Electric Monitoring System for Residential Customers Using Wireless Technology

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Abstract. Power grids continue to develop and it is increasingly difficult to guarantee the quality of service offered to the user. In several developing countries, consumption is calculated on the basis of visual inspection, which is prone to errors. Consequently, this document outlines the construction of electrical consumption telemetering equipment. This is designed to reduce human error through manual measures and have a web backup that can be accessed from anywhere. To develop the prototype voltage and current sensors are used, and the signal is conditioned for the control stage. The processing unit is the Arduino Mega embedded board, which incorporates a GPRS Shield (General Packet Radio Services) that handles communication with a LAMP server (Linux, Apache, MySQL, PHP) connected to the Internet. It also incorporates a block of connection and disconnection of the electrical service that would leave the whole house without service. Two functionalities are used to present the data, one is local on the LCD display of the equipment installed in the home (user) and the second is remote access to a website (server). The results show that in comparison with a standard voltage device it presents an error of 0.28% and 4.12% in current. In this way, the use of this prototype for real-time monitoring of electricity consumption is validated, since it works similarly to a conventional one.

Keywords: Electrical networks · Telemetry · LAMP

1 Introduction

The rapid growth of electrical networks has made it difficult to monitor their quality That has been replaced by the development of smart grids (SG) [1]. Their purpose is to support today's complex electrical systems, providing greater reliability and safety [2].

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With information channels, you can learn about supplier and customer requirements for improved system efficiency and value for money. Implementation of the technology in existing networks could reduce existing emissions by 5% or more according to research described in [1]. The main issues are sudden power outages affecting industrial activities worldwide. It has a direct impact on the economy that needs electricity to develop its activities [3]. Consequently, investigations have been conducted when smart grids (SG) are used to prevent power outages, as in [4].

In conventional networks is not precisely known as customer load consumption and trends. Other factors include system congestion, obsolete infrastructure, lack of maintenance, increased demand, and lack of investment. Monitoring allows to define the places where the demand is highest, as well as the schedules and their frequency, and to manage accordingly an adequate decision. Conventional active energy meters register information on an energy meter that is read monthly by company personnel. Thus, a form is generated by the department, where this information is available to the user after the end of the month. It is very common for the supplier not to obtain the actual reading numbers and to make an approximate estimate of consumption whereas the user only knows the consumption produced at home at the end of each month. It is difficult to define whether there are defects in the home network or heavy consumption in the devices to damage them [5].

Nowadays, efforts have been made to improve the performance of this equipment by combining advances in information and communication technologies (ICT). In addition, the problems mentioned above have promoted the development of several investigations where innovative technological proposals are made. The use of smart meters has gained notoriety among consumers as exposed in [6]. In [7], the acceptance of this equipment in Malaysia is described, demonstrating the interest of users in energy-saving and their remarkable environmental awareness. Similarly, [8] shows that smart meters are widely used in the European Union, as a tool to reduce costs. The surveys were carried out to reveal the desire of households to acquire these devices and the need to incorporate more tools to take care of the environment. Not only do users require service improvements, but providers constantly lose resources to non-technical losses (NTL). Therefore, in [9] they have implemented a control algorithm based on hybrid deep neural networks that allow the detection of operating problems and anomalies in smart meters. This proposal does not require data pre-processing, which simplifies the system that shows good results.

In many Latin American countries, the measurement of monthly electricity consumption is manual and prone to human error. This is adhered the failures described above do not allow evidence of reality and service providers make an inefficient estimate of monthly consumption. Nor is there a mechanism that allows the automatic disconnection or connection of the electrical service for customers who have not paid their bills on time. For this reason, the need to implement smart devices for telemetering consumption in real-time, which emit alarms in the event of problems, has become evident. Current commercial equipment is expensive and its integration with the current system would mean a significant investment. This results in technological stagnation for nations with limited resources and higher charges for consumers. That is why, in this research, it is proposed to develop a meter for residential electricity. Thus, daily consumption can be evidenced and reported when there are signs of damage to the system or the internal

connections of the home. As a hypothesis, it is expected that the built device will have a good performance, with an error of less than 5% compared to a commercial device.

