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PRESENTADO POR

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Smart Energy Meter Prototype For Single-Phase Power Lines In Peru

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Abstract - *World energy demand is increasing as a result of population growth and industrial development. Nowadays, in Peru, electricity consumption has significantly increased. Elec- tric companies in Peru depend on their staff to record the consumption of meters; on the other hand, users do not have the easiness of monitoring their consumption day by day or the access to the information of their consumption. Given the problem described, in this project, the development of a smart meter based on Wi-Fi communication technology is presented. The Wi-Fi transmission allows saving the consumption of a user in a database. The present research project implements an intelligent electric consumption meter that can calculate and display the monetary expenditure of a residence. The implemented prototype has an electronic system that records the electrical energy consumption by means of sensing the current and voltage signals through a developed algorithm that is able to calculate the electrical energy consumption in kilowatt per hour. This in order to provide the user with easy access to information in real-time and to help them in managing their consumption better. The proposed solution intends to contribute to the saving of electrical energy, which represents a saving in monthly billing for the user and overall a reduction in Peruvian household's CO2 emissions.*

Keywords — *Microcontroller, Single-phase, Kilowatt, Alternating Current, Wi-Fi.*

I. INTRODUCTION

In Peru, the Higher Agency for Investment in Energy and Mining indicates that 94% of the population has electric energy [1]. In Peru, electrical energy has significantly increased, due to a large part of the domestic use of electronic devices and the evolution of technology in electronic devices. In the last decade, there have been important advances in access to electric power. According to the National Institute of Statistics and Informatics (INEI) [2], the national coverage went from 72.1% to 89.7% between the years 2001 and 2011. In the rural sector, the advance was from 27.6% to 64.2%, while in the urban areas, the increase was from 88.1% to 98.4% in this same period [3].

The smart meter is an advanced energy meter that measures the energy consumption of a consumer and provides detailed information to the service company provider and the user through a bidirectional communication scheme. People are in an efficient way on informed about their energy consumption, so they can take better decisions to save electricity consumption and minimize the environmental impact and additionally they can reduce CO_2 emissions that produce their electronic equipment. Therefore, the company that supplies the products will not need the old-fashioned way of reading the energy consumed since the information would be automatic. This project focuses on the research to improve the use and consumption of electricity in a residency striving for innovation in regard to the technology of traditional meters to promote the concept of intelligent meters in Peruvian households.

Regarding the aforementioned, the intention is to know the process of measurement of electrical consumption in Peruvian households. An antecedent of a system for measuring energy consumption is presented in a study where the author performs the voltage and current signal sensing using modeling techniques such as phasor analysis and Fourier transform [4]. Another important antecedent is the development of an electrical consumption single-phase meter, where the authors perform improvements to the commercial meter using more components customized for the user. This meter is designed with an LCD screen with better visualization of electrical network data, in a way to give knowledge to the user of what is consumed and thus to promote saving in the energy consumption [5].

Considering the situation of providing easy and safe access to the energy consumption to the service provider and the users, this proposed project will present an electronic device that records and manages energy consumption. By means of sensing the voltage and current signals through the developed algorithm, the consumption of kiloWatt per hour (kWh) will be calculated. Then, the collected data will be sent to the internet to be taken to a management server where graphs of the consumption of each user will be presented. With this, it is sought to facilitate access to the information of the electrical network data in real-time to the user through a web page and also to the service provider who will be managing the server.

II. METHODOLOGY

A. System design and architecture

The proposed developed system will work with an interface of visualization of data consumption through a connected LCD screen. However, the solution will not bring any benefit with respect to the devices. One of the advantages of the created system appears when it is interconnected to a web device for visualization in the cloud. From this perspective, the developed solution operates on a conventional server-client model in which the measurement prototype represents the customers, while the cloud application is a server that could be managed by the electrical company. For the energy management system, the proposed system will develop the application software based on the web for reading the parameters of the counters such as current in amps (A), a voltage in volts (V), power in watts (W), and energy in kWh. In Fig. 1, the whole schematic of the architecture of the system can be observed.

