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IOT BASED SYSTEM FOR MONITORING AND CONTROLLING OF ELECTRICAL ENERGY FOR LEATHER INDUSTRY A CASE STUDY IN KENYA

Joseph Muriu Kiguta

A Project Report Submitted in Partial Fulfillment of the Requirements of the Award the Degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology

Arusha, Tanzania

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ABSTRACT

Nowadays, most industries receive large energy consumption sheets daily, making it challenging to monitor and control energy consumption. This suggests a need for the development of an energy monitoring system to help observe the energy consumption behavior and be able to make timely corrections in energy consumption. Therefore, this project aimed to develop the electronic prototype of the monitoring and control system from an application for a cell phone with an Android system. The energy monitoring system could help in saving precious non-renewable sources. This project employed the agile methodology to allow for system requirements and analysis, system development, system implementation, integration, and testing. The information was acquired using energy consumption sensors and analyzed based on statistical tables stored in the cloud, for four days. The sensors communicate via a wireless network that operates on the 2.4GHz frequency, where the NRF 24 L01 + transceiver was used. Moreover, a Raspberry pi Zero was utilized for the configuration of the central node, and this was responsible for the collection of the information gathered in the sensors and publishing it in the cloud every hour. For the android system-based application, the data was collected graphically. Lastly, the developed system also produces real-time consumption data, which were then analyzed to identify the devices with the highest consumption level relative to the total number of devices. The information gained after the analysis of the data was also useful in identifying any damaged equipment or machine. The damaged equipment and machine portrayed different behaviors (they appear to be outliers) in their energy consumption when compared to undamaged ones.

DECLARATION

I, Joseph Mirui Kiguta, do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this project report is my original work and that it has neither been submitted nor being concurrently submitted for a degree award in any other institution.

Joseph Muriu Kiguta		25.07.2022
Name of Candidate	**Signature**	**Date**

The above declaration is confirmed by:

Dr. Judith Leo		11.08.2022
Name of Supervisor 1	**Signature**	**Date**

Prof. Kisangiri Michael		11.08.2022
Name of Supervisor 2	**Signature**	**Date**

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Nelson Mandela African Institution of Science and Technology, a project report titled *"IoT" and machine learning-based system for monitoring and prediction of electrical energy for the leather industry in Kenya"* in partial fulfillment of the requirements for the degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology.

Dr. Judith Leo		11.08.2022
Name of Supervisor 1	**Signature**	**Date**

Prof. Kisangiri Michael		11.08.2022
Name of Supervisor 2	**Signature**	**Date**

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DEDICATION

This work is dedicated to my family, my wife Catherine, the support of my life, and my parents who with their words of encouragement have not let me faint from the beginning of my student life until today. that another achievement has been achieved at an academic and personal level, I have nothing left but to dedicate the present to it, that more than a challenge it has been a practically endless work, like wanting to reach the top of a mountain, many times you can no longer see the summit, it only remains to look at the feet and walk with the words of affection and encouragement of the people who surround us and love us.

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LIST OF ABBREVIATIONS AND SYMBOLS

AC	Alternating Current
ADC	Analog-Digital Converter
AES	Advanced Encryption Standard
AWS	Amazon Web Services
CRC	Cyclic Redundancy Check
CSV	Comma Seperated Values
DC	Direct Current
E	Energy
EPB	Electric Power Board
GPIO	General-Purpose Input/Output
GSM	Global System for Mobile communication
I	Current
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
IoE	Internet of Everything
IoT	Internet of Things
IP	Internet Protocol
ITU	International Telecommunication Union
J	Joules
KPLC	Kenya Power and Lighting Company
kwh	Kilowatt-Hour
LCD	Liquid-Crystal Display
m	Meters
MWSN	Mobile Wireless Sensor Network
P	Power
PC	Personal Computer
PCB	Printed Circuit board
PWM	Pulse Width Modulation
REST	Representative State Transfer of Type
RMS	Root Mean Square
SPI	Serial Protocol Interface
temp	Temperature
TKIP	Temporal Key Integrity Protocol
UMTS	Universal Mobile Telecommunications Service

USD	Universal Serial Bus
V	Voltage
VCC	Voltage Common Collector

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

As is public knowledge, energy is an essential resource for the development of its activities and the well-being of society. The generation of energy directly affects global warming, which in turn exposes human life to risk. Under this, two forms of energy control have been proposed; common sense, and the use of technology. In this paper, the later form of energy control is proposed for monitoring the consumption of electrical energy in industries and that the use of this is carried out more efficiently. Outlined below are some of the topics that have been used as a basis for the development of the current project.

Design and implementation of an electronic energy meter for housing with an orientation to the prevention of consumption and energy-saving. This project allows access to information on the reading of energy consumption either through a text message through a GSM module, as well as accessing the server information through a web interface, an Arduino board is used for data acquisition and a Raspberry pi for data storage, in which a database is managed (Minchala-Avila *et al.*, 2016).

Electronic monitoring and control system for the distribution of electrical energy in homes. This project uses a computer, or a mobile device connected to the same network, in the data acquisition stage, it uses a non-invasive current sensor, and to the voltage, a step-down transformer said information is processed on a data logger board, information acquired is displayed on an LCD screen (Noroña & Vásquez, 2017).

Landaluce *et al.* (2020) also posited that WSN contains many tiny sensor nodes that are deployed over a particular geographical area, also known as the sensing field. The sensor nodes are generally low-power devices that integrate computing, sensing capability, and wireless communication. The sensing nodes group themselves into networks and clusters and work together to perform the assigned energy monitoring and control functions, without human interventions (Landaluce *et al.*, 2020).

In the market, existing devices monitor energy consumption for industries and have a high cost. These devices monitor the power lines that originate in the distribution board, and in most cases, at an additional cost, present modules to monitor or control the intakes of two computers, the information is accessed through a web portal.

This project proposed a system that aimed to help in obtaining information from the monitoring of energy consumption obtained in real-time, which can be viewed from a PC, or a mobile device. Through analysis of the gathered data, the proposed system would help to identify if there is excessive consumption of (damaged) equipment. The analyzed data also helped track the amount of energy consumed at different time points, hence helping in determining the causes of extreme energy consumption. As a result, an appropriate plan would be implemented to optimize energy consumption. Additionally, using a machine learning algorithm helped in predicting future energy consumption.

1.2 Statement of the Problem

With the passage of time and technological advances, human beings are always looking for a way to facilitate their lifestyle. This has led to the development of new electrical and electronic devices. The devices, however, have increased the amount of energy consumed in the industrial environment.

It is also worth mentioning that in everyday life, most industries receive energy consumption sheets on monthly basis. It is until they find an alarming high energy consumption that they get curious about the causes of such energy hikes. For this reason, it is essential to develop an energy monitoring system to combat such problems.

The energy monitoring system would be a useful tool for industries because it can help them observe the energy consumption behavior graphically in real-time, as well as access the consumption history, from any device with internet access. This way, these industries would be able to locate anomalies in energy consumption and make timely corrections as soon as possible.

1.3 Rationale of the Project

As the industrial sector is progressing, it is apparent that energy consumption continues to increase (Aliero *et al.,* 2021). However, to control energy consumption, there is a need to minimize energy usage through the Internet of Things (IoT). According to Deebak and Al-Turjman (2020), IoT has a significant impact on the technical perspective as it provides the ability to transfer information over a network without the need for any kind of interaction. Thus, IoT technology plays a major role in enhancing the development of remote energy monitoring systems for energy-wastage control.

Moreover, the technological advancement in recent years has contributed to the increased use of wireless sensor networks, which are an essential technology for IoT. A wireless sensor network is effective in providing accurate evaluations, particularly in situations where human presence is impossible (Deebak & Al-Turjman, 2020). According to Alippi *et al.* (2009), WSNs consist of small size, low power, and low-cost sensors, which are used to remotely collect physical/environmental data. As such, they are essential in sensor networks as they help in regular monitoring and control of the environment, providing necessary request information, as well as providing a trigger when an unexpected event happens.

Various studies have been conducted on the development of energy monitoring systems based on wireless sensor networks (Dong *et al.*, 2010; Kim *et al.*, 2011; Shafique *et al.*, 2018). In particular, Dong *et al.* (2010) developed an energy monitoring system based on a wireless sensor network to control energy consumption in home-based buildings. They concluded that the developed system saved energy through the use of a cluster formation method that does not consume node energy.

Similarly, Kim *et al.* (2011) developed a system based on a wireless sensor network that aimed to save energy by allowing users to monitor and control home-based appliances using the web and mobile devices. Shafique *et al.* (2018) also designed a system based on a wireless sensor network, which also aimed to monitor and control domestic energy consumption. Based on these studies, it was evident that the developed systems are generally effective in monitoring and control of energy in the environment. However, these studies were inclined toward domestic conservation of energy without paying attention to energy management and control in the industries.

Thus, this Project was aimed to fill the gap by developing an IoT and Machine Learning based system to control and manage electrical energy in the industry context. In particular, this Project was aimed to develop remote energy monitoring systems that utilize IoT and machine learning algorithms to enhance the effectiveness of energy management and control. The system was based on wireless sensor networks that were developed for monitoring and prediction of electrical energy for the leather industry in Kenya. Thus, by developing the proposed system, energy monitoring based on the Internet of Things solution would be significant for the leather industry in Kenya.

1.4 Project Objectives

1.4.1 Main Objective

The main objective is to develop an IoT-based system for monitoring and control of electrical energy.

1.4.2 Specific Objectives

(i) To identify and collect requirements of the proposed system of an IoT and machine learning-based system for monitoring and prediction of electrical energy.

(ii) To develop the electronic prototype of the monitoring and control system from an application for a cell phone with an Android system to help in accessing and graphically viewing the consumption history.

(iii) To test and implement the developed system.

1.5 Project Questions

(i) What are the requirements for industrial energy monitoring systems based on IoT?

(ii) What are the design features for the development of a remote energy monitoring system based on a wireless sensor network?

(iii) Is the proposed remote energy monitoring system working as expected?

1.6 Significance of the Project

Generally, industry managers need to stay updated with the information on how electrical energy is being used in the industry (Sakya, 2020). Besides, the existing procedures and tools used by the electric power company in Kenya, control and management of the usage of electrical energy have been a big challenge. In particular, the available tools and procedures have not been efficient in reading the current and voltage, calculating the real power, power factor, and apparent power in the industries. Additionally, the information has been sometimes unavailable to regular electrical energy consumers.

Therefore, this Project was aimed to solve the existing problem by developing a Remote Energy Monitoring System based on a wireless sensor network. Thus, by the end of the project, we would be able to come up with an energy monitoring based on the Internet of Things solution that would be helpful to industries and more so the leather sector. It was anticipated that the system would be advantageous in that it would be easy to install, easy to use, and reliable in providing up-to-date information. Figure 1 is a visualization of how the system works:

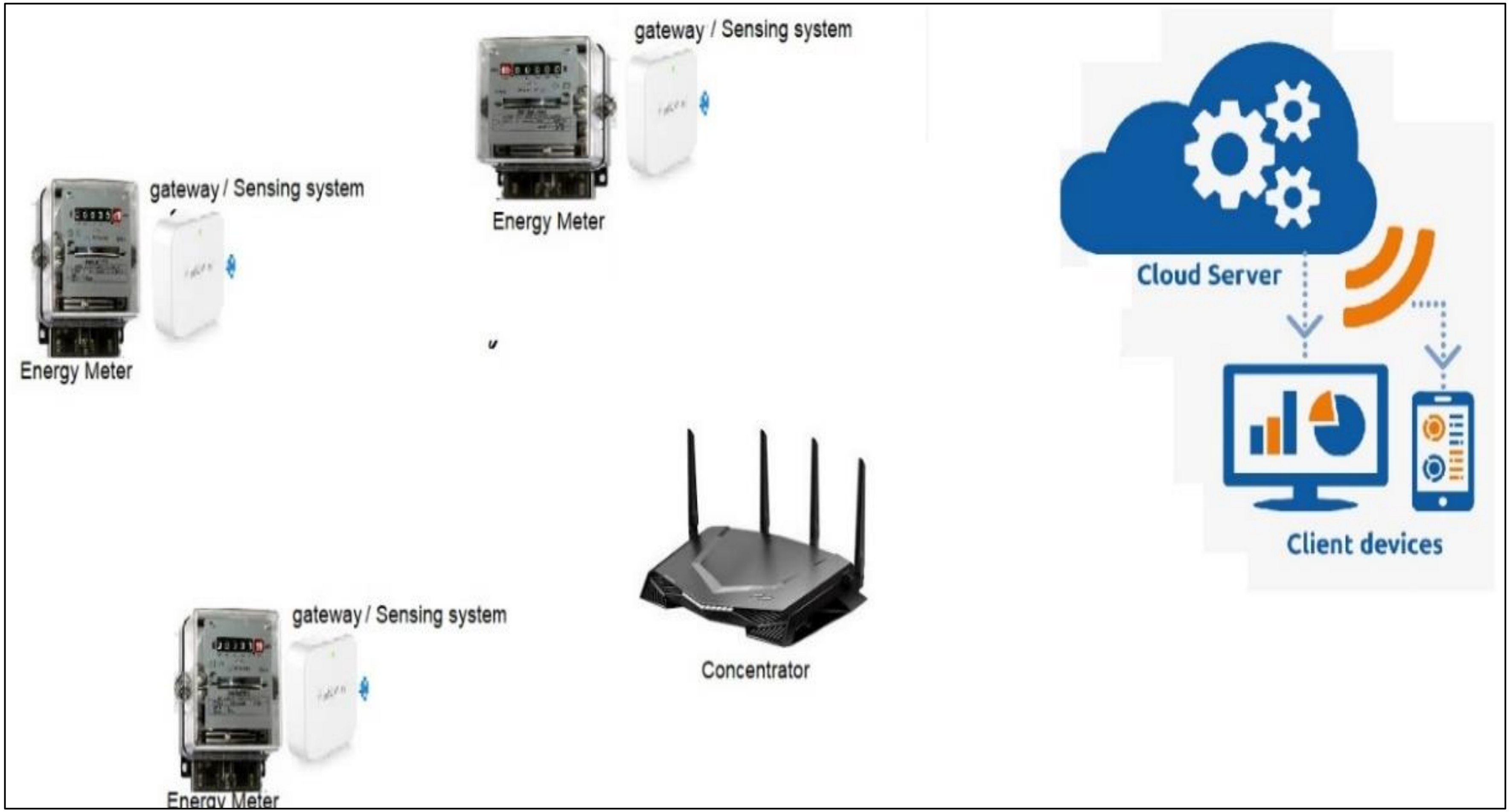


Figure 1: Simple Remote Energy Monitoring System Configuration

According to Costa *et al.* (2018), some utility organizations such as the current Electric Power Board (EPB) have been able to provide reliable electrical energy information about energy usage to managers in most industries. Although this is a web-based system that reports daily/monthly energy consumption, they are limited because they do not provide readings for each room in all the departments of an industry (Costa *et al.,* 2018). In other words, the readings provided by the current Electric Power Board generalize the energy consumption of the entire industry, rather than differentiating the energy consumption for every single room in the industry. Thus, by developing the Remote Energy Monitoring System based on a wireless sensor network, the effectiveness would be improved such that energy consumption in each room within the industry would be monitored and controlled.

1.7 Delineation of the Project

This project proposed a system that aimed to help in obtaining information from the monitoring of energy consumption obtained in real-time, which can be viewed from a PC, or a mobile device. Through analysis of the gathered data, the proposed system would help to identify if there is excessive consumption of (damaged) equipment. The analyzed data also helped track the amount of energy consumed at different time points, hence helping in determining the causes of extreme energy consumption.

CHAPTER TWO

LITERATURE REVIEW

2.1 Electric Power

Electric energy today has become one of the main sources of non-renewable energy. It is used in every area in which human beings develop life and their different activities, including the daily bustle of the office, domestic work, as well as, in leisure activities. The use of electrical energy is unlimited. For instance, electric energy is widely used in homes for electric kitchens, electrical power supplies, fans, televisions, in the industry in lighting systems, electric motors, air conditioning, etc. The frequent use of electric energy is due to its various benefits. Some of these benefits include versatility, easiness to control, as well as, being clean energy in the place of consumption (DeFaria *et al.*, 2015).

2.1.1 Electric Energy as a Product

Electricity has become a non-renewable energy source. It is consumed at the time it is generated and its transportation requires a system of specific transmission lines that must comply with the different laws of physics such as Kirchhoff, more than the aforementioned electrical energy cannot be stored.

Most countries need to create gigantic, expensive, and sophisticated structures to generate and commercialize energy. The basic unit of measurement is the Joule and the second (s) is the basic unit of the unit of time, that is:

$$Power = \frac{Energy\ (E)}{Time\ (t)}$$

In such a way that the energy is equal to $Energy = Power\ (P)\ x\ Time\ (t)\ EC^2$

In other words, electricity consumption is obtained from the product of power in watts, by time in hours (Enríquez, 2009). Energy measurement unit is Wh.

2.1.2 Calculation of Power

Due to the nature of the components of the loads, the calculation of power in circuits fed by alternating signals causes the current leads 900 to the voltage in a capacitive load circuit XC, or the current lags the voltage to 900 in a circuit with inductive load XL. For a purely resistive circuit, the angle between the current and the voltage is considered to be 00. In a resistive, inductive, and capacitive circuit, the calculation of the power is more complex because there are phase differences in the current and voltage.

(i) Apparent Power "S"

When performing the power calculation in a circuit (Fig. 2), the voltage must be multiplied by the value of the current, p = VI.   Considering that the load is resistive if the load is resistive and reactive when performing the multiplication, this value does not represent the real power nor the reactive one. In this case, VI represents the apparent power that is represented by the letter S, where Ve and I are the RMS values of the voltage and current respectively (González, 2008).

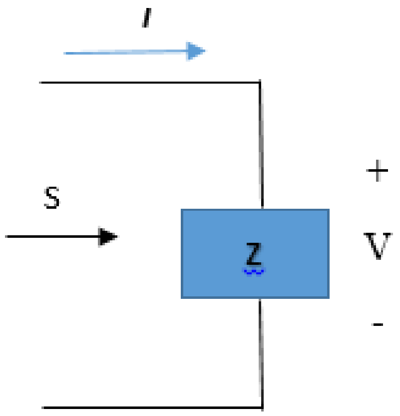


Figure 2: Apparent Power

The apparent power is calculated from the formula:

$$S = VI[VA]$$

Where:

S = apparent power whose unit of measurement is volta- Ampere V = voltage in volts [V]

I = current in amperes [A]

Figure 3 shows the different elements that intervene to obtain the apparent power observed, for example, an inductive load is used, an imaginary positive part Q, and a real part P.

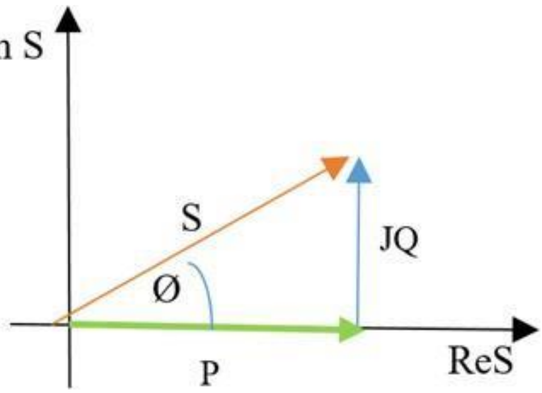


Figure 3: Triangle of Powers

(ii) Reactive Power

The reactive power does not generate useful work, it is the energy consumed by a coil to generate a magnetic field to generate the movement of a motor or that energy stored in the capacitor. The capacitive vector has a negative polarity and the inductive vector is positive, so they can be added mathematically (Ecuared, 2013).

Calculation formula: $Q = VI\,sin(\emptyset)$

Where Q = reactive power unit of measure [VAR] V = voltage in volts [V], and

I = current in amperes [A]

(iii) Active Power

Active power is that electrical energy whose useful work is used to generate other forms of energy such as heating, light, thermal, and chemical. Loads of this power are considered purely resistive, that is, the current is in phase with the voltage (Ecuared, 2013).

Calculation formula: $P = VI\,cos(\emptyset)$

Where P = active power whose unit of measure watt [W] V = voltage in volts [V],

I = current in amps [A], and Ø = Phase angle = 0

2.1.3 Origin of Electricity

Electricity originates from a phenomenon where there is a potential difference, which originates from inducing a force outside the system to tear an electron from an atom. This force further generates a flow of electrons inside a conductive material capable of creating light energy, heat, or electromagnetic phenomena. Throughout the world, several power plants generate energy using different natural resources such as:

(i) Thermal Power Stations

Electric energy originates from the combustion of solid fuels (natural coal), liquid, and gaseous fuels (i.e., energy from thermal combustion energy).

(ii) The Water Vapor Generated in the Boilers

Allows the movement of the turbines on their axis, as well as the turbines, can be driven by gases obtained from the burning of natural gas, or distilled petroleum oil.

(iii) Hydrothermal Power Plants

This power plant uses the thermal energy stored in large areas of water such as the ocean.

(iv) Solar or Heliothermic Power Plants

These power plants use the energy from the sun in the form of electromagnetic radiation. In particular, solar panels are used to gather this kind of energy and the collection of this type of energy depends on the weather conditions. For instance, on a clear day, $1 kW/m^2$ can be collected.

(v) Wind Power Plants

These plants use the wind or air currents to move their power generators. The minimum speed required to generate this kind of power is 6 m/s.

(vi) Nuclear Power Plants

The electrical energy that is produced in a nuclear power plant has its origin in the generation of nuclear energy. The main fuel for this form of energy is Uranium, where, fission occurs in the reactor, which releases a large amount of energy. The amount of energy generated yields a high temperature capable of generating water vapor, which in turn, moves the power-generating turbines. Out of the three nuclear elements, uranium is the only element that can be obtained from nature to generate electrical energy.

(vii) Centrals Hydroelectric

They are infrastructures that use the force of water which is dammed, piped, and controlled to move large hydroelectric turbines. Although the generation of electricity in hydroelectric plants is less costly, their implementation requirements are very expensive.

Based on the review of the different power plants, it is clear that the energy must be transported to the point of consumption. Thus, it is necessary to raise the voltage in lifting chambers to a range from 66 kV to 400 kV. The distributed energy enters the chambers of voltage-reducing transformers where voltages are managed in the range of 30 to 20 kV or also called medium tensions. These reducing chambers can be located close to urban sectors for which the energy is destined (Sánchez, 2008). Figure 4 displays the energy generation and transport scheme.

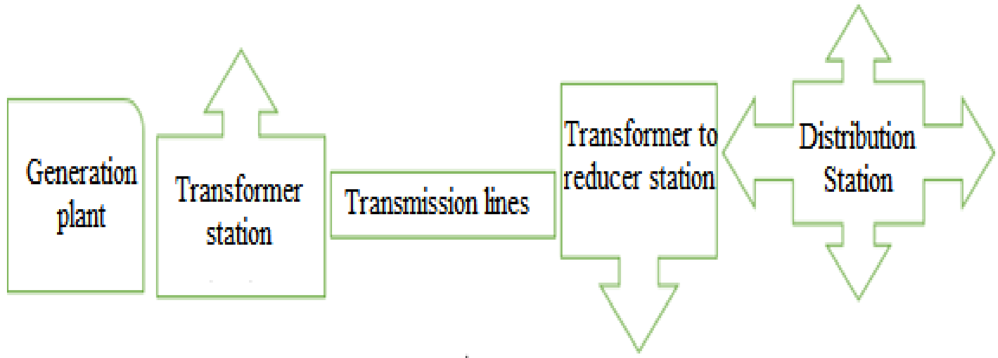


Figure 4: Energy Generation and Transport Scheme

In the last decade, several energy projects have been carried out in the country to utilize natural resources to generate electricity. Some of the resources that have been used include the water flow of the different rivers among other natural resources such as wind. The objective of these numerous projects is to obtain energy independence in the short-term and long-term. In addition, the projects are focused on reducing CO_2 emissions, and energy import costs, as well as, creating employment opportunities.

2.2 Systems for Reading Electrical Energy

An energy measurement system allows the measurement of the energy consumption of a certain electrical system or service used in industry. This allows the calculation of energy consumption in kW/h either from an electrical service or of a complete system. In Kenya, the reading of the electricity consumption within industries is carried out by electromechanical energy meters, which store values of energy consumed over some time. The readings of these devices are carried out by the electrical company personnel once a month. These energy meters calculate the monthly energy consumption of the different homes, and with these values and by performing some mathematical operations, they obtain the value to be paid from the payroll. For the different types of supplies, there are meters: Single-phase, Two-phase, and Three-phase.

2.2.1 Electromagnetic Counter

The traditional or electromagnetic meters are those whose operation is based on the principle discovered by Galileo Ferraris in the nineteenth century, where two coils are used. One of current opposed to one of voltage, which makes a rotating disk rotate. The electromagnetic counter has been used for several years because it is associated with high precision of measurement of energy consumption for low frequencies. However, this device is limited by the great difficulties to make readings in different components in high frequency.

2.2.2 Electronic Counter

The electronic counter (Fig. 5) is a fully programmable device in the user can define through software. With the type of readings that the solid-state device can perform, it is possible to obtain energy consumption readings whether reactive, active, or apparent. In addition, the device provides reading for the maximum power demand, voltage, and current values, power factor, and other important factors of the network that help in measuring the power quality (Kindschi & Barrows, 1991).

The electronic meter has a processor and a sufficient memory capacity to store the different data acquired by the sensors and store the results obtained from the different processes. The presentation of the information can be done on a PC, or on a display of the device itself. According to the function that this type of meter fulfills, they are classified as:

(i) Demand Counters

During 24 hours, they measure and store electrical energy consumption in a single period and at a single rate (Kindschi & Barrows, 1991).

(ii) Multi-tariff Counters

The energy consumption is read either by sections of the system or the complete system. It also performs the different measurements of energy consumption in different periods within 24 hours (Kindschi & Barrows, 1991).

Figure 5: Electronic Counter

2.3 Project Electronics

The development of this project incorporated various technologies such as Arduino, and Raspberry PI, as well as, passive and active elements. Among them, the following are mentioned: Sensors for data acquisition, NRF 24 wireless communication devices, 16x2 LCD, and “cellular” Android mobile devices for data visualization, the different electronic devices, and some of their technical characteristics were detailed in the following paragraphs. These helped in the acquisition, processing, storage, and displaying of the different data obtained in an energy consumption system.

2.3.1 Power Supplies

The power supply is an electronic device that converts an alternating voltage signal into a direct voltage signal. Figure 6 shows an example of a non-commutated source. This type of device uses elements such as rectifiers and capacitive filters to stabilize the signal of the alternating electrical network to a continuous electrical signal. However, the device is limited by its non-linearity which causes a high number of harmonics in the electrical network (Kaya, 2008).

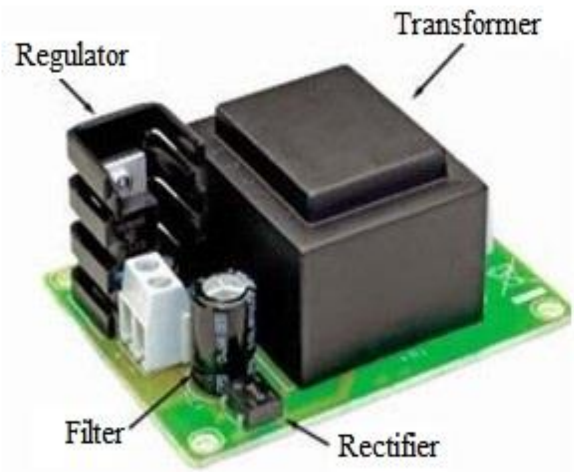


Figure 6: Linear Font (Bloger, 2015)

A switched source is shown in Fig. 7. As technology advances, the demand for AC/DC sources is increasing and requires higher performance. Since the current equipment requires lower voltages and is more susceptible to damage due to voltage variations, switching sources were developed. These switching sources are much smaller and reduce the power factor compared to linear sources (Kaya, 2008).

Figure 7: Source Switched (Bloger, 2015)

2.3.2 Relay-Relay

The diagram of a relay and its different main components (Fig. 8):

(i) The coil,

(ii) Connection contacts that are normally open (NO) and normally closed (NC).

(iii) The armor,

(iv) Coil energization terminals.

