INDIVIDUALIZED POWER CONSUMPTION MONITORING FOR SMALL BOARDING HOUSES AND SHARED HOUSES

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Chapter 1

Introduction

Rationale

In using electricity in the community, power distributor companies and consumers mainly rely on electric meters to measure the power consumption on households and buildings from time to time. Although many advancements on electric meter technologies have been made to improve its accuracy, performance and features, little improvements have been made when it comes to measuring the power consumption of an individual person. Measuring and obtaining data of an individual consumer's electric energy consumption has been very difficult and challenging especially when most residential electricity meters only measure the total power consumption of an entire household or building establishment. These electric meters that are used to measure the electric power consumption are commonly installed close to the household premises and due to their bulky size, mass and equipment cost, these conventional electric meters are only limited to one or few applications.

In the Philippines, people that rent boarding houses pay for their monthly electricity as part of their monthly rental expenses without even knowing their fair share of the household/building's electric power consumption. In some cases, they might pay additional expenses based on the number gadgets and appliances that they own while in the boarding houses. This is the same for group of people that live together in one apartment. They pay for electricity without even knowing their own or their fellow boarder's /tenant's electric consumption.

This study aims to design and create a functional system that is capable of measuring and monitoring the individual electric power consumption of multiple users and provide real-time notification of their electric power consumption at the end of every month.

Background of the Study

In the ASEAN countries, the Philippines is among the five largest electricity-consuming countries in ASEAN. It is accountable for 90% of ASEAN total electricity consumption alongside Indonesia, Thailand, Malaysia, and Vietnam based on (IEA, 2010). As stated by (Gumaru & Banta, 2019), the yearly electricity consumption of the nation has reached a total of 127,649, 475,695 kilowatt-hours from the year 2015-2018 and Region 8 – Eastern Visayas sharing 2,918,567,075 kilowatt-hours (0.02%) of the country's energy consumption. These numbers continue to rise as time progress and as the country's economic growth means more demand for electric energy. And the energy demand of the Philippines is forecasted to increase by 2851.41-megawatts from January of year 2017 up to December of 2022 (Urrutia & Antonil, 2019). In the past decades, the electric consumption of the country has grown at a fast pace. In 2015, the average household power consumption in the country was about 248.1-kilowatt hours according to (Sanchez, 2020). This is mainly due to the residential sector heavily relying on electricity as the most convenient household energy source available. Besides the residential sector, the intensified electrification efforts throughout the country also contributed to this growth in electric energy demand. Decreasing the number of people without access to electricity from 1.2 billion in the year 2010 to 840 million in the year 2017 (The World Bank, 2019). The residential sector continues to be the leading largest consumer of electricity taking up 28.8% of the country's total electricity consumption followed by the industrial (26.6%) and commercial sector (24%) according to (DEPARTMENT OF ENERGY, 2020). (Philippine Statistics Authority, 2013) indicated that an estimated 87% of the household and residential sector out of 21 million uses electricity from March to August 2011. About 70% of the household uses electricity for lighting purposes, and an estimated 79% and 66% of the households use electricity for recreation and space cooling.

Most college students that came from far places resort to seek and stay on temporary housing or impermanent living accommodation facilities near college campuses known as boarding houses (Navarez, 2017). Not only students in particular but also people who work or stay far from their homes that need a temporary place of residence. Many students nowadays own gadgets to aid their learning and studies as mentioned by (Javier, 2015). And the majority of them, rating an estimate of 93.01%, pay add-on fees for their gadgets and appliances (Matilde L. Malana & Javier, 2020). Additional appliances such as electric stoves, rice cooker, electric fans, etc. consume more electricity and so student-boarders are required to pay an additional charge. The cost of the additional charge of owning gadgets and appliances in boarding houses varies from one locality to another. Yet from the findings of (Matilde L. Malana & Javier, 2020), most boarding houses around the Cagayan State University Aparri Campus charge around 50 – 74 pesos add-ons per gadget per month. This method of charging for electricity fee on boarding houses does not seem to be fair as the landlord/landlady just consider by how much appliances and gadget a student-boarder owns and not their actual electricity consumption. Furthermore, the method shows the disadvantages of not obtaining factual numerical data on how much a student boarders energy consumption is. Therefore, it is not possible to rank and evaluate who among the boarders uses more electricity and it is theoretically impossible to calculate and quantify each student boarders' fair share of the household's monthly electricity bill. Moreover, it also affects the side of the student-boarders as unmonitored electricity consumption of their fellow tenants may lead to an increase of the boarding house's electricity fee per gadget and appliances consequently increasing their living expenses. The only devices capable of continuously measuring the amount of electricity consumption on boarding houses are electric energy meters, which are installed at the customer's premises for billing purposes (Enertiv, 2019). The types of electric meters that are commonly used in households and residential areas in the Philippines are Electromechanical and Electronic meters.

Conventional electromechanical meters, the type of meters that you see with a rotating disc and dials, are used to measure electrical energy in many residential homes. But these types of electric meters have been known to suffer from numerous disadvantages such as having low accuracy, being prone to friction errors, and their performance could be affected by temperature and electromagnetic interference, therefore, making them susceptible to fraud. Although energy meter manufacturers put more effort and research into the development of more precise electromechanical meters, adding the necessary upgrades to improve performance and precision justifies the necessary investment. Hence, the electromechanical energy meters continue to be pervasive for residential applications (E. Markran, 1992; S. Goldberg and W.F. Horton, 1987; M. M. Saied, 1995). Electronic meters come to replace these kinds of meters due to their higher accuracy, low power consumption, temperature independence, and security. At a very light load, electronic meters perform measurements with high accuracy and fewer errors in comparison to electromechanical meters (ENOKELA, J.A., 2007). And with the advancements of microcontroller technology during the past decades, energy meters embedded with microcontrollers have been developed and it holds promising outcomes proving the possibility that electrical energy consumption can be measured using a microcontroller, an alternative to electromechanical meters. These types of electric meters are not subjected to the disadvantages of electromechanical meters as it doesn’t have rotating parts and it helps in the prevention of fraud due to tampering. Moreover, microcontroller-based electricity meters are also estimated to have low production cost in addition to their accuracy and precision in measuring electricity consumption.

This study intends to incorporate the use of microcontrollers and to utilize their capabilities to develop a prototype system that could measure electricity consumption with a high rate of accuracy and therefore provide proper knowledge of each individual's electricity consumption. Consequently, eliminating the unequal division of electric bill charges and at the same time, establishing fairness.

Significance of the Study

Boarders of small boarding houses and shared houses

Utilization of the system can greatly benefit the boarders and tenants by providing them with data about their actual electrical energy consumption. This could also benefit groups of people that share one apartment or dwelling establishment. The system will offer a sense of fairness to both boarders and their landlords/landladies when it comes to dividing their share of the household's monthly electricity bill. Allowing the boarders to check and calculate how much they are going to pay for electricity concerning the standard electricity fee per kilowatt-hour, eliminating doubts and speculation. This opens the possibility of removing the additional fee per number of gadgets and appliances owned, as the electricity consumption of each individual boarder will be automatically measured and monitored by the system.

Landlords and Boarding house owners

Boarding house owners could also benefit from the system utilization. By having a reliable power monitoring system, they can retrieve and evaluate the data of their boarders and have knowledge of how much electricity they consume. It also gives them the power to rank the electricity consumption of their boarders and accurately identify who among them consumes more power than the others. Although this may seem to have some drawbacks in terms of business, it would greatly improve the quality of life of the boarders, leading to good results and feedback, and eventually attracting more boarders. The system could also raise awareness of the student-boarders and promote saving energy, leading to the reduction of the establishment's electricity energy consumption.

Objectives of the Study

The primary objective of this study is to design and develop a microcontroller-based system that is capable of measuring and monitoring Electrical Power consumption using an Arduino microcontroller.

Specifically, it aims to:

1. Design and develop a semi-automated electric power consumption monitoring system using Arduino;
2. Provide real-time display monitoring of electric energy usage;
3. Distinguish a registered user and measure its electric energy consumption in kilowatt-hours individually;
4. Keep and store the power consumption data of each registered individuals in case of a power interruption or power loss scenario;
5. Notify the registered user of its monthly electricity consumption through short message service (SMS);
6. Evaluate the performance of the developed system in terms of:
    a. Functionality
    b. Accuracy and
7. Produce an operational manual and safety guide of the system.

Scope and Limitations

The study focuses on the means of developing a power consumption monitoring system for small boarding houses and shared houses, and aims to provide a solution to the problem of uncertain division of electricity power consumption. The study limits its coverage to boarding houses and shared houses with less than or equal to ten individual people living in the same establishment.

The study aspires to include and develop safety and hazard protection features for the system and also a working system manual to prevent future problems in terms of use. Hence, any occurring future scenarios that may take place due to user negligence are outside the scope of the study.

This study will also take high consideration of the confidentiality as well as the security of the user's data. Each respondent's access and restrictions to information will be clearly stated and described in the study. And the system's program architecture will also be designed to not allow modifications to the power consumption data for the purpose of data protection and prevention of fraud.

Definition of Terms

Electric meter. Refers to devices that are used to measure the electrical energy usage of a home, building, or other electrically powered devices. They are used to provide accurate billing to customers (Afework, et al., 2020).

Kilowatt hours. The unit of work or energy equal to that expended by one kilowatt in one hour or to 3.6 million joules (Mirriam-Webster, 2021). In this study, it would be the unit that will be used for measuring electrical energy consumption.

