Prototype Development Open Source Platform-Based Electricity Meter with Minimum Rate of Change According to Module Five of the Electricity Distribution Procedure in the Brazilian National Electrical System (PRODIST)

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Abstract

The article proposes the development of a low-cost, well-performing open source residential energy consumption demand meter compared to commercial meters in order to achieve accurate results and remain within the limits determined by technical standards, with the objective of measuring real and instant energy consumption through microcontroller and current sensor. The prototype has the ability to provide energy consumption data for a low voltage residential load or wiring to obtain the final amount of energy consumption Data is collected in stages by collecting current and voltage, the microcontroller receives analog stimuli from sensors, as voltage and current samples are processed to calculate power, current and voltage. The use of the device leads the consumer to clarify the instantaneous energy consumption per installed component and it is possible to compare the cost benefit in relation to the energy consumption, providing consumers the follow up and a detailed view of its consumption, leading *to efficient and sustainable use, enabling the improvement of the quality of energy supply to equipment connected to the distribution system.*

Keywords: micro controller; sensors; electricity meter;

1. Introduction

With the crisis of fossil fuel power sources, several countries have gone in search of other power sources with the intention of maintaining security and stability in global energy supply and mitigating man-made impacts to the environment. One of the main objectives with obtaining new sources of energy is to achieve energy autonomy and weaken the link with sources of generation from fossil sources. During the twentieth century there was a major economic advance in the country, requiring a greater supply of energy to meet demand and keep up with technological developments. A determining factor that drove Brazil to seek the generation increase was the growing expansion of industries and the emergence of new technologies with their constant evolution. In the 1970s, large industries expanded to occupy larger demographic spaces, and along with economic developments there was also a large urban sprawl aggravating the need for more energy sources to keep up with the accelerated growth that intensified over a 30-year period, tripling in 2000 [1]. Then it was noted that population development was growing beyond existing available demand, the demand deficit became evident in the first crisis in 2001, where there was a mismatch between demand and supply of energy resources. [2]. In humid periods, with excessive rainfall, the participation of hydroelectric plants remains in constant generation to meet the demand of energy consumption that reaches 90%, however in periods of rain shortage this supply capacity may decrease, being necessary the supply of energy from other sources, since consumption demand remains the same. According to (EPE, 2019.) about 30% of the country's power generation comes from thermoelectric power plants and other adjacent sources, especially fuel burning plants. [3]. In need of diversifying the energy matrix and improving energy conscious consumption many measures have been agreed at major sustainability events around the world. The present work proposes the development of a low cost electric energy consumption meter for homes with the purpose of generating consumer information and comparing the data obtained with the results of commercial meters, in order to achieve accuracy of results and keep within the limits determined by national which allow uncertainties to vary by up to 2%.

2. Theoretical Referential

Energy is anything that can produce heat, mechanical work, light, radiation, etc. In a general sense, it could be defined as the basic substrate of all things, responsible for all the processes of transformation, propagation, and interaction that take place in the universe. Electric energy is a special type of energy through which we can achieve the above effects; It is used to transmit and transform the primary energy from the power source that drives the generators into other types of energy we use in our homes.[4].

2.1 *Electric Power Meters*

Energy meters were accepted as science in the early nineteenth century in the year 1872, because at that time the quantification of energy was done inaccurately, by estimation with constant loads and no variation of currents and its variation only in periods of consumption having by creator Samuel Gardiner [5]-[6]. Over the years and the constant effort to quantify energy consumption, in 1878, a meter was developed by JB Fuller, an alternating current-hour meter, consisting of a pair of coils that vibrated with the frequency of in this way there was an advance of the counting in the clock-recorder, and with this the recording of the energy [6]. Evolution called for even more advancements and continued to go through the ideas of engineer Thomas Edison, who from 1878 to 1880 developed the first meter of the amount of energy consumed based on chemical reactions.[6].Five years after the invention of Thomas Edson, Italian professor Galileo Ferraris with the discovery of the induction principle developed a more accurate meter, this meter is based on the magnetic flux produced by two coils acting on a metal rotor that produces a force and the makes it spin. This is the working principle of alternating current electromechanical meters manufactured to this day [5]. Electromechanical meters use the principle of electromagnetic induction for their operation and the electronic meters through integrated circuits, both of which are designed to operate at purely sinusoidal [7]. Currently, most installed energy meters are induction type and consist of the following components:

- Motor element;
- Movable element (disk):
- Permanent magnet;
- Recorder;
- Adjusting devices;
- Structure for mounting the components.

