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# IoT-Based Alternating Current Electrical Parameters Monitoring System

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**Abstract:** Energy monitors are indispensable for achieving efficient electrical grids and even more so in the age of the Internet of Things (IoT), where electrical system data are monitored from anywhere in the world. This paper presents the development of a two-channel electrical parameter-monitoring system based on the M5 Stack Core2 kit. The acquisition of variables is done through PZEM 004T V3.0 sensors, and the data are sent to the ThingSpeak cloud database. Local readings are done through the LCD, and data re stored on a micro SD card. Remote monitoring is done through two applications, namely a web application and a mobile application, each designed for different purposes. To validate this proposal, a commercial device with IoT features (Gen 2 Vue Energy Monitor) is used, comparing the active power and active energy readings recorded continuously for 7 days. The results indicate an accuracy of up to 1.95% in power and 0.81% in energy, obtaining a low-cost compact product with multiple features.

**Keywords:** IoT; monitoring system; electrical parameters; energy monitor; cloud database; mobile application; low cost

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## 1. Introduction

### 1.1. Motivation

Electric energy is an important part of the modern world; it is one of the basic products that are used every day. Therefore, it is necessary to satisfy the demands for electrical energy in constant growth and reduce greenhouse gases, for this is useful to monitor and manage industrial, commercial, and residential electrical devices [1]. These electrical systems are constantly wasting energy due to inefficient equipment, inefficient power dispensing, unreliable communication and monitoring, and a lack of smart technology. Other challenges are growing energy demand, reliability, security, emerging renewable energy sources, and outdated infrastructure designs [2,3].

The main applications of wireless sensor networks are emergency systems, control systems, supervision systems, warning systems and monitoring systems. In general, wireless networks fall into five categories: personal area network (PAN), which relies on techniques such as Bluetooth, wireless USB, Insteon, IrDA, and ZigBee to exchange data between two devices; local area network (LAN), which is defined by the family of IEEE 802.11 standards and offers the possibility of integrating terminals of a home or business network; metropolitan area network (MAN), which communicates several LAN networks and are based on the IEEE 802.16 standard; wide area network (WAN), which extends over geographical areas such as countries or continents; global area network (GAN), which allows communication worldwide, such as the Internet [4]. The progressive use of Internet of Things (IoT) technologies in almost all sectors and the use of low-cost devices supports the development of these applications [5–8]. Currently, system on chips with multiple features are available for the development of IoT projects, with some have integrated screens that allow the creation of attractive interfaces for the user, present the data locally, and send it to the internet for remote viewing [9,10]. Likewise, commercial sensors also facilitate the implementation of these intelligent systems because these include communication to deliver the data to the processing device through some known protocol [11,12]. IoT allows to offer innovative solutions in the field of electrical grids, incorporating the cloud and artificial intelligence as part of the solution [13–15].

Energy monitoring systems have evolved and now measure energy consumption and provide analysis on electrical energy use regularly. For this, it incorporates an integrated system for data processing and sending data through wired or wireless media [16–18]. These monitors have become a necessity in renewable energy-generation systems around the world, and real-time information has become essential to managing these systems, especially if these are installed in remote areas [19–21]. Even the most basic monitoring proposals have made it possible to improve energy management in commercial and domestic settings [22,23].

A remote monitoring system requires an application that accesses the shared data through some database of the IoT platform [24]. In this context, mobile applications are very popular today because almost everyone has a smartphone available all the time. These applications are highly linked to IoT projects because they provide a friendly graphical interface with multiple features, and this has greatly facilitated the expansion of intelligent systems in recent years [25,26]. Another facilitating component of these proposals is the IoT service platforms, which currently have cloud databases that can be managed directly from the web [27]. All these advances have allowed the development of new and better energy monitors, but there are no proposals validated by comparison with commercial devices with similar characteristics.

### *1.2. Related Works*

In the literature, there are some contributions to the development of energy monitors using IoT. In [19], the authors used LoRaWAN technology and an Arduino microcontroller to measure the energy consumption of a photovoltaic system and send data in real time to the utility company through the Internet for billing. The measured parameters are voltage, current, power, energy, light intensity, temperature, and humidity. Connectivity between the system and users is achieved through smartphones and computers. Results demonstrate smooth system operation with detailed measurements of electrical usage and environmental conditions.

In [28], the authors developed an IoT-based energy monitor using an Arduino board, which can track and analyze electrical parameters, including current, voltage, active power, and energy consumption; these data are used to control hybrid solar and wind power plants through a smart grid. On the other hand, in [29], a smart household distribution system was developed that allows the collection and storage of voltage, current, and power data, presenting the information locally on two LCD screens and remotely on a mobile and web application. Experimental results show that this system can be used effectively for real-time home energy management.

In [30], a prototype of an energy monitor assisted by analysis in the cloud with artificial intelligence for demand-side management focused on smart homes and using Arduino technology to implement a proof of concept was designed and implemented, and the acquired data are sent to a cloud database for remote viewing. Likewise, in [31], the energy consumed by different electrical devices is acquired to be sent to a server using the Arduino Uno board with the help of the ESP8266 Wi-Fi module. In addition, energy consumption is displayed on an LCD, and consumption profiles are displayed through the home energy-monitoring website; the variables monitored are voltage, current, power, energy, and power factor.

In [32], an IoT-based SCADA system was described that incorporates web services for the control and supervision of electrical parameters of direct current. This proposal uses analog current and voltage sensors, the low-power ESP32 Thing microcontroller, a Raspberry Pi microcontroller, and a local Wi-Fi router. The data are sent to the IoT platform of the local Thinger.IO server. Similarly, in [33], a monitoring system dedicated to visualizing the operation of lithium-ion batteries using IoT was presented, and the Grafana software is applied for data analysis and visualization, which is hosted on a Raspberry Pi microcomputer. Finally, in [34], a single-channel electric power and energy meter (OpenZmeter) based on an ARM board and designed for houses in urban or rural areas was presented, which can be easily used. This system was validated in a real house with readings for two weeks.

In this article, a two-channel alternating current electrical parameter monitor with remote monitoring functions through the IoT is developed. The proposed system is based on an M5Stack Core2 device and PZEM-004T alternating current communication modules. The information collected is viewed and stored locally and is also sent to a cloud database. For remote monitoring, ThingSpeak services are used, which allow electrical parameters to be viewed from a web server and a mobile application. Finally, the final product is evaluated by comparing the measurements with respect to a commercial energy monitor. This document has been organized as follows: Section 1 contains the introduction and review of the literature; Section 2 describes the materials and methods used; Section 3 presents the results of the tests carried out; Section 4 contains the discussion of this work; and Section 5 presents the conclusions obtained.

## 2. Materials and Methods

### *2.1. General Description*

The proposed system is oriented towards the monitoring of electrical parameters in electrical distribution boxes of buildings with Internet access through Wi-Fi communication. At least 2 reading channels are required to work independently, even allowing data to be recorded from different energy supplies. For this, compact sensors of electrical variables are required as well as a data acquisition and processing unit that includes IoT features. It is also planned to read and store the information locally. In addition, the information sent to the IoT platform must be registered in a cloud database, so the user can access this information from a web server and a mobile application from anywhere. Figure 1 presents the general scheme of the proposed system.

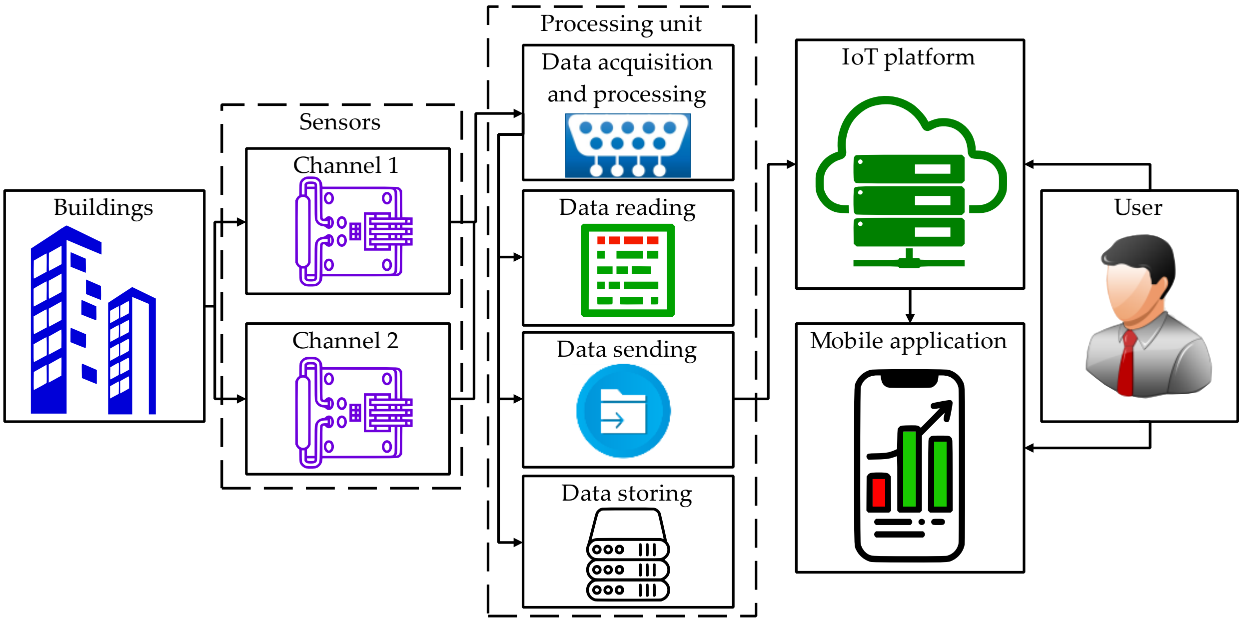



**Figure 1.** General diagram of the alternating current electrical parameter-monitoring system.

The electrical parameters to be measured are voltage, current intensity, active power, reactive power, apparent power, power factor, and active energy, and the requirements in detail are described in Table 1. Electrical supply in buildings in almost any part of the world requires a voltage between 120 and 240 volts (V) with a frequency between 50 and 60 Hertz (Hz) and a maximum current of 100 A. With these values, the ranges in the rest of the electrical parameters are approximated, and the reactive power and apparent power are found from these variables. A desired accuracy of 5% is set for all electrical parameters.

