International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V72I6P125
Volume 72 Issue 6, 259-272, June 2024

Original Article

Design and Implementation of a Monitoring and Alert System Applied to the Residential Electrical Network Using NodeMCU

Ramces Cavallini-Rodriguez[1], Pedro Portillo-Mendoza[2]

[1,2]*Universidad Tecnológica del Perú, Lima, Perú*

[2]*Corresponding Author : c16985@utp.edu.pe*

Received: 25 March 2024 Revised: 01 June 2024 Accepted: 08 June 2024 Published: 29 June 2024

Abstract *- The object of study of this research is to determine to what extent a monitoring and alert system of a residential electrical network using NodeMCU is efficient, with the purpose of supervising and optimizing the efficiency of electrical power consumption in a home. For this, current data collection techniques were used through the induction sensor, then an electronic analysis technique for voltage reading by voltage division, which consists of scaling the AC input voltage to the reading ranges of the microcontroller in D.C. Finally, the MQTT technique is used for the communication protocol that consists of the transmission of values from a microcontroller to a database via Wi-Fi. In this research, electronic modules were used to capture current and voltage data, and different computer programs, such as Eagle, for the electronic and electrical design of the system; Autodesk Inventor for the development of the schematic of the system components and the design of the prototype of the case that houses the electronic components; UltiMaker Cura 5.2, to configure 3D printing of the case; Arduino IDE, for the development of the ESP32 microcontroller programming code that is carried out in C++ language; Firebase Google, to obtain monitoring and alerts through an IDE interface which was programmed with HTML code and finally Visual Studio Code was used to create the graphical user access interface on the web page. The results demonstrated that this proposal made it possible to optimally monitor and obtain power consumption locally and remotely based on initial magnitudes of voltage, current, and power, obtaining a low error percentage of 0.39% and 3.12% in voltage and current measurements, respectively, comparing them with previously calibrated Fluke brand high precision measuring instruments. In addition, a calculated precision of 97.9289% was obtained for the power based on the values obtained by the instruments. With these parameters, the control algorithm displays the power locally through an LCD screen and remotely through a web page. Finally, the system can notify when an anomaly, such as a power outage, occurs through a notification to Gmail and the website interface.*

Keywords *- Power Consumption, IoT, Low-cost Monitoring System, Google Firebase, NodeMCU.*

1. Introduction

Today, homeowners do not have a simple device that allows them to see the power consumption absorbed by their electrical appliances directly and that allows them to carry out an action plan to optimize their consumption. Although homes indeed have energy meters installed by the companies that supply the energy, however, this situation is complex since there is little knowledge of the interpretation of the reading of this equipment. Furthermore, this equipment totals the consumption of all connected equipment at the same time; consequently, it is not known what the real and specific consumption of each of the electrical appliances installed in the home is. Therefore, this situation does not allow the owner to optimize the energy consumption of his home.

Thus, the implementation of a device for each electrical appliance installed in the home is proposed in such a way that it allows recording energy consumption through electrical power locally and remotely. In this way, an action plan can be developed to decide which devices will be used more or less frequently in order to optimize energy consumption. Various researchers have proposed alternative solutions in this regard, considering the use of Arduino Uno, Raspberry Pi 2, Xbee, NodeMCU and Wemos D1 Mini; however, they focused on the exclusive implementation of local systems or remote systems, using versions previous versions of these drivers. For this research, a device capable of detecting apparent power using voltage and current sensors has been designed and implemented, with which the aim is to determine the effectiveness of the sensors in data acquisition and, in this way, to be able to replicate it later in all the other electrical appliances in the home. After demonstrating that the device is adequate both in the detection of voltage and current parameters and in its ability to interconnect via the Internet with a NodeMCU electronic microcontroller device, the installation of the device can be replicated in all the other electrical appliances that make up the home., and thus, the owner will be able to map the consumption of each appliance and carry out his optimization plan.

2. Related Works

Various investigations have been carried out around the world to address this problem, such as the use of Smart meters that store data hourly on a web server for subsequent studies [1-2]. Other researchers used the combination of two development boards (Arduino Uno and Raspberry Pi 2) to make voltage measurements [3]. There are disturbances that affect the quality of the measurement, such as the operation of non-linear loads, natural phenomena or due to human effects such as incorrect maneuvers in the distribution plant [4]. In addition, these problems are addressed with the use of smart electrical meters such as the PZEM-004T to perform electrical metrics on the power consumed with the electrical variables to be analyzed [5-6]. Although the vast majority of homes have electrical services [7], audits are not provided to compare the data when there are problems in reading energy consumption.

The recording of the energy consumed is in charge of the electric meter, which is responsible for processing the voltage and current values [8]. Monitoring and control products are mostly used by companies in order to know the status of the machinery and because they must protect their high investment [3]. Given this, various investigations have been carried out with the purpose of implementing systems that help us monitor and identify faults and/or breakdowns in the electrical system of homes. The implementation of “Smart Grid” in the electricity supply diagnoses the possible causes of these damages and monitors the conditions that affect the reliability of the service to end customers [9]. Likewise, in [10], it is indicated that there should be different programming and monitoring strategies for household appliances to improve electrical efficiency and reduce energy costs in homes, thus preventing and saving unnecessary current by controlling and monitoring factors with the technology of the Internet of Things (IoT).

In [11], they propose the objective of developing a unit that controls the electrical energy of homes in Malaysia so that consumers can find out the values of electricity consumed and calculate their monthly billing cost. Taking the same idea, in [2], they design a smart monitoring project for household appliances by measuring pulses of electrical consumption on an hourly basis. Also, [1] uses data collection techniques with the help of an LDR sensor, while in [12], they address the idea of using the ZMPT101B sensors for voltage and the SCT-013-030 sensor for current. Others use ZigBee technology [15]; he points out the use of Arduino UNO and the ESP8266 microcontroller, which are responsible for analyzing and digitizing the energy data, whose values have been obtained experimentally.

In [16], the economical ESP32 development board is used, being the most powerful of the NodeMCU family that manages to have a relative error below 20% in non-linear loads of the measured parameters. Other researchers use the Wemos D1 Mini microcontroller [17] due to its benefit of being smaller and more compact so that it can be placed in a reduced structure thanks to its dimensions. Therefore, single-phase and three-phase networks can be analyzed with this microcontroller. In [18], a quantitative methodology is used to measure electronic values of the single-phase electrical system of the line current (IL) of the home network.

It has been found that other scholars use the same method to investigate electricity consumption [3]. In [19], it uses a 16x2 I2C LCD to see the values of the analyzed parameters and even be monitored through a Local Area Network (LAN), entering a local IP address (192.168.1.X) from where it is components installed physically close to each other. In [17], it is proposed to place a 1.54-inch TFT screen with a resolution of 240x240 pixels that is implemented with a capacitive touch panel, with which the person can see the numerical values of the sensed variables that are stored in the flash memory of the processor ESP8266.

In [20], it uses the Bluetooth signal, given off by the programmable integrated circuit, to display on a phone that is a maximum of 10 meters from the system and whose data is stored on an SD memory card. Some scholars optionally propose how to transmit the data remotely to be viewed from anywhere in the world using a transmission channel such as Wi-Fi or other communication protocols [5], [21] or with a mobile application which uses Google Sheets Excel to save the values obtained from the sensors [6].

From the research reviewed, it is observed that although the monitoring of electrical variables using NodeMCU technology has been related, however, the following have not been implemented: local - remote monitoring and alert at the same time, the notification system in Google Firebase, the cost per energy consumed, historical graphs or technologies that are easy to understand for the common user.Therefore, it is a necessary starting point to carry out this monitoring and alert research applied to the residential electrical network that allows knowing the behavior of the voltage and current, given that peaks or excesses of these magnitudes possibly damage the connected devices to the energy supply.

3. Materials and Methods

The methodology that was applied for the development was carried out considering five sequences of tasks in the design process in each engineering domain, such as mechanical, electronic and computer design. Figure 1 shows the development of the methodology used, which has been divided and ordered in a Work Breakdown Structure (WBS) for a better understanding of the design and implementation of the proposed system.

