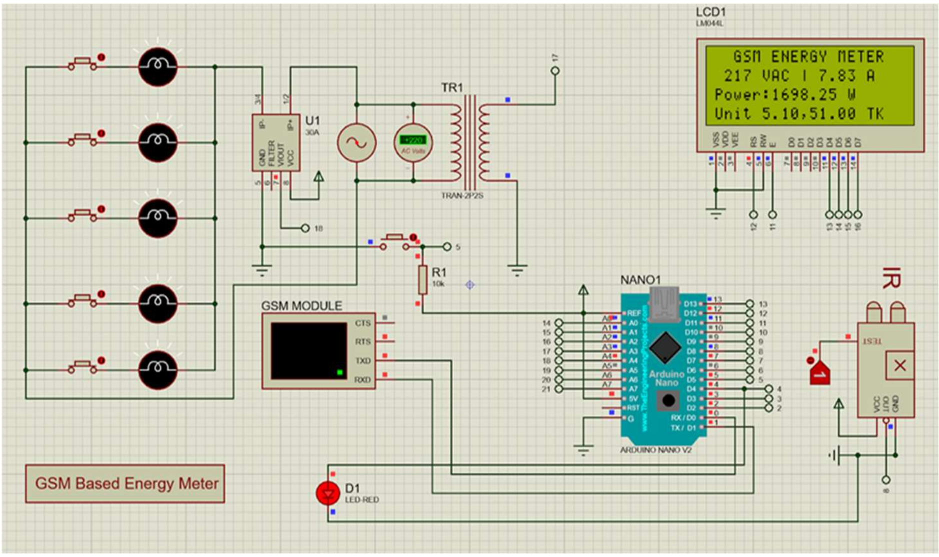


Figure-18: Simulation of fully activated loads and IR

Result:

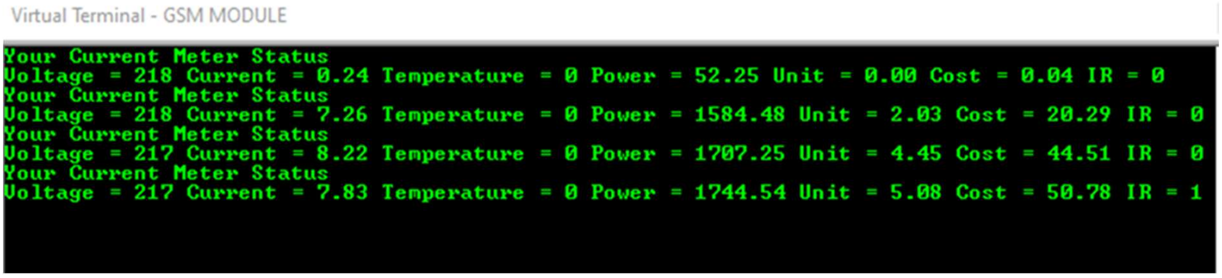


Figure-19: Overall results of different activated loads and IR

Design 3 (optocoupler based):

Sending data from existing meter (Using optocoupler):

Here in design-3, we use another different method to send consumption data to the customer. We can use this system as a sub-device with an existing meter. Currently, existing meters distributed by power supply authorities have a Cal Led, which blinks when energy is used. We can count the blinks with an optocoupler and calculate the energy used (for example: 1600 blinks= 1 kWh).

Efficiency: Less efficient than existing meters.

Component Level Cost: 1560 taka

Usability: To send meter reading data to the customer via cloud networking.

Manufacturability: All components available in the market.

Impact: Only share the consumption data remotely to the customers.

Sustainability: System can malfunction in a bright area and sensor can over count reading.

Maintainability: Design requires zero maintenance.

Test cases:

Case-1: Showing 2 units

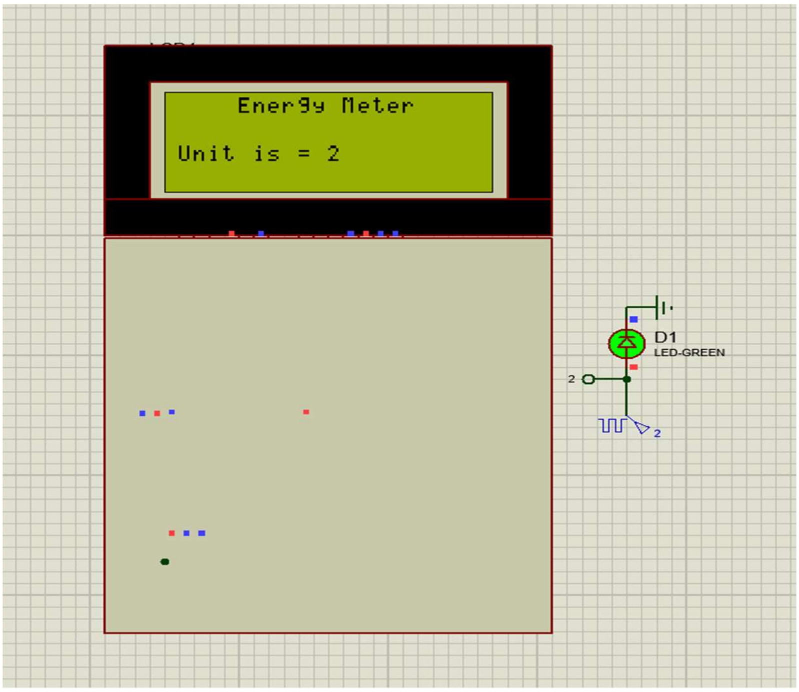


Figure-20: Simulation of displaying up to 2 units

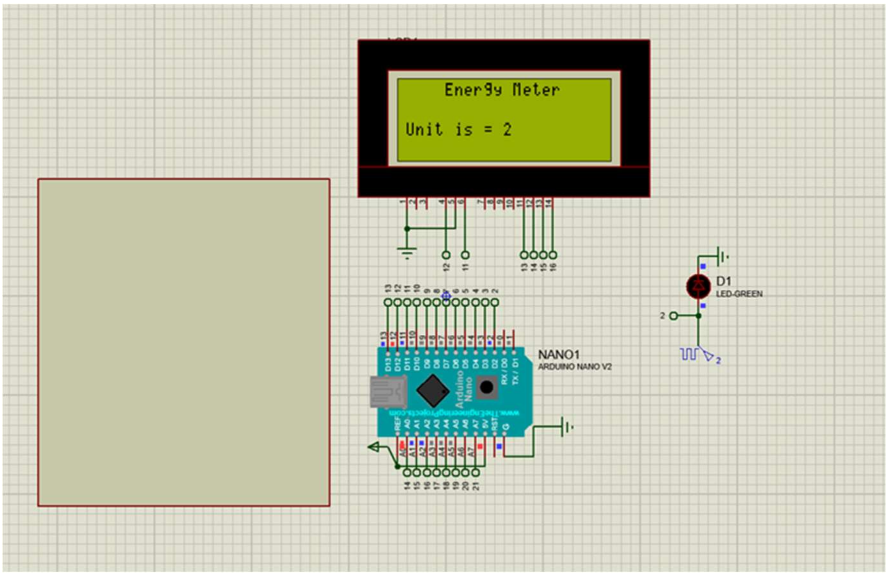


Figure-21: Simulation of displaying up to 2 units (without the cover of the meter)

Case-2: Showing 4 units

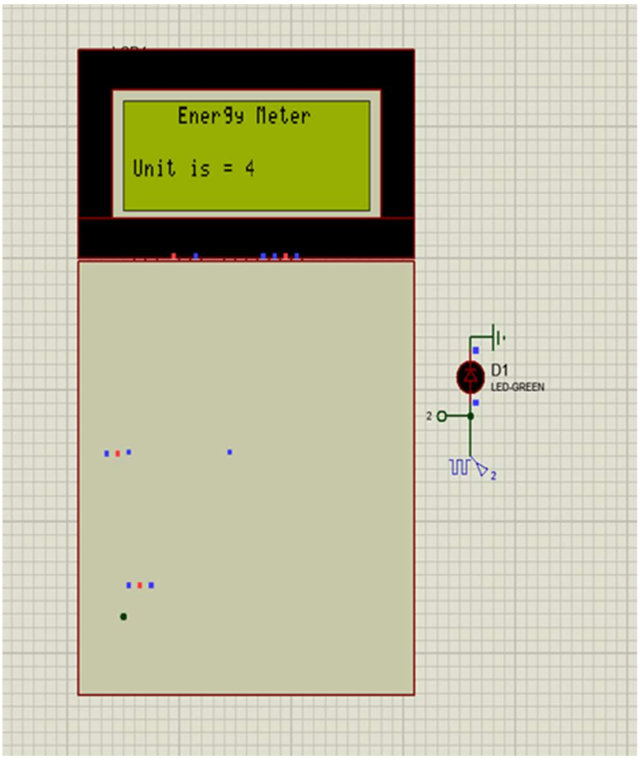


Figure-22: Simulation of displaying up to 4 units

Case-3: Showing 6 units

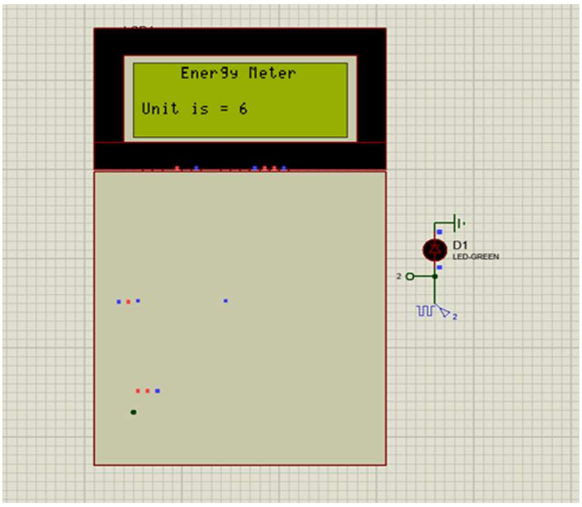


Figure-23: Simulation of displaying up to 6 units

4.3 Identify optimal design approach:

Table for design comparison:

Sl. no.	Criteria	1st design approach	2nd design approach	3rd design approach
1.	**Number of components**	11	13	5
2.	**Connectivity**	More stable	Less stable	More stable
3.	**Extra service charge/cost**	No extra cost	Extra cost due to sending messages	No extra cost
4.	**Displaying multiple parameters**	Shows 7 parameters	Shows 7 parameters	Shows 1 parameter
6.	**Sustainable**	More sustainable	sustainable	Less sustainable
7.	**Budget (taka)**	3280 taka	5509 taka	1560 taka

Table-6: Comparison of the attributes of different criteria

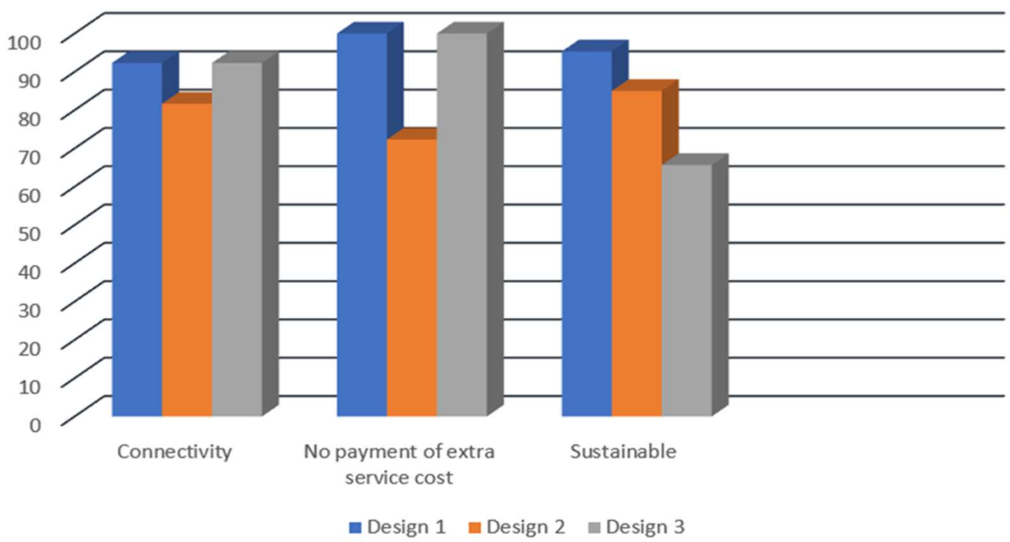


Chart-1: Weighted Matrix of the qualitative criteria

After comparing all the analysis of the three systems through various simulation and other stated above factors, we choose **Design 1 Wi-fi based energy meter**.

3-D of the Proposed Design:

Figure-24: 3-D of the proposed final hardware design

Updated budget for selected optimal design:

Component Name	Unit	Price
ESP32	1	850
Voltage Sensor (ZMPT101B)	1	150
Current Sensor (ACS-712)	1	1350

Resistor (10k)	1	15
Capacitor (10μF)	1	5
Resistor 100 ohm	1	2
PCB	1	250
LCD Display (LM044L)	1	230
Potentiometer (10K)	1	60
IR sensor	1	50
Step Down Transformer (~12 V,2A)	1	200
Buzzer	1	20
Cloud server (Blynk)		Free
Total		3280 **BDT**

Table-7: Updated budget for optimal design

4.4 Performance evaluation of developed solution:

Design:

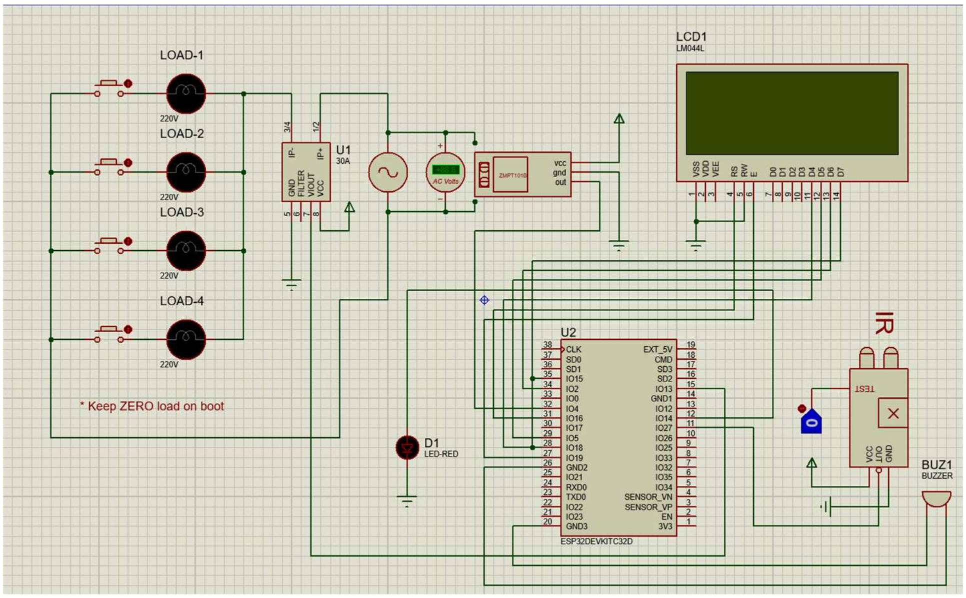


Figure-25: Optimal Design Software

Figure-26: Optimal design hardware

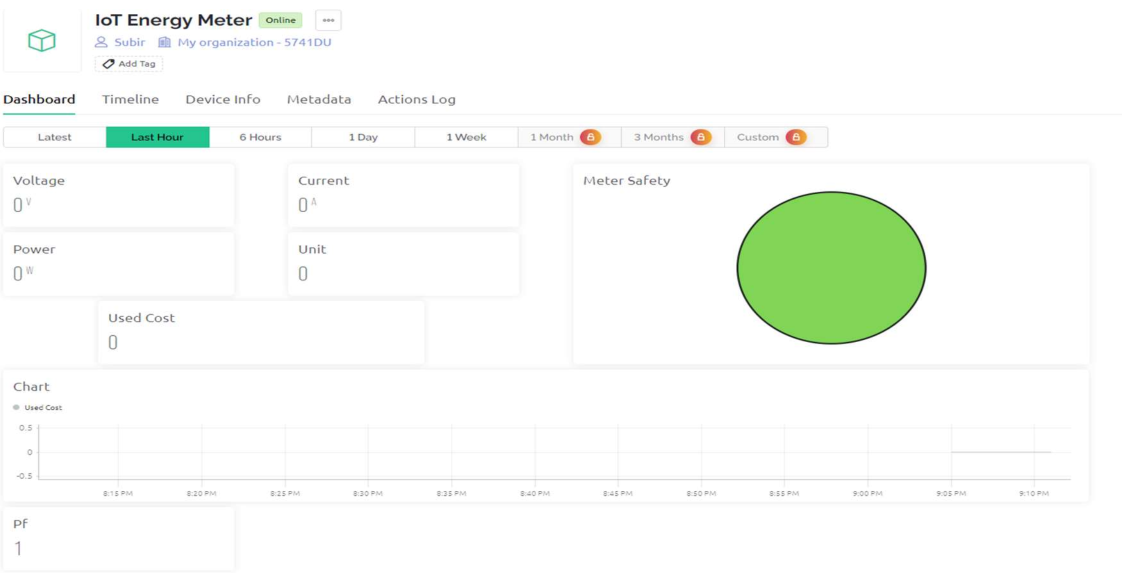


Figure-27: Web view

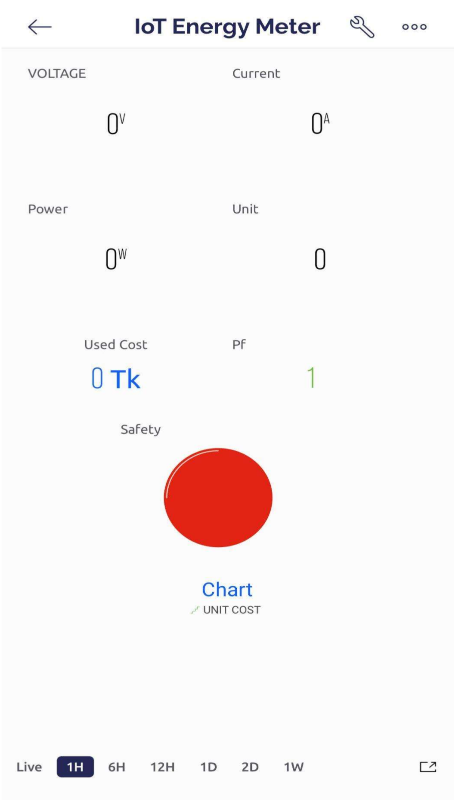


Figure-28: App view

Test Case:

Here we used a current sensor (ACS-712) which operated within 5A. So, we have tested our designed meter within 1000W load. For testing purpose, we have used 50W, 100W light bulb and 150W table fan as load.