**Table 1.** Alternating current electrical parameter monitoring system requirements.

| Requirements | Description | Details |
|---|---|---|
| Electrical parameter sensors | Voltage<br>Frequency<br>Current<br>Active power<br>Power factor<br>Active energy | R: 120–240 V, Ac: 5%<br>R: 50–60 Hz, Ac: 5%<br>R: 0–100 A, Ac: 5%<br>R: 0–20 KW, Ac: 5%<br>R: 0–100 %, Ac: 5%<br>R: 0–1000 kWh, Ac: 5% |
| Data acquisition and processing | Serial communication<br>Programmable | Full duplex<br>Structured language |
| Local reading | LCD screen | IPS |
| Internet connectivity | Wireless connection | Wi-Fi |
| Local storage | Micro SD | 128–1024 MB |
| IoT Platform | Database<br>Web server<br>Data access | Online data visualization<br><br>API |
| Mobile app | User interface<br>Web access | Option menu<br>Data reading and graphing |

Other requirements of the proposed system are also detailed in Table 1. To acquire the data, full duplex serial communication is required that allows access to the sensor data through structured programming. For local reading of the data, an in-plane switching (IPS) LCD screen is required to reduce energy consumption and obtain a good response time. A micro SD is also required to save the information locally, with at least 1024 Mb of storage. On the other hand, the IoT platform must include a cloud database, a web server, and an application programming interface (API) to access the data from the web browser and the mobile application.

### 2.2. Hardware

The hardware of the proposed system is made up of the processing unit, the sensors of the reading channels, and the case. Each of these components is detailed below, including the electrical connections.

#### 2.2.1. Processing Unit

There are several options on the market for integrated processing systems for the development of IoT applications. The widely used options are boards based on the ESP32 family of chips that include Wi-Fi and Bluetooth technology, and these features of a system on chip are accessible at a low cost. In this area, a novel proposal is the development kits of the M5Stack brand and the most recent product based on ESP32 is the M5Stack Core2, which is presented in Figure 2. This hardware platform includes an IPS LCD screen of 2 inches, touch buttons, physical buttons, and ports for different purposes. Details of the features of interest for this proposal are presented in Table 2. Power supplies and ports are located on the back of the device, where there are two hardware serial ports and one configurable serial port for a third serial communication full duplex (Serial1). This includes a TF card slot to insert a micro SD with a maximum capacity of 16 GB.

The embedded microcontroller allows programming development on multiple platforms, such as MicroPython and Arduino IDE. The operating temperature of the equipment is between 0 and 60 [°C], which is sufficient for non-industrial environments in countries such as Ecuador, where temperature variations are minimal. The device frame is fitted with hexagon head base screws for fixing. The cost of this processing unit is a maximum of 100.00 dollars (USD).

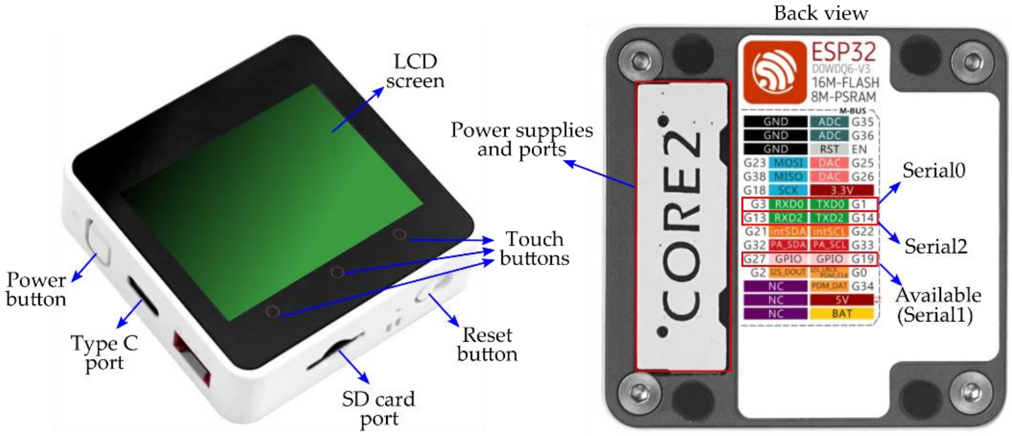



**Figure 2.** Components of interest of the M5Stack Core2.

**Table 2.** Interesting features of the M5Stack Core2 [35].

| Feature | Details |
|---|---|
| ESP32-based | 240 MHz dual core, 600 DMIPS, 520 KB SRAM, Wi-Fi, Bluetooth |
| Connections | M-Bus socket and pins |
| TF card slot | 16 G maximum size |
| IPS LCD Screen | 2.0”@320x240 ILI9342C |
| Multi-platform development | UIFlow<br>MicroPython<br>Arduino<br>.NET nanoFramework |
| Buttons | Virtual screen button × 3 |
| Operating temperature | 0 to 60 °C |
| Product size | 54 × 54 × 16 mm |
| Base screw specifications | Hexagon socket countersunk head M3 |

### 2.2.2. Data Acquisition

For data acquisition, the PZEM 004T V3.0 alternating current communication module of the Peacefair brand is used. This device fulfills two functions: it transduces the electrical voltage and current inputs to obtain digital readings and sends these data through asynchronous serial communication. Figure 3 shows the components and the operation diagram of the measurement module. At one end of the module are the power terminal blocks; two terminal blocks are used for the direct input of the voltage to be measured, and the other two terminal blocks allow the current intensity to be measured through a clamp-on flexible toroidal split-core current transformer. At the other end is the TTL communication port that is used for data exchange. The module receives the input signals and power supply from the module at the same time, subsequently inputting the data to the measurement system to acquire the readings. Next, the signals are isolated using optocouplers to finally obtain the digital data to be sent through the TTL interface.

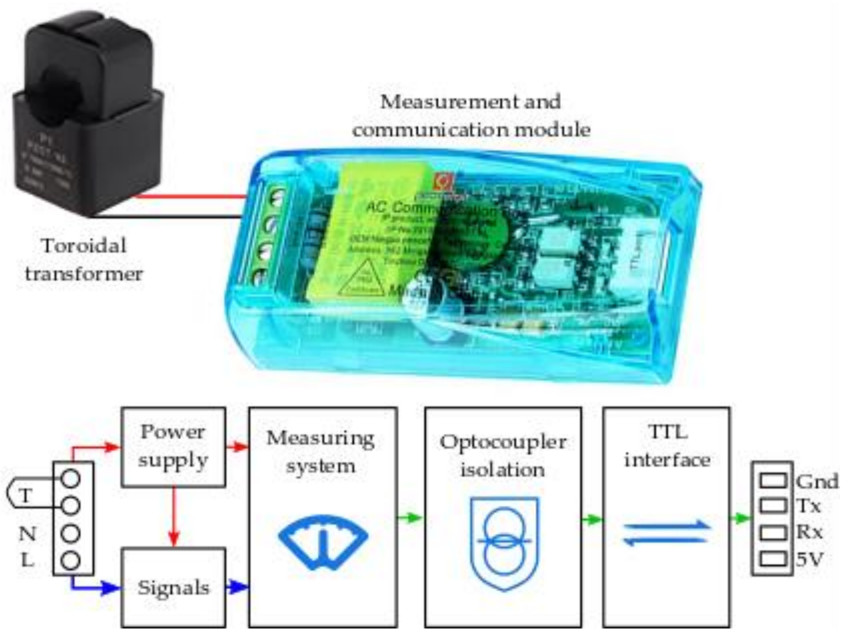



**Figure 3.** Alternating current measurement and communication device (PZEM-004T V3.0).

Table 3 details the technical characteristics of the PZEM-004T V3.0 module. The voltage range (R) that can be measured is from 80 to 260 V with a resolution (Res) of 0.1 V and a maximum current of 100 A thanks to the external transformer. The maximum active power that can be measured is 23 KW with a resolution of 0.1 W, and the maximum active power is almost 10,000 kWh with a resolution of 1 Wh. The detectable frequency is in the range of 45–65 Hz, and the full range of power factor can be measured with a resolution of 0.01. In all cases, a precision of 0.5 % is indicated except for the power factor, whose precision is 1%. All these specifications allow meeting the requirements established for the proposal. Regarding the application protocol of the communication module, the device uses the Modbus-RTU protocol, which allows reading and configuring through registers. The reading by Modbus allows to obtain the measurements of the electrical parameters and the configuration is used for the calibration of the sensor. On the other hand, the operating temperature range is from −10 to 60 °C, which is sufficient for non-industrial environments in countries such as Ecuador. The cost of each sensor is a maximum of USD 40.00.