This document consists of four sections, including the introduction in Sect. 1. Section 2 describes the materials and methods used and Sect. 3 the results. Finally, conclusions are presented in Sect. 4.

2 Methods and Materials

The electrical energy telemetry equipment is made up of three main blocks: measurement equipment, communication, and the server. This is indicated in Fig. 1 which shows the general diagram for electrical telemetry.

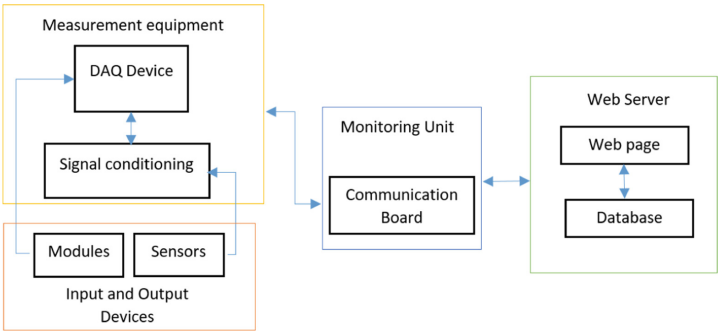


Fig. 1. Block diagram telemetering equipment.

2.1 Measurement Equipment

The measurement equipment is a set of electronic elements, designed to be installed independently in the home. Its purpose is to collect information on current and voltage sensors to send them to the server through the communication board.

Data Acquisition. For this, there is a sensing stage, hardware data acquisition, and software information processing. The voltage sensor is responsible for providing a signal that can be read by the microcontroller and used to calculate power consumption. The voltage transformer was selected since it measures AC voltage directly from the electrical network, which works at a nominal 120 V. For total current measurement, the SCT013-000 alternating current sensor is used, which detects variations in magnitude and generates a proportional signal that can be voltage, analog current or a digital signal. This hall effect type sensor has a clamp-like structure that facilitates its installation on the phase or neutral line and can measure up to 100 A.

Signal Conditioning. This stage performs a signal preparation that is used as a current limiting and coupling circuit, in addition to standardizing the data from the sensors. The current sensor has an output of 500 mA for a current of 100 A, so its conditioning is done through a shunt resistor (RL) where the voltage drop is measured. Two 470 KΩ resistors

are used and the voltage is measured at RL, which is linked to one microcontroller port. A controller with a 10-bit ADC converter is used, that is, at the time of quantization of the analog signal, it is represented in values from 0 to 1023. A similar circuit is used for conditioning the voltage signal, considering that the transformer output is 12 VAC when there is 120 VAC at its input. To reduce this voltage, a voltage divider is used between resistors, while the remaining resistors generate a DC component of 2.5 V, which is the midpoint of the microcontroller's analog pin input signal.

2.2 Monitoring Unit

The microcontroller is the specialized hardware that is responsible for processing the data delivered by the conditioning stage after sensing. It executes all kinds of calculations, processes, and required instructions. The Arduino Mega 2560 was selected as it has 54/54 digital I/O pins and 16 analog input pins, I2C, EMI, SPI and USART interfaces. Also, an analog converter with a resolution of 10 bits, as indicated above. Using the DS1307 module, it is possible to obtain date and time data in real-time, using I2C communication with the processor unit. This information is kept up-to-date as it has a built-in battery that maintains power when the main power is off. Using the Arduino compatible SIM900 SIMCOM module provides wireless communication via the GSM/GPRS cellular network. This is because no data transport network of its own connects the meter to the webserver. In addition, its coverage range is practically global since it communicates through the existing mobile network. To register on the mobile network, it is necessary to use a sim from any local operator that is compatible with the module.

This information obtained is registered using the Micro SD module that uses the SPI communication protocol compatible with Arduino. The time, date, voltage, current, and consumption data are stored here. Finally, a two-channel contact relay module is incorporated, with an output of 10 A for a 250 VAC input. In the prototype, it is used as a control to perform a disconnection/connection of the electrical service in the terminal block of the energy meter. This is when the user is in default due to non-payment of their service bill on time, prior authorization from the electricity distribution company. The display screen is used to present the electrical energy data that is accumulated in the controller. Therefore, a 16×2 LCD with I2C communication has been chosen, which facilitates the exchange of information with Arduino.