Megawatt. A unit of electrical power equal to one million watts (Mirriam-Webster, 2021)**.**

Electromechanical meter. Also known as disk meters, a combination of Mechanical and Electrical Technology that is used for electrical energy measurement. These types of meters have a mechanical disk present inside that rotates when the load is applied (Sarwar, 2017).

Electronic meter. A type of Electrical meter that gives a separate reading, in the form of a decimal number, for each given input quantity (Collins Dictionary, 2021).

Load. The resistance, weight, or power drain sustained by a machine or electrical circuit (THE AMERICAN HERITAGE® SCIENCE DICTIONARY, 2021). In this study, the load will be applied to simulate electricity consumption.

Microcontroller. A control device that incorporates a microprocessor (Lexico, 2021). Microcontrollers will be used in this study as the main controls of the system and also deal with data processing and task handling.

Arduino. An open-source electronics platform or board and the software used to program it (Technopedia, 2021). In this study, it will be the fundament upon which the system would be developed.

Chapter 2

Review of the Related Literature

The need for an individualized power monitoring system is raised due to unmonitored power consumption and problems that come with the division of payment for the electricity bill in small boarding houses. (Matilde L. Malana & Javier, 2020) stated that 93 percent of student-boarders pay add-ons for the boarding house for every gadget and appliance that they own and use within the establishment. Additional payments are being charged by boarding house operators without a numerical and statistical basis of how much the boarder's average power consumption is, and the price of the add-on payments varies between different boarding houses and different localities. Electric meters are the only devices capable of measuring power consumption continuously. Electric meters are crucial because they measure electricity consumption and they are important for power distribution companies because they serve as the basis for computing the electricity bills of consumers. It enables the systematic pricing of energy consumed by the consumer as it measures the amount of electrical energy consumed by a residence, business, or electrically powered device (Ndinechi, et al., 2011). These devices operate by measuring instantaneous voltage and current, finding the product of these to give instantaneous electrical power, which is then integrated against time to calculate the energy used. Electric meters are classified by type according to their measuring principles and are classified as electromechanical (induction meter) and electronic energy meters (Wasion Group, 2012). Electromechanical meters operate and measure electricity consumption through a magnetic mechanism, that puts a disk into movement, that is connected to the load's energy demand. The electronic type meters measure electricity usage with the use of digital technology and are also capable of measuring other electrical parameters: phase voltages, phase currents, frequency, power factor, etc... These meters operate without moving parts and are not prone to the disadvantages of the electromechanical types, making them more secure and accurate. Integrating the technologies of electronic-type electric meters with microcontrollers to develop a power monitoring system that measures individual consumption will solve the problem of unmonitored power consumption.

Microcontroller-based electronic meters

Electronic power meters are capable of taking readings and storing them in their memory, and they operate by refining the quick estimations of voltage and current measurements continuously to get the power consumption in kilowatt-hours. Electronic meters are now more often used due to their accuracy, energy efficiency, and reliability over the electromechanical types.

(Islam, et al., 2012) developed an electronic meter that utilizes the low-cost ATMEGA8L microcontroller to control the whole system. The current and voltage sampling is done separately and processed to achieve power measurement. Experiments on the measurement accuracy of the design were approximately 100% when measuring linear types of load, but showed poor results when measuring non-linear types of load. Aside from the design having a memory storage for power measurement consumption, it does not have a storage device for timely measurements and therefore can not play a role in power demand forecasting. The system was designed with a backup battery to act as a temporary power source when there is no electricity on the mainline. With this feature, the system could safely store the already calculated power measurement into its memory in case of a blackout or brownout. This feature is extremely useful, specifically in the Philippines, where power outages are pointed out to be the main problem for electricity users. According to (Brucal & Ancheta, 2018), 9 out of 10 of the country‘s electricity-consuming households are experiencing "brown-outs" and 7 out of 10 households in Western Mindanao are reported to have been experiencing voltage fluctuations. Some regions of the country experienced an energy deficit which led to rotating power outages, which happened in Cebu during the years 2009 and 2010 and still continues in other regions up until this day. The backup battery feature is really helpful for allowing the system's continuous operation, and this feature could be highly utilized in power grids where problems with electricity quality largely occur.

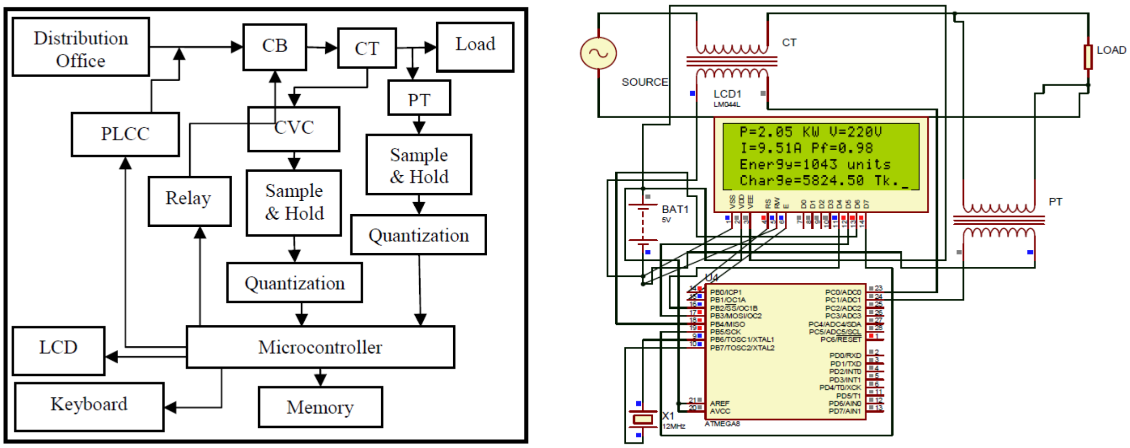

Figure 1. Complete block diagram of the energy measurement system (left) and it's schematic layout (right). (Source: Islam, et al., (2012))

In a study by (Tamkittikhun, et al., 2015) entitled "AC Power Meter Design based on Arduino: Multichannel Single-Phase Approach", a power meter was proposed to improve real power measurement accuracy by sampling voltage and current simultaneously. The system was designed to let the user choose the current sensors for suitable use concerning the appliances. As a consequence, calibration factors must be changed according to the selected sensor. To facilitate the user so as not to engage with the source code, configuration files are used for storing configuration variables. A designed firmware for the power meter provides a configuration API for external computing nodes to be able to update the configuration files remotely. However, the configuration feature may reduce the system's potential in terms of perceived ease of use, as configuring the system may require the use of a computer and a sufficient, if not average, understanding of electrical knowledge. In a study by (Stragier, et al., 2010), perceived ease of use was found to have a strong influence on perceived usefulness. This implies that people will consider devices and appliances more useful if operating them is not a hard thing to do. (Amin, et al., 2014) also emphasized that it is important to understand the convenience of the services provided, which is considered as the first variable for user satisfaction and is referred to as "user-friendliness" in most literature. This means that ease of use has to be considered and taken into account in the development of these devices to have an "Easy to Use" perception to the user, or at least not be more difficult to use than regular household appliances, which will highly contribute to a positive attitude. Furthermore, the proposed system design of the power meter of study does not include a backup power supply to allow it to function continuously during a power breakout. Nonetheless, the experimental results of the study were well above a satisfactory level. The study concludes that power measurement can be achieved with much less RMS error using the Simultaneous sampling design and it proves that the use of an Arduino microcontroller is feasible for the measurement of electrical power and other electrical parameters.

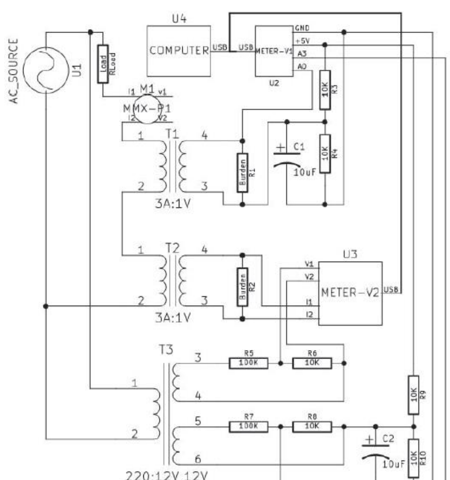

Figure 2. Schematic Layout of AC Power Meter Design based on Arduino. (Source: Tamkittikhun, et al., 2015)

Power Sampling and Measurement

(Tobi & Van Harling, 2021) designed a prototype for a wireless energy transmission system with the use of a PZEM004T module for measuring power and other electrical parameters and an Arduino as the processing unit of the system. The PZEM004T is a low-cost power sensor module from China that boasts the capabilities of measuring current, voltage, and power. The output from PZEM004T is via TTL serial communication, which can be connected to the serial data pins of the Arduino and measure the electrical parameters using the PZEM004T Library (olehs, 2016).

(Khwanrit, et al., 2018) performed a study on accuracy comparison of present low-cost current sensors, and among the sensors that were tested was the PZEM004T module, along with 3 other sensors: ACS712, WCS1800, and SCT013. Two different industry-tested power meters were used as a reference for testing the accuracy of the sensors, and the four sensors were tested by measuring load currents of up to 20 Amps. The experimental procedure yielded results of PZEM004T and SCT013 having similar and more accurate results, less than 0.5% error, than the other 2 sensors above 5 Amps of current. The study concluded that the PZEM004T gives the best performance at a good price, and it can measure voltage and power, which can further be utilized for other applications. Although it is slightly more difficult to install the PZEM004T because a connection point of the electrical system needs to be cut in order to put the wire through the iron core of the sensor module. (Bluejay, 2016) stated that most modern residential circuits are 15 to 20 amps, with a max load of either (15A x 120V =) 1800 watts or (20A x 120V =) 2400 watts before the breaker trips. Therefore, the PZEM004T sensor module’s compatibility shows that it is highly reliable for application on residential wall outlets.