**Table 3.** Features of PZEM-004T V3.0 [36].

| Features | Details |
|---|---|
| Voltage<br>Current<br>Active power<br>Active energy<br>Frequency<br>Power factor | R: 80–260 V, Res: 0.1 V, Ac: 0.5%<br>R: 0–100 A, Res: 0.001 A, Ac: 0.5%<br>R: 0–23 KW, Res: 0.1 W, Ac: 0.5%<br>R: 0–9999.99 kWh, Res: 1 kWh, Ac: 0.5%<br>R: 45–65 Hz, Res: 0.1 Hz, Ac: 0.5%<br>R: 0–1, Res: 0.01, Ac: 1% |
| Measuring range 100 A | External transformer |
| Phase | Single phase |
| Physical protocol | UART to TTL communication interface, baud rate is 9600, 8 data bits, 1 stop bit, no parity |
| Application protocol | Modbus-RTU |
| Operating temperature | −10 to 60 °C |

### 2.2.3. Electric Connections

Regarding the electrical connections between the components of the system, there are two types, namely external and internal, according to Figure 4. The external connections allow the interaction of the sensors of the two channels with the electricity consumers, in this case buildings or different sections that use an electric line. These connections are made directly with the inputs of the PZEM-004T V3.0 and in the conductors installed after the safety breakers. On the other hand, the internal connections link the TTL ports of the sensors to the ports of the M5Stack Core2. The communication pins of the sensors are coupled to the Serial1 and Serial2 ports in a cross connection (Tx with Rx), avoiding using Serial0 because it has functions assigned for the operation of the processing unit.

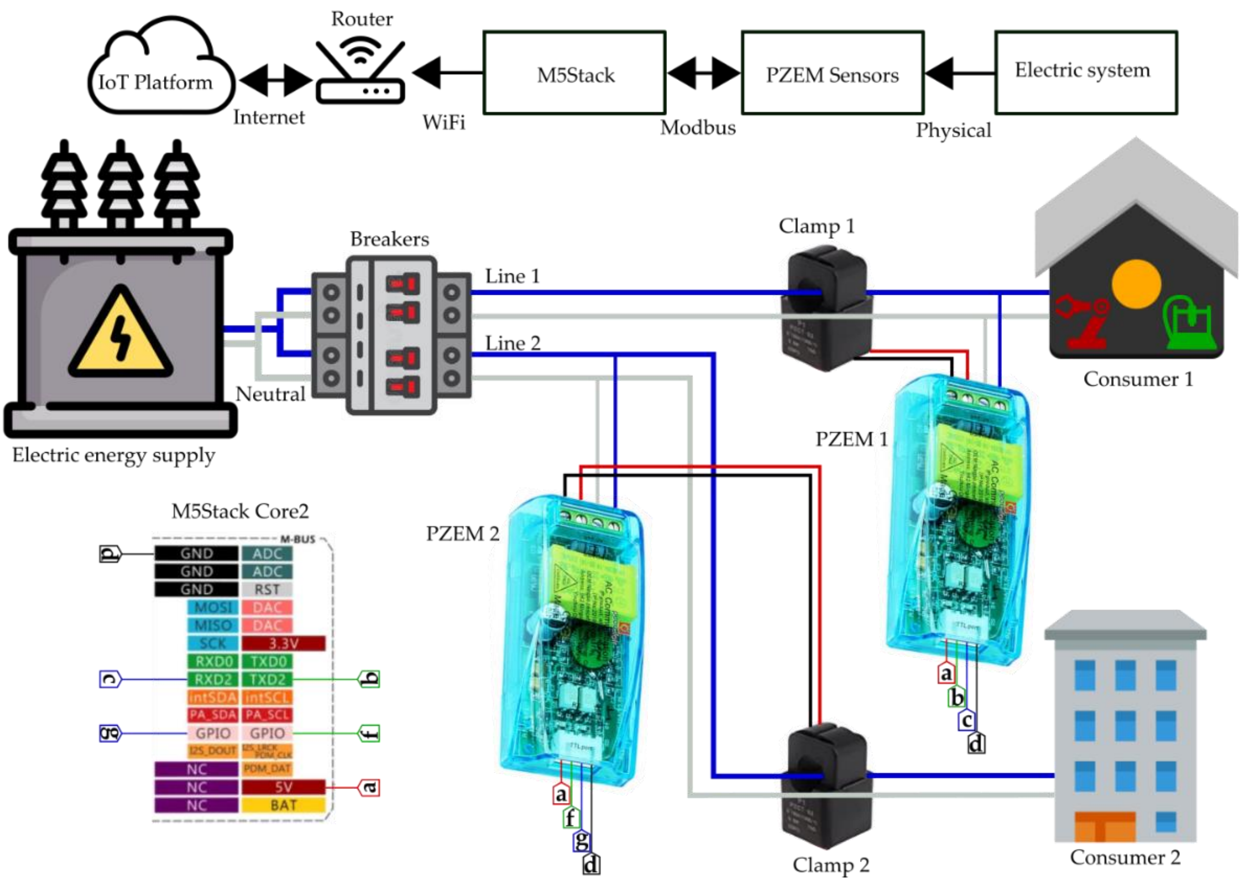



**Figure 4.** Connections for the acquisition of electrical parameters of two channels.

### 2.2.4. Case

To assemble the local measurement equipment, a case is required that serves as a container for the data acquisition and processing elements. Figure 5 shows the 3D design of the case, including the exploded view with all internal components. In the images, it can be seen that the screen of the M5Stack Core2 is exposed to present the information of the readings, and the rest of the elements are hidden inside the case. Slots are also left to use the physical buttons and ports of the M5Stack Core2. In addition, external connectors for the sensors are included, avoiding the wear of the connectors integrated into the PZEM 004T V3.0 module. It is planned to manufacture this design using 3D printing, with a maximum cost of USD 20.00.

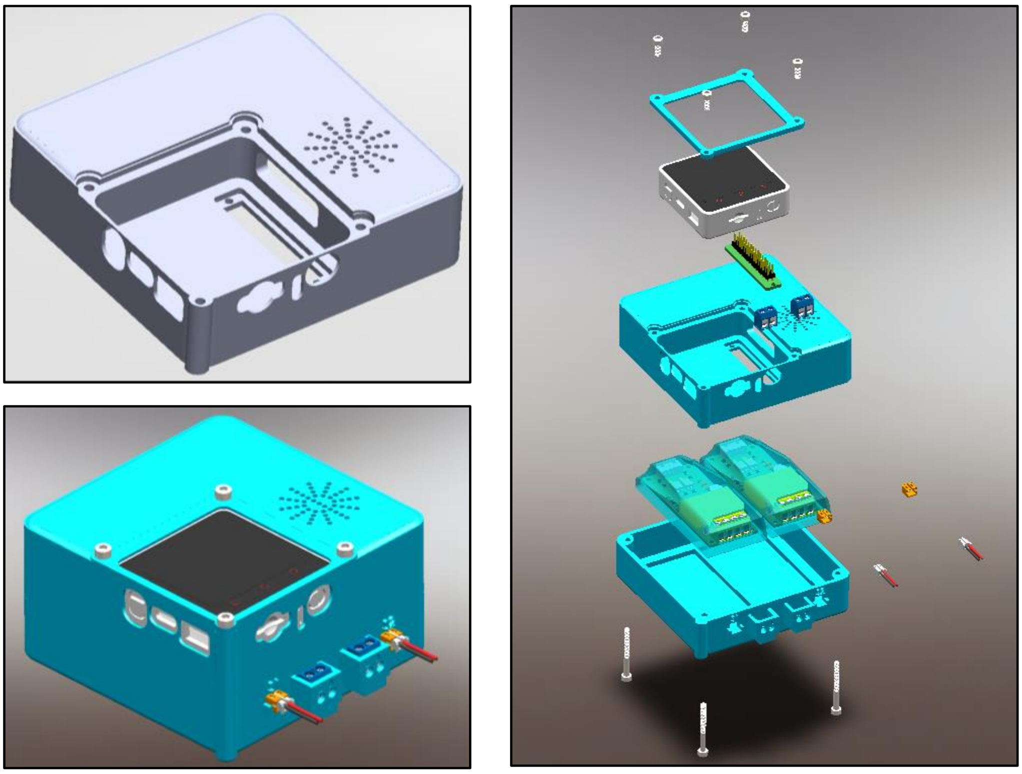


**Figure 5.** Case design for the electrical parameters monitor.

### *2.3. Software*

The software of the proposed system is composed of three elements: the main program of the M5Stack Core2, the web application, and the mobile application. Regarding the IoT platform, ThingSpeak services are used, which include a cloud database, web server, and API. The link with ThingSpeak platform is performed over TCP/IP communication.