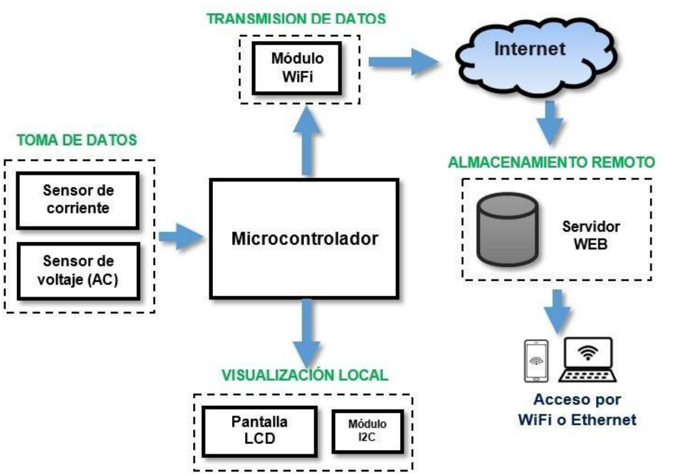

Fig. 1 Block diagram of the architecture showing the ESP6288 WiFi-based smart electricity consumption meter with TCP/IP communication protocol, which is represented by the Wi-Fi module

B. Hardware design

The idea of the proposed system is to develop a very low-cost digital smart energy meter based on an Arduino board, which will allow monitoring commercial power. The following electronic components were selected for their design and implementation:

- Arduino Nano.
- ESP8266 Wi-Fi module.
- ZMPT101B Tension Coupler.
- SCT-013 Current Sensor.
- I2C module.
- LCD screen.
- Led indicators.
- Resistors.
- Capacitors.

The design of the implementation is composed of two stages; the first is the stage of the prototype or electronic device, which is the energy meter and which has as the main element the Arduino Nano board equipped with an ATmega328 microprocessor and an external 16 MHz oscillator. The main function of the Arduino Nano is to calculate the parameters of current, voltage, power, and energy. The second stage is the ESP8266 module, which is the processing unit of the system and responsible for the communication between the energy and the webserver. In Fig. 2, the hardware design can be seen.

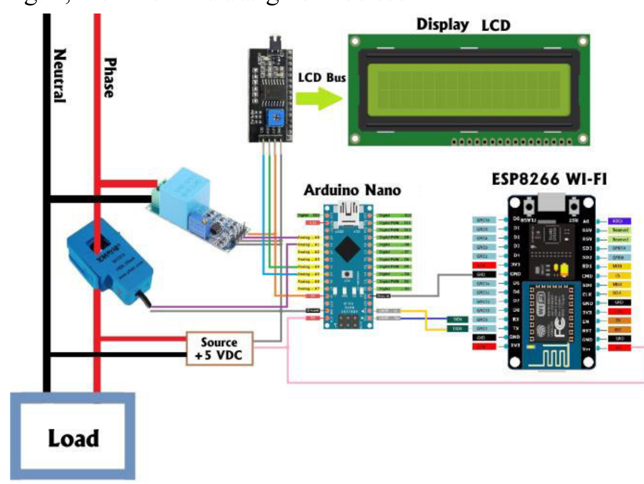

Fig. 2 Design of the electric energy meter prototype.

For the detection of energy consumption, the voltage and current signals are separately analyzed, and then with mathematical calculations, the power is obtained. It has to be taken into account that the voltage and current signals can not be directly sent to the microcontroller (Arduino Nano) as it would immediately damage all its components. Therefore, sensors and couplers are required for sending the signals to the Arduino Nano board. The current sensor SCT-013 used has the characteristics of a current clamp; therefore, based on Faraday's and Ampere's laws [6], the measurement of the magnetic field that surrounds the conductor can be performed; from this conductor, the current signal is obtained. The current sensor of the meter is capable of operating with a maximum of 20 Amps. The voltage coupler ZMPT101B reduces the amplitude of the input voltage of 220 VAC at a scale less than 5 V thanks to the built-in high voltage precision transformer. The input voltage of the coupler is 250 VAC.

In the communication stage, the prototype has the ESP8266 Wi-Fi module, which is a very low-cost Wi-Fi chip module produced by the Chinese manufacturer Espressif Systems [7]. This module has a system autonomous with TCP/IP protocol that can give access to any microcontroller to the Wi-Fi network. The ESP8266 connects to the internet to send the recorded data to the storage of the server. For testing, a server is used, which is the ThingSpeak platform which provides instant views of data with the ability to run MATLAB code to perform the analysis, data processing, and electrical consumption graphs [8]. The server from this platform is costless.

C. Software design

The code was developed using the environment of the Arduino IDE programming. For the software design, a flow chart was constructed, which gives a better sense of the project operation. The main purpose of the design of the software is to build the programming code for the Arduino Nano and the ESP8266. In addition, the software MATLAB will be used to make the graphics on the ThingSpeak server. The developed programming algorithm is divided into two parts since there are two development cards of different makers.