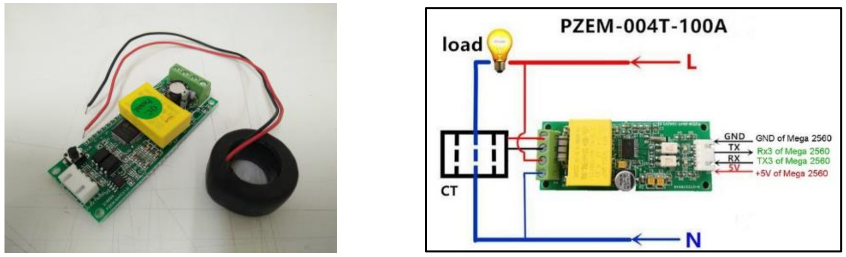

Figure 3. PZEM004T (left) and It's wiring procedure (right). (Source: Khwanrit, et al., 2018.)

Wireless Data Transmission and Display

Wireless communication is the mode of information transfer between two nodes that are not connected physically. Wireless communication has many different types and protocols. The most common wireless communication used by many when it comes to developing wireless data transmission systems with Arduino is Radio Frequency. Radio Frequency can reach ranges of up to 100-250 meters with an antenna and can transmit data at a rate of up to 2 Mbps (Circuitrocks, 2021) . Among its advantages are its low power consumption during operation, versatility, and its low cost of equipment, which makes it perfect for indoor data transmission.

(Credo, 2019) used radio frequency for data transmission in his study titled "Wireless Power Consumption Monitoring and Data Logging System for SMEs: A Prototype System Development and Evaluation". A transmitter and a receiver device were designed in the study, which uses a one-way communication channel through radio frequency communication with the RF modules placed outside each of the enclosure boxes of the devices to minimize obstacles and for better signal transmission. The transmitter device is connected between the breaker and the electrical loads to monitor and gather data on power consumption. Data is then transmitted via RF and received by the receiver device, which is connected to a PC or laptop which would serve as the monitor for the whole system. However, the design of the system's operation only allows a one-way channel communication, which does not support the receiver device sending commands and data to the transmitter device. In addition, the system needs the assistance of an external computer in order to perform sorting, data-logging and can only display the measured power consumption through the connected computer. Despite being able to successfully measure and perform data logging of the power consumption of SME (small and medium-sized enterprises), the system's effectiveness is limited to just being able to measure the power consumption of SME establishments entirely and not the per-individual power consumption.

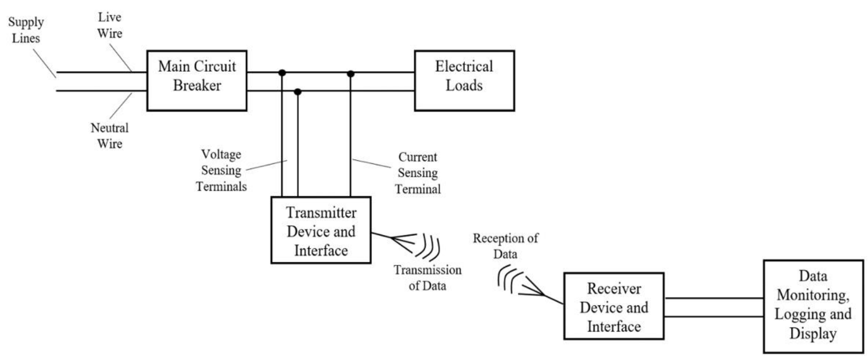

Figure 4. Schematic Diagram of the Wireless Power Consumption Monitoring and Data Logging System. (Source: Credo, 2019.)

The NRF24L01 Transceiver module is the most popular radio frequency communication module used in many microcontroller-based home automation systems as it has the capabilities of sending and receiving data, supporting two-way communication. The NRF24L01 is capable of operation using carrier frequencies from 2.400 GHz to 2.525 GHz, divided into 126 RF channels. The breakout board has another advantage in terms of size over the other wireless solutions, as it only has a size of 34mm X 17mm and it can also actively listen to up to 6 devices, so creating a wireless network with more devices with the NRF24L01 is possible (Circuitrocks, 2021). The module uses SPI to communicate with the microprocessor and operates at 3.3 Volts logic and is also 5 Volts compatible. But working with the RF communication protocol comes with several problems and factors that may affect the communication. Such factors are signal interruptions with the environment due to other devices that operate on radio frequency protocols such as WIFI, Bluetooth, etc. and unreliable data transmission due to loss of data packets to the environment. To prevent eventual electromagnetic interference with foreign RF networks operating in the same ISM band, it is appropriate to use carrier frequencies above the value of 2.5 GHz (Babusiak, et al., 2019).

(Zinner, 2014) in his study titled "Remote Power Meter" incorporated the use of the NRF24LO1 module for wireless data transmission. The SSD1306 OLED was used in the study to display the menus and the power consumption data rather than the commonly used TC1602A-01T, which is a 16x2 Character LCD display. The LCD display has eight wire connections for communication, and the number of pins utilized can be lowered by utilizing an LCD driving IC, but this would necessitate the employment of additional hardware and the sacrifice of more space. If there is low visibility, a rear light is required since the contrast is insufficient to be readable without one. In addition, the LCD display draws as much as 150mA of current when operating. The OLED display, on the other hand, does not require a backlight because the contrast is strong enough to make it viewable even in dim lighting. It has the advantage of being considerably smaller than the LCD display, and it can display a lot more information (16x8 characters). It also has a current draw of 30mA and can communicate with the microcontroller through UART, I2C, and SPI communication protocols. The OLED display is prone to suffering long-term image retention (‘burn-in’) under extreme conditions, and the potential risk of burn-ins makes the OLED display a poor candidate for digital signages (Thornton, 2017). However, if its application is on indoor embedded systems and devices, then it is a viable solution. OLEDs also have a limited lifetime, which was quite a problem a few years ago. But there has been constant progress, and today this is almost a non-issue (Chen, et al., 2012).

A study by (Indra, et al., 2018), demonstrated a Smart Energy Meter that utilizes the use of an Arduino UNO as its main microcontroller and a Global System for Mobile Communications (GSM) module to allow the user to communicate with the system and monitor their current power consumption anytime from anywhere via Short Message Services (SMS) by using their mobile phone. A Real-Time Clock (DS1307) was used to get the real-time count and also served as a time reference to reset the counter every month. The data of the electricity consumption is displayed on an LCD display and is stored through the use of an electrically erasable programmable read-only memory (EEPROM). The use of transmitting and accessing data through mobile phone SMS proves to be a more practical solution in areas where there is no favorable internet connection. Especially in the Philippines, where the telecommunication infrastructure remains underdeveloped in most areas, as the number of cell towers is far less than that of its neighboring countries. The Internet of things (IoT) is one of the networking technologies that the Philippine youth expects to have a great impact on their lives in the future (Microsoft Philippines PR Team, 2017). However, (Estella & Löffelholz, 2019) stated in their study that six out of 10 Filipino respondents felt that the country was "not ready to adapt to digital disruptions". (Chiu, et al., 2016) even pointed out that the country’s internet speed has become a source of daily frustration for Filipinos doing online activities such as downloading, sending emails, and quick online transactions. And the internet connection is only available and centered in cities, and it is difficult if not impossible to try and get an internet connection when traveling to suburban areas. In 2015, the Philippines ranked 104th out of 144 qualifying countries worldwide, and 13th out of 15 Asia Pacific countries, with an average internet speed of 2.8 Mbps (Salac & Kim, 2016). Meaning that, in terms of internet connection speed, the Philippines is among the countries with the lowest. And in terms of cost, the updated average price per month for internet connection in the country, with an average speed of 60 Mbps, is USD 47.15 (PHP 2,253) according to (Moneymax, 2021). Which is very expensive for the majority of Filipinos to afford. Hence, the use of SMS to send information and notification messages from the system to the user is the preferred choice with regards to the conditions and communications signal quality in the Philippines.

Individualized Power Management System

In recent years, there has been a growing interest in home energy management systems (HEMSs), which allow monitoring and control of power use in residential homes. And smart energy control systems have been increasingly implemented in the smart home scenario due to the possibility of conditioning and controlling residential energy consumption to reduce energy losses and unnecessary electricity consumption (Andrade, et al., 2020). The attempt to measure individualized power consumption started by integrating the assistance of Smart Energy Control Systems (SECS), Smart outlets (SO), and User Indoor Identification (UII). But the effort resulted in a massive implementation of sensors throughout the residence, misinterpretation of the data generated by the residents, and difficulty in the identification of multiple residents. And thus, measuring the electric power consumption of an individual in a home residence remains to be resolved.

