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RESEARCH ARTICLE OPEN ACCESS

DEVELOPMENT OF A PROTOTYPE OF A SINGLE-PHASE ELECTRONIC ENERGY METER USING A LORA NETWORK

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ABSTRACT

Electric energy meters are equipment capable of measuring the consumption of electricity in a consumer unit. Electrical energy metering devices are present in most homes and homes in the world, from a small commercial room to a large industry. This study can be considered exploratory because it provides greater knowledge on the subject, of an applied nature, establishing the practice of specific problems of the organization with the intention of solving them, and qualitative, seeking to understand its concepts, under two aspects, bibliographical research with the purpose to identify the authors' approaches through books, theses, articles, electronic sites and, case study, in order to analyze the development of a prototype of an electric energy meter using a LoRa network in the company Wasion. The LoRa meter was developed to meet the following needs of electricity utilities: Pricing, long-distance monitoring and quality of services delivered to customers who are far from large urban centers and without internet access (rural areas). With this development, it was possible to monitor the energy consumption of customers, monitor the quality of energy delivered, and safely and effectively check the bad weather to which the meters are subjected at their installation site with measurement of temperature and humidity.

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INTRODUCTION

Electricity meters are equipment capable of measuring the consumption of electricity in a consumer unit. Electricity meters are present in most homes and dwellings in the world, from a small commercial room to a large industry (1). The use of it is of extreme importance for the verification and calculation of the electric power consumption of the electric circuit that is interconnected to it. Among the conventional electric energy meters, electronic meters have been standing out, where through electronics, it is possible to obtain greater ease and innovation in the usual way of measuring electric energy (2), (3). The employment of electric energy meters associated with data communication networks comes with the intention not only to decrease the number of occurrences of failures, but mainly to provide more information in real time of the user of the electrical network and the pursuit of innovation of the electrical system in the world (4).

There are basically two types of electricity meters, the electromechanical meter and the electronic meter (5). They can vary between single-phase, two-phase and three-phase meters, presenting other various characteristics. With the advancement in technology, especially in the electric power distribution system, it was noticed a modernization in the electric power consumption measurement, which before, were made through manual readings by electromechanical meters (5). The electronic meters, in turn, can ensure a more accurate reading of consumption and in real time, which makes it more effective in measuring (6). Another point of great importance is the fact that when connected to a network, it is possible to monitor consumption remotely, avoiding losses in manpower and travel to make the readings (7). With this, the end consumer can have a better quality energy, reducing problems with interruption and variations in the power system. With the use of electronic meters, it is possible to obtain significant advantages compared to electromechanical energy meters (8):

- ation of the electric energy measurement process;
- Reduction of employee time in performing manual

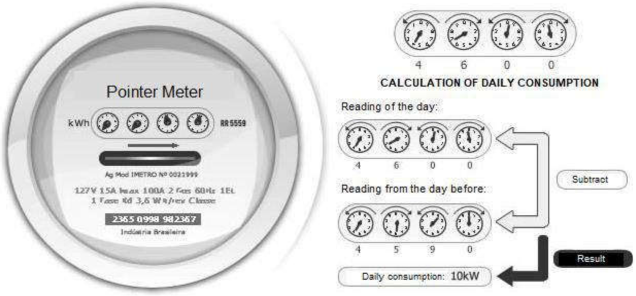
measurements;
- Real-time monitoring;
- Reliability in the gauged measurements.

The Wasion Group is the leading provider of Chinese smart metering, smart energy distribution and utilizationand integrated energy savings management solution with the mission to commit to being the Expert in Energy. Metering and Energy Saving". In 2005 it started developing energy solutions outside its home country, in 2019 it started its activities in Manaus, seeking to provide solutions in electronic energy meters for the entire national territory. With a focus on the development of meters with liquid crystal display, observing the greatest market demand which had a great acceptance with their customers, which created a great expectation for other products and the consequent need for expansion of its product line. This work aims to develop a prototype of a single-phase electronic energy meter using the LoRa network. Its main advantage is to establish remote communication between the product and the utility network. This work presented important contributions to the field of electric energy measurement. It explored the application of Industry 4.0 features, such as Internet of Things and Big Data. The most relevant contributions of this work extend in the technological and business contexts. With respect to technology, a LoRa device is able to offer optimal transmission power ratio, receiver sensitivity over long distances, low hardware cost, and a low inconsistency rate in reading the transmitted information. In rural IoT applications, these are features that aid in the deployment of rural connectivity. In this way, sensors (that normally would have no network) can be arranged in several remote locations (urban and rural), with an efficient and secure data transmission, and with the ability to provide the devices with internet connectivity through Gateways. In other words, the technology is well suited for data to reach considerable distances in large areas, consuming little power for transmission. In the business context, the company's strategy, in order to stand out from the competitors, is to make a designfocused on manufacturing and high performance in the field and to differentiate itself in production costs and operational excellence. The meters produced by WASION use a visual system of gauging by the operator, the cyclometric system, this system has measurement uncertainty performed by the professionals of the electric power concessionaires, since, when the numbers were between one digit and another, the personnel responsible for measuring the consumer's KWATTS/HOURS assigns the highest value, therefore not being the correct value measured. With the development of the energy meter using the LCD display it is much easier and practical the consumption measurement by the professionals of the concessionaires, avoiding errors of measurement. Wasion is specialized in the development of single-phase electronic meters - It measures only one phase of the electric network (domestic Clients), with the technological evolution, we intend to implement LoRa in our products.

