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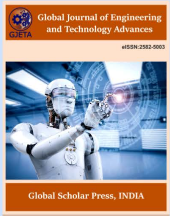

(RESEARCH ARTICLE)

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Comparison of electrical measurements between different devices for smart meter applications

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Abstract

The integration of smart electrical networks aims to better respond to faults, and distribute and control energy consumption, all of this would be difficult to achieve without the functions of smart meters that allow the sending of information between electricity companies' services and the consumer, which is why it is important to guarantee the reliability of the information that is shared. In this work, the validation of the EVM430-F6736 meter and the PZEM-004T sensor is carried out concerning conventional devices for measuring electrical variables such as multimeters and wattmeters. The results show the error percentages between the measurements of the different devices.

Keywords: Smart meter; Smart grid; EVM430-F6736; PZEM-004T

1. Introduction

Due to the need to supply the increase in global electrical energy demand, which according to Statista [1] increased by 6.53% in 2022 compared to 2020, and contributed to the reduction of greenhouse gases, alternatives have been sought for the generation of electricity in a clean and renewable way, such as distributed energy systems that allow generating electricity in remote places with renewable energy and integrating them into the electrical grid or working in isolation [2].

In order to make the delivery and supply of electricity efficient in a sustainable manner, the concept of Smart Grid (SG) was developed, which refers to an electrical network that can intelligently integrate the actions of all users connected to it, generators, consumers, and those who do both. Using the SG allows for improving response time to failures, distribution, and control over energy generation and consumption, and giving the end user more information about their consumption [3]. One of the most important tools within a Smart Grid is Smart Meters, which are capable of obtaining information from users' charging devices in real-time such as voltage, current, frequency, and power, they can measure energy consumption and provide additional information to the utility company, system operators and can display user data on a device within the home, which helps to improve service monitoring and billing [4,5,6].

So that the SM to perform its purpose optimally, it has a series of essential functions [7], such as dynamic prices that inform the user of the price of the energy consumed, bidirectional communication to send data between users and the energy distribution company, remote service that allows companies to disconnect, connect, detect theft and detect power outages as well as send invoices and warnings of abnormal consumption to users, in addition an SM presents a local area network (HAN) functionality to interconnect submetering devices, displays, thermostats and load control devices.

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Since SMs are a fundamental part of smart electrical networks, in recent years, several low-cost systems have been proposed that implement some of the functions of SMs and mostly use sensors such as the PZEM-004T and microcontrollers such as ESP8266, Arduino, and Raspberry Pi.

For example, Khoa [8] and Muthukumar [9] use three PZEM-004T sensors and WeMos D1 R1 ESP8266 and ESP32 boards to obtain and process power consumption data in three-phase systems. For single-phase systems in [10], the PZEM-004T is used to obtain electrical measurements, and the ESP8266, which receives information from the sensor and two passive infrared (PIR) sensors and displays the values on a liquid crystal display (LCD), in addition to sending them to Firebase to visualize and analyze the behavior of energy consumption in a specific room. Other related works employing similar sensors and microcontrollers are described in [11] and [12].

On the other hand, the Raspberry Pi3 card has been used in the system described by Khanna [13], where the measurement of energy consumption is carried out and an application for Android devices is also provided that allows the user to view their consumption data. Like the above, Hussein [14] designed a system that uses the PZEM-004T as a measurement device, reads the data with an Arduino Uno, and subsequently sends it to a Raspberry Pi3 that is used as a local server and will create a panel, which will be sent to a web page to show measurements.

Using the PZEM-004T module and Arduino Mega 2560 board by Syafii [15] proposes a system that monitors the energy consumption of a load and the energy generated by a solar panel, and determines whether the energy is being exported or imported from the electrical system. Furthermore, through a web page, you can show graphs of the energy produced, the energy consumed and the difference between them.

2. EVM430-F6736

The EVM430-F6736 is a single-phase smart meter developed by Texas Instruments (TI), which uses the MSP430-F6736 processor. The maximum voltage it can measure is 230 V at a frequency of 50/60 Hz; it has a single voltage input for phase and neutral and two inputs for current reading, although it should be considered that only one of them counts with an integrated current transformer (CT) [16, 17]. It can be powered by an external source or use the power supplied by the voltage input; it has the option of connecting to a computer via an RS-232 cable to observe measurements in real-time and calibrate the device; it can also send measurement information with the ZigBee protocol using CC2530EMK evaluation kit [17].