#### 2.3.1. Main Program

The algorithm of the main program is presented in Figure 6. The declared libraries are M5Core2.h, PZEM004Tv30.h, WiFi.h, ThingSpeak.h, and SD.h. The configuration parameters include the Wi-Fi network connection data, the credentials to access the ThingSpeak database, and the serial communication pins. Then, the LCD screen and communication with the server are initialized. In the repetitive loop, it is checked whenever there is communication with the Internet and reconnected in case of disconnection. The electrical parameters of both communication channels with the sensors are read. The data obtained are processed by averaging the 15 s readings for greater precision and finding the missing electrical parameters. The sampling time is limited by the PZEM sensor, with a sampling time of 200 ms. The results obtained are stored locally on the micro SD card in plain text format and are also sent to the ThingSpeak database. These processed readings are also displayed on the LCD screen, displaying the electrical parameters one channel at a time to avoid information clutter, and channel selection is made via a touch button named "Change" button. Lastly, another touch button is configured to shut down the system when the user needs to stop the measurements. This main program is developed in open-source Arduino Software (IDE).

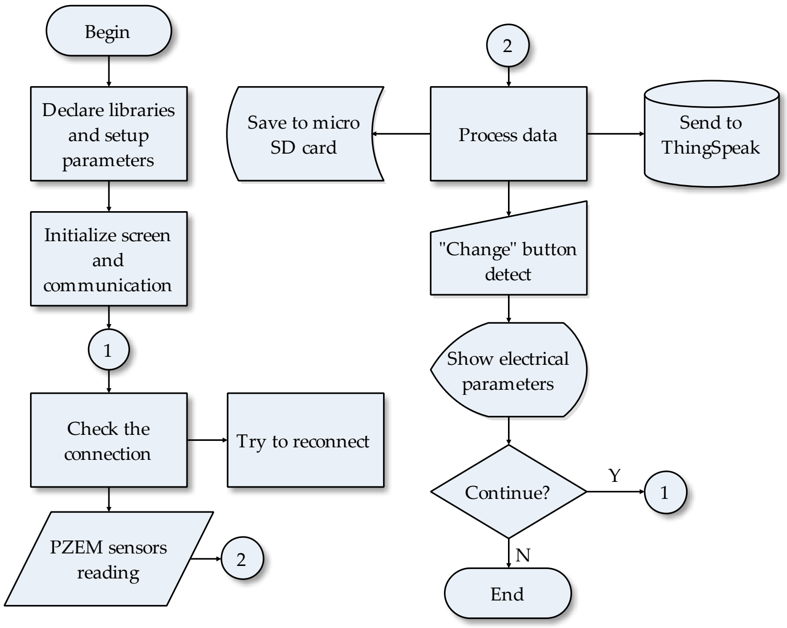



**Figure 6.** Main program flow chart for M5Stack Core2.

### 2.3.2. Web Application

ThingSpeak is an IoT platform that facilitates the exchange of information through the cloud. The services are structured in the format of channels and fields, each channel can contain up to eight fields; these are the variables that both ends of the communication share, and each channel has its identification and API access credentials. In this proposal, two channels are configured, each with seven fields to store the electrical parameters. Although the services include graphs of the fields individually, it is not possible to monitor both channels at the same time to supervise the readings. Thus, a user interface is designed that allows the fields of both channels to be observed simultaneously, according to Figure 7. This user interface will be developed in HTML code using a Google Gauge-type Plugin in the ThingSpeak web environment.

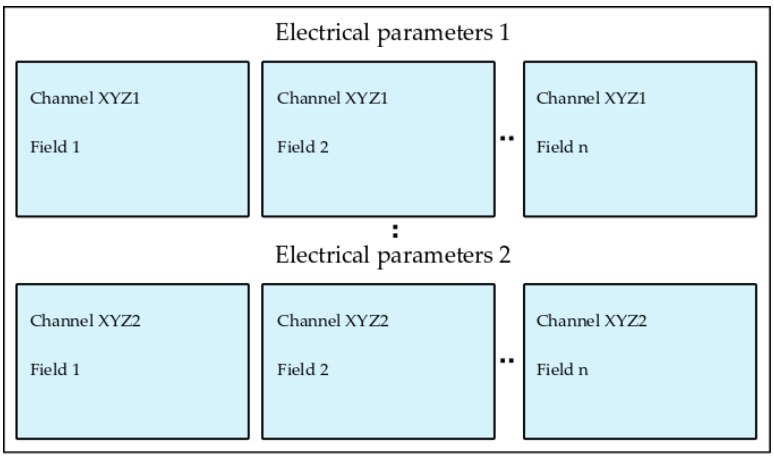



**Figure 7.** User interface design for web application.

### 2.3.3. Mobile Application

Currently, remote monitoring systems are characterized by portability, and mobile applications are the main method for managing IoT applications. In this proposal, a mobile application is incorporated for the individual supervision of each acquired electrical parameter, due to the dimensions of the smartphone, which makes it difficult to visualize multiple data at the same time. Figure 8 shows two screens of the user interface design for the mobile application; the screen on the left shows the menu to select the sensor and the electrical parameter to monitor, while the screen on the right shows the display format of data for all variables. The readings of the electrical parameters are presented in two formats, namely numerical and graphic; for this, web viewers are used that directly access the ThingSpeak widgets and charts, respectively. This mobile application is developed on the latest version of App Inventor.

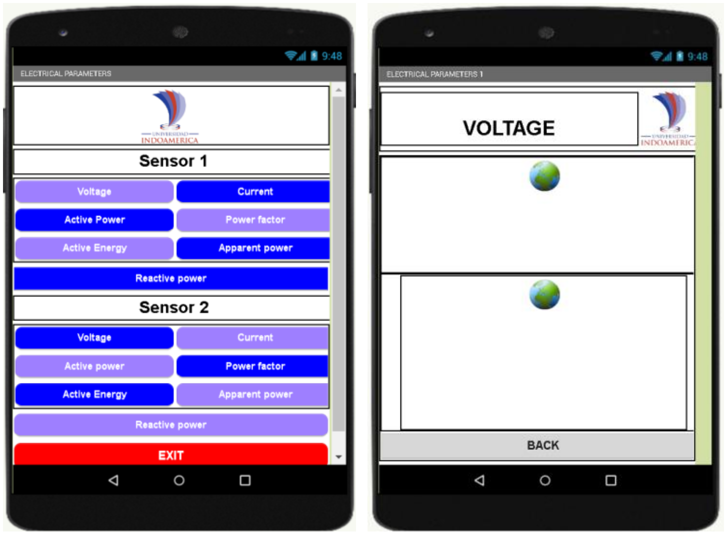



**Figure 8.** User interface design for mobile application.

### *2.4. Validation Device*

For the validation of the proposed system, it is planned to compare the measurements obtained with a commercial device with similar features. The Emporia-branded Gen 2 Vue Energy Monitor is a low-cost device that enables remote active power and active energy monitoring via a mobile app. Table 4 presents the characteristics of the Gen 2 Vue Energy Monitor with current sensors; this device allows measuring a voltage range from 100 to 240 V with a maximum current of 200 A using external clamp-type sensors. The monitor is conditioned for single-phase and three-phase electrical systems. In addition, the monitor also includes Wi-Fi communication, international standard certification, and an operating temperature range between −10 and 50 °C. This device has a maximum cost of USD 150.00.

**Table 4.** Features of the Gen 2 Vue Energy Monitor with current sensors [37].

| Features | Details |
|---|---|
| Input voltage | 100–240 V |
| Current | Max 200 A |
| 200 A sensor ports | 3 mm × 3.5 mm two-pole audio connector |
| Frequency | 50–60 Hz |
| Power consumption | Max 3 [W] |
| Phase | Single-phase up to 240 V line-neutralsingle, split-phase 120/240 Vthree-phase up to 415Y/240 V (no Delta) |
| Wi-Fi | 2.4 GHz 802.11b/g/n |
| Certification | UL/IEC/EN 62368-1 |
| Operating conditions | −40 to +50 °C ǀ 0 to 80% RH |

The Gen 2 Vue Energy Monitor is installed according to the connections in Figure 9, monitoring two alternating current lines that are also monitored with the proposed system. Similarly, the connections are made after the safety breakers, and each current sensor measures a different building or electrical distribution section.