In a study by (Kondo & Takami, 2018), a system design was proposed to manage the power consumption of an individual user. The target environment of the proposed system of the study is shared houses: rental establishments with shared spaces that have separate private rooms. The proposed system is designed to be connected to home appliances via a wireless network and monitor the state of power consumption and allow the user to control the power remotely or automatically. The system requires each resident to carry a Bluetooth Low Energy (BLE) tag all the time. With the use of the BLE tag, the system identifies the person who has used the home appliances per outlet. Personal outlets were developed by inserting a smart outlet between an ordinary outlet and a home appliance. By doing so, it becomes possible to monitor the power consumption of the home appliance, and remotely control the power of the appliance on and off. The measured power consumption data is then fed to an app on a smartphone or PC to display the current or past power consumption. However, when two users or several people are using an outlet at the same time, the smart meter can not measure the power consumed by an individual for the reason that the meter can only measure the power consumption per outlet. This poses a complication in identifying the power user, as the user has to be near the outlet when using it to be correctly identified by the system. The proposed smart meter in the study also does not come with a backup power circuit since the smart meter forwards data about the measured power consumption every second in real-time via Bluetooth to the smartphone application designed for the system, and thus the addition of a backup power circuit is irrelevant. The recommendation of the proponents emphasizes the development of a room entry monitoring system to be added to the individualized electric power management system to prevent failures in the identification of the power user at personal outlets while power is used. A possible solution to the problem is having multiple flexible semi-personal outlets around the establishment where each user can use an outlet exclusively and also use more than one outlet if no one is using it. This way, users can still access any outlet within the establishment and the system can successfully identify the power user and perform measurement and monitoring.

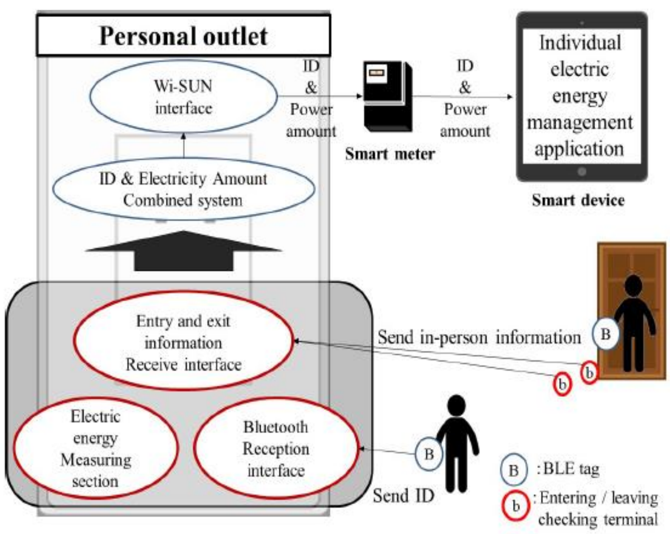

Figure 5. Individualized Electric power management system conceptual diagram. (Source: Kondo & Takami (2018))

Chapter 3

Methodology

Purpose of the Study

The development of an individualized power monitoring system is built upon the goal of measuring the power consumption of an individual in boarding houses and shared houses, sorting and saving each individual's power consumption data, and notifying the registered users of their power consumption at the end of each month or on the billing date. With those as the primary goals, other features were also considered during the planning and design of the system to be added to further improve its performance and usability. Taking into account the Power Surge protection feature to prevent damage to the load devices during the occurrence of electric power surges in the grid. An additional uninterrupted power supply circuit is also added into the system to prevent data loss, allow proper data saving into memory, and ensure proper operation of the system in unprecedented power loss scenarios. And a Self-Switching feature even without manual supervision for energy efficiency.

The system will utilize the use of SMS messages for the notification of the registered users of their respective power consumption. The internet connection in the Philippines is sluggish compared to the other countries implementing IoT-based systems in their home management systems. And while prepaid internet data signals can relatively support fair internet connectivity in urban communities, the majority of the country's inhabited locations still struggle in terms of internet signal reception. Not to mention the cost of internet connection data plans by local internet providers and the quality of the service provided that has earned quite a negative feedback. Hence, the use of SMS messages as the notification feature has been chosen for the study.

Methods

The progress flow on the development of the individualized power monitoring system is shown in Figure 6.

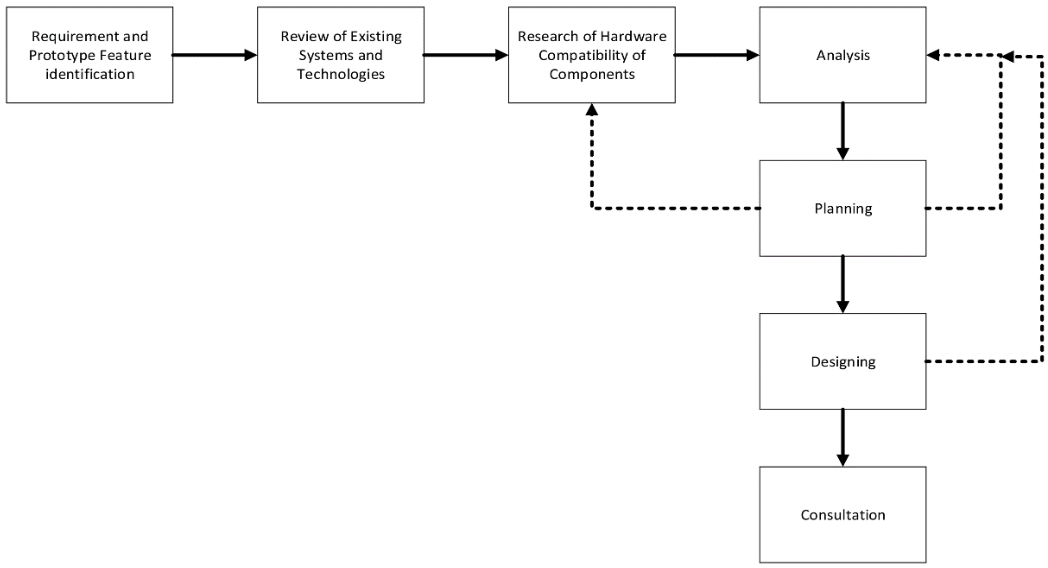

Figure 6. Block Diagram of the Flow of the Study

Upon deciding about the concept of the study to be focused on the development of a device to measure the power consumption of an individual, attention was directed into identifying what features would be included in the development of the system. The first stage was the requirement and prototype feature identification of the system in which all necessary system requirements were enumerated and defined. The defined requirements would play a huge role throughout the development of the system. Second is the Review of Existing Systems and Technologies where existing System Designs on Smart Energy Meters and Home Energy Management Systems were considered. It was thought thoroughly and decided that the new system is to be developed with two separate devices: one to where the user can register/unregister an individual, store and manage the data of power consumption, and send SMS notification (Main Unit) and one to measure power the power consumption as a customized AC outlet

(Meter Unit). The Research for Compatibility of Hardware Components follows with the Analysis stage where hardware requirement and information of every component to be used on the development of the system are gathered. The planning and designing stage follow accordingly, each of the component's configurations and connections is double-checked according to their specific information and further research and backtracking are done to ensure that each component will coordinate with other components of the system and not cause complications in the future stages of the development. And lastly, the consultation stage where the proposed design of the system undergoes review and correction by Field Experts and Knowledgeable Personnel.

Testing for the proposed power monitoring system in terms of Performance and Operation can be done by the experimental set-up of comparing the developed system alongside two more electric meters that are used for residential and industrial purposes. By testing such meters alongside the proposed design with the same electrical load and the same time frame, the performance of the proposed design could be assessed and identified if it performed better or worse than the other electric power meters.

And the energy efficiency of the prototype can be measured by how much total current it draws from the AC source during the span of the operation. (Equation 1) shows how the power consumption of the proposed system (Pps) can be calculated: by subtracting the Total Power Consumption Data recorded by the Proposed System in kilowatt-hours (TPps) from the Measured Power Consumption of the Building's Main Electric Meter in kilowatt-hours (Pb).

$$P_{ps} = P_b - TP_{ps}$$

Equation 1. Formula for the Power Consumption of the proposed system.

System design

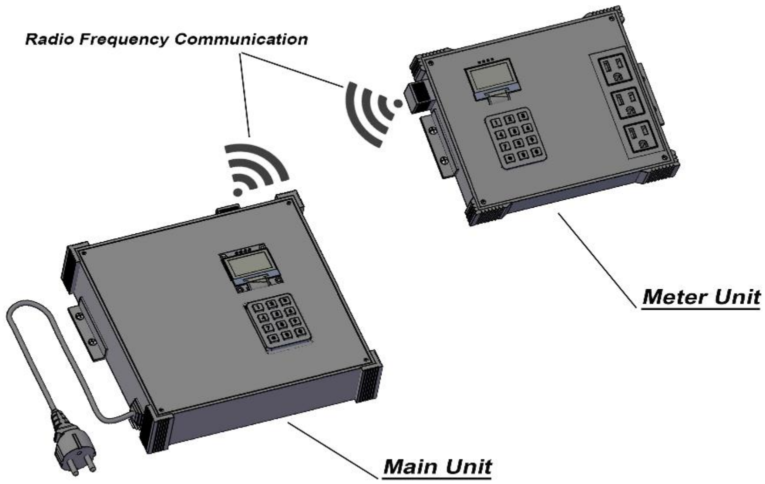

Figure 7. Perspective View of the System.

Figure 7 shows the perspective design of the system. The system is composed of two main devices: the Main Unit and the Meter Unit. The Main Unit acts as the Master device and performs the functions of registering/editing user contact information, real-time keeping, SMS message notification, and sorting and storage of Power Consumption data of each registered user. While the Meter Unit controls the access to AC Power and measures the power consumption of the user, in which calculated data is then sent to the Main Unit for sorting and storage in memory. Each device possesses an Arduino microcontroller serving as the main processing unit with the Main Unit having an Arduino Mega and Arduino Nano for the Meter Unit. Data of registered users are sent from the Main Unit to the Meter Unit as well as Data for the Calculated Power Consumption in vice versa through the Wireless RF communication between the two devices. The system will utilize the NRF24L01 transceiver module for the wireless data transmission between the Main Unit and the Meter Unit.

