IoT-BASED REAL-TIME ENERGY MONITORING AND MANAGEMENT SYSTEM

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Approval Page

This research, titled "IoT-based Real-Time Energy Monitoring and Management system," has been assessed and approved by the Department of Computer Science and Mathematics Committees in the Faculty of Natural Sciences and Environmental Studies, Godfrey Okoye University, Enugu, Nigeria.

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Dedication

First and foremost, this project is a dedication to Almighty God for His divine grace, guidance, protection, and wisdom from the time I commenced writing it till now and even throughout my entire academic life.

Secondly, I would like to dedicate this work to my parents who through their unwavering love, sacrifice, prayers, encouragement, and provision of financial resources to me made it possible for me to succeed.

Thirdly, this project is a dedication to my family members, friends (Huncho, Slaze, Mark, David), lecturers, and all those who have encouraged me throughout the years of my studies.

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Abstract

The increased use of electricity and its efficient use has led to the creation of need for smart energy monitoring systems. Traditional energy meters give less amount of information and lack real-time energy monitoring capability which makes it hard for people to efficiently manage energy usage. This project highlights the design and development of IoT-Based Real Time Energy Monitoring and Management System for monitoring electrical parameters like current, voltage, and energy consumption in real time. An ESP32 microcontroller is used along with ACS712 current sensor, OLED display module and Blynk IoT platform for collecting data, processing and displaying energy consumption data wirelessly. The ESP32 acts as a processing unit which performs computations and sends data to cloud for remote monitoring using Blynk mobile application. The system was tested by connecting it to various electrical loads such as electric kettles, irons, power banks and mobile phones among others. The results showed that the system successfully captured real time energy consumption data. The system can therefore be considered as a cheap and efficient means of energy monitoring which helps in minimizing energy waste.

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CHAPTER ONE:

INTRODUCTION

1.1 Background of Study

Electric energy has always been the main resource for modern societies as it powers everyday activities of many households, various businesses, public infrastructure, transportation, and communication systems, as well as hospitals, among others. There is also a continuously increasing rate of energy consumption as urbanized populations and urban economies grow and expand. Accordingly, electric energy consumption is typically defined as the volume of electricity consumed per period by electric instruments, facilities, or even power networks and is measured in KWh (Kilowatt Hour). Thus it is important to understand the place, how, and why energy is consumed since it ensures stability and effectiveness in the power framework, prevent wasting of electrical resources and undue expense complaints (Ageed et al., 2021).

Moreover, as the population keeps developing and the need for electric energy as well as energy management continues to increase, the measurement of energy consumption became an issue for several economic as well as technical reasons (Parhamfar and Zabihi, year not available). Economically speaking, the measurement allows for honest electricity billing, controls expenditure, and provides good decision making for the customer whereas the technical side implies that measurements are essential for efficient prediction, troubleshooting and stability. It is not difficult to conclude from all these that modern, electricity-usage related problem cannot be resolved with any conventional meter, for instance by manually writing down readings or relying on estimates for bill preparation, that often leads to discrepancies that consumers and providers themselves do not enjoy at all; on top of that, they are time consuming and provide poor feedback (Rahman et al., 2020).

Currently, energy usage measurement relies on metering systems that determine total energy/power consumption over the charging period. However, in our area, like other developing regions, pre-paid meters have been installed for all electric consumers so as to reduce electricity costs associated with incorrect estimation and also ensure that consumers make advance payments for electricity before actual usage (Iloh et al., 2023), which has helped energy distribution companies, to a great extent, remove errors from bills and cut the revenue loss to some degree. However, pre-paid meters still have a number of issues, the most important of which are; they store simple cumulative readings for a predetermined billing period only and not real-time instantaneous values of power/energy and no useful data relating to appliance power usage, they cannot detect power theft and they do not offer any kind of remote control nor real-time usage display. Consumers, in the other hand, and as well as electricity Distribution Companies fail to perform efficient real-time load management and monitoring remotely from where they are located, thereby leading to the poor usage efficiency of the energy, a rise in the distribution company power losses and the poor quality of electricity service delivered to customers (Depuru et al., 2015).

Therefore, an energy based monitoring system designed by utilizing an internet of things (IoT) technologies combined with different electrical sensors, microcontrollers, such as ACS712 and ESP32 to enable efficient monitoring of individual appliances' energy consumption over time based on acquiring electricity data such as, real-time monitoring of current, voltage and power measurements as well ascumulative energy. The recorded data acquired will be processed, then send to a local servers (such as an IoT cloud platform or a smart phone) via wireless fidelity (Wi-Fi) connection to be further presented through visualization dashboards so as to provide real-time energy usage rates per consumer device in the network (Choi et al., 2018). This, thus enable the consumers to be fully aware of current consumption in each electrical loads, therefore.

In operation, then the appliance is able to be controlled by this appliance remotely, to have a higher level of energy saving as well as the ability to support the taking of appropriate decisions (Adebisi & Ndjuluwa, 2024).

Unlike the pre prepared meter now used in Nigeria, which accounts only the energy consumption in the aggregate form and needs the user's physical presence for detailed data, the system proposed in this work will solve several important problems, it supports users in acquiring device-level monitoring and controlling appliances remotely to attain high energy efficiency. Also, Unlike prepaid meters that typically do not measures individual consumption rate of a device, and rather track total energy consumed between recharges/top-ups, consumers can hardly know which device consumes most of the electricity, or what caused an unusual consumption spurt, unless manually tracing their use in a way that requires considerable effort. Contrary, an IoT based monitoring system transmits energy consumption data instantly, thus enables effective management of loads and takes immediate action in preventing wastage (Bedi et al., 2018).

Meanwhile, energy based system in general has proven to be a effective approach to trace energy consumption in general for a long time and aids in long term planning of energy production/consumption through their detailed history (Morello et al., 2017). This systems applied on in the environment where operations go on, such as on industry and academic sectors, it will help to optimum operational efficiency and thus reduce operational cost; And in houses the systems will assist consumer to make informative decisions on electricity usage by providing energy-saving decision support, therefore adoption of such system is significant for the progress in energy management (Alahakoon, 2016).

1.2 Statement of Problem

The ability to actively and accurately monitor the energy consumption of consumers have grown to be a major concern in the energy sector as most energy distribution companies still rely on the traditional energy monitoring systems which have in turn given birth to a lot of problems, which includes but are not limited to the following:

1. Lack of accurate measurement and management of electrical energy consumption across private and public customer facilities.
2. Absence of real-time energy usage tracking and feedback mechanisms on the side of energy consumers.
3. High operational and maintenance costs due to poor visibility into patterns of energy consumption.
4. Limited data to be used to support informed decision-making, planning of energy and sustainability initiatives.

1.3 Aim and Objectives

This primary aim of this work of research is to design and successful implement an IoT-based Energy Monitoring System that works in real-time to help enhance the visibility and management of electrical consumption in residential and small-scale facilities. However to achieve this aim, there are objectives that are to be pursued and these objectives include To:

1. Design and develop a hardware data acquisition unit using ACS712 sensor and ESP32 microcontroller to Measure electrical energy, power and electrical consumption in real time across customer usage facilities.
2. Establish a wireless communication link using ESP32 microcontroller's Wi-Fi module to monitor and record energy usage data continuously.
3. Integrate digital platform for displaying energy consumption information using the Blynk mobile application.
4. Display the energy consumption data in real-time using an OLED screen for instant user feedback.
5. Implement the system circuitry using Arduino, the C++ programming language and the Blynk console tools.

1.4 Significance of Study

This project work has a lot of important significance to these following outlined persons.

1. Personally owned facilities.
2. Government owned facilities.
3. Energy distribution companies.
4. Educational and Researchers.

However, this system that is proposed in this study highlights the significance of the aforementioned individuals in the following ways:

1. It assists and provides personal users with accurate energy consumption data, thereby enabling better budgeting, cost control and informed policy decisions.
2. It helps government own facilities to accurately keep energy consumption in check, promoting better budgeting.

3. For the energy distribution companies to help them keep track of the consumer energy consumption rate.
4. On the side of the educational researchers it provides reliable framework and empirical data that can be used to improve academic evaluation systems.

1.5 Scope of The Study

This project is majorly concerned with the designing of an Energy-based monitoring system for monitoring real-time energy consumption. The domain of work in this thesis is measuring the consumption of electrical energy of various institutions,monitoring and recording the same,visualising it on different platforms. The research work addresses real-time energy monitoring, consumption estimation and to provide basic analytical assistance for better energy management and decision support. The work does not involve power generation, automatic energy billing at the utility scale and automatic control over electrical load however the project addresses in detail implementation utilizing hardware devices,data capture techniques and appropriate software for the given purpose.

1.6 Limitations of The Study

Notwithstanding the fact that this detailed work of research has come to solve some already existing problems, there are some other limitations that were encountered during the cause of the work. Some of these limitations of this work of research include but are not limited to the following;

1. **Scalability**: While the project involves the construction of a prototype, scalability may not easily be achieved, for residential buildings, it would be tough to apply to larger residential and non-

residential settlements. This, regarding smooth extension over areas, is limited by the capacities of Arduino hardware and a minimal reach area of Wi-Fi modules.

2. **Power Supply Requirement:** Provision of Power is necessary to run sensors, microcontrollers and communication modules. Sustaining a power supply in off-grid regions could pose challenges without additional resources such as solar panels or backup batteries.
3. **Maintenance and Calibration Requirements:** These are essential for maintaining the accuracy and reliability of sensors. The ongoing need for labor upkeep might offset some of the benefits, in labor efficiency brought about by automation

1.7 Operational Definition Of Terms

There are many terms that are related to this research project, but for the purpose of this study, we will only take into account the ones that are stated here.

1. **Electric Energy:** Electrical power that is used to operate devices and systems that depend on electricity to function.
2. **Electric Energy Consumption:** The amount of electrical energy that is used over a period of time, usually measured using Watt-per-hour or KiloWatt-per-hour.
3. **Energy Based Monitoring System:** A system that is used to measure and track electrical energy usage.
4. **Energy Monitoring:** The process of observing and recording the rate at which energy is used.
5. **Smart Energy Meter:** An electronic device that is used to measure energy consumption automatically.
6. **Real-Time Monitoring:** The ability to monitor the usage of something as it occurs.
7. **Energy Wastage:** Unnecessary or inefficient use of electrical energy.
8. **Power Distribution System:** A system that delivers electrical energy to users.

9. **Data Acquisition:** The collection of energy usage data from sensors or meters for processing and analysis.
10. **Energy Management:** The practice of controlling and reducing energy use, reduce waste lower cost and improve efficiency.
11. **Academic Environment:** An educational setting such as a university or college.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Major portion of this project deals with the design and development of a hardware based Energy-based monitoring system to ensure monitoring real-time electrical energy usage. The topic considered in this thesis is to estimate the electrical energy consumption across various institution, monitor, record and display the same across different platforms. Real time energy monitoring, consumption estimate and some analytical tools are discussed for decision support with an intent for improved energy management. Power generation, automated energy billing in case of a larger utility, automated energy load management are not included in the scope, however the hardware-based implementation with a combination of relevant data capture technologies and software is taken up for this project.

2.2 Theoretical Background

2.2.1 Overview of Energy based monitoring system

Energy Based Monitoring Systems fundamental principles Electrical Energy-Electrical energy generation (Suvaryan et al., 2025). Since all components are installed on the electrical circuit and connected in series for current and in parallel for voltages the reliable management depends from ability to Measure, Transmission and Analysis of the Electrical Energy consumption [9].