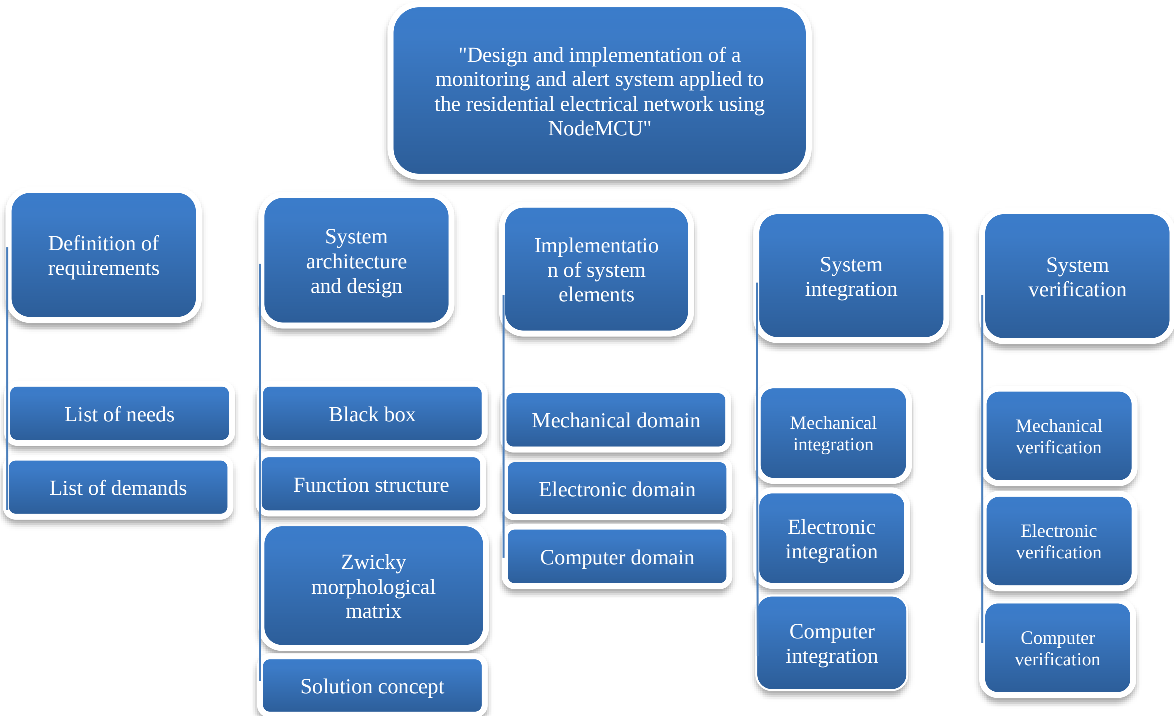

Fig. 1 Work breakdown structure (WBS)

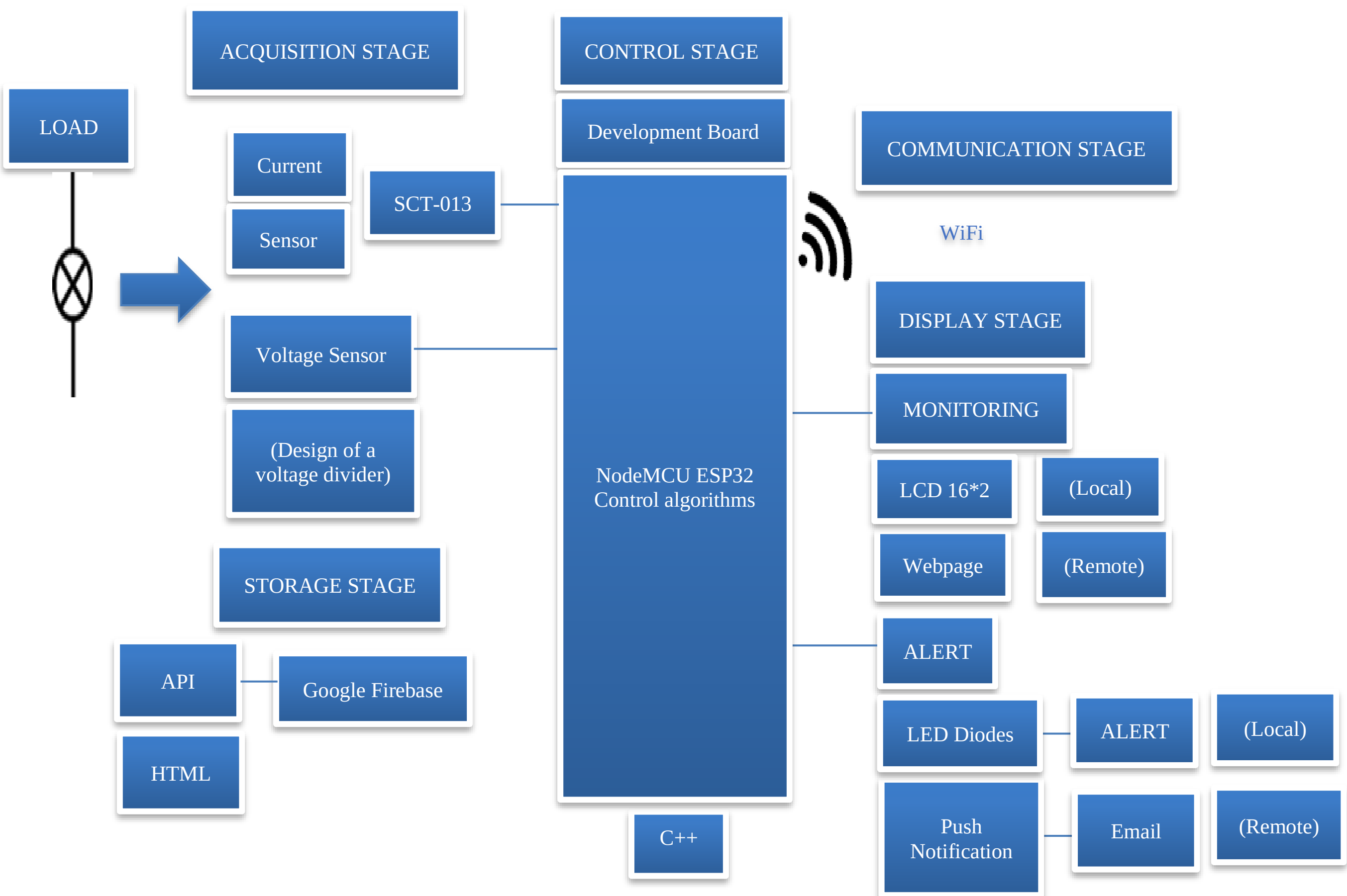

Fig. 2 Block diagram of the monitoring and alert system

The parts that make up the research system are organized using the indicated methodology to achieve the objective. To do this, the requirements are defined based on a list of demands: Main function, Design, Dimensions, Energy, Material, Connectivity, Signals, Safety, Ergonomics, Manufacturing, Installation, Transportation, Use, Calibration and Costs.

3.1. Determination of the Monitoring and Alert System

Figure 2 shows a block diagram with its respective stages, which are first, the signal acquisition phase through the sensors, the control stage using the NodeMCU microcontroller of the ESP32 type, the communication stage with the use of the Wi-Fi network, the data visualization stage through the 16X2 LCD and finally the storage stage with an API connection to the Google Firebase database. These stages are related to each other to fulfill the purpose of optimizing the monitoring and alerting of the electrical consumption that occurs in the home.

The system has a 12VDC voltage source, which provides energy for the entire system and in case the power supply goes out, it has a built-in 12V Lithium Ion battery. Likewise, it does not have a power button since it has a direct “Plug” type connection to the SCT-013-030 current sensors and the self-made voltage sensor module, which transmits the voltage ranges to a microcontroller. The NodeMCU family of the ESP32 type transmits wirelessly via Wi-Fi to Google Firebase, which stores and transmits to graphic indicators and in a list in the form of a history that can be viewed in real-time, thereby there is a display of voltage, current, and power data. When the system does not detect voltage and current signals, which indicates that there is a power outage or an error in the system, it sends a remote warning via email and “Push” notification on the web and a local alert through a red LED diode and audible by a Buzzer Module.In addition, the parameters can easily be read by the user locally using an LCD screen; all of this can be stored in an Excel table, which can be downloaded to have a historical report later.

3.2. Mechanical Structure

Figure 3 shows the manufacture of the casing, and it was decided to use 3D printing, which allows for more detailed and specific parts to be made since it needs to be compact, resistant and able to house all the components. The Polylactic Acid (PLA) material is a thermoplastic made from corn or sugar cane, which provides good characteristics such as better mechanical resistance, low cost and ease of printing, being chosen to build the casing. An ANET ET5 3D printer with UltiMaker Cura software was used to manufacture the casing.

3.3. Selection of System Components

The selection of electronic components is carried out, taking into account a series of properties and calculations of each element of the system to be analyzed and put into operation. It was decided to use a switched voltage source of 12VDC 5A that provides enough energy for the system to be stable, then it goes to a voltage regulation of 5VDC, and a commercial voltage regulator is used, which is the LM2596 BUCK STEP-DOWN module.