The device allows eight measurements to be made whose values can be observed from the liquid crystal display (LCD) or from the computer, which is updated every two seconds [17]. Table 1 shows the types of measurements along with the symbols that correspond to each one.

Table 1 Measurements that EVM430-F6736 can perform

Measure	**Symbol**	**Measure**	**Symbol**
Voltage	V	Apparent Power	S
Current	C	Frequency	F
Active Power	P	Power Factor	FC o FL
Reactive Power	Q	Active Energy consumed	E

3. Master MAS830L digital multimeter

An instrument that allows measurements of direct current (DC) and alternating current (AC) voltage, DC current, resistance, continuity, diodes, and transistors. It can measure voltages up to 600 V AC with an accuracy of ±1.2% [18]. It has an LCD screen to observe measurements and has a data hold button.

4. MT87 Hook Multimeter and Ammeter

An instrument that allows measurements of DC and AC voltage, AC current, continuity, and resistance. The range of amperes it can measure in AC reaches up to 400 A, with a precision of ±2%. One of the advantages is that the ammeter is a hook-type, so it is unnecessary to open the circuit to connect the device [19]. Measurements can be viewed on the integrated LCD

5. EW604 electronic wattmeter

It is a device used to measure the active power that is generated with a load, it makes measurements with a maximum error of 2.3%, and it has the ability to measure current power ranges between 0.05 to 10 A, and voltages between 5 to 1000 V since it has knobs to adjust these ranges and make a more precise measurement, so the range of power it can measure goes from 0.25 to 10,000 Watts [20]. It has two inputs where the power supply must be connected and two terminals to connect the load. The measurement result is displayed on a coil meter, which must be multiplied by the current and voltage range set to obtain the final value.

6. PZEM-004T V3.0

It is a module used to study systems that use AC that can perform measurements of voltage, current, power, and frequency with the ranges shown in Table 2 [21]. It has two configurations: by itself, it can measure up to 10 A, and using a CT, it can measure up to 100 A. The circuit that performs the measurements is fed directly from the energy that is connected in phase and neutral, as it does not have an integrated means to directly display measurements, it has a universal asynchronous receiver-transmitter (UART) communication interface so that measurements can be viewed from another device [21].

Table 2 Measures that PZEM-004T can perform

Measure	Range	Precision	Measure	Range	Precision
V	80-260 V	±0.5%	F	45-65 Hz	±0.5%
C	0-100 A	±0.5%	PF	0.00-1	±0.5%
P	0-23 kW	±0.5%	E	0-9999.99 kWh	±0.5%

7. Testing

The loads used for the tests were three light bulbs to generate a resistive load, a capacitor, and a transformer as an inductor, as shown in Figure 1.

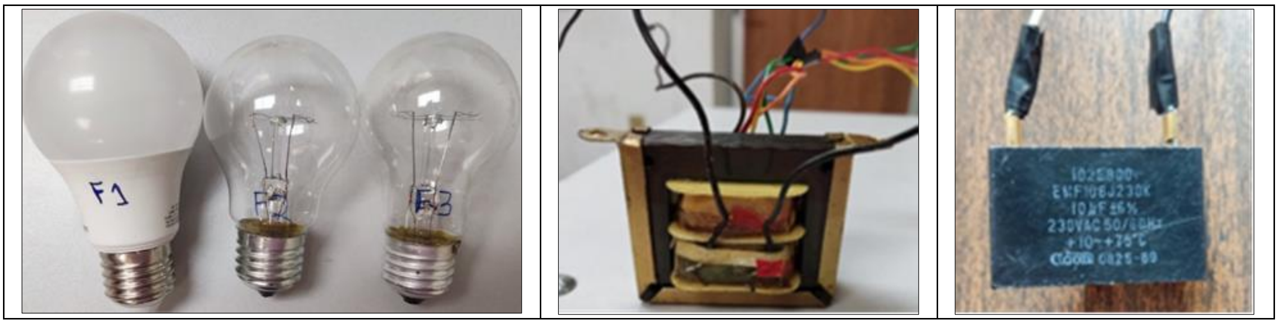

Figure 1 Loads used to validate EVM430-F6736

Regarding resistive loads, F1 is an LED bulb with a consumption of 9 Watts, F2 and F3 are filament bulbs of 100 and 60 Watts, respectively, the capacitor used has a value of 10 uF, and, finally, as an inductive load, a transformer was used. During the measurements, the three bulbs were used, and subsequently, it was chosen to use F3 in series with the capacitor and the inductor.