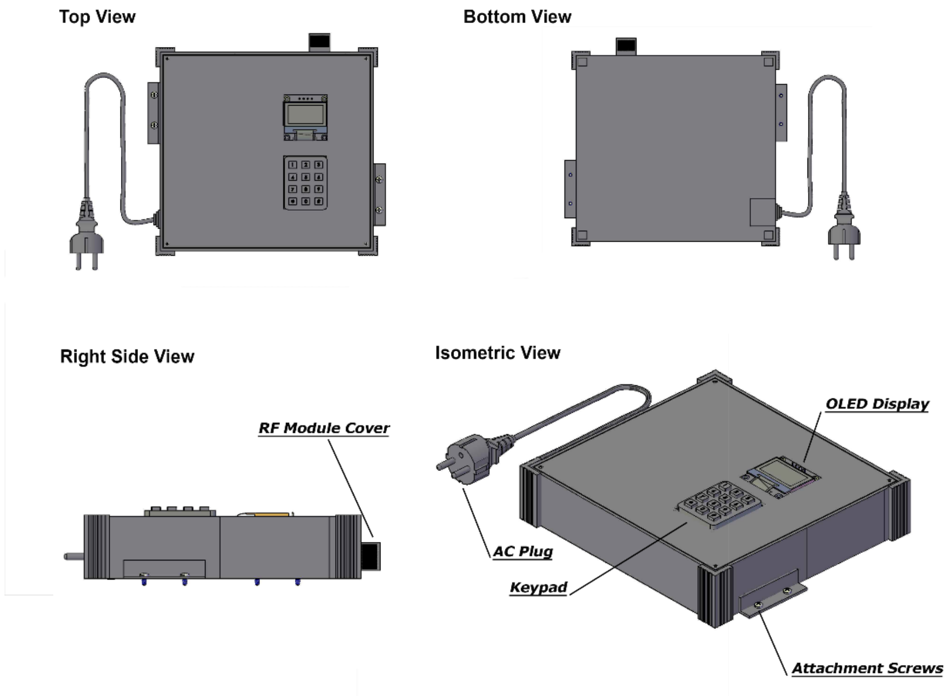

Figure 8. Design of the Main Unit.

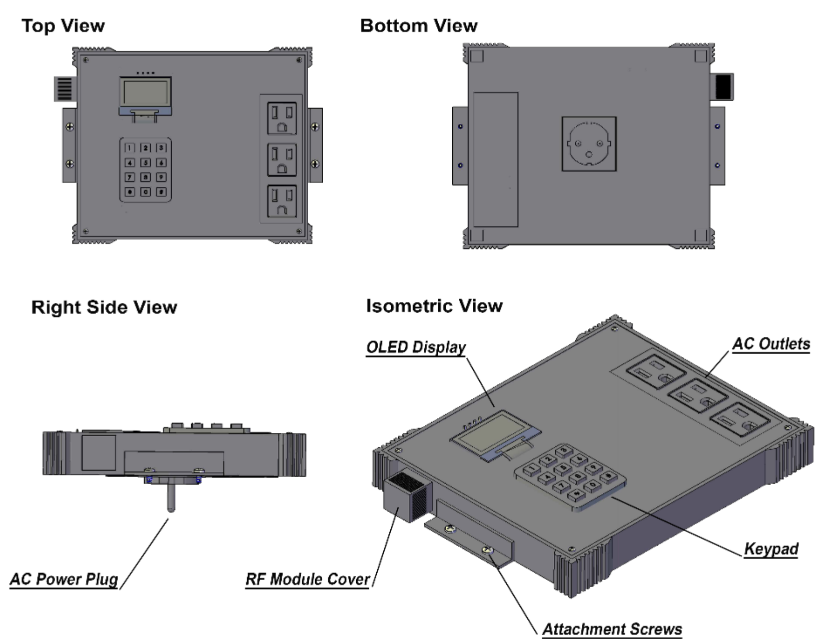

Figure 9. Design of the Meter Unit.

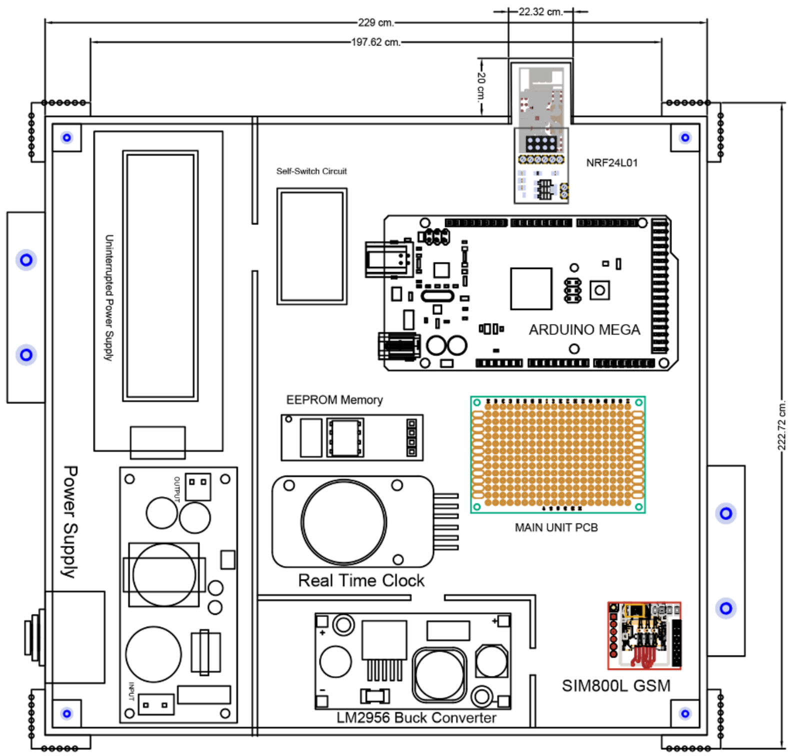

Figure 10. Internal Layout Design of the Main Unit.

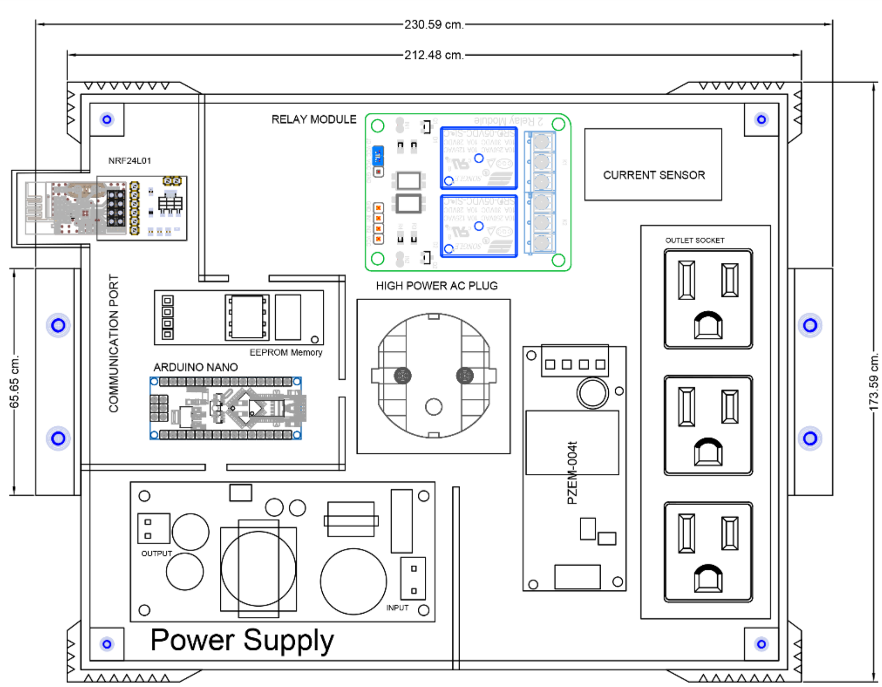

Figure 11. Internal Layout Design of the Meter Unit.

The NRF24L01 can only support up to 6 devices, but it is possible to create a wireless network that could support many more devices. By utilizing the RF24Network Library, we can build an Arduino wireless network with many boards communicating with each other at the same time (Dejan, 2018). This functionality is exploited by the RF24Network library to construct a network organized in a tree topology, where one node is the base, and all other nodes are children of either that node or of another. Each node can have up to 5 children, and this can continue 5 levels deep, which means it's possible to form a network of total 3125 nodes.

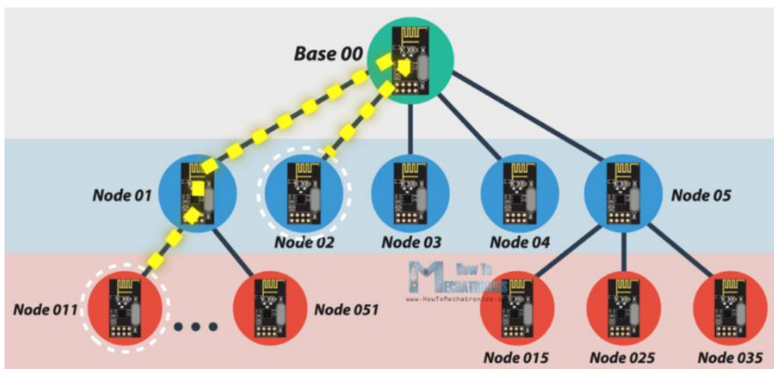

Figure 12. Wireless Tree Network Topology. (Source: Dejan, 2018.)