2.3 Software

Data Processing. A program was developed in the Arduino development environment (IDE). The microcontroller inputs and outputs are configured, and the ports for serial communication with the modules and communication with the webserver connection manager module are initialized. The calculation of current, voltage, and power consumption is performed in a script. Furthermore, communication is established with the

real-time module to request the time and date. The data is saved in a micro SD memory as a backup and has two display methods. They can be viewed locally on a liquid crystal display and also through a web server from any browser.

Server. For the management of information, a concept called client-server architecture is used. From a communications standpoint, a server process listens on a TCP communications port (by default, 80), and waits for connection requests from Web clients. Once the connection is established, the TCP/IP protocol is responsible for maintaining the communication and guaranteeing an error-free data exchange; to access the server you need an internet domain, without this, it is not possible to access the information that is stored in a database, to be able to communicate the client uses HTTP. This model attempts to provide usability, flexibility, interoperability, and scalability in communications.

The LAMP server functions are programmed on one machine and the other operates as a client. The server is Apache, which operates under the HTTP hypertext transfer protocol, keeping the information available 24 hours a day, with a secure connection that prevents possible failures or errors in the services. Once the Apache package is installed, the static IP of the computer is configured, this address will be the one used to access the server. To check that the Apache installation was successful, you can enter the server address from a web browser and the configured message will be displayed. All data on power, consumption, voltage, date, and time, reach the server via the Internet.

Client. A web browser must be used which must be installed in the application layer on the client-side, HTTP is based on simple request/response operations. The client establishes a connection to the server and sends a message with request data, while the server replies with a similar message, containing the status of the operation and its possible result. All operations can attach an object or resource on which they act; each web object (HTML document, media file, or CGI application) is known by its URL. The web browser that is used can be any, but it will depend on the platform or device that is used to request the server. This guarantees that regardless of the operating system, the generated information will be displayed transparently. The client manages all the functions related to data handling and display, so they are developed on platforms that allow the construction of graphical user interfaces, as well as access to services distributed anywhere in the network.

Database. The database management system used is MariaDB, which fulfills the same functions as MySQL, including important improvements such as compatibility with multiple storage managers, faster queries and subqueries, open-source code, and fewer errors. Once installed, the system will ask you to provide a password for the root user and when the service is restarted it is already operational.

2.4 Implementation

For the implementation, a connection diagram is made that is detailed in Fig. 2. In the diagram, you can see the location of each element used in the development of the prototype. The embedded Arduino mega 2560 card is in charge of executing all the mathematical operations and the program that controls the inputs and outputs. There is also a SIMCOM 900 wireless communication module that establishes communication via GPRS with the webserver. Additional two STC 013-100 current sensors and two 120 VAC-12 VAC voltage sensors are responsible for sending electrical signals to the data acquisition card. The DS1307 real-time module provides the time and date, an 8 GB micro SD module for recording electrical parameters, a relay module responsible for connecting and disconnecting the user, and an LCD screen to display electrical consumption.

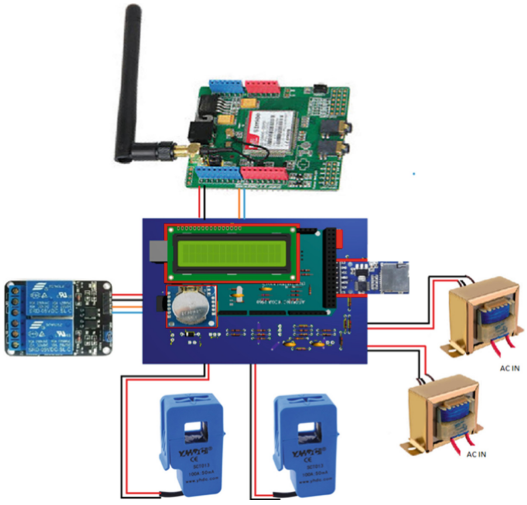
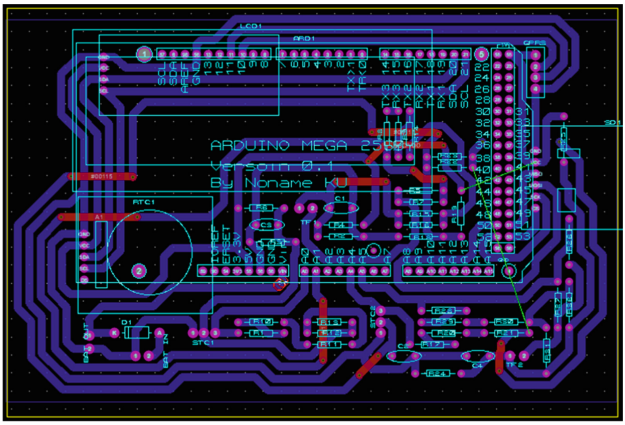