During the tests carried out with the TI module and the measuring devices, the diagram shown in Figure 2 was used. On the left side, the connections made with the EVM430-F6736 are shown and configured so that the integrated capacitive voltage source is powered by power from the outlet. On the right side, the connections made with the three measuring devices are shown.

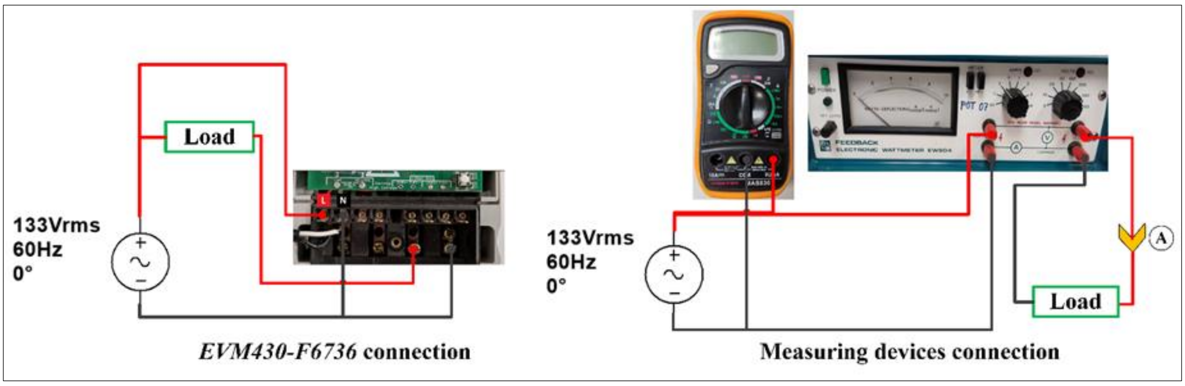

Figure 2 General diagram of the connections made during measurements

The next test carried out was between the TI module and the PZEM-004T, where the configuration of the EVM430-F6736 is identical to that used in the tests with the measuring devices, as for the PZEM, it was decided to use the configuration that allows measuring AC current of up to 100 A, so the connections made are shown in figure 3. The measurements of both devices were carried out every two seconds; in the EVM430, they were shown on the integrated LCD, and those of the PZEM were obtained through an ESP8266 NodeMCU, using the UART and showing the measurements from the serial port that has the Arduino integrated development environment (IDE).

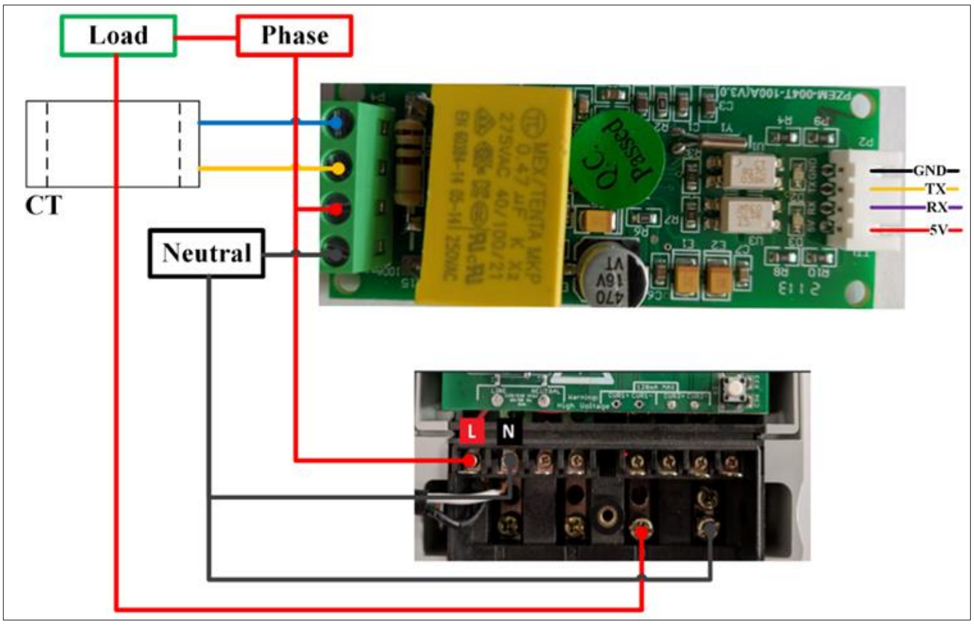

Figure 3 EVM430-F6736 and PZEM-004T connections made during measurements

8. Results

With the measuring devices used, it is possible to measure voltage (V), current (I), and power (P), so to obtain an additional value for comparison with the measurements of the EVM430-F6736, the calculation of the power factor (PF), apparent power (S) and reactive power (Q) of each of the tests was carried out according to the equations 1- 4.