However, with the evolution of electronics in the 1970s, began the introduction of electronic meters of electricity that in addition to informing energy consumption, have information on quality and availability of electricity. Electronic energy meters will grow in use due to the expansion in smart grid connection projects and the customer's need for real-time consumption information [8].

2.2 *Electric Power Measurement*

The importance of measuring the demand for electricity consumption is directly linked to the coherent survey of the energy consumption of each customer in order to apply the prevailing energy tariffs. Therefore, this measurement is the responsibility of the electricity utility, being at the discretion of the customer. The same is the use of the electromechanical or electronic meters, but the most adopted today are the electromechanical because they have simple handling, measurement accuracy, robustness, long service life and good performance over the years [8].Electricity is a valuable commodity with the power to change the direction of a country's development, which is currently traded by energy utilities.

2.3 *Operation principle*

The voltage coil is connected in parallel with the load and the current coil is connected in series with the load and the aluminum disc forming the movable assembly. From the power supply of the coils the electric energy passes through the coils generating a magnetic field that interact with each other, giving rise to the phenomenon of electromagnetic interaction. This phenomenon generates a force that forces the disk to rotate, each revolution that the disk makes equals energy consumption, informed by the manufacturer on the disk, the shaft is coupled to gears that rotate registers providing the reading (figure 1) [9].

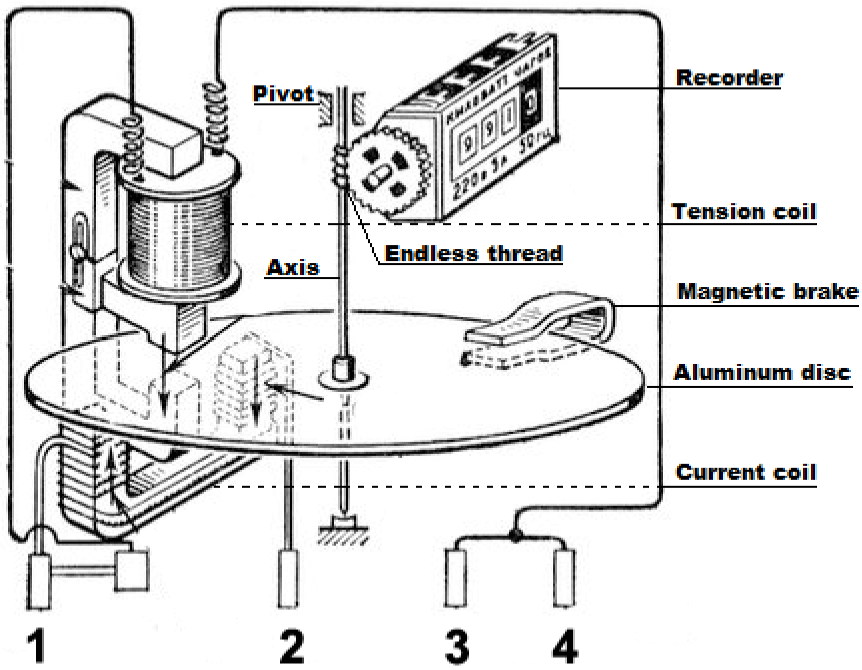

Figure 1. Internal Operation of an Electromechanical Meter (Nova Eletrônica, 2019. [10].)

3. Methodology

The prototype was developed from the Arduino platform, using a set of electronic components widely used in projects and prototyping that require satisfactory performance hardware with low cost[7]. The prototype has its hardware divided into three parts: sensors for reading energy variables: current and voltage, control and processing of variables and the user interface. The prototype operates in two stages by monitoring and conditioning the current and voltage signals to act within the working range of the microcontroller ranging from 0 V to 5 V. The module responsible for conditioning the input signals is represented by the diagram in figure 2.