Over the years improvement of Computing and communication technologies permits us to collect process analyze and show information in a various manner in comparison to old method system. However viewing from electrical point of view all the monitoring based on electrical energy consumption must use sensors to precisely measure constantly all parameters, the key to be aware of electrical consumption consist in the reliable measurement of electrical circuit parameter (Voltage current) [10].

2.2.2 Conventional Methods of Energy Monitoring Systems

The conventional energy monitoring systems have for long now relied on electromechanical meters and other basic digital meters that are installed at some primary distribution points. These meters however measures the total electrical energy consumption typically recording the data in kilowatt-hours (KWh), and readings collected manually at set intervals (Gungor et al., 2015). In addition to this, while they serve as a basic tool for billing and broad usage tracking, they lack the capacity needed to provide real-time feedback, electrical consumption detailed breakdowns by location or device and most especially an automated data logging that are necessary for proactive management (Tolas et al., 2024). However, these conventional methods demands the high use of human labour both for the collection of data and also for the interpretation of the collected data, thereby making large-scale implementations to be costly and prone to error when applied across many buildings and facilities, and at this highlights the need for systems that are computer-based which combines the capabilities of both sensing, data processing, and communication.

2.2.3 Internet of Things (IoT) approach to Energy-Based Monitoring systems

Now the use of the Internet of Things (IoT) technology creates a technological basis and an all-in-one unified monitoring platform that effectively handles this problem by integrating embedded systems, sensors and network communication. Such IoT-based energy monitoring system works by embedding microcontrollers that are considered intelligent to collect electrical data from the power system continually and then broadcast wirelessly to centralized servers for processing and visualization (Ali & Alrkabi, 2022). As well as programming typically done by C, C + +, Java and python in the development ofEmbeddedhardware and higher-level language to process data.

For example, the application of IoT technologies into the problem has been demonstrated in the real-time and better management of real-time energy efficiency that enhance with higher efficiency and greater reliability in challenging environment like Universities (Sithole et al., 2024). Combining the theories of electrical measurement toIoT Technologies the system can generate intelligent energy based monitoring toolthat helps to facilitate in informed decision making, effective control of cost and a comprehensive management of sustainable energy

2.3 Review of Related Works

Many current systems that are existing now are connected to this project work in one way or another, but even at this, just a few of them will be discussed in this part of the project.

Purwania et al, (2020), looked into the application of Internet of Things (IoT) technology in energy management systems in response to the rapid increase in the demand of energy and the declining in the availability of energy. Their study focused on how uncontrolled energy consumption contributes to environmental degradation where they analysed existing IoT-based energy management solutions. The study however identified key components that are commonly used in such systems and identified Arduino and NodeMCU together with current and voltage sensors to be playing a significant role in improving energy monitory and management efficiency.

Luan & leng (2021), designed an enterprise-level energy monitoring system based on Internet of Things (IoT) technology to support remote and real-time energy management. they made use of browser-server (B/S) architecture and a combination of a lot of other tools including, integrated digital instrumentation, communication networks, software applications and databases to be able to achieve a centralized and decentralized control.

Salunkhe, Kanse & Patil (2022) all worked together to develop a type of new system for energy meter monitoring by ESP32 & Cloud platform. They did hardware system for the monitoring system in the physical form. The data is taken with help of the RS-485 communication with an interfacing a smart meter to observe 3-phase current and Voltage active & reactive power at regular interval to overcome the wastage of power and the increase of the bill. It monitors the energy in real time using ESP32.

Chooruang & Meekul (2024), both worked together to develop an IoT-base energy monitoring system that is cost effective, for application of electricity bill and home automaton. They made use of hardware components which were very much affordable including the PZEM-004T module, non-invasive current transformer sensors, the SD3004 energy measurement chip, and the ESP8266 Wemos D1 mini microcontroller for data acquisition and transmission. However, the system was built in a way that it sends energy data to a remove server through the internet for the purpose of monitoring, to which it performed fairly.

Mudaliar & Sivakumar (2020), worked together beside each other to develop an IoT-based real-time energy monitoring system for controlling and monitoring the consumption of energy in switchgear industry. They made use of Raspberry Pi as the core hardware because of its reliability and cost effectiveness. It also made use of Node.js for data collection from existing energy meters, stored the data locally and visualized it using Grafana and however allowed access to the stored data through laptops and mobile devices.

Patil et al., (2020), all worked together to discussed the role that internet of things plays in integrating physical energy systems with platforms that are computer-based in other to improve efficiency and reduce human intervention. The study therefore, focused on monitoring the usage of energy that is renewable specifically solar energy, through an IoT-based system developed using Raspberry pi and the Flask framework. At the end, they provided an online display of daily solar power consumption to support the user analysis and help study the patterns of energy usage.

Bhau et al., (2023), looked into the application of Internet of Things (IoT) technology in monitoring the use of renewable energy with their main focus being on solar power systems. The work showed how IoT enables remote sensing and control of systems that are physical to improve efficiency and reduce the intervention of humans. The system was however developed using Raspberry Pi in combination with the Flask framework in other to track daily usage of renewable energy through smart monitoring tools and at that help users to understand their pattern of consumption better.

Thakere et al., (2025), developed an IoT-based energy monitoring system with the main aim of addressing the growing imbalance between the generation of power and its demand. The system made use of Arduino microcontroller to monitor the consumption of electrical energy at the device level as the system was developed to measure the power usage of individual appliances, upload the data to a server and then display it using a monitoring platform that is based on the web.

Rani et al., (2023), studied the use IoT for monitoring and improving the performance of solar systems. Their study stressed on increasing demand for energy which is caused by industrialization and the need to reduce the dependence on fossil fuel by using sustainable solar power. Their work employed the use of IoT to in monitoring and tracking system health to maximize the output of energy.

Choi et al., (2023), looked into the implementation of a remote monitoring system for the generation of renewable energy. The main focus of the study was on addressing the instability of wind and photovoltaic power through continuous monitoring and operational analysis. The system made use of an IoT-based architecture which was developed using Arduino, Raspberry Pi, and LoRa communication network which was low-cost.

Selvaraj et al., (2023) suggested a monitoring system for smart buildings using Artificial intelligence. In their work, focused on optimizing the utilization, recycling and consumption of energy as well as the integration of renewable energy within smart city environments. Their system in which they referred to as AIMS-SB, made us of prediction models to analyse the production of renewable energy, the use of energy and the processes involved in recycling of energy.

Shamshiri et al., (2021), developed and energy management solution to help ditch the high cost of electricity in industrial plants and commercial buildings, by focusing improving the efficiency of energy. The system worked by communicating with digital energy meters through the use of Modbus protocol. The researchers deployed the prototype of the system to the Universiti Teknikal Malaysia Melaka.

Chen et al., (2024) developed an IoT energy monitoring system for the purpose of increasing efficiency and managing system for machining workshops which are known for consuming high energy without efficiency. The researchers however defined important indicators for efficient energy and developed a monitoring framework that is based on IoT. However, when the system was tested it confirmed that opportunities to save energy and reduce the consumption of energy.

Hussien et al., (2021) developed a monitoring system based on IoT to keep track of electrical parameters like voltage, current and the power consumed in the buildings of a university using smart sensing to monitor and control electric devices based on different rates of tariff. The system was designed with Arduino, wireless power meter with Wi-Fi connectivity that is not invasive in combination with current transformers split-core to collect and transmit data to a monitoring platform that is based on the web.

Karuppusamy, (2020). Developed an electrical monitoring device based on IoT with the aim of improving the efficiency of energy through remote control and supervision. In their study, they installed sensor-based monitoring units near electrical devices and connected them to a remote-control station using the Blynk server and the internet. The system enabled the display of status in real-time and the operation of devices remotely without physical inspection, in other to improve energy utilization efficiency and overall system management.

Saleem et al., (2021) studied the roles that smart meters and IoT have played in improving the management of energy on the side of the consumer amid the increase in the demand of energy. The researchers designed a SEMS based on IoT technology and integrated it with different communication protocols, with the use of Entrack software for the purpose of collecting data and analyzing it. The system was therefore deployed across four buildings of a private company in Pakistan.

2.4 Summary of Related Works

S/N	AUTHOR(S)	CONTRIBUTION OR (WORK DONE)	TECHNIQUE	LIMITATIONS
1.	Purwania et al, (2020)	Looked into the application of Internet of Things (IoT) technology in energy management systems in response to the rapid increase in the demand of energy and the declining in the availability of energy	Systematic review approach	Only identified the key components commonly used in energy-based monitoring systems
2	Luan & leng (2021)	Designed an enterprise-level energy monitoring system based on Internet of Things (IoT) technology to support remote and real-time energy management	Browser-server (B/S) architecture	The scope was limited to China
3	Salunkhe, Kanse & Patil (2022)	Developed an IoT-based smart energy meter using the ESP32 microcontroller and AWS cloud platform for real-time monitoring of three-phase voltage, current, active and reactive power, with data visualization through a web-based graphical dashboard.	ESP32 microcontroller with RS-485 communication , MQTT protocol, and AWS cloud platform for industrial three-phase power	The system targeted industrial three-phase power systems only and was not adaptable to single-phase residential loads.

			monitoring)	
4	Chooruang & Meekul (2018)	Developed an IoT-base energy monitoring system that is cost effective, for application of electricity bill and home automaton	Kanban (agile methodology)	Depended heavily on internet signals to function.
5	Mudaliar & Sivakumar (2020),	Developed an IoT-based real-time energy monitoring system for controlling and monitoring the consumption of energy in switchgear industry	Object oriented analysis and design (OOAD)	The scope was limited to switchgear industry.
6	Patil et al., (2020).	Focused on monitoring the usage of energy that is renewable specifically solar energy, through an IoT-based system developed using Raspberry pi and the Flask framework	Object oriented analysis and design (OOAD)	The scope was limited to solar power.
7	Bhau et al., (2023),	showed how IoT enables remote sensing and control of systems that are physical to improve efficiency and reduce the intervention of humans	Object oriented analysis and design (OOAD)	The scope was limited to solar power.
8	Thakere et al., (2025)	Developed an IoT-based energy monitoring system with the main aim of addressing the growing imbalance between the generation of power and its demand	Arduino microcontroller	Failed to track energy consumption in real-time.
9	Choi et al., (2023)	implementation of a remote monitoring system for the generation of renewable energy.	LoRa communication network	The scope was limited to solar power.

10	Shamshiri et al., (2021),	developed and energy management solution to help ditch the high cost of electricity in industrial plants and commercial buildings, by focusing improving the efficiency of energy	Modbus Protocol	Was only tested using one location.
11	Chen et al., (2024)	developed an IoT energy monitoring system for the purpose of increasing efficiency and managing system for machining workshops which are known for consuming high energy without efficiency	IoT-based system framework	The scope was limited to only workshop application.
12	Hussien et al., (2021)	developed a monitoring system based on IoT to keep track of electrical parameters like voltage, current and the power consumed in the buildings of a university using smart sensing to monitor and control electric devices based on different rates of tariff	IoT-based system framework	The scope was limited to only to university buildings. application.
13	Karuppusam, (2020)	Developed an electrical monitoring device based on IoT with the aim of improving the efficiency of energy through remote control and supervision.	IoT-based system framework	Failed to monitor energy consumption.
14	Saleem et al., (2021)	The researchers designed a SEMS based on IoT technology and integrated it with different communication protocols, with the	SEMS	The scope was limited to Pakistan

		use of Entrack software for the purpose of collecting data and analyzing it		

Table 1: Summary of Related Works

2.5 Research Gap

In light of various existing research works and systems in similar domains to this project, this project work contributes to the domain by showcasing that the use of IoT has potential to enhance real-time electrical energy monitoring. This implies that the usage of affordable sensors with inexpensive microcontrollers along with software toolkits will assist in making possible accurate and auto-matice supervision on consumption of energy reducing the work of manual counting process. Hence, the system introduced by this project takes the step to fill the gap that already existing in Energy Monitoring domain by providing an effective tool which highlights the usage pattern of energy so that the user can analyze and cut down the waste of energy and the sustainability is preserved. Moreover, it also provides the practical tool for residential areas, industries, academia etc., bridging the gap between obsolete methods of measurement and the IoT based applications which are efficient.