Test Result Using Resistive Load:

Different Loads	Voltage(V)	Current (Amp)	PF angle	KWH
200W (Resistive load)	216	0.9	1	0.0323
400W (Resistive load)	217	1.8	1	0.065
650W (Resistive load)	217	3	1	0.1085
800W (Resistive load)	217	3.6	1	0.1302
1kW (Resistive load)	219	4.5	1	0.1643

Table-8: Test result using resistive load

Test result using Resistive & inductive Load:

Different Loads	Voltage(V)	Current (Amp)	PF angle	KWH
200W (Resistive load + Inductive load)	216	0.9	0.8	0.0227
400W (Resistive load + Inductive load)	217	1.8	0.85	0.043
650W (Resistive load + Inductive load)	218	3	0.45	0.0982
800W (Resistive load + Inductive load)	217	3.6	0.53	0.1123
1kW (Resistive load + Inductive load)	219	4.5	0.68	0.1267

Table-9: Test results for resistive and inductive load in use

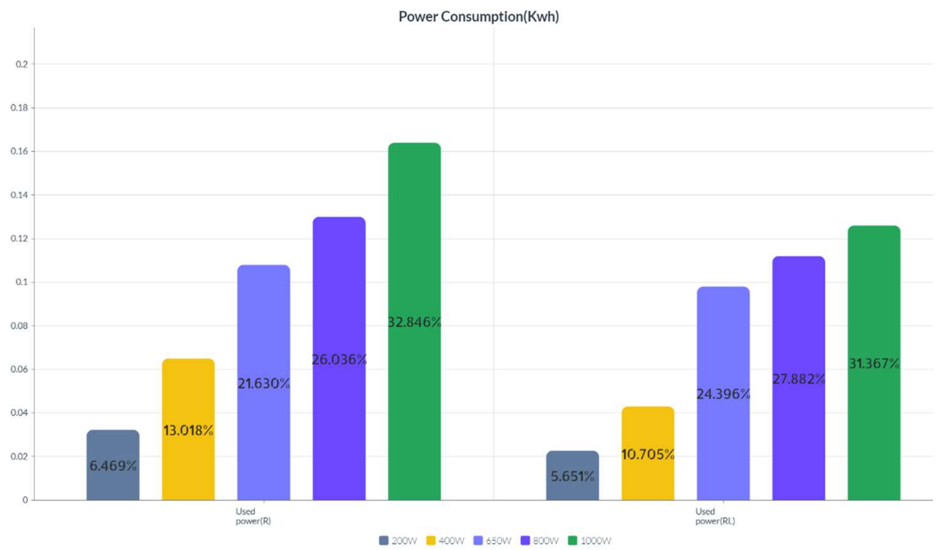


Chart-2: Power consumption of resistive loads in use (left) and both resistive and inductive loads in use (right)

4.5 Conclusion:

The chosen design approach for an automated energy meter is design-1 based on wi-fi. It uses an ESP32 microcontroller with built-in wi-fi, providing stable connectivity and displaying six parameters: voltage, current, power, unit, cost, and theft alert. Users can view their energy consumption history on an IoT platform. Design-2 based on GSM sim requires extra cost for a GSM module and has connectivity issues. Design-3 based on wi-fi is low cost but only displays the unit consumed and lacks efficiency. Overall, design-1 is the optimal solution due to its low cost, good connectivity, efficient and sustainable features, and multiple parameter display.

Chapter 5: Completion of Final Design and Validation. [CO8]

5.1 Introduction:

A crucial phase of any project, but especially one involving engineering and product development, is the completion of the final design and validation. It involves finishing the design, testing, and validating the product to make sure it complies with all applicable regulations and satisfies the necessary requirements for quality and specifications. The product's desired functionality is helped to ensure by the final design and validation stage. To ensure that the product complies with the desired specifications and requirements, all components are tested to ensure that they function together without any issues. Any dangers that may have gone unnoticed earlier in the design phase can now be identified and mitigated. Before the product is made available, potential operational or design problems might be found and fixed through testing.

5.2 Completion of final design:

First, we made a final simulation design with in cooperation all features which were proposed later and upgraded the old design for optimal output.

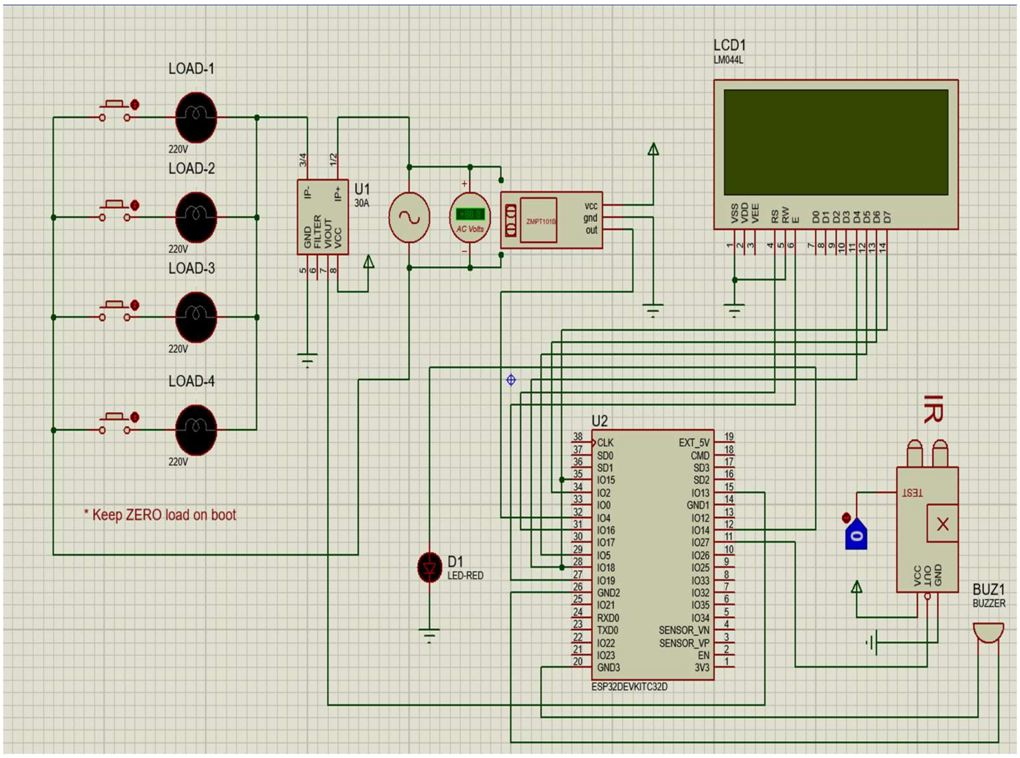


Figure-29: Simulation Design

After a successful run in the simulation phase then we moved on for 3D designing of our prototype and made an outer layer structure and we designed a PCB as per our requirement of the simulated design for better and oriented performance.