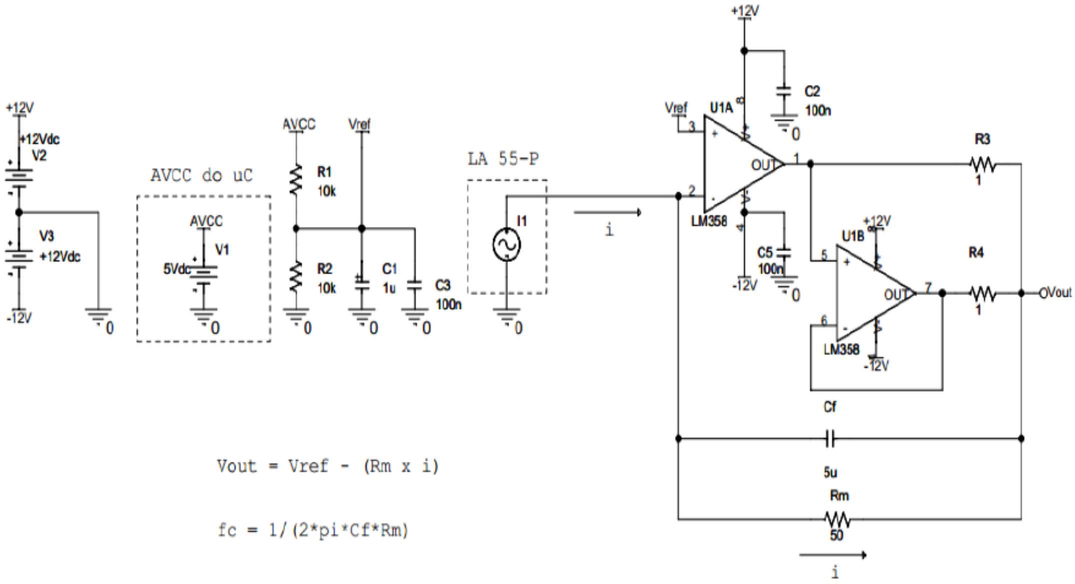

Figure 2. Diagram of the processing circuit and conditioning of current signals.

The circuit features a Hall Effect sensor with passive electromagnetic transduction behavior capable of transforming current amplitude into voltage amplitude, which in turn will be applied to the analog input of the microcontroller. In this way, the output voltage will be in a range of - 2.5 V to 2.5 V, so that you have a real sampling of the electrical signal in a smaller scale [11]. The sensors for reading current and voltage used were selected to meet the reading ranges of low demand residential loads.

The LA 55-P sensor operates in the 0 A to 50 A range of current. Receiving an external 12 V supply, a VH voltage perpendicular to the 'I' current direction arises across the semiconductor when placed in the presence of a B magnetic field. The current sensor obtains real sine stimuli collected directly from the mains, so it was necessary to conditioning of the current signal converted to voltage. The voltage sensor circuit uses a 220 VAC: 12 VAC transformer, generating an output signal proportional to the input voltage, like the current signal, the output voltage signal will be in the range of -2.5 V to 2.5 V, also requiring polarization for voltage levels to operate within the maximum control range of the micro controller ranging from 0 V to 5 V. To monitor monitored signals from voltage and current output to analog inputs Arduino, you need to shift the signal so that there is no more negative component. The developed circuit has the Summer function, adding the continuous signal to the monitored signals and shifting the alternating signal, making it possible to apply it to the A / D converter input of the micro controller. The program was developed in C language and compiled by the Arduino IDE. The created prototype aims to acquire signal samples through sensors, to calculate the consumption, active power, apparent power, power factor and present the results of these calculations on Arduino own IDE serial output.

4. Analysis and Discussion of Results

According to NBR 14519, electronic meters must pass several tests until their acceptance. Therefore, four tests were performed to evaluate the prototype behavior in order to compare and validate the results. For the first test performed in the laboratory, a load with known power of 750 W was used, with the aid of a standard multimeter of electrical quantities MMW02- WEG 50/60 Hz, calibrated and calibrated and sharing the same circuit both the multimeter and the prototype were installed to verify the total power. Using the 750 W power load, the results obtained in table 1 can be observed.