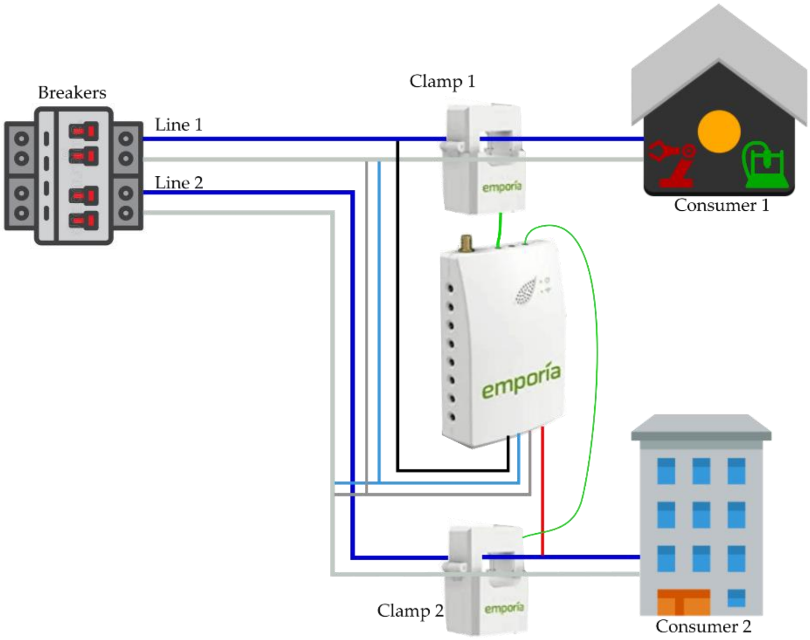



**Figure 9.** Gen 2 Vue Energy Monitor electrical connections.

## 3. Results

The monitor of the developed system and the commercial monitor are installed in the electrical distribution box, as evidenced in Figure 10. This electrical distribution box belongs to the Universidad Tecnológica Indoamérica, monitoring two lines of 120 V; one line belongs to the engineering laboratories section (Sensor 1), and the other line belongs to a classroom and office building (Sensor 2). All materials used in the development of this monitor have a maximum cost of USD 200.00, which represents a low cost for the benefits obtained.

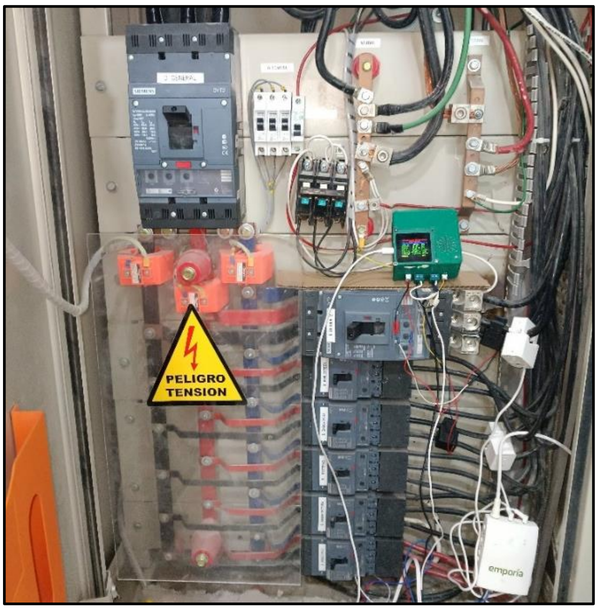



**Figure 10.** Installations in the electrical distribution box.

### *3.1. Functionality Test*

The functionality tests are carried out locally and remotely with the different applications developed.

#### 3.1.1. Local Readings

Figure 11 shows photographs of the developed device together with commercial multimeters. To measure voltage, the professional digital multimeter EM5513 of the allsun brand is used, and to measure current, the clamp ammeter MUT-202 of the TRUPER brand is used. In all cases, the electrical parameters obtained by the proposed monitor are displayed, observing close values between the proposed system and the reference devices. Table 5 presents the measurements and the errors obtained in these readings, and the relative errors are with respect to the measurements in the commercial device for all cases from now on. The voltage has an absolute error of 0.55 V, which represents a relative error of 0.4324%. Sensor 1 current has an absolute error of 0.15 A, which represents a relative error of 1.3979%, and Sensor 2 current has an absolute error of 0.05 A, which represents a relative error of 0.3372%. All the errors of these instantaneous readings are within the tolerance established in the initial requirements (5%).


**Figure 11.** Photographs of local readings of electrical parameters.

**Table 5.** Measurements and errors of local readings.

| | Voltage | Current 1 | Current 2 |
|---|---|---|---|
| Reference | 127.2 V | 10.73 A | 14.83 A |
| Proposed system | 126.65 V | 10.58 A | 14.78 A |
| Absolute error | 0.55 V | 0.15 A | 0.05 A |
| Relative error | 0.4324% | 1.3979% | 0.3372% |

#### 3.1.2. Remote Monitoring

Remote monitoring is done from the web application and the mobile application. Figure 12 presents a screenshot of the developed web application, visualizing the electrical parameters of the two channels; in total, 14 graphs of electrical data are presented. The web interface has been configured to present the readings of the last 30 min: 120 readings of each electrical parameter. In addition, if the user needs details of an electrical value, he can select within the graph using the cursor, obtaining the exact value, date, and time of the reading. The web application is viewed from a web browser on a computer and using ThingSpeak credentials for access.

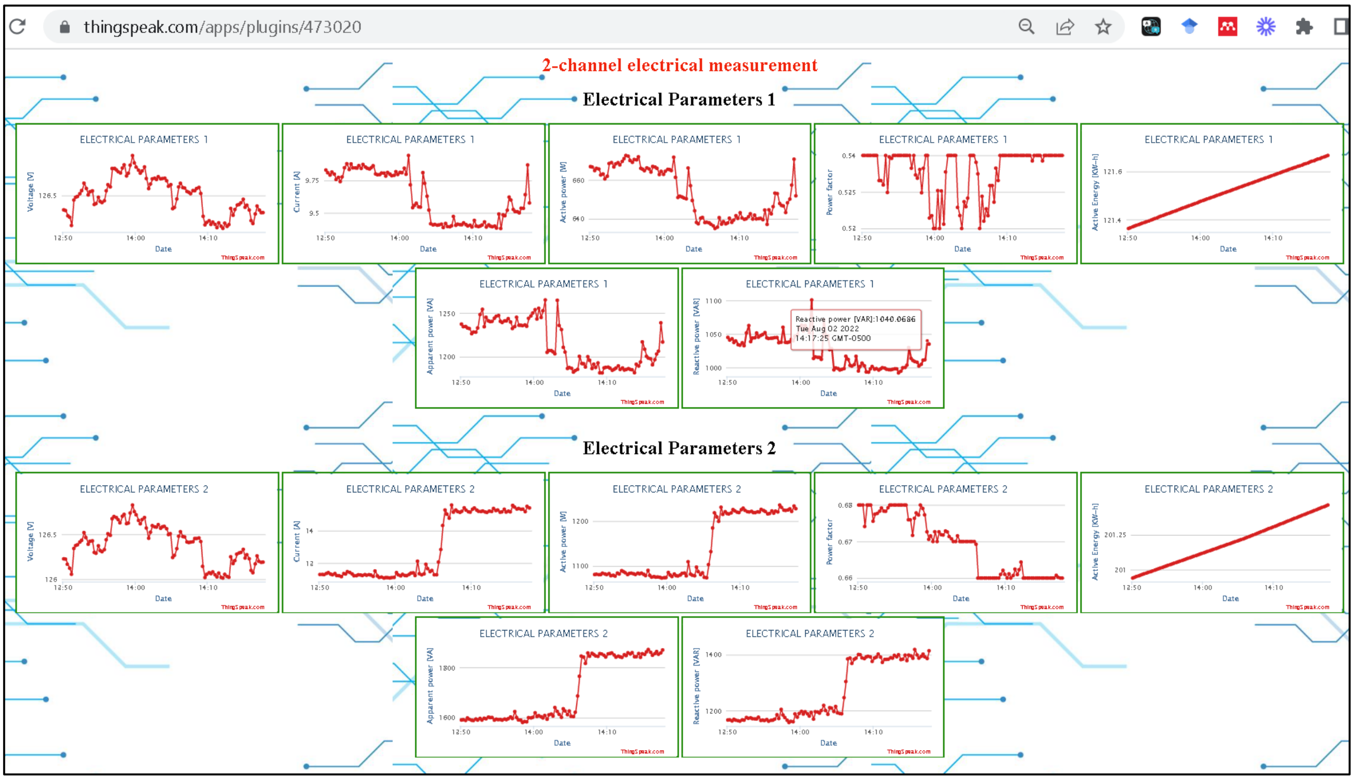



**Figure 12.** Screenshot of the web interface for remote monitoring of electrical parameters.

Figure 13 shows screenshots of a smartphone with the developed mobile application, in which the electrical parameters of Sensor 1 are observed. For this mobile interface, the data of one variable at a time are presented, graphing the readings of the last 150 min and numerically displaying the last recorded reading. The graphs allow viewing the details of the reading when selecting the point of interest, and the value presented on the numerical display corresponds to the reading of the last 15 s.

### *3.2. Measurement of Electrical Parameters*

The graphs in Figure 14 belong to the readings of electrical parameters obtained with Sensor 1 of the proposed system, carried out during a period of 7 days, on the dates from 23 June to 30 June 2022. In total, 168 h of readings correspond to 40,320 values for each electrical parameter, approximately. Active energy was waxed at the beginning of this period. Some observations are obtained from the graphs. The hours and greatest use of electricity on weekdays are from 07:30 to 18:00, and the lowest electricity consumption was recorded on weekends. The power factor was worse at night due to the operation of low-consumption electronic systems that provide harmonics.

Table 6 presents some statistics of the measurements obtained by Sensor 1 during this week, observing a voltage variation between 121.8016 and 129.2377 V with an average of 126.545 V. Regarding the current, the variation is wide, with values from 1.1571 to 26.1165 A with an average of 5.2574 A. The active power has an average consumption of 327.2443 W with a standard deviation (SDe) of 443.645 W. The power factor has a mean of 37.02% and an SDe of 14.01%; this low power factor is common in engineering laboratories where electrical machines and electronic devices are used. Active energy reached 55,297 kWh of consumption in the 7 days observed.