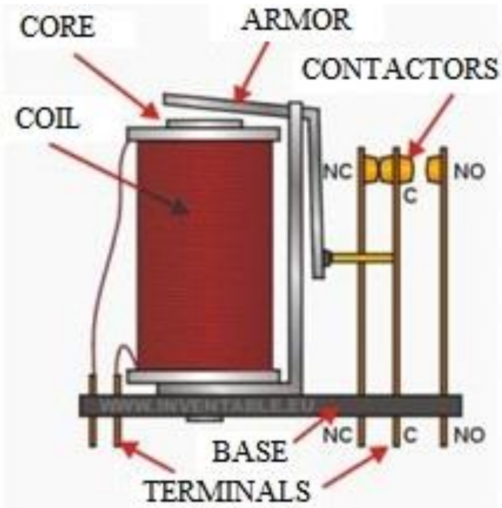


Figure 8: Scheme of a Relay

The relay is a switch that is activated or deactivated by inducing a voltage in the terminals of the electromagnet, which attracts or repels a small arm called an armature, allowing a connection or not between two or more terminals.

2.3.3 Arduino

Arduino is an electronic platform that integrates from an Atmega brand microcontroller. It also provides extra circuitry such as voltage regulators and a USB port, for configuration and testing of electronic control and communication with the chip, from any pc in a simple way. The different Arduino models that exist on the market are physically appreciated (Fig. 9), where the difference in size between one and another model is especially appreciated.

Figure 9: Arduino Boards Types (Isaac, 2017)

The Arduino board is powered by 5V, direct voltage. In addition, the Arduino board makes available several pins (the number depends on the card model), and they can be used as input or output of digital signals of any device that is capable of sending or receiving digital signals between values of 0 to 5 volts (Louis, 2016). The Arduino board also makes available several analog inputs and outputs, which allow the reading of signals obtained by sensors in the form of voltage variations. Of the existing types of Arduino boards, the one that provides the number of analogs and digital inputs necessary to perform the processing of the signal acquired by the current and voltage sensors, and to integrate the device for wireless communication is sought (Isaac, 2017).

A comparison is made between the different types of Arduino, and the one that met the requirements for this project was chosen (Table 1). When comparing several Arduino boards, a lot of similarities are observed in their technical characteristics, with some differences such as the capacity of the processor, the voltage at the output of its terminals, and its size.

Table 1: Arduino Comparison Chart

Arduino	Processor	Frequency	RAM	Digital Pin Input /Departure	Tension / Current At Pins	Resolution
Pro Mini	AVR Atmega 168 'or 328 8 BITS	16 Mhz	2 kIB	14/14	3.3V-5V 40 mA	10 bits 1024 values
Elder brother	AVR Atmega 168 'or 328 8 BITS	16 Mhz	2 kIB	14/14	5V 40mA	10 bits 1024 values
One	AVR Atmega 328 8 BITS	16 Mhz	2 kIB	14/14	5V 40mA	10 bits 1024 values
Mega / Mega 2560	AVR Atmega 2560 8 BITS	16 Mhz	8 kIB	54/54	5V 40mA	10 bits 1024 values
Micro	AVR Atmega 32UE 8 BITS	16 Mhz	2.5 kIB	20/20	5V 40mA	10 bits 1024 values

2.3.4 Analog Inputs

Analog signals can take on any physical magnitude that varies with time, space within a VCC, and - VCC interval. It is worth noting that the analog inputs must be within the range of 0 - 5V. The analog inputs are scarce and their processing is slower compared to the digital signal inputs. A digital input only works with two values, a high 5 V and a low 0 V. Conversely, an analog input provides a value encoded with some N bits (10 bits).

2.3.5 Measurement Accuracy

Arduino nano has an embedded analog-digital converter (ADC), which is responsible for converting an analog signal into a digital signal encoded with N number of bits. Arduino nano provides 1024 digital levels and boasts an accuracy of +/- 2.44 mV.

2.3.6 Relative Precision

The measurement accuracy of an Arduino for a signal is within the range of 0-5V using the 10-bit digital-analog converter with an approximate precision of 4.88 mV relative to the 5 V voltage, having a relative precision of 0.1%. In practice, analog signals present variations throughout the range of the reference signal. For instance, if a signal between 0 and 1 V is considered, the relative relationship of 4.88 mV is maintained, and the precision would fall to 0.5%.

2.3.7 Analog Voltage Reference

To perform a relative reference correction, Arduino gives the facility to change the reference voltage by the analog converter with the AnalogRef function. In Table 2, you observe the different reference voltages for the Arduino board. When working with the reference voltages, the limit must not be exceeded to avoid damaging the Arduino.

Table 2: Arduino Reference Voltage Values

Reference Analog	Voltage values: Voltage Common Collector
Default	5V or 3.3V
Internal	1.1V (Atmega 168 and 328)
External	p.IN Vref (0-VCC)
External	1.1V and 2.56 (Arduino Mega only)

2.3.8 Analog / Digital Converter

The block diagram of an analog-digital converter is presented, showing the process that the analog signal undergoes when passing through the different blocks until the digital signal is obtained (Fig. 10).

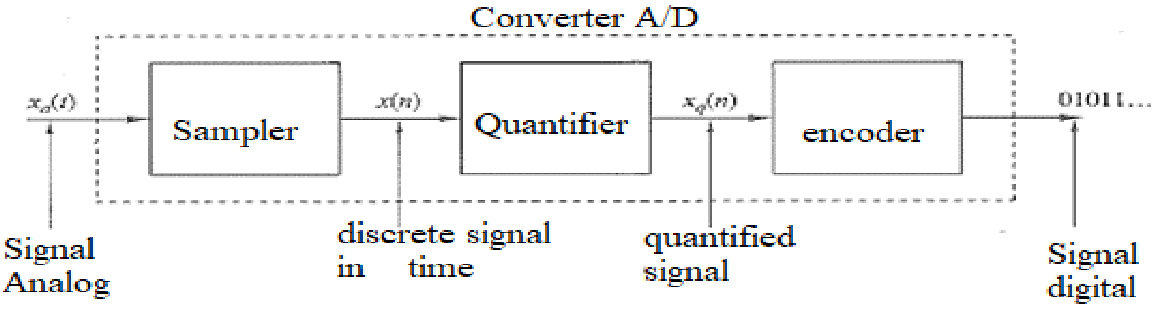


Figure 10: Analog Converter

The analog-digital converter integrated with the Arduino nano Atmega controller makes available 8 channels with a 10-bit resolution, which delivers values between 0 and 1023. The main function of the analog inputs is to read data obtained by the different connected sensors. To the board, these pins can also be programmed to perform general-purpose input and output functions. Similar to pins 0 to 13.

2.4 Sensors

In the daily activities in the life of human beings, all the time censored through the senses which are receiving information that is processed by our brain. Figure 11 show an example how the sensors emulate people's senses. The technology tries to develop sensors based on the sense of human beings with which it intends to sense the different events that happen in an environment. Designing countless devices that collect information and send it to the processor to obtain information required for a process (Tian *et al.*, 2017).

Figure 11: The Sensors Emulate the Senses

2.4.1 The SCT 013 Current Sensor

The image of the non-invasive current sensor is appreciated as a transformer through whose core the conductive wire of a circuit crosses (Fig. 12). This is the line or the neutral, but not both together. They are very practical and can even be used to measure the energy consumption of a building if necessary. It is a non-invasive sensor so it can be connected without physically intervening with the cable.

Figure 12: Non-Invasive Current Sensor

It is composed of a primary winding, a core, and a secondary winding, the cable from the connection to the building or the electrical circuit line. The primary winding and the secondary winding use a low gauge wire and a high number of turns (Open Energy Monitor). Figure 13 shows the components of the non-invasive current sensor of the SCT family.

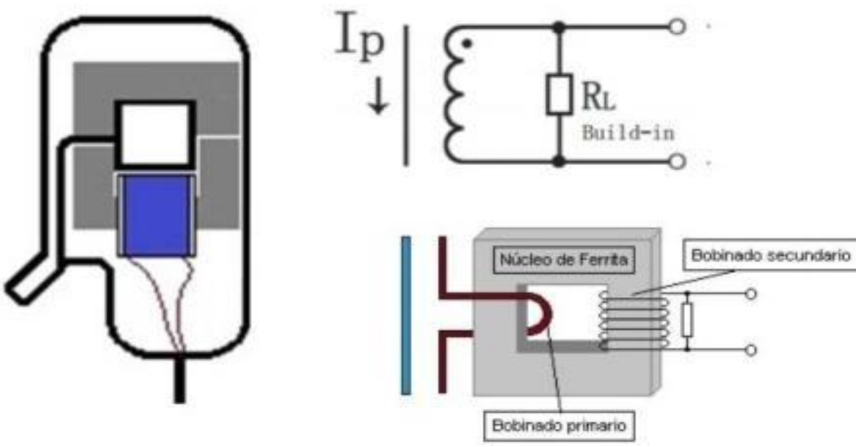


Figure 13: Non-Invasive Current Sensor Electrical Diagram (Mechatronics, 2016)

The secondary winding is galvanically isolated from the core to avoid physical contact between the winding and the core. The sensor to be used in this project has a built-in load resistance. As such, it delivers a voltage to the output of the terminals. The sensors of the SCT-013- 000 family contain an embedded protection system intended to reduce the risk of an electric shock.

2.4.2 Alternative Current Voltage Transformer - ZMPT101B

The transformer shown in Fig. 14 allows measurements to be taken directly from the domestic electrical outlet and outputs a voltage signal that is within the operating parameters of the Arduino analog inputs that work with positive values in the range of 0-5V (Mechatronics, 2016).

Figure 14: Voltage Transform (Mechatronics, 2016)

In the primary winding of the transformer, the alternating signal supported by the transformer, which is 250 V is connected, to the output of the secondary winding. It is necessary to reference the voltage in addition to using an operational amplifier, the displacement voltage depends on the supply voltage VCC. The module also allows you to adjust the peak voltage with the help of a potentiometer built into the board (Ocampo-Urióstegui, 2020).

With the signal delivered to the output of this transformer, any device processes the signal and obtain a voltage value. In Table 3 (Appendix 4) presents some technical characteristics of the AC voltage transformer coupling circuit - ZMPT101B, also Table 4 presents the properties of the transformer.

Table 3: Reference Voltage Values of the Coupling Circuit

Voltage performance	3.3V-5V DC
Voltage entry	250 V AC maximum
Secondary voltage (sinusoidal signal)	5V AC

Table 4: Transformer Property

Input and output current	2 mA
Input electrical isolation	300V
Ratio in-out	1000:1000
Phase difference	<300 (at 50 Ohm)
Linear range	o-3mA (at 50 Ohm)
Linearity	1%
Precision	0.2%

2.4.3 Raspberry Pi

It is a minicomputer designed for the implementation of small projects and to encourage the learning of computer systems in study centers. Figure 15, shows a Raspberry Pi model. Several operating systems have been developed for the Raspberry board, the main one being based on Linux with some modifications of the original system, Debian (also called Rasbian) so that it is functional on a board with specific hardware requirements. Unlike traditional computers, Raspberry Pi uses a processor with ARM architecture of the RISC type (Reduced Instructions Set Computer). This architecture uses really simple instructions, to reduce energy consumption (Raspberry pi paratorpes, 2013).

Figure 15: Raspberry Pi 3 Model B

Currently, other operating systems have been developed, and use the Raspberry Pi, including the Windows 10 IoT version Core. The use of one operating system or another differs in most cases due to the use of licenses, or the characteristics of each operating system. For example, in Windows 10 IoT, the core is a closed system compared to Rasbian (an open operating system that adjusts more easily to the developer's requirements). Also, the enthusiast who wants to develop their projects in Raspberry has the help of the community that provides support for the use of the operating system, the existence of online help for Windows 10 IoT Core is currently unknown (Raspberry pi paratorpes, 2013).

Raspberry Pi Zero W is observed, which is much smaller than the Raspberry pi B (Fig. 16). Similarly, there is a smaller number of inputs, for example, the Internet connection is made wireless using a Wifi.

Figure 16: Raspberry Pi Zero W

In the market there are various types of Raspberry boards, for the development of this project the Raspberry pi Zero W was chosen, which is a variable of the conventional Raspberry Pi, low cost and quite small in size that meets the needs (Appendix 3) and specifications as shown in Table 5.

Table 5: Features Raspberry Pi Zero W

CPU Broadcom BCM 2835 single core 1 GHz	
RAM	512 MB
Storage slot	Micro SD
Video output	Mini HDMI and composite video output with no connector mounted
WIFI	Uses cypress CYW43438 microchip, supports 802.11/n
Bluetooth	Bluetooth 2.0/4.1
Input and output general purpose (GPIO)	40 pins
Supply voltage	5V, 2.5 A via micro-USB
Dimensions	65 mm x 30 mm x 5 mm

2.5 Data Communication Networks

2.5.1 Internet

The Internet is the largest technological infrastructure that man has been able to create. It is in charge of intercommunicating with millions of people around the world. In the past, the Internet network was supported only by desktop computers. However, with the increasing technological advancement, the number of electronic devices such as computers, televisions, tablets, cell phones, etc., that uses internet network has increased. In computer language, all these devices are called hosts or terminals (Garnet, 2014).

In 2015, the number of terminals connected to the internet was greater than 5000 million. It was estimated that by 2020, the number would rise to 25 billion. In 2015, the number of beneficiaries connected to the internet worldwide was over 3200 million, corresponding to approximately 42% of the world's population (International Telecommunication Union [ITU], 2015).

2.5.2 Internet of Things

Currently, the use of the internet has become a prevailing need. A clear example is the use of cell phones. The number of electronic equipment that allows internet connectivity from a carpet to a vehicle has increased. For example, a Smart Watch takes readings of a person's behavior and gives alarms of distance traveled, leisure time, and hours of sleep throughout the day. All of this information is recorded and can be observed from our cell phones with the help of an application (Garnet, 2014).

The evolution of technology and the need to create intelligent devices have opened a door that can be exploited by a hacker. A hacker can make use of the so-called internet of things and access information from data servers, and use toys connected to the internet to talk with children. For such reasons of insecurity and confidentiality, most people who still do not use this technology have become more afraid to adopt these advanced technologies.

2.5.3 Internet of Things Platforms

Currently, countless platforms can be used in different projects focused on the internet of things. Some of these platforms the Arduino Cloud, Cayenne, Thingerio, aREST, ThingSpeak, Artika Cloud, etc. All these platforms are available for the user to make use of their technological features. The choice of use of one platform over another is determined by its ease of use or the features offered such as the number of data they allow to store, and compatibility with the different cards. Electronic such as Arduino, Raspberry Pi, ESP8266 wifi module, Lora Wan, etc, the data update time, and the libraries to access these, are some guidelines that allow choosing the most suitable for the development of this project (Fig. 17).

Figure 17: ThingSpeak

ThingSpeak, is a free and open-source platform that makes available several channels, 8 in its free version, and stores 8200 data per channel. It also allows access to MATLAB, which help in performing various mathematical operations, thus, allowing a better view of the acquired data. This platform is user-friendly, and with Raspberry PI or Arduino, the transmission of data collected by sensors or found in a database is done using the HTTP protocol either to send to the internet or a local area network (ThingSpeak, 1994-2020).

The platform also allows monitoring the objects or sensors because it supports a simple integration of third parties such as Twitter, in which the change in sensor readings can be viewed through a change of status in the social network account. By using the free version and being open source, it is widely used in the implementation of things on the web.

2.5.4 Data Communication Network

It is a system made up of hardware and software, which communicate with each other using physical, wireless, or any means of communication. The data communication network allows data transmission by sending either electrical pulses or electromagnetic waves to provide a service or resource such as the Internet (Wesolowski, 2009). The hardware component includes: Structured cabling, workstations, equipment, and network nodes while the software component includes different operating systems that are used to administer the network (Network operating system).

In communication networks, four important items that intervene in their concept of operation are as follows:

(i) Communication Protocol

It is the set of rules, and norms that provide all the facilities for communication so that the exchange of information can be carried out in the same language between the sender and receiver. There are many network protocols, but the most widely used is TCP/IP (a protocol used by the internet).

(ii) Topology

Describes the connection structure of the different nodes connected in a network. The known topologies are ring, tree, star, and point-to-point bus.

Ring topology

In this typology, the network terminals are connected one after the other (series) (i.e., the last terminal connects with the first). Since there is a single communication path, communication can be lost if one of the items stops working. Figure 18 shows an example of the ring topology.

This type of technology uses a token or tokens, which is responsible for delivering or collecting information from one terminal to another to avoid loss of information (Kurose & Ross, 2017). It is worth noting that in the past, communication was carried out in a single direction, where, the terminal had a transmission card and a reception card for the information. However, this technology is presently being used with two-way communication.

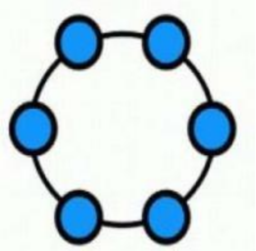


Figure 18: Ring Topology

Star Topology

This topology presents a central node where all the terminals are connected. This means that when a faulty terminal is found, the operation of the data network is not altered, and all communication passes through the central node. The difficulty of this topology is the sending of the information packets, where, the router is responsible for sending these to their destination.

Bus Topology

This topology seen in Fig. 19, uses a single data bus, in which the terminals or host are connected through interface units and shunts. The breakdown of the bus or communication channel causes the terminals to be disconnected and the network is disabled because there is no other communication channel (Kurose & Ross, 2017).

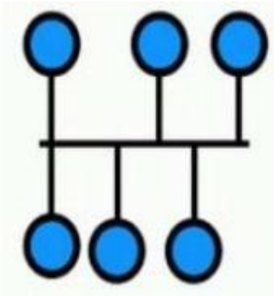


Figure 19: Bus Topology

- **Tree Topology**

This topology could be summarized as the sum of several star-type networks, where nodes are connected. The failure of a node in a tree topology does not prevent intercommunication between equipment, as long as they are not connected to this node. Figure 20 presents the outlook of tree topology.

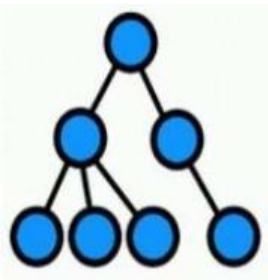


Figure 20: Tree Topology

- **Mesh Topology**

In the mesh topology**,** the nodes are connected one by one or with several of them (Fig. 21). The fact that it has several paths to reach its destination and each server has its connection resource prevents the information from being lost.

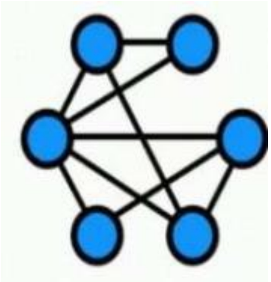


Figure 21: Mesh Topology

(iii) Security

They are the different parameters that are responsible for responding to confidentiality, authenticity, and data integrity.

(iv) Means of Transmission

They are the ways or paths that technology uses to send information, through electrical or electromagnetic pulses. It differs in the means of transmission:

Physical Environment

As its name indicates, it is the transmission of information through physical means such as copper wires. In computer networks, the multi-pair cable is the most used. A category 5 patch cord is shown in Fig. 5. As technology advances, physical media are required that provide greater speed, such as fiber optics.

Figure 22: Category 5 Network Cable

Wireless Medium uses Air or Free Space as a Transmission Medium

Technically speaking, it uses the electromagnetic spectrum comprising the frequency range from 3 KHz to 300 GHz (Carruthers, 2002). Figure 3 shows the frequency range of the electromagnetic spectrum used in telecommunications.

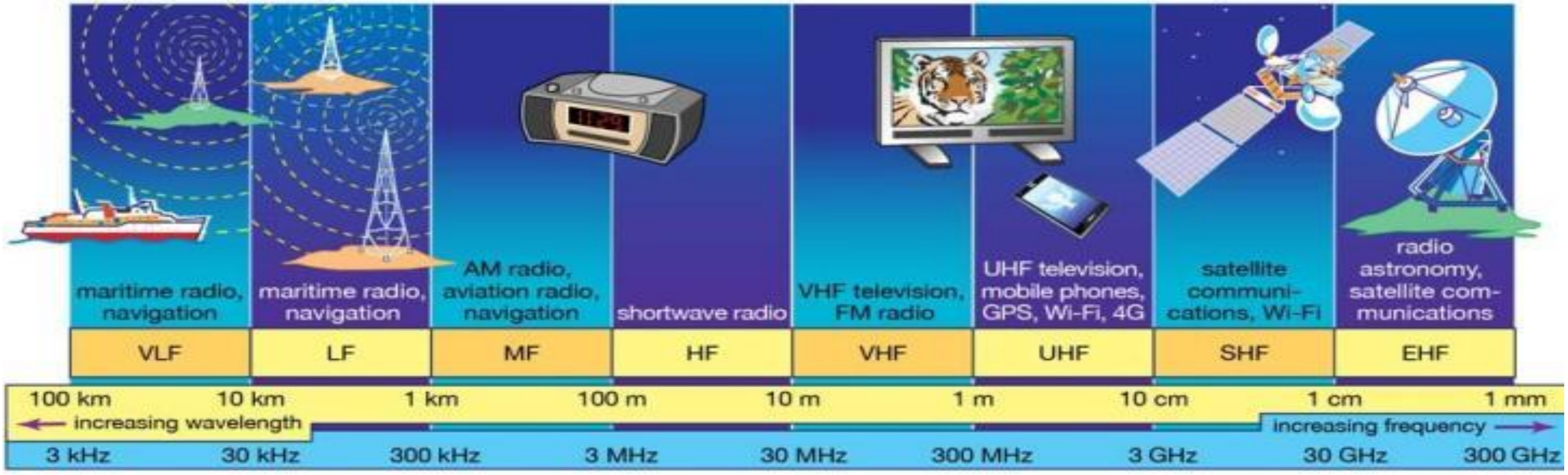


Figure 23: Electromagnetic Spectrum Commercial Bands

The range of frequencies most used in wireless communications are:

(i) Infrared IR Frequency (300 GHz and 400THz)

They are used for point-to-point communications and are limited by the fact that they do not cross objects. It is commonly used in remote control of televisions. They were rarely used for communication of electronic equipment that was practically next to each other.

(ii) Microwave (1 GHz to 300 GHz)

The frequency range is used especially in satellite telecommunications, and terrestrial point-to-point. They are an alternative to coaxial cable and fiber optics. They are also used in more common wireless communications such as WLAN, Bluetooth, and UMTS. Microwaves are mostly directional waves.

(iii) Radio Frequency (300 Hz 300 GHz)

This electromagnetic space is used especially in FM, AM, and digital terrestrial television transmission. They can cross obstacles with relative ease and are omnidirectional.

(iv) Other Frequencies

Other frequencies of the electrical radioelectric spectrum such as X-rays, and Gamma rays of higher frequency, in theory, would provide greater benefits. They are not used because they can be dangerous for living beings. In addition, it is very difficult to produce and modulate them.

2.5.5 Infrastructure Mode

This type of wireless network has a WLAN access point as the central part of the network. Communication between the devices is done through the router, which allows communication with a wired network. Thus, the devices can communicate within the wireless network as well as have access to the wired network (Brother, 2014). Figure 24 shows an example of a connection using the infrastructure mode.

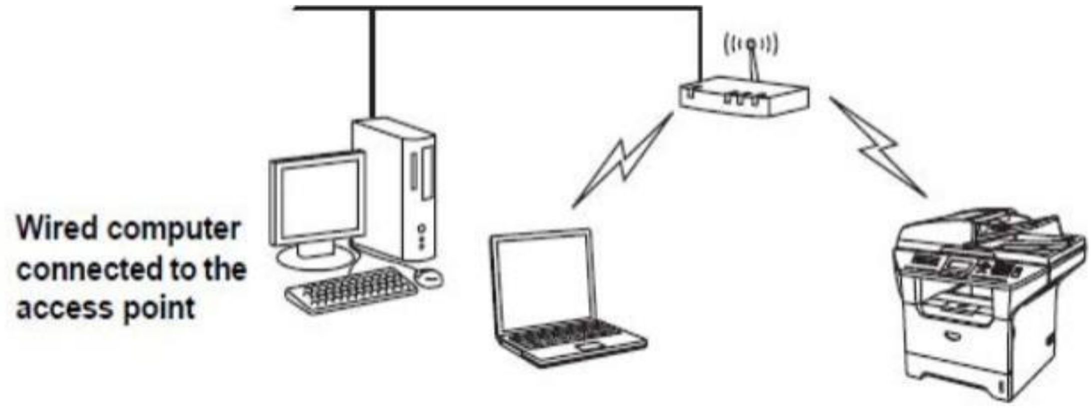


Figure 24: Infrastructure Mode (Brother, 2014)

2.5.6 Ad-Hoc Mode

It is a wireless network mode shown in Fig. 25. Unlike infrastructure mode, it does not have a router or central point. Each wireless device communicates directly with another (Brother, 2014).

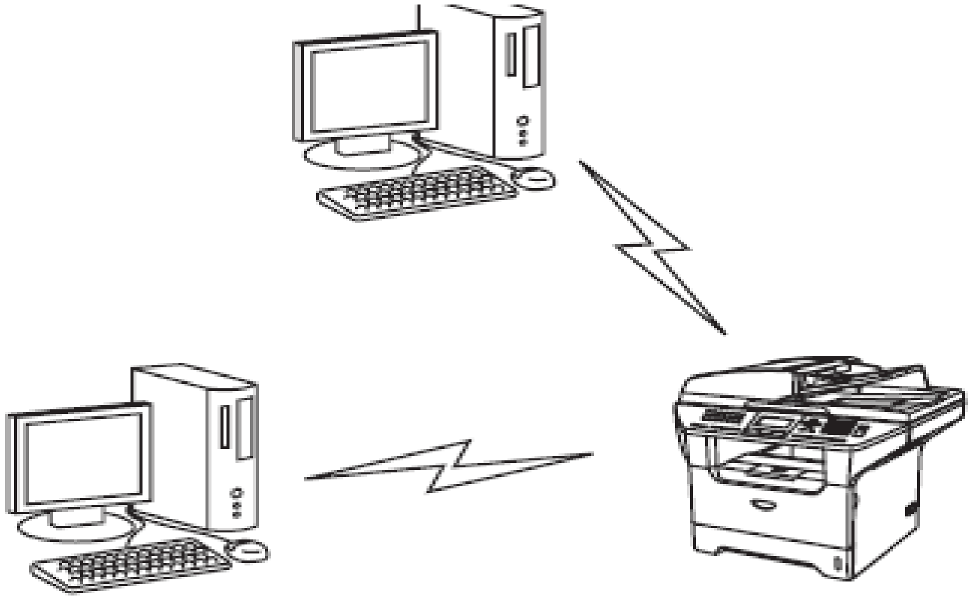


Figure 25: Ad-hoc mode (Brother, 2014)

2.5.7 Wi-Fi Networks

Based on the 802.11 standards (dedicated to wireless broadband networks), it is increasingly easy to connect to the internet wirelessly across the world. Internet access has become a basic need for the development of modern life. It has been adopted in most institutions including municipalities, and universities. Most modern libraries have created infrastructure to freely access wireless networks to reduce digital inequality and infrastructure.

In many countries, the creation of Internet access places has been proposed. In particular, Wi-

Fi technology has been adopted because it does not require a license to use electromagnetic space. However, the great limitation is the scope to cover an area similar to that covered by a cellular antenna 4G, which pays millions of dollars for the use of the electromagnetic spectrum, has become a financial obstacle to the implementation of these networks (Okhrel & Williamson, 2018). Based on the IEEE, the 802.11 standard makes known a series of specifications of which the following are mentioned (IEEE.ORG, 2011):

(i) IEEE 802.11a

This protocol is aimed at the transmission of packets. Although it does not provide an optimal quality of service, the transmission speed is 54 Mbps, at the frequency of 2.4 GHz.

(ii) IEEE 802.11b:

Initially known as WI-FI. The transmission speed is up to 11Mbps, in the 2.4 GHz frequency band.

(iii) IEEE 802.11g:

Evolution of IEEE 802.11b. The maximum transmission speed is 54 Mbps, working frequency 2.4 GHz.

(iv) IEEE 802.11i:

It was developed to improve security in authentication and encryption protocols. This standard covers the 802.1x, TKIP, and AES protocols through the WPA2 protocol.

(v) IEEE 802.11n

Works at the 2.4 GHz and GHz frequencies, with a maximum speed of 600 Mbps. This type of protocol is compatible with different devices according to the IEEE 802.11 standard, providing ease of working in the 5 GHz frequency. This makes it more reliable.

2.5.8 Zigbee Technology

The development of the 802.15.4 protocol has greatly contributed to the optimization of the resources of a network. That is, its use is focused on sensor networks or WSN wireless networks. Due to the time in which the information census is performed at set times, they do not require a network as robust as a computer network.

