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Energy efficiency manager for electrical installations at home

Diseño de un medidor y gestor de consumo eléctrico

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Abstract

The enormous energy consumption in homes, offices and schools that is increasing day by day requires taking the use of Smart Grid and IoT to a higher level for the optimization of smart meters, whose function is data extraction and statistical generation of energy consumption. Next, a prototype of visualization and energy management is proposed through an Android mobile application, focused on domestic electrical networks where daily and historical energy consumption can be visualized, as well as warnings of statistics outside the average, monitoring peaks of consumption physically and remotely from the mobile application. This prototype is designed with LoRa and Arduino technology, it must be installed in parallel to the original CFE meter, the collection of readings is acquired through the PZEM 004T sensor, with the help of the RTC DS3231 Module, the exact date and time are assigned, and these readings are saved in the micro-SD of the H95 Reader Module to transmit data via LoRa and Bluetooth through LILYGO TTGO LoRa32. Thus, this prototype makes it possible to optimize consumption in domestic electrical networks.

Energy consumption, Home networks, Monitoring and optimization

Resumen

El descomunal consumo energético en las casas habitación, oficinas y escuelas que día a día va en aumento, exige llevar a un nivel superior el uso de Smart Grid y el IoT para la optimización de medidores inteligentes, cuya función es la extracción de datos y la generación estadística del consumo energético. A continuación, se propone un prototipo de visualización y gestión energético por medio de una aplicación móvil Android, enfocado en redes eléctricas domésticas, donde se puede visualizar el consumo energético cotidiano e histórico, así como advertencias de una estadística fuera del promedio, monitoreando los picos de consumo de manera física y remota desde la aplicación móvil. Este prototipo está diseñado con tecnología LoRa y Arduino, se instala de manera paralela al medidor original de CFE, la recopilación de lecturas se adquiere por medio del sensor PZEM 004T, con ayuda del Módulo RTC DS3231 se les asigna la fecha y hora exacta, y dichas lecturas se guardan en la micro SD del Módulo lector H95 para transmitir los datos mediante LoRa y Bluetooth a través de TTGO LoRa32. Así pues, este prototipo permite optimizar el consumo en redes eléctricas domésticas.

Consumo energético, Redes domésticas, Monitoreo y optimización

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Introduction

High electricity demand, bad consumption habits, high costs, complaints to the electricity supplier [8] are caused by the lack of use of Smart Grid or technological products within the household for monitoring electricity consumption.

Improving electricity management and metering arises from two main parts; generation and demand.

In terms of energy generation, based on obtaining energy from fossil fuels and alternative energies, in 2018 Mexico had a gross consumption of 318,236GWh, of which 15.8% (50,285GWh) corresponds to the Central East Zone [9]. In terms of demand, there are several factors that influence its consumption, such as climate changes and users' consumption habits, to name a few, which easily lead to complaints about high and inexplicable energy consumption. In 2020, the Central East Zone of Mexico registered 891 complaints about electricity consumption [8]. Unfortunately, investment projections for 2018-2022, it is planned to acquire 2. 7 million electronic self-management meters to achieve some AMI features, and 3 million meters with radio frequency cards will be installed [10], which lack the ability to manipulate and restrict energy consumption on their own, but offer the end user real-time energy consumption information about their home, giving little opportunity for the consumer and energy supplier to manage and measure energy use and behaviour, depriving the former of establishing and planning energy savings and the latter of having feedback to make changes in energy generation [11].

Therefore, the need arises to implement solutions to these circumstances by creating new technologies in the home, such as the creation of a prototype for real-time monitoring and visualisation of consumption behaviour by hour, day, week and month, as well as alarms and warnings related to consumption, for example; offers the option of control over the activation and deactivation of the power supply due to a low or high voltage in the electrical grid, warning when there is a jump in consumption level over the tariffs imposed by CFE; and forecasting energy based on the stored energy history giving the latter as an added value to many other existing research and/or products.

By managing energy thanks to warnings, alarms, forecasts and the daily energy rhythm, users could be convinced and made aware of the need to reduce their consumption, thus protecting the environment by reducing excessive energy generation and avoiding huge CO_2 emissions into the atmosphere. [9].

Development

In order to fulfil the optimal performance simulation of this prototype, a descriptive methodology [2] is used, which is implemented in an electrical service at 127VAC, i.e., a single-phase service.