**Figure 13.** Screenshots of the mobile application for remote monitoring of electrical parameters.

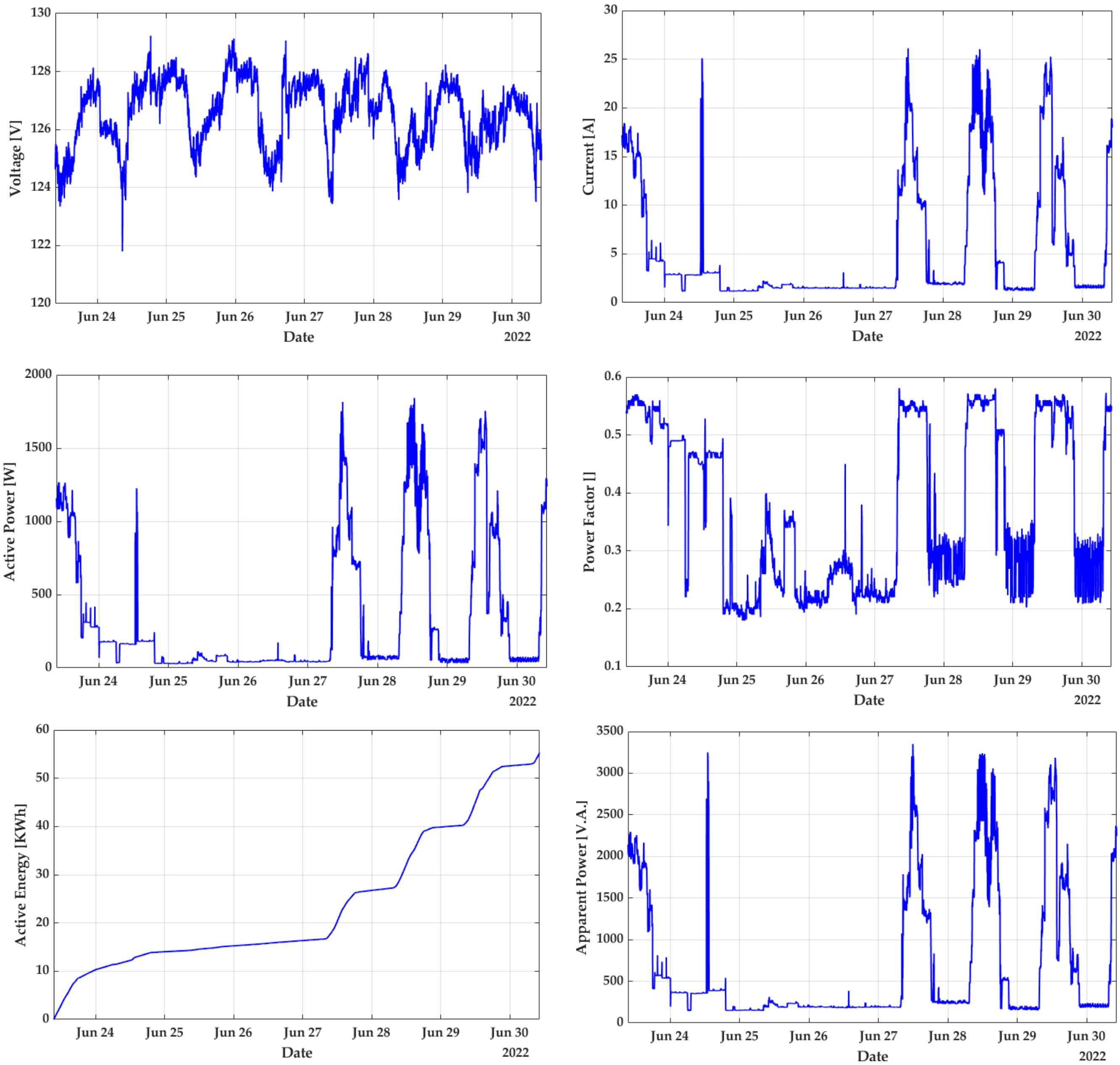



**Figure 14.** Measurements of electrical parameters obtained by Sensor 1 of the proposed system during the dates of 23 June and 30 June 2022.

**Table 6.** Statistical data of the readings made with Sensor 1 of the proposed system during the dates of 23 June and 30 June 2022.

| | Voltage (V) | Current (A) | Active Power (W) | Power Factor (%) | Active Energy (kWh) | Apparent Power (V.A.) |
|---|---|---|---|---|---|---|
| Min | 121.8016 | 1.1571 | 27.6679 | 18 | 0 | 144.2786 |
| Max | 129.2377 | 26.1165 | 1842.1 | 58.09 | 55.297 | 3349.5 |
| Mean | 126.545 | 5.2574 | 327.2443 | 37.02 | 24.0888 | 662.0064 |
| SDe | 1.1541 | 6.1112 | 443.645 | 14.01 | 14.4145 | 766.4659 |

On the other hand, the graphs in Figure 15 belong to the electrical parameter readings obtained with Sensor 2 of the proposed system, carried out over 7 days, on the dates from 23 June to 30 June 2022. In total, 168 h of readings were obtained, corresponding to approximately 40,320 values for each electrical parameter. The active energy of this channel was also waxed at the beginning of this period. Some observations are obtained from the graphs. The scheduled and greater use of electricity on working days are from 07:00 to 21:00, and the weekends record the least electricity consumption although there is more activity compared to the data from Sensor 1. The power factor is better at night because only some lamps work.

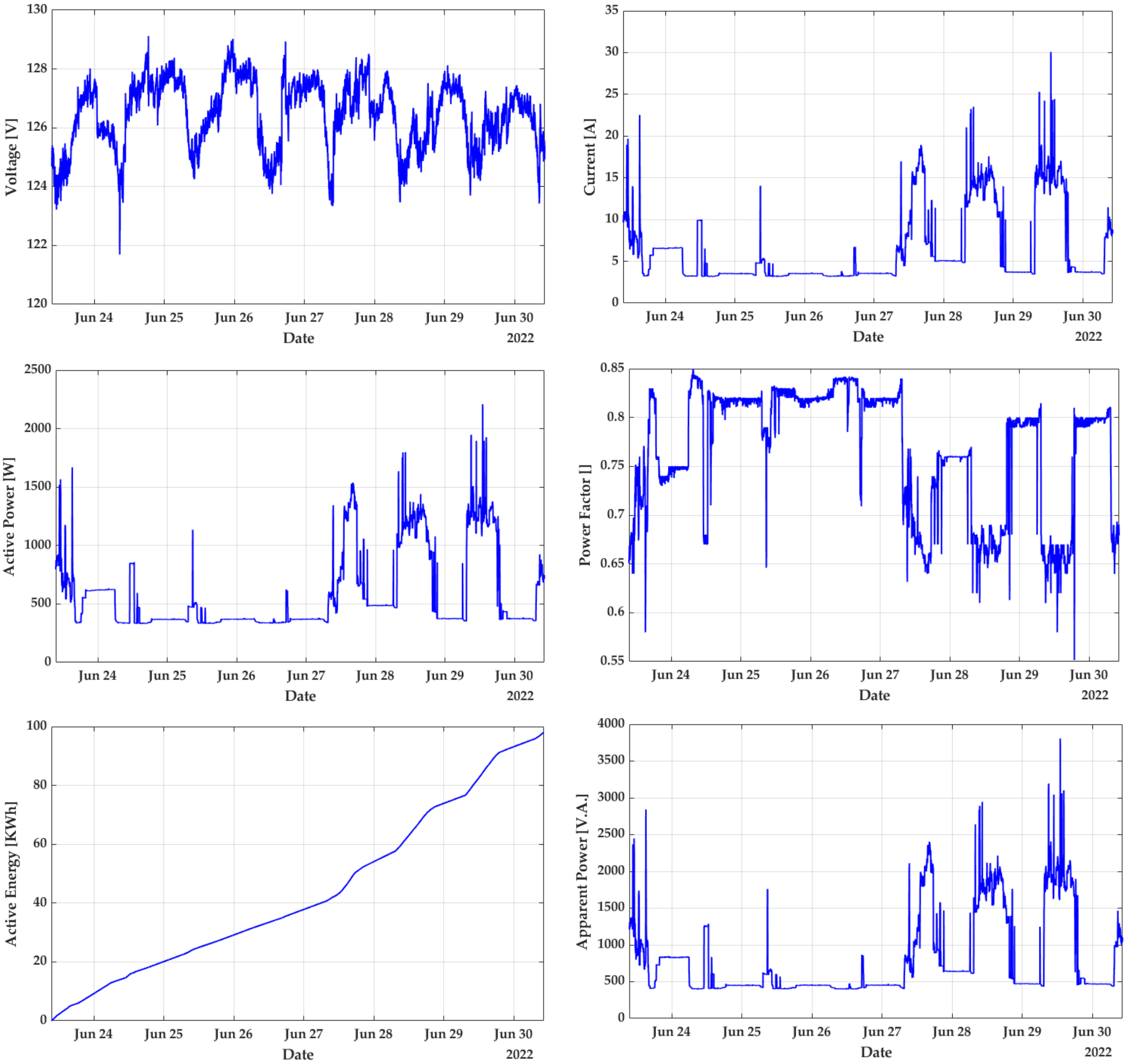



**Figure 15.** Measurements of electrical parameters obtained by Sensor 2 of the proposed system during the dates of 23 June and 30 June 2022.