CHAPTER THREE

METHODOLOGY AND SYSTEM ANALYSIS AND DESIGN

3.0 Introduction

This chapter of this project stands to show in detail the methodology that was adopted while designing and implementing the Energy-Based Monitoring System. It dives deep into the data that was used in developing the system was gathered, analysed and used while designing the system. It also gives a detailed examination of the systems that are already existing, identify their limitations, and most importantly describes how the proposed system improves the monitoring of energy through the use of IoT technologies in a very clear manner. In addition to the above, this chapter outlines in detail both the functional and non-functional requirements of the system.

3.1 Information Gathering

This was one of the most important phases of developing the proposed system as it discusses in detail all the process that were involved in collecting data and technical knowledge that are relevant to this project and which were required to fully understand the problem that prompted the development of the proposed system. This was a meticulous process to aid the researcher in designing a solution that is effective and smart. The detailed steps that were taken in gathering information is discussed in detail below.

3.1.1 Primary Data Collection Techniques

This work of research did not rely heavily on the primary method of data collection methods such as questionnaires or interviews. This decision was made because the project is system-based and as such it focuses on developing a prototype that is working rather than involving and studying the opinions of users. However, informal observations were made by the researcher on how the users of electricity do interact with prepaid meters. These observations however revealed that users of electricity in most cases lack access to real-time data of how they consume energy at the appliance level, of which affects their very own ability to manage energy efficiently.

3.1.2 Secondary Data Collection Techniques

The major source of the data that was used in this work of research was secondary data, which was obtained from sources that are credible and relevant to the domain of this research.

- **Scholarly Articles and Journals:** The researcher employed research papers that are relevant on the domain of IoT-based energy monitoring systems using platforms such as Google scholar, IEEE Xplore, and ResearchGate. These materials however were able to provide insights into he design of the system, sensors, communication methods, and performance evaluation.
- **Technical Documentation:** The researcher studied an array of manuals for the different components that were used in building the system such as ESP32, ACS712 current sensor, and OLED display in other to understand their functionality and integration.
- **Online Resources:** The researcher also looked out on technology websites that are reliable and also on IoT documentation platforms in other to be able to understand the techniques of implementation, approaches to programming and the system architectures.
- **Existing Systems (Prepaid Meters):** The researcher also gathered information about prepared meters that are currently being used in Nigeria in other to be able to understand how they operate and also understand their strengths and limitations in detail.

3.2 Privacy and Ethics Considerations

In as much as the researcher consulted a lot of sources to be able to gather enough information/data to aid him in the development of the proposed system, the study however does not involve the collection of data that are personal or sensitive. The system was however designed to monitor the electrical parameters only. It is important to note that all the data that was gathered was strictly related to the consumption of energy and it was solely used for the evaluation and improvement of the system.

3.3 Data Analysis

Data analysis in this work of research involves the detailed analysis of data with the sole aim of understanding electrical parameters and how they can be measured, processed and equally displayed using and IoT system that is embedded.

3.3.1 Analysis of Electrical Data

The system is designed to focused o measuring the following key parameters that are essential to the operation of the system.

- Current (Amperes)
- Voltage (Volts)
- Power (Watts)
- Energy (kWh)

In analysing the electrical data, the ACS712 sensor measures current, while power is now calculated using the standard formular for electricity.

$$Power(W) = Voltage \times Current$$

Where the consumption of Energy is the computed over time using the formular:

$$Energy(kWh) = Power \times Time$$

3.3.2 Data Processing and Storage

The ESP32 microcontroller was used in the system to process signals that are in analogue format which are received from the sensor. It therefore responsible for performing the following functions:

- Filtering of electrical signals
- Calculation of RMS current
- Computation of power
- Accumulation of energy.

3.3.3 Data Visualization and Transmission

After the data is gotten and processed, it is then: Displayed locally on an OLED screen that is attached as a component part in the system, in other that the user may be able to view it and act accordingly

3.4 System Analysis

The scope of System analysis to this research is a detailed investigation of the different parts/units that makes up the developed system and also their methods of communicating/interacting with each other. A detail study is done in relation to this topic, considering, review of existing energy monitoring based systems, analyse constraints of those existing based systems and suggestions to improvement, and analyse in detail in regard to the proposed system. This section of the proposed system analysis however, includes system modelling using use case diagram, activity diagram and class diagram.

3.4.1 Analysis of Existing Systems

There are lots of methods for measuring the consumption of energy but the one that is most prominent in Nigeria is the prepaid meter system. These meters are used by Residential electricity consumers, commercial users and also the utility providers. These meters however work by:

- Users purchasing electricity units in advance
- The meter deducts units based on the total consumption of the user
- The usage of Energy is now displayed in an aggregated form

3.4.1.1 IoT Energy-Based monitoring systems

- **Purwania et al, (2020) IoT-Based energy monitoring system:**

  The system was built using Internet of Things (IoT) technology in response to the rapid increase in the demand of energy and the continuous decline in the availability of energy. The system was built using identified Arduino and NodeMCU together with current and voltage sensors.

- **Luan & leng (2021) IoT-Based energy monitoring system:**

  The system was an enterprise-level energy monitoring system based on Internet of Things (IoT) technology to support remote and real-time energy management. they made use of browser-server (B/S) architecture and a combination of a lot of other tools including, integrated digital instrumentation, communication networks, software applications and databases to be able to achieve a centralized and decentralized control.

3.4.1.2 Conventional Energy Monitoring Systems

- **Electronic Energy Meters:**

  These are electronic devices installed in buildings and infrastructures to help keep track of the energy consumption rate. They often rely on manual operations, which are prone to human error and are in most cases labour-intensive. They are however tend to be employed in most part of the country especially in residential buildings and offices.

3.4.2 Limitations of Existing Systems

- **Purwania et al, (2020) IoT-Based energy monitoring system:** This system's weakness comes from the system only identifying the key components commonly used in energy-based monitoring systems and also the work functions mainly as a systematic review that identifies IoT components tat are common but it lacks a specific implementation that is localized.
- **Luan & leng (2021) IoT-Based energy monitoring system:** The weakness of this system however lies in its complexity in enterprise-level and reliance on browser-server architecture which on the other hand, may be too resource-intensive for use in residential environments that are small-scale with an internet connectivity that is not stable.
- **Electronic Energy Meters:** This system's weakness comes from the system's reliance on manual operations and physical inspection, which are labour intensive and also highly prone to human error.

There are a lot of other limitations that affect the currently existing system with these limitations including but are not limited to the following:

1. No real-time monitoring at the appliance level
2. The system lacks consumption insights that are not detailed enough

3. The system having a limited user interaction and control.
4. The system delaying awareness of energy usage that is excessive.

3.4.3 Benefits of The Proposed System

The Energy-based monitoring system that is proposed by this project work is helpful because it facilitates the understanding of electrical energy consumption in real-time. The system is very beneficial to the energy industry because it gathers precise data on voltage, current, and power consumption using sensors and Internet of Things components that are very dependable, and which in-turn helps users trust the information offered. However, users can check energy consumption at any time without being physically present because the system allows remote monitoring via a mobile interface. This therefore, facilitates early detection of energy waste and prompt action to cut needless expenses. All things considered, the system promotes better use of energy, reduces the cost of electricity, and supports an environment that is more energy-conscious in a straightforward and useful manner.

3.4.4 Analysis of the Proposed System

The Energy-based Monitoring System that has been proposed in this project is designed to overcome the limitations that have been stated in the previous section of this work using IoT technology. The system however hopes on achieving the following, in line with the objectives that was stated at the earlier sections of this work:

- Provide the monitoring of how energy is being used in real-time
- Track the consumption of energy at the device level
- Display the energy consumption data locally using the LED screen that is attached to the system.
- Enable the users make better energy management decisions.

It however improves on the exiting systems by doing the following

- Unlike the prepaid meters that are currently in use, it offers live feedback on the amount of energy that is consumed in real-time
- It provides a detailed breakdown of energy consumption
- It most importantly improves the awareness of users on the control of how they make use of energy.

In conclusion, the system provides a way of measuring energy that is much more efficient and effective by offering real-time monitoring at the device-level instead of the usual bulk tracking of consumption that is evident in the currently existing prepared meters.

3.5 System Requirements

System requirements is a term that is used to refer to the processes or statements of what a system should be able to do or what quality a system is supposed to have.

3.5.1 Functional requirements and Non-functional requirements of The System

The system that have been proposed by this project work of research is defined requirements that are both functional and non-functional, which collectively outlines the capabilities of the proposes system that are essential, attributes that are operational, and the overall performance of the system. specifically, the design must fulfil the following criteria:

a. The interface of the front end must be straightforward and intuitive in other to allow users to navigate and interact with the platform efficiently and also without confusion.
b. The system must capable of continuously monitoring the consumption of electricity and project the active usage metrics immediately to the dashboard of the system.

c. The system just go beyond just displaying numbers, and be able to process and present this information clearly so that the users of the system can easily understand their actual pattern of consumption.

3.6 Proposed Methodology: Object Oriented Analysis and Design

Object Oriented Analysis and Design is a software development methodology that is tailored for the managing of applications that are complex by organizing the system requirements into classes and relationships that are distinct. The framework therefore relies on three main pillars which include the following: use cases which is used in defining the interactions of the user, the Unified Modelling Language diagrams which is used to visually map the components of the system, and then the Object Oriented Programming to build the actual architecture of the software.

3.6 Unified Modelling Language

Unified Modelling Language diagrams are software engineering tools that are crucial which allows stakeholders of a system to visually design and communicate the architecture of the system to the readers of a research work. In this project work, the use case diagrams act as a blueprint of the system that is proposed in this project by defining how the entities that are external tend to interact with the system in other for the system to be able to fully fulfil its functional requirements. Complementing this, the activity diagram provide a view of the system that is dynamic by mapping the workflows and parallel processed that are sequential, which ultimately helps the developers to identify bottlenecks and also optimize the performance of the system.

3.6.1 Use Case Diagram of The Proposed System

Use case diagrams is one of the unified modelling language diagram that is important for discussing the intricacies of a digital system. it is usually consists of four main elements: the use cases that are functional, the external actors, the associations between them and the boundaries of the system. the IoT platform that is proposed in this project work, makes use of two primary actors which include the user and the system administrator with the standard user being able to manage functions that are specific which includes the installation of the application of the system, management of power, and monitoring of energy in Realtime.

Use case diagram:

Figure 3.1: Use case diagram of the proposed system

The activity of the use case in the system that is suggested in this project is shown in the diagram above. The system consists of two primary entities which are the system and the user. The user can perform a myriad collection of activities which involves installing the system application, switching the system on/off, connecting the system to electricity in other for it to be able to monitor energy consumption, etc while the system on the other hand can collect the consumption data using the different sensors of the system and display the energy data in real-time using the mobile interface.