With this module, it is adjusted to 5VDC, and its advantage is that if the input voltage varies by having a fixed output voltage, then you can have a stable system. In order to measure the voltage with the ESP32, the measurement range must be reduced from (0 – 240 VAC) to (0 – 3.3 VDC), which is compatible with the inputs of said microcontroller. The method is used to reduce the input voltage (0 – 240 VAC). In order to do this, a transformer must be used to obtain outputs of (0 – 18 VAC). Then, the alternating voltage must be separated into positive and negative, and this is done using a diode bridge; then, an electrolytic capacitor of 100uF at 25V is used to reduce the curves already separated by the diodes to obtain a more linear result of positive and negative.

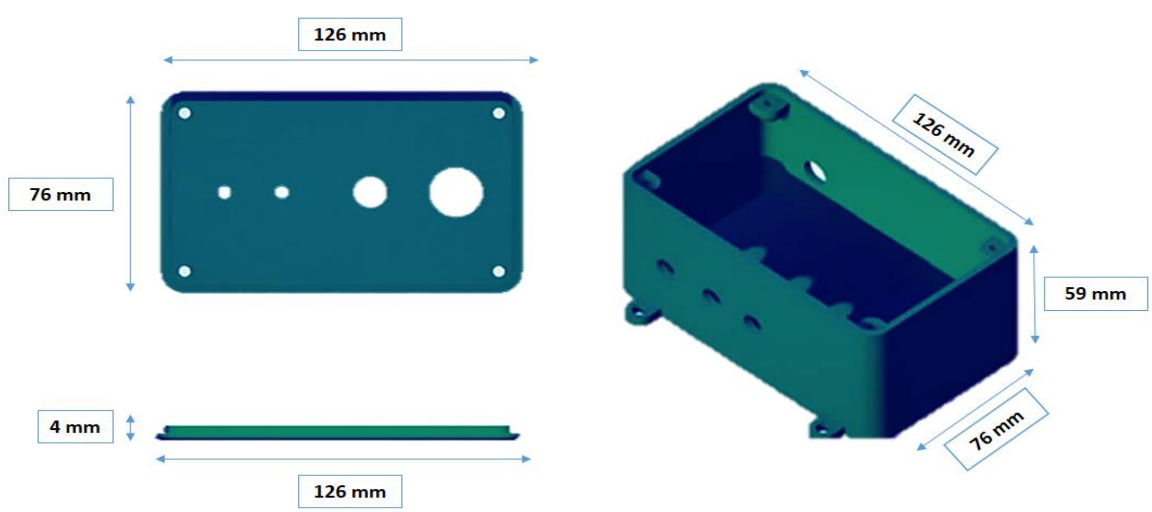

Fig. 3 Housing design

Having the voltage already in direct current in ranges of (0 – 20 VDC), the design of a voltage divider is carried out to obtain the maximum 3.3 VDC that is needed. It should be taken into account that for the ESP32, the current entering the reading pin must be limited, and this current must be 0.3 mA. R2 = 1155 Ohms. Therefore, the commercial resistor R2 = 1K Ohm, R1 = 6K. The ESP32 has 12 reading bits for its analog inputs, which means that it ranges from 0 – 4095 within the program. To obtain the reading in the necessary range (0 – 240 VAC) on the controller, the analog reading must first be converted into voltage within the program, as shown in Equation (1):

$$V = \left[3.3 \times \frac{analogRead(35)}{4095}\right] \times Constant \quad (1)$$

V is in the range from 0 to 2.8, at the programming level, is the real input voltage variable; then this real input voltage must be converted to ranges from 0 to 240 VAC; for this, the real Vmax is multiplied by a constant to reach 240V which is the voltage that you want to read, that constant is found with Equation (2):

$$Constant = \frac{V_{max}}{Vmax\ real} \quad (2)$$

Replacing:

$$Constant = \frac{240}{2.8} = 85$$

With this constant, you can complete the mathematical reading formula within the program:

$$V = \left[3.3 \times \frac{analogRead(35)}{4095}\right] \times 85$$

Figure 4 shows the current sensor, which is made up of the SCT013-030 module, whose parameters can be seen in its datasheet. This sensor to perform a reading through the microcontroller has 3.3V logic inputs with which an array of resistors is made to be able to perform the system reading analysis. This non-invasive sensor generates a signal in the range of -1.42 to 1.42 V. In order to use the ESP32, this range must be passed to voltages above 0V. This voltage is obtained using the controller supply voltage and a voltage divider. Figure 5 shows the electronic arrangement of the current sensor, where Vcc is 3.3 VDC, and using the voltage divider through the 500k resistors, 1.65 VDC is obtained. Being in series, it is added to the voltage generated by the current sensor, thereby obtaining new ranges.

$$V_{out} = 1.65 + (-1.42\ to\ 1.42)$$

$$V_{out} = 0.23\ to\ 3.07\ VDC$$

The ESP32 has 12 reading bits for its analog inputs, which means that it ranges from 0 – 4095 within the program. Equation (3) is used to convert the analog reading to voltage within the program with voltage reference given by the sensor specification (30A 1V).

$$V_{sensor} = \frac{analogRead(22) \times 1.1}{4095} \quad (3)$$

Using Equation (4), the voltage reading must be multiplied by the sensor factor (30A) to obtain the current.

$$a = V_{sensor} \times factor \quad (4)$$

Replacing:

$$a = V_{sensor} \times 30$$

Having chosen and designated its configuration, the characteristics that the sensors meet for correct operation are observed, having a precision of less than 5%. Being non-invasive, it allows different points of a residence to be analyzed and monitored without needing to cut the connections of the circuit to be analyzed, having measurement ranges corresponding to a current sensor that is from 0 to 30 amps and a voltage sensor. 50-250 VAC, working at temperatures ranging from 21°C to 40°C.