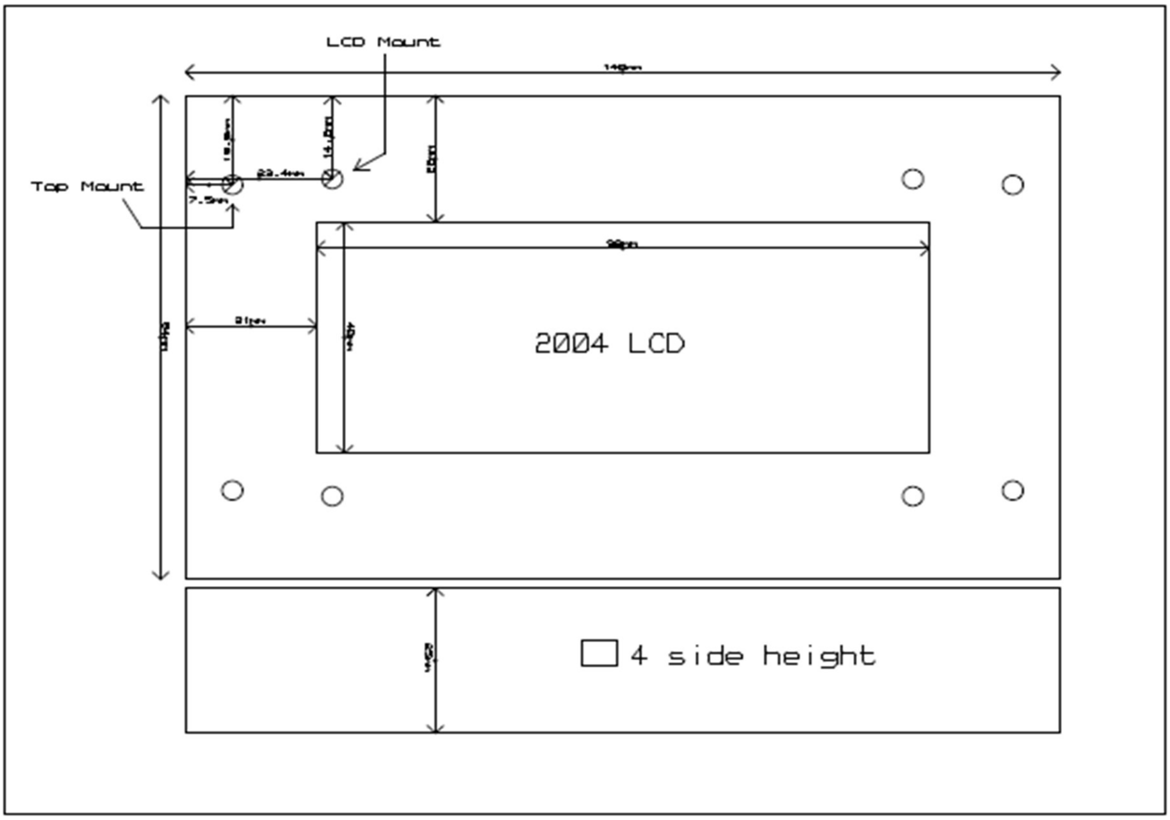


Figure-30: 3D design

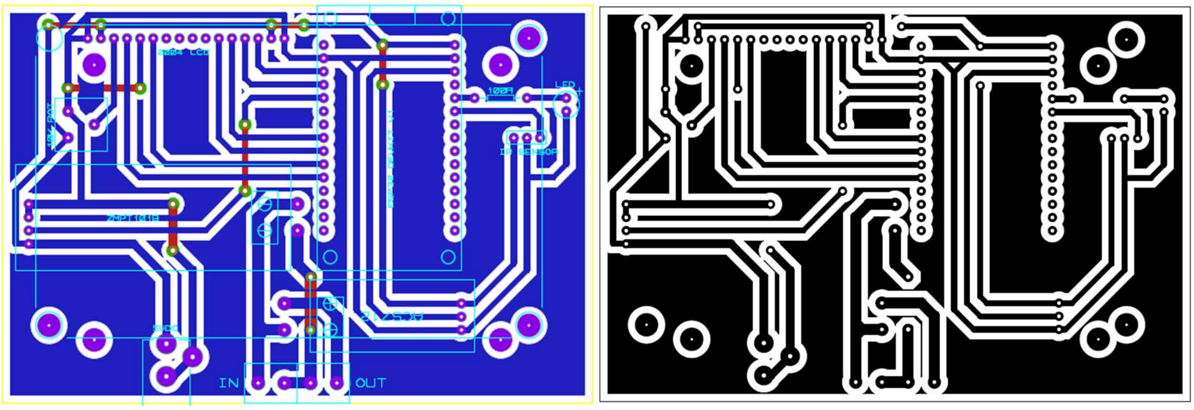


Figure-31: PCB Design

After printing the PCB, we started to assemble the components together and tested if all connections worked properly. Here found a minor problem with the pf correction as frequency input was not delivering required data and we had to improvised and re-wired the VAC pin with a different input port of ESP32 to calculate the accurate phase angle. Then we completed our final hardware design and were ready to test under different circumstances.

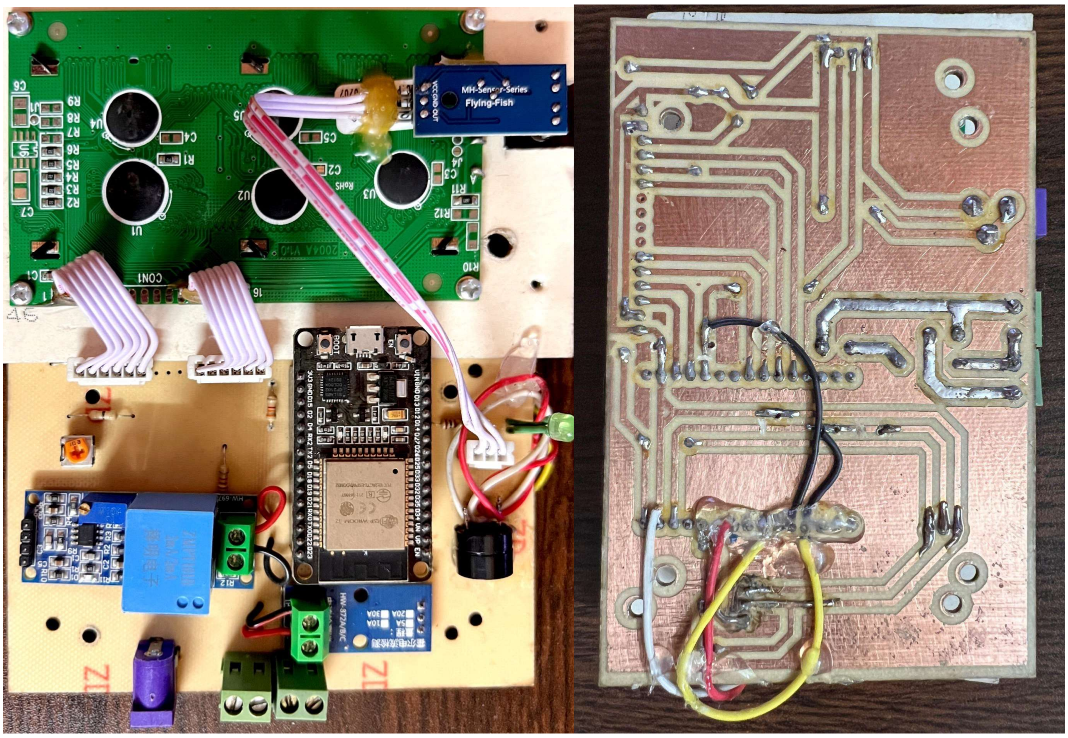


Figure-32: Hardware internal view

Figure-33: Hardware Top View

5.3 Evaluate the solution to meet desired need:

Here to justify our meter reading we tested our meter with an BSTI certified meter. Our testing criteria is to check that under same power of load both meter’s combustion reading (kWh).

Figure-34: BSTI certified Energy meter

Different load	**Designed Meter Consumption (kWh)**	**BSTI Certified energy Meter Consumption (kWh)**
200W	0.0227	0.028
400W	0.043	0.051
600W	0.0982	0.085
800W	0.1123	0.12
1000W	0.1267	0.13

Table-10: Comparison of both meter reading

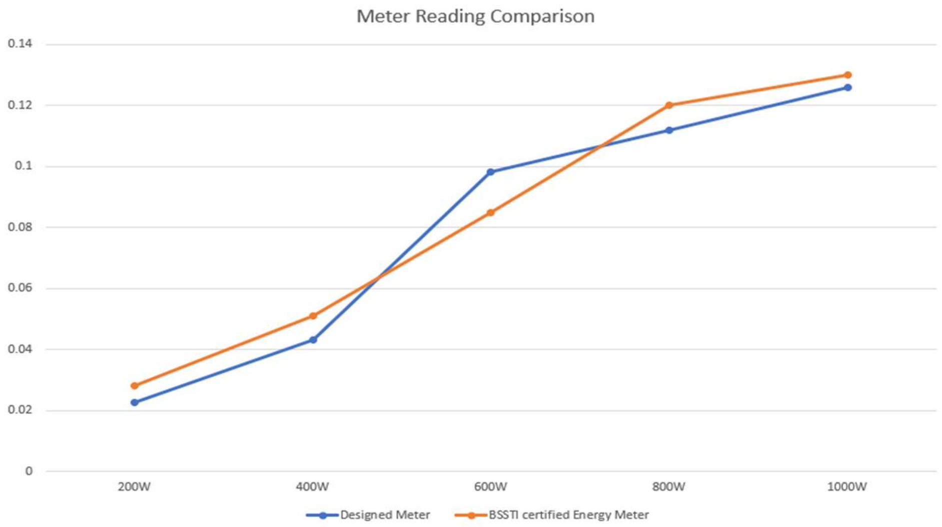


Figure-35: Comparison between designed meter and a BSSTI certified energy meter

Theft Detection Test: After testing the reading then we tested our anti-theft system to check the meter sending the proper alarm.