$$P = VIcos(\theta) = VI(PF) \rightarrow PF = \frac{P}{VI} \text{ .... } (1)$$

$$S = VI \ldots\ldots\ldots\ldots..(2)$$

$$\cos(\theta) = PF \rightarrow \theta = \cos^{-1}(PF) \quad \ldots\ldots\ldots\ldots\ldots\ldots. (3)$$

$$Q = Ssen(\theta) \ldots\ldots\ldots\ldots\ldots..(4)$$

Table 3 shows the measurements obtained for V, I, P, Q, S, frequency (f), and PF using EVM430-F6736 with the five test loads.

Table 3 Measurements obtained by the EVM430-F6736

Load	V	I	P	Q	S	f	PF
F1	133.9 V	0.102 A	8.75 W	1.72 VAR	8.9 VA	59.98 Hz	0.978
F2	133.91 V	1.016 A	135.79 W	0.64 VAR	135.42 VA	59.99 Hz	1
F3	133.71 V	0.543 A	72.72 W	0.6 VAR	72.66 VA	59.95 Hz	1
F3+L	133.46 V	0.091 A	5 W	10.4 VAR	11.5 VA	59.99 Hz	0.434
F3+C	133.6 V	0.415 A	32.53 W	44.68 VAR	55.3 VA	59.94 Hz	0.588

Table 4 shows the measurements obtained for V, I, and P with measuring devices and the calculation of Q, S, and PF.

Table 4 Measurements obtained with measuring devices

Load	V	I	P	Q	S	PF
F1	132.4 V	0.08 A	8.8 W	5.89 VAR	10.59 VA	0.831
F2	132.1 V	1.02 A	136 W	0 VAR	134.74 VA	1.009
F3	132.3 V	0.52 A	70 W	0 VAR	68.80 VA	1.01
F3+L	132 V	0.09 A	4.8 W	10.87 VAR	11.88 VA	0.404
F3+C	132.6 V	0.38 A	32 W	38.93 VAR	50.39 VA	0.635

Table 5 shows the error percentages between the EVM430-F6736 and the measuring devices calculated from Equation 5.

$$\%Error = \left|\frac{EVM430F6736\ measure - Measuring\ devices\ measure}{EVM430F6736\ measure}\right| * 100 \ldots\ldots\ (5)$$

Table 5 Error percentages between EVM430-F6736 and measuring devices

% Error EVM430-F6736 vs Measuring devices						
Load	**V**	**I**	**P**	**Q**	**S**	**PF**
F1	1.12	21.57	0.57	242.44	18.99	15.03
F2	1.35	0.39	0.15	100.00	0.50	0.90
F3	1.05	4.24	3.74	100.00	5.31	1.00
F3+L	1.09	1.10	4.00	4.52	3.30	6.91
F3+C	0.75	8.43	1.63	12.87	8.88	7.99

With most of the loads, acceptable results were obtained (between 0.15 to 12.87%) except for F1, where the highest error percentages were present, therefore a second test was carried out connecting F1 and F2 in series and using an oscilloscope F2 voltage waveform was observed, obtaining what is shown in figure 4.

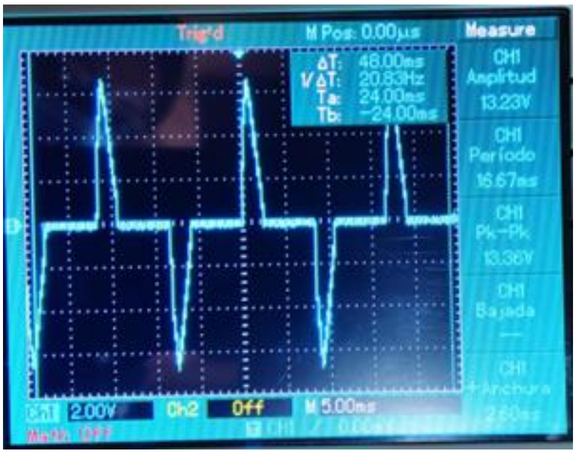

Figure 4 F2 voltage waveform

The waveform obtained at F1 was sinusoidal, while at F2, a considerable distortion was observed, as shown in Figure 4, indicating that F1 causes a distortion in the current because the second load is purely resistive.