3.6.2 Activity Diagram of The Proposed System

The activity diagram represents another modelling component that is vital within the framework of unified modelling language. This proposed system therefore captures the behavioural characteristics of the application that is dynamic, thereby mapping out workflows that is operational in a manner that is similar to a flowchart that is detailed. It traces the operational steps and logic paths visually executed throughout the system. however, in this project, the diagram details the activities of the platform in a sequential manner, tracing the process from the initial hardware power connection and application synchronization to the final energy consumption measurement of an appliance.

Activity diagram of the proposed system:

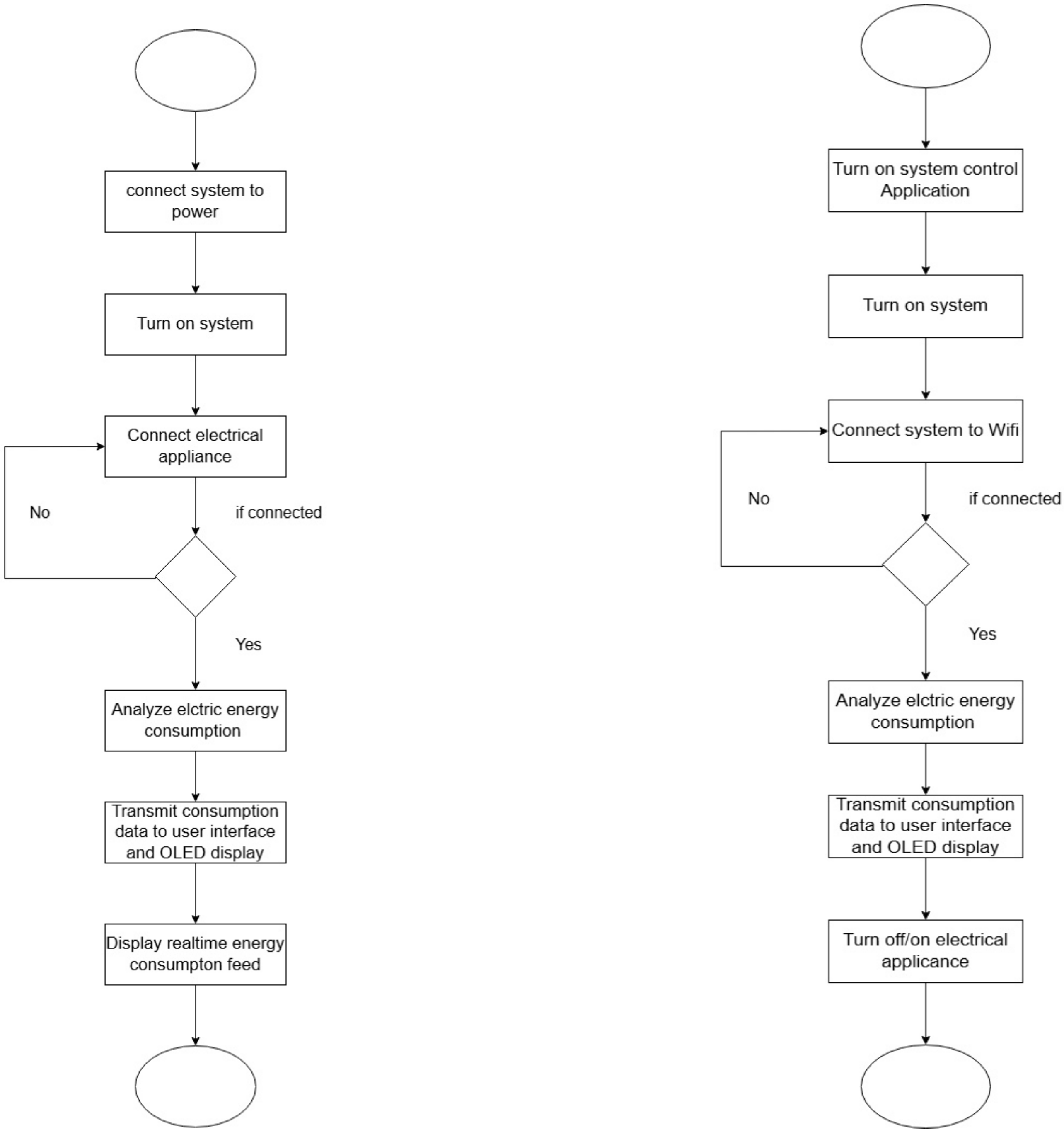


Figure 3.1: Activity diagram and energy monitoring process of the system

The activity diagram that is shown above provides a step by step visual representation of the system's workflow of operation. It however maps out the entire sequence of events, right from the initial time the power of the device is activated and ending with the real time display of energy metrics on the dashboard of the application.

3.6.3 Class Diagram of The Proposed System

class diagrams are Unified Modelling Language (UML) diagrams that are structural which defines a software system by mapping its classed, attributes methods and object relationships. However, the specific class diagram architecture for this proposed IoT system is illustrated below

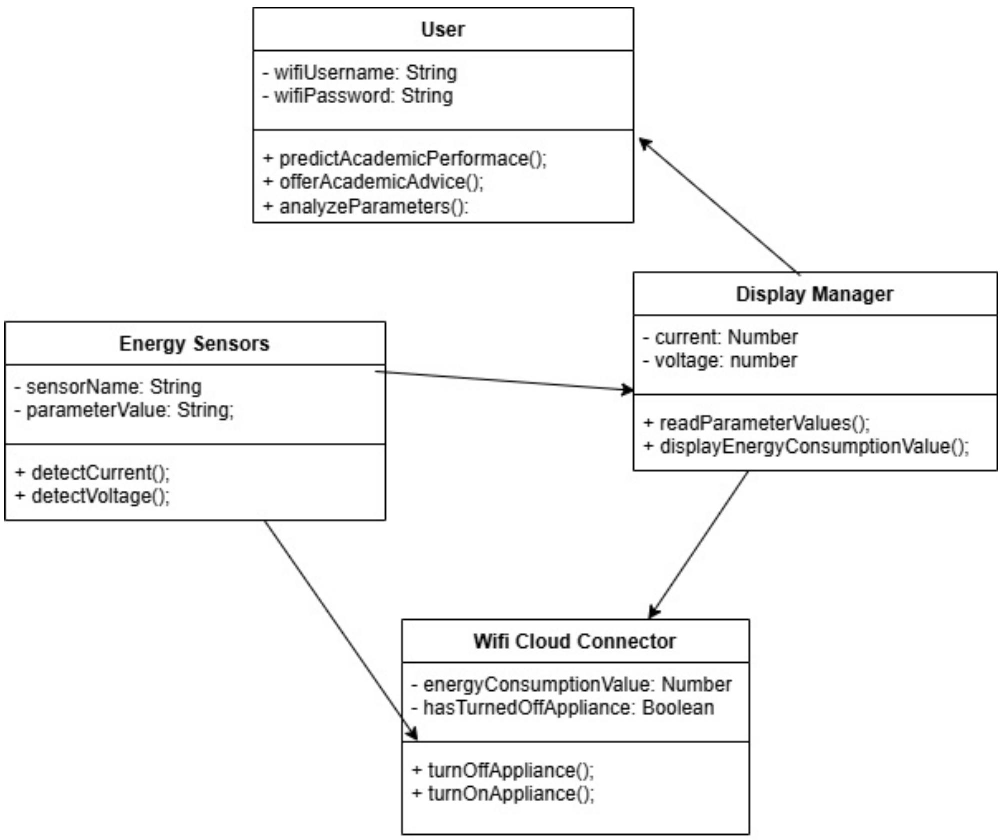


Figure 2: Class diagram of the proposed system

This class diagram demonstrates the engineering and management of the system's core processes by mapping the relationships that are exiting between its various module. However, it serves to clarify the dependencies that are architectural and also the design that are structural of the platform for the person who is reading he project.

3.6.4 Sequence Diagram

The UML sequence diagrams model the exchanges of messages that happen between the objects of system over time in a dynamic, chronological interaction way. It is made up of lifelines, messages and activation bars, and they explicitly illustrates when and how the different architectural components collaborate to execute a use case. Ultimately, they serve as a communication tool that is powerful which simplifies technical logic that are complex for both the developers and the stakeholders, therefore making it easier to collaborate, understand the behaviour of the system and also identify opportunities for enhancements in the future.

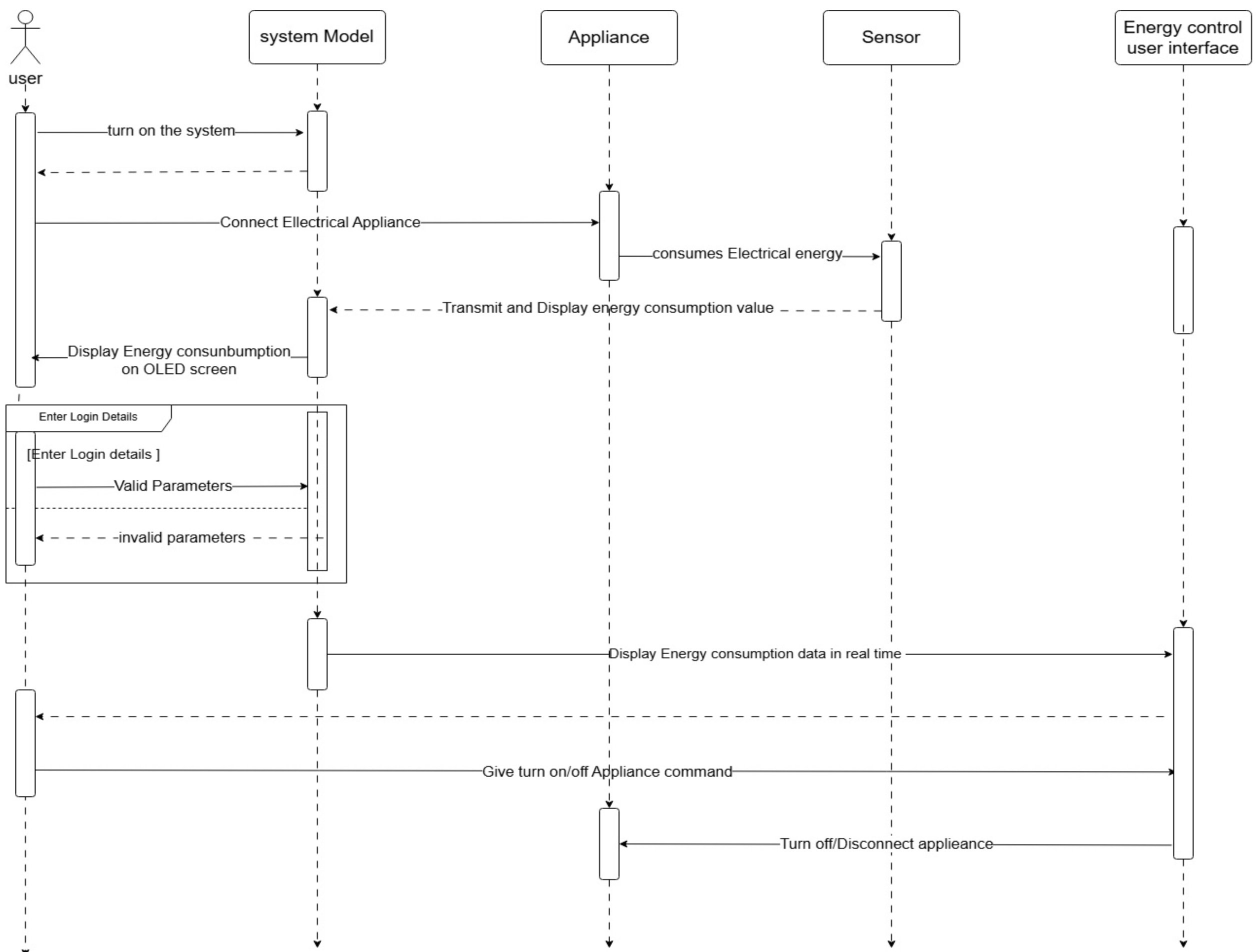


Figure 3: Sequence diagram of the proposed system

The sequence diagram that is shown above details the chronological flow of events in the proposed system. it maps out the exact timeline for exchanging messages and activities, starting with the activation of the device and concluding with the displaying of the energy consumption metrics live on the user interface.