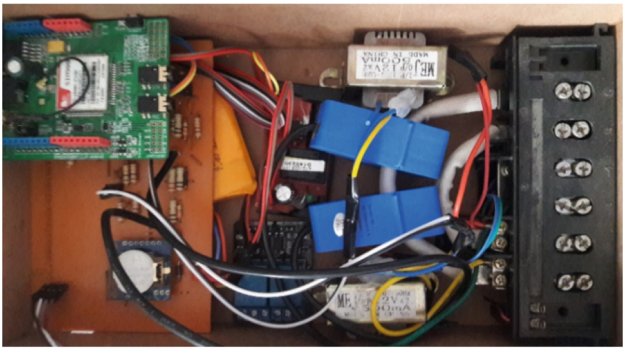
Fig. 2. Prototype electronic design.

Continuing with the implementation process, begins with the conditioning of the sensors, for this, a PCB is made, as shown in Fig. 3(a) The PCB is mounted on top of the Arduino Mega 2560 development board; With this, compact and functional equipment is obtained. In conditioning, a direct connection is made pins A0, A1, A4 and A5 are taken. The current and voltage sensors are installed at the terminal board of the conventional electric energy meter as indicated in Fig. 3(b).

Data Transmission. For data transmission, the prototype was programmed to send the information to the server at intervals of 1 min. It should be noted that the data sending time can be configured according to the system requirements. Once the connection with the webserver database is established, a table assigned for registration is entered and the entered data is saved. Figure 4 shows the table assigned to this record, which contains 7 fields. In order, they are user ID (integer), phase 1 and phase 2 utility voltage values



(a)



(b)

Fig. 3. Prototype electronic design. Arduino Conditioning-DAQ Shield: (a) PCB design. (b) Actual implementation.

assigned as Vrms1 and Vrms2 respectively (units are in V). The fourth column records the power (Watts) and the fifth the accumulated electrical consumption (kWh). The sixth column indicates the address where the meter is installed (location) and the last column records the date and time when all this information was taken.

3 Results

3.1 Voltage Measurement

For the execution of the tests, the measurement equipment was installed in a house and the values of voltage, current, and power were analyzed. These measurements were taken at the input terminal blocks of the prototype, previously connected to the electrical network that supplies a home. For the voltage sensor, the data displayed on the screen of the remote measurement equipment is compared with the values measured with a Fluke

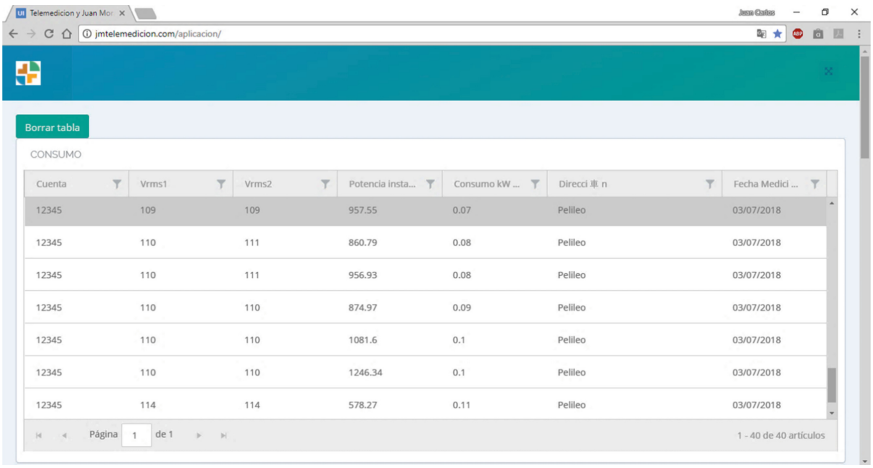


Fig. 4. Consumption information on the website.