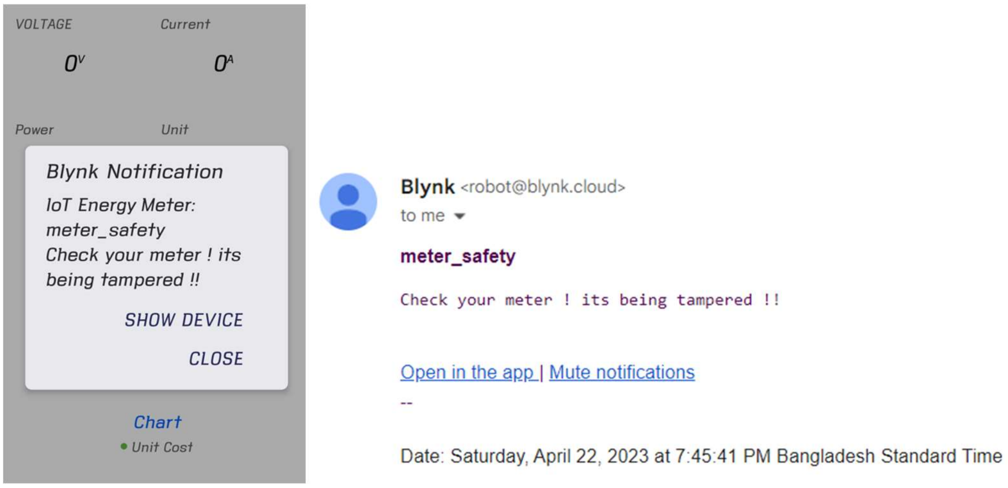


Figure-36: Mobile app notification and Email

5.4 Conclusion:

In conclusion, it is critical to complete the final design and validation to make sure a product satisfies the intended requirements, complies with laws, lowers costs, and improves customer satisfaction. After analysis the optimum design and testing the whole prototype we found that we can meet our desired outcome with this final design which works fine under specified environment.

Chapter 6: Impact Analysis and Project Sustainability. [CO3, CO4]

6.1 Introduction

Every electronic item has some spectrum of impact among the users' lifestyle and on the society collectively. Items like speakers and TVs have great impact on the entertainment sector of the society while items like PCs, laptops and mobile phones serve to impact the society in a broader scale on a wide range of sectors such as education, entertainment, healthcare services, civil services and business to name a few. But then there are electronic products like our automated energy meter that serve to make fundamental necessities of life a bit easier to deal with. Our energy meter is aimed to make the lives of people easier by allowing users to remotely monitor their electricity consumption each day for years to come and get the billing invoice directly on their smart devices through a cloud network. However, it is worthwhile considering tentative areas of further impact our design may have on the environment, animal life, infrastructure and civilian well-being; whether it be positive or negative. At the end of the day the sole purpose of this project is to have greater favor for positive impacts on the society and environment than for negative ones.

6.2 Assess the impact of the solution

The solution we came up with shows potential of impacting mainly the following:

1. Health and safety of civilians, animals and wildlife

Our meter uses common electronic components that have been used for over decades in several electronic items around us thus there is little chance that any electronic component will have a direct detrimental effect on the safety and well-being of humans, animals or wildlife. Apart from that all the meters shall be enclosed in isolated rooms away from random access of any human or animal thus ensuring safety. The meters, having been thoroughly tested, have little to no chance of malfunctioning to such an extent that it causes extreme hazards such as catching fire or burning out mid operation.

2. Environmental

The system does not rely on any components that need to be replaced manually for the continual performance of the meter thus avoids the hassle of component disposal. Many electronic systems that require battery power to operate need replacement of worn out or discharged batteries at regular intervals. The disposal of batteries is a major concern for pollution of the environment and fortunately our system will only require direct input from mains to power it up. Besides powering up the device, any technical fault resulting in replacement of components for continued usage of the system will not affect the environment as all the parts used in the system are not hazardous to the environment and can be disposed safely or even re-used later if fixed.

3. Legal limitations

Almost all meters are tampered with nowadays even if they are placed away from the vicinity of people. Tampering with meters goes against the law and causes consumers a significant loss while paying for fractions of the electricity they didn't even consume. Our meters incorporate a simple yet slick anti-theft system that will immediately notify the user of any activity near the meter of which the user is oblivious about prior hand. This anti-theft system provides security of the meter and has a positive impact on society where users will be able to feel much more confident about the bills they will pay.

4. Technical contexts

This project will utilize wireless technology integrated with energy meters which is quite a fascinating impact on the line of energy meters. The use of a major communication medium merged with something as fundamental as electricity consumption records along with billing is a significant and progressive technical impact. Alongside that, our project also utilizes a microcontroller as the core of the unit where all the power calculations will be processed thus it's another important impact as it merges the fields of electronics and power synergistically.

6.3 Evaluate the sustainability

The system does not use any components that need to be disposed of and thus will not affect the environment directly. The use of a modern microcontroller such as the ESP32 allows further enhancements to the system being made when necessary. The system is dependent on real time data collection and transmits this data through wi-fi to the customer end via a cloud server. The use of a microcontroller and a cloud server simultaneously are modern day IoT tools and can be easily made improvements upon by an expert in the field. Keeping a level price in mind, all the parts and components were chosen for the system in such a manner that both price of construction and quality of the components that build up the system, compliments each other to provide a stable and efficient service for consumers. Total process of the energy meter takes place autonomously and the bills are directed to the customers remotely thus ensuring that users are not burdened with extra hassle as with regular meters. The user interface of the cloud server is very simple and easy to handle keeping in mind all age groups of users while the app-based feedback aids the users in keeping a track of their meter condition and electricity consumption though a generated graph summarizing electricity consumption of the user. All factors considered, the system proves to be quite sustainable in terms of modern IoT based products.

Table below shows the decision matrix for the final design rated by all the authors based on factors affecting the sustainability of the product:

	Subir	Aysha	Sayeda	Hassan	Total / 10
Health and safety	9.5	9	9.5	9	9.25
Technical	9	9.5	9	8.5	9
Legal	8	9	9.5	9	8.875

Table-10: Decision matrix for sustainability of optimum design

6.4 Conclusion

The above sections highlight the potential positive impact of an automated energy meter. We tried our best to emphasize the importance of considering the possible environmental impact of the project, and concluded that the use of common electronic components and the availability of safe manual component replacement will reduce negative impacts on the environment. We also note that the anti-theft system will have a positive impact on society by reducing the incidence of tampering with meters. Finally, the use of wireless technology and a microcontroller in the project are seen as positive technical impacts that will merge the fields of electronics and power. Overall, we aim to emphasize the importance of positive impacts on society and the environment in the development of this automated energy meter.

Chapter 7: Engineering Project Management. [CO11, CO14]

7.1 Introduction:

In order to complete this project, we have made some plans & strategies according to the date. Our work process of FYDP-P starts with an introduction meeting of knowing group members & selection of a research topic. According to our plan, we tried to find some topics & started our research about the topic. Then we discussed among ourselves and selected a problem statement & consulted with our ATC. Then we started to specify the problem. Then after specifying the problem, we made a design flow diagram to solve the problem. After starting to solve the problem, we faced many weaknesses of our project by analyzing the project deeply. We noted all the difficulties & weaknesses. Then, we started our documentation. Then We consulted with our ATC about the documentation process. They checked our documents. Then we presented our project documentation in front of the FYDP panel members. Then, we changed our plan according to our time & date. Then, we started designing the simulation. Then we started the testing process. Then, we found out the impact of our project. Then, we completed our final testing. Then, we showcased our project and then we started our documentation of the report. Then finally our ATC checked our design simulation & our documentation.

7.2 Define, plan and manage engineering project:

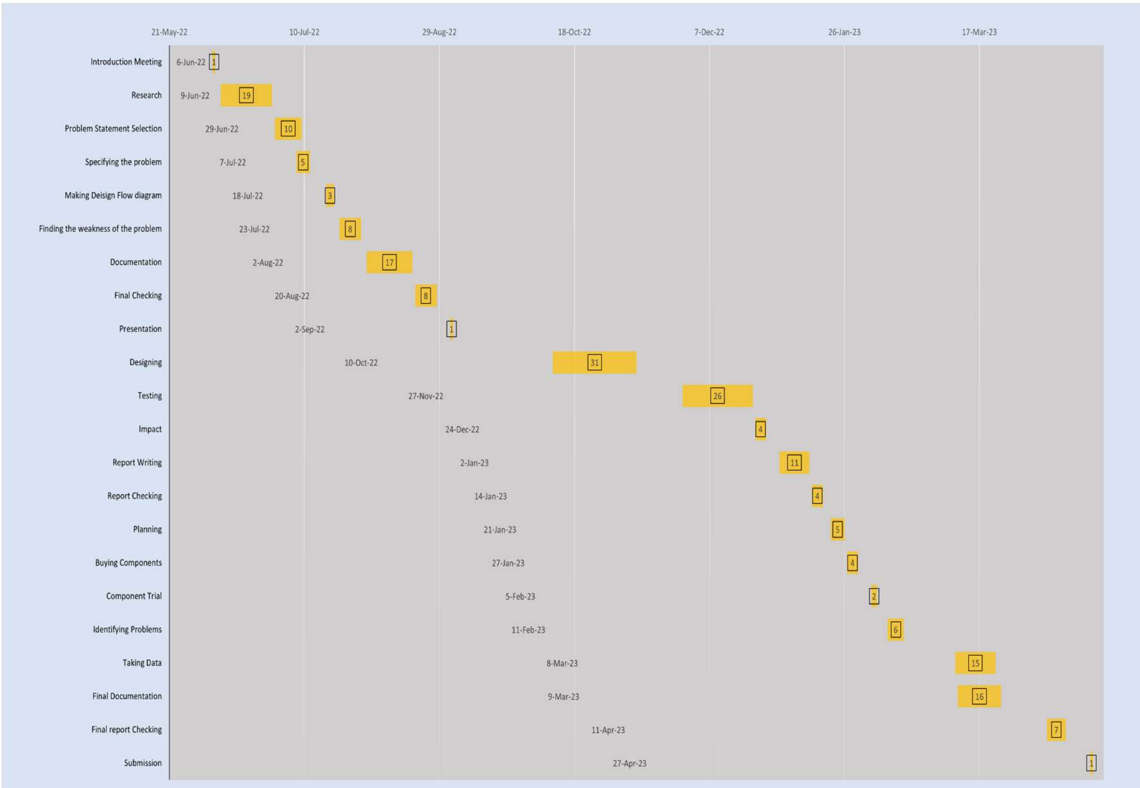


Figure-37: Project management timeline

7.3 Conclusion:

In this project, we have pre-planned everything for completing it timely. Our previous plan was to start working at the project from 6/06/2022 and after approaching accordingly step by step, we wanted to finish the project at 15/09/2022.But as we had some complications & difficulties regarding our project we changed our plan accordingly. It took some delay in the plan. After changing our plan some new changes also came to our project plan. But finally, we came a conclusion that we will conclude our project at 27/04/23 after submitting our final report of this project.