The general structure of the proposed design is shown in figure 1, in it the CFE supply (1) that supplies energy to the house is observed, which in turn is delivered to the main meter (2), which provides as the only data the historical consumption in KWh, highlighting that this information is little understood by the user, the reading is generally outside the house and the consumption data are delivered with the charge included, which prevents the opportunity to have control over consumption, while it lacks energy monitoring at all times. However, the CFE meter will always be present. Given this situation, the prototype (3) is connected after the main meter but inside the house to visualize the consumption readings at any time by means of the local display (4) of the prototype, also locally all the events occurred are stored in a SD card (5) thanks to the LoRa module located inside the cabinet. In addition to this, remote data transmission via Bluetooth to an Android mobile device (6) is included, and finally the data is sent to the software via serial communication. (7).

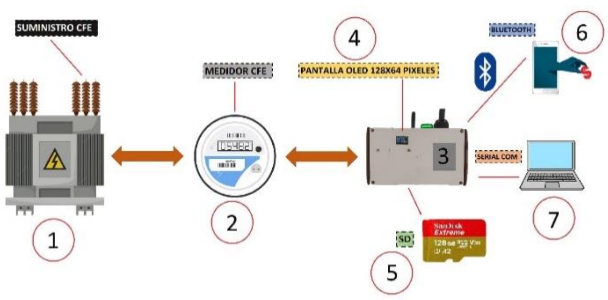

Figure 1 Overall project architecture

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Architecture

The construction of this prototype (figure 2) is made up of four important blocks: the first one is made up of the PZEM 004T V3 module, which provides the way to acquire information directly from the energy consumption that is obtained from the sockets and controlled with the switches; the second block is made up of the RTC module that provides the precise time and date recording of each event sample delivered to TTGO LoRa ESP32, which is the IoT board that carries out the processing, analysis and data acquisition to perform the calculations and predictions of energy consumption; In the third block, with the support of the voltage booster and the H-bridge, the control signal is transferred on the high or low voltage peaks so that the relay protects the domestic electrical network and cuts the power; finally in the fourth block is the OLED display, the SD slot and serial port, to deliver the display of the information, in parallel the Bluetooth transmits this information to the Android App.

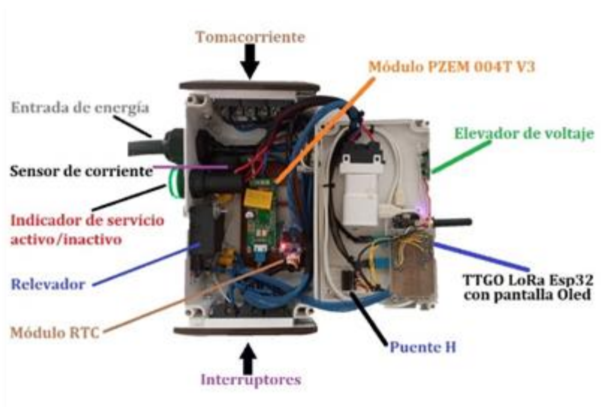

Figure 2 Smart meter design system

Data acquisition

By means of the PZEM 004T V3 sensor (figure 3) the electrical parameters of voltage, current, frequency, power factor, active power and consumption are obtained, friendly with voltages of 127/220VAC so it is not necessary to make any modification to the sensor as it has characteristics and parameters (table 1) suitable for its direct study [3].

Figure 3 PZEM 004T V3

Characteristic	Range	Resolution	Accuracy
Voltage	80-260v	0.1v	0.50%
Current	0-100A	0.001A	0.50%
Active Power	0-23KW	0.1W	0.50%
Power Factor	0-1	0.01	1%
Frequency	45-65Hz	0.1Hz	0.50%
Consumption	0-9999KWh	1Wh	0.50%

Table 1 Electrical characteristics and parameters of PZEM 004T

Data Processing

In this project, to perform the prediction calculations on the sensor readings, we started with the active power, which is transformed into useful energy either in mechanical work or in the form of heat. This energy is measured in watts (W) and is the energy consumed by mixed loads [5], which optimally reflects the energy being consumed in the home. Given the uninterrupted energy use in households, the standard unit of measurement used by the CFE to measure energy consumption is the kilowatt-hour (kWh, equivalent to one thousand watt-hours).

The basis for the prediction of instantaneous energy consumption, which allowed the values to be determined, is set out in formula 1 with the rational analysis of the behaviour of the power demanded over time.

$$\text{prediction} = \frac{P*t}{1\,000} \qquad (1)$$

P= Power demand (W)

t=Time lag to be predicted(hours)

Once the initial prediction has been extracted, it is used to obtain the predictions per minute, hour, day, week and month elapsed.

We work in parallel with a second option of prediction by event (minute, hour, day or month) to offer another way of predicting consumption, obtaining the equation 2.