111 multimeter (pattern). Table 1 shows the average voltage values of 10 measurements for each of the 12 items evaluated and the absolute and relative errors calculated for each sample using (1) and (2). The similarity in the measurements can be appreciated in a better way in Fig. 5. Voltage values remain similar when connecting different types of loads, with semi-industrial equipment generating a slight voltage drop. The measurements made with the prototype show a relative error of less than 0.3%, which allows inferring that there is a good accuracy. It should be clarified that the Fluke device is only used as a reference to analyze the measurements obtained, but it does not function by itself as a measurement device similar to the one proposed.

$$\text{Absoluteerror} = |\text{V}_{\text{PROTOTYPE}} - \text{V}_{\text{COMMERCIALMETER}}| \tag{1}$$

$$\text{Relativeerror} = (\text{Absoluteerror}/\text{V}_{\text{COMMERCIALMETER}}) * 100\% \tag{2}$$

3.2 Current Measurement

Similarly, a comparison of the measurements of the prototype and a commercial equipment is made. A Fluke 322 clamp meter was used, which has an AC measurement range of 400A with an accuracy of 2% ±5 digits, in frequency from 45 to 65 Hz and 2,5% from 65 to 400 Hz. Table 2 shows the respective values and errors, while Fig. 6 shows their graphic representation. The current values obtained by the prototype tend to approach the values of the measuring instrument. However, when using a Hall Effect current sensor, the measured value can vary due to poor handling or impurities (garbage in the ferrite) found in its core, causing measurement errors when the current values are small. This percentage error decreases when the connected load is greater, reaching a

Table 1. Voltage measurement multimeter/prototype.

Appliance	Voltage measurement		Voltage error	
	Fluke 111	Prototype	Absolute error	Relative error [%]
DVD reader	115,6	115,3	0,3	0,26
Talking	115,0	114,9	0,1	0,09
Saving focus	115,0	115,1	0,1	0,09
TV	114,1	114,4	0,3	0,26
Soldering iron	114,9	114,7	0,2	0,17
Refrigerator	113,4	113,2	0,2	0,18
Blender	114,5	114,4	0,1	0,09
Washer	114,6	114,5	0,1	0,09
Sewing machine	114,1	113,9	0,2	0,18
Cloth cutter	114,4	114,1	0,3	0,26
Heater	111,0	110,9	0,1	0,09
Industrial iron	109,9	109,6	0,3	0,27
Motor	105,4	105,7	0,3	0,28

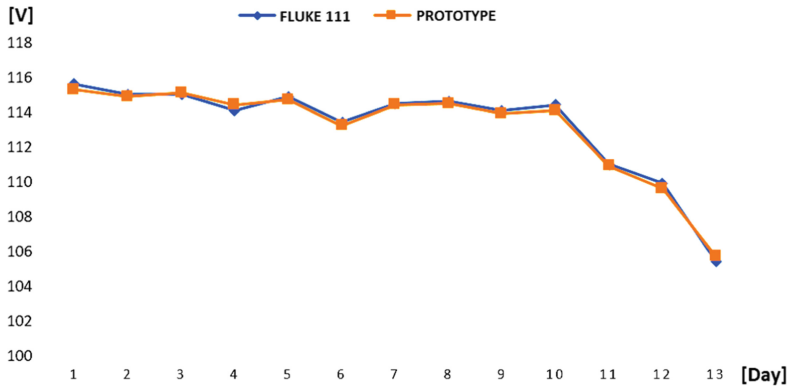


Fig. 5. Voltage analysis.

relative error of 0,14%, *i.e.,* behavior is close to optimal. With respect to Table 1 it can be seen that now the current values do vary considerably according to the connected load. When small equipment is connected, the current consumption is low, while when larger equipment such as a washing machine is operating, the current is higher.