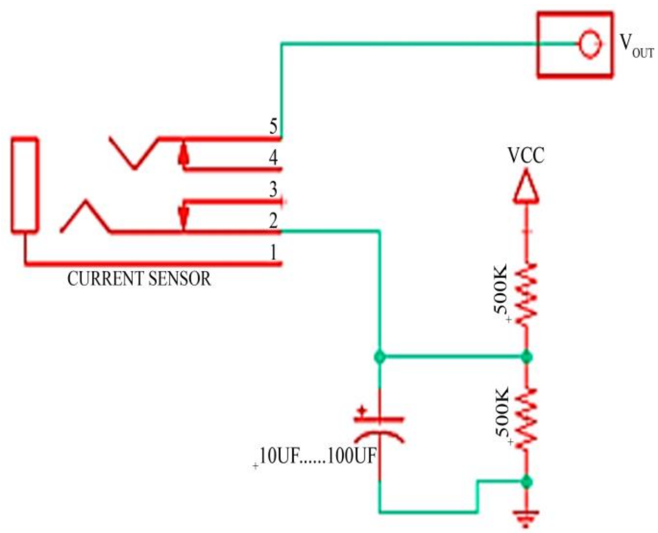

Fig. 4 Diagram current sensor method diagram

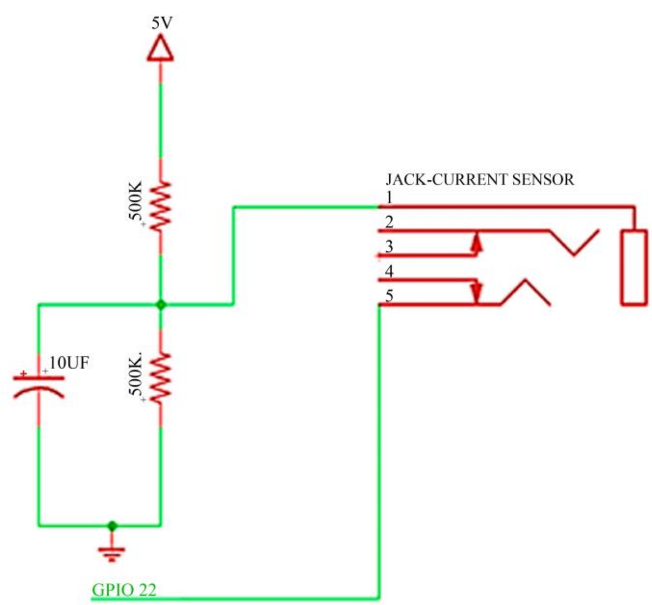

Fig. 5 Current sensor configuration

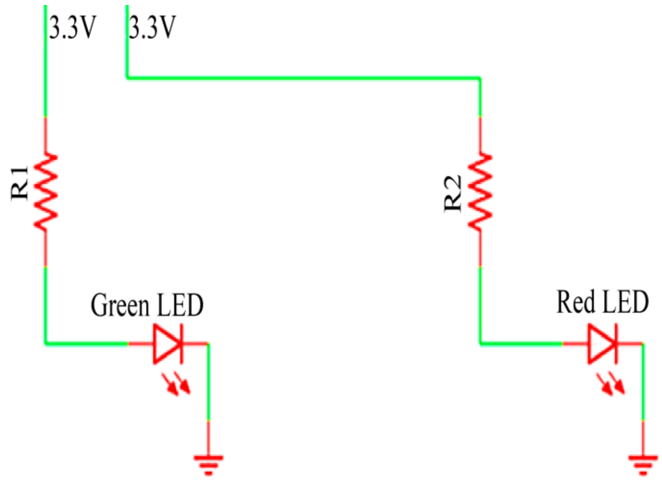

Fig. 6 Electronic configuration of LEDs

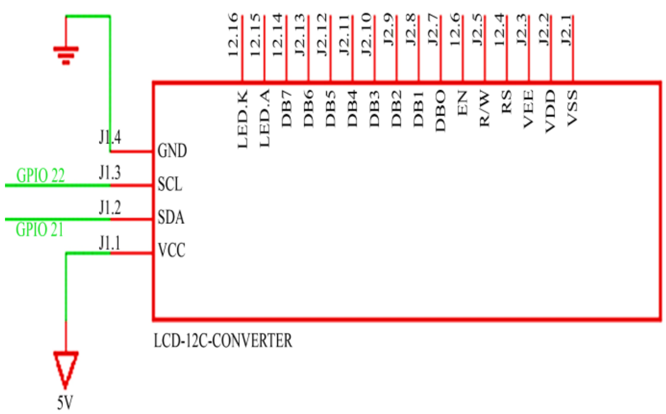

Fig. 7 Electronic configuration of the LCD screen

3.4. System Hardware

For the control stage, according to the demands and characteristics, the ESP32 development board was chosen, which is a high-power NodeMCU; it has a 4 MB flash memory and a clock speed of up to 240 MHZ, which is ideal for the development of the electrical consumption monitoring and alert device. Thanks to its Wi-Fi connectivity capacity and ease of programming, the NodeMCU ESP32 was selected, as it is a versatile and powerful development platform that combines wireless connectivity, processing power and ample memory with ease of use.

For the visual alert module, the LED diodes used to indicate correct operation are green and red, which indicate good and bad operation, respectively. Figure 6 shows the configurations of both diodes that are connected with a resistor that is activated with a logic signal that varies in voltage ranges from 0V as off and 3.3V on. In order to determine the values of the resistances of the LEDs, the ideal voltage of the diode was taken between 3.1 V and where its maximum current consumption is 20 mA. Figure 7 shows the connection of the LCD Screen; first, the GND input must be energized to ground, and the VCC to 5V, and then the SCL input of the screen is connected to the GPIO22 port of the microcontroller; in the same way, the SDA input is connected to the GPIO21 input of the NodeMCU.

For the sound alert module, a buzzer was chosen, which is a device that produces a sound when current is applied. This helps us to indicate any anomaly in the system with a sound alert.

The integration of the peripherals to the NodeMCU development board in its GPIO ports and its stages, such as the acquisition, control, database, communication and visualization phase, allows us to achieve an optimal system to monitor electrical consumption in a home.

Figure 8 shows the design of the electronic schematic of the system, which begins with the 12 volt power supply that is supplied by a switched supply that passes through an LM2596 regulator with which a 5V DC power supply is obtained that supplies the energy for the sensors and the development board.

The voltage reading is done with the voltage divider, which is connected to the GPIO 35, and the voltage ranges can be obtained, counting on the current signal that has a 3.5mm Jack connector and is connected to an array of 500k resistors and a 10uF capacitor and gives the signal through the GPIO22 pin. The buzzer is previously connected to an output that is the GPIO14 pin where the alert signals can be issued; the GPIO12 and the GPIO13 are the output signals to be able to activate the green and red LEDs that are previously connected to their resistors 120 Ohms.

Figure 9 shows the final layout of all the electronic modules well fitted and placed in their corresponding position. In the box part is the ESP32 NodeMCU, which has the voltage regulator that provides power to the system. In one corner, the module containing the transformer with a diode bridge and the voltage divider is placed; in the back part, the “Jack” type connector is housed, which allows connection to the power source. In the rear section, there is the 3.5 mm female “Jack” type connector connected to the 30 amp current sensor and, finally, two “female banana” type connectors to be able to place the “male bananas” that allow system voltage readings to be taken.

Figure 10 shows the cover where the buzzer is housed with the two LEDs; the green LED indicates when the system is in incorrect operation, and the red LED indicates a system alert; in the main box part, there is the voltage sensor, the regulator with the aforementioned resistor arrangement and the ESP32 module, which is the controller. On the side parts is the LCD screen, and on the other side is the 3.5 mm Jack-type connector that connects the current sensor; there are the “female banana” type connectors that are connected to the voltage sensor, fulfilling the objective of having a stable and easy-to-operate system.