Table 7 presents some statistics of the measurements obtained by Sensor 2 during this week, observing a voltage variation between 121.69 and 129.119 V with a mean of 126.4349 V. The current varies from 3.1765 to 30.0675 A with a mean of 4.3525 A. The active power has an average consumption of 579.3522 W with an SDe of 332.4549 W. The power factor has a mean of 76.78% and an SDe of 6.32%; this power factor is better than that obtained in Sensor 1 because it belongs to an office building, where lighting systems are used and some electronic devices. The active energy reached 98.0120 kWh in the 7 days observed, which was a higher consumption because the number of users was higher compared to the engineering laboratories.

**Table 7.** Statistical data of the readings made with Sensor 2 of the proposed system during the dates of 23 June and 30 June 2022.

| | Voltage (V) | Current (A) | Active Power (W) | Power Factor (%) | Active Energy (kWh) | Apparent Power (V.A.) |
|---|---|---|---|---|---|---|
| Min | 121.69 | 3.1765 | 330.4159 | 55.15 | 0 | 396.078 |
| Max | 129.119 | 30.0675 | 2208.2 | 85 | 98.0120 | 3806.6 |
| Mean | 126.4349 | 6.3152 | 579.3522 | 76.78 | 44.1475 | 796.461 |
| SDe | 1.1523 | 4.3525 | 332.4549 | 6.32 | 27.6603 | 545.7108 |

### 3.3. Validation

To validate the proposed system using the Gen 2 Vue Energy Monitor, data were collected for an additional week with both devices. The analysis period is from 30 June to 7 July 2022, obtaining approximately 168 h of readings. The parameters to validate in both electrical distribution lines are active power and active energy. Although in this work, the data of 2 weeks are presented, the system was subjected to 3 months of continuous operation without presenting problems.

#### 3.3.1. Active Power

Comparing the active power in line 1 recorded by both monitors, the graph in Figure 16a was obtained, observing small differences between the data. In addition, the measurement errors of the proposed system with respect to the commercial monitor are presented in Figure 16b, showing the greatest errors in the highest magnitudes of active power. In general, it is graphically evidenced that the proposed system records active power measurements that correspond to the data obtained by the reference monitor.

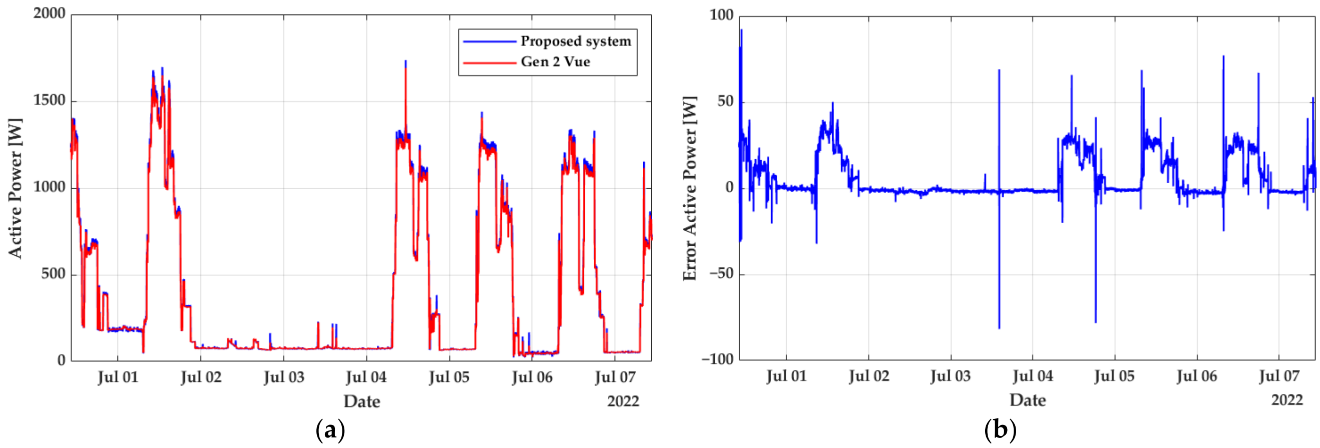


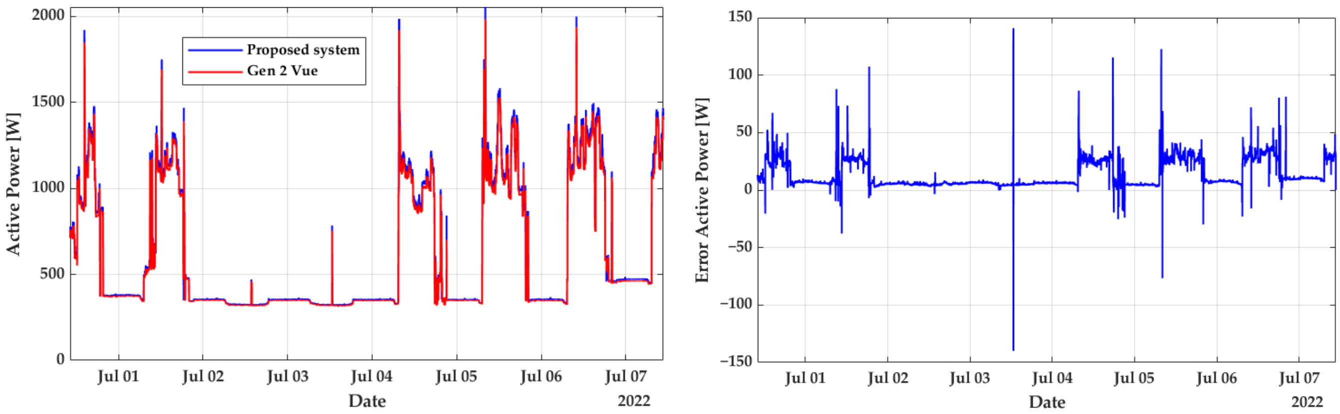

**Figure 16.** Active power in line 1: (**a**) comparison between the proposed system and the commercial monitor; (**b**) measurement errors of the proposed system with respect to the commercial monitor.

The data of both monitors in the active power readings of line 1 are presented in Table 8. The minimum, maximum, and average values of active power are similar between them; this is corroborated by a mean absolute error of 7.654 W and a mean relative error of 2.1059%. This allows validating channel 1 of the proposed system to measure active power with an accuracy of less than 3%. However, the absolute difference between the maximum values reaches a value of 44.8 W, which represents an instantaneous relative error of 2.6486%, showing that readings of greater magnitude can affect the precision.

**Table 8.** Active power data in line 1 obtained by both monitors.

| | Proposed System | Gen 2 Vue |
|---|---|---|
| Min | 23.6567 W | 26.7 W |
| Max | 1736.2 W | 1691.4 W |
| Mean | 383.3336 W | 378.1132 W |
| SDe | 456.1866 W | 445.3159 W |
| Mean absolute error | 7.654 W | |
| Mean relative error | 2.1059% | |

The comparison of the active power in line 2 recorded by both monitors is presented in the graph of Figure 17a, observing small differences between the data. In addition, the measurement errors of the proposed system with respect to the commercial monitor are presented in Figure 17b, showing the greatest errors in the highest magnitudes of active power. In general, it is graphically evidenced that the proposed system records active power measurements that correspond to the data obtained by the reference monitor.




(**a**) (**b**)

**Figure 17.** Active power in line 2: (**a**) comparison between the proposed system and the commercial monitor; (**b**) measurement errors of the proposed system with respect to the commercial monitor.

The data of both monitors in the active power readings of line 2 are presented in Table 9. The minimum, maximum and average values of active power are similar between them; this is corroborated by a mean absolute error of 13.2544 W and a mean relative error of 1.9487%, which is close to the error obtained in line 1. This allows validating channel 2 of the proposed system to measure active power with an accuracy of less than 2%. However, the absolute difference between the maximum values reaches a value of 126.2 W, which represents an instantaneous relative error of 6.3673%, showing that readings of greater magnitude can significantly affect the accuracy.

**Table 9.** Active power data in line 2 obtained by both monitors.

| | Proposed System | Gen 2 Vue |
|---|---|---|
| Min | 320.2310 W | 312.6 W |
| Max | 2108.2 W | 1982 W |
| Mean | 599.0149 W | 606.2047 W |
| SDe | 354.9327 W | 363.6557 W |
| Mean absolute error | 13.2544 W | |
| Mean relative error | 1.9487% | |

#### 3.3.2. Active Energy

The active energy readings obtained in line 1 by both monitors are presented in Figure 18a, and the differences of these readings are plotted in Figure 18b. In both graphs, it is observed that the active energy error increases as time progresses, and this can negatively affect the readings for prolonged data acquisition times.