Zigbee is considered the most promising protocol when it comes to wireless sensor networks. Some of its characteristics are observed in Table 6. The protocol defines the physical and access control layer for wireless networks. The Zigbee configuration topology is a tree, mesh, or star (Non-IP Smart Object Technologies, 2010).

Table 6: Zigbee Protocol Parameters

Frequency working	**2.4 GHz**
Scope (Transmitter 1 mW)	100 m line of sight, 30 m indoors
Speed	Up to 256 Kbps
Number of devices per network	65535

2.6 Zigbee Device Types

The confirmation of a Zigbee network (Fig. 26). Zigbee coordinator is responsible for the network to turn on and functioning properly as a whole. Zigbee router is responsible for routing for him to send the packets. Lastly, the end device (monitoring device).

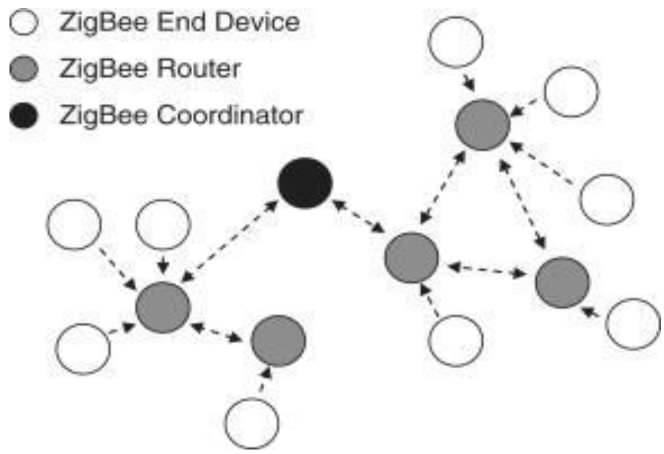


Figure 26: Zigbee Devices

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This Chapter describes how the remote energy monitoring system was designed, as well as the tools and components used in its development. It also describes how the data was collected and analyzed to assess the effectiveness of the developed system. Therefore, the Chapter is organized into various sections, which include; materials, hardware design, software design, hardware implementation, and software implementation. The project consists of the following stages as identified in Fig. 27.

(i) Wireless modules for taking voltage and current measurements

(ii) Implementation of a sensor network, in a star topology

(iii) Data collection in ThingSpeak.

(iv) Viewing energy consumption data

(v) Consumption control

(vi) System automation

(vii) Energy prediction

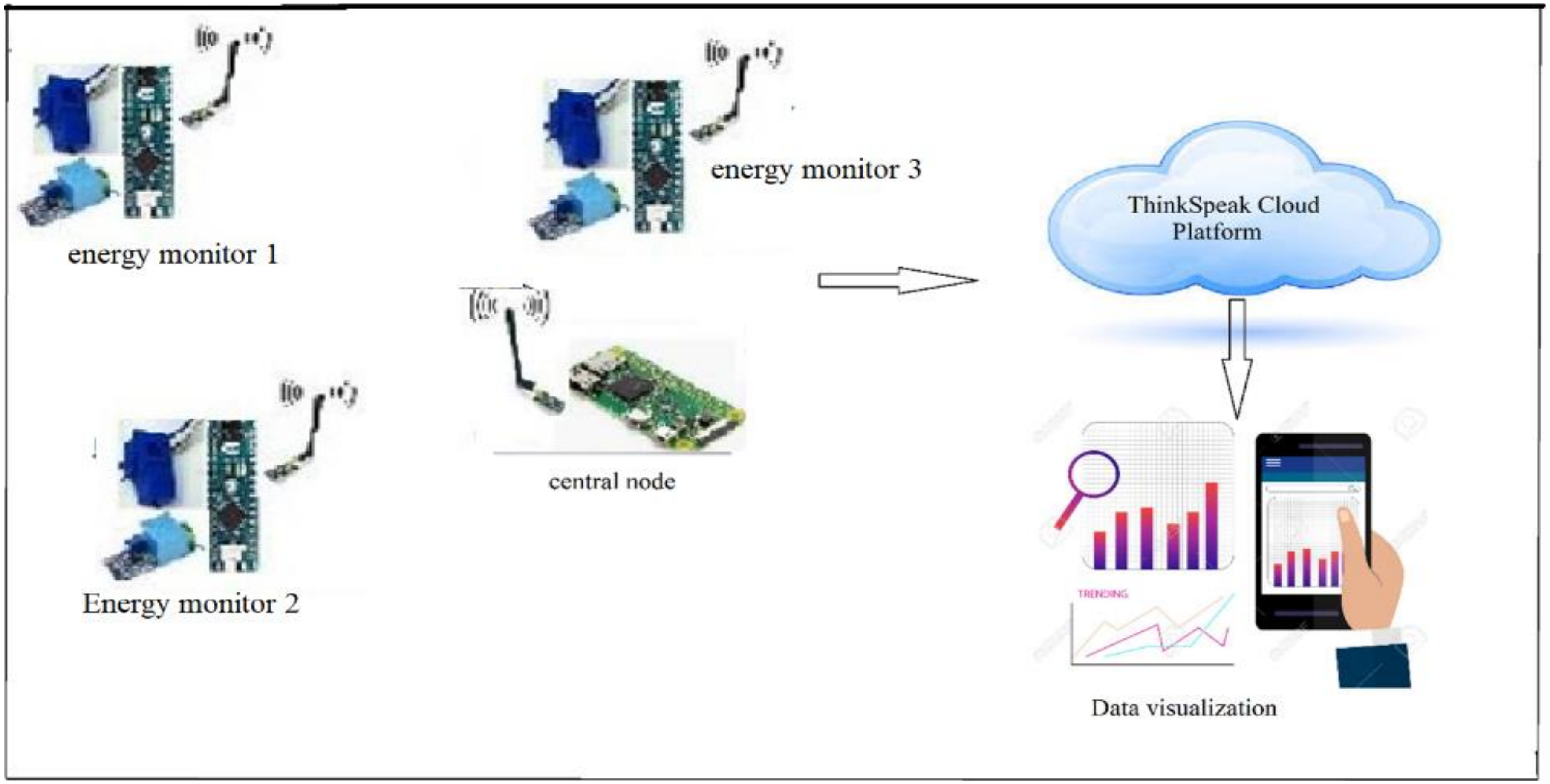


Figure 27: Prototype Architecture

3.1.1 Wireless Modules for Taking Voltage and Current Measurements

The monitoring system consisted of three portable wireless terminals and the main one. The portable terminals are made up of the Arduino nano, to which two sensors were connected at the inputs of the ADC analog-digital converter. The first is a non-invasive current sensor SCT 013 and a second voltage sensor ZMPT101B, the two sensors. They take samples of the current and voltage values that are consumed by the electrical device, connected to the monitoring module. These values are stored in a floating variable and are used to calculate the consumed power. A sampling of the input signal is performed in 10 minutes, in which it receives the order from the central node, to collect the information.

The main terminal, unlike the portables, presents values of voltage, current, and power consumed by the entire electrical system of the home on a 16x2 LCD. Figure 28 shows the block diagram of the transmitter data acquisition module.

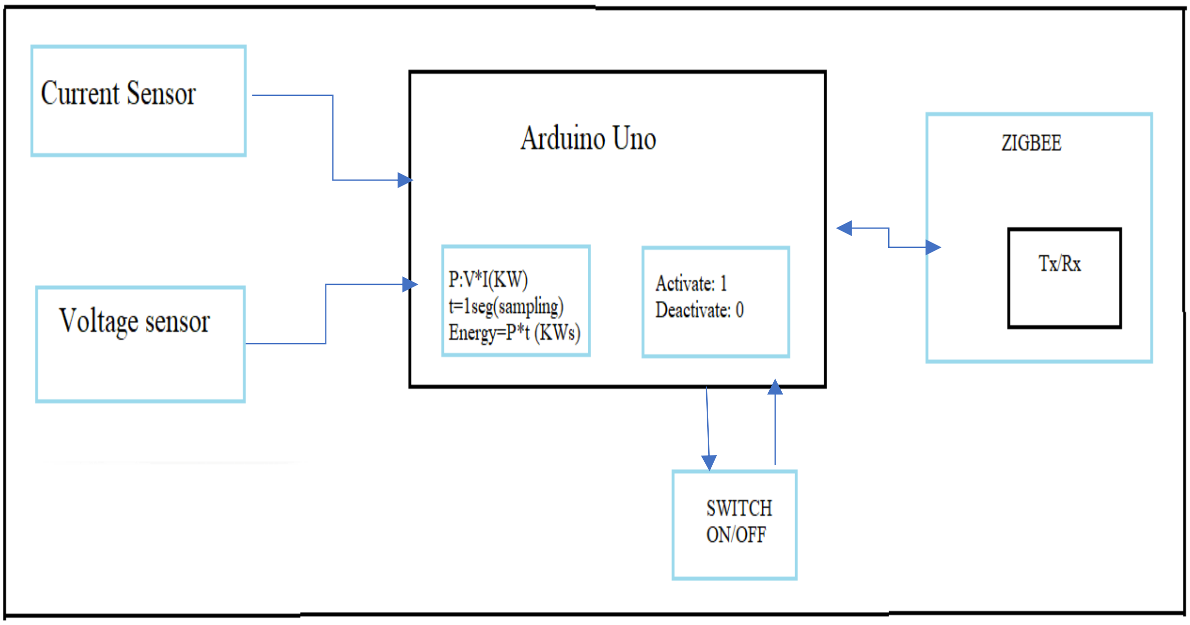


Figure 28: Transmitter, Receiver Module Design

In addition to allowing energy consumption monitoring, the relay signal conditioning digital output from the Arduino platform has been assigned to each module to control a relay. Figure 29 shows the configuration implemented to the digital output of the Arduino board. When applying a voltage at the base of the transistor configured in the cut-off and saturation zone allows or not to activate the relay. The diode guarantees the current discharge stored in the coil during the transition periods between on and off.

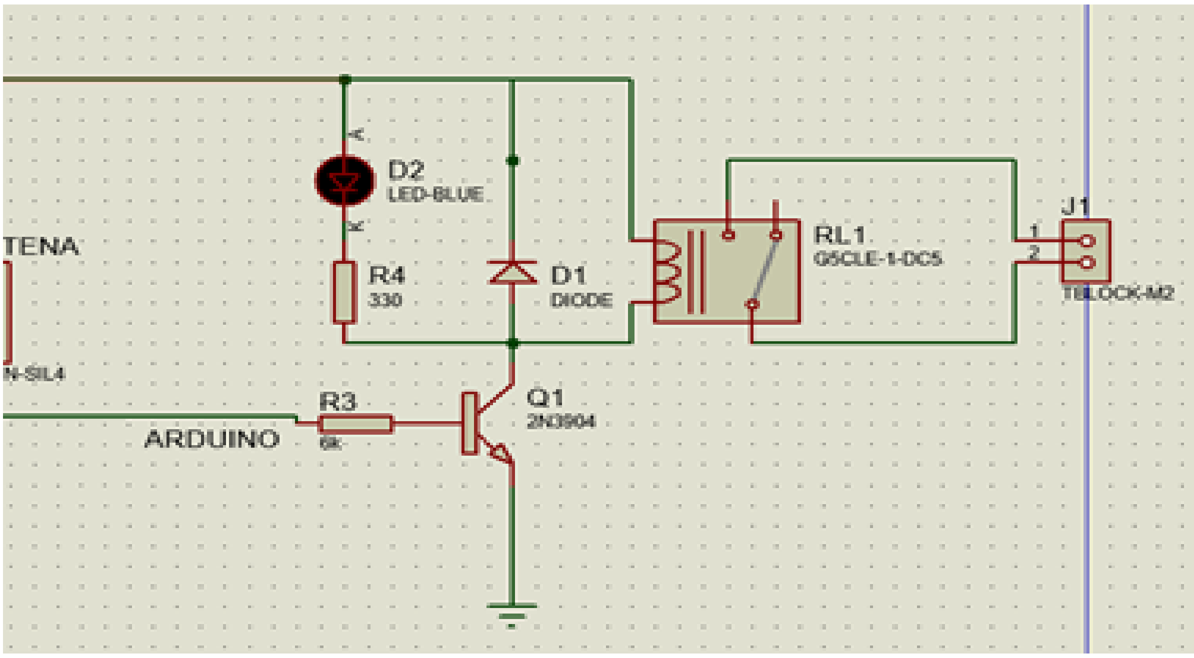


Figure 29: Relay Control Circuit Design

Regarding the calculations, it is necessary to consider that the PNP transistor works in cut-off and saturation:

DATA: $V_{CE=0\,V}$ $\quad$ $\beta = 100$ (Data sheet) $I_C = \beta\, I_B$

$VCC = V_{C=5\,V}$

$R_{Relay} = 70\Omega$

Mesh 1

$V_{DC} = V_C +$

$V_{EC}\ V_C = R_C *$

I_C

$I_C = \frac{VC}{R_C} = \frac{5}{70\Omega} = 71mA$

Mesh 2 $V_{SA} =$

$V_{RB} + V_{BE}\ I_B$

$= 714\mu A$

$R_B = \frac{V_{SA} - V_{BE}}{I_B} = \frac{4.3}{714\mu A} = 6020\ [\Omega]$

(i) Measurement Technique

To calculate the total energy consumed by a home, it is necessary to measure both the current and the voltage that enters through the connection cable. Similarly, to monitor the consumption of various specific loads within the home, the value of voltage and current that circulates in the conductor that originates in the distribution board and ends in the current outlet of a home environment must be taken.

(ii) Root Mean Square or Effective Value

The RMS value is the one obtained after taking the square root of the mean squared value. The equivalent RMS value of a sinusoidal signal is approximately $1/\sqrt{2} = 0.707$ of the maximum value of its amplitude, also called the effective value, calculated from the expression:

$$v_{RMS} = \sqrt{\frac{1}{T}\int_0^T V^2 * dt} \quad \ldots(1)$$

Figure 30 shows a sinusoidal signal that would be observed in which the RMS and maximum values of the signal are indicated.

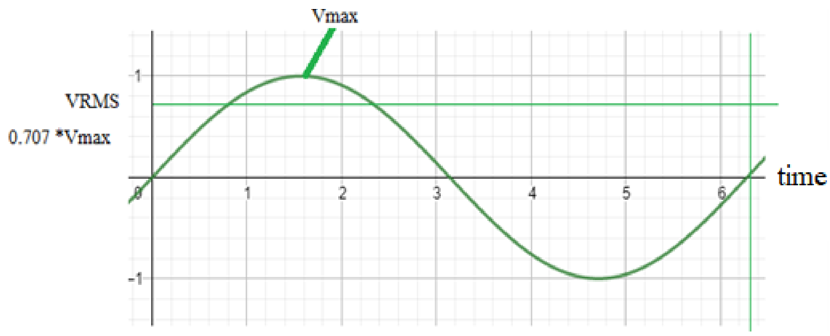


Figure 30: Root Mean Square Value of a Synodal Signal

(iii) Voltage Measurement

To measure the different power supplies at certain or main points of an electrical network using sensors (which are part of a voltage measurement system), take samples of the sinusoidal signal and the algorithm in the Arduino programming. Calculates the RMS voltage value, Equation 3. Figure 31 shows the coupling circuit diagram that allows referencing the signal that enters the analog-digital converter, which enters the analog input of the microprocessor.

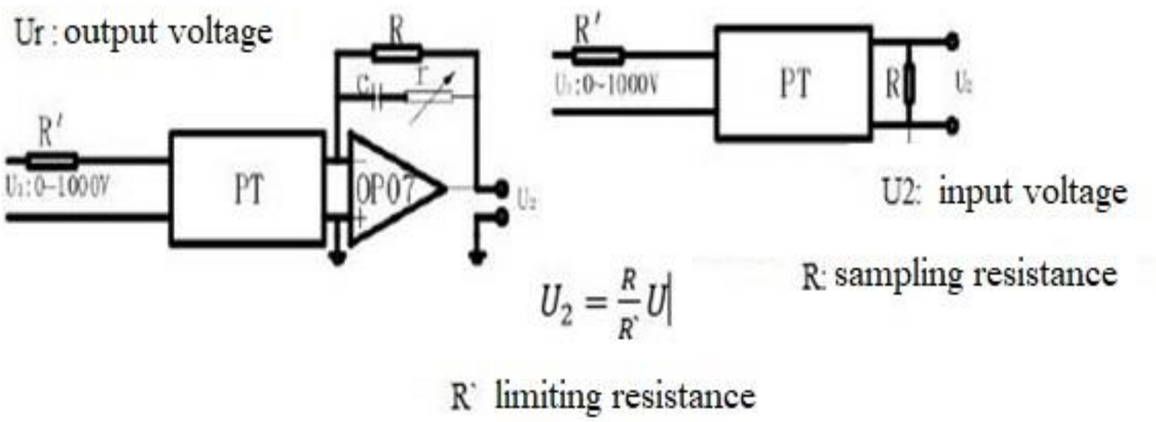


Figure 31: ZMPT101B Sensor Diagram

The input signal to the microprocessor is referred to with a value of 2.5 V. Considering that the Arduino board does not work with negative values, the coupling circuit provides the Arduino inputs with values between 0-5 VAC.

(iv) Current Meter

Current sensors or transducers obtain the value of current that circulates in a conductor, delivering a voltage or current proportional to the current that circulates through the conductor at the output. Due to their ease of use, hall-effect sensors are widely used because are not invasive, clamp type. Although there is also this type of invasive, the driver in which the data is to be acquired must be intervened.

Figure 32 shows the sensor coupling circuit, where the reference point at 2.5 V DC is detailed, to only supply positive voltage values, between 0 and 5 V DC.

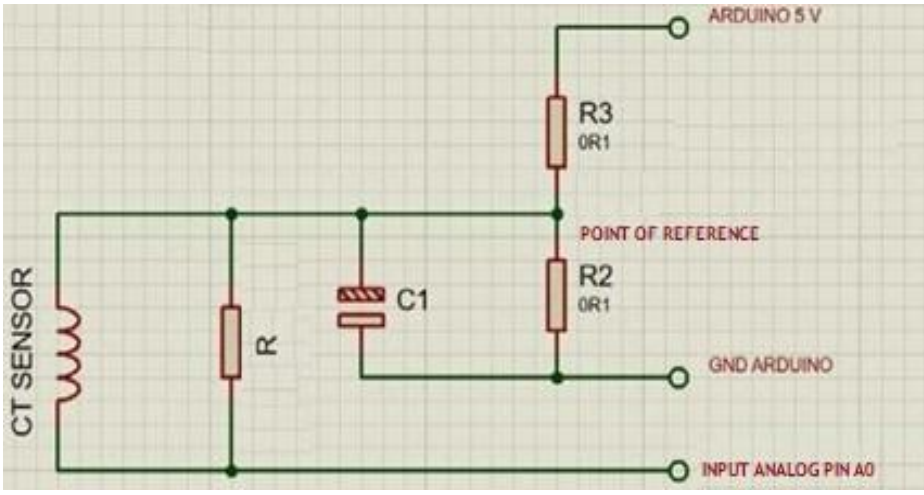


Figure 32: Voltage Measurement Scheme

DATA:

VO = 5 V VREF = 2.5 V

$$VREF = \frac{R2 * V0}{R_1+R_2} \rightarrow R1 = R2 \quad ......(2)$$

(v) Data Processor

To process the data collected by the current and voltage sensors and calculate the energy consumed in the home or specific environments, an Arduino electronic development board was used. Nowadays, Arduino has become one of the boards for the development of electronic projects and is mostly used in the implementation of projects. Its software and hardware are based on free technology. It also provides the user with many libraries that facilitate its use. In addition, it uses the C ++ programming language.

(vi) Arduino Nano

It is a fairly compact plate as can be seen in Fig. 33, with dimensions of 1.83 cm x 4.25 cm. The type of USB connector type B differs from the Arduino UNO by a type B micro power supply jack and its pins are header type (Appendix 3). Arduino nano makes available 14 pins that can be used as digital input or output, out of which, 6 can be used as PWM. In addition, there are 6 analog inputs and a 16 Mhz crystal and most importantly it has an Atmega328P technology processor.

Figure 33: Arduino Nano

(vii) Arduino Integrated Development Environment

For the development of the algorithms for Arduino, there is a free software platform developed by Arduino of the same name. It is of the IDE type (integrated development environment) and allows the user to compile the code and send it to the chip via USB cable. Another tool provided by this software is the serial monitor, which allows quick code performance tests. The programming language is a simplified version of C ++, which allows you to import and use several of its libraries.

3.1.2 Implementation of a Sensor Network, in a Star Topology

The network topology used for the development of this project was a star type configured in an ad-hoc network. This type of network is used to make sensor network configurations:

General monitoring, health, surveillance, etc. Sensor networks are used to optimize resources or when there is no infrastructure mode wireless network, in turn, a Raspberry Pi Zero W is used, configured as a central node, and the sensors was configured as terminals.

For the wireless communication of the sensors, the NRF 24 module was used, which works in the 2.4 GHz frequency. The manufacturer makes available the open-source library tmrh20, which builds the TCP/IP parameters on this wireless module for its configuration, due to its low cost compared to a Zigbee module and similar performance characteristics, this module is quite attractive for use in sensor networks (Saha *et al.*, 2017).

The central node is connected to the terminals both the portables and the main one that fulfills the function of monitoring the energy consumption of the home. Raspberry Pi is in charge of requesting the update of information acquired by the measurement modules every ten minutes. The information is then sent to be stored in the Raspberry pi that generates a text document for each device. The information received from each monitoring module was stored for 60 minutes, after which Raspberry pi sent this information for storage in the cloud (ThingSpeak).

(i) Remote Node Characteristics

To create a network with modularity, it has been decided that the remote nodes are not known. With the intention that each module is independent, if there is a need to replace or modify any node, this process does not affect the operation of the network. It is also achieved with the remote nodes only focusing on the exclusive communication with the central node and if there is a future need to create new modules, the implementation would be easier. The remote nodes was processed and controlled with Arduino nano because it has the necessary characteristics to meet the needs of the proposed network.

(ii) Central Node Characteristics

Since this node is where the different variables collected in the remote nodes converge, the access and management of the information must be promptly and easy. Given the work that the central node is going to perform, it must have the information storage capacity. Based on the required features, Raspberry pi has been chosen for this project because it can provide similar features to a desktop PC and is relatively cheap compared to other devices. The characteristics that the central node must meet are: (a) Connecting to an internet, (b) General-purpose input and output interface, (c) A friendly operating system that allows the management of storage and configuration of the previous characteristics and (d) Low energy consumption.

Raspberry pi uses a micro-SD card for storage, where the operating system created by the same Raspberry developers is installed. Once the Raspberry pi is operational, some parameters must be configured such as: Assigning a static IP, the SSH protocol is enabled to be able to access the command lines remotely. The Raspberry also allows the Internet connection, without forgetting the configuration of general-purpose input and output ports for peripheral control.

(iii) Wireless Communication

Once the platform on which to work had been chosen, the same time they needed for wireless communication means that allows communication between the different nodes was generated. After comparing some alternatives in the market, it was concluded that it is a good option to work with the NRF 24L01 + module, due to its low energy consumption, its low cost. In addition, it has enough power to meet the project requirements. It also has a large amount of documented information available, such as the ease of working with control platforms like Arduino and Raspberry, and all this at a relatively low cost.

(iv) The NRF 24L01 Transceiver Module

It is an electronic device developed by the Nordic Semiconductor company, whose chip integrates a complete transceiver that works in the 2.4 GHz frequency. It is also provided with an LNA preamplifier (low noise amplifier). It has a baseband monitor (Enhanced Shock Burst ™), designed to operate on wireless networks of low energy consumption.

The NRF 24L01 module uses the communication standard SPI (Serial Peripheral Interface) and 8 pins for its connection interface. Figure 34 shows the transceiver. It is small in size and has a long reach.

Figure 34: The NRF 24L01 Transceiver Module

Table 7 presents several of the technical characteristics of the module for wireless communication NRF 24LO1 (Appendix 3).

Table 7: Technical Characteristics of Transceiver

Voltage performance	1.9V-3.3V
Port voltage IO	0 ~ 3.3V/5V
Level of exit	7 dB
Sensitivity RX	≤ -90 dB
Scope	15 – 30 meters, closed spaces up to 100 meters line of sight
The transmission speed of data	250Kbps – 1Mbps up to 2Mbps
Energy consumption	In the order of 20 20 µA

The TMRH20 has developed several libraries that can be used to configure the NRF 24 module to work with Arduino as it is also compatible to work with Raspberry Pi. Table 8 presents TMRH20 libraries and their equivalent in TCP / IP (Saha *et al.*, 2017).

Table 8: The NRF 24L01 Network Libraries

TMRHH20 Library 24 TCP/IP Equivalent	
RF 24 Mesh	Application layer (DHCP)
RF 24 Ethernet	Transport layer
RF 24 Network	Internet / network layer
RF24	Link layer

The NRF chip implements a variation of the ANT protocol (down to the transport layer). Packet routing in the multi-hop network is handled by the TMRH20 library, a driver that implements an algorithm based on the MANET protocol called "Fidelity-based Secure Routing Protocol and Manager" (AFSR), which guarantees secure routing through the network. This help in choosing a manager node based on will and fidelity, after which a node only communicates with that security (Saha *et al.*, 2017).

(v) Serial Protocol Interface Communication Protocol

Serial protocol interface (SPI) communication can be understood as the sending of information from a transmitter and its reception by a receiver, or simply the exchange of information between two devices. The wireless communication protocol used by NRF 24 is the SPI, the serial communication protocol (Fig. 35). Today, it is one of the most popular protocols for communication between microcontrollers due to its simplicity and speed of transmission. The SPI protocol works in full-duplex mode. It allows bidirectional communication between the central node with the remote terminals through different channels. Since it is a synchronous protocol, it has an additional channel for synchronization.

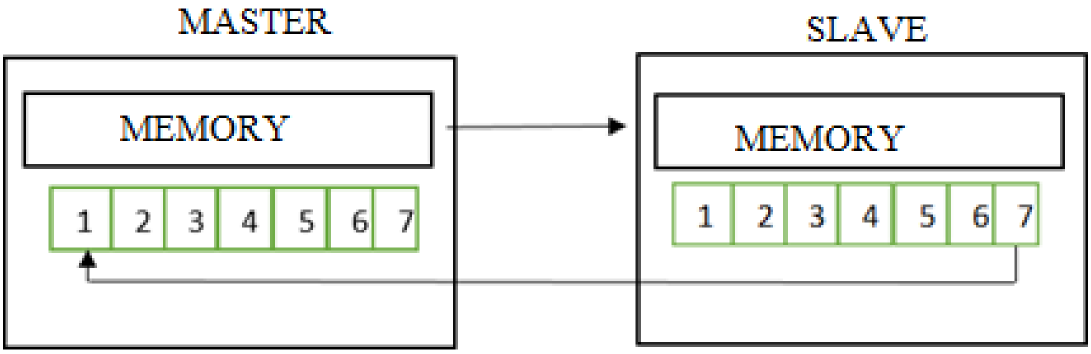


Figure 35: The Main Structure of the SPI Protocol (Sanz Fernández, 2014)

Some other features includes: (a) It has a form of an acknowledgment of receipt system or automatic self-recognition without the intervention of the microcontroller. This system is known as Enhanced Shockurst. When the transmitter sends an information packet, the receiver automatically send a message of having received a data packet (Narayanan & Gayathri, 2013), (b) The verification and validation of the information are carried out through a 3–5-byte address as well as a 1 or 2-byte cyclic redundancy verification code (CRC), (c) It is a six-channel system for data reception, (d) An outdoor transmission rate of 1 to 2 Mbps, (e) It has 125 RF transmission channels and, (f) The chip requires a power supply of between 1.9 and 3.5 VDC.

(vi) Receiving Channels and Data Packets

The NRF 24L01 + wireless communication module has a TX transmission channel and 6 RX reception channels. It can receive information from six different devices, which are duly identified from their origin by the packet address. This allows communication from one device at a time. Figure 36 shows a possible configuration between a central node and six transmitters is illustrated, on the same working frequency.