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$$pronos_t = \Delta 2et_f - et_o \qquad (2)$$

where:

$pronos_t$ = Energy forecast for the following event.

et_o= Energy with respect to event start.

et_f= Energy with respect to the final time of the event.

Equation 2 is also used to obtain the predictions of any event.

Control

The power cut-off occurs when a voltage deficit is detected below 105.3VAC and when an excess voltage is detected above 139.7VAC, this power cut-off is done by the microcontroller with two electrical pulses with a pulse width of 10ms to the L293D, which is responsible for amplifying and switching the weak signal of the microcontroller LoRa.

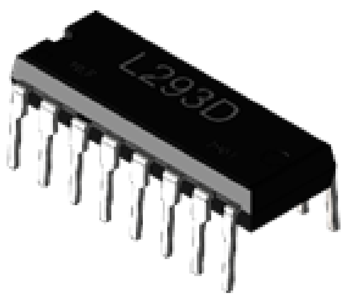

Figure 4 L293D

And finally the amplified signal reaches the KG-K125 relay (figure 5) which uses the magnetic principle to control the on/off switching of the power supply.

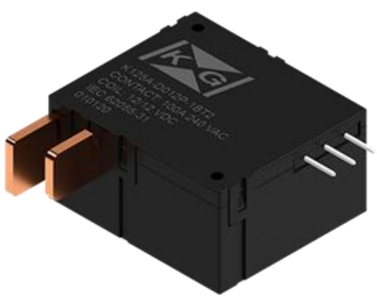

Figure 5 Relay KG-K125

Display and storage of data

In order to display and store data about the sensor readings locally, it was necessary to implement the DS3231 RTC module (figure 6) to date and time each event, which is a high-precision clock with a temperature-compensated crystal oscillator (TCXO). The integration of the crystal oscillator into the integrated circuit itself, in conjunction with the temperature compensation, ensures long-term accuracy. [7]

Figure 6 RTC module DS3231

TTGO LoRa32 915Mhz V1.6.1 was also used which features an OLED display, microSD memory slot, bluetooth, as well as connection to the serial monitoring port.

As broken down below; TTGO LoRa32 is a development board based on the ESP32 family, which incorporates a LoRa 868 / 915 MHz module allowing bi-directional data transmission over long distances (approx. 300m), it incorporates an OLED display and a 915Mhz V1.6.1 V1.6.1 V1.6.1 V1.6.1 OLED display.), incorporates an OLED display of 128×64 pixels, which is connected internally to the ESP32 in the pins: GPIO 21, GPIO 22 and GPIO 16, which correspond to the SDA, SCL and RST (OLED) pins of the display as shown in the figure and communicate through the I2C communication protocol. [5]

Figure 7 TTGO LoRa32 TTGO board pin layout

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The way in communicating to the Arduino IDE platform to display the data on the serial monitor is through its micro USB connector which also supplies power for the overall module operation. [6]

And the display wirelessly for prediction and power consumption, bluetooth module was used which will send data packets to the Android device as seen in figure 8.

Figure 8 Android App

The collection of data obtained by the PZEM 004T sensor, which the TTGO LoRa ESP32 module processes and analyses, samples voltage, current, power, frequency, power factor and historical consumption in kWh, as well as the prediction and trend of consumption in the next minute, hour and day, to send them via Bluetooth to the Android device and in parallel to the SD memory placed in the slot of the microcontroller as shown in figure 9.

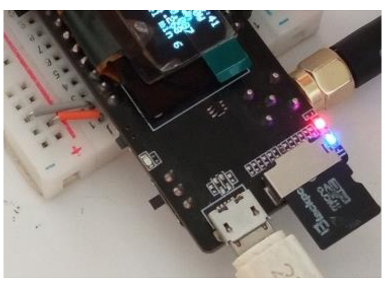

Figure 9 SD slot

Results

A user-friendly prototype with a clean and aesthetically pleasing external design (figure 10) was achieved, showing: A) contacts for the control of the sockets to be measured; B) the voltage cut-off indicator light and the display with the most important parameters for the user; and C) three sockets controlled by the contacts for a more controlled and efficient testing system.

Figure 10 External design of the prototype

Considering in the internal part (figure 11) top quality materials such as, rigid casing, use of Bakelite, electrical connectors and harnesses together with cable mesh, resulted in a solid and tidy internal structure capable of being a heavy duty design.