Table 1. Comparison of energy totalization on standard meter and prototype.

Readings	Power active (W)	Power within1 hour (kWh)
Multimeter	742,33	0,740
Prototype	741,81	0,734
Error (W)	0,52	0,006
%error (W)	0,07%	0,81%

As in the energy totalization test it was verified the result of the current flow readings with the multimeter and prototype sensors arranged in series, and in parallel the voltage amplitudes, the results obtained from the flow and amplitude readings can be observed. Table 2, as well as the percentage of error between the prototype and the multimeter MMW02-50 / 60 Hz.

Table 2. Comparison of readings of electrical variables in standard and prototype meter.

Rated voltage	**Standard meter MMW02-50/60 Hz**		**Prototype**		**Error**		**% error**	
127 V	Tension	Current	Tension	Current	Tension	Current	Tension	Current
	125,51 V	5,94 A	124,17 V	5,98 A	1,34 V	-0,04 A	1,07%	-0,67%
220 V	Tension	Current	Tension	Current	Tension	Current	Tension	Current
	217,60 V	3,45 A	215,28 V	3,49 A	2,32	-0,04 A	1,07%	-1,16%

As observed in the data obtained from the first test it can be considered that the percentage of loss of the prototype is practically negligible having very low errors compared to the standard meter.

The next test performed on the meter is to compare the measured quantities within a given time period and compare with the calculated uncertainty. To obtain 1 kWh it is necessary to apply a voltage of 100 V and a current of 10 A within one hour, and this is the expected result of the prototype at the end of the test. During the test the readings were stored for the development of the uncertainty calculations, allowing extracting the data of active, reactive, apparent energy, power factor, effective voltage and effective current according to table 3. Active power is the power used. By a device for producing useful work, apparent power is characterized by the product of RMS voltage and RMS current and power factor, in simple terms, indicates how efficient an electrical device is.

Table 3. Sampling data collected within one hour interval.

Hora	***W***	***Q***	***S***	***FP***	V_{RMS}	I_{RMS}
19:00	3	0	3	1	99,7 V	9,90 A
19:01	17	0	17	1	99,2 V	9,92 A
19:02	31	0	31	1	99,5 V	9,91 A

19:03	48	0	48	1	99,72 V	9,90 A
19:04	64	0	64	1	99,79 V	9,89 A
19:05	82	0	82	1	99,82 V	9,96 A
19:06	98	0	98	1	99,93 V	10 A
19:07	116	0	116	1	99,75 V	9,93 A
19:08	131	0	131	1	99,69 V	9,90 A
19:09	149	0	149	1	99,68 V	9,92 A

The behavior of the effective voltage during the test as a function of the time of application of voltage and current in the prototype can be observed in figure 3.