3.7 Summary

This chapter of this project have successfully explained the methodology that was employed in the development of the Energy-Based Monitoring System. It has therefore covered how the data that was used in developing the system was collected, analysed and applied in the designing of the system. It also examined the prepaid meter system which is currently used in a wide range among the residents of Nigeria, identified the various limitations that the system has faced over time and most importantly showed how the proposed IoT-based system provides a solution that is more efficient, real-time and user-friendly solution for monitoring energy.

CHAPTER FOUR

SYSTEM IMPLEMENTATION

4.0 Introduction

This chapter of this project work exists to fully explain in detail how the IoT-Based Real-Time Energy monitoring system which have been proposed in the earlier section of this project was implemented in detail. In line with the designs that have been presented in the preceding chapters of this project. This particular chapter therefore focuses mainly on how the system was translated from the point of idea conception to full standard system that is working. In addition, this chapter also outlines all the tools, technologies and processes of development that were used while implementing this system. Each of the component of the system was carefully selected, tested, and integrated to ensure that the final solution is efficient, reliable, and suitable for real-time safety monitoring on construction sites.

4.1 Development Environment And Tools (Hardware and Software Requirements)

An Integrated Development Environment is a computer software application that offers computer programmers all the tools that they need to develop a software program. During the process of this research, the researcher employed the Arduino IDE in writing the C++ codes which is then uploaded to the Arduino board. However, the following reasons propelled the choice of Arduino IDE after all other IDEs were tested:

I. It is very much beginner-friendly and much easier to use.

II. It provides a platform that is very much standardized for programming and uploading

III. It ensures compatibility and ease of integration with the Arduino hardware

IV. It provides a development environment that is integrated with code editor, compiler and uploader.

4.1.1 ESP32 Micro Controller

The ESP32 Microcontroller serves as the main control and processing unit of the whole entire system. It was employed in this project to read analogue data of currents from the ACS712 sensor using ADC, perform signal processing and RMS calculation of current, compute power (W) and the consumption of energy (kWh), store the energy data in the EEPROM in other to prevent data loss during periods of power failure. After storing data in the EEPROM it in turn sends data to the Blynk Cloud over Wi-Fi in real time and by so doing, it controls and updates the data that is displayed on the OLED screen. However, in summary it manages the timing for measurements, EEPROM saving, and transmission of data.

Figure 4: Sample Image of the ESP32 Micro Controller

4.1.2 ACS712 Current Sensor Module

This is an integral part of the system which functions mainly for measuring the AC current that is flowing to the connected load. It works by using the Hall-effect principle to sense current without any form of electrical contact, it then produces an analogue voltage output that is proportional to the current. During this time, output signal is cantered around mid-supply voltage and the AC current appears as a sine wave around this midpoint. This component was employed in this project to measure the load current that is drawn from the AC socket, sends an analogue voltage signal to the ESP32 and through this, enables safe isolation between high-voltage AC and low-voltage electronics.

Figure 5: Sample Image of the ESP32 Micro Controller

4.1.3 AC to DC Power Supply Circuit

This is one of the most important component part of the system which functions by converting high-voltage current AC power into a safe low-voltage DC supply that is required by the ESP32 and sensors. It therefore works by stepping down 220-240V AC to low voltage, Rectifies current by converting AC to DC, smooths the DC voltage and provides stable 5V or 3.3V DC to the ESP32. It was employed in this project in other to help supply the appropriate current that is required by the ESP32, OLED, and ACS712, ensure stable and safe operations and most importantly prevent damages that happen due to the fluctuation in voltage. The logical power AC to DC power supply circuit diagram that was employed in this project work is attached below:

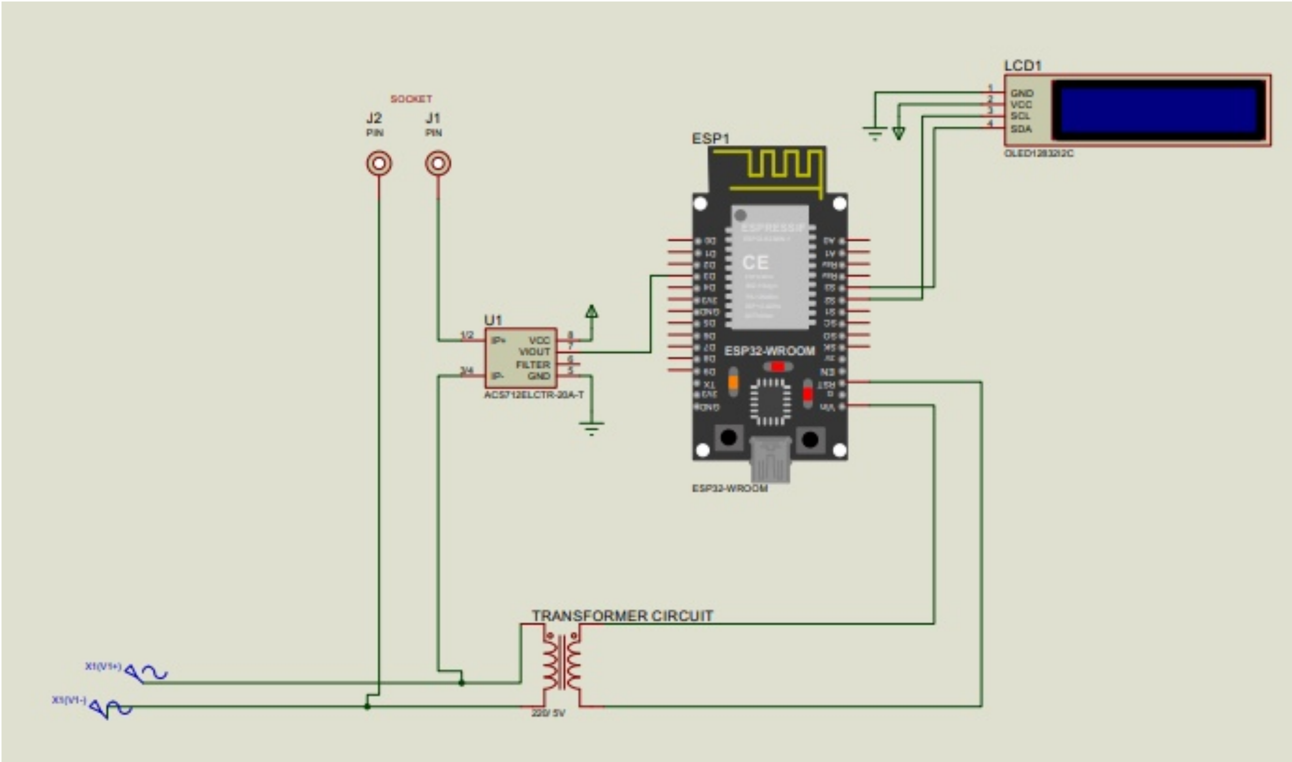


Figure 6: The logical power AC to DC power supply circuit diagram

4.1.4 OLED Display (SSD1306)

This is an integral part of the IoT based real-time energy monitoring system that provides local real-time visual feedback of electrical parameters. It functions to display various parameters such as Current (Amperes) and Power (Watts), Energy consumed (kWh). It was employed in this project implementation in other to allow the user to monitor the usage of power in real-time when they are physically present without a mobile phone, it also plays a keen role by displaying the status of the system and readings in real time.

Figure 7: Image of the OLED display (SSD1306)

4.1.5 AC Socket (Load Outlet)

This AC socket is a very keen part of the proposed system which serves as the point of connection for electrical loads like bulbs, fans, and other appliances. It was however employed in this project to supply AC power to the connected load by serving as a passage way for current to flow through the ACS712 sensor and most especially to enable the system measure the load of consumption in real-time.

Figure 8: Diagram of AC Socket (Load Outlet).

4.1.6 Bynk Console APP

The Bynk console app is simply an IoT platform that acts as the cloud abstraction layer and user interface for an IoT system which facilitates telemetry visualization and remote load management in real-time. It is made with features to enable a cloud dashboard that is responsive where data that is streamed over WiFi from the ESP32 such as, current, power, and energy consumption is parsed and displayed on graphical widgets like charts and gauges in other to make it easy for the users of the system to be able to understand. It’s use was however employed in this project to enable the users of the system to be able to view consumption data freely and remotely by just using their mobile phone.

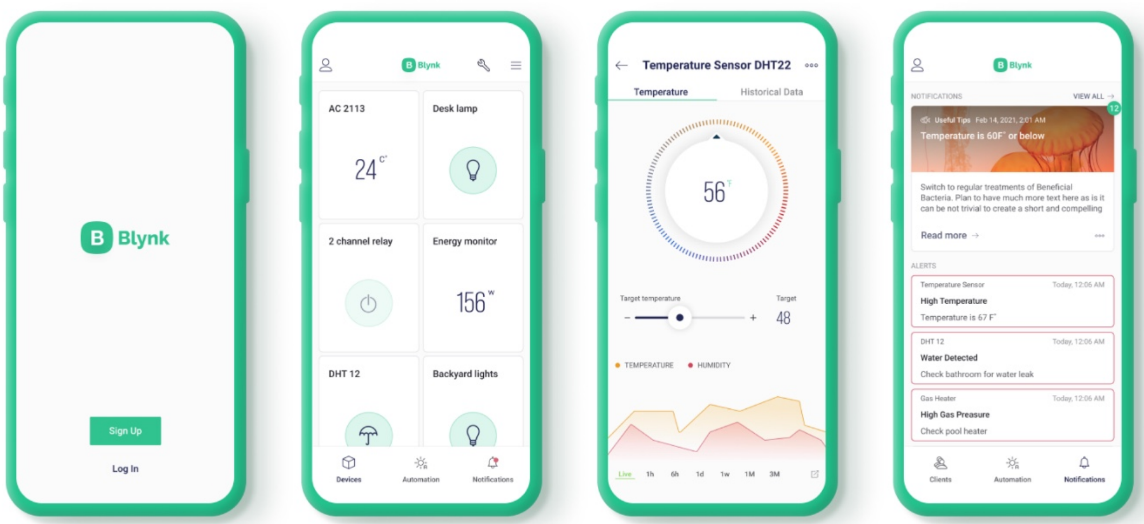


Figure 9: Sample image of the Blynk App interface.

4.2 System Implementation

The complete architectural design of the proposed IoT-Based Real-time Energy Monitoring and Management System relies on an integrated edge-to-cloud data pipeline where electrical sensors that are connected physically capture data continuously in a form of waves from connected loads. These raw signals are ingested by the ESP32 which on the other hand executes signal processing that are of high-speed in other to calculate active power (W) and cumulative energy consumption (kWh). The ESP32 therefore wirelessly transmits these metrics that have been preprocessed to the Blynk Cloud using the native Wi-Fi stack. These live parameters and analytics of energy consumption are then pushed to the user interface of the Blynk Smartphone Application for the user to be able to view it. This interface of the Blynk Console app however allows the users to monitor and control the consumption of data in real-time.