In the first part (Fig. 3), the algorithm for the operation of the Arduino Nano was written. In this part of code 2, analog inputs were enabled to let the passage of the voltage and current signals, the A0 and A1 pins, respectively. With this and the use of the Internal ADC and TIMER, the periodic sensing of voltage and current is possible. Once the ADC performs the conversion, the algorithm performs the calculations of the sum of squares of the instantaneous values of current and voltage to finally be able to find the RMS value. Then the CosFi calculations are carried out by means of the sign variation of the voltage and current values, both per rising edge and downstream of these signals, in order to register the crossings by zero to then obtain the real power, apparent power, and the power factor. This part ends with the sending of data by the UART serial communication between the Arduino Nano and the ESP8266 module.

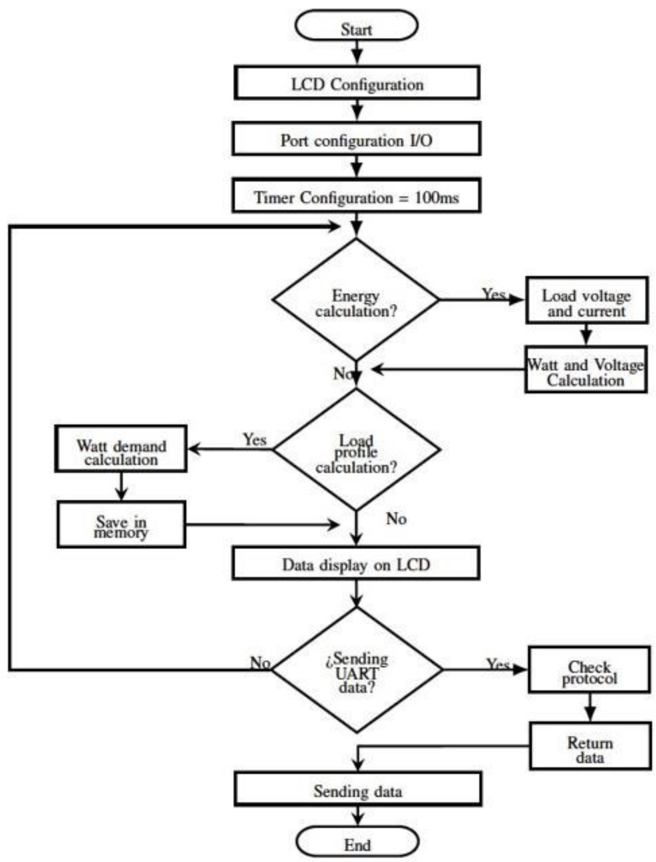

Fig. 3 . Flow chart for the Arduino Nano.

In the second part (Fig. 4), there is the ESP8266 Wi-Fi which, thanks to the installation of the available firmware, the code could be developed on the same Arduino platform. In the ESP8266 module, we attach the library for its use and Wi-Fi configuration of a LAN network defining as main characteristics the SSID and PASSWORD of the network.

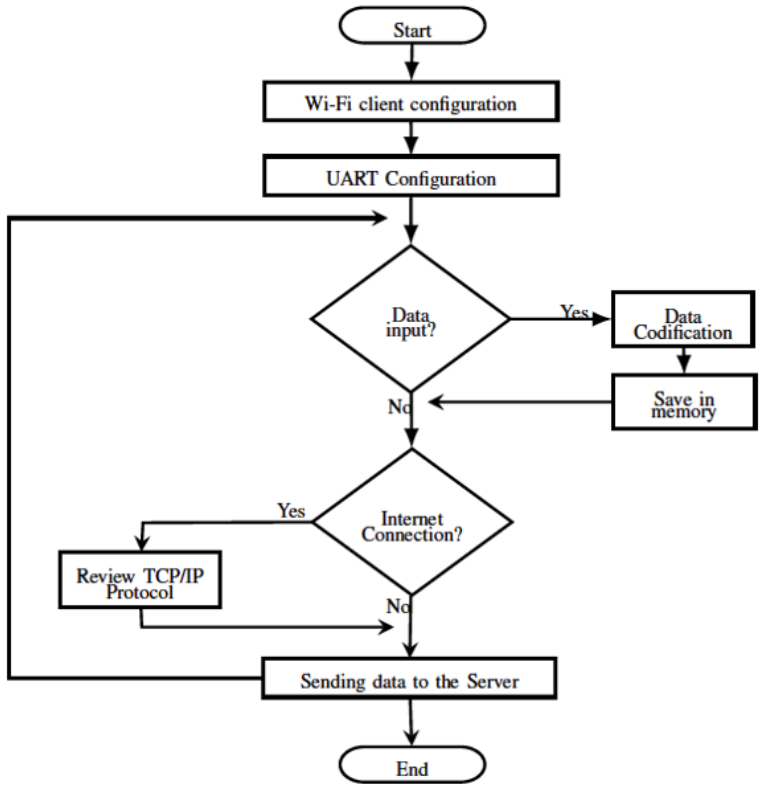

Fig. 4 . Flow chart for ESP8266 Wi-Fi.