3.3 Power Calculated

In the area of electrical consumption, it is usual to know the power consumed by a device, because the energy consumption will be based on this. The power of an electrical device

Table 2. Current measurement multimeter/prototype.

Appliance	Voltage measurement		Voltage error	
	Fluke 322	Prototype	Absolute error	Relative error [%]
DVD reader	0,12	0,12	0,00	0,00
Talking	0,11	0,13	0,02	18,18
Saving focus	0,17	0,19	0,02	11,76
TV	0,31	0,34	0,01	9,68
Soldering iron	0,32	0,35	0,03	9,37
Refrigerator	1,82	1,92	0,1	5,49
Blender	1,94	2,02	0,08	4,12
Washer	2,23	2,27	0,04	1,79
Sewing machine	2,75	2,78	0,03	1,09
Cloth cutter	4,55	4,59	0,04	0,88
Heater	6,87	6,83	0,04	0,58
Industrial iron	8,36	8,42	0,06	0,72
Motor	14,61	14,59	0,02	0,14

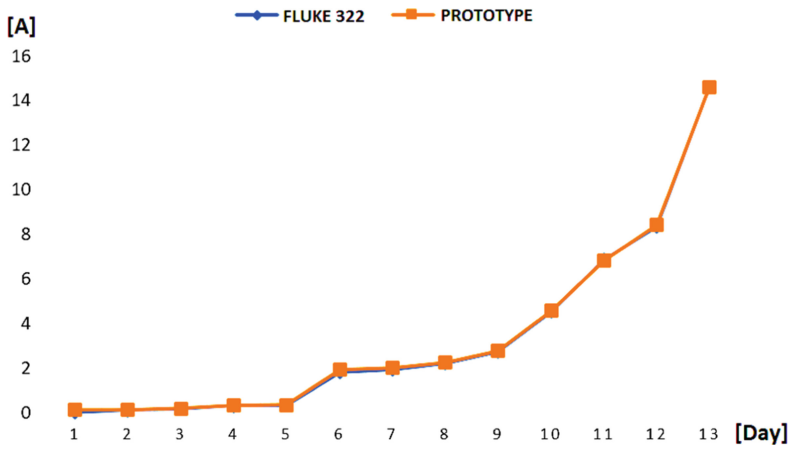


Fig. 6. Current analysis.

is the product of the voltage (V) to which it is connected and the intensity of the current (I) passing through it, as shown in the equation in (3). For the power comparison, the average voltage and current values from the previous tables were used. The data is presented in Table 3 and graphically in Fig. 7.

$$P = V * I \tag{3}$$

Table 3. Power calculated.

Appliance	Voltage measurement		Voltage error	
	Calculated	Prototype	Absolute error	Relative error [%]
DVD reader	13,872	12,683	1,18	0,00
Talking	12,65	14,937	2,28	1,99
Saving focus	19,55	21,869	2,31	2,02
TV	35,371	38,896	3,52	3,09
Soldering iron	36,768	40,145	3,37	2,94
Refrigerator	206,388	217,344	10,95	9,66
Blender	222,13	231,088	8,95	7,82
Washer	255,558	259,915	4,35	3,80
Sewing machine	313,775	316,642	2,86	2,51
Cloth cutter	520,52	523,719	3,19	2,80
Heater	762,57	757,447	5,12	4,62
Industrial iron	918,764	922,832	4,06	3,70
Tape recorder	1539,894	1542,163	2,26	2,15
Average				3,62

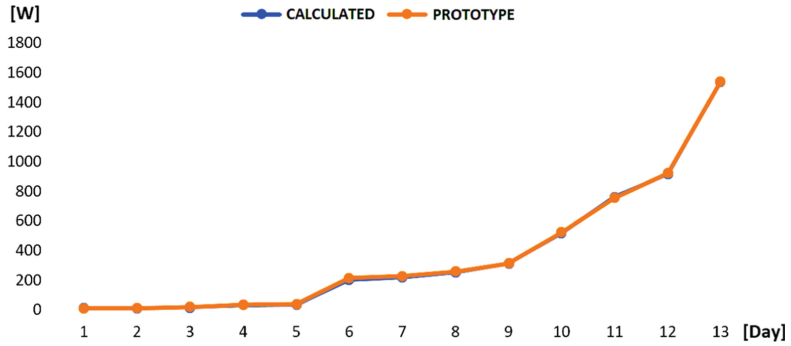


Fig. 7. Power analysis.