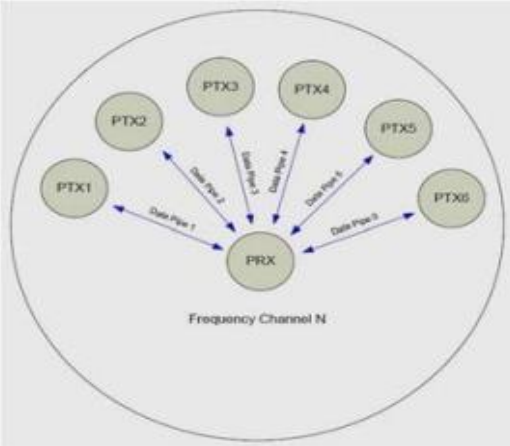


Figure 36: Receiving Information through Various Channels

Sending and receiving information through various channels is feasible thanks to its package structure that includes 3 to 5 bytes (by default 5) for the verification and validation of the information (Fig. 37).

Preamble 1 byte	Address of 3 - 5 bytes	9 bits	Payload 1-32 bytes	CRC 1-2 bytes

Figure 37: Representation of the Data Packet

(vii) Enhanced Stock Burst Protocol

This protocol bases its operation on automatic recognition for the validation, verification, and forwarding of data packets of up to 32 bits. During the data reception process, a security protocol is established to avoid failures. The rest of the information packet is processed when the validation signal has been correctly validated. The CRC verification is, then, carried out, only if is Validation code is correct. The information packet is transferred to the RX FIFO buffer, for transmission or storage.

3.1.3 Internet of Things Platform and its Communication

ThingSpeak is a platform created for the development of IoT projects. This free software platform stores all the information in the cloud, which the user can access in an easy and fast way, being able to use it as it suits him best. The platform data is protected by an API password, which is controlled by the account user. When logging in, the beneficiary can access their information and even download it if necessary. The formats in which people can access the data accumulated in the cloud through application development are CSV or JSON, through APIREST which allows for creating and updating charts and channels. Representative State

Transfer of Type (REST), is an architectural style designed as a request-response model that communicates over HTTP. To use the REST API, the correct keyword is required (TINKSPEAK, 1994-2020). Figure 38 shows the configuration structure of a network of sensors is presented, which publishes the information on an internet server such as ThingSpeak

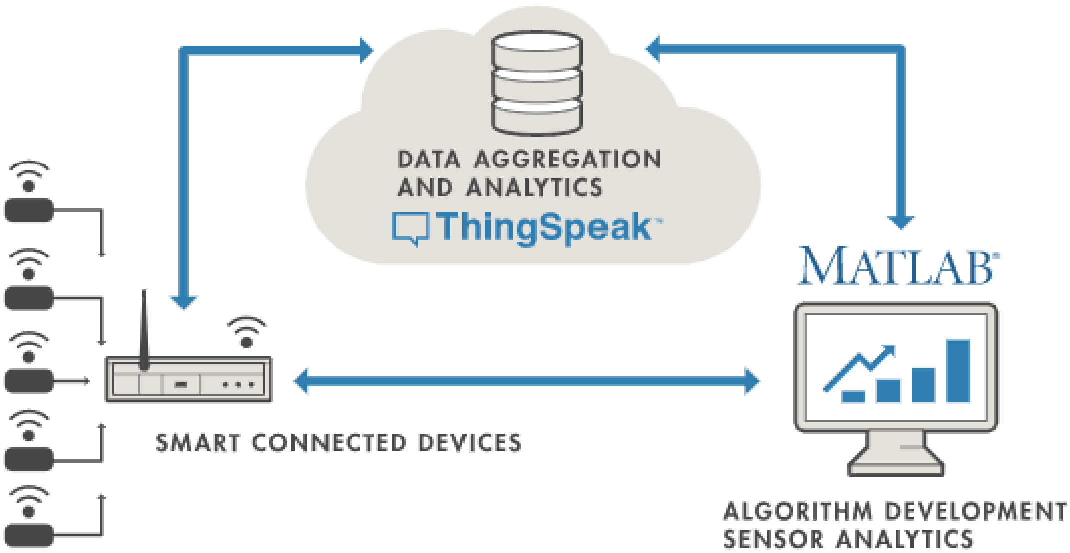


Figure 38: Diagram of Devices Connected to ThingSpeak

ThingSpeak is the storage platform for 8200 messages per day and around 3 000 000 messages per year in its free version and was used in this prototype.

3.1.4 Viewing Energy Consumption Data

To access and display the data stored in the cloud (ThingSpeak), a free-to-use web tool was used. This tool has easy access to its resources, where an application for a cell phone with an Android platform was used. This helped in accessing the account information and present the energy consumption values of each measurement sensor, graphically.

(i) Android Application Development Tool

The design of the cell phone application was carried out on the visual and intuitive online development web platform that has more than six million registered users with a Google or Gmail account. This tool that bases its operation on blocks allows the user to build tablet or mobile apps within no time. The MIT App inventor wants the conventional user not only to use technology but to develop their own. Figure 39 shows the MIT aAPP inventor page logo. Block-based programming seeks the creative intellectual development of young people, children, and fans, who make a difference, thereby achieving a social impact. To access the MTI APP inventor platform, just write the URL address: http://appinventor.mit.edu/, where you just have to click on create applications and have access to the tools for the design of the required application.

Figure 39: Website Logo for APP Development

(ii) Graphical Development Environment

Figure 40 shows the design interface, which is divided into four parts:

(a) Palette is located on the left side of the screen and provides all the necessary components for creating the application.

(b) Viewfinder: This space shows a virtual screen of a cell phone, which allows to visualize the design of the application as well as adding the components that is part of the application.

(c) Components present a list of all the components used for the design of the application.

(d) Properties allow you to select the components, access and modify their properties (text, add images, change colors, etc.).

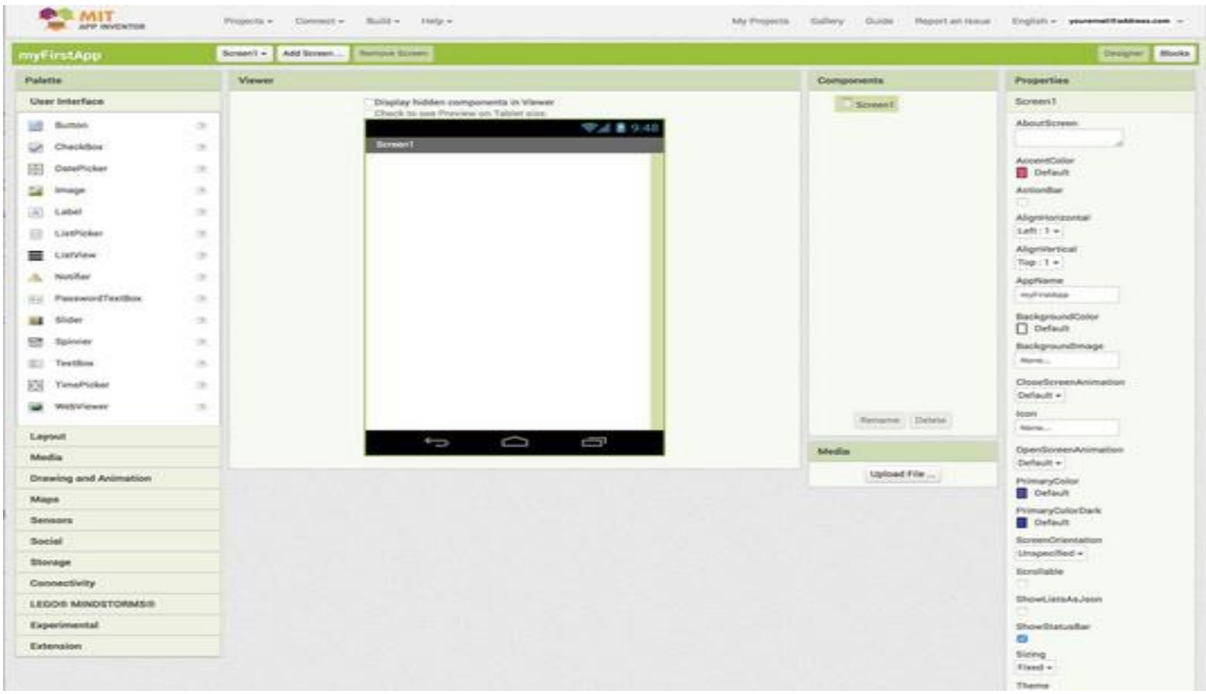


Figure 40: The APP Inventor Interface to Choose Components

Once the application design is completed, the block design continues.

- Block design: Figure 41 shows the environment for programming in the blocks. In particular, it is where the programming that the different elements must comply with is carried out.

▪

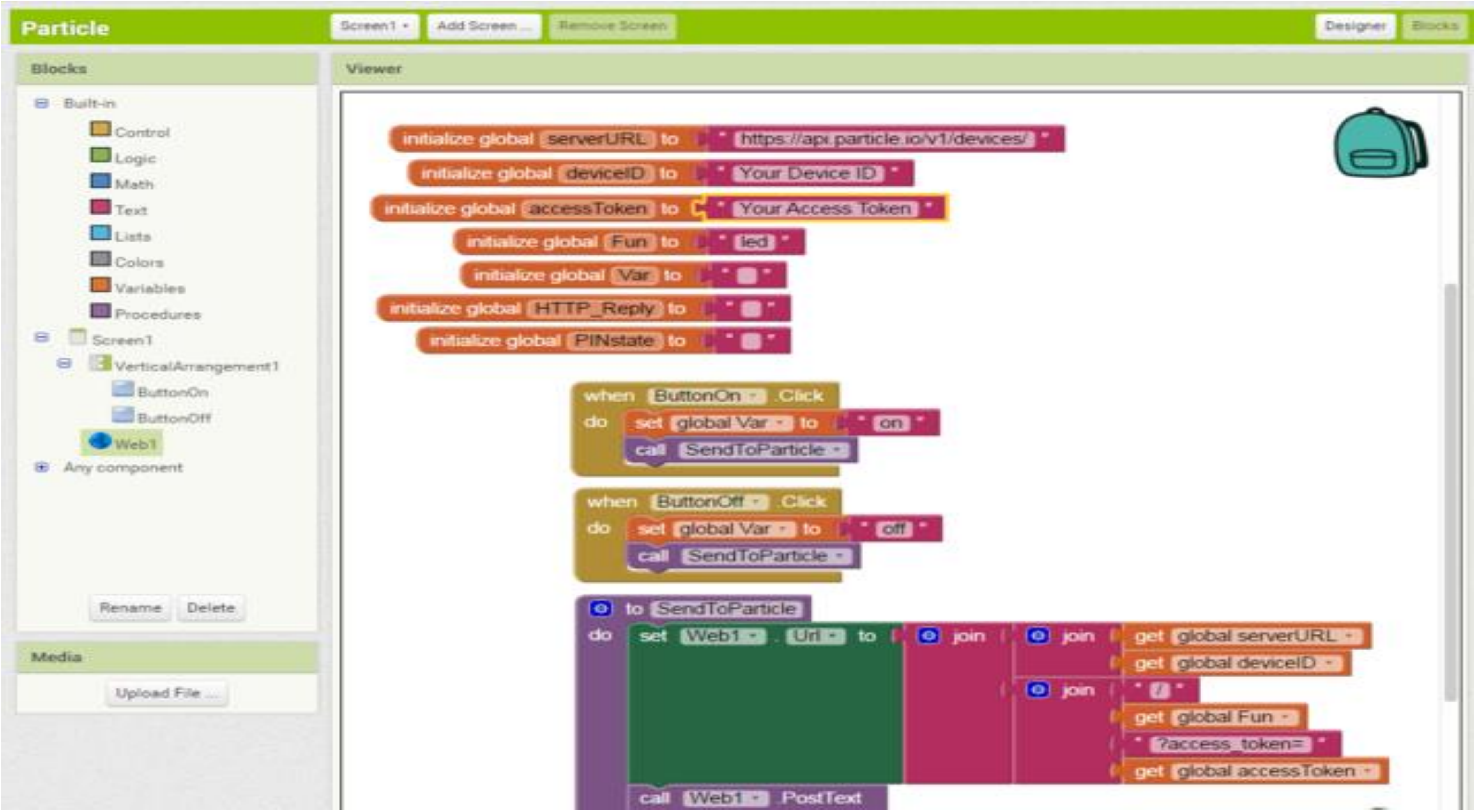


Figure 41: The APP Inventor Interface Block Diagram

- Emulated: Figure 42 present an emulator of the Android operating system where tests are carried out that allow testing the configurations as the program develops.

▪

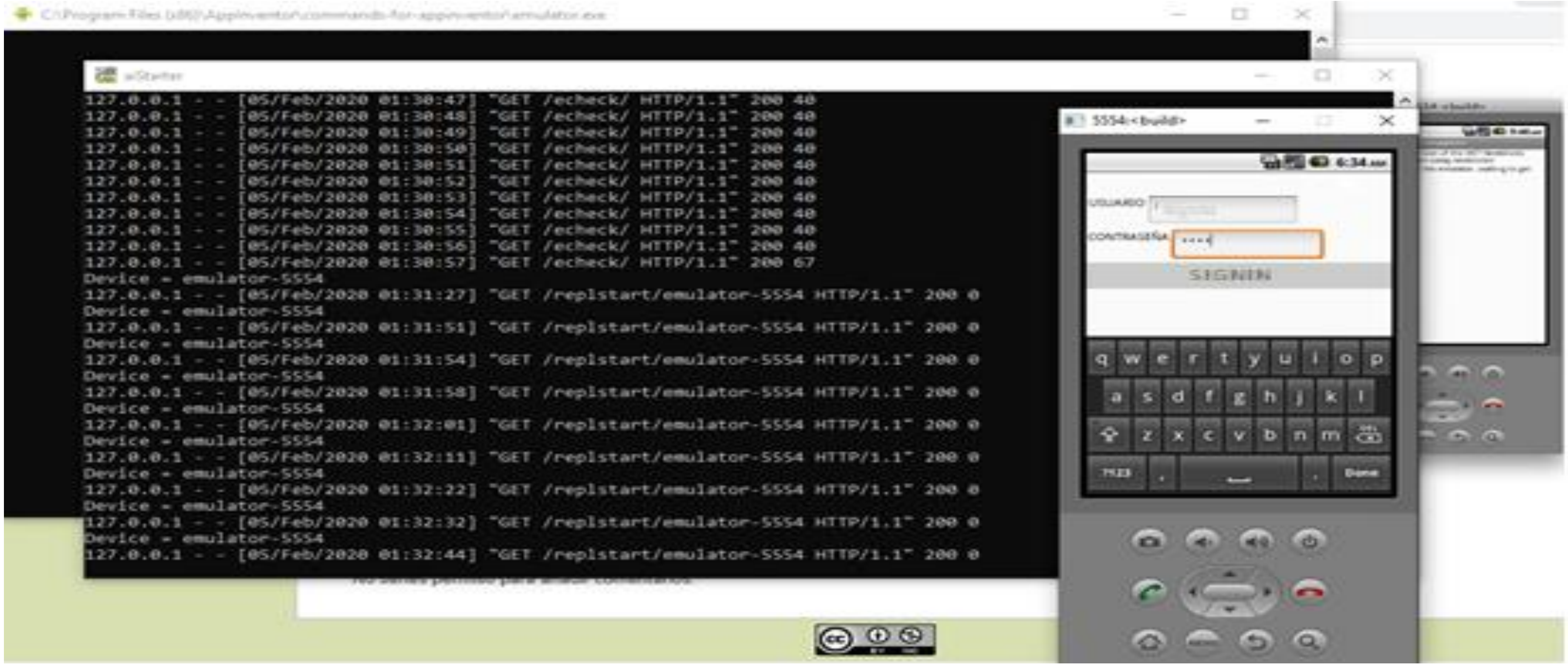


Figure 42: The APP Inventor Simulator Interface

(iii) The App Design Observes Data

To access the information in the database, an application was developed to work on the Android platform and it consisted of:

(a) Environment 1: Figure 43 shows the first user screen, where you must enter a username and a password to access the data stored in the cloud.

Figure 43: Screen Layout 1 user Input

(b) Environment 2: On the second screen as shown in Fig. 44, the user can observe the three monitoring modules. In addition, by using a graphic alarm, one can know which module is active and loaded. From this environment, the user can have access to activate or deactivate any module if he needs to do so.

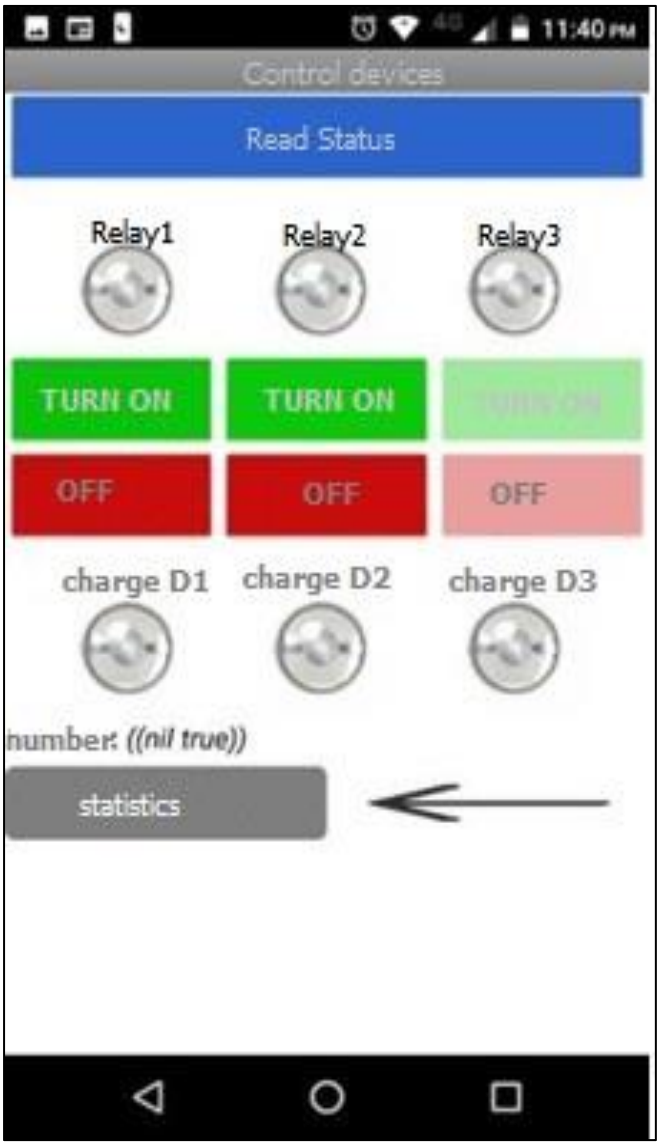


Figure 44: Design Screen 2 Monitoring Device Status

(c) Environment 3: In the third environment as can be seen in Fig. 45, the user can choose the module they want to monitor on a daily, weekly, and monthly basis. The data is then displayed graphically in bars.

(d)

Figure 45: Design Screen 3 data Presentation Status

3.1.5 Consumption Control of the IoT System based on Power Factor Reading

(i) Approach to the Control Scheme

A consumption control model is proposed based on the monitoring of the Power Factor. Through the reading of said variable, it is possible to verify that the set of loads connected to the system does not generate a Power Factor value that is too low, demonstrating a low capacity of said loads to absorb active power. A low Power Factor has negative effects on the distribution line to the houses because higher currents are required to deliver a certain value of power demanded by the load.

For this reason, a surcharge or penalty applied to a specific residence that does not meet a minimum Power Factor is included in the tariff schedule (Fig. 46).

$$FP_r = \begin{cases} P_{B_{FP}} = 0 & si\ FP_r \geq 0.92 \\ P_{B_{FP}} = B_{FP} \times FSPEE_i & si\ FP_r < 0.92 \rightarrow B_{FP} = \dfrac{0.92}{FP_r} - 1 \end{cases}$$

Figure 46: Power Factor Tariff Schedule

As seen in Fig. 46, the penalty for a low power factor applies to consumers whose Power Factor is less than 0.92. Based on this, it is proposed to implement the consumption control scheme precisely at said limit value, to guarantee that the system serves as a guide for the user to avoid being penalized.

Therefore, the consumption control model is proposed as an alert system, capable of notifying the user that the set of loads that have been connected to the system is generating a Power Factor that can lead to a billing penalty by the Electric Company. This consumption control scheme also recommended the value of the capacitor that should be connected in parallel to correct the Power Factor towards a value of 0.92, through the mobile application. Considering the power triangle (Fig. 47), it is possible to define the procedure followed to calculate the capacitor bank.

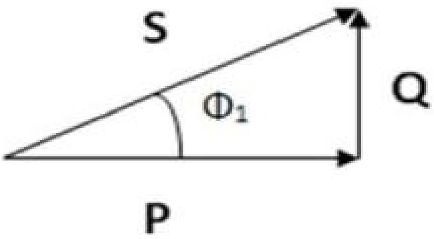


Figure 47: Power Triangle (González, 2008)

The Power Factor delivered by the system is defined as fp.1, while the desired Power Factor is defined as fp. 2, whose relationship with the power triangle is:

$$Fp_1 = Cos\,\varnothing_1$$

$$Fp_2 = Cos\,\varnothing_2$$

On the other hand, reactive powers can be calculated as follows:

$$Tg\,(\varnothing_1) = \frac{Q_1}{P} => Q_1 = Tg\,(\varnothing_1) \cdot P$$

$$Tg\,(\varnothing_2) = \frac{Q_2}{P} => Q_2 = Tg\,(\varnothing_2) \cdot P$$

As such, it is observed that the Reactive Power value to be compensated is given by the difference between the existing Reactive Power, minus P.

R. that one seeks to have. $dif = Q_1 - Q_2$

Finally, the necessary Capacitance value can be determined through the equation:

$$C = \frac{P}{V^2 \cdot \omega}$$

Where P = *diff*, and $\omega = 2 \cdot \pi \cdot f$

(ii) Implementation at the Level of the Service Module

A function is developed for the connection module that allows calculating the desired capacitor value, taking into account the power factor desired to arrive and the power factor that is being obtained at the time the measurement is carried out. This allows the calculation of the reactive power that must be handled, to reach said power factor, and thus, obtain the required reactance value. In the end, the necessary capacitor value is calculated to compensate for the power factor and is within the margins stipulated by law:

$$Q\text{C} = P\text{act}tan\ (\emptyset a) - P\text{act}tan\ (\emptyset d)$$

$$Q\text{c} = V2\ /\ X\text{c} = V2\ /\ (1\ /\ wc)$$

$$C = Q\text{c}\ /\ (V2 * W)$$

(iii) Raspberry and Server Level Implementation

A Python program is developed which requests the calculated capacitor data from the service meter by radio frequency communication. This script runs every hour at minute 57 by using the Crontab and save it in a text file called “capacitor.txt”. In the script "cloud.py" in charge of uploading the energy data to the cloud, was also used to send the capacitor data that is needed to ensure a power factor greater than 0.92. For this, Field 7 of the already used IoT channel of the “ThingSpeak” page is used.

(iv) Implementation at the Mobile Application Level

A function is developed that reads the last data from Field 7 in .xml format from the IoT channel, which was be executed every 20 minutes. If the data received is different from zero, the message of the capacitor that the user needs to put in his connection is notified and thus ensures an fp greater than 0.92 and avoids penalties.

3.1.6 System Automation

For the monitoring system to be autonomous (i.e., the different modules do not need the manipulation of the administrator, but only the different monitoring modules are plugged into the electrical outlet and all its functions begin to work) Cron was used, which starts after the operating system boots.

(i) Cron

Cron comes from the Greek Cronos = time. A Cron is a background process manager program, which allows the execution of activities that have been scheduled to be carried out at a certain time and date. These processes are recorded in the Crontab file.

(ii) Crontab

Crontab is a task scheduler, which uses the Cron daemon to execute such activities. Crontab is a text file where a list of commands runs at times specified by the user. Crontab is responsible for confirming the time, date, and permissions to execute a program. This was done in the background so it is imperceptible for the user to access Crontab. Figure 48 shows the codes to start configuring the Crontab command.

```
pi@raspberrypi:~ $ export EDITOR="nano"
pi@raspberrypi:~ $ crontab -l
no crontab for pi
pi@raspberrypi:~ $ crontab -e
no crontab for pi - using an empty one
```

Figure 48: Command to start the Crontab

Figure 49 present Crontab file where the periods that specific activities are carried out are edited.

```
pi@raspberrypi: ~
  GNU nano 3.2                 /tmp/crontab.yoOzUm/crontab                 Modi

# To define the time you can provide concrete values for
# minute (m), hour (h), day of month (dom), month (mon),
# and day of week (dow) or use '*' in these fields (for 'any').
#
# Notice that tasks will be started based on the cron's system
# daemon's notion of time and timezones.
# For example, you can run a backup of all your user accounts
# at 5 a.m every week with:
# 0 5 * * 1 tar -zcf /var/backups/home.tgz /home/
# m h  dom mon dow   command
```

Figure 49: EditorCrontab text

Where:

m: the minute the script runs, the value from 0-59

h: exact hours, 24-hour format values, 0-23

Sun: the day of the month on which the executed script is specified

mon: the month the script run.

dow: day of the week 0-6 where zero is Sunday.

command: route complete script or command to execute

3.2 Implementation

In this part, the design and implementation of the home energy consumption monitoring prototype based on the Internet of Things are explained. The sequence of steps and procedures for the development of the prototype is detailed below.

3.2.1 Design and Implementation of the Electronic Card of the Main Power Module

Figure 50 shows the design of the electronic energy monitoring card for the electrical connection presented in three dimensions.

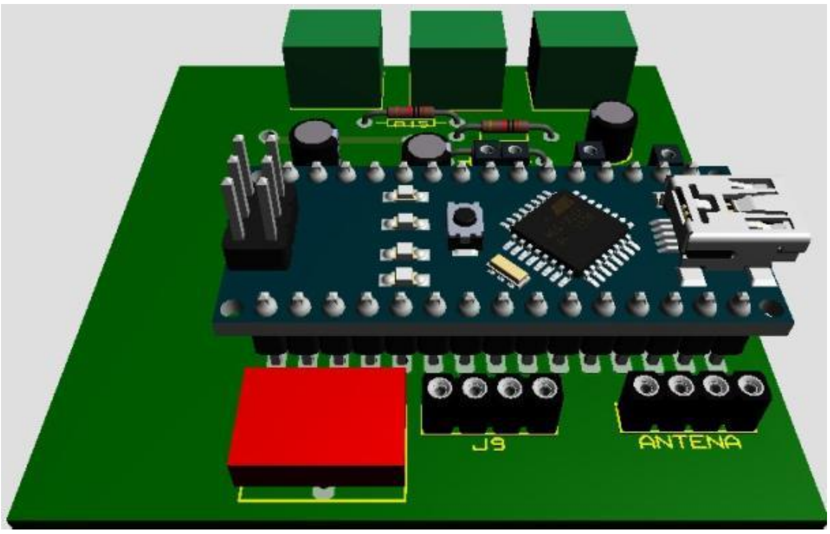


Figure 50: Diagram of the third Resignation of the Secondary Modules Integrating Card

Figure 51 shows the electronic diagram made in the Proteus electronic design.