A function is also created to decode the data sent by the serial port and save each data received in a variable. In the main function, a condition is created to detect each data saved and then assign it a variable like, for example, Volts or Amps depending on the condition of each data to finally be sent to the cloud and to store the data in the remote ThingSpeak server.

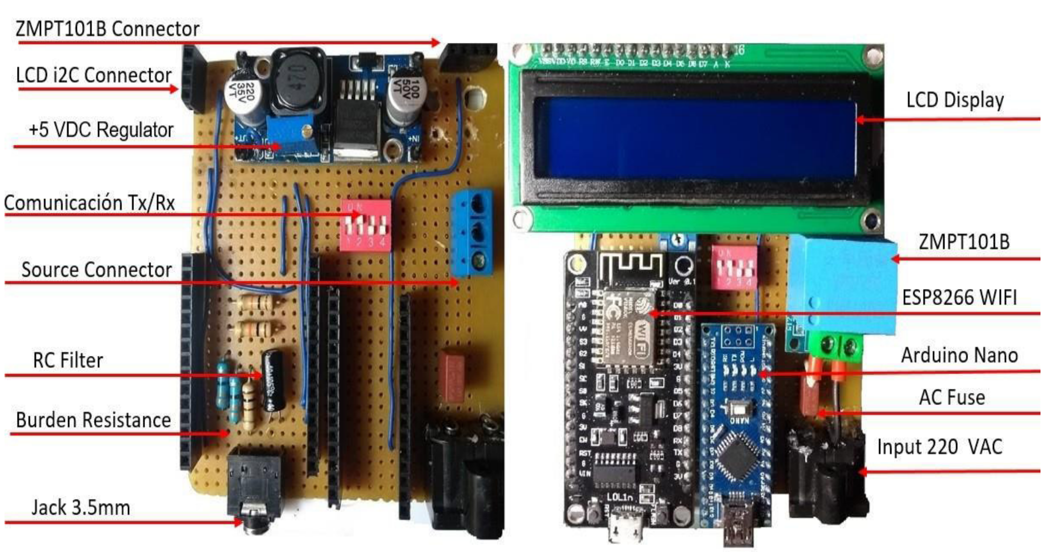

Fig. 5. Smart energy meter prototype.

Fig. 6. Prototype calibration and testing with the Fluke 381 Clamp Meter.

III. RESULTS

In this section, the experimental results of the load profile of the reading of the parameters of the meter will be demonstrated. Additionally, the information collected from the page ThingSpeak web using time graphs will be shown. In Fig. 5 the smart energy meter prototype for single-phase power lines is presented.

After programming, the configuration of the components and design tests in the web application was carried out. All the system was coupled into the prototype. Like all equipment measurements, the prototype presented was calibrated following a procedure to decrease the percentage of data collection error. The tests performed were with a 2 Amp load, which is shown in Fig. 6. It has to be indicated that a current clamp with a removable display was used: Fluke 381 for the comparison with the data from the current obtained.

The important part of the presented system is that the prototype sends the data string obtained as the voltage, current, actual power in watts, and the power factor at the remote server ThingSpeak. The server, in turn, shows us the graphs with the information of the date and time of each data registered, as shown in Fig. 7. It is important to mention that thanks to the algorithm developed, the parameter of the power factor was properly obtained (Fig. 8), which allows measuring the performance of the electrical network according to [9], who mentions that good performance electric ranges between 0.8 - 0.95, with 1 being the ideal.