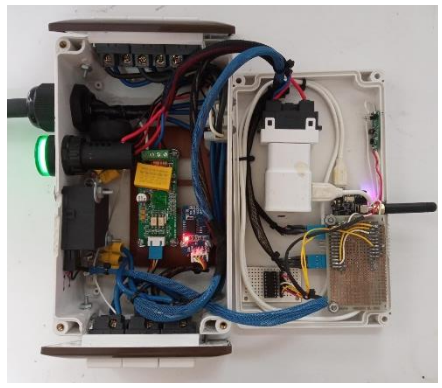

Figure 11 Internal prototype design

Complementing the prototype with a user-friendly and simple application for mobile devices (figure 12) where the user monitors consumption and clearly visualises energy predictions.

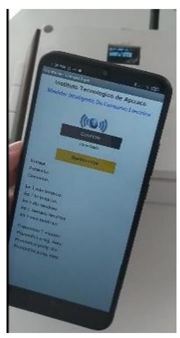

Figure 12 Application on mobile device

The voltage, current, power, stored energy in KWh, as well as the frequency and power factor measured by the PZEM004T sensor were read and recorded, as shown in lines two to seven of figure 13, having a consumption storage capacity of 9999.99kWh [3] or three years of regular consumption of an average house [1]. The prediction was calculated and recorded based on time, i.e. the consumption of the next minute, hour, day, week and month, as shown in lines eight to twelve of figure 13.

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And the margin of error of less than 5% on the estimated consumption predictions was calculated by recording this information in line 15 of figure 13.

```
08/13/2023--06:59:59
Voltaje: 122.50V
Corriente: 0.95A
Potencia: 73.30W
Energía: 1.511kWh
Frecuencia: 60.0Hz
Fac_Pot: 0.63
SSATEN en 1mi 1.512
SSATEN en 1h 1.584
SSATEN en 1di 3.270
SSATEN en 1se 13.825
SSATEN en 1me 54.287
Consumo al iniciar la hora 1.466 KWh
Consumo al terminar la hora 1.511 KWh
% error pronos_hora_anterior 2.98 %
Felicidades, tu consumo fue menor al esperado!!
Pronos_sig_hora 1.556 KWh
KWh-En hora anterior: 0.045
```

Figure 13 Energy consumption readings and forecasts

In all statistical, non-exact events such as prediction, error is inevitable. Below is a graph (figure 14) made with data taken at random from multiple samples from one day of an event. Good results were obtained by having a maximum error of 3.71% with respect to predicted consumption (yellow) vs. actual consumption (green) at the end of each event (hours). The other predictions were even better with an error of even less than 1%. Making the calculation of the error of the predicted vs. actual consumption reliable.

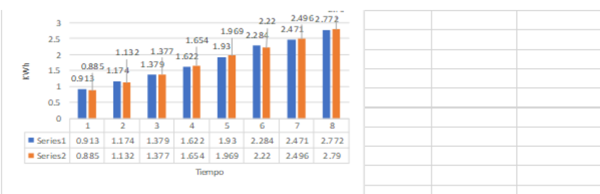

Figure 14 Prediction error statistics.

The most relevant data such as date and time, real time power sensed every second, accumulated consumption and instantaneous power predictions for the next hour and the next day based on real power consumption were also recorded on the screen as shown in figure 15.

Figure 15 Data on Display

Finally, power control was achieved as a preventive measure against damage to the electrical installations of the house and the electrical appliances connected to it, by cutting off the power supply with the help of the KG-K125 contactor activated by high and low voltages, warning the user that the power supply was cut off due to high or low voltage as shown in figure 16.

```
08/30/2023--23:57:32
Voltaje: 155.35V
Corriente: 0.02A
Potencia: 0.00W
Energía: 0.000KWh
Frecuencia: 60.0Hz
Fac_Pot: 0.00
Suministro eléctrico desactivado debido a un alto voltaje, se reestablecerá cuando sea ideal
SSATEN en 1mi 0.000
SSATEN en 1h 0.000
SSATEN en 1di 0.000
SSATEN en 1se 0.000
SSATEN en 1me 0.000
```

Figure 16 High voltage power control

Acknowledgement

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Conclusions

Nowadays it is essential to be aware of the effects of energy consumption, as well as the care of the environment, this design contributes to consumers, making decisions about their daily energy consumption, in this project the design and implementation of a smart meter based on LoRA and Arduino technology was broken down in detail.

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The module calculates the electrical energy used in the home based on the power demand provided by the PZEM004T sensor, allowing the user to view daily, weekly and monthly consumption readings on the prototype's screen and on their mobile device, as well as warnings about tariff changes due to consumption, the management of high and low voltage power cuts, as well as short and long term consumption predictions and forecasts, providing the user to identify what, when and where excess energy consumption is created and its behaviour, reducing the user's financial burden, while contributing to the care of the environment.

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