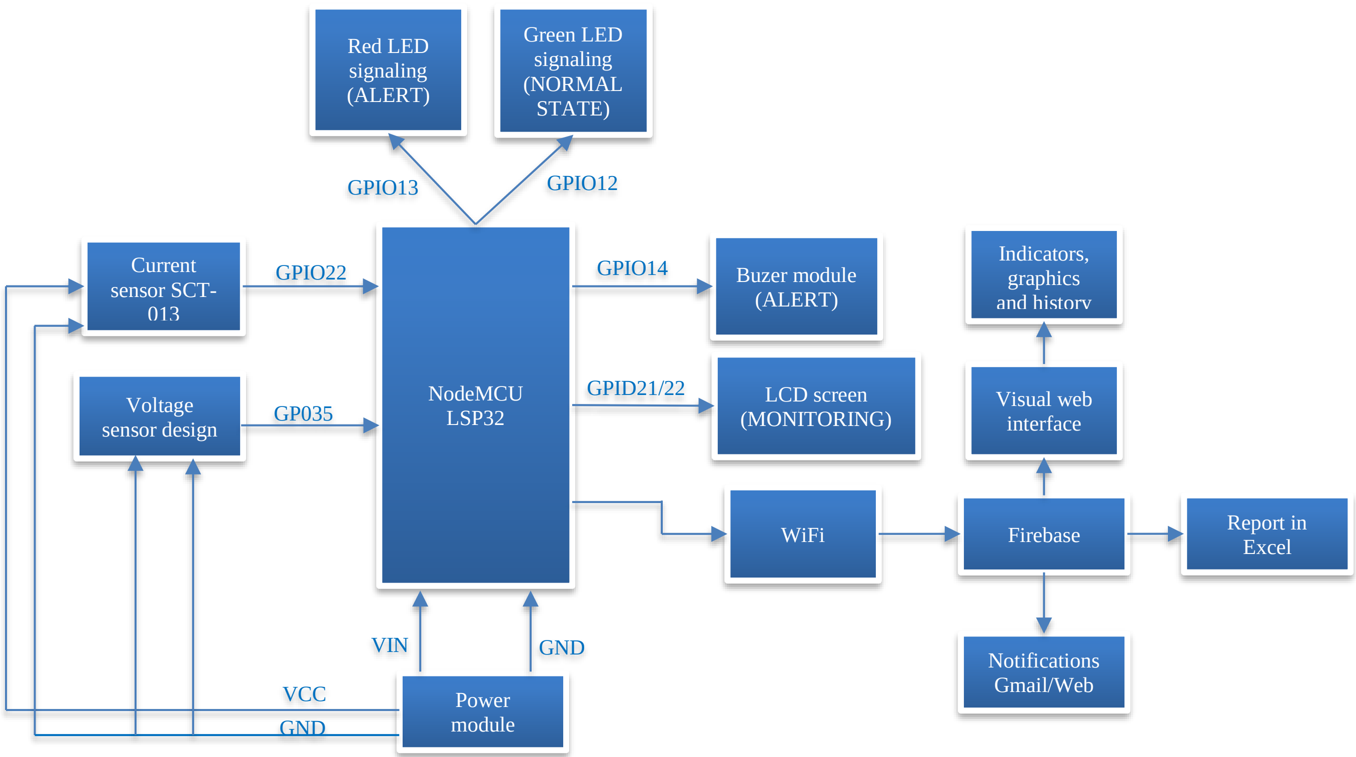

Fig. 8 Resulting schematic of the system

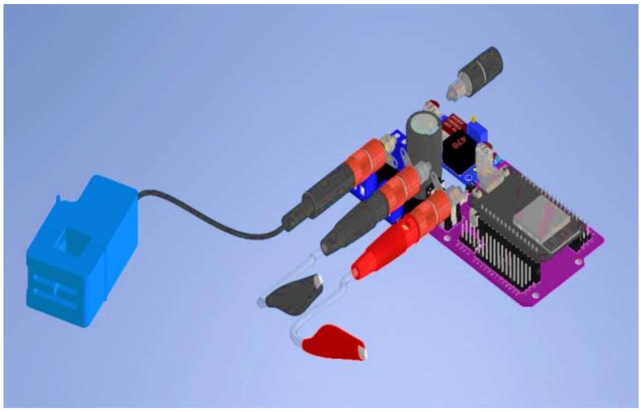

Fig. 9 View of the electronic structure

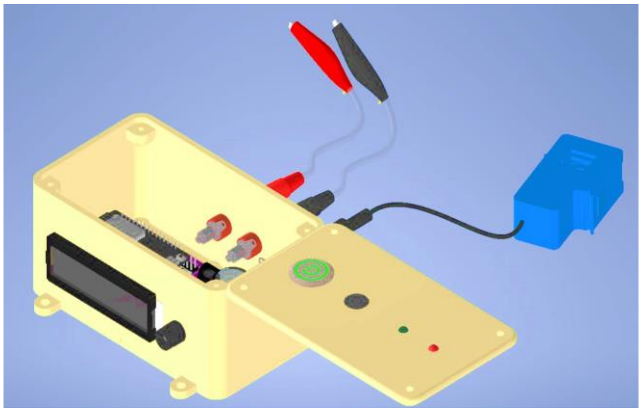

Fig. 10 Isometric view of electronic integration with structure

Figure 11 shows the operation of the system in a block diagram and is based on seven blocks with a branch. After energizing and installing the system through the current and voltage sensors, electrical signals are obtained, which are transmitted and received in the NodeMCU that transforms these signals through conversions having three values, which are voltage, current, and power. All this information is transmitted through a wireless Wi-Fi connection to Firebase, which does the necessary processing to carry out the visualization on a website with the help of Visual Studio and HTTP programs. In this part of the system it branches into two options, which are visualizations that are entered into a website where the data can be observed in real-time and can be observed in the next branch. Once there is a power outage anomaly, the system sends notifications to an email and through the web.

3.5. *Software*

Figure 12 shows the analysis of the system, where the system is activated by its energy source, and then the current and voltage sensors are read, which sends the signals to the processor, which converts these signals into digital values, which are processed and converted into voltage, current and power values. These parameters are sent remotely through a Wi-Fi connection to the Google Firebase tool, which, upon receiving the data and processing it, sends it to a website with which you can view the variables of the system to be measured and whether the system detects that there is a system disconnection, sends an alert via a registered email.

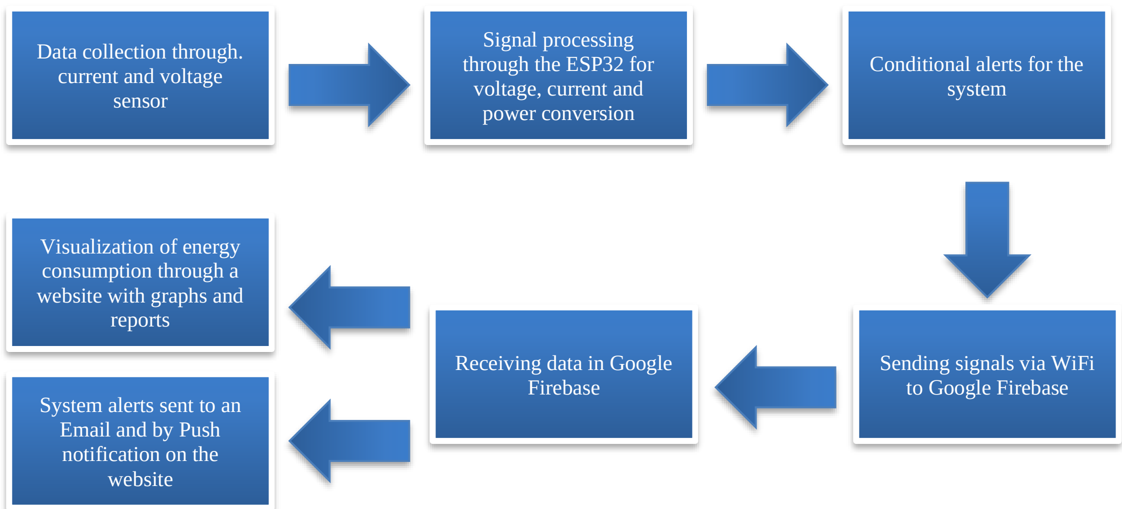

Fig. 11 Programming block diagram

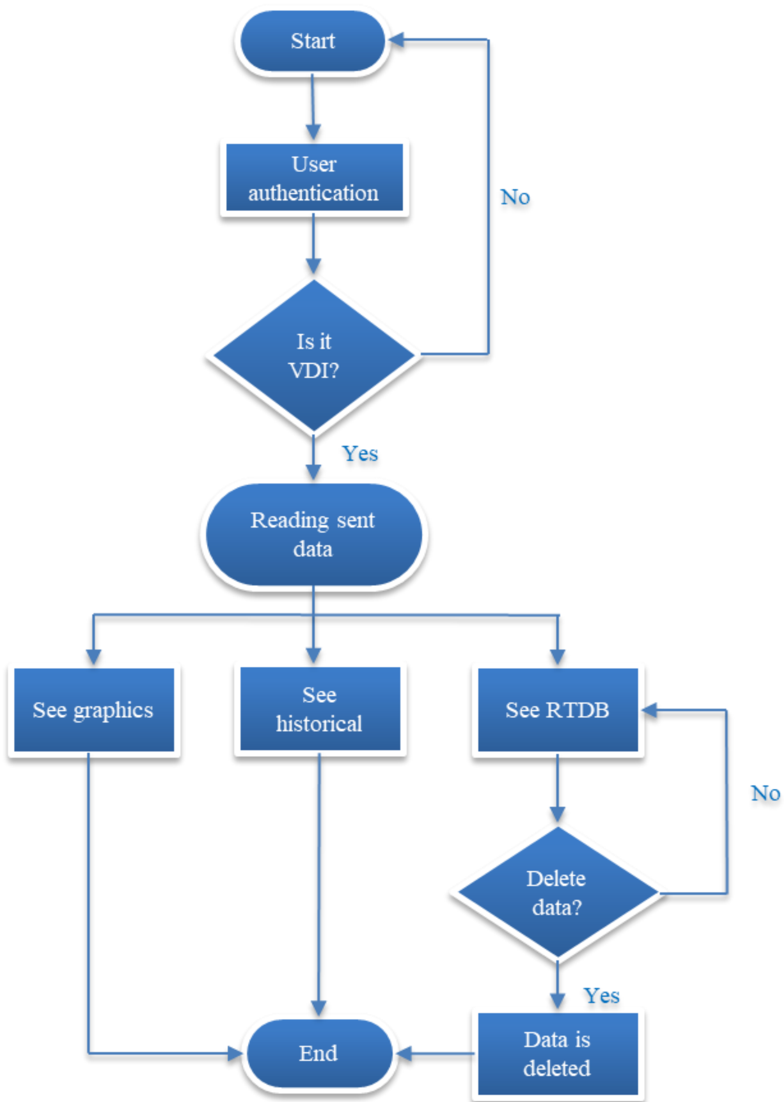

Fig. 12 Programming flow chart

3.6. Data Transmission to the Cloud

The programming code has been developed using the Arduino IDE and Visual Studio Code development platforms. Various programming languages have been used, including C++ for the Arduino environment, JavaScript, HTML and CSS for the project as a whole. For the programming process, the components are initialized with the code, HTTP requests from the Web Server are handled, Firebase data is updated, and the power outage is checked to send alert emails. A verification of Wi-Fi credentials is performed to ensure their accuracy. In case the credentials are incorrect, the program goes into an infinite loop until a valid Wi-Fi connection is established.