Figure 10: Image of the IoT-based Real-time energy monitoring and management system

4.3 System functionality and Modules

The proposed system is designed as a cyber-physical edge-to-cloud ecosystem divided into three distinct operational layers: data ingestion, edge computing and cloud visualization. The system by function therefore bridges the gap between physical and electrical infrastructure and frameworks for digital monitoring. The system is however made up of different modules which includes the following:

- **Data Ingestion and Signal Conditioning Module:** This module of the system forms the physical interface of the system, consisting of the ACS712 Hall-Effect current sensor and voltage transformer circuitry connected to the electrical mains. This module however functions to continuously step down high-voltage AC parameters into a low voltage analogue signal that is safe and readable by a microcontroller.
- **Local Processing and Calculation Engine:** This module is housed completely within the ESP32 microcontroller's application core and functions as the mathematical heart of the edge node

which continuously samples the analogue signals from the ingestion module via its internal Analogue-to-digital converter.

- **State Preservation module:** This module prevents data corruption or total loss of cumulative energy metrics during time of blackouts. This module therefore manages localied memeory and safety automation on the ESP32. It interacts directly with the calculation engine to periodically commit cumulative kWh data to the non-volatile **EEPROM storage.**
- **Cloud Upload and Network Module:** This module is responsible for handling all the telemetry data pipelines that exists wirelessly in the system and running on the ESP32's dedicated network core via its Wi-Fi stack that is integrated.
- **User interface and Remote Actuation Module:** This is the final interaction layer for the end user in the system. It functions by fetching the uploaded telemetry from the cloud data centre and populates the graphical widgets that are responsive for the user to view.

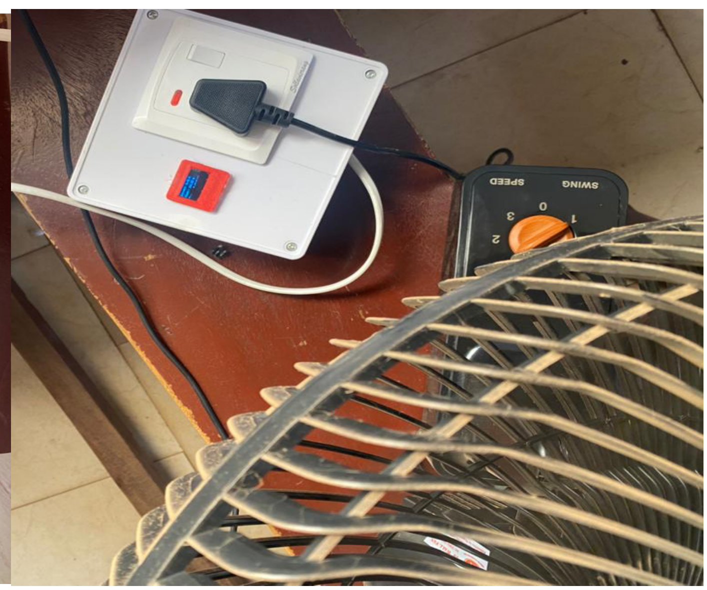
4.4 System Testing and Evaluation

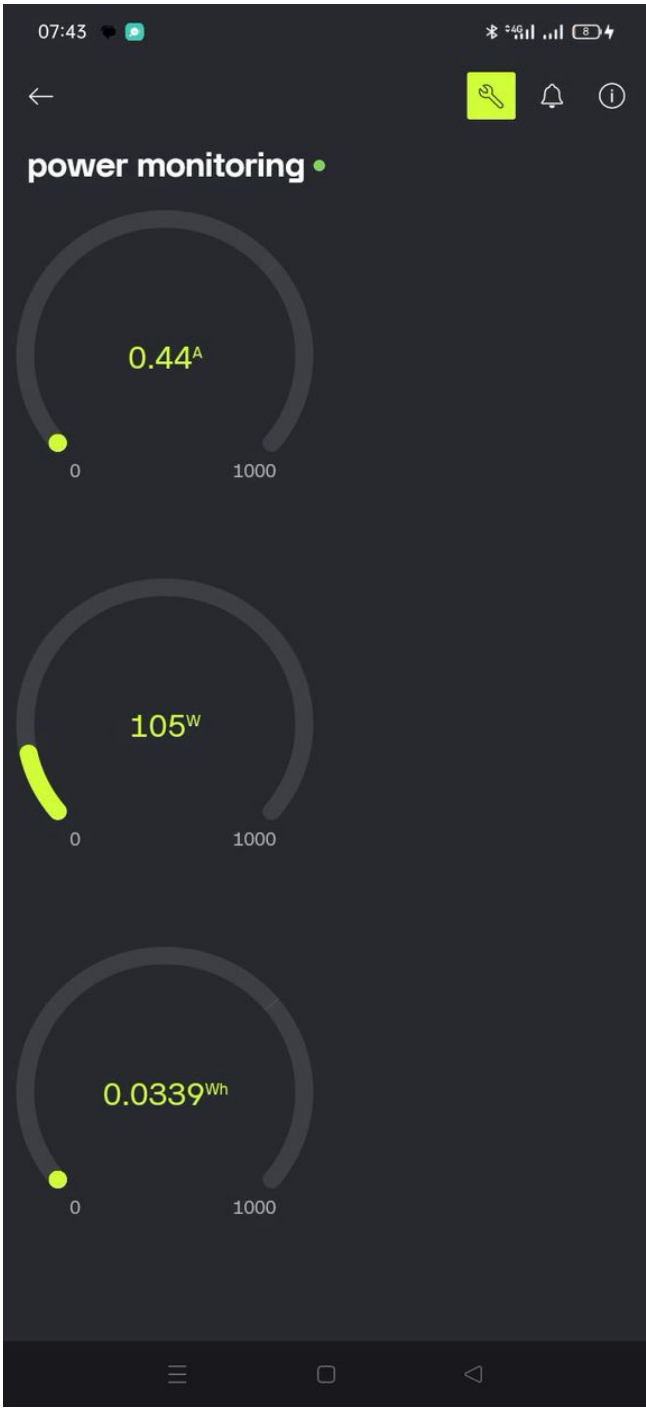
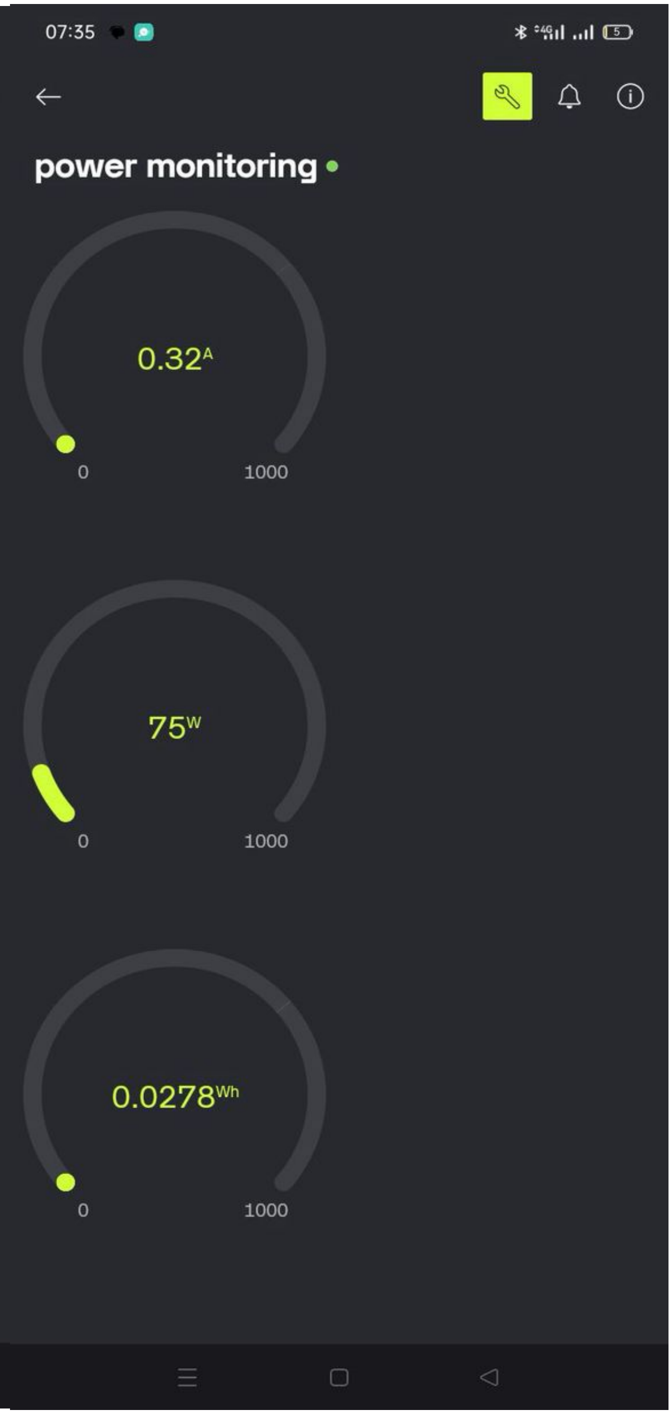
After constructing the system, the system was tested in real-time using 220-240v electrical power in Godfrey Okoye University Enugu in an attempt to evaluate the effectiveness of the system and also test its ability in providing solutions to the identified problem statements. The testing process of the system stated by connecting the system to power and powering it on, the system was then connected to the user's mobile phone through the use of Wi-Fi network and the Blynk console app, after which the different electrical appliances were connected to the system for the system to determine the amount of power which those appliances were consuming. The appliances tested include but were not limited to the following: power banks, phones, microwaves, electric iron, hot plates, electric kettles to name a few and the system actually proved to be functional by detecting and displaying the amount of power those electrical appliances were consuming in real-time.

Figure 11: Images showing the items used in the testing process of the proposed system.

4.5 Results presentation, Analysis and Discussion of Findings

while the system was being tested the system was able to accurately detect when the electrical appliances where connected and disconnected, the system was also able to show the accurate readings of the electrical power that is consumed by the different appliances that were connected to the system. At the end of the testing proceedings, it was observed that the system is sufficient in solving the problems that lead to the development of the system. The pictorial representation of the results from the testing process are outlined in detail below.