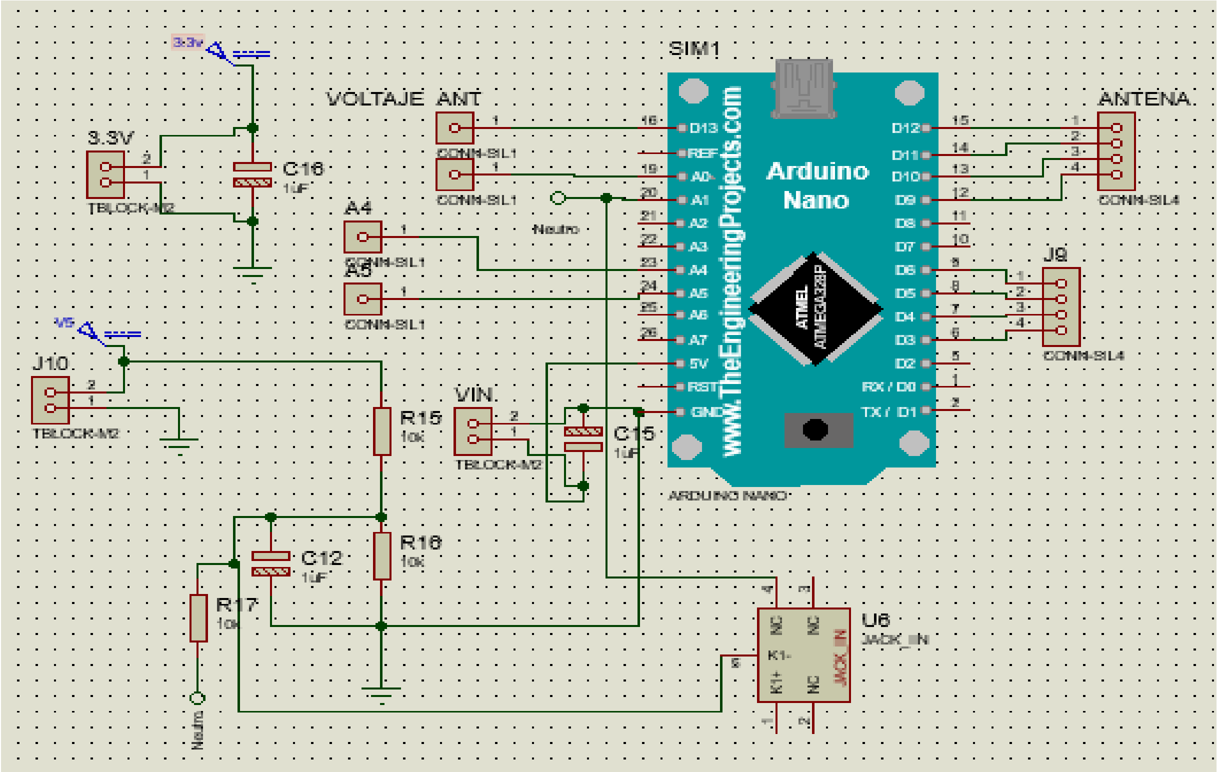


Figure 51: Main Module PCB Board Electronics Diagram

In this module, the consumption information is reported through an LCD. Besides being sent to the cloud, it represents the total current consumed by the three modules, as well as the voltage that is connected in parallel with each point of the residence. This module cannot enable or disable the flow of current to the load, since its function lies solely in monitoring the current that enters the entire installation. Thus, the "Act and Define a Response" stage does not include the configuration of any digital output, since there is no relay installed.

3.2.2 Items to use in the Monitoring Sensor

The following are the items to be used in the monitoring sensor:

(i) SCT013-30A clamp

(ii) ZMPT101B AC Voltage Meter

(iii) Arduino NANO

(iv) NRF 24L01 transceiver

(v) Resistors 10 K

(vi) Resistance 1.5 K

(vii) Capacitor 47Uf

(viii) Module Power Supply Voltage (Switching Source) 5V / 650 mA

(ix) 1 LCD I2C module (For Service module)

(x) 15 A current socket

(xi) 1 meter 14 AWG electrical wire

(xii) connection cables

Figure 52 and 53 present the design of the printed circuit ready to be transferred to a bakelite integrator card for the remote sensors. Figure 53 shows the three-dimensional design of the integrating card. On the other hand, Fig. 52 shows the electronic diagram created in the Proteus electronic design software. This integrating card allows the elements to work together. It also include the additional electronics necessary for each portable monitoring module.

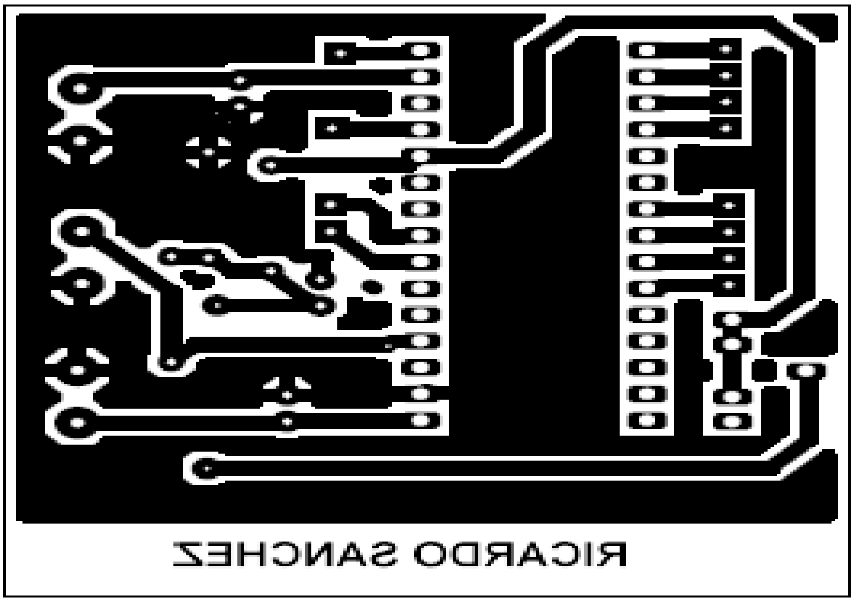


Figure 52: Integrated Card Track Routing Design

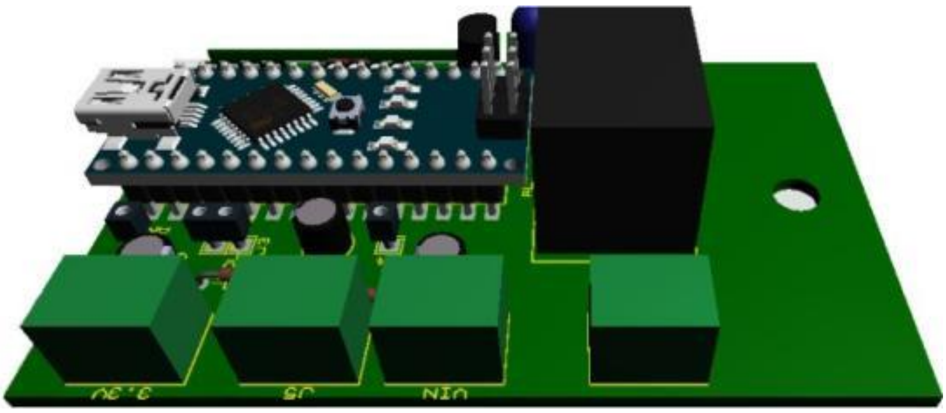


Figure 53: Three-Dimensional Diagram of the Integrating Card, Secondary Modules

3.2.3 Design and Implementation of the Electronic Card of the Remote Energy Modules

Once the materials to be used in this project had been determined, we proceeded to design the PCB.

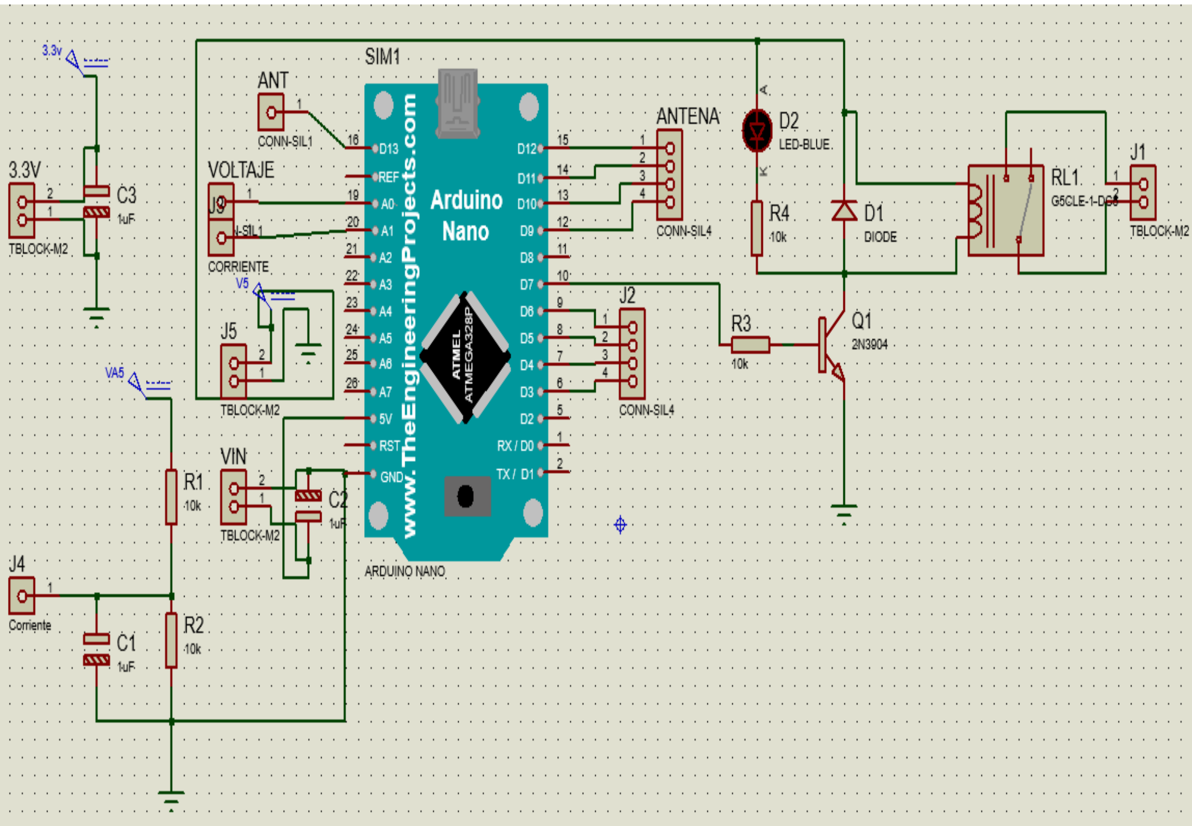


Figure 54: Printed Circuit Board Electronics Diagram

Items to use in the monitoring sensor are:

(i) SCT013-30A clamp

(ii) ZMPT101B AC Voltage Meter

(iii) Arduino NANO

(iv) NRF 24L01 transceiver

(v) resistors 10 K

(vi) 4 resistance 1.5K

(vii) 4 capacitor 47Uf

(viii) 4 transistor 2N2222A

(ix) 4 diode Common Use 1N4007

(x) relay 5V / 15 A @ 110 V AC

(xi) module Power Voltage (Switching Source) 5V / 650 mA

(xii) 1 LCD I2C module (For Service module)

(xiii) 15 A current socket

(xiv) 1 meter of 14 AWG Electrical Cable

(xv) Connection cables

Figure 55 shows the design of the printed circuit for the remote sensors made in Proteus. This is transferred to the bakelite using one of the transfers printing techniques and then using a chemical process to remove the excess copper.

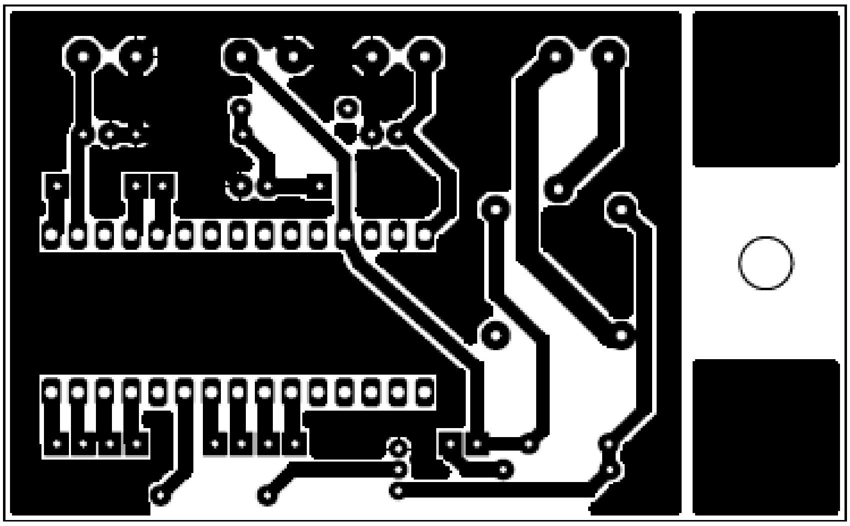


Figure 55: Integrated Card Track Routing Design

Figure 56 shows the process of elaboration of the printed circuit carried out.

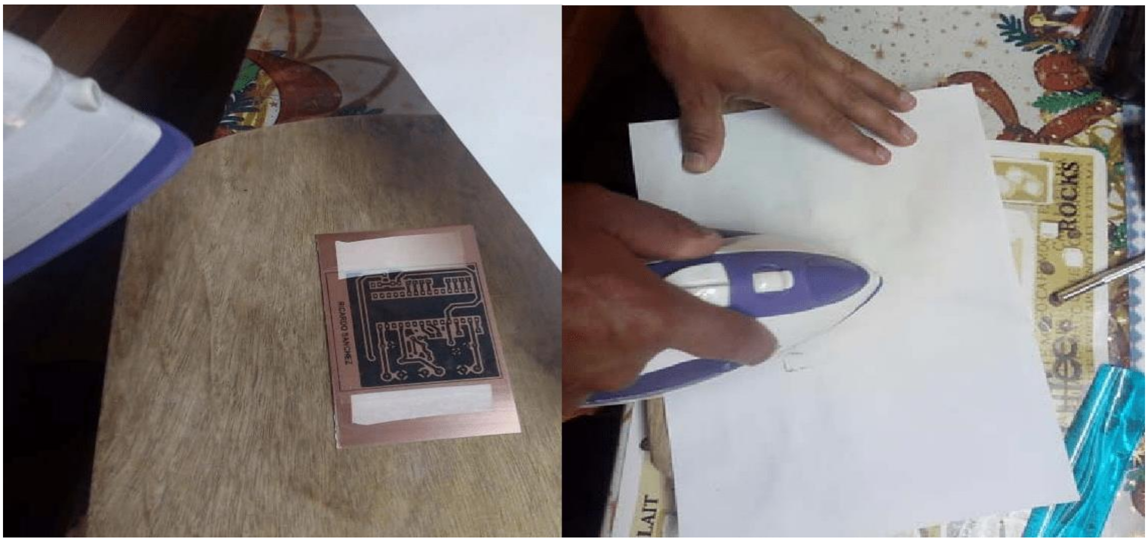


Figure 56: Bakelite Heat Printing

Figure 57 shows the copper cleaning process.

Figure 57: Chemical Process Copper Removal

Once the chemical process has concluded, the surface is cleaned with the help of water sandpaper, to remove all excess acid, ink from the permanent marker, to proceed to the perforation, and weld, the elements welded to the bakelite. This is evidenced in Fig. 58.

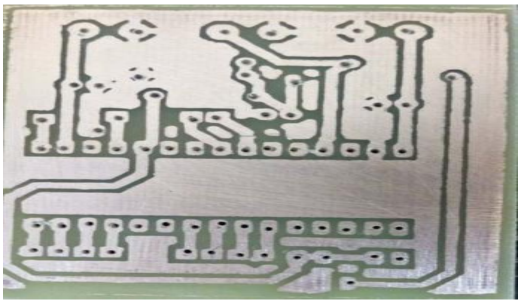


Figure 58: Bakelite Ready for Element Welding

This electronic card preparation process is used for all other devices. Figure 59 show the rear and front images of the integrating card and the elements that make up the monitoring sensors.

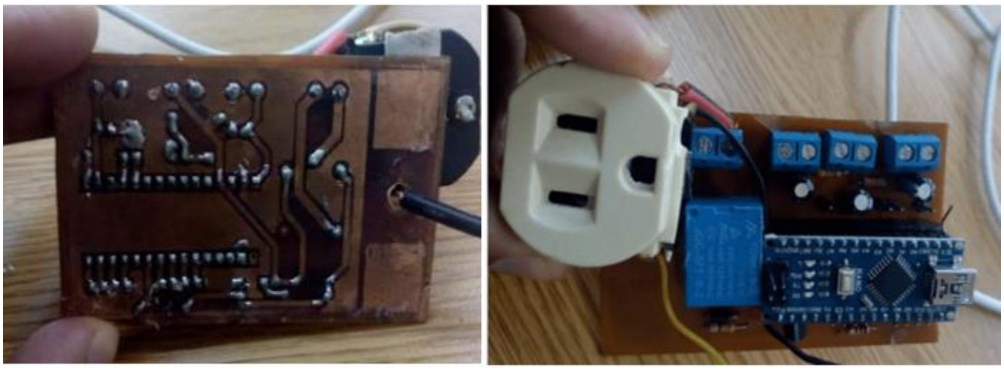


Figure 59: Integrated Card Track Routing Design

Assembly and functional tests of the different electronic modules, of communication between the electronic card and the central node are shown in Fig. 60.

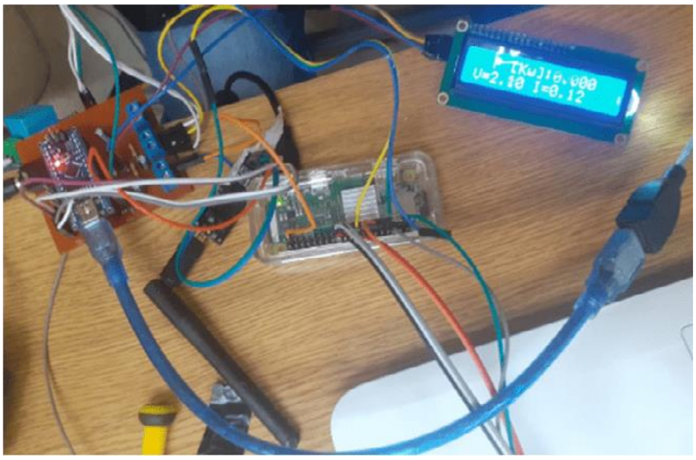


Figure 60: Implementation of the Main Module

The completed modules are shown below: Figure 61 with the main module and the remote sensor located.

Figure 61: Remote module

3.2.4 Software Implementation of the Data Acquisition Prototype

Figure 62 shows the block diagram that explains the operation of the programming algorithm in the remote power modules (Appendix 6).

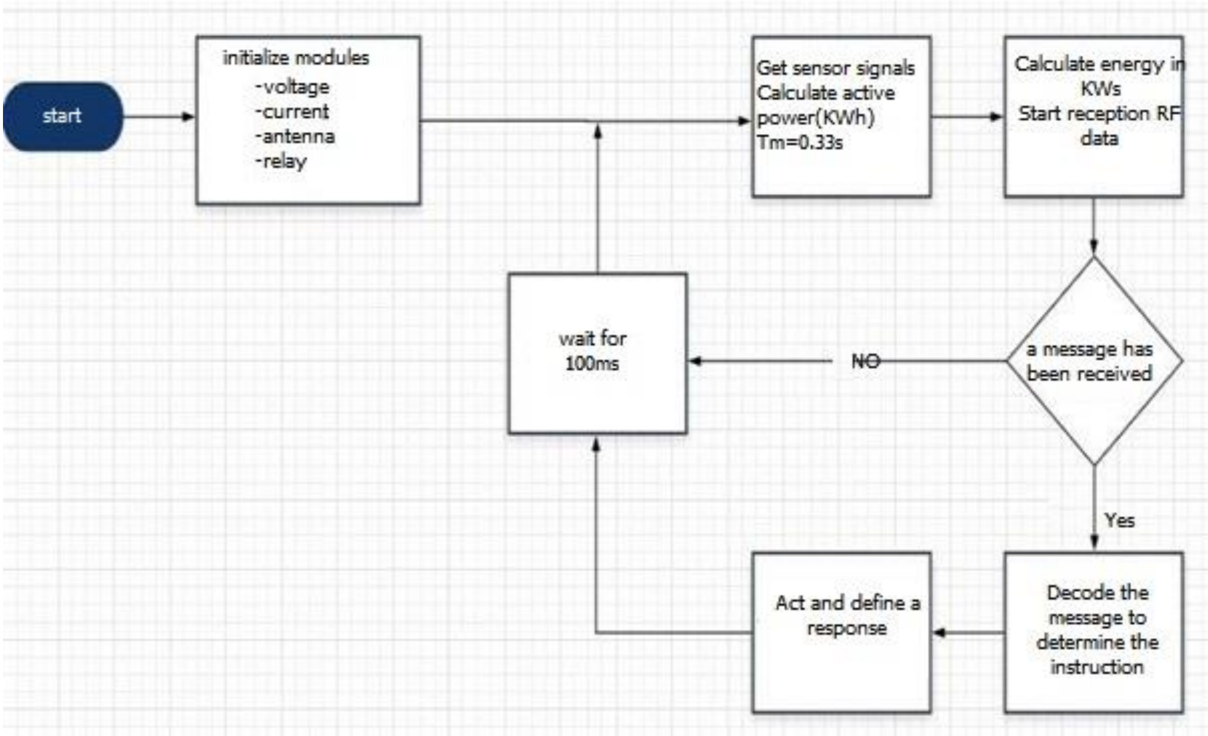


Figure 62: Remote Modules Block Diagram

The stages are briefly described:

(i) Initialize Modules

Only stage outside the normal operating loop of the Arduino, where each of the inputs (digital and analog) is configured as digital outputs necessary to perform all the measurement, control, and communication actions.

(ii) Calculate Power

The first stage within the repetition loop consists of the process of acquiring the analog signals with a sampling time of 0.33 [s], equivalent to 3.03 Hz. Once the Voltage and Current signals have been decoded, the calculation is carried out with Active Power, fundamental data for the operation of the system.

(iii) Calculate Energy

The stages are described as follow:

Start Reception:

During this stage, the discrete calculation of Energy is carried out using an "accumulator" variable of the power values obtained over time. To avoid saturation of this variable, the data is sent for 10 min. To do this, the central module sends the corresponding instruction to each slave device, so that said device sends the calculated energy variable and proceeds to wax said value.

A message has been Received

At this point, it is determined if there is an instruction from the central node (Raspberry), from which the corresponding decisions are made. In the absence of a command, the system goes to the final stage, otherwise, it is acted upon according to the instruction.

Decode the Message

This stage involves all the necessary processes to determine what type of instruction is contained in the message that has arrived. This verifies exactly what is being requested from the device. Instructions include: Report Power, Turn On Load, Turn Off Load.

Act and Define Response

In this stage, in particular, we proceed to act according to the instruction given, configuring the digital output in such a way that conduction through the relay is allowed or prevented.

Wait 100 ms

Small delay applied to guarantee the operation of the programming loop based on possible external interruptions due to the communication element.

Figure 63 shows the libraries required for the elaboration of the algorithm. The different variables are also defined, storing the values of voltage, current, power, time, energy, and energy consumption.

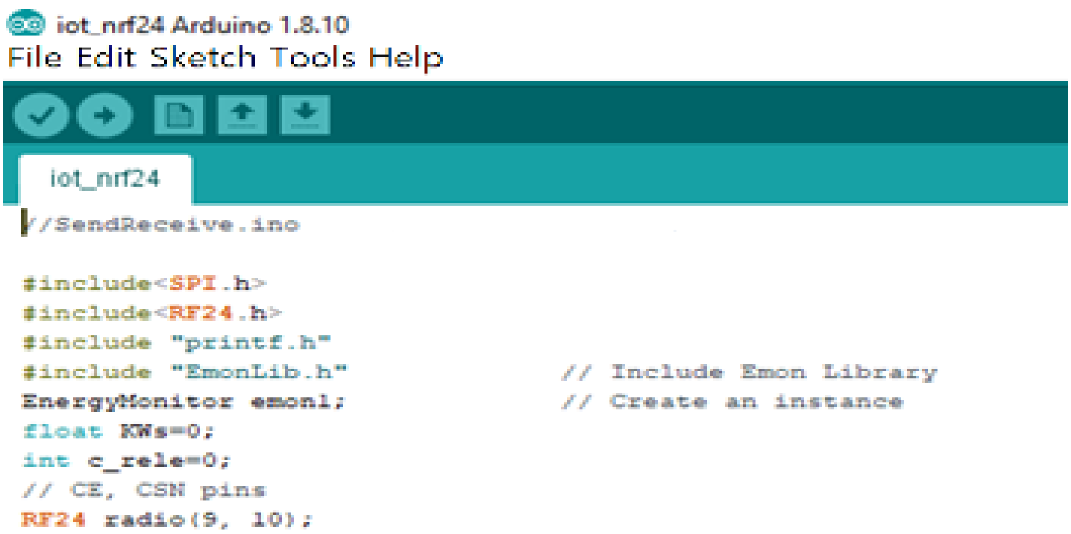


Figure 63: Library "EmonLib" on Arduino

Next, the code developed for the Arduino NANO board contained in each measurement element without display is presented.

3.2.5 Software Implementation of the Prototype for Service

The algorithm of operation can be explained through the following block diagram as shown in Fig. 64. It is essentially similar to the previous one, only that this module reports consumption visually through an LCD:

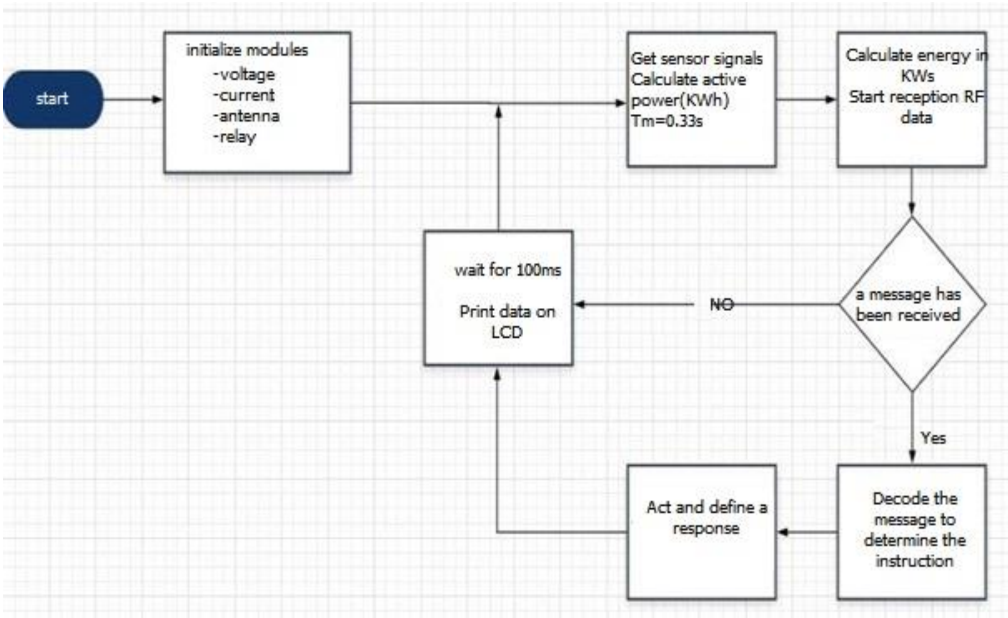


Figure 64: Flowmeter Block Diagram

This module differs, among other things, in the fact that consumption information is reported through an LCD, in addition to being sent to the cloud. The information obtained through this module represents the total current consumed by the three modules, as well as the voltage that is connected in parallel with each point of the residence.

This module cannot enable/disable the flow of current to the load, since its function lies solely in monitoring the current that enters the entire installation. Thus, the "Act and Define a Response" stage does not include the configuration of any digital output, since there is no relay installed.

3.2.6 Calibration

Once the different libraries and variables have been defined, the voltage and current sensors are calibrated. This is done following technical specifications provided by the manufacturer, as well as carrying out necessary calibrations. Before starting the calibration process, certain safety factors must be considered to avoid electrocutions. Some of the factors include:

manipulating the electrical network where the line voltage has a magnitude of approximately 120 VAC could be dangerous, placing a load resistor to reduce the value of current delivered to the output of the sensor terminals, reducing the output current, and obtaining a voltage at the output of 1 VAC referenced to 2.5 Vdc, which is delivered to the analog inputs of the processor that only uses positive values up to five volts. Figure 65 shows the connection diagram for the current and voltage sensor is presented.