Using the Firebase library in the Arduino IDE, credentials are verified to ensure accuracy and confirm that the address provided is correct. A secure connection point is established between Firebase and ESP32 using the HTTPS (Hypertext Transfer Protocol Secure) protocol, which encrypts data transmitted between the Arduino device and Firebase servers. The sensor data is then transmitted for proper storage in Google Firebase. This encryption ensures the confidentiality and integrity of information during communication, guaranteeing secure and reliable transmission of data between the device and the Firebase platform. The structure of the data coming from the sensors for subsequent storage in a JSON format contains three fundamental data: voltage, amperage and power. This data is sent to Firebase at predefined time intervals, for example, every 10 seconds or more, while the system is in an infinite loop, thus ensuring a regular and accurate update of information on the Firebase platform.

Then, the SMTP Client is configured, and the email is sent. This feature is designed to send emails using the SMTP protocol. A comparison is made to check if the equipment is disconnected or if there is a power outage. If any of these conditions are met, the automatic sending of an alert message to the email previously configured in Gmail is activated as a preventive and notification measure for critical situations. This configuration can be edited depending on the type of alert you want to notify the user.

The Google Sheets refresh feature is intended to establish a connection with Google Sheets and send accurate voltage and amperage data for recording and storage. The operation is essential to ensure the reliable transfer of relevant information, thus ensuring accurate and detailed recording of voltage and amperage values in the Google Sheets platform. The HTML page provides an interface to modify the alert and set the recipient of the associated email. Importantly, this functionality can be performed without the need for an Internet connection, offering flexibility and ease of configuration without relying on online connectivity. In the investigation, graphic elements such as tables and charts were implemented to display the data coming from Firebase, which ESP32 had previously sent. These elements provide a structured and understandable visual representation of real-time information on the web page. Upon completion of the code, the JavaScript files were included. These files are essential for the dynamic operation and interactivity of the web application. Users can view real-time data, including voltage, amperage and power, using interactive graphs and charts. Additionally, it offers the ability to access historical data through graphs and tables, providing a complete and detailed perspective of system performance at different times.

The code is responsible for creating a table that represents the stored voltage, amperage and power data, displaying the information along with the corresponding date and time on which it was sent. This results in the generation of small graphic patterns, which makes it easier to interpret variations in voltage over time visually. Implemented a circular indicator for a detailed graphical representation of the voltage and amperage values received from Firebase.

CSS styles are applied to the corresponding HTML elements in the web application, providing a consistent and pleasing visual design for users. The web application is then created, and the script is published. The website is accessed to authenticate the user and provides a code, which is saved from being used with the ESP32, leaving the project configured and created in Google Sheets to program the Firebase. Afterwards, the Visual Studio Code software is installed to make and configure the web application. Initially, you need to establish the packages in VScode to install the other software that is used, such as Node.js and Firebase Tools.

The electronic analyses were corroborated thanks to the previous design of the circuit in the Eagle software, obtaining a few clues for the elements and verifying their correct connection with the system components. In the verification of the computer domain, the NodeMCU microcontroller code was compiled in the Arduino IDE software to make the Wi-Fi connection with the Google Firebase database, and finally, it was reviewed that the interface was intuitive with programming language. Easy programming for sensed parameters in the form of graphs, statistical data and historical reports. Subsequently, the Visual Studio Code software is installed to be able to make and configure the web application.

The Firebase web application project is configured by creating a "project" folder and a new terminal. Log in to Firebase with the command (firebase login) and authenticate the account to be able to enter the project. Then, a template is created with different folders, which are added to the schedule to obtain the appropriate project and configure the web in Firebase. To deploy the application, the command (firebase deploy) is used, which helps save the changes that were made to the program so that they can be executed. Transmission routes and frames are configured, which are String-type data of voltage, amperage and power, which indicates the date and time from which the signals are transmitted.

The verification of the computer domain was done with the compilation of NodeMCU microcontroller code in the Arduino IDE software to make the Wi-Fi connection with the Google Firebase database, and finally, it was reviewed that the interface is intuitive with programming language in Visual Studio to easily observe the sensed parameters in the form of graphs, statistical data and historical reports.

4. Results and Discussion

The design and implementation of the monitoring and alert system to supervise the power consumption of a home based on devices that use the Internet of Things (IoT) allowed for optimizing the supervision of the power consumed based on the analysis of the voltage and current of the installed load.instalada.

4.1. Regarding the Optimal Monitoring and Alert System

According to the design for the proposed optimal system, Arduino hardware and software were implemented to collect data from the home locally. Figure 13 shows the data on the LCD screen of the voltage, current and power parameters, where it can be seen that the green LED indicator indicates that the system is connected to the power supply and in operational status.

According to system monitoring, a web link of the graphical user interface with a stable web page and secure credentials was obtained through free access at the link: https://esp32-firebase-read-amp.web .app/. Figure 14 shows a very friendly visual website where you can view the voltage, current, and power data of the sensing device in real-time.

Fig. 13 System indicators

Fig. 14 Web program indicators

Figure 15 shows in circular graph format the voltage and current parameters that are being sensed in real time. Figure 16 shows the obtaining of historical data, where the parameters regarding each reading are indicated with date and time.

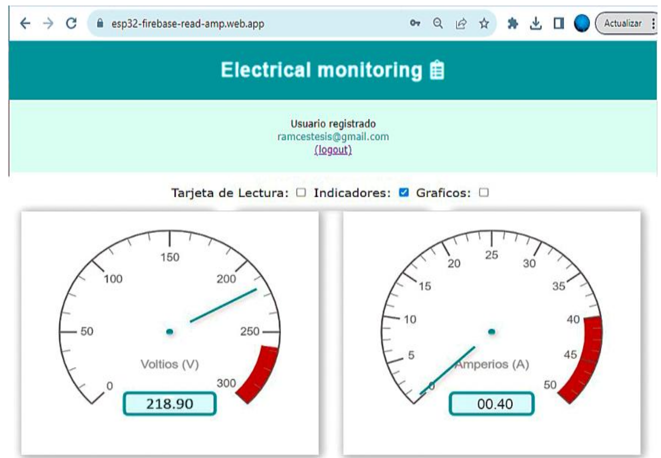

Fig. 15 Web program graphics

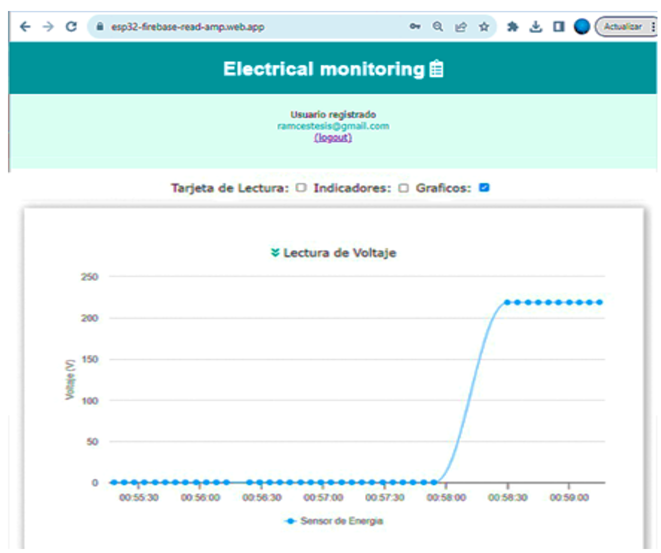

Fig. 16 Historical report of the web program

Fig. 17 Local disconnection alert

Regarding the system alerts, it responded very well when sending outage alerts. Figure 17 shows that the system turned on the red LED and sounded the buzzer when it detected this power outage anomaly and began to use the backup battery.

Figure 18 shows that the system warned with "Push" type notifications in the web page interface to warn of a system power outage. The message appears at the top automatically when you first access the website with the username and password that was previously configured. Figure 19 shows the alert that the equipment is disconnected from the electrical network, obtaining a message in the user's Gmail message tray. This message has a high and safe priority, which is why it appears in the main inbox and not in spam so that the client can see it immediately.

4.2. Regarding the Selection of Components

The selected LCD screen was optimal, since it is evident that its ports are compatible with the NodeMCU ESP32 microcontroller and also that its configuration libraries are open access so that any user has the ability to configure the variables they wish to display. The associated sensors allowed automatic updating at each time interval that was previously configured, thanks to its compatibility and the ESP32 development board, since it is the fastest microcontroller in the NodeMCU family and for its ability to be a device designed to control IoT devices remotely using Wi-Fi.