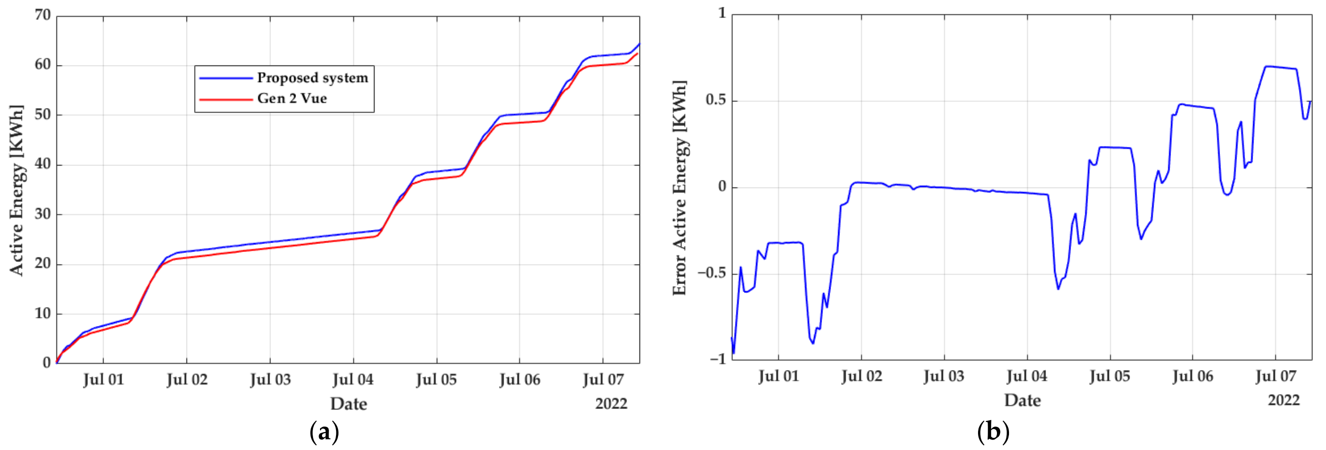



**Figure 18.** Active energy in line 1: (**a**) comparison between the proposed system and the commercial monitor; (**b**) measurement errors of the proposed system with respect to the commercial monitor.

Some statistical data of both monitors in the active energy readings of line 1 are presented in Table 10. The minimum, maximum, and average values of active energy are similar between them, and this is corroborated by a mean absolute error of 0.2625 kWh and a mean relative error of 0.8137%. This allows validating channel 1 of the proposed system to measure active energy with an accuracy of less than 1%. However, the active energy error at the end of the 7 days has a value of 2.0047 kWh, which represents an instantaneous relative error of 3.2066%. This gradual increase of the error can be solved by resetting the active energy periodically.

**Table 10.** Active energy data in line 1 obtained by both monitors.

| | Proposed System | Gen 2 Vue |
|---|---|---|
| Max | 64.5230 kWh | 62.5183 kWh |
| Mean | 32.2543 kWh | 31.0064 kWh |
| SDe | 17.0677 kWh | 16.8887 kWh |
| Mean absolute error | 0.2625 kWh | |
| Mean relative error | 0.8137% | |

On the other hand, the active energy readings obtained in line 2 by both monitors are shown in Figure 19a, and the differences in these readings are plotted in Figure 19b. Similar to line 1, it is observed in both graphs that the active energy error increases as time progresses, and this can negatively affect the readings for prolonged data acquisition times.

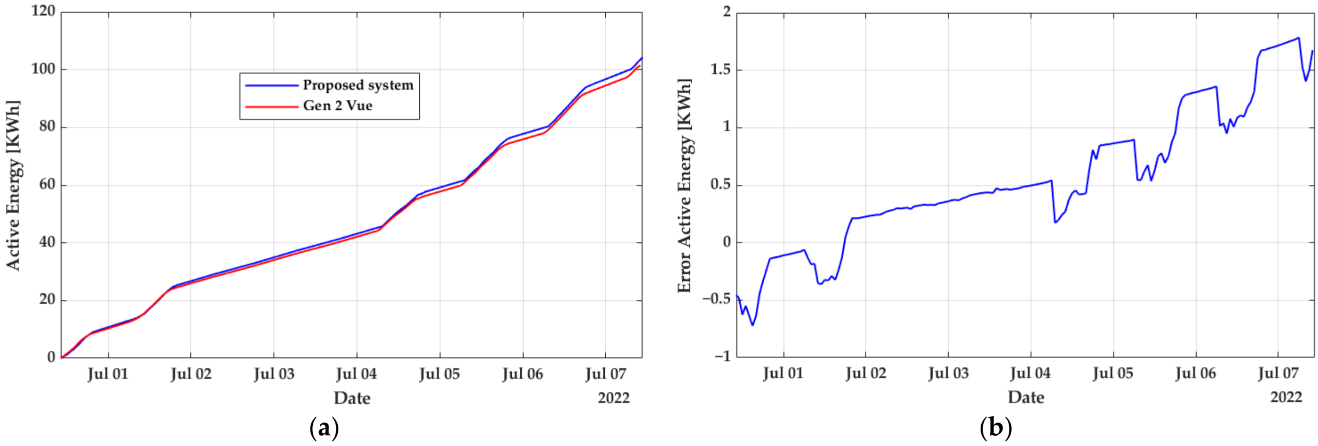



**Figure 19.** Active energy in line 2: (**a**) comparison between the proposed system and the commercial monitor; (**b**) measurement errors of the proposed system with respect to the commercial monitor.

The statistical data of both monitors in the active energy readings of line 2 are presented in Table 11. The minimum, maximum, and average values of active energy are similar between them; this is corroborated by a mean absolute error of 0.656 kWh and a mean relative error of 1.3627%. This allows validating channel 2 of the proposed system to measure active energy with an accuracy of less than 2%. However, the active energy error at the end of the 7 days has a value of 2.8532 kWh, which represents an instantaneous relative error of 2.8119%. This gradual increase of the error can be solved by waxing the active energy of both sensors periodically.

**Table 11.** Active energy data in line 2 obtained by both monitors.

| | **Proposed System** | **Gen 2 Vue** |
|---|---|---|
| Max | 104.3190 kWh | 101.4658 kWh |
| Mean | 48.6651 kWh | 47.4118 kWh |
| SDe | 28.0198 kWh | 27.6273 kWh |
| Mean absolute error | 0.656 kWh | |
| Mean relative error | 1.3627% | |

## 4. Discussion

The literature presents some proposals related to this research work, and all of them present monitors of electrical variables that are generally focused on obtaining the consumption of power or electrical energy. For example, ref. [38] presented a basic system to measure power, voltage, and current, and for this, it uses an Arduino board and easily accessible sensors although this work does not send the information to the Internet and does not present data validation either. Similarly, ref. [30] also used an Arduino microcontroller to detect power spikes and generate an alert. Although these works obtained readings of electrical parameters, these are limited by the number of variables measured.

Other research used multiple devices to measure electrical parameters and sent the data to the internet. In [19], an Arduino board and a LoRa communication module were used to obtain direct current readings and send them to a cloud database. In this case, it is not possible to carry out a local reading of the electrical parameters obtained. Although measurements using commercial devices are compared, the data are limited to readings of a few minutes, and the error of the readings are not determined. Similar results were presented in [20] although in this proposal, alternating current is monitored. In [39], energy measurement was developed with an Arduino board, an ESP8266 module, and an LCD Shield. In this case, the data are sent to ThingSpeak, obtaining energy consumption readings for 1 month, but the results are limited to comparing the final value with the electricity supplier's record.

The proposals that use a system on chip still acquire few parameters due to the use of sensors with limited characteristics, as in [40], which uses an ESP32 board but only obtains current readings to determine some electrical variables. Other proposals use sensors with better performance, as in [29], which obtains some electrical parameters with two channels that use PZEM sensors from the previous version; these modules still do not provide the power factor. The data presented are limited to a short period of time, without validating their results or determining the error of the readings. Although this proposal has a low cost of USD 100 dollars maximum, it is not a compact prototype that is ready to use.

Some works measured parameters that this document does not present in our proposal. In [28,31], the authors obtained the total harmonic distortion, but these proposals do not compare their readings over a considerable period of time with respect to monitors with similar features. Similarly, there is a compact device for measuring electrical parameters [41], which describes a power-quality detector built with a low-cost microcontroller; in this case, the device is limited to data acquisition. In the literature, the author did not find a work that allows monitoring all the electrical parameters of our proposal. In addition, none compare their results with respect to other commercial devices with IoT features.

## 5. Conclusions

In this work, an electrical parameter monitor was built using the M5Stack Core2 and PZEM 004T V3.0 sensors. In addition, two applications for remote supervision were developed: a web application for computers and a mobile application for smartphones. The proposed system allows the monitoring of the electrical parameters of buildings through two data acquisition channels. The readings obtained for 168 h are compared with the Gen 2 Vue Energy Monitor, obtaining the precision based on the relative error that does not exceed 3% in active power and 2% in active power. The implemented monitor has a maximum cost of USD 200.00 dollars, which is an attractive value for the features offered, providing more electrical parameters than the commercial device used in the comparison.

In practice, this proposal offers the opportunity to analyze the performance of the electrical system in buildings for obtaining solutions to excessive payments for electrical energy and detecting faults in electrical lines. Regarding the limitations, this proposal does not consider the effects of magnetic fields inside the electrical distribution box. Computer security in these remote monitoring systems should also be analyzed. It is proposed to study these drawbacks in future works.

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