LITERATURE REVIEW

Electrical energy meters: Since its invention, the kilowatt-hour meter (kWh) started to be used by the utilities to measure the consumption of electricity of their consumers, for this, two types of meters are used: electromechanical and electronic (9). The electromechanical uses the principle of electromagnetic induction for its operation and the electronic works through integrated circuits, both designed to work in purely sinusoidal voltages (10). According to (11), (12), energy meters can be of two types: electromechanical, which works by the principle of electromagnetic induction, and electronic, which uses integrated circuits. Within the low-voltage consumption range, the induction meter is generally used, known by this name for its operation identical to that of an induction motor. Some of these meters have electronic displays, with the use of a display, but the form of measurement remains the same (13).

Electromechanical meters: This type of meter works by the principle of electromagnetic induction, through coils that measure voltage and current (14). It is a consolidated, robust, and reliable technology. For residential consumer use, they record only the information of active energy consumed on the kilowatt-hour (kWh) scale. Induction meters are basically composed of a motor whose torque is proportional to the flow of energy passing through it, and a reference disk connected to this motor (15). Through the principle of eddy currents induced in the motor and disk, the electromagnetic interaction between the induced currents will produce a force that will cause the assembly to rotate, and a recorder that counts the number of revolutions of the motor will convert it intoits equivalent in watts per hour (16). A household electric power meter is commonly found in two configurations: pointer and cyclometric (17). The pointer meter is composed of four or five circles with numbers similar to a clock and the value of the numberrecorded from the reading depends on where the pointer is located.



Source: (18).

Figure 1. Electricity meter with pointers

As shown in Figure 1, the configuration of this model meter has four hands. To make the reading, it is necessary to identify the position of the hand on the clocks from left to right. The cyclometric electric energy meters have a numeric display that shows the accumulated consumption reading and the number is indicated on the numeric panel, as shown in Figure 2.

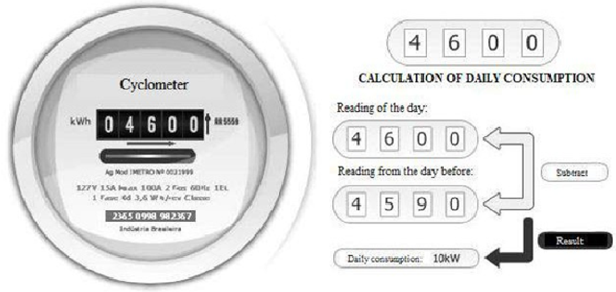


Figure 2. The cyclometric configuration

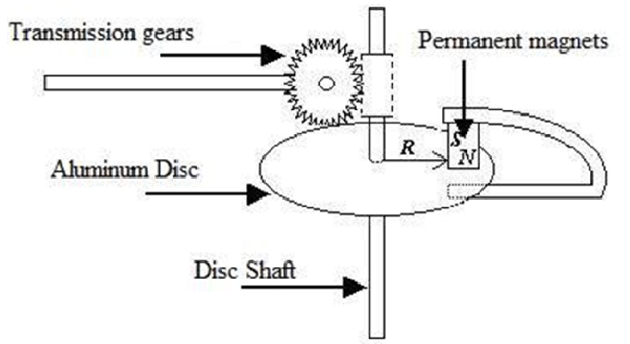
Shown in Figure 2, the cyclometric configuration has a consumption recorder similar to the vehicle odometer, in which the record is made according to consumption. According to (19), (20). The working principle of this meter model is based on the phenomenon of electromagnetic induction, which states that a conductor flowing with a current I in the presence of a magnetic field B is subjected to a force F whose direction is given by the right hand rule and has a module given by:

$$F = B \, x \, I \, x \, L \, x \, sen \quad (1)$$

Where:

L: Conductor length under magnetic field action; α: It is the angle between the vector