Chapter 8: Economical Analysis. [CO12]

8.1 Introduction:

By an economic analysis we can evaluate the benefits and costs of the project. We can compare the parameters with previous systems in order to identify and investigate the cost-benefit. Automated energy meters have a high accuracy and consistency. It does not require any manual interference. The existing energy meters have a great possibility of theft and wrong calculation of bills. Due to the shortage of electricity in our country and the domestic level and industry level theft of electricity, it is affecting the GDP growth of Bangladesh [13]. With the automated energy meter, it is possible to avoid such drawbacks of our regular manual metering system. On the basis of modern communication systems, the automated energy meter is well suitable to be implemented throughout the country in order to minimize the errors, theft and loss of resources.

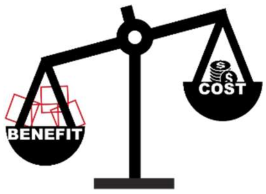
8.2 Economic analysis

The main purpose of the automated energy meter is to reduce the costing for the billing process. Generally, for manual meters a person goes from door to door to gather the information about the monthly bill. This process has many errors, time consuming and less efficient. In order to increase efficiency and reduce the extra costing for the meter maintenance it is best to use an automated energy meter. The automated energy is very cost effective and does not have any hidden charges like other prepaid meters. According to an article of the newspaper The Financial Express, it is said that several electricity supply companies are charging extra costs from the consumers [14]. According to the article the distribution companies (BPDB, DESCO, DPDC, REB and WZPDCL) are charging the consumers the rental fees of the prepaid meters for an endless period of time and they are also pressurizing the consumers to increase their load limit even though they do not use up that much electricity [14]. The BPDP stated that the cost of a single electric meter ranges from 5000 taka to 6000 taka [14]. On the other hand, the automated energy meter will cost comparatively less than those meters.

8.3 Cost benefit analysis

Here we have analyzed the benefits and cost of the implementation and use of the automated energy meter. The budget of all three designs are compared. The first design is wi-fi based. The second design is GSM sim based and the third design is optocoupler based.
According to the calculation of the cost price of all the designs, it is seen that the design-1 is the most cost effective. For design-1 we have a budget of 3280 taka, for design-2 the budget is 5509 taka and for design-3 the budget is 1560 taka. Again, the cost of other electric meters from the electricity distribution companies are ranging from 4000 taka to 6000 taka [4].
Moreover, some of the benefits of this metering system are: Our optimal design shows 7 parameters (voltage, current, power, unit, used cost, PF and meter safety) with zero installation cost. Again, this automated energy meter has a theft detection system which will send mobile notification, email to the end users and a buzzer on the meter, it has a great chance of reducing

electricity theft and meter theft. Reducing the electricity theft, the consumers and electricity supply companies will be benefitted. After proper research we can say that our meter can be manufactured with a price tag of 2200 Taka. If we compare our meter with our market meters in terms of CBA (Cost Benefit Analysis) we can find that our designed meter returns more benefit than its manufacturing cost compare to other meters.



	Automated Energy Meter (Our design)	Prepaid Meter (BSTI certified)	Analogue Meter (BSTI certified)
Manufacturing Cost	2200TK	4500Tk	1200Tk
Accurate Meter Reading	✓	✓	✓
Remote Consumption Monitoring	✓	✓	✗
Theft-Detection	✓	✗	✗
Real Time Data Sharing	✓	✗	✗
Battery Maintenance Cost	✗	✓	✗

Table-11: Analysis of cost and benefit of automated energy meter with other types of energy meter.

8.4 Evaluate economic and financial aspects

The consumption of electricity in Bangladesh is increasing day by day. However, there is great insufficiency of electricity in our country for which there is an electricity outage. This huge demand of electricity will only be fulfilled by increasing the electricity supply and proper maintenance of electricity. Thus, automated energy meter with theft detection feature with a precise billing calculation without any errors will be able provide a better chance of the cost management.

8.5 Conclusion

In conclusion, the automated energy system is more economic friendly than other energy meters. This metering system can help the users to have a safe meter and gives no erroneous values. In terms of cost benefit and economic situation of Bangladesh we need to protect the misuse of electricity and energy meters.

Chapter 9: Ethics and Professional Responsibilities CO13, CO2

9.1 Introduction

Designing an electronic system from scratch with either co-existing concepts or freshly derived ones requires immense accuracy and precision from start to finish. Without proper accuracy and care taken the project at hand can neither be completed to serve its purpose fully nor be safe to be put into action. A lack of ethical values undoubtedly proves poor motivation towards the project; not only that, it can also jeopardize the lives of civilians and safety of any associated infrastructure. To ensure a smooth workflow contributing to the construction of the system and well round security of civilians, nature and infrastructure we engineers must follow certain protocols and codes of practice that adhere to the ethics and professionalism. In this chapter, the authors have put forward the ethical considerations along with professional responsibilities that were required to be applied while designing the lifeless system into life so that it serves safely and efficiently the purpose it was constructed for.

9.2 Identify ethical issues and professional responsibility

The number one priority at hand when it came to ethics was the choice of electrical components and their interconnecting performance when put together. The choice of electrical components greatly depended on the quality of the items used alongside their working capacity especially during interaction with other parts of the system. Along with choosing the component there emerged professional responsibility of knowledge used while choosing so. An amateur and irresponsible engineer will make poor component choices no doubt as they will lack the proper knowledge required to make a confident decision or skip researching for better alternatives. Let's assume all went well and a perfect choice of electronic items were listed down for the system and properly tested for faults before assembly but does that conclude the ethical and professional responsibilities of the engineer then and there? No, it does not obviously. After a proper selection of items are made there arises the issue of restrictions of operation modes. What do we mean by that? What we mean is not all components operate at a certain voltage level. Some components require a solid 5V and above input to serve its purpose while some require a much lower input voltage to run safely. Being careless with operating ratings of the chosen components will no doubt result in total system failure and in the worst-case scenario a life hazard to civil and animal life along with surrounding infrastructure damage. In the world of engineering, nothing is certain unless you have tested a product thoroughly for faults and defects; our designed system was no different.

Even if all the components were chosen with utmost professionalism and then put together adhering to the operating protocols of individual components, we knew that the system could still malfunction if not tested thoroughly. Haste in creating a project and showcasing it publicly without proper verification of its safe operation also goes against ethics and professional responsibilities of an engineer.

Our system was designed keeping in mind a few main purposes it shall serve i.e provide real time current, voltage and power consumption readings as well as store them in the cloud server for future reference, provide bills incurred right at finger tips of users, provide a statistical result of electricity consumption in the form of consumption graph over a specific period of time and lastly to notify if the meters are being tampered with. In harnessing the solutions for the total system further ethics and professional responsibilities needed to be applied throughout the design process. The system being designed was an IoT based product and it needed to be made sure that a proper microcontroller be used as the main source of operation for the system. Besides choosing the right microcontroller, all other components chosen need to be compatible with the microcontroller and other components as well so that at no stage of operation does the system produce any erogenous results that might prove to be biased towards any parties. The sensors used for sensing current and voltage needed to be well calibrated so that ultimately the power readings were accurate and faulty bills were not produced. It needed to be ensured that the heart of the system, the ESP32 was a reliable enough unit to serve the purpose of operation for at least 10 years flawlessly.

Apart from ethical issues concerned with construction of the system, professional responsibilities extend beyond the scopes of system design into team coherence and competency. Team coherence and competency relates to a presence of mutual understanding regarding design and components, between individuals involved in the design. We had to make sure that all the team members gave in their best delivery of knowledge and practice throughout the duration of the entire project sincerely and honestly.

9.3 Apply ethical issues and professional responsibility

Glancing at the issues discussed above in section 9.2, the major ethical issues at hand in short were:

- Honest and sincere choice of components
- Having sufficient knowledge required for handling components
- Assure components' operational and functional safety as a safety for the system as whole
- Thorough testing of the system before showcase
- Honest delivery of knowledge and practice by all authors

Upon pinpointing the tentative issues at hand, tackling them for the greater good was quite straightforward. We made sure to find the optimal components for our project throughout extensive research and mutual consent. Thorough comparison was made between components from different sources and scaled on the basis of quality and price. Further details can be found in the budget listing in section-2. As a team we made sure to keep tags on each other's contributions and delivery of knowledge throughout the entirety of this project. Keeping civilian, animal and infrastructure well-being in mind we made sure to cross check all components for faults that might lead to a mishap, test all the components for faults while system is active, test if all input and outputs are ported right with adherence to correct ratings and test the system thoroughly multiple times for varying durations until a consistent performance was achieved for lengthy durations.