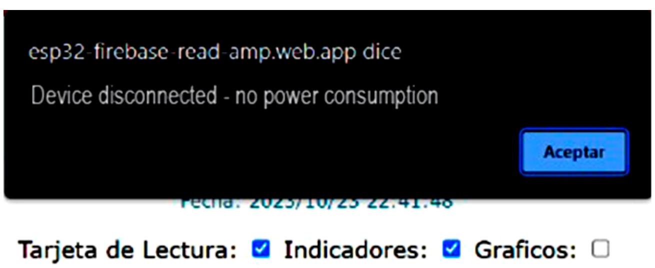

Fig. 18 "Push" notification on the website

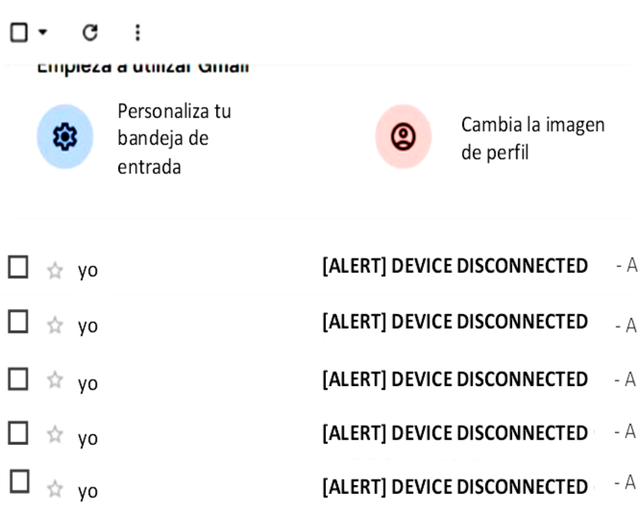

Fig. 19 Remote system alert via Gmail

Fig. 20 Prototype testing vs. commercial instruments

4.3. Regarding the Percentage of Error and Comparison of Data

To evaluate the power of the system, around 28 tests were carried out for the proposed system, using calibrated measuring instruments from recognized brands such as the Fluke multimeter that has a precision level of 0.7% ± 2 digits for the AC voltage and Fluke clamp meter that has a 2% ± 5 digit accuracy level in AC current analysis; Both teams have an accuracy of 0.5% to verify with the values measured by the proposed system. Voltage, current and power measurements were carried out with a lamp that represents an installed load of the home, thus obtaining the power consumed by the device over a period of time. Figure 20 shows the values obtained between the proposed system and traditional measurement equipment, demonstrating high precision when comparing the current and voltage values delivered by the sensors.

Table I shows the values obtained from the 28 tests to record the voltage variable. To do this, the results of the proposed system were compared with the Fluke brand multimeter to perform statistical error calculations.

In Equation (5), the percentage error of the voltage is found:

$$\%E_{T(V)} = \frac{\sum_{n}^{1} |V_{multimeter} - V_{sensor}|}{n} \times 100\% \qquad (5)$$

Replacing:

$$\%E_{T(V)} = \frac{0.10848}{28} \times 100\%$$

$$\%E_{T(V)} = 0.39\%$$

Table II shows the values obtained from 28 tests to record the current variable to apply statistical calculations. To do this, the results of the proposed system were compared with the Fluke brand current clamp to perform statistical error calculations.

Table 1. Test of the multimeter and module voltage

Test	Voltage		V error	% V error
	V multimeter	***V sensor***		
N° 1	219.6	220.2	0.00273224	0.27%
N° 2	220.2	220.2	0	0.00%
N° 3	219	219.6	0.002739726	0.27%
N° 4	219.2	219.6	0.001824818	0.18%
N° 5	219.4	219.6	0.000911577	0.09%
N° 6	220.4	219.6	0.003629764	0.36%
N° 7	219.2	219.6	0.001824818	0.18%
N° 8	219.2	219.6	0.001824818	0.18%
N° 9	218.8	219.6	0.003656307	0.37%
N° 10	219.7	219.6	0.000455166	0.05%
N° 11	220.7	219.6	0.004984141	0.50%
N° 12	220.3	220.2	0.000453926	0.05%
N° 13	220.4	219.6	0.003629764	0.36%
N° 14	221	219.6	0.006334842	0.63%
N° 15	220.9	219.6	0.005885016	0.59%
N° 16	220.7	219.6	0.004984141	0.50%
N° 17	220.3	219.6	0.003177485	0.32%
N° 18	217.9	219.6	0.007801744	0.78%
N° 19	218.4	219.6	0.005494505	0.55%
N° 20	220.3	219.6	0.003177485	0.32%
N° 21	217.6	219.6	0.009191176	0.92%
N° 22	219.1	220.2	0.005020539	0.50%
N° 23	217.8	219.6	0.008264463	0.83%
N° 24	218.2	219.6	0.006416132	0.64%
N° 25	220.4	220.2	0.000907441	0.09%
N° 26	221.5	220.2	0.005869074	0.59%
N° 27	219	220.2	0.005479452	0.55%
N° 28	220.6	220.2	0.001813237	0.18%
Total voltage error			**0.003874421**	**0.39%**

In Equation (6), the percentage error of the current is found:

$$\%E_{T(I)} = \frac{\sum_{n}^{1}\left|I_{current\ clamp} - I_{sensor}\right|}{n} \times 100\% \qquad (6)$$

Replacing:

$$\%E_{T(I)} = \frac{0.875}{28} \times 100\%$$

$$\%E_{T(I)} = 3.12\%$$

Table 2. Test of the current clamp and SCT-013 sensor

Test	Current		I error	% I error
	I current clamp	***I sensor***		
N° 1	0.4	0.42	0.05	N° 1
N° 2	0.4	0.42	0.05	N° 2
N° 3	0.4	0.39	0.025	N° 3
N° 4	0.4	0.39	0.025	N° 4
N° 5	0.4	0.39	0.025	N° 5
N° 6	0.4	0.41	0.025	N° 6
N° 7	0.4	0.39	0.025	N° 7
N° 8	0.4	0.39	0.025	N° 8
N° 9	0.4	0.39	0.025	N° 9
N° 10	0.4	0.41	0.025	N° 10
N° 11	0.41	0.41	0	N° 11
N° 12	0.4	0.42	0.05	N° 12
N° 13	0.4	0.41	0.025	N° 13
N° 14	0.4	0.41	0.025	N° 14
N° 15	0.4	0.41	0.025	N° 15
N° 16	0.4	0.41	0.025	N° 16
N° 17	0.4	0.41	0.025	N° 17
N° 18	0.4	0.41	0.025	N° 18
N° 19	0.4	0.41	0.025	N° 19
N° 20	0.4	0.41	0.025	N° 20
N° 21	0.4	0.41	0.025	N° 21
N° 22	0.4	0.42	0.05	N° 22
N° 23	0.4	0.41	0.025	N° 23
N° 24	0.4	0.41	0.025	N° 24
N° 25	0.4	0.42	0.05	N° 25
N° 26	0.4	0.42	0.05	N° 26
N° 27	0.4	0.42	0.05	N° 27
N° 28	0.4	0.42	0.05	N° 28
Total current error			**0.03125**	**3.12%**

4.4. Regarding the Efficiency of the System

With this, the results are compared to calculate the efficiency of the system with the values of the variables measured in the tables. First, the calculations are made with commercial measuring instruments, which are the multimeter and the Fluke brand clamp meter. To do this, Equation (7) is used to find the average voltage of the multimeter, then Equation (8) is used to find the average current of the current clamp and finally Equation (9) is used to find the average power.

$$V_{avg\ multimeter} = \frac{\sum_{n}^{1}\left|V_{multimeter}\right|}{n} \qquad (7)$$

$$I_{avg\ current\ clamp} = \frac{\sum_{n}^{1}\left|I_{current\ clamp}\right|}{n} \qquad (8)$$

$$P_{avg\ tool} = V_{avg\ multimeter} \times I_{avg\ current\ clamp} \quad (9)$$

Replacing:

$$V_{avg\ multimeter} = 219.6357\ V$$

$$I_{avg\ current\ clamp} = 0.4003\ A$$

Multiplying both values from the average voltage and current measurements of the instruments:

$$P_{avg\ tool} = 87.9327\ VA$$

Then, the current, voltage and power values of the proposed system are calculated using the same equation.

$$V_{avg\ system} = 219.7714\ V$$

$$I_{avg\ system} = 0.4085\ A$$

$$P_{avg\ system} = 89.7923\ VA$$

With these results obtained, the percentage of efficiency of the system with respect to commercial Fluke measurement instruments is calculated using Equation (10):

$$\%Efficiency = \frac{P_{avg\ tool}}{P_{avg\ system}} \times 100\% \quad (10)$$

Replacing:

$$\%Efficiency = \frac{87.9327}{89.7923} \times 100\%$$

$$\%Efficiency = 97.9289\%$$

This proves the high efficiency of the proposed system based on the results obtained with commercial measurement tools. From the results, the system supports local and remote monitoring for the supervision of different electrical parameters, which has as its fundamental element the NodeMCU ESP32 microcontroller that optimally interconnects with the selected components such as the current sensor, the voltage, the LCD, the buzzer and the LEDs to complement the designed device. Likewise, the efficiency evaluation resulted in 97.9289% with an error percentage of 0.39% and 3.12% with respect to the voltage and current analyzed, respectively.