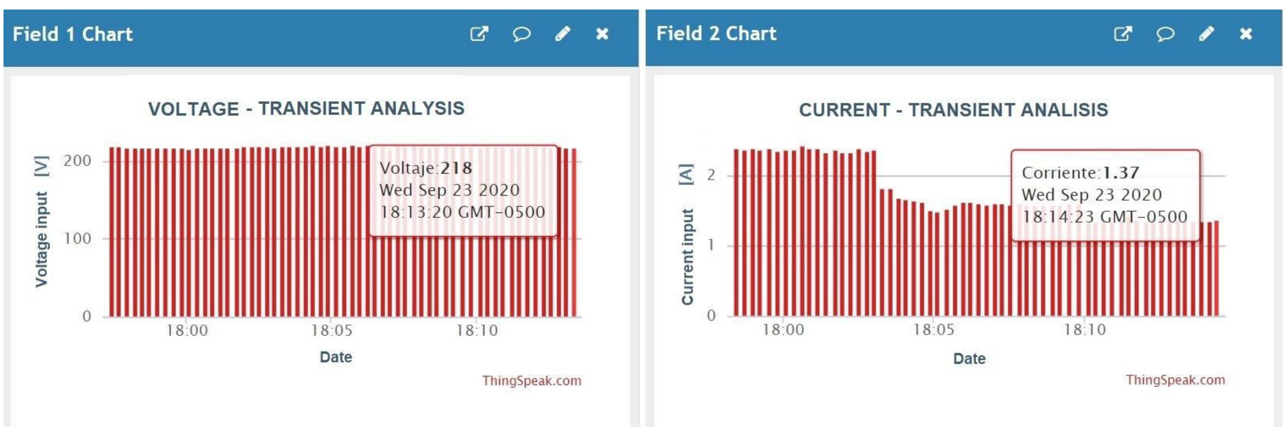

Fig. 7. Voltage and current input analysis.

IV. CONTRIBUTIONS AND BENEFITS OF THE RESEARCH

This work will benefit Peruvian public service companies, retail providers, and also customers (users). Such benefits will be reflected in increased efficiency and the reduction of labor costs for the supplier of public energy. Timely use of the information will be available to the clients in order to provide better management of electrical energy consumption.

V. CONCLUSIONS AND FUTURE WORK

In this research work, a smart energy meter has been proposed based on Wi-Fi for internet access with a low-cost implementation. The proposed system can overcome and improve the challenges of energy efficiency and management capacity. Regarding the meter, it has energy parameters that can be read correctly and reliably, such as the demand value, the load profile, and the total energy consumption. Regarding the implementation of the stage of communication, the ESP8266 Wi-Fi module works smoothly and in a reliable way so that the information for visualization on the website across the entire server ThingSpeak can be submitted.

In short, this study has presented a smart energy meter of very high reliability at a very low cost. The proposed system was achieved with not so many complicated steps using the ESP8266 Wi-Fi module built into the meter with the protocol TCP/IP.

This protocol allows communications between the web application and the meter. Regarding future work, it will include notifications of interruptions in the electrical network, performance in terms of tampering detection, and the development of a mobile application so that the user can see their consumption at all times.

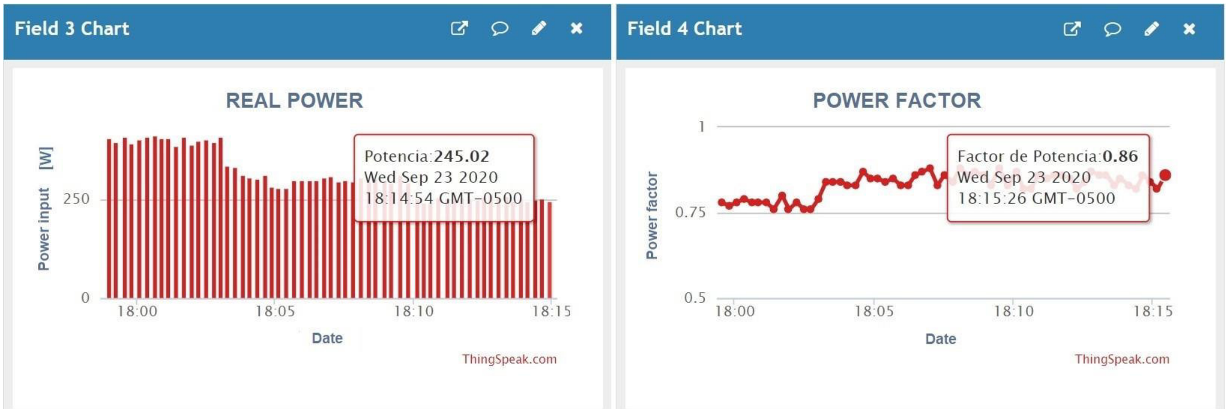

Fig. 8. Input analysis of the real power and the power factor.

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