By implementing the use of this network topology, the wireless communication of the system can be increased and the connection extended to every corner of the establishment. The main unit will be the base device of the wireless network and support multiple meter units and therefore receive the calculated power consumption data from these units.

Block Diagram of the System

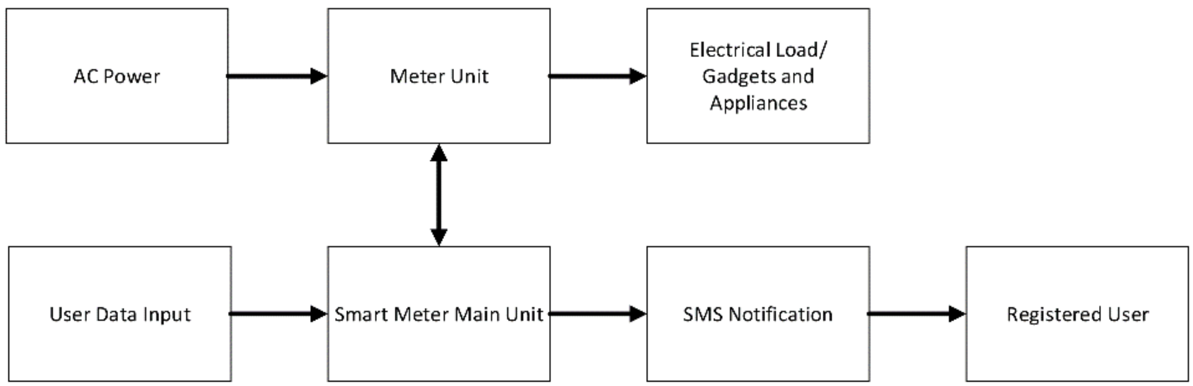

Figure 13. Block Diagram of the System.

Figure 13 shows the block diagram of the proposed system. The system starts by gathering data on the user input from the administrator/operator of the system (landlord/landlady). This stage is where the billing date is set, input/editing of the user phone number, and the passcode is assigned. Inputs on such information are needed in order for the system to send notification messages at the exact date even without manual intervention and supervision. The Main Unit executes commands to update the memory list of the Meter Unit after changes are made. AC Electric Power can be accessed by the registered users through the Meter Unit by entering their assigned passcode generated by the system. The meter unit then validates their input and allows access to AC electric power through the outlet terminal of the device and starts measuring the power consumption of the connected electrical load (Gadgets/Appliances). The power consumption data is then sent to the Main Unit through wireless RF Communication where it is sorted, incremented to the specified user’s previous Power Consumption Data, and saved into memory. The main Unit acts as a Master device over the meter unit and accepts data from other meter units. By the time of the month the billing date was set, the Main Unit will send a message to each registered user’s phone number notifying them of their Power Consumption expressed in kilowatt-hours. Table 1 shows the function of the two main components of the system.

Table 1. Functions of System Components.

System Component	Functions and Capabilities
Main Unit	▪ It accepts input data from the administrator for the billing date and has the function to add, modify, and update the list of registered users; ▪ Responsible for sending SMS notifications to the registered users; ▪ Read, sort and store the power consumption data of each user; ▪ It allows the administrator access to view the power consumption of every user.
Meter Unit	▪ Validate and allow access to AC power; ▪ It measures the power consumption and other electrical parameters and displays them in real time; ▪ Communicate and send power consumption data to the main unit.

Architectural design

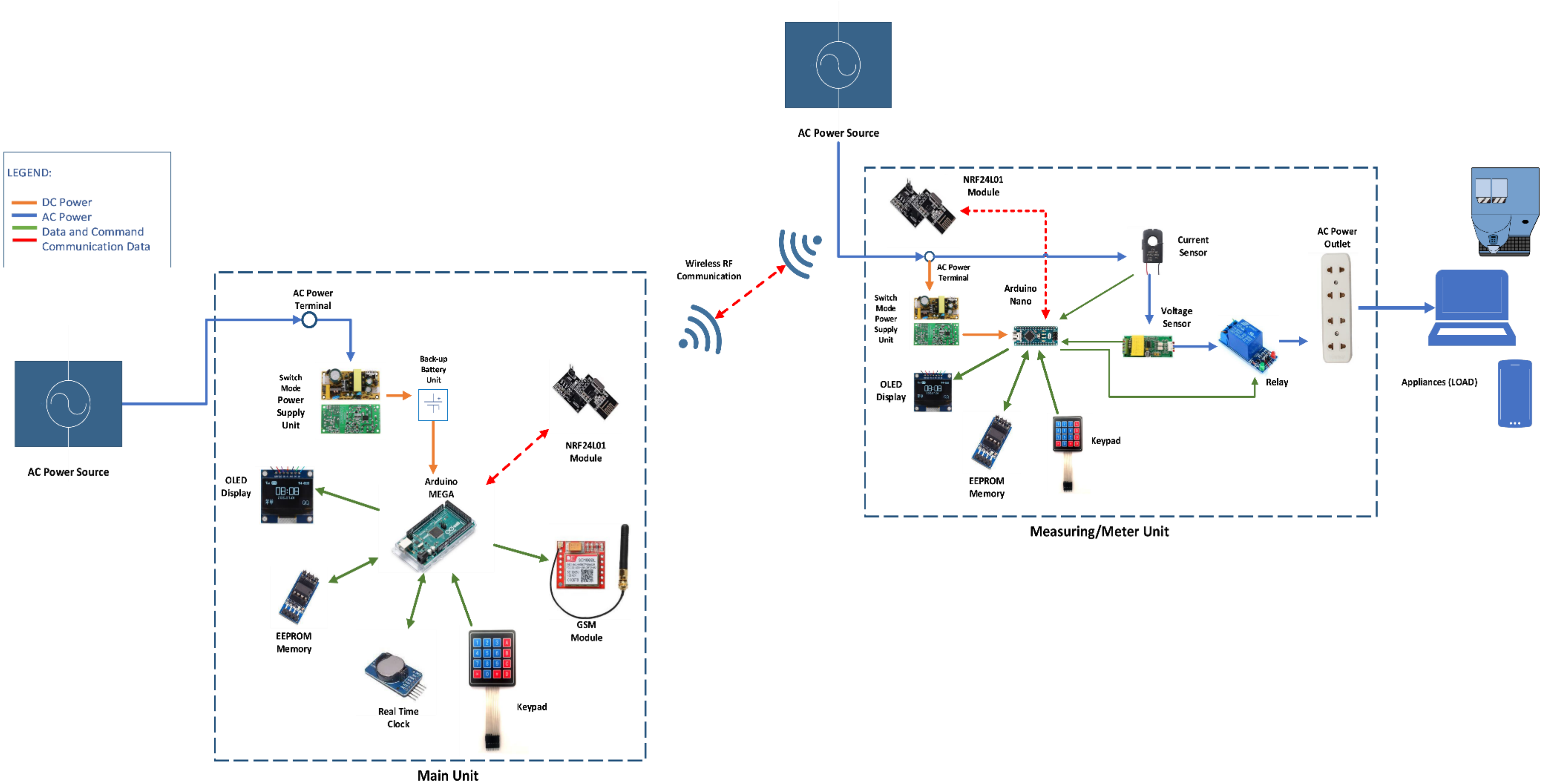

Figure 14. Architectural Design of the System.

Figure 14 shows the Architectural Design of the system. The arrows in the diagram represent pathways and connections of the components which are color-coded according to their type and intended function in the system. The arrows pointing to/from determine whether the components are inputs/outputs. The two devices of the system are also isolated with each having a box with a dashed line to indicate that they are two separate devices.

The Main unit of the system is powered using AC Electricity channeled through a Switch Mode Power Supply to convert into DC which is then channeled through the Back-up battery circuit component which is utilized as an Uninterrupted Power Supply feature of the System. This then powers the Arduino Mega and all the other components in the Main Unit of the system. The OLED display provides visual and graphical interaction with the user as the keypad is used to input information into the Main Unit and the EEPROM Memory saves the data updates and changes that are done. The Real-Time Clock serves as a time reference for monitoring the date and time of the month in order for the Main unit to determine whether it is time to send messages of power consumption to each registered user. And the SIM800L GSM Module is used as a peripheral for sending SMS messages.

The Meter unit of the System communicates to the Main unit via Wireless Radio Frequency network purpose of sending/receiving data and commands from the Main Unit. The Meter unit has its own Switch-Mode Power Supply and it gets its power from a parallel connection from its AC Plug connected to the AC source, which is then connected in series to the outlet socket of the Meter Unit. This connection is channeled through the current and voltage sensor and then to a single-channel relay before it ends in the outlet of the Meter Unit. In this way, the meter unit can measure the power consumption of the load as well as have control over the connection and only permit registered users to access electricity. The keypad and OLED Display of the Meter Unit provides interaction when the user inputs data. The proposed system design allows the maximum number of 3 electrical loads to be connected to the meter unit as shown in Figure 9.