It should be noted that this proposed system was implemented, and its operation was verified in a real way with the respective hardware and software. Although it is true that a single device was built, which allows knowing the general consumption of the load installed in the home, devices can also be installed in each of the electrical equipment that the home has in such a way that there is a mapping of all consumer devices to perform an optimization based on the consumption of each of them. In the same way, this device can be installed in each home supplied by the same electrical substation and, in this way, verify that the consumption of all of them is the same as that recorded by the totalizing meter installed in the substation, being able to quickly detect theft of energy.

4.5. Discussion

From the results, it is concluded that the system supports local and remote monitoring for the supervision of different electrical parameters, which has as its fundamental element the NodeMCU ESP32 microcontroller that optimally interconnects with the selected components such as the current sensor, the voltage, the LCD, the buzzer and the LEDs to complement the designed device. Likewise, the efficiency evaluation resulted in 97.9289% with an error percentage of 0.39% and 3.12% with respect to the voltage and current analyzed, respectively. There are few researchers who point out error percentages in their system for calculating power. Thus, [14] results in an error of 0.018% and others [16] show errors below 20%. However, they do not compare their results with calibrated measuring instruments to obtain the efficiency of the system, as has been evidenced in the present proposed system.

According to the literature reviewed, researchers managed to monitor the variables through an LCD screen [17-19]; others were able to view the magnitudes through their respective monitoring platform [15]; however, they do not present “Push” type notifications. ” on the web nor alerts via email when the equipment is disconnected nor historical reports of the measured variables. In this case, it could be achieved thanks to the programming of the code in Java Script and the configuration of the appearance of the website in CSS that allows the voltage, current and power data to be easily displayed on the Google Firebase platform.The components used by other researchers [15] are mainly Arduino microcontrollers, others [13] used Xbee modules, as well as [16-17] used NodeMCU. From this, it can be stated that the latter is more efficient and economical.

5. Conclusion

The design of the system, implementing both local monitoring through the values displayed on the LCD, as well as remote monitoring with values displayed on a web page, allows us to record in real-time based on indicators, graphs and historical electricity consumption of the home within optimal ranges of the measured variables, thereby ensuring the precision of the proposed system. A monitoring system with NodeMCU is viable for remotely monitoring the electrical power consumption of one or more loads installed in a home, with the purpose of supervising and optimizing its electrical consumption. According to the results obtained with calibrated measuring instruments, an efficiency of 97.9289% has been obtained; therefore, it can be stated that a monitoring and alert system applied to the residential electrical network using NodeMCU is efficient and allows through the ESP32 microcontroller to track the sensed variables through a web platform in an intuitive and easy-access way for the user.For future work, it is recommended to make comparisons with more high-precision commercial instruments, such as the Fronius Smart Meter 63A Single-Phase, to more accurately determine the error percentages and system efficiency. It is suggested that a SIM800/SIM900 module be attached in the communication stage so that data transmission is through a GSM chip from a local company. Likewise, the microcontroller could be replaced and evaluated by a smaller one, such as the Attiny85 and can be applied in a three-phase electrical network for the industrial sector.

References

[1] Anang Suryana, "Monitoring Electrical Energy Consumption Through Impulse Detection Using LDR Sensors and Relay With NodeMCU ESP8266," *2019 5th International Conference on Computing Engineering and Design*, Singapore, pp. 1-7, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[2] R. Bharathi, M. E. Madhushree, and Priyanka Kumari, "Power Consumption Monitoring System Using IOT," *International Journal of Computer Applications*, vol. 173, no. 5, pp. 23-25, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[3] Dyah Lestari, Irawan Dwi Wahyono, and Irham Fadlika, "IoT Based Electrical Energy Consumption Monitoring System Prototype: Case Study in G4 Building Universitas Negeri Malang," *2017 International Conference on Sustainable Information Engineering and Technology*, Malang, Indonesia, pp. 342-347, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[4] T.M. Thamizh Thentral et al., "Implementation of Protection Circuit for Over Voltage and Under Voltage Protection," *Materials Today: Proceedings*, vol. 45, no. 2, pp. 2460-2464, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[5] J.P. Iloh, A.C. Odigbo, and C.B. Mbachu, "Internet of Things Concept for Improving Energy Metering in Power Distribution Networks," *International Peer-Reviewed Journal*, vol. 6, no. 11, pp. 632-641, 2023. [Publisher Link]

[6] Thanh Ba Nguyen, and Tri Cao Nguyen, "Design and Fabrication of an IoT-Based Smart Electrical Meter for Residential Energy Management," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 30, no. 3, pp. 1259-1268, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[7] Electricity Statistical Yearbook 2022, Ministry of Energy And Mines (Peru), pp. 1-383, 2022. [Online]. Available: https://www.minem.gob.pe/_estadistica.php?idSector=6&idEstadistica=13609/

[8] The Electricity Industry in Peru: 25 Years of Contributions to the Country's Economic Growth, Osinergmin, pp. 1-178, 2016. [Online]. Available: https://www.gob.pe/institucion/osinergmin/informes-publicaciones/483410-la-industria-de-la-electricidad-en-el-peru-25-anos-de-aportes-al-crecimiento-economico-del-pais

[9] I.O. Zaitsev et al., "Line Electrical Transmission Damage Identification Tool in Distributors Electrical Networks," *IOP Conference Series: Earth and Environmental Science*, Ukraine, vol. 1254, no. 1, pp. 12-36, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[10] Fransiscus Yudi Limpraptono et al., "Design of Power Monitoring and Electrical Control Systems to Support Energy Conservation," *Proceedings of the Pakistan Academy of Sciences: Part A*, vol. 58, pp. 1-7, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[11] Muhammad Faiz Bin Mohd Kamal et al., "IoT-Based Electric Monitoring System for Smart Electric Meter Application," *Control and Measurement Applications for Smart Grid*, vol. 822, pp. 209-218, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[12] Paul Stone Macheso, and Doreen Thotho, "ESP32 Based Electric Energy Consumption Meter," *International Journal of Computer Communication and Informatics*, vol. 4, no. 1, pp. 23-35, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[13] Darwin Alulema, Mireya Zapata, and Miroslava Aracely Zapata, "An IoT-Based Remote Monitoring System for Electrical Power Consumption via Web-Application," *2018 International Conference on Information Systems and Computer Science*, Quito, Ecuador, pp. 193-197, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[14] Wiwid Suryono et al., "Monitoring and Controlling Electricity Consumption Using Wemos D1 Mini and Smartphone," *International Conference on Advanced Mechanical and Industrial Engineering*, Banten, Indonesia, vol. 909, pp. 1-10, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[15] Oltean Andrei et al., "IoT Power Monitoring Device Using Wi-fi and Arduino," *2021 9th International Conference on Modern Power Systems*, Cluj-Napoca, Romania, pp. 1-6, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[16] Firdaus Jonathan, and Tri Wahyu Oktaviana Putri, "Prototype of Home Power Monitoring Tool for Electrical Outlet Using ESP32," *2021 International Conference on ICT for Smart Society*, Bandung, Indonesia, pp. 1-5, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[17] Huan-Liang Tsai, Le Phuong Truong, and Wei-Hung Hsieh, "Design and Evaluation of Wireless Power Monitoring IoT System for AC Appliances," *Energies*, vol. 16, no. 1, pp. 1-27, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[18] Komkrit Chooruang, and Kraison Meekul, "Design of an IoT Energy monitoring System," *2018 16th International Conference on ICT and Knowledge Engineering*, Bangkok, Thailand, pp. 1-4, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[19] Abdul-Waliyi O. Muhammed et al., "Design and Implementation of an IoT Based Home Energy Monitoring System," *2022 5th Information Technology for Education and Development*, Abuja, Nigeria, pp. 1-7, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[20] Ewerton L. de Sousa et al., "Development a Low-Cost Wireless Smart Meter with Power Quality Measurement for Smart Grid Applications," *Sensors*, vol. 23, no. 16, pp. 1-21, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[21] Suhanto et al., "The Electrical Energy Usage of Monitoring System at Real-Time Using IoT as the Primary Policy of Energy Efficiency," *International Conference on Advanced Mechanical and Industrial Engineering*, Banten, Indonesia, vol. 909, pp. 1-9, 2020. [CrossRef] [Google Scholar] [Publisher Link]