07:43
power monitoring
0.44A
0
1000
105W
0
1000
0.0339Wh
0
1000

07:35
power monitoring
0.32A
0
1000
75W
0
1000
0.0278Wh
0
1000

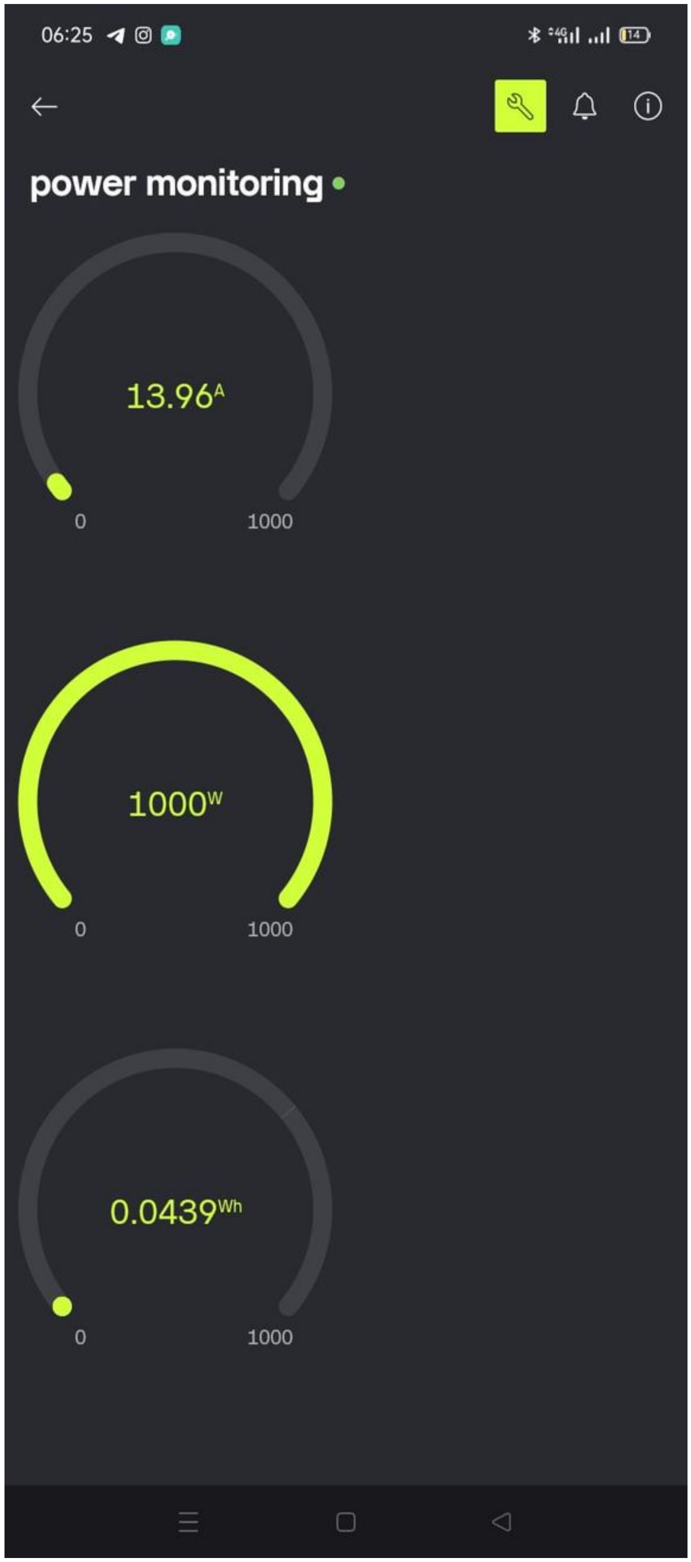


Figure 12: Images showing the energy consumption reading detected by the system when testing the appliances shown above.

The images above shows the results that were gotten when the system was tested using different home electronic appliances. The OLED screen however showed in real-time, the amount of electric energy in which each of the appliances where consuming in real-time. The Blynk console interface however also showed the real-time energy consumption readings indicating that the system is able to offer users the flexibility to monitor their energy consumption levels in real-time even when not being there physically.

However, it is important to note that the system has been built as a prototype and not as a fully fledged system and at that the system is suitable for the monitoring of energy consumption at a very small scale in other for the system to reach its full potential and achieve the aim for which it was developed and adopted.

4.5.1 Samples of User Interface

This section of this research work is going to contain user interfaces of different sections of the Blynk console application which was used in developing the software program for controlling the system from the mobile device of the user. This will however include the login page, the real-time energy monitoring page, the notification interface etc.

4.5.2 The login home page for the smart farm irrigation system

The login homepage consists of IoT-Based real-time energy monitoring login interface, which is made up of the E-mail section, Password section, Forgot password section in case the user forgets his/her password and finally the login section.

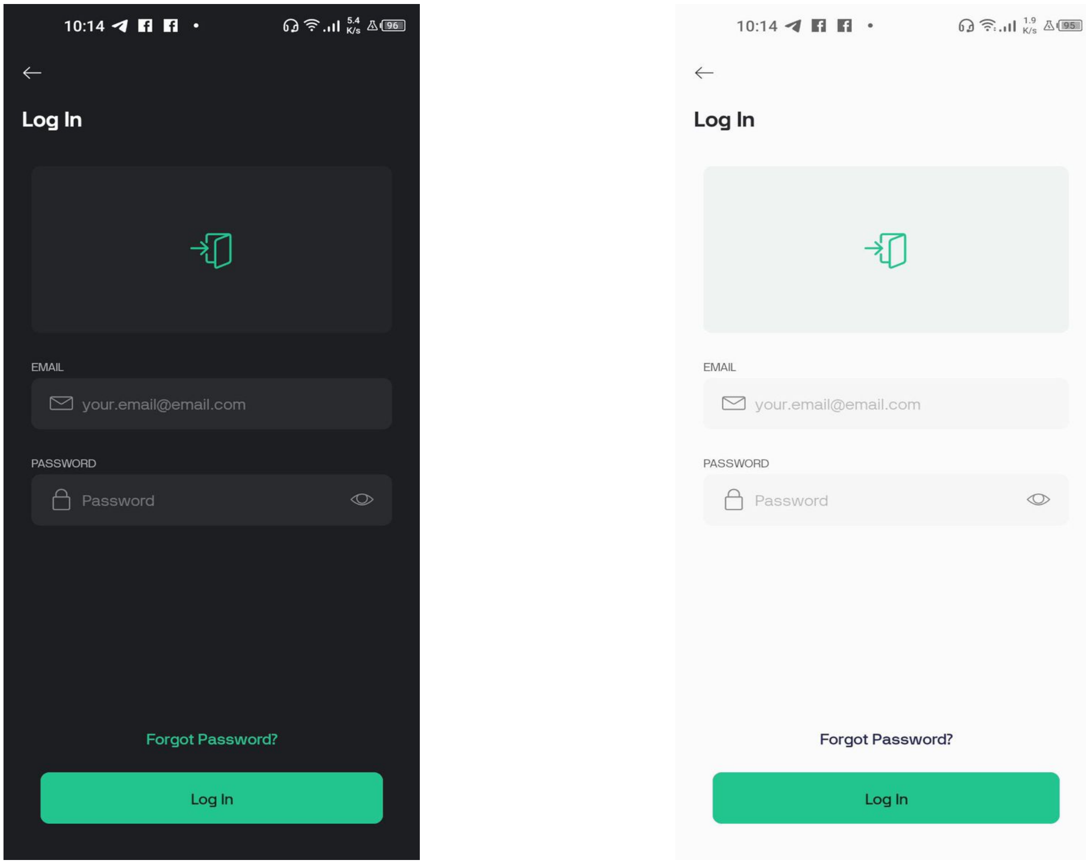


Figure 13: The Login home page for IoT-based Real-time energy monitoring system the on both dark and light mode

4.5.3 The system's monitoring interface

This section of IoT-Based real-time energy monitoring and management system functions to aid the users to be able to continuously monitor the power consumption of the user based on the readings of the system. The screen comprises of 3 different readings which include, the measurement in amps, watts and kilowatt/hour (kwh). These readings are represented using circular charts for easy interpretation by the user who is making use of the system.

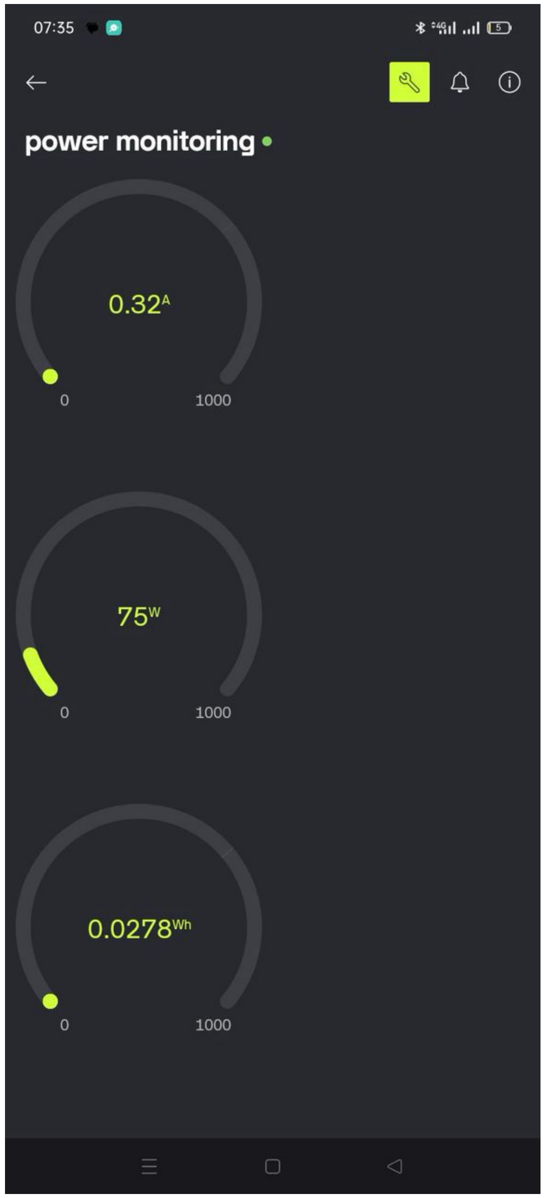


Figure 14: The home page for the of IoT-Based real-time energy monitoring system with monitors for electrical consumption in Amps, Watts and Killo watt hour (kwh).

4.5.4 Menu page of the smart farm irrigation system

This section of of IoT-Based real-time energy monitoring and management system stands to show the different list of commands or facilities displayed on the app. We have profile of the user that has been registered on the platform. This page also contains the Settings, Help, About, Billing (if the user needs to pay or upgrade the version of app to make use of other features) etc.