Procedural design

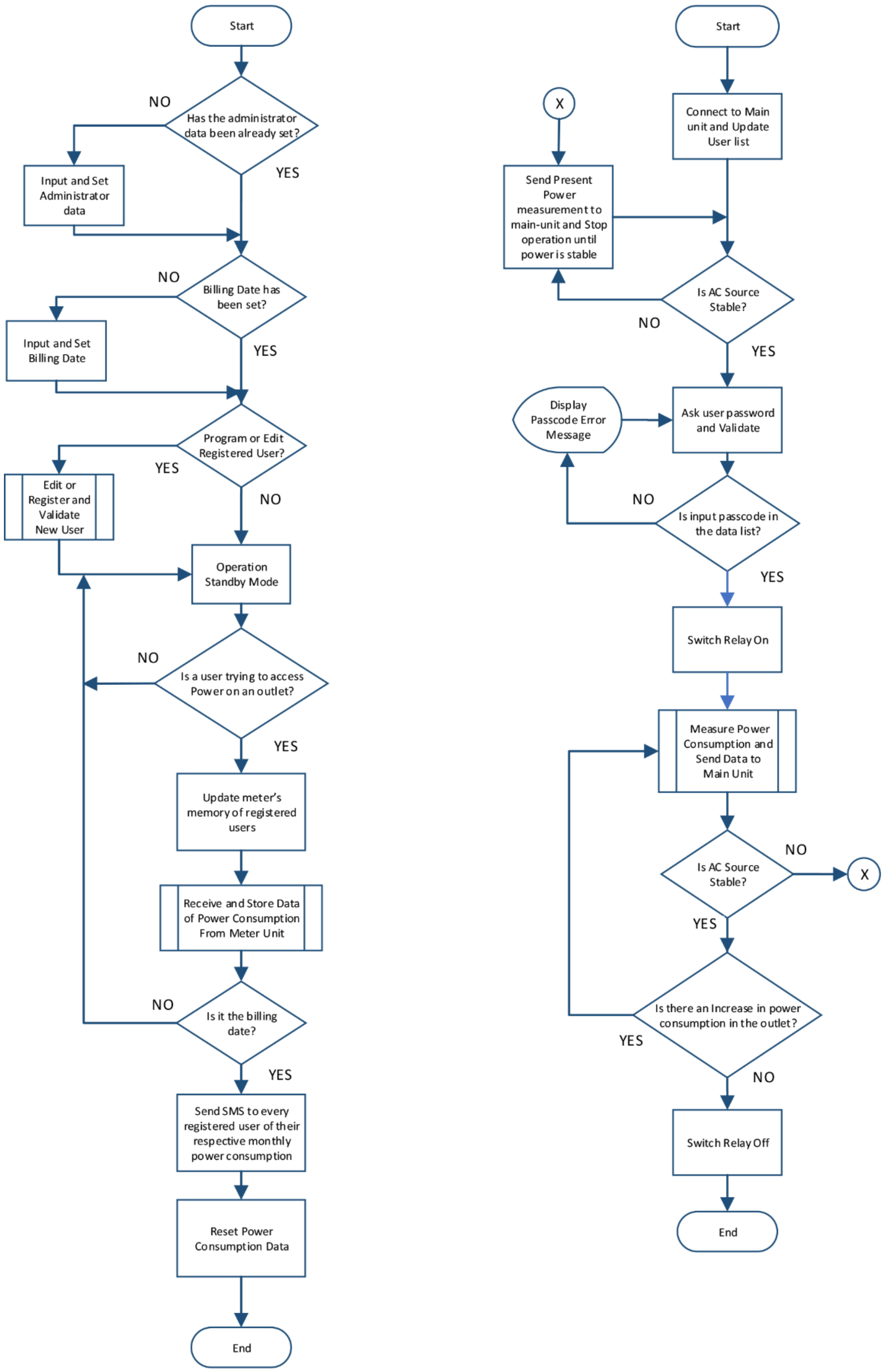

Figure 15. Procedural Design of the Main Unit (Left) and the Meter Unit (Right).

Figure 15 shows the flowchart of processes of the Main Unit and the Meter Unit. Both are part of the same system but have different functions and processes. The main reason why the system is designed with two separate devices is to divide the tasks and function of the system and not rely on only one microcontroller to do the processing. The power consumption measuring process needs to be uninterrupted during operation and so making a customized meter to do the measurement is a fair choice presented that there is also a need for more power outlets in the environment.

Upon powering the system for the first time, the Main Unit would ask for the administrator data. This data would be used to grant administrator access to the Main Unit that would allow for the modification of registered user's data, modification of the Billing date, and allow the user to view the present power consumption of each registered individual. But the data on the Power Consumption is strictly off-limits to anyone and not even the administrator can edit the stored data. The Main unit will then ask for the billing date if it has not been set, the inputted date would then be the reference date on when messages to notify the registered user are needed to be sent. The program will then prompt an option to register/edit the list of the registered user. If the user wanted to make a modification to the user list, the program will ask for the contact number of the user, generate a unique passcode for the new user, and sent it via SMS message for confidentiality. If a user wants to change the passcode, then the administrator would simply delete the user's present data and re-enter the user's contact number and a new passcode shall be generated and given. In the instance that a user will be delisted off the system, his/her power consumption data would also be deleted. At first-time set-up, the main unit will update all the connected meter unit's memory with the list of the registered users in the system by executing a command that would clear the memory contents of the meter unit and then load the updated list. This procedure would only be performed by the system if any changes are done by the administrator to the list of registered users. The Main Unit would then receive data of Calculated power consumption and user data from the meter unit when someone accesses electricity. The received data would then be added to the total power consumption of the designated user and stored in the memory of the Main Unit. The reference billing date will be checked daily in order for the system to decide whether it is time to send the SMS notification messages. And when it is the day for the billing date, an SMS notification will be sent to each registered user and their Total Power Consumption for the month will be reset.

The Meter Unit when powered on will communicate with the Main Unit upon first boot up and receive the list of the registered user, which will be then stored to the Meter Unit's own EEPROM Memory. The Meter Unit will monitor the quality of power on the AC line and prevent access to the user if the Power is unstable, this is to prevent devices and appliances from damages caused by Voltage Fluctuation and Power Surges. If the power from the AC line is assessed to be stable, the Meter Unit will ask for passcode input. The program then validates the input and if the passcode is on the memory, the control relay will be switched on and the Power measuring and calculation process will follow. If the input is not within the list of passcodes, then an Error message will be displayed on the OLED Display. The Meter Unit will continue to monitor the quality of power on the AC line while executing the power measuring process and sending data to the main unit at the same time. If ever the power on the AC line becomes unstable, the control relay is triggered off and access to electricity will be cut off and only be continued when the power becomes stable.

Table 2. Account types and their Access and Permissions

Account type	Access and Permissions
Administrator (Landlord/Owner)	▪ Modify and Edit the List of Users; ▪ Can access both the Meter and Main unit; ▪ The account is excluded from the power consumption monitoring; ▪ Can view the power consumption data of every registered user; ▪ Will receive an SMS message about the power consumption of every registered user; ▪ Cannot modify and change power consumption data in the system's memory.

User (boarder/tenant)	▪ Can only access the meter unit; ▪ Will only receive SMS messages about his/her own power consumption. ▪ Cannot modify and change power consumption data in the system's memory.

Table 2 shows the two types of accounts in the system. The administrator account is given to the landlord/owner and has the authority to modify and edit the list of registered users in the system. The administrator account also has access to both the meter and the main unit and is also excluded from the power consumption monitoring. The administrator can view the present power consumption of each registered user through the main unit and also receive SMS messages containing information about their individualized power consumption. The user account is to be owned by the boarders/tenants and can only access and use the meter unit of the system. The user account will also only receive an SMS message notification that is all about his/her own power consumption. In this way, the confidentiality of the user's data is protected. Both the administrator and the user account are prohibited and are not given the option to modify the power consumption data that is stored in the memory of the system. This is a preventive measure to avoid fraud and tampering with the system in order to maintain its functionality.

Hardware Compatibility and Configuration

Table 3. Materials and Components of the System.

▪ Arduino Mega 2560	▪ Keypad
▪ Arduino Nano	▪ AT24C256 EEPROM Memory Module
▪ AC-DC 5V Switching Power Supply Module	▪ Real Time Clock
▪ ESP32S Charger Board 18650 Battery Charging Shield with battery	▪ AC Plug
▪ PZEM-004TAC Voltage and Current Sensor	▪ AC Outlet
▪ Monochrome-OLED-display	▪ Single Channel Relay Module
▪ LM2956 Buck Converter	▪ Jumper Wires
▪ Sim800L GSM module	▪ N-channel MOSFET
▪ Connecting Wires	▪ PNP Transistor
▪ PCB	▪ Stranded Wires
▪ 100k and 330k Resistor	
▪ NRF24L01 module and adapter	