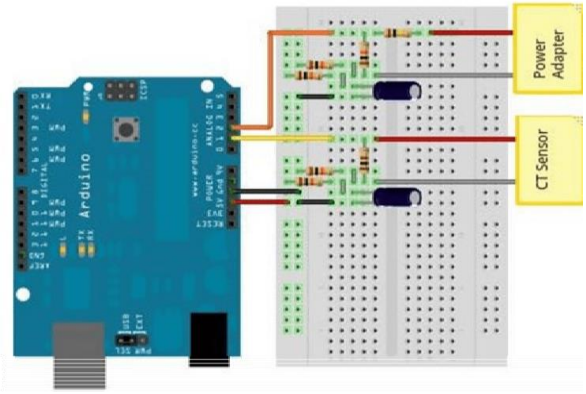


Figure 65: Diagram for Connection of current and Voltage Sensors

(i) Current Sensor Calibration

The current sensor that was used in the project is from the SCT 013 family. The calculation of the calibration factor is carried out taking into account that at the sensor output the voltage to be manipulated is approximately 1 VAC. The procedure is as follows: (a) The nominal current of the primary is divided by the voltage of the secondary (voltage is calculated from the current through the secondary winding by the load resistance) and, (b) For the SCT 30A/1V sensor, it is not necessary to calculate the load resistance since it is already included in the factory and delivers 1 VAC. The aforementioned is represented in the equation for the calculation of the value of the current constant:

$$\text{Current Constant} = 30\ [A] \cong 30\ [N * m]$$

$$1\ [V]\ C$$

(ii) Voltage Sensor Calibration

The sensor that was used to read the voltage entering the system is the AC voltage transformer - ZMPT101B. Similarly, to calculate the voltage value of the input to the analog signal A0, the Arduino's value must be considered at the input of this Open Energy Monitor (the signal of the voltage of the electrical network is divided by the voltage of the signal that must enter the analog input A0):

$$\text{Voltage constant} = \frac{120\ [V]}{1\ [V]} \cong 120$$

Figure 66 shows the value of the calibration constants observed for the voltage sensor as for the current sensor, the values may vary from the calculated due to the nature of the materials, to validate the measured values the different measurement tests were carried out, which in from practice it can be observed that the value of the constant for the voltage is 154 and the calibration constant for the current sensor is 27.

```
void setup(void){
  pinMode(7,OUTPUT);
  emon1.voltage(A0, 164.5, 0);   //
  emon1.current(A1, 29);        // C
  printf_begin();
  while(!Serial);
  Serial.begin(9600);
```

Figure 66: Programming Code, Sensor Calibration

In Table 9 the calibration constants for each of the monitoring sensors are described.

Table 9: Calibration Constants

	Calibration Content	
Device	**Voltage**	**Current**
Main Module	159	29
Module 1	164	28
Module 2	151	28
Module 3	151	29

In the functional test, once the calibration of the data acquisition sensors is finished, measurements are made of the values they acquire and they are compared with the theoretical or nominal values of the loads.

Module 1

Load 1: 40W incandescent lamp:

$$P = V * I \ldots\ldots\ldots(3)$$

$$I\ [A] = \frac{40\ [W]}{120\ [V]} = 0.33\ [A]$$

Figures 67 and 68 show the measurement of current and voltage respectively is evidenced, in addition to the parameters obtained for Module 1.

Figure 67: Measurement of Current in Milliamps

Figure 68: Voltage Measurement

The error calculation is done with the equation shown below:

$$E\% = \left(\frac{\text{Calculated - Measured}}{\text{Calculated}}\right)$$

I Calculated [A] I measured [A]

0.330.33

Stream reading error:

$$E\% = \left(\frac{0.333-0.336}{0.333}\right) = 0.9\%$$

Power

Nominal Power [W]	Measured Power [W]
4040.5	

Calculated power error:

$$E\% = \left(\frac{40 - 40.5}{40}\right) = 1.25\%$$

Module 2:

I Calculated [A] I measured [A]

0.330.33

$$E\% = \left(\frac{0.333-0.334}{0.333}\right) = 0.3\%$$

Nominal Power [W]	Measured Power [W]
4039.89	

$$E\% = \left(\frac{40-39.89}{40}\right) = 0.27\%$$

Module 3:

I Calculated [A] I measure [A]

0.3330.34

$$E\% = \left(\frac{0.333-0.34}{0.333}\right) = 0.3\%$$

Nominal Power [W]	Measured Power [W]
4041.75	

$$E\% = \left(\frac{40-41.75}{41.75}\right) = 4.37\%$$

(iii) Calculation of Power and Energy

Figure 69 shows the parameters calculated by the programming algorithm, which measures and calculates all the parameters that intervene in the power triangle presented in Chapter 1. These values are stored in the different variables of the program and are used in the consumption calculations of energy.

```
float starttime=millis()/1000;
emon1.calcVI(20,2000);         // Calculate all. No.of half wavelengths (crossings), time-out
/ emon1.serialprint();          // Print out all variables (realpower, apparent power, Vrms, Irms, power factor)
float realPower       = emon1.realPower;        //extract Real Power into variable
```

Figure 69: Programming Code, Real Power Calculation

Of all the calculated parameters, only the value of the real power is considered, which is multiplied by the time variable to obtain the energy consumed up at the moment. Figure 70 shows a part of the programming language where the energy calculation is carried out. The algorithm to calculate the time is also observed and it is stored in kWs, it is worth noting that it has been decided to handle the energy consumption value, with the reference of time in seconds since the value in kWh is very small.

Therefore, it is converted to kWs so that it is not so negligible. This process is carried out until the moment it receives a message of sending and receiving from and to the server for storage. Once the reception of said variable has been sent and confirmed, the central node sends a new message to reset the energy account and restart the process.

```
void loop(void){
  emon1.calcVI(20,2000);         // Calculate all. No.of half wavelengtl
  //emon1.serialprint();          // Print out all variables (realpowe
  float realPower       = emon1.realPower;
  float supplyVoltage   = emon1.Vrms; //extract Vrms into Variable
  float Irms            = emon1.Irms;//extract Real Power into variable
  float powerFActor     = emon1.powerFactor;
  float endtime=millis()/1000;
  if (endtime-starttime >=1){
  KWs= realPower/1000+KWs;
  starttime=millis()/1000;
  }
```

Figure 70: Programming Code, Energy Calculation

3.2.7 Node Network Configuration

The steps are described in the node network configuration:

(i) Step 1

The operating system and necessary settings are installed on the Raspberry Pi Zero W, and then proceed to connect the NRF 24L01 + for wireless communication to the Raspberry Pi as shown in Fig. 71.

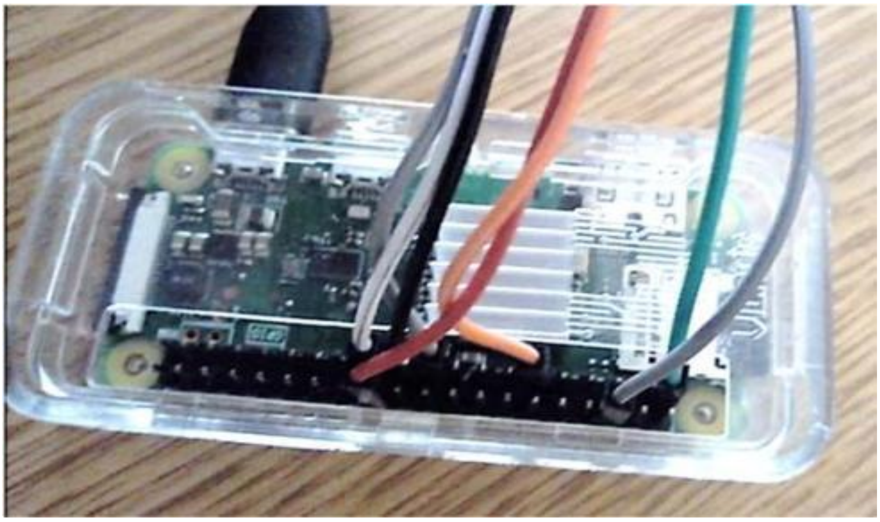


Figure 71: Connecting the NRF 24L01 + Module to the Raspberry pi

(ii) Step 2

In the same way as the Raspberry server, we proceed to connect the NRF 24L01 + module to the integrator board with Arduino of each of the energy monitoring modules, as shown in Fig. 72. This procedure was carried out based on the material provided by the developer of the TMRh20 library.

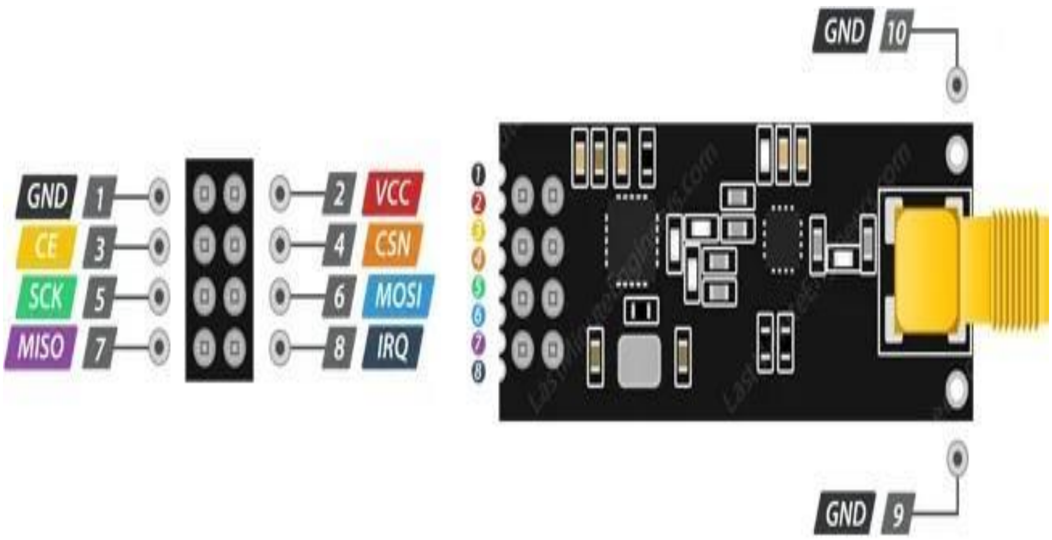


Figure 72: The NRF 24L01 + Modules Pinout

Table 10 presents a summary of the pin distribution and connections of the wireless device with the boards that was used as nodes of the sensor network.

Table 10: Wireless Card Connection Arrangement with the Different Boards used as Nodes

Number of Pins	Pin arrangement NRF 24l01 +	Pin arrangement Arduino nano	Pin arrangement Raspberry Pi
1	GND	GND	6
2	VCC	3.3V	1
3	EC	D9	eleven
4	CSN	D10	24
5	SCK	D13	23
6	MOSI	D11	19
7	MISO	D12	twenty-one
8	IRQ	-	

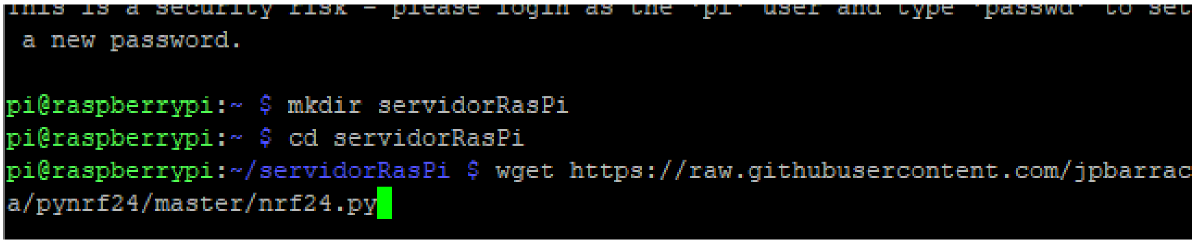
When solving the hardware problem, we continued with the configuration stage for communication between the remote nodes and the central

3.2.8 Wireless Communication

First, bidirectional wireless communication must be established between the central node (server) and Arduino nano used as a sensor. The command executor (the Python programming language) for Raspberry was used and for programming, in Arduino, the own programming language was used from Arduino. The procedure that must be followed on the Raspberry pi includes: (a) Install and configure the libraries required for the control of NRF 24L01 +, (b) Install and configure the required libraries for general-purpose input/output (GPIO) control, and (c) Execution of the Program. The procedure that must be followed in the Arduino includes: (a) Installation and configuration of NRF 24L01 + libraries, (b) Execution of the Program and, (c) Bidirectional communication test.

(i) Install and Configure the Required Libraries to Control NRF 24L01 + on Raspberry pi

To use the existing resources and give the nodes of the wireless network greater functionality, a program was developed that allows calling the functions of the TMRH20 library, with which communication between nodes is carried out. The first thing that must be done is the installation of libraries for communication and activation of GPIO inputs. Some parts of the procedure used are observed in the text console and the different commands used for the installation of the NRF 24 library (Fig. 73).



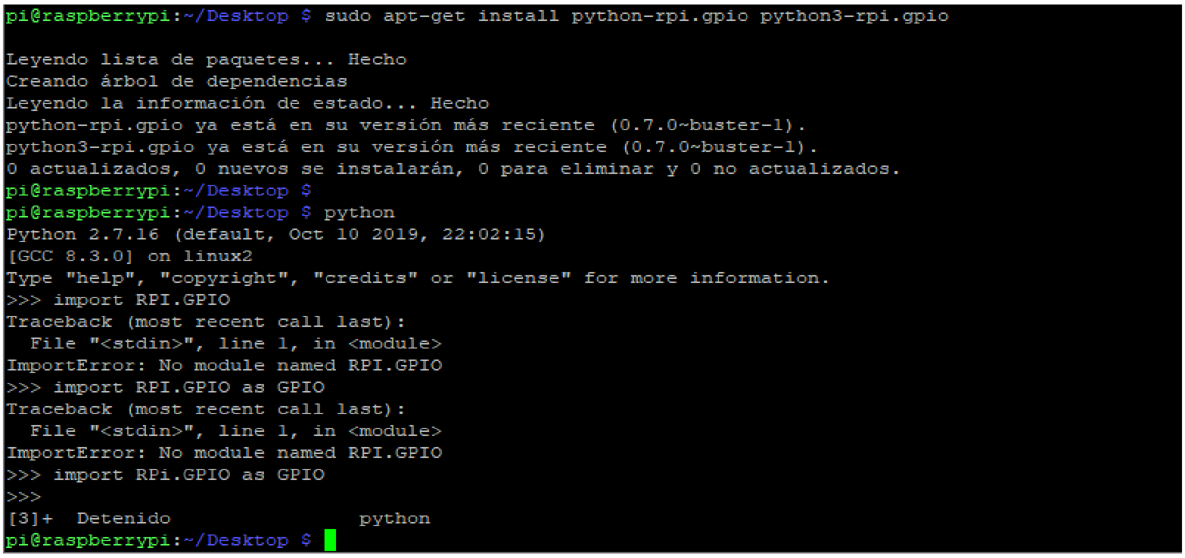
```
This is a security risk - please login as the 'pi' user and type 'passwd' to set
 a new password.

pi@raspberrypi:~ $ mkdir servidorRasPi
pi@raspberrypi:~ $ cd servidorRasPi
pi@raspberrypi:~/servidorRasPi $ wget https://raw.githubusercontent.com/jpbarrac
a/pynrf24/master/nrf24.py
```

Figure 73: Communication Library Installation

For addressing the NRF 24 wireless modules, they use 40 bits, that is, 5 bytes are required for each address. There is also a wide range of addresses to use.

(ii) Install and Configure the Required Libraries for General-Purpose Input/Output Control

These libraries (Fig. 74) allow you to designate what function the different general-purpose pins of the Raspberry board fulfill. In this case, they are used to control, send and receive packets through the use of the wireless communication library. The assignment of the pins is made according to the recommendations manufacturer.



```
pi@raspberrypi:~/Desktop $ sudo apt-get install python-rpi.gpio python3-rpi.gpio

Leyendo lista de paquetes... Hecho
Creando árbol de dependencias
Leyendo la información de estado... Hecho
python-rpi.gpio ya está en su versión más reciente (0.7.0~buster-1).
python3-rpi.gpio ya está en su versión más reciente (0.7.0~buster-1).
0 actualizados, 0 nuevos se instalarán, 0 para eliminar y 0 no actualizados.
pi@raspberrypi:~/Desktop $
pi@raspberrypi:~/Desktop $ python
Python 2.7.16 (default, Oct 10 2019, 22:02:15)
[GCC 8.3.0] on linux2
Type "help", "copyright", "credits" or "license" for more information.
>>> import RPI.GPIO
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
ImportError: No module named RPI.GPIO
>>> import RPI.GPIO as GPIO
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
ImportError: No module named RPI.GPIO
>>> import RPi.GPIO as GPIO
>>>
[3]+  Detenido                python
pi@raspberrypi:~/Desktop $
```

Figure 74: Installation of GPIO Libraries

(iii) Running the Program

Figure 75 shows the Python library, as well as some other parameters such as the addresses of the different modules to which data is sent and received. The communication channel has also been configured.

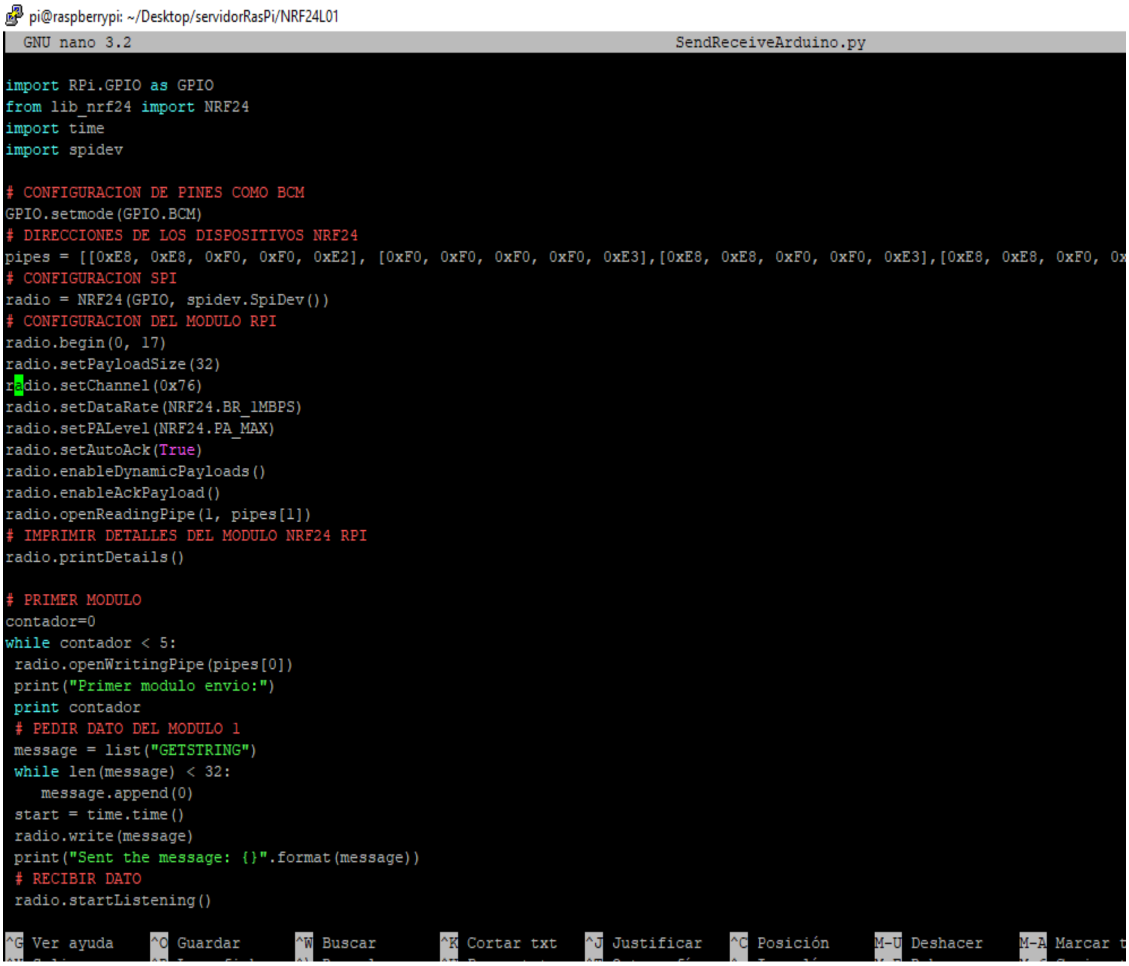


Figure 75: Python Library for NRF 24

Table 11 displays the addresses used in addressing between the server and the terminals.

Table 11: Addressing Table

Node	Address
Teacher	0xf0f0f0f0e3
Device 1	0xe8e8f0f0e2
Device 2	0xe8e8f0f0e3
Device 3	0xe8e8f0f0e4
Device 4	0xe8e8f0f0e5

The wireless module has 125 channels at its disposal. The 125 central nodes could be implemented working at the same time with total independence between them. Each channel can use up to six addresses (i.e., the central node can communicate with up to six terminal nodes at the same time).

(iv) Installation and Configuration of NRF 24L01 + Libraries on Arduino

For updating the libraries (Fig. 76), the tool used for the programming software provided by its manufacturer was used to access the updates to the libraries and install new ones, such as the one required to control the NRF 24L01 + communication card.

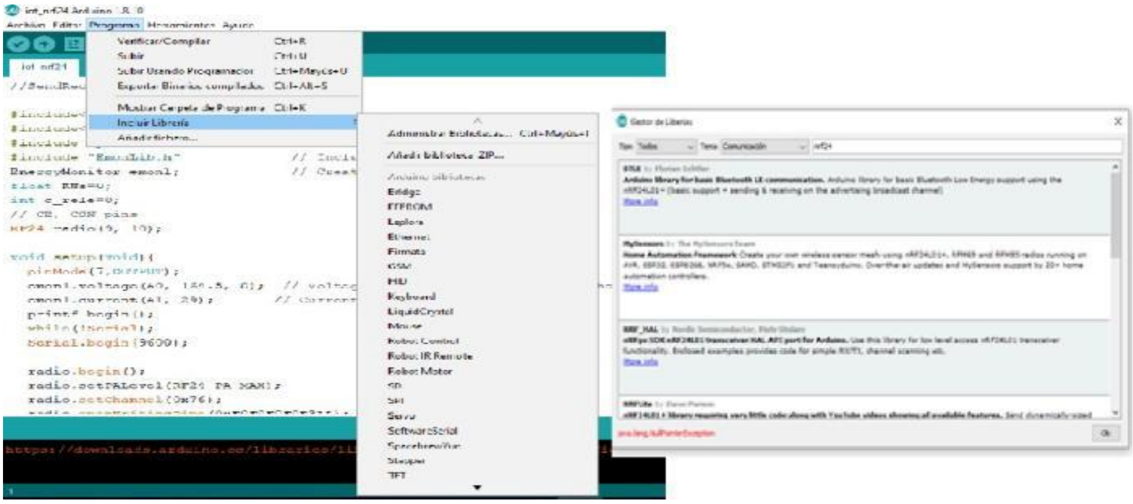


Figure 76: **Arduino Library Manager**

(v) Execution of the Program

Once the required libraries have been updated correctly, we proceeded to enter the parameters that allow communication between the server and the remote terminals. Figure 77 presents configuration of the addressing parameters between the server and the terminal as well as the communication channel is registered.

Figure 77: **Execution of the NRF 24L01 Library**

3.2.9 Bidirectional Communication Test

The communication test between the server and the monitoring terminal is done by sending an encoded verification message from the server to the terminal. The said message is received and decoded. If the message is false, the terminal sends a message back to the server with an error message, again requesting the server to resend the message. This process is repeated until the receiver correctly receives and reads the message. The terminal sends back a correctly received message. This process is carried out in the same way for all terminals. Figure 78 shows the communication test between the server and the sensor.

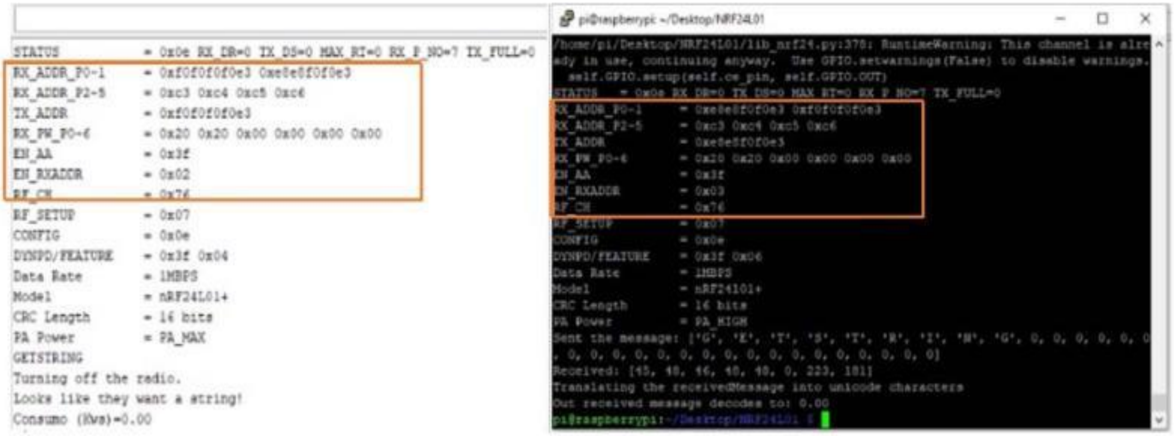


Figure 78: Wireless Modules Connection Tests

3.2.10 Receiving and Sending Data from Arduino to Raspberry and Vice Versa

Each energy meter takes the values from the network through sensors and they are stored in variables defined in the program. Through the NRF 24 communication library, the data is encoded and sent to the server, where the information is decoded, as shown in Fig. 79. The data is then stored in a text-type document, creating a document for each energy measurement module. This procedure is carried out every 10 minutes. The server sends a “getstring” message to the terminals, they validate the received message and send the information.

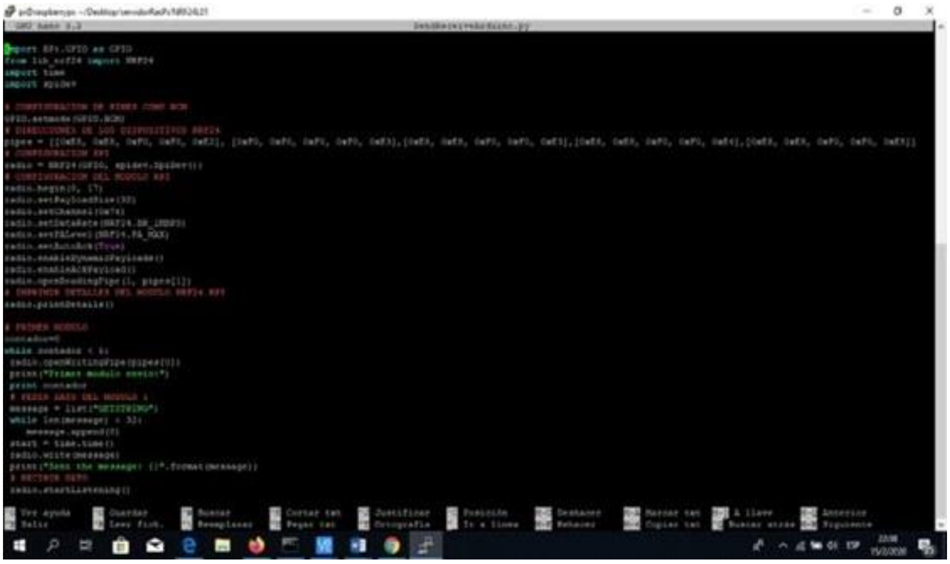


Figure 79: **Programming Algorithm Sending and Receiving Data**

Figure 80 shows the part of the programming language, where the information is sent and decoded and validated in the server. This sends a message to reset the energy value measured up to that moment.

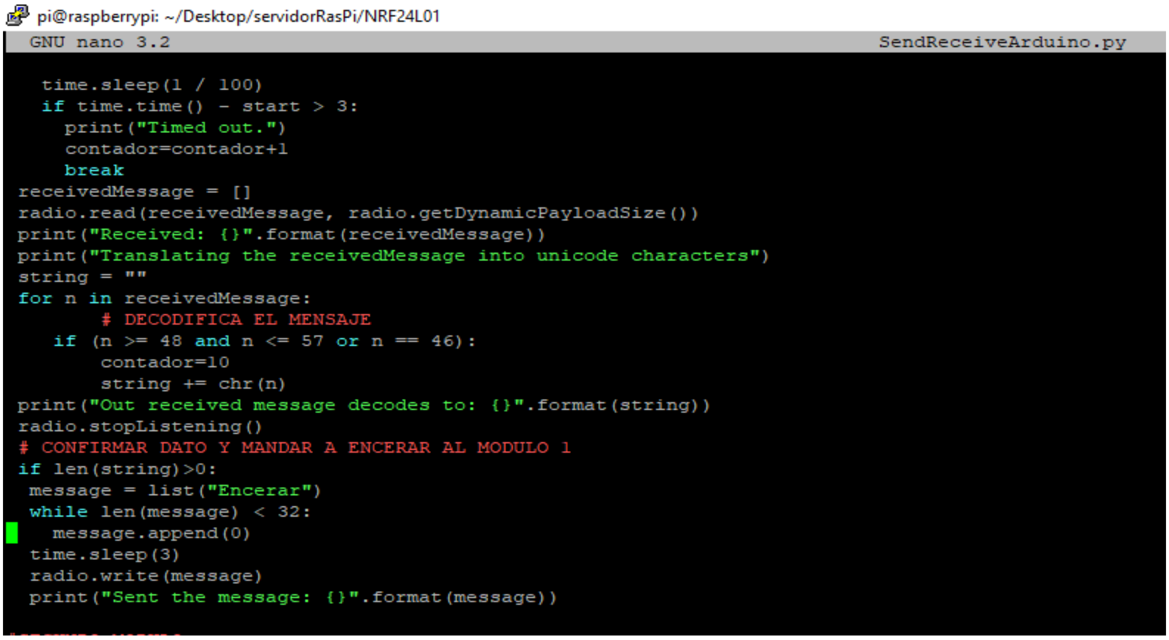


Figure 80: **Algorithm for Sending Data to the Server**

3.2.11 Cloud Server Configuration

Once the IoT platform is defined, ThingSpeak account is created, where the data from the energy monitoring system is stored. This is displayed in Fig. 81.