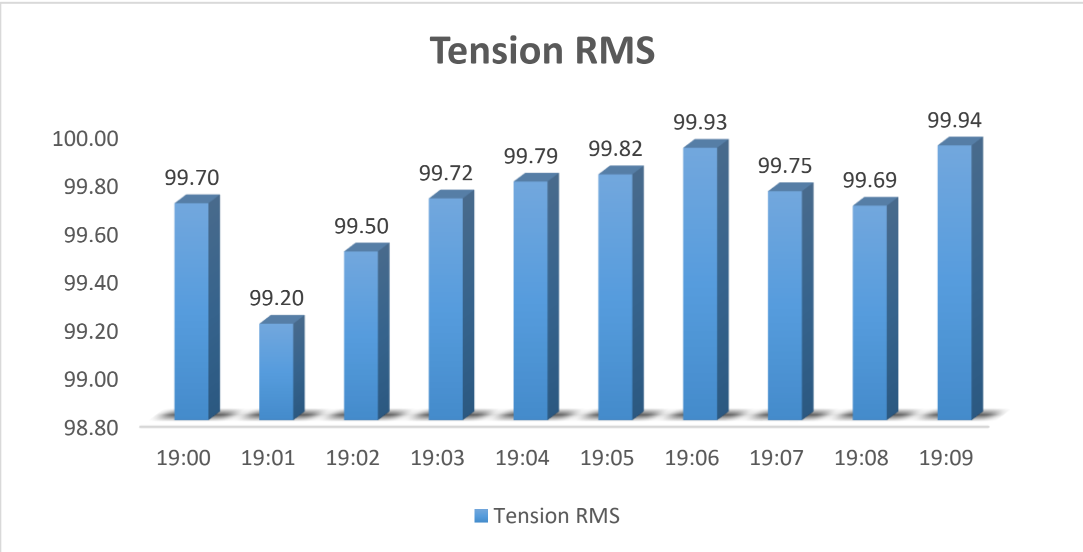

Figure 3 - VRMS behavior as a function of time.

Figure 3 shows the collection of the first ten samples at one minute intervals, at the end of the test the meter presented the value of 987 Wh of energy. With the obtained data it is possible to calculate the total uncertainty of active energy. The calculation of the uncertainty percentage found was described by the equation below:

$$\sigma_{total} = \left(1 - \frac{987}{1000}\right).100 = 1{,}3\%$$

(Equation 1)

The actual condition test was performed based on purely resistive loads. The load used for this test was a 1000 W / 220 V semi-automatic washing machine. For measurement standard a digital voltmeter and a fluke 302 + ammeter was used, the load was monitored for approximately ten hours to better observe the behavior of meter, the results collected can be seen in table 4.

Table 4. Active and apparent power, power factor, Vrms, Irms and consumption extracted by the prototype.

Active power (W)	Apparent power (VA)	Power factor (%)	VRMS (V)	IRMS (A)	Consumption (Wh)
981,03	1245,42	78,77	214,76	5,80	18,00
976,02	1198,13	81,46	214,66	5,60	18,31
975,96	1216,49	80,23	214,84	5,66	18,62
971,29	1205,75	80,55	214,67	5,62	18,92
969,79	1212,47	79,98	215,08	5,64	19,23
966,94	1157,09	83,57	214,88	5,38	19,53
996,30	1255,34	79,37	215,11	5,84	19,84
979,09	1232,63	79,43	214,91	5,74	20,15
985,13	1275,79	77,22	215,26	5,93	22,92
959,77	1115,99	86	215,06	5,19	23,22

After observing the performance presented by the meter and the measurements obtained, it is possible to prove that the low cost meters have a good performance compared to commercial meters. In order to further explore the capacity of the meter it is proposed for future work to increase the connectivity capacity of the equipment with communication modules and network protocol for long distance readings and increments in programming to obtain not only the electrical quantities but also the values related to the consumption in kWh.

5. Conclusion

According to the project development, we can conclude that the results obtained in the meter tests corroborate the theoretical prediction, proving that it is possible to develop a electricity meter with a maximum error of 2% and characteristics that fit within the acquisition standard of signals in accordance with current national technical standards. To validate the meter, tests were performed in the laboratory and under real domestic use conditions over a period of time where it was possible to observe the working characteristics of the prototype. Among the tests performed, the test of the influence quantities stands out, presenting satisfactory results with an uncertainty calculation of 1.3% of variation below the value determined by technical standard. The total uncertainty calculated for the prototype was 1.463% below the stipulated value of 2% according to the electricity distribution procedure in the national electric system.

From the observations during the operation of the meter it was possible to diagnose small delays in the data collection of the electric grid as a function of the sensors used, since they have losses considering that they are not ideal components, making visible that an improvement of the system can be achieved. since more accurate sensors, resistors with smaller tolerances and a dedicated microcontroller can be used to reduce calculated uncertainty errors. However, the errors obtained can be considered insignificant, enabling the consumer to make a good study of the quantity of energy consumption. Based on the results, it was possible to verify the prototype acuity compared to the commercial meters used as standard, but it is important to stress that the project is not intended to show the tariff values of energy consumption but the possibility of developing a low meter. cost with equal performance compared to commercial meters governed by standards.

In future work, hardware with dedicated components for use and calibration, associated with the use of reactive energy, apparent energy, effective voltage, effective current and frequency, will be made or improved. And as future work and approval with bodies accredited by INMETRO.

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