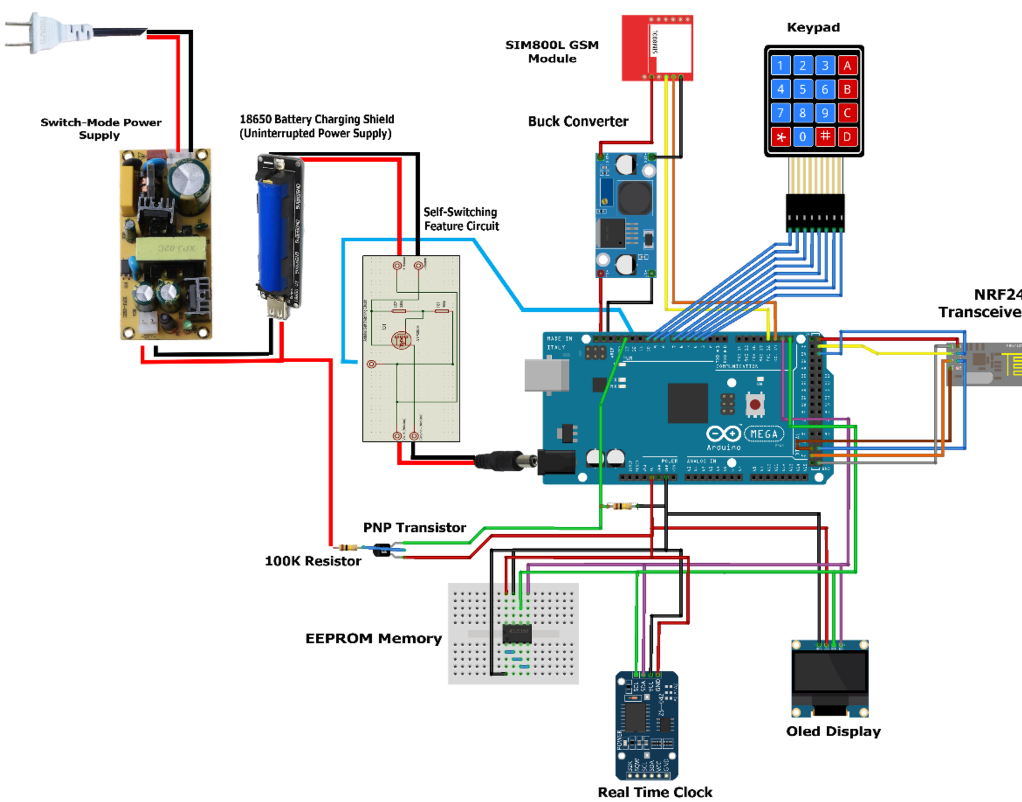

Figure 16. Pictorial Circuit Diagram of the Main Meter.

Table 3 shows the list of materials and components to be used in the fabrication of the system. Figure 16 shows the pictorial circuit diagram of the Main Unit of the system. A Switch-mode power supply module is used to convert AC into DC in order to power the Arduino and the components of the main system. A switch-mode power supply is used for its efficiency over Linear type power supply and because switch mode type power supply does not generate too much heat, unlike the linear type. A Battery charging shield circuit is utilized for the UPS circuit and is connected in series with the power supply. The battery charging shield is commonly used by micro-computers like the raspberry pi as an uninterrupted power supply and its application is integrated into this study for its capabilities to act as backup power in an occurrence of power loss. Another circuit is connected in series to the connection before the Arduino for self-switching purposes. This circuit is composed of a P-channel MOSFET and two resistors, and one pin or the Arduino mega is connected to this circuit to turn the power on and off from the Arduino code.

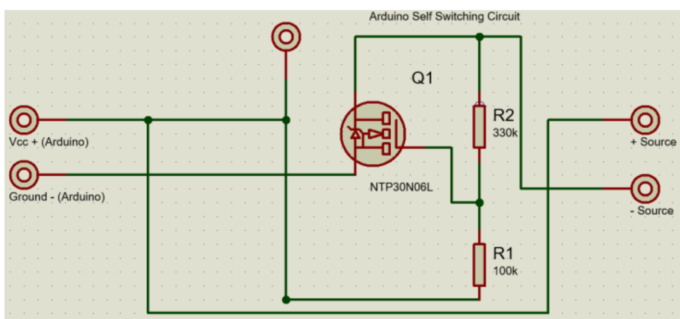

Figure 17. Self-switching Circuit Schematic.

A PNP type transistor is connected in parallel between the Power Supply and the UPS circuit as a sensor in order for the Arduino Mega to determine if the power supply still powers the system. In this way, the main unit can determine if there has been a power loss or a brownout and save the calculated power consumption data into the memory and safely turn off the system power using the self-switching circuit. The EEPROM, Real-Time Clock, and the OLED Display are connected to the Arduino Mega by means of the I2C communication protocol, which provides good support for slow devices and only uses two wires for communication. Each of the devices that are connected via the I2C communication protocol will have a unique address in which the microcontroller can assign when sending data and executing commands. The I2C communication protocol has been chosen as the means for communication of the Arduino Mega and the peripheral components of the Main Unit due to the reason that it only good for short-distance communication. The keypad is connected to the digital pins (pins 3 to 10) of the microcontroller and a Buck Converter is used in series to the SIM800L GSM Module to lower the 5-volt supply from the Arduino Mega down to 4.1 volts. This is due to the reason that the SIM800L module does not come with an onboard voltage regulator, and the recommended ideal voltage requirement of the module is between 3.4V to 4.4V (Ideal 4.1V). The SIM800L module is connected to the data pins (RX/TX), which are Pins 18 & 19, of the Arduino Mega. The NRF24L01 RF module is connected to the Arduino Mega by the SPI (serial peripheral interphase) communication pins, this is because the module only supports the SPI communications. The module is connected to the other 5-volt pin and ground pin of the microcontroller on the left side of the board to utilize maximum space and capacity of the Arduino Mega.

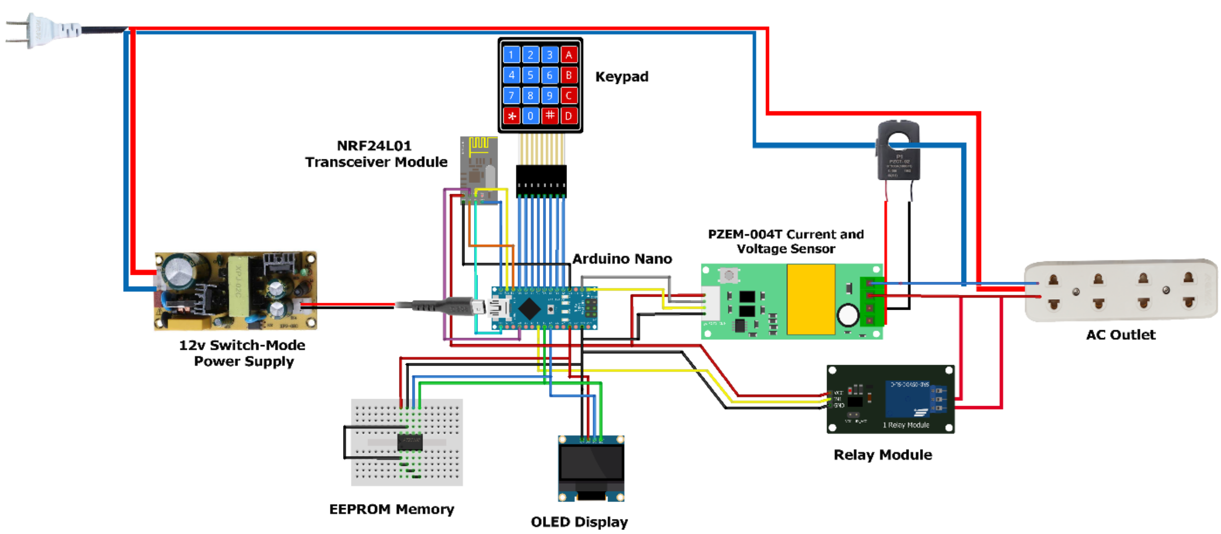

Figure 18. Pictorial Circuit Diagram of the Meter Unit.

Figure 18 shows the pictorial circuit diagram of the Meter Unit of the system. A Switch-Mode power supply module is used to power the Arduino Nano and the peripheral devices of the Meter Unit.

The keypad is connected to the digital pins of the Arduino Nano (pins 2 to 9) to be used for user input. And the EEPROM memory and OLED Display are powered through the 5 volts and ground pin of the Arduino Nano, with both connected to the microcontroller by the I2C communication protocol. The PZEM-004T current and voltage sensor is connected in parallel to the AC power line to measure the electric parameters on the power line. The PZEM-004T current and voltage sensor can measure the voltage, current, power, energy, frequency, and power factor on an AC Power line and can communicate with microcontrollers like Arduino and ESP8266. Which makes it suitable to be used for the programmable single-phase smart meter system. The PZEM-004T is connected to the serial data pins (pins 0 and 1) of the Arduino Nano. By reading the electrical parameters in the AC power line, the program of the Meter Unit can the power consumption of the electrical load connected to the outlet and also assess the quality of power in the AC power line and determine whether the power in the AC line is stable or not. A single channel relay is connected in series with the AC power line and acts as a control switch that allows the microcontroller of the Meter unit to open and close the AC circuit. The single-channel relay is powered through the Arduino Nano and its control pin is connected to one of the analog pins of the microcontroller. An AC outlet with multiple sockets is connected at the end of the AC Power line for the electric loads and appliances to be connected and have access to the AC electric power. The NRF24L01 used for communication of the Meter unit is connected to the SPI pins (pins 10, 11,12, and 13) of the Arduino Nano and is powered through the 5v pin of the microcontroller board. The RF module of the meter unit is configured as a slave device in this wire configuration, with the Microcontroller of the Meter unit being the master device.

Time Frame of Development and Implementation the Study

	Months									
	1	2	3	4	5	6	7	8	9	10
Planning, Designing and Consultation										
Purchasing of Materials										
Testing of Materials										
Fabrication of the System										
Coding										
Coordinating the Code and System										
System Error Troubleshooting										
System Implementation and Operation										
Data Gathering and Conclusion Fabrication										