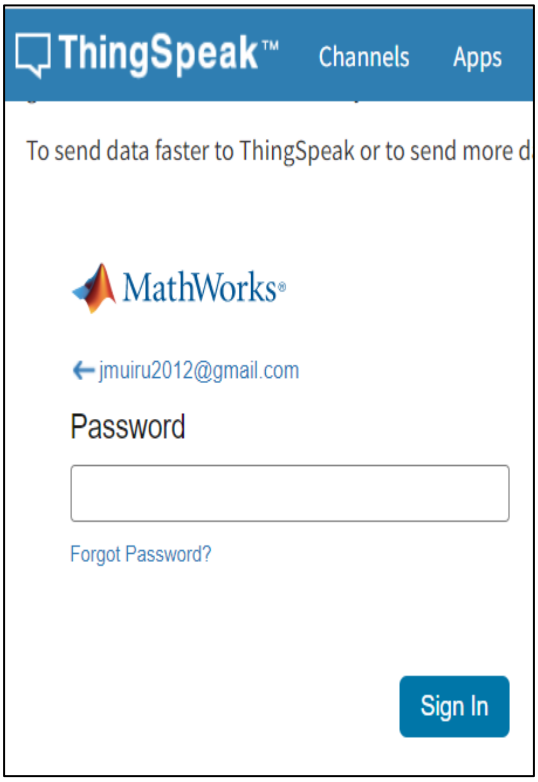


Figure 81: Log in to the Database Account

Figure 82 shows the fields that must be entered for the channel configuration, where it is specified where the data of the energy meters are stored.

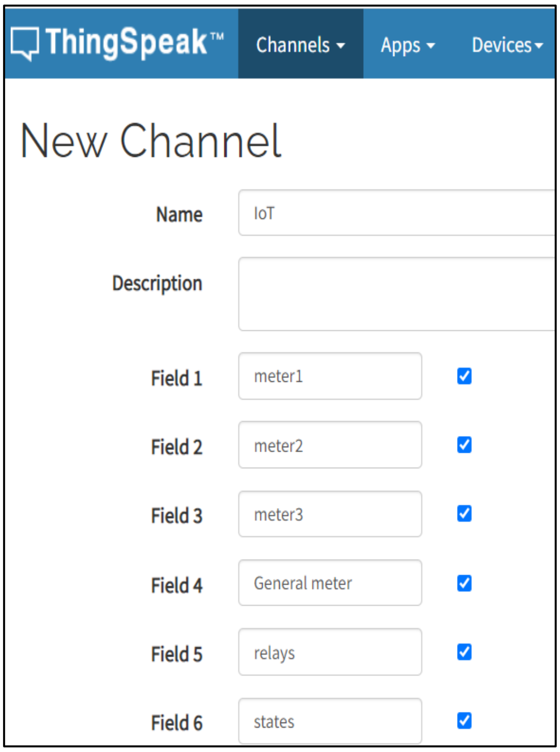


Figure 82: Storage Fields

3.2.12 Communication Configuration between the Central Node and the Server

An account has been created for the project to use the resources of the free platform

ThingSpeak. To access the information from the IoT server, there is an API for data writing: MFWN7K1P1ARPQD4S and one for data reading: OZ4AP9MLBCS3Y7KQ

To access the information in the cloud, the “urllib2” library is used, according to (Fig. 83) which allows accessing and retrieving data from the internet using the HTTP protocol. In this case, the ThingSpeak account is accessed to write or read the information on each channel.

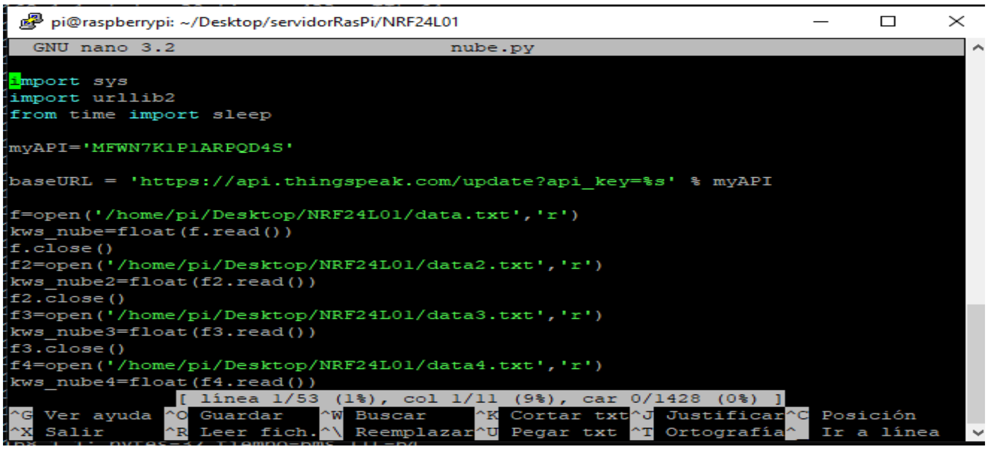


Figure 83: Library Configuration to Access Data in the Cloud

The algorithm reads the text documents that have been created and saved. For each of the energy meters, before the data is sent, the numerical value of each variable is validated and the information is sent to the cloud to be stored in the different fields of the canal. After this procedure, the order is given to reset the text documents, where the new information updated every hour is stored.

3.3 Development of the Application

The application developed on the MTI APP inventor web platform was made up of three screens that are:

3.3.1 Login Screen

On the home screen (Fig. 84), two fields are displayed that the user must fill. These are the username and a four-character password for the respective tests. For instance, the username is Kiguta and the key is 1234.

Figure 84: Starting Screen

In the block diagram (Fig. 85), the programming logic and the fields that have been populated are observed to validate the fields specified above.

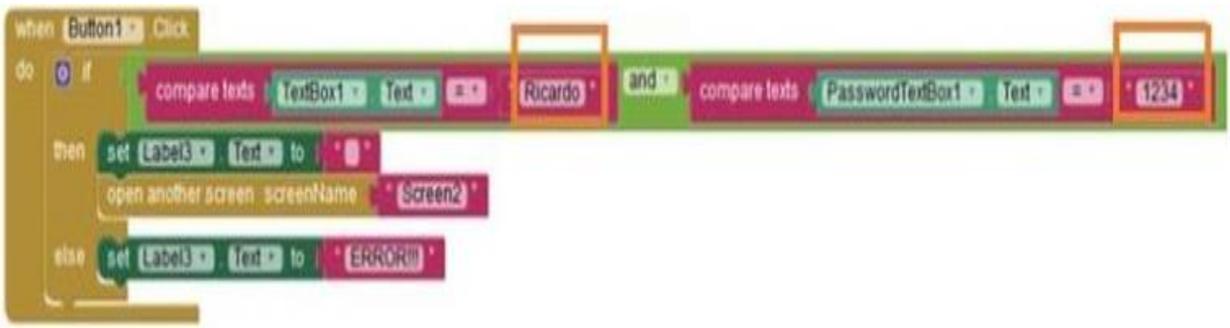


Figure 85: Block Diagram of the main Screen Programming

Part of the program used to visualize these data is also shown in Fig. 86.

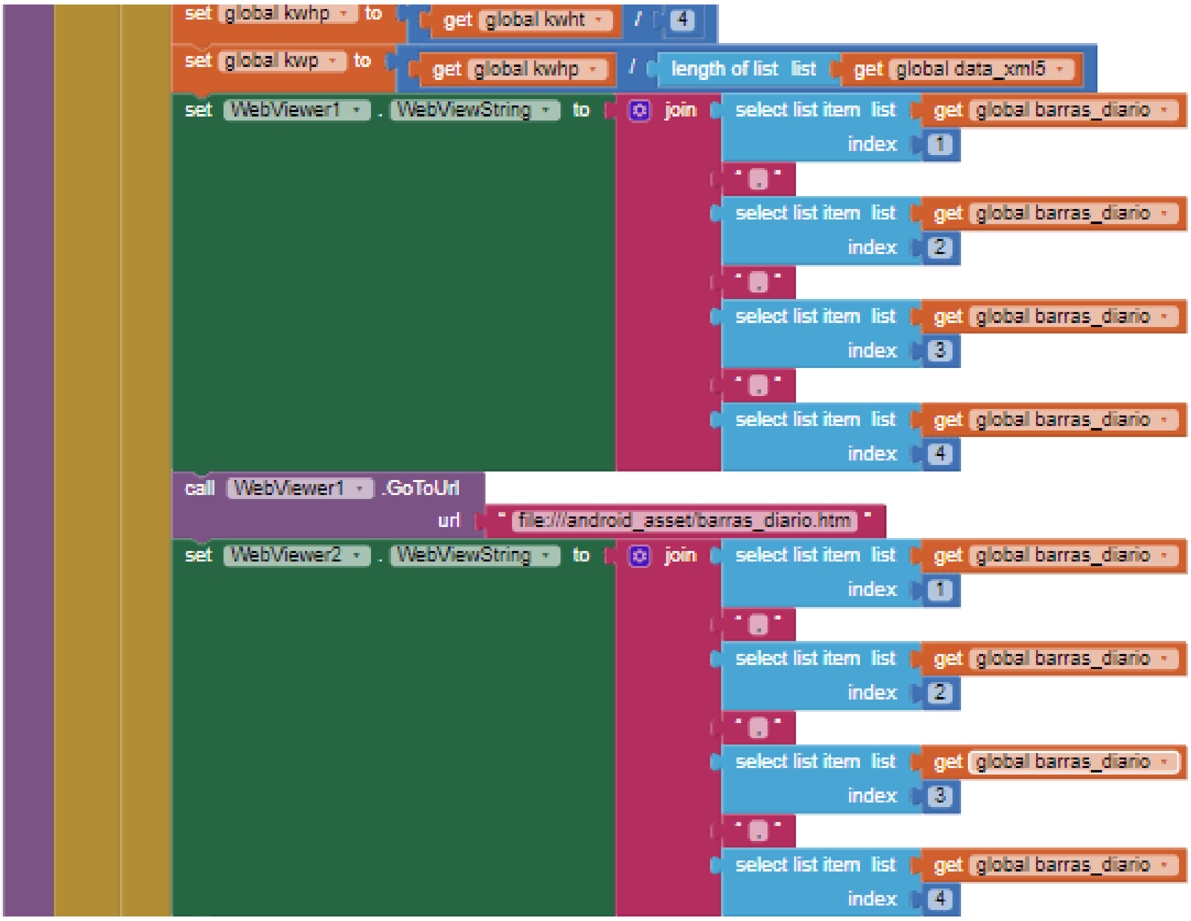


Figure 86: Block Diagram for Data Visualization

3.3.2 Crontab Configuration

To set the Crontab for the system to start automatically when the server is turned on, two activities have been configured.

(i) The First Run

The first run the program called "SendReceiveArduino.py", which is an algorithm made in Python, which asks for data verification between the different modules every ten minutes. In addition, he requests the sending of the values stored in the Arduino memory of each module. The information is read and stored in a text-type file.

(ii) The Second Program

The second program that was executed is cloud.py, which is responsible for publishing in the cloud, information stored in the text file that is created in the aforementioned program. This information is stored in the field of the cloud server. This process run every hour. As seen in Fig. 87, the Crontab configuration allows running the programs at set times.

```
# For example, you can run a backup of all your user accounts
# at 5 a.m every week with:
# 0 5 * * 1 tar -zcf /var/backups/home.tgz /home/
@reboot python /home/pi/Desktop/NRF24L01/receivenube.py 1> /dev/null 2> /home/pi/Desktop/NRF24L01/error.log
#* * * * * sh ./home/pi/Desktop/NRF24L01/prueba.sh
*/10 * * * * python /home/pi/Desktop/NRF24L01/SendReceiveArduino.py > /home/pi/Desktop/log.txt
0  0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23 * * * python /home/pi/Desktop/NRF24L01/nube.py > /home/pi/Desktop/d.txt
```

Figure 87: Crontab Configuration

Once the prototype has been fully implemented and the different functional tests have been carried out, the sensor network composed of the central server and the four energy consumption sensors is shown in Fig. 88.

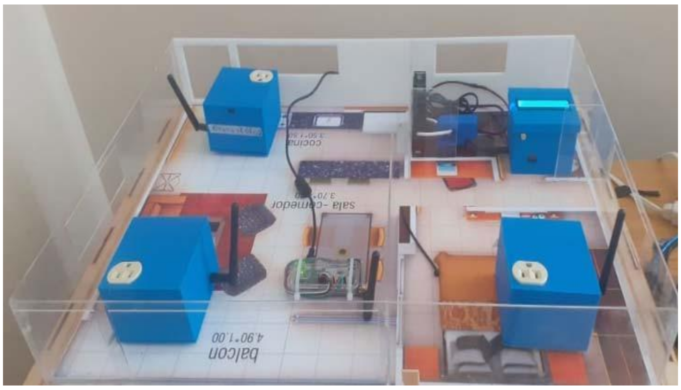


Figure 88: Mockup with Data Acquisition Sensors

3.4 System Testing and Validation

The system was tested and validated before its use. The testing process aimed to identify the system defects and make necessary improvements before implementation. In this project, system testing and validation were conducted to meet its functionalities and energy consumption needs as per the proposed objectives. On the other hand, system validation was conducted to identify any errors and make corrections in the program codes used. Various testing and validation procedures were performed during the development of the IoT-based energy monitoring system.

3.4.1 Unit Testing

This testing involved testing the specific program units to ensure there were no defects. In particular, each module of the system was tested to check if it operated correctly as expected and whether it met all the requirements. As a result, bugs that were detected were fixed, which helped in reducing the cost that would arise if the bugs were identified in the final phase of system development.

3.4.2 Integration Testing

This testing was achieved by testing the combined program units to determine whether they worked as intended. In particular, the integration testing was conducted during user registration and login system to ensure that client's information was secured and stored in a database, and retrieved as needed.

3.4.3 System Testing

The system testing was conducted to monitor how the energy monitoring system behaved. This involved checking for system component compatibility and the interaction between the system and the collected data across interfaces.

3.4.4 User Acceptance Testing

This phase of system testing and validation involved testing whether the developed energy monitoring system was acceptable to the end users. The system was used to collect energy consumption data, which after analysis revealed that the system was valid to be used by the end users.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results from IDE Platform

Figure 89 shows the data presented in the Arduino IDE, with the parameters of voltage, current, power factor, and the consumption of a load in kW.

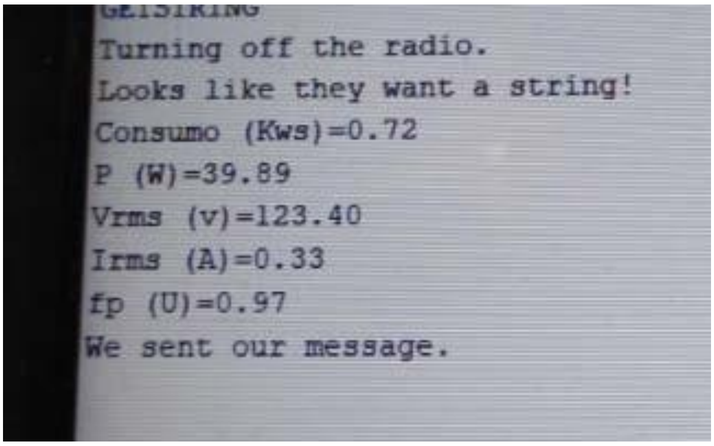


Figure 89: Arduino IDE Data Presentation

Table 12 shows the calculated energy values for 30 min, with an energy consumption of 72kWs. Figure 90 shows the value stored in the IoT server.

Table 12: Theoretical Energy Values for 30 Minutes

	Hour Of start	Load	Unit	Weather In seconds	Theoretical consumption Ws	kW	Value in the app	Final hour
Meter 1	13:00	40	W	1800	72000	72		13:30

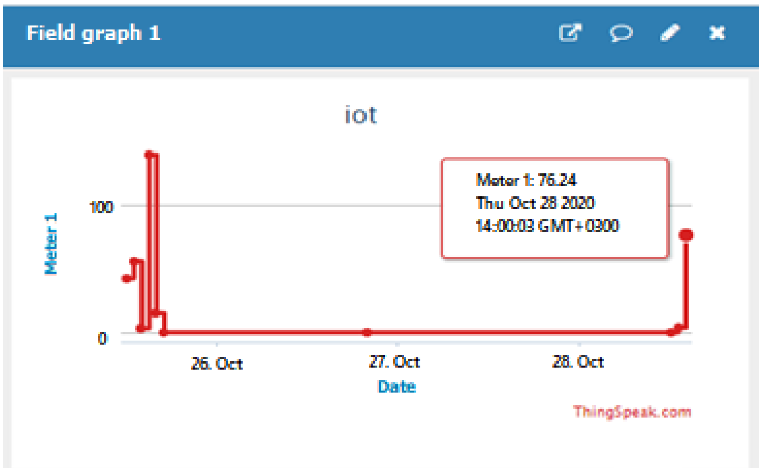


Figure 90: Measured Power Values Stored in the IoT Server

4.2 Results from Mobile Application

The home page of the app was shown in Fig. 91. The username section and password were required to sign in to the mobile application.

Figure 91: Mobile App Home Page

4.3 Screen for Viewing Connected Devices

This screen has three buttons: the first button called "Read Status", sends a message to the server in the cloud and stores it. This field is read by the network server and executes an algorithm, which once finished sends data to the cloud with information on the status of the relay. The (on-off), also informs if a load greater than 5W is connected. In Table 13 shows the different comparisons and combinations that the algorithm delivers to the cloud.

Table 13: State Combinations Delivered to the Cloud

State 1	State 2	State
TO	TO	No load and relay off
TO	B	No-load relay on
B	B	With load and relay on

4.5 Analysis of the Measured Results

To calculate an estimate of the measured energy consumption in an industry, the Table has been taken as a reference 1.2 of Chapter 1, issued by KPLC regulates the kWh value. Table 14 shows the average value used to approximate the consumption calculation in dollars.

Table 14: Average Cost Value kWh

Consumption range	Consumption stratum	Energy USD / kWh	Commercialization
kWh			**(USD / Consumer)**
0-50	AND	0.091	
51-100	AND	0.093	
101-150	D	0.095	1414
151-200	C	0.097	
201-250	C	0.099	
251-300	B	0.101	
301-350	B	0.103	
351-500	TO	0.105	

To know the behavior of electrical machines in the industry, the most widely used ones in the author's selection have been selected, taking samples over 4 days. The following numbers indicate the energy meters in the established period.

4.5.1 Energy Meter 1

A refrigerator has been selected since it practically remains connected to the electrical outlet all the time. Table 15 shows the data downloaded from the platform storage, to know the working behavior of the device based on variations in energy consumption.

Table 15: Energy Consumption Module 1 - Cutter

	Module 1 Cutter [kWs]				
Date creation	**Sunday**	**Monday**	**Tuesday**	**Wednesday**	**Thursday**
21/11/2021 7:00 AM	63.33	330.63	0.03	175.72	401.61
21/11/2021 7.30	0	217.21	0	0	302.83
21/11/2021 8:00	17.36	0	0	0	248.56
21/11/2021 8:30	0	0	133.08	0	0
21/11/2021 9:00	0.02	0	289.67	0	0
21/11/2021 9:30	0.03	0	272.84	0	0
21/11/2021 10:00	0.02	9.67	144.12	0.09	53.67
21/11/2021 10:30	105.35	295.46	0.01	293.01	292.88
21/11/2021 11:00	0.33	283.94	0	301.6	271.84
21/11/2021 11:30	0.14	0.05	0	291.08	
21/11/2021 12:00 PM	0.04	0	0	59.5	
21/11/2021 12:30	0	0	93.83	0.4	
21/11/2021 13:00	0	0	390.08	0	
21/11/2021 13:30	0.01	0.11	0	0	
21/11/2021 14:00	287.42	0	0	0	
21/11/2021 14:30	253.96	211.61	768.09	136.47	
21/11/2021 15:00	0	378.63	0	291.73	
21/11/2021 15:30	229.38	266.16	0.06	278.37	
21/11/2021 16:00	72.04	198.75	0	79.48	
21/11/2021 16:30	0	0	0.25	0.01	
21/11/2021 17:00	0.03	105.98	0.04	0.04	
21/11/2021 17:30	130.46	270.52	0	0.04	
21/11/2021 18:00	363.21	0.05	140.24	0	
21/11/2021 18:30	1523.13	0	290.03	151.24	
TOTAL CONSUMPTION	3,046.26	2568.77	2522.37	2,058.78	1571.39
Total consumption in kWh				3.26	
Consumption in Dollars				0.29	

When analyzing the consumption values of the cutter, higher consumption is observed on

Sunday. This is because the user uses the equipment more frequently, that is, the cutter has been opened for a longer time. Figure 92, shows the normal behavior of the machine where it maintains a fairly continuous behavior (i.e., if the machine does not work correctly, energy consumption would be observed for longer times or with higher energy consumption peaks).

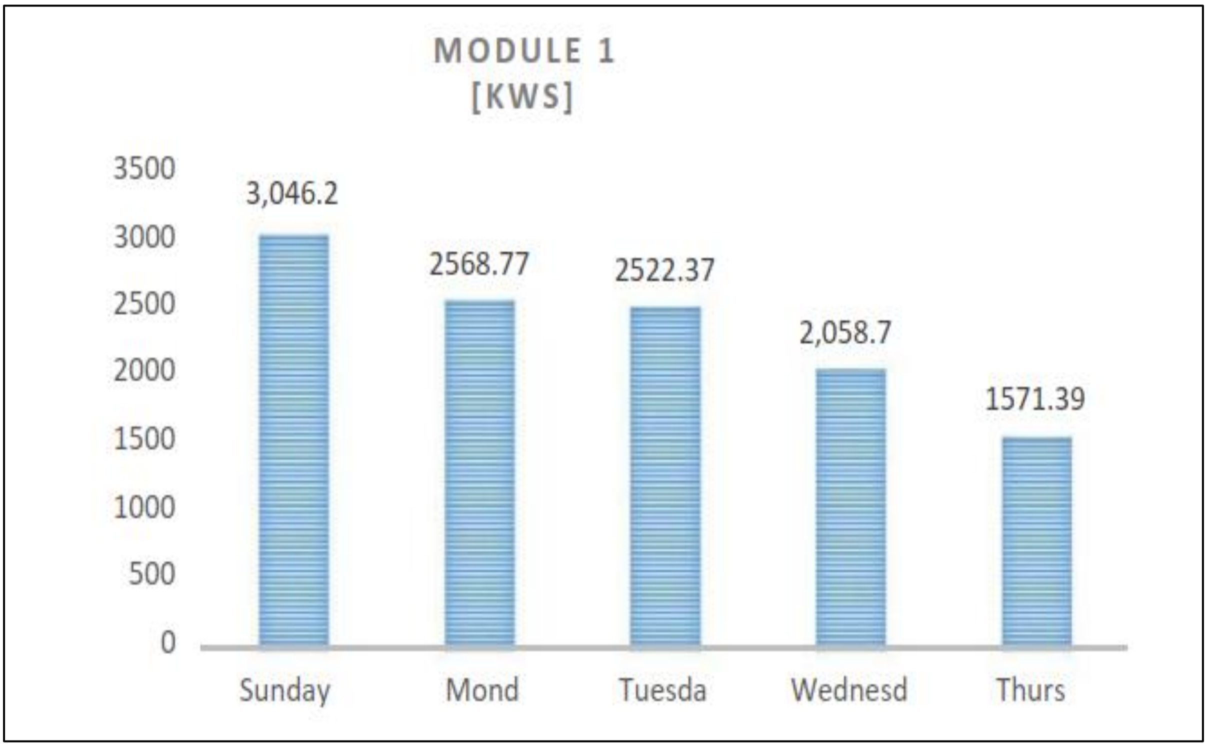


Figure 92: Module 1 Energy Consumption Behavior

4.5.2 Energy Meter 2

The second device that has been selected for data analysis is a skin heater since it is practically used for longer periods. Table 16, shows the data downloaded from the storage platform which allows us to know the working behavior of the device. The variations in energy consumption during the time that it has been monitored for four days.

Table 16: Power Consumption Module

Creation day	**Sunday**	**Monday**	**Tuesday**	**Wednesday**	**Thursday**
21/11/2021 7:00 AM	14.33	159.39	5.88	4.08	4.44
21/11/2021 7.30	2.95	152.17	5.22	5.95	0.13
21/11/2021 8:00	6.71	3.62	5.45	0	0
21/11/2021 8:30	9.62	0	5.55	0.96	0
21/11/2021 9:00	0.11	0	5.62	0	0
21/11/2021 9:30	0.17	0	5.59	0	0
21/11/2021 10:00	0.14	0	5.33	0	0
21/11/2021 10:30	136.02	0	4.68	0	0
21/11/2021 11:00	187.69	0	3.95	0	0
21/11/2021 11:30	160.18	82.81	113.41	0	61.91
21/11/2021 12:00 PM	70.42	160.94	85.62	0	173.5
21/11/2021 12:30	70.59	99.93	113.51	0	149.89
21/11/2021 13:00	66.82	155.97	151.17	0.02	0
21/11/2021 13:30	90.39	300.94	0	0	208.74
21/11/2021 14:00	158.08	66.81	0	125.96	0.72
21/11/2021 14:30	192.8	3.44	244.7	151.09	0.84
21/11/2021 15:00	249.34	3.61	176.23	77.62	0.67
21/11/2021 15:30	235.71	3.03	144.79	52.77	0.82
21/11/2021 16:00	88.79	4.18	0	99.28	0.76
21/11/2021 16:30	99.33	29.86	251.53	114.97	147.68
21/11/2021 17:00	35.9	11.3	209.72	183.21	183.19
21/11/2021 17:30	131.21	0	187.11	183.88	157.48
21/11/2021 18:00	189.08	449.33	0	0	147.92
21/11/2021 18:30	189.08	209.02	5.03	0	147.46
CONSUMPTION TOTAL	2385.46	1896.35	1730.09	999.79	1386.15
Total Consumption in kWh				2.33	
Amount in dollar				0.23	

Figure 93 shows the behavior of the use of the heater, observing that by controlling the dead times and then proceeding with the shutdown of the equipment, the energy consumption is reduced.

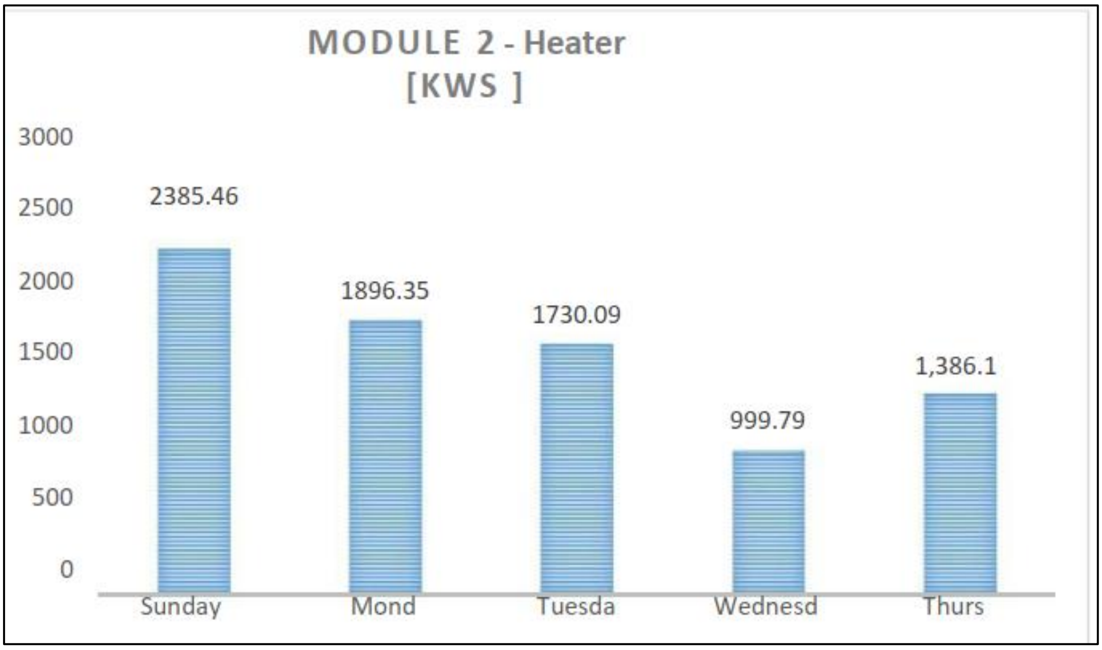


Figure 93: Modulo 2 energy consumption behavior

4.5.3 Energy Meter 3

For the operational tests in module three, a Stitcher has been used and an analysis of energy consumption is carried out. Table 17 shows the information collected over some time 4, and Fig. 94 shows the optimization of the energy consumption of the same module.