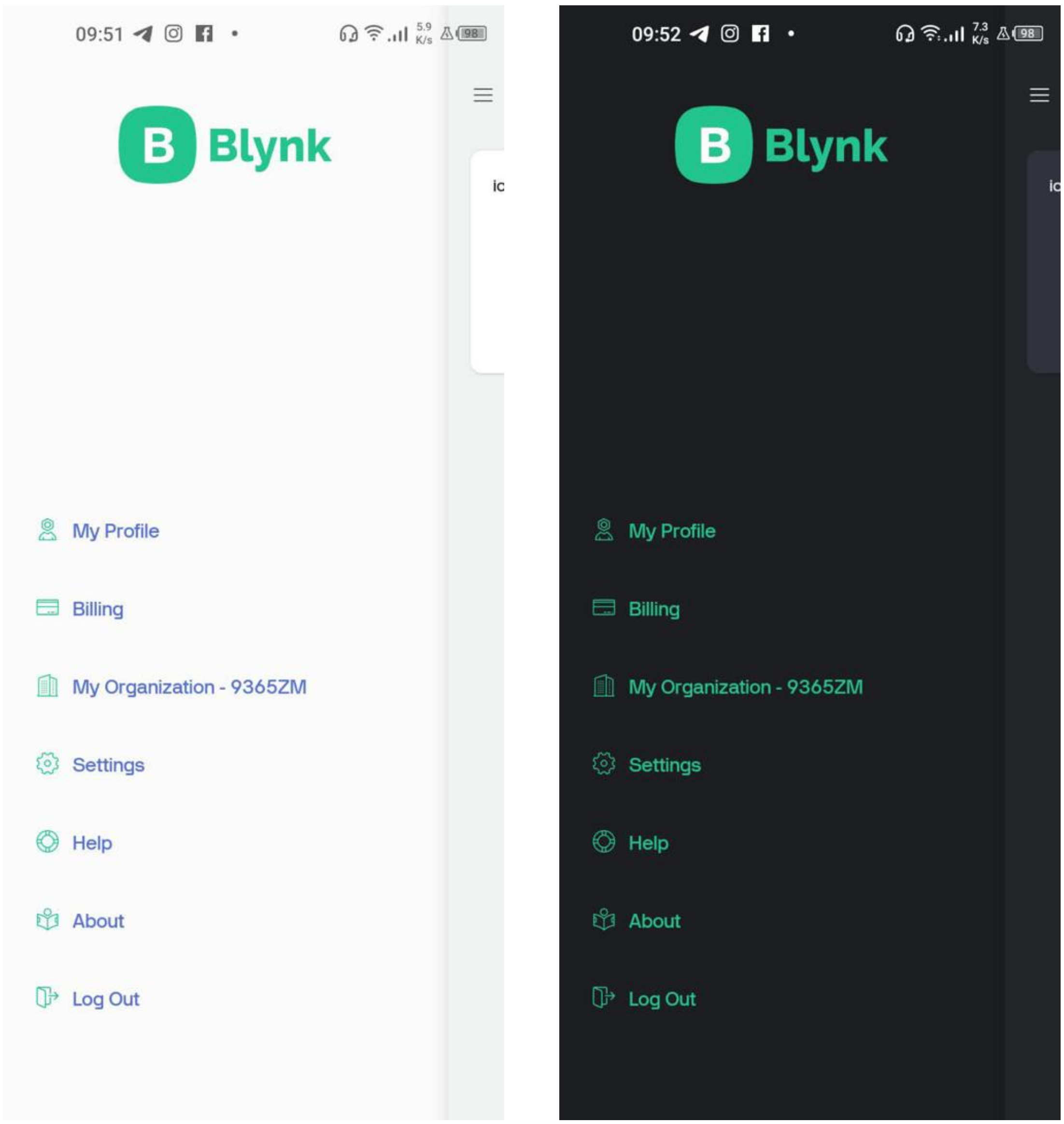


Figure 15: Menu page on both dark and light mode

CHAPTER FIVE

SUMMARY, RECOMMENDATIONS AND CONCLUSION

5.1 Overview

This chapter of this project work concluded the project by summarizing the entire project, by outlining the practical recommendations for future work and presenting key conclusions, there by offering recommendations for future development in this domain. It also, discusses in detail, what plans the researcher has for the system in other to improve the system's usability and performance.

5.2 Summary

This chapter presents in a comprehensive manner, the conceptual design, detailed development and technical implementation of the proposed IoT-Based Real-Time Energy Monitoring and Management System. with the main aim of this project defined in the chapter one of this work of research, the project research commenced with critically analysing the current methods of tracking energy consumption and the challenges that have surfaced as a result of using these manual methods of monitoring energy consumption. By Identifying these challenges, the study at it earlier stage, provided a foundational understanding of the solutions that have been offered by the adoption of IoT technology in energy monitoring.

However, in line with the conventional system development life cycle, the problem identification and research phase was followed by the design phase where the exact structural relationship between the different hardware nodes and software modules that are to be employed in the system were defined. The physical architecture of the system was therefore designed in a way that it was modular, safe and highly compact, so as to ensure the easy deployment of the developed system within residential or industrial consumer units. The core firmware of the system was programmed using the C++ programming language within the Integrated Development Environment (IDE) of Arduino. The codes for the firmware was however compiled and flashed onto the microcontroller.

Subsequently, the system was passed through integration testing in other to calibrate the calibrate the sensor data acquisition pipeline and verify the bidirectional transmission latency between the edge node and the cloud gateway, and also to make sure that the system was able to achieve the objectives for which the research was embarked on. However, at the end of the testing process, the results that were gotten looked promising confirming that the system was able to measure and calculate power consumption in real time while seamlessly synchronizing the electrical readings on the cloud based Blynk console Application.

5.3 Conclusion

The main aim of this research was to develop and implement an IoT-Based Real-Time Energy Monitoring and Management System for the purpose of giving users an automated edge-to-cloud system that helps users track electrical parameters to reduce energy losses. The main goal of building this robust data ingestion system was achieved after combining the ACS712 and circuitry of the voltage transformer, which captured clear raw analog waveforms. The secondary goal of building a robust local processing system was also achieved after the ESP32 was implemented, and the firmware was able to perform the real-time signal processing to determine and display active power (W) and total energy consumption (kWh). Lastly, the goal of providing users remote access and automation was also achieved after a bidirectional Wi-Fi connection to the Blynk Cloud was established to provide users with real-time telemetry and load control automation.

However, quantitative data from the testing phase confirmed that the ESP32-based energy management system was able to detect changing electrical loads and transmit data packets to the smartphone interface with an average transmission latency of less than two seconds. Some factors inhibited the complete optimization of the proposed system. Among them was the native 12-bit successive-approximation register (SAR) ADC of the ESP32, which demonstrated a slight non-linearity at ultra-low current levels that led to small calculation errors for very small standby loads. Additionally, there was a limitation of only testing single-phase systems due to the testing time constraints, meaning there is a lack of evidence for the system performance in multi-phase industrial environments. Based on the aforementioned, the proposed system is an extremely relevant and scalable architecture for the integration of modern smart grids and sustainable power management, and is essentially low-cost.

5.4 Recommendation

Considering the empirical results and structural constraints of the IoT-Based Real Time Energy Monitoring and Management System, the following suggestions for enhancements, adaptations, and extensions of the system are outlined below.

- **Dedicated External ADC Modules Are a Must:** Future versions of the system should incorporate dedicated external energy metering chips (for example, ATM90E26 or ADE7753) to replace the internal ADC of the ESP32. By doing this, silicon non-linearity will be eliminated, automatic phase compensation will be added, and measurement accuracy of low-current standby appliances will be improved.
- **Increased Coverage of Multi-Phase Power Systems:** Future versions of the system will be required to monitor three-phase industrial and commercial electrical networks. To achieve this, the system will need to deploy triplicated sensor networks and the processing algorithms will need to be restructured to account for phase angle shifts (i.e. separated by 120^0) and total harmonic distortion (THD).

- **Deploy Edge Machine Learning for Appliance Load Monitoring:** Adding non-intrusive load monitoring to edge nodes will enable a significant upgrade from monitoring to automation. Using lightweight load machine learning to develop edge nodes via TinyML and machine learning models will allow users to see a detailed breakdown of individual appliance consumption, as the edge nodes will develop the capability to learn appliance signatures from a single current sensor.
- **Incorporate Alternative Wireless Protocols:** For large scale deployments, where local Wi-Fi or local Internet cannot be relied upon, the network layer will need to be based on low-power wide area network protocols, such as LoRaWAN or NB-IoT. This will enhance range and reliability for the local Internet and significantly limit the operational requirements of the local Internet.
- **Develop a Localized Web Server Fail Safe:** Internal asynchronous web servers will be implemented. This allows the ESP32 to be upgraded to a localized human-machine interface without dependency on third-party cloud platforms. The developments can be cited IP wise, allowing system control and data availability even where other cloud servers are down.

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Appendixes

```
#define BLYNK_TEMPLATE_ID "TMPL2fLyxA0ch"

#define BLYNK_TEMPLATE_NAME "power monitoring"

#define BLYNK_AUTH_TOKEN "pCXdrq0bkU61Phkm_jstMkH9QHFD9fcn"



#define BLYNK_PRINT Serial



#include <WiFi.h>

#include <WiFiClient.h>

#include <BlynkSimpleEsp32.h>

#include <Wire.h>

#include <Adafruit_GFX.h>

#include <Adafruit_SSD1306.h>

#include <EEPROM.h>

#include "ACS712.h"




char auth[] = BLYNK_AUTH_TOKEN;
```

```
const char* ssid = "Infinix HOT 10";

const char* pass = "112345677";


/* ---------------- OLED ---------------- */

#define SCREEN_WIDTH 128

#define SCREEN_HEIGHT 64

Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, -1);


// ESP32: pin, Vref, ADC max, mV/A

ACS712 ACS(34, 3.3, 4095, 185);   // change 185 to 100 if 20A module


double AmpsRMS = 0;

double Watt = 0;

double energy_kWh = 0.0;


/* ---------------- TIMING ---------------- */
```

```
unsigned long lastEnergyUpdate = 0;

unsigned long lastEEPROMWrite = 0;


/* ---------------- EEPROM ---------------- */

#define EEPROM_SIZE 64

#define ENERGY_ADDR 0


BlynkTimer timer;


void setup() {

  Serial.begin(115200);


  /* EEPROM */

  EEPROM.begin(EEPROM_SIZE);

  EEPROM.get(ENERGY_ADDR, energy_kWh);

  if (isnan(energy_kWh) || energy_kWh < 0) energy_kWh = 0;


  /* Blynk */
```

```
Blynk.begin(auth, ssid, pass, "blynk.cloud", 80);


/* OLED */
if (!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) {
  Serial.println("OLED failed");
  while (true);
}


display.clearDisplay();
display.setTextSize(1);
display.setTextColor(WHITE);
display.setCursor(0, 0);
display.println("Power Monitor");
display.display();
delay(1500
ACS.autoMidPoint();
Serial.print("ACS Midpoint: ");
Serial.println(ACS.getMidPoint());
```

```
  timer.setInterval(1000L, sendToBlynk);
}
void loop() {

  /* -------- CURRENT (AC RMS) -------- */
  int mA = ACS.mA_AC_sampling();
  AmpsRMS = mA / 1000.0;

  /* -------- POWER -------- */
  Watt = AmpsRMS * 240.0;   // change if DC or different voltage

  /* -------- ENERGY -------- */
  unsigned long now = millis();
  if (lastEnergyUpdate == 0) lastEnergyUpdate = now;

  double elapsedHours = (now - lastEnergyUpdate) / 3600000.0;
  energy_kWh += (Watt * elapsedHours) / 1000.0;
```

```
lastEnergyUpdate = now;


/* -------- EEPROM SAVE (every 60s) -------- */
if (now - lastEEPROMWrite >= 60000) {
  EEPROM.put(ENERGY_ADDR, energy_kWh);
  EEPROM.commit();
  lastEEPROMWrite = now;
}


/* -------- SERIAL -------- */
Serial.print("I: ");
Serial.print(AmpsRMS, 3);
Serial.print(" A | P: ");
Serial.print(Watt, 2);
Serial.print(" W | E: ");
Serial.print(energy_kWh, 4);
Serial.println(" kWh");
```

```
/* -------- OLED -------- */

display.clearDisplay();


display.setCursor(0, 0);

display.print("Current: ");

display.print(AmpsRMS, 3);

display.println(" A");


display.setCursor(0, 16);

display.print("Power: ");

display.print(Watt, 2);

display.println(" W");


display.setCursor(0, 32);

display.print("Energy: ");

display.print(energy_kWh, 4);

display.println(" kWh");
```

```
  display.display();

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

void sendToBlynk() {
  Blynk.virtualWrite(V1, AmpsRMS);
  Blynk.virtualWrite(V2, Watt);
  Blynk.virtualWrite(V3, energy_kWh);
}

/* Reset Energy Button */
BLYNK_WRITE(V10) {
  if (param.asInt()) {
    energy_kWh = 0;
    EEPROM.put(ENERGY_ADDR, energy_kWh);
```

```
    EEPROM.commit();

  }

}
```