3.4 Electricity Consumption

Subsequently, to compare the measurement of electricity consumption, standard equipment from the local service provider was used (electronic two-phase measurement of electrical energy). The data from six days were evaluated, obtaining the data shown in Table 4. The equipment taken as a pattern only displays whole figures, while the prototype has decimal figures, presenting an average error of 3.42%.

Figure 8 shows voltage variations suffered by the electrical network during certain time intervals, a phenomenon known as voltage profile. The evaluation interval is from

Table 4. Comparison of consumption measurements.

Day	Commercial meter	Prototype	Absolute error	Relative error [%]
1	0	0,0	0,0	0,00
2	1	0,9	0,1	4,30
3	3	3,1	0,1	5,00
4	7	7,1	0,1	2,50
5	10	9,9	0,1	3,30
6	15	15,1	0,1	2,00
Average				3,42

17:27 to 17:38. Changes in the network voltage reading are observed and then its return to the initial state during another time interval. Similarly, in Fig. 9 an overview of the power profile corresponding to the load connected in the prototype is presented. As in the previous figure, jumps are observed that are generated by the change in the load of the dwelling.

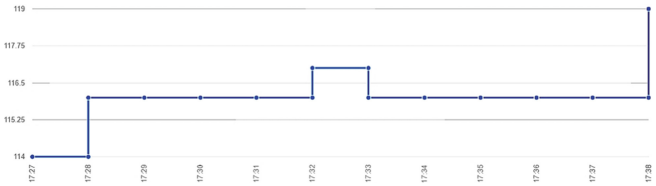


Fig. 8. Voltage profile.



Fig. 9. Load power profile.

Within Fig. 10 there is an orange box that shows the accumulated consumption of electrical energy [kWh], which is stored in the database and changes as energy is consumed in the home.

3.5 Cost Analysis

Based on the budget indicated in Table 5, it has been established that the approximate cost of the implemented prototype is $167, a value that justifies all the characteristics



Fig. 10. Accumulated consumption.

presented. This provides a more accessible alternative through the use of free hardware and software.

Table 5. Summary of costs of materials used.

Item	Description	Amount	Unit value	Total value
1	Voltage sensor	2	$10	$20,00
2	Current sensor	2	$15	$30,00
3	Arduino Mega 2560	1	$12,5	$12,50
4	GPRS module	1	$45	$45,00
5	LCD	1	$8	$8,00
6	I2C LCD module	1	$3,5	$3,50
7	Relay module	1	$4,5	$4,50
8	MicroSD module	1	$4	$4,00
9	RTC module	1	$4,5	$4,50
10	Battery	1	$7,5	$7,50
11	Resistor	32	$0,1	$3,20
12	Capacitor	4	$0,1	$0,40
13	Male sprat	1	$2,5	$2,50
14	Case	1	$10	$10,00
	PCB	1	$3	$3,00
Total				$167,00

Given that the average useful life of this type of equipment is established at 10 years, the time required to recover the investment is analyzed. The internal rate of return expressed in Table 6 refers to the current value of the measurement equipment, in each year until its useful life is fulfilled, at the end of the 10 years it will have a residual value of $42,70.

Table 6. Internal rate of return.