9.4 Conclusion

Ethical considerations made were sincerely tackled with the utmost devotion of our team throughout the working period. Starting from components choice to applied knowledge, none of the authors cut slack in their workflow and determination as a contribution to this project. It was mandatory that all the authors come to a mutual agreement of what sort of ethical considerations shall be most significant in development of the system and be carried towards finding a solution for it.

Chapter 10: Conclusion and Future Work.

10.1 Project summary/Conclusion

With all details of the system considered in this book, our ultimate goal was to design such a device that can make peoples' lives a bit easier by reducing the manual labor required every month in order to pay the electricity bills. The whole idea of tackling this problem was to find a solution that is digital and hence the project name "Automated Energy Metering System". Once the goal was finalized and we came to a square decision that the system shall be an IoT based project, our next move was deciding on its medium of data transfer. Alongside data transfer we had to consider aspects such as data storage, data visualization, data analysis, fundamental processing unit of the system and a way to avoid tampering of the meter. Upon setting up three design methodologies, it seemed most efficient in this modern world to proceed forward with the design that used wi-fi to transfer data from the device to the customer. Other methods included using GSM as a mode of data transfer but we deemed it to be inefficient due to extensive network connectivity variation area wise. In an alternative design we considered an optocoupler to keep count of the energy consumption units but later disposed of that idea as it turned out to be not economic or majorly digital. That being said, the best design required a theft detection that alerted the user if anyone was tampering with the system hence the addition of an IR sensor to the system in a nifty manner. With all things considered the system needed a good microcontroller as the processing unit as ESP32 was the ultimate choice as it had a built in wi-fi module. With the major selections having been made, we came with an idea of storing all the real time data to generate an analysis in the form of energy consumption graph and thus chose a third-party online cloud server called Blynk to get the job done. On Blynk we added features such as real time voltage, current, power consumption and total units display. Apart from energy consumption data, the user would also be able to see and get a notification regarding meters safety. Energy consumption over time can also be tracked in summarized form through the graph we added to the Blynk server homepage of the meter. Before assembling all the pieces of the equipment, we simulated the total design on Proteus software using an Arduino to test if all the readings and hardware functions would be fine when connections would be made in real life. Due to the absence of ESP32 in Proteus we stuck to using Arduino in our simulation as the microcontroller in use didn't affect major operations except for ESP32 having a built in wi-fi module that ultimately contributed to a reduced production cost. Once the simulation appeared to be reliable and the data was being read properly, we assembled all the components into a compact PVC enclosure giving it a traditional meter look. After assembly, the hardware was tested thoroughly for any faults before running it. And there it was, our automated energy meter was fully functional after 1 whole year of researching, gathering, failing and distressing about what the outcome would be and we couldn't have been any more relieved. Throughout the entirety of the project our sole purpose was to ethically and professionally handle the project that aimed towards a digital solution to an old way of life.

10.2 Future work

Even though the system has been completed for final display, a year of preparation and research isn't sufficient to fully make a system that goes hand in hand with the modern technology hence there still needs to be improvements made on the system that can make it one of a kind. We aim to tackle the following in the future:

1. App development:

We aim to develop an app instead of a third-party server being used to keep track of energy consumption data and provide analysis of energy consumption. The app will still have all the functions that we added in Blynk in addition to a better user interface and better analysis of energy consumption besides a graph. We plan on adding a detailed listed summary of the energy consumptions made each day from different loads and keep a record of it so that the user can refer to the data any time and take necessary actions to efficiently utilize electricity in their homes.

2. Digital Transactions:

Upon successful development of the app, affiliations with digital mobile banking companies such as Nagad or Bkash will allow the users to pay their bills right from their phones. A separate "Pay Now" option shall be created on a separate window of the app that will redirect the user to a page where they can pay their bills through either Nagad or Bkash just with one click of their finger in the comfort of their homes.

3. Upgraded theft detection:

We were adamant on including a theft detection option in the meter but we needed to come up with a way of utilizing a method within the given time frame of the project hence we came up with the idea of IR sensor. However, we do not consider it a very neat way of detecting tampering or theft hence we aim to upgrade this theft detection using AI; but since the world of AI is vast and with so many options such as image processing, speech recognition, facial detection and digital fingerprint scans to choose from we still need to figure out what would work best and at the same time be easier to deliver to the customers fingertips within economic margins. Hence, it's a decision still in progress.

Chapter 11: Identification of Complex Engineering Problems and Activities.

11.1: Identify the attribute of complex engineering problem (EP)

Attributes of Complex Engineering Problems (EP)

	Attributes	Put tick (√) as appropriate
P1	Depth of knowledge required	√
P2	Range of conflicting requirements	
P3	Depth of analysis required	√
P4	Familiarity of issues	√
P5	Extent of applicable codes	
P6	Extent of stakeholder involvement and needs	
P7	Interdependence	√

11.2: Provide reasoning how the project address selected attribute (EP)

Depth of knowledge required: We needed knowledge from different fields, for example microprocessor and coding knowledge, communication system knowledge and so on.

Depth of analysis required: We needed to analyze lots of research papers (articles, journals, etc.) and also an in-depth analysis of our own design to get to the optimal design and our desired outcome.

Familiarity of issues: All the difficulties that we have face are no something very new to the global society. The obstacles and raw ideas are among the existing ones.

Interdependence: There are three sub-systems in our project and all three of these are interdependent on each other. If one of the sub-systems is missing either the whole system will not work or it will not fulfill our desired requirement/output.

11.3 Identify the attribute of complex engineering activities (EA)

Attributes of Complex Engineering Activities (EA)

	Attributes	**Put tick (√) as appropriate**
A1	Range of resource	√
A2	Level of interaction	
A3	Innovation	
A4	Consequences for society and the environment	√
A5	Familiarity	√

11.4 Provide reasoning how the project address selected attribute (EA)

Range of resource: We needed different kinds of resources for this project, for example, software resource, research paper resource, IoT resource, information from Google etc.

Consequences for society and the environment: The society will benefit from the project because of its accurateness and safety system and it will cause no environmental harm (such as: soil pollution, air pollution, etc.)

Familiarity: This kind of project is already existing around the globe. So, it is a familiar one and not an innovation.

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Appendix

Logbook:

	Final Year Design Project (C) Summer 2021		
Student Details	**NAME & ID**	**EMAIL ADDRESS**	**PHONE**
Member 1	Subir Mazumder Drubo, 18221033	subir.mazumder@g.bracu.ac.bd	01628672116
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Member 3	Sayeda Sultana Elma, 19121023	sayeda.sultana.elma@g.bracu.ac.bd	01648955162
Member 4	Hassan Sakeef Soailim, 19121080	hassan.sakeef.soailim@g.bracu.ac.bd	01304330093
ATC Details:			
ATC 1			
Chair	Dr. A.H.M. Abdur Rahim	abu.hamed@bracu.ac.bd	
Member 1	Tasfin Mahmud	tasfin.mahmud@bracu.ac.bd	
Member 2	Md. Mehedi Hasan Shawon	mehedi.shawon@bracu.ac.bd	
Member 3	Dr. Saifur Rahman Sabuj		

Date/Time /Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
26- 01- 23 Discord	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Ordered the components.	1. All	
31-01-23	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Received some of the components.	1. Subir	
02-02-23	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Started working on the design process.	1. Arduino code: Aysha, Sayeda 2. PCB design: Hassan 3. Hardware design: Subir	
08-02-23 University (Thesis Lab)	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Progress meeting	1. All	
12-02-23	1. Subir	1. Progress meeting		Shawon sir:

University				1. Soon the ATC meeting will be arranged.
16-02-23 University	1. Hassan	1. Progress meeting		<u>Shawon sir:</u> 1. 3-D designing needed
23-02-23 University	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. ATC general meeting		<u>Abdur Rahim Sir:</u> 1. Try to develop the content of your project. 2. Do more research.
25-02-23 Discord	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Evaluating Arduino code	1. All	
26-02-23	1. Subir	1. Received rest of the components.	1. Subir	
01-02-23 University	1. Aysha 2. Sayeda 3. Hassan	1. Reported Adbur Rahim sir that Subir will not participate in the progress presentation due to his grandfather's death.		<u>Abdur Rahim sir:</u>

				1. Ask Subir to submit an application mentioning the reason for his absence.
02-02-23 University	1. Aysha 2. Sayeda 3. Hassan	1. Progress Presentation 2. Subir was absent due to his grandfather's death	1. Hassan: Intro & multiple design approach 2. Sayeda: Optimal design and test case. 3. Aysha: Modern engineering tools and conclusion	<u>Mohsin sir, Abdur Rahim sir:</u> 1. Need to show hardware progress. 2. If preparation is not completed at least show the pictures of the hardware construction.
09-03-23 University (Thesis Lab)	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Working on hardware development.	1. All	
13-03-23 University	1. Subir 2. Aysha 3. Sayeda	1. Working and editing on the code. Needed to change the code for the new microprocessor. Previously we have used the arduino microcontroller for the simulation, now for the hardware we have		<u>Abdur Rahim sir:</u> 1. Finish and then show me the progress.