As shown in Table 6, PZEM-004T is not capable of measuring S and Q. However, equations 2-4 were used to calculate these values. Table 6 shows the measurements obtained for V, I, P, Q, S, f, and PF using EVM430-F6736 and PZEM-004T with the five test loads.

Table 6 Comparison of measurements between the EVM430-F6736 and PZEM-004T

EVM430-F6736							
Load	**V**	**I**	**P**	**Q**	**S**	**f**	**PF**
F1	133.74 V	0.103 A	8.74 W	1.8 VAR	8.91 VA	59.99 Hz	0.979
F2	133.59 V	1.015 A	135.62 W	0 VAR	135.57 VA	59.96 Hz	1
F3	133.61 V	0.544 A	72.66 W	0 VAR	72.67 VA	59.95 Hz	1
F3+L	133.95 V	0.092 A	5.04 W	10.68 VAR	11.77 VA	59.99 Hz	0.428
F3+C	134.01 V	0.415 A	32.82 W	44.84 VAR	55.46 VA	59.98 Hz	0.59
PZEM-004T							
Load	V	I	P	Q	S	f	PF
F1	133.40 V	0.11 A	8.63 W	11.63 VAR	14.48 VA	60.00 Hz	0.61
F2	133.13 V	1.01 A	134.99 W	0.00 VAR	134.99 VA	60.00 Hz	1.00
F3	133.31 V	0.54 A	72.39 W	0.00 VAR	72.39 VA	60.00 Hz	1.00
F3+L	133.49 V	0.09 A	5.09 W	10.96 VAR	12.08 VA	60.00 Hz	0.41
F3+C	133.40 V	0.41 A	32.11 W	44.55 VAR	54.92 VA	59.90 Hz	0.58

Table 7 shows the error percentages between the EVM430-F6736 and the PZEM-004T calculated from equation 6.

$$\%Error = \left| \frac{EVM430F6736\ measure - PZEM\_004T\ measure}{EVM430F6736\ measure} \right| * 100 \quad \dots\dots\dots\dots\dots\dots \ (6)$$

Table 7 Percent error between measurements of the EVM430-F6736 and PZEM-004T

% Error EVM430-F6736 vs PZEM-004T							
Load	**V**	**I**	**P**	**Q**	**S**	**f**	**PF**
F1	0.25	6.36	1.27	84.52	38.47	0.02	60.49
F2	0.35	0.50	0.47	0.00	0.43	0.07	0.00
F3	0.23	0.74	0.37	0.00	0.39	0.08	0.00
F3+L	0.34	2.22	0.98	2.54	2.59	0.02	4.39
F3+C	0.46	1.22	2.21	0.64	0.98	0.13	1.72

Table 7 shows error percentages lower than those obtained with the measuring devices, with a maximum error percentage of 4.39% for four loads and up to 84.2% with F1.

9. Conclusions

The tests carried out on the three devices gave very different measurements for the LED bulb F1, after analyzing the voltage waveform by placing the F2 in series, it was concluded that the distortion in the current waveform is due to the circuit of coupling that it has integrated, hence the differences in the values of S, Q and PF shown in the tests.

The results obtained in the comparison of the measurements made with the measuring devices and the EVM430-F6736 show that despite the data offered by the manufacturers on the precision of the measurements, there are somewhat high error percentages, in addition, if monitoring was to be carried out with the three devices used during the tests, it would require considerable space and regular battery changes compared to the IT module that is powered by power from the outlet..

The PZEM-004T was shown to provide measurements with an error rate of less than 5% for most test loads despite the price difference with the EVM430, and the option to obtain measurements via UART allows it to be used a wide variety of microcontrollers that have internet connectivity, so monitoring of the electrical system could be done remotely.

The EVM430-F6736 device offers good information for monitoring the electrical system, although it can also give incorrect measurements, as in table 3, where it gives Q values when FP is equal to 1, which could not be possible, in addition to Monitoring requires opening the circuit for current measurement.

After making the comparison, the EVM430-F6736 is a useful device. However, there are devices like PZEM-004T that offer very precise measurements, allow measurements to be made without the need to disconnect the system for current measurement, and the information can be handled by easy-to-use and fairly accessible microcontrollers.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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