Year	Operational flows	t	1+r	(1+r)t	1/(1+r)t	BN*(1/(1+r))t
0	−$167,00	1	1,08	1,00	1,00	−$167,00
1	$30,1	2	1,08	1,08	0,93	$27,9
2	$30,1	2	1,08	1,17	0,86	$25,8
3	$30,1	3	1,08	1,26	0,79	$23,9
4	$30,1	4	1,08	1,36	0,74	$22,1
5	$30,1	5	1,08	1,47	0,68	$20,5
6	$30,1	6	1,08	1,59	0,63	$19,0
7	$30,1	7	1,08	1,71	0,58	$17,6
8	$30,1	8	1,08	1,85	0,54	$16,3
9	$30,1	9	1,08	2,00	0,50	$15,1
10	$30,1	10	1,08	2,16	0,46	$21,7
Residual value						$42,70

3.6 Discussion

One point that should be highlighted is how the technology is reaching all households, institutions and industries around the world. Smart meters are already a reality of common use in Europe as shown in [6, 8]. Similarly, in Asia they are having a good acceptance due to the benefits they have presented for a better monitoring of existing networks [7]. It should be noted the importance that smart devices have nowadays in the industry and in the home. Smart meters have greater interconnectivity with other elements of the house, which translates into greater convenience for the person. There is greater security, because the readings are now reliable, which translates into energy efficiency and therefore economic savings.

Temneanu & Ardeleanu [10] developed a smart meter for measuring the consumption of various electrical appliances, but they did not compare it with a commercial one, so we cannot compare it with ours either. Zainab et al. [11] developed a meter that incorporates distributed computing, however they focused on communication data and also do not allow a proper comparison. The equipment developed by Koutroumpina et al. [12] allows to identify when the appliance is off, this is due to the use of sensors with higher resolution. The results show an accuracy of 97%, however, they have not been compared with a standard equipment and because of its high cost it cannot be incorporated in the region of this study. Although it has not been possible to adequately compare this study with other similar studies, it is clear that there are different approaches and that the economic aspect must be considered in this case. However, there is much to be expanded in the future as technology advances.

4 Conclusions

Current distribution networks require renewal and the implementation of proposals that merge the conventional with technology. The theoretical foundation made it possible to demonstrate the need to change conventional electric meters, providing them with intelligence to enhance their performance. This document has described the process of designing and building a prototype for remote measurement that has been tested in a residence but can also be used in industrial environments. Through the measurement tests and when comparing it with a standard FLUKE 111 instrument, a difference of 0,3 V on average is observed, with an error of ±0.28% (in a range of 110 V a 130 V). The current tests with loads from 0 to 20 A presented an error of ±4,12% concerning the standard Fluke 321 equipment. The current measurement presents a greater error than the voltage measurement, this is attributed to the fact that the current sensor has a range of measurement of 0 a 100 A and it is less accurate to measure relatively low currents (less than 5 A).

The prototype calculates the instantaneous power using the measured current and voltage values. When performing the tests, the calculated error is 3,16%, this error for a measurement range between 0 and 1550 W. While when carrying out the consumption analysis, an error of 3,42% was generated, since the conventional meter only presents the information in whole figures, and the prototype if it has decimal figures. Despite this, it has been verified that this error does not affect the reading. It is recommended that this equipment be installed in a visible and easily accessible place with the transmission antenna since obstacles interfere with the cellular network signal.

For the use of the equipment, it must be considered that the design was made for the Latin American environment where it operates at a maximum of 220 V in residential meters, i.e., two phases and one neutral. In the case of replicating, it in Europe or other parts of the world, the necessary changes in the design must be considered. Also, to prevent injuries, the personnel making these connections must have electrical knowledge to couple the voltage sensors to the electrical network. Likewise, it is advisable to review the installation of the current sensors so that they do not present erroneous measurements and therefore an adequate calculation of the instantaneous power. Another advantage it has over commercial devices is the ease of its integration with other platforms because it is developed with free software. Greater security can also be added to the network, which is difficult on a standard device that is mass-produced. In case the DC and AC sources are different, the prototype should be adjusted according to the working conditions. If there are many variations in the network, a conditioning stage should be included to regulate the input to a reference value so that the rest of the system is not altered and can be coupled to the AC source.

The main limitation of this study is that the current sensor does not present ideal linearity at the output. Also, they cannot detect small voltage and current variations, so if there were small loads, they would be automatically disregarded. To carry out the measurements and reduce their error, other devices with a lower relative error could be evaluated, but which will increase the cost proportionally.

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