		changed the microcontroller to ESP32.		
15-03-23 Discord	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Still editing the code.		
20-03-23 University	1. Subir 2. Aysha 3. Sayeda	1. Working on the power factor problem. 2. Facing problem to interface the energy meter with mobile phone. 3. No problem in receiving the meter readings on the laptop. 4. Working on the PCB simulation.		Abdur Rahim sir: 1. Bring the hardware in the next meeting.
25-03-23 Discord	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Will order the PCB design after finalizing the simulation design.	1. All	
27-03-23 University	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Showed sir that the meter is working correctly and displaying the meter reading on both the meter itself and the Blynk website.		Abdur Rahim sir: 1. Do more research on both national and

		2. The theft detection has a slight misreading due to the brightness of the loads. 3. Still having problems interfacing the meter with the mobile phone.		international papers and see if you can add something new to your project. 2. See if you can show the theft detection notification in the form of mobile phone SMS.
29-03-23				
02-03-23				
05-04-23 University	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. The theft detection problem is solved. 2. We are working on the report writing.		<u>Abdur Rahim sir:</u> 1. Show me the rest of the progress in the next meeting.
09-04-23 Discord	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Work distribution of the report.	**1. Subir:** Project design approach (2.1, 2.2, 2.3, 2.4, 2.5), engineering project management (7.1, 7.2, 7.3, 7.4), economic analysis (8.1, 8.2, 8.3, 8.4, 8.5).	

			2. Aysha: Use of modern engineering and IT tools (3.1, 3.3, 3.4), introduction (1.1.3, 1.2.4). **3. Sayeda:** Introduction (1.1, 1.1.1, 1.1.2, 1.1.4, 1.2.1, 1.2.2, 1.3), Use of modern engineering and IT tools (3.2, 3.3). Identify complex engineering problems and activities (11.1, 11.2, 11.3, 11.4) **4. Hassan:** Introduction (1.2.3, 1.4), impact analysis (6.1, 6.2, 6.3, 6.4), ethics and professional responsibilities (9.1, 9.2, 9.3, 9.4), conclusion (10.1, 10.2). **5. All:** Optimization of Multiple designs and finding the optimal design (4.1, 4.2, 4.3, 4.4, 4.5), completion of final design and validation (5.1, 5.2, 5.3, 5.4).	

10-04-23 University	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Showed Abdur Rahim sir that the hardware is working fine. 2. Asked Tasfin sir about the poster work and report work.		<u>Tasfin sir:</u> 1. The guidelines of the poster will be given soon. 2. After completion of everything you can show me the report or the poster for any corrections.
16-04-23 Discord	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Completed the main points of the report. 2. Next we will finish the small writing and editing of the report. 3. Started testing of our hardware.		
19-04-24 Discord	1. Subir 2. Aysha 3. Sayeda	1. Completed most of the report work. 2. Testing is done. Now we will finish the “Completion of Final Design and validation” .		
22-04-23 Discord	1. Subir 2. Aysha 3. Sayeda	1. Writing the chapter-5 of the project.		

	4. Hassan	2. Discussing about how to start with the poster work.		
24-04-23 Discord	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Bullet-points for the poster are done. Will start to make the poster next. 2. Still working on the report. Finishing the missing writing sections.		
25-04-23 Discord	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Working on the report. Almost done. 2. Started the poster making.		
26-04-23 Discord	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Finalizing poster. 2. E-mailed ATC-2 members about the feedback of the poster 3. Finalizing the report.		Tasfin sir: The poster looks great. No need to change anything. Make sure the pictures in the poster are clear.
27-04-23 Discord	1. Subir 2. Aysha 3. Sayeda 4. Hassan	1. Project showcase.		

Related code/theory:

Code:

```
#include <WiFi.h>
#include <WiFiClient.h>
#include <LiquidCrystal.h>
#include <ZMPT101B.h>

#define BLYNK_TEMPLATE_ID "TMPLm_izrQTU"
#define BLYNK_TEMPLATE_NAME "IoT Energy Meter"
#define BLYNK_AUTH_TOKEN "05879LC1BZP2aWU0M_pTF3ueLpn4Pkys"
#include <BlynkSimpleEsp32.h>

char ssid[] = "Shield";
char pass[] = "drubo19999";

#define voltPin  35
#define currPin  34
#define hzPin    33
#define mVperAmp 185

#define IR  27
#define led 14
#define buz 26

LiquidCrystal lcd(21, 19, 18, 5, 2, 15);
ZMPT101B voltageSensor(voltPin);

long prevMs;
int vSense;
float cSense;
bool irFlag;
int pTime, unitCost = 20;
float power, unit, cost;

// for power fector
float rads = 57.29577951; // 1 radian = approx 57 deg.
float degree = 360;
float frequency = 50;
float nano = 1 * pow (10, -6);
float pf, angle, pf_max;
float angle_max, pangle;
int ctr;

void setup() {
  Serial.begin(9600);
  lcd.begin(20, 4);
```

```
  lcd.setCursor(0, 2);
  lcd.print("CONNECTING WIFI...");
  Blynk.begin(BLYNK_AUTH_TOKEN, ssid, pass);

  voltageSensor.calibrate();
  pinMode(IR, INPUT);
  pinMode(hzPin, INPUT);
  pinMode(led, OUTPUT);
  pinMode(buz, OUTPUT);

  Blynk.virtualWrite(V0, 0);  // Write
  Blynk.virtualWrite(V1, 0);  // Write
  Blynk.virtualWrite(V2, 0);  // Write
  Blynk.virtualWrite(V3, 0);  // Write
  Blynk.virtualWrite(V4, 0);  // Write
  Blynk.virtualWrite(V5, 0);  // Write
  Blynk.virtualWrite(V6, 0);  // Write
  lcd.clear();
}

void loop() {
  Blynk.run();
  //----------- Data Reading from Sensors
  vSense = voltageSensor.getVoltageAC();
  cSense = getCurrentAC();
  if (vSense < 150) vSense = 0;
  if (cSense < 0.25) cSense = 0;

  irFlag = digitalRead(IR);
  if (irFlag == 1) {
    digitalWrite(led, LOW);
    digitalWrite(buz, HIGH);
    Blynk.logEvent("meter_safety");
  }
  else {
    digitalWrite(led, HIGH);
    digitalWrite(buz, LOW);
  }

  if (millis() - prevMs >= 1000) {
    pFactor();
    calculate();
    lcd.begin(20, 4);
    lcd.setCursor(0, 0);
    lcd.print((String)"P.Fector: " + pf_max + "  ");
    lcd.setCursor(1, 1);
    lcd.print((String)vSense + " VAC | ");
    lcd.print(cSense, 2);
    lcd.print(" A  ");
    lcd.setCursor(0, 2);
```

```
    lcd.print((String) power + " W, " + (!irFlag ? "PROTECTED" : "BROKEN!!!") + "  ");
    lcd.setCursor(0, 3);
    lcd.print((String) "Unit " + unit + ", " + cost + " TK ");

    Blynk.virtualWrite(V0, vSense);
    Blynk.virtualWrite(V1, cSense);
    Blynk.virtualWrite(V2, pf_max);  // updated
    Blynk.virtualWrite(V3, power);
    Blynk.virtualWrite(V4, unit);
    Blynk.virtualWrite(V5, cost);
    Blynk.virtualWrite(V6, !irFlag);

    prevMs = millis();
  }
}

void calculate() {
  if (cSense > 0.1) pTime++;
  else if (cSense < 0.1) pTime = 0;
  power = vSense * cSense * pf_max;  // updated here
  if (cSense > 0.5) {
    unit += (power * (pTime / 36000.)) / 1000;
    cost += unit * unitCost;
  }
}

void pFactor() {
  for (ctr = 0; ctr <= 4; ctr++) {
    angle = ((((pulseIn(hzPin, HIGH)) * nano) * degree) * frequency);
    // pf = cos(angle / rads);
    if (angle > angle_max) {
      angle_max = angle; // If maximum record in variable "angle_max"
      pf_max = cos(angle_max / rads); // Calc PF from "angle_max"
    }
  }
  if (angle_max > 360) {
    angle_max = 0; // assign the 0 to "angle_max"
    pf_max = 1; // Assign the Unity PF to "pf_max"
  }
  if (angle_max == 0) {
    angle_max = 0; // assign the 0 to "angle_max"
    pf_max = 1; // Assign the Unity PF to "pf_max"
  }

  pangle = angle_max;
  angle = 0; // Reset variables for next test
  angle_max = 0;
}

float getCurrentAC() {
```

```
  float result;
  int readValue;
  int maxValue = 0;
  int minValue = 4096;

  uint32_t start_time = millis();
  while ((millis() - start_time) < 300) {
    readValue = analogRead(currPin);
    if (readValue > maxValue) maxValue = readValue;
    if (readValue < minValue) minValue = readValue;
  }

  result = ((maxValue - minValue) * 3.3) / 4096.0;
  double VRMS = (result / 2.0) * 0.707;
  double AmpsRMS = ((VRMS * 1000) / mVperAmp);
  Serial.print("Current: ");
  Serial.println(AmpsRMS);
  return AmpsRMS;
}
```