Table 17: Power Consumption Module 3 Stitcher

Creation Date	Monday	Tuesday	Wednesday	Thursday
21/11/2021 7:00 AM	5.51	0	0	17.83
21/11/2021 7.30	5.12	0	0	7.2
21/11/2021 8:00	5.43	0	0	0
21/11/2021 8:30	5.42	0	12.68	0
21/11/2021 9:00	5.38	0	0	0
21/11/2021 9:30	5.33	0	0	0
21/11/2021 10:00	5.31	0	0	0
21/11/2021 10:30	5.39	0	0	0
21/11/2021 11:00	5.2	0	0	0
21/11/2021 11:30	5.75	10.49	0	0
21/11/2021 12:00 PM	5.06	23.33	0	1.71
21/11/2021 12:30	4.65	15.67	7.35	0
21/11/2021 13:00	4.26	7.7	1.28	0
21/11/2021 13:30	10.05	0	0	0
21/11/2021 14:00	1.64	0	11.33	7.59
21/11/2021 14:30	5.2	13.86	5.55	13
21/11/2021 15:00	5.19	7.34	4.72	27.16
21/11/2021 15:30	6.62	17.47	5.82	0
21/11/2021 16:00	6.3	0	0	2.81
21/11/2021 16:30	1.81	19.95	1.19	24.35
21/11/2021 17:00	6	4.19	0	19.85
21/11/2021 17:30	30.75	19.13	3.12	14.25
21/11/2021 18:00	30.94	0	0	2.36
21/11/2021 18:30	22.77	1.24	12.68	6.5
21/11/2021 7:00 AM	195.08	140.37	65.72	1.23
Total consumption	390.16	280.74	131.44	145.84
Total consumption in kWh			0.26	
ıate consumption in dollars			0.026	

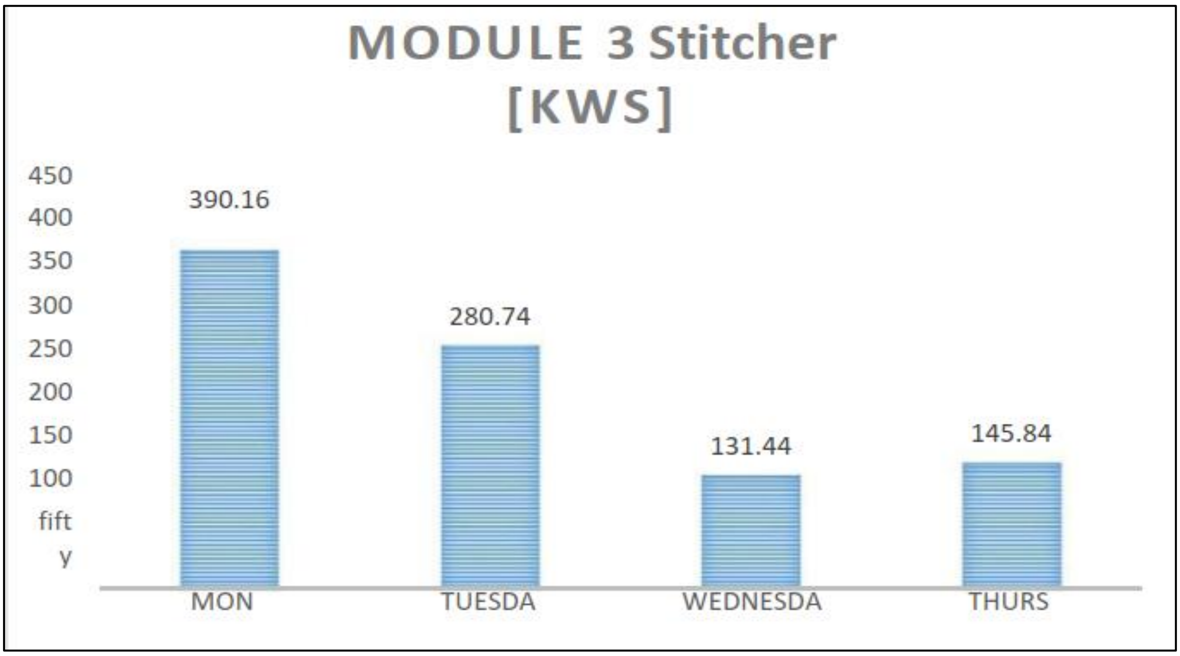


Figure 94: The behavior of Energy Consumption Module 3

4.5.4 Energy Meter 4 Rush

The device is responsible for monitoring the total consumption of the equipment connected to the electrical network within the industry. As a control, it identified, which among the connected devices has the highest energy consumption after comparing the readings acquired in the modules of individual loads, this is seen in Table 18.

Table 18: **Total Module Energy Consumption of the Line**

Creation Date	Monday	Tuesday	Wednesday	Thursday
21/11/2021 12:00 AM	0	89.74	211.4	430.59
21/11/2021 1:00	430.69	33.87	163.77	249.36
21/11/2021 2:00	0	33.79	0	201.63
21/11/2021 3:00	89.74	76.65	164.62	193.95
21/11/2021 4:00	95.4	119.05	152.58	159.56
21/11/2021 5:00	63.9	107.65	25.48	29.41
21/11/2021 6:00 AM	90.06	97.29	65.65	104.02
21/11/2021 7:00	29.3	69.32	309.11	212.04
21/11/2021 8:00	140.65	32.65	126.48	156.48
21/11/2021 9:00	209.3	253.38	117.06	308.57
21/11/2021 10:00	469.25	266.1	91.22	278.13
21/11/2021 11:00	279.9	272.33	86.09	261.93
1/3/2020 12:00	165.98	528.69	74.76	0
21/11/2021 13:00	64.07	0	0	961.4
21/11/2021 14:00	212.26	0	225.67	88.64
21/11/2021 15:00	175.31	882.84	309.32	132.66
21/11/2021 16:00	159.15	271.17	279.3	262.41
21/11/2021 17:00	266.69	248.51	223.28	251.28
21/11/2021 18:00	89.39	0	188.03	174.45
21/11/2021 19:00	80.08	330.78	338.97	355.72
21/11/2021 7:44 PM	812.88	379.01	449.82	441.73
21/11/2021 20:00	439.99	257.42	361.74	516.04
21/11/2021 22:00	398.55	285.33	0	332.32
21/11/2021 23:00	341.1	284.64	579.34	329.57
Total consumption	5103.64	4,920.21	4,543.69	6431.89
Total consumption in kWh			5.83	
Approximate value in dollars			0.57	

Figure 95 shows the data acquired during the monitoring time.

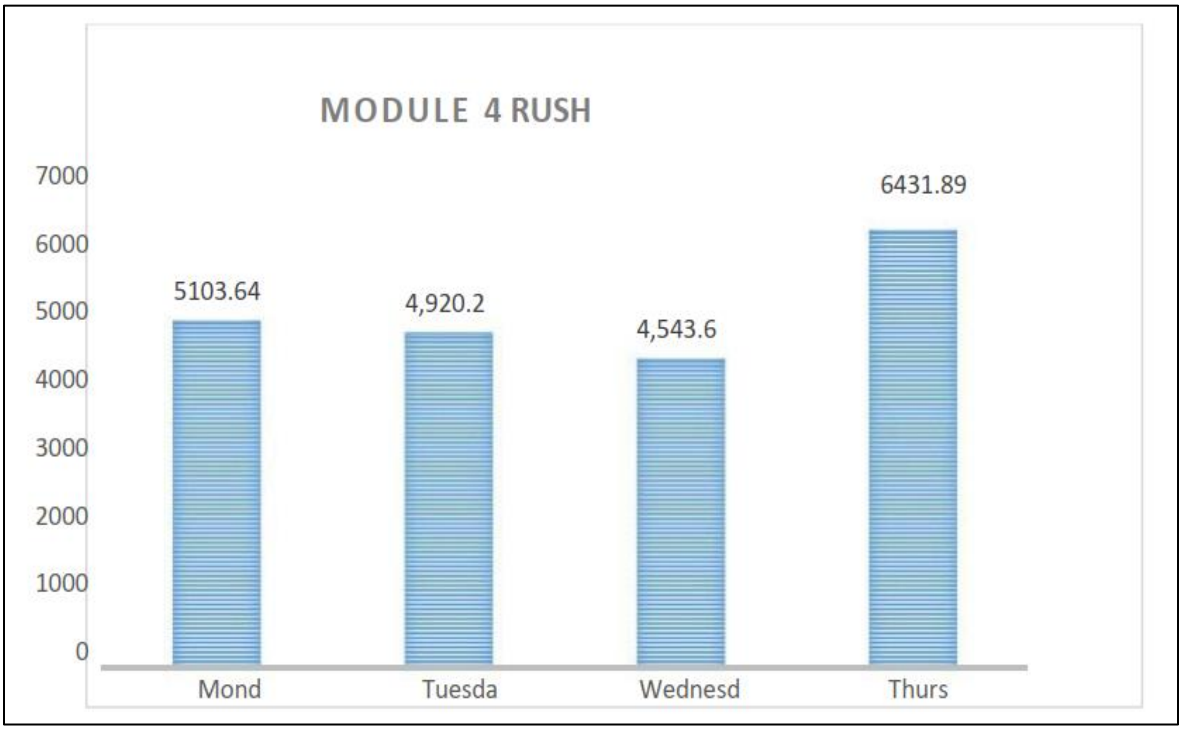


Figure 95: Power Consumption Module 4 Connections

It should be noted that the central module presents an increase in consumption on the fourth day of monitoring, due to an increase in the use of loads that have not been considered. To obtain the reading of measurements and observe its behavior, taking into account that the Devices chosen to be monitored constitute approximately 48% of the load used (i.e, in the electrical system, there are several additional loads such as printers, computers, laptops, etc., which are not considered for the present calculation of energy consumption).

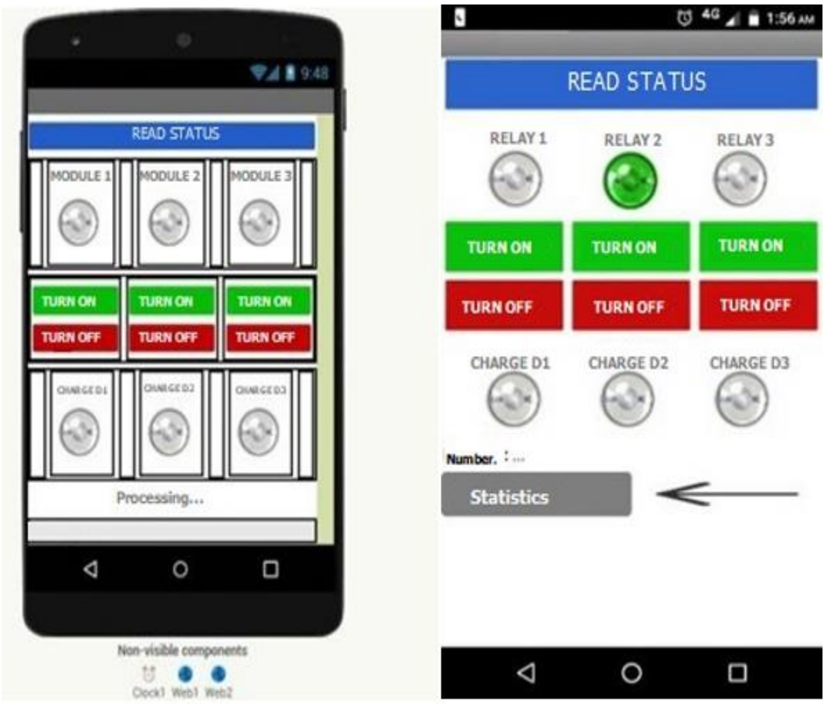


Figure 96: Switch Status of Each Device

In the same way, if there is a load connected to the interface, the loading icon lights up as shown in Fig. 97.

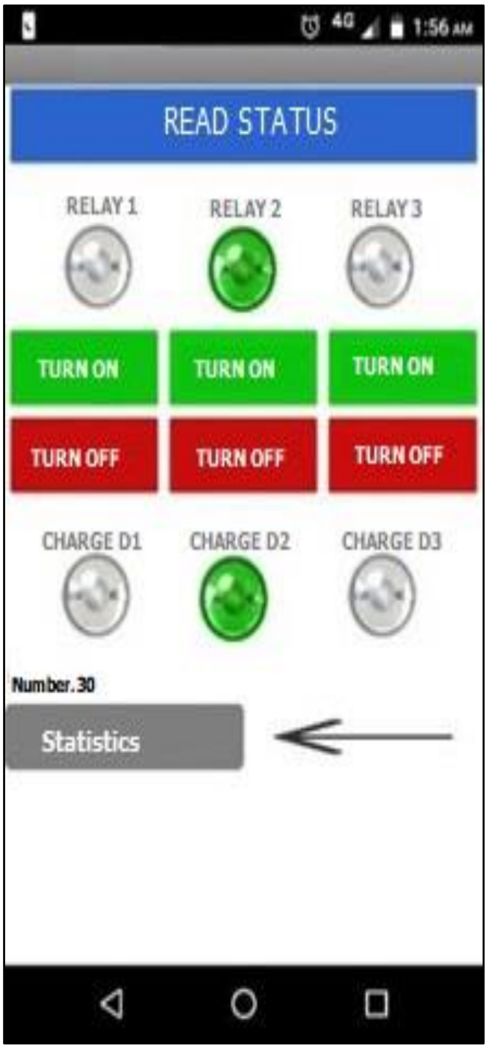


Figure 97: Reading of States in the Measuring Devices

On and off buttons, by pressing one of these buttons a value is sent to the cloud that allows activating or deactivating a relay in any of the three monitoring devices. The data is stored in a field called a relay. Depending on the value that it receives, it activate or deactivate a switch of the selected device, as specified in Fig. 98.

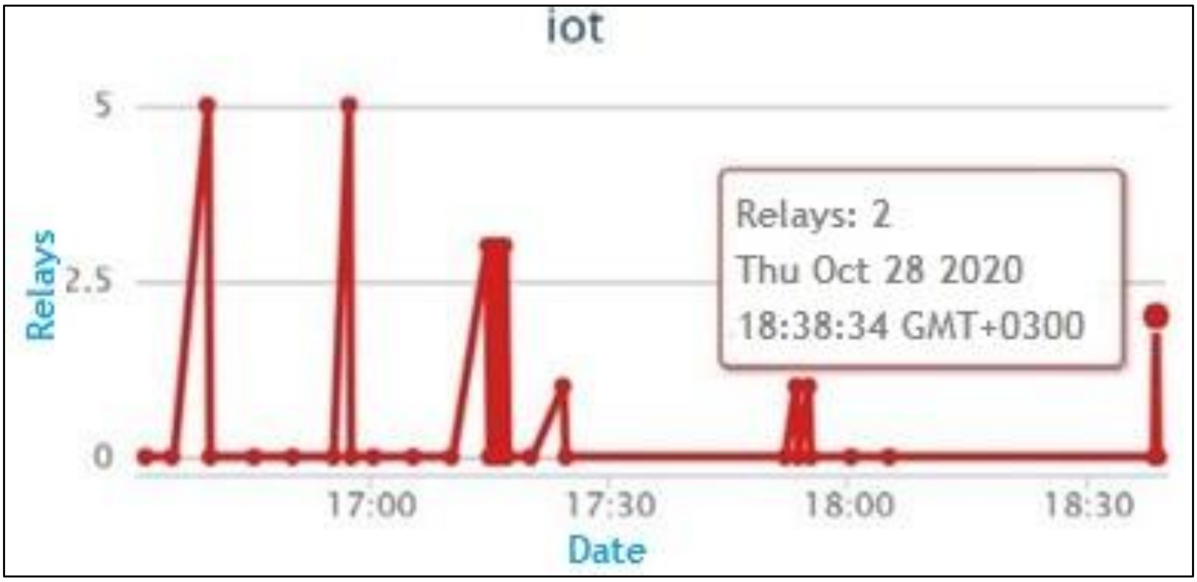


Figure 98: Relay Status

Table 19 shows the values that are sent from the cellular application to the cloud. These values are stored in the relays field, which is read by the server to perform the different actions on the devices.

Table 19: Values Delivered from the Application for Relay Control

Device	Value to activate	Value to disable
1	1	2
2	3	4
3	5	6

4.5.5 Screen for Displaying Energy Consumption Data

To access the energy consumption information, a third screen has been designed (Fig. 99), where the readings made are appreciated. For the visualization of the data, a web viewer has been configured, which allows one to visualize them graphically after accessing the Url address and extracting the required information.

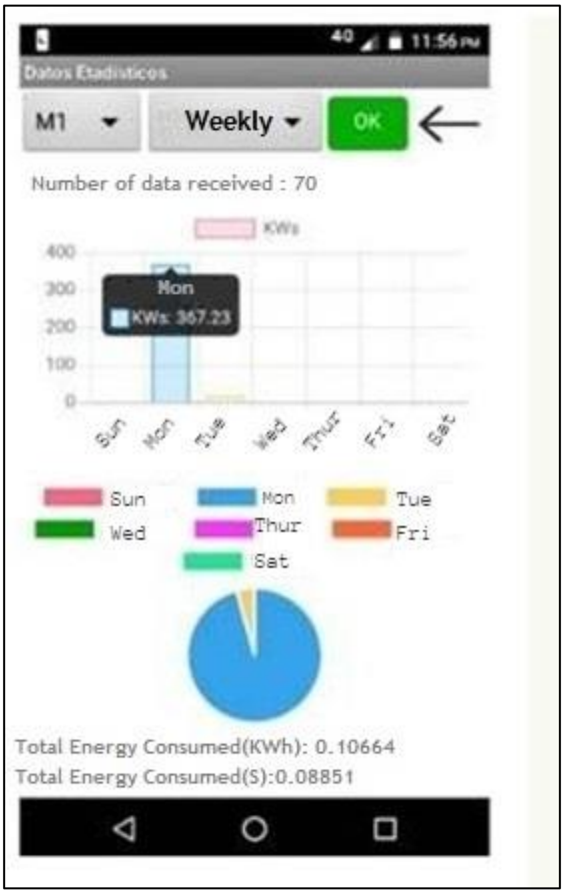


Figure 99: Third Screen Data Display

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The information is acquired with the help of energy consumption sensors and analyzed based on statistical tables stored in the cloud, for four days, for the loads with the highest consumption in the author's house. For the communication stage between the sensors and the server, the NRF 24L01 + module was chosen due to its low cost and ease of configuration, as well as providing sufficient documentation from the manufacturer for its use. Regarding the control of energy consumption, an application for the Android system was implemented, which verifies that the power factor is within the allowed range fp. = 0.92.

Through an application designed on the MIT App inventor platform, an electronic stage is controlled that activates or deactivates a relay, supplying energy to each load or not. By using the MIT App inventor platform, an application was created for the Android system in which the user views the consumption history that has been stored in the cloud. The history was presented with the help of statistical graphs in which the consumption behavior of the devices is observed for four days. In addition, the statistical information on consumption can be accessed using the Android application.

For the validation of the prototype, functional tests were carried out in the company of the tutor, which consisted of controlling the loads located at the author's attachment industry through the Android application

5.2 Recommendations

Given the existence of loads in the industries that work with 220 V, the design of a biphasic monitoring system is proposed. The analysis in longer periods provides more reliable information and thus design an energy-saving plan.

It is necessary to avoid the use of jumpers or cables for the connection of the NRF 24L01 module to avoid crosstalk. As for the power factor, this must be as close to unity, otherwise, it could lead to a consumption penalty due to a power factor lower than the allowed one.

The use of the MIT App inventor application is recommended as it provides several tools for designing an application for the Android system. The use of free platforms such as ThingSpeak is important for the development of prototypes based on the concept of the Internet since they provide enough tools for the execution of prototypes.

It is advisable to enable an effective internet access point, to carry out satisfactory tests of the operation of the project based on the internet of things. Given that machine learning has not been fully addressed due to limited time, further studies should employ machine learning algorithms to make predictions on electrical energy consumption.

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APPENDICES

Appendix 1: Technical Characteristics

(a) Technical Characteristics of Electronic Elements

NORDIC SEMICONDUCTOR nRF24L01+ Preliminary Product Specification

1.1 Features

Features of the nRF24L01+ include:

- Radio
  - Worldwide 2.4GHz ISM band operation
  - 126 RF channels
  - Common RX and TX interface
  - GFSK modulation
  - 250kbps, 1 and 2Mbps air data rate
  - 1MHz non-overlapping channel spacing at 1Mbps
  - 2MHz non-overlapping channel spacing at 2Mbps
- Transmitter
  - Programmable output power: 0, -6, -12 or -18dBm
  - 11.3mA at 0dBm output power
- Receiver
  - Fast AGC for improved dynamic range
  - Integrated channel filters
  - 13.5mA at 2Mbps
  - -82dBm sensitivity at 2Mbps
  - -85dBm sensitivity at 1Mbps
  - -94dBm sensitivity at 250kbps
- RF Synthesizer
  - Fully integrated synthesizer
  - No external loop filer, VCO varactor diode or resonator
  - Accepts low cost ±60ppm 16MHz crystal
- Enhanced ShockBurst™
  - 1 to 32 bytes dynamic payload length
  - Automatic packet handling
  - Auto packet transaction handling
  - 6 data pipe MultiCeiver™ for 1:6 star networks
- Power Management
  - Integrated voltage regulator
  - 1.9 to 3.6V supply range
  - Idle modes with fast start-up times for advanced power management
  - 26µA Standby-I mode, 900nA power down mode
  - Max 1.5ms start-up from power down mode
  - Max 130us start-up from standby-I mode
- Host Interface
  - 4-pin hardware SPI
  - Max 10Mbps
  - 3 separate 32 bytes TX and RX FIFOs
  - 5V tolerant inputs
- Compact 20-pin 4x4mm QFN package

(b) Technical Characteristics of the NRF 24L01 + Module

2.2 Pin functions

Pin	Name	Pin function	Description
1	CE	Digital Input	Chip Enable Activates RX or TX mode
2	CSN	Digital Input	SPI Chip Select
3	SCK	Digital Input	SPI Clock
4	MOSI	Digital Input	SPI Slave Data Input
5	MISO	Digital Output	SPI Slave Data Output, with tri-state option
6	IRQ	Digital Output	Maskable interrupt pin. Active low
7	VDD	Power	Power Supply (+1.9V - +3.6V DC)
8	VSS	Power	Ground (0V)
9	XC2	Analog Output	Crystal Pin 2
10	XC1	Analog Input	Crystal Pin 1
11	VDD_PA	Power Output	Power Supply Output(+1.8V) for the internal nRF24L01 Power Amplifier. Must be connected to **ANT1** and **ANT2** as shown in Figure 30.
12	ANT1	RF	Antenna interface 1
13	ANT2	RF	Antenna interface 2
14	VSS	Power	Ground (0V)
15	VDD	Power	Power Supply (+1.9V - +3.6V DC)
16	IREF	Analog Input	Reference current. Connect a 22kΩ resistor to ground. See: Figure 30.
17	VSS	Power	Ground (0V)
18	VDD	Power	Power Supply (+1.9V - +3.6V DC)
19	DVDD	Power Output	Internal digital supply output for de-coupling purposes. See: Figure 30.
20	VSS	Power	Ground (0V)

Table 1. nRF24L01 pin function

(c) Technical Characteristics Raspberry PI

Raspberry Pi hardware

The hardware in the Raspberry Pi

- Schematics
  - Schematics for the Raspberry Pi
- BCM2835
  - The Broadcom processor used in Raspberry Pi 1 and Zero
- BCM2836
  - The Broadcom processor used in Raspberry Pi 2
- BCM2837
  - The Broadcom processor used in Raspberry Pi 3 (and later Raspberry Pi 2)
- BCM2837B0
  - The Broadcom processor used in Raspberry Pi 3B+ and 3A+
- BCM2711
  - The Broadcom processor used in Raspberry Pi 4B
- SPI Boot EEPROM (Pi4)
  - The boot EEPROM used in Raspberry Pi 4B
- Boot modes
  - A description of the available BCM2835/6/7 boot modes
- Mechanical drawings
  - Mechanical drawings of the Raspberry Pi
- Power
  - Powering the Raspberry Pi
- USB
  - USB on the Raspberry Pi
- GPIO
  - General Purpose Input/Output pins on the Raspberry Pi
- SPI
  - SPI on the Raspberry Pi
- DPI (Parallel/RGB Display)
  - DPI on the Raspberry Pi
- Peripheral addresses
  - How to access peripheral addresses using the bcm_host helpers
- Standard conformity documentation
  - Conformance documentation for the various standards bodies
- Revision codes
  - Raspberry Pi revision code reference
- OTP Bit definitions
  - Register and bit definitons for the One-Time Programmable (OTP) memory on the Raspberry Pi
- Processor frequency and thermal management
  - Information on how the Raspberry Pi manages CPU frequencies and heat dissipation

Appendix 2: The SCT 0013 Current Sensor Features

SPECIFICATION

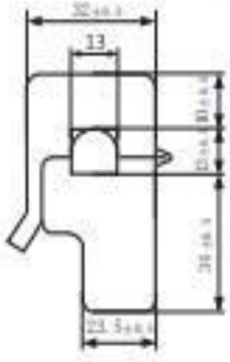
Customer Title : XiDi Technology

Product Name: Spilit-core current transformer

Manufacture Model : SCT-013-000

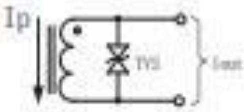
Charateristics: open size:13mm×13mm
1m leading wire
Core material:Ferrite
Fire resistance property:in accordance with UL 94-V0
Dielectric strength: 1000V AC/1min 5mA
(between shell and output)

Outline size diagram:(in mm)



Front View

Side View



TVS: Transient-voltage Suppressor

Current output type

Schematic Diagram

Typical table of technical parameters:

input current	output voltage	non-linearity	build-in sampling resistance (RL)
0-100A	0-50mV	±3%	Ω
turn ratio	resistance grade	work temperature	dielectric strength(between shell and output)
100A:0.05A	Grade B	-25℃~+70℃	1000V AC/1min 5mA

Customer Sign:

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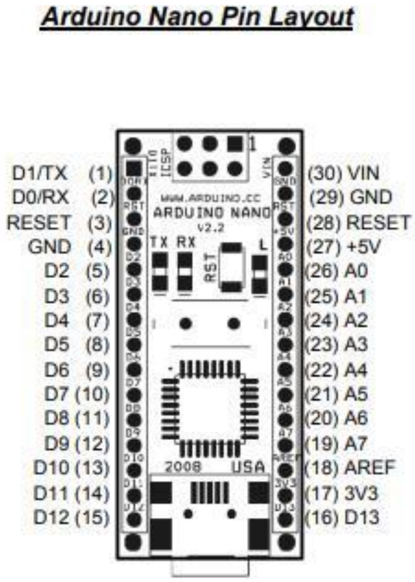
Phone: 0355-7929199-803
Cell: 13693334514
Contact Name: Engineer Chen

Approve Sign:Chenjianping

2011-7-26

Appendix 3: Arduino Nano Technical Characteristics



Pin No.	Name	Type	Description
1-2, 5-16	D0-D13	I/O	Digital input/output port 0 to 13
3, 28	RESET	Input	Reset (active low)
4, 29	GND	PWR	Supply ground
17	3V3	Output	+3.3V output (from FTDI)
18	AREF	Input	ADC reference
19-26	A7-A0	Input	Analog input channel 0 to 7
27	+5V	Output or Input	+5V output (from on-board regulator) or +5V (input from external power supply)
30	VIN	PWR	Supply voltage

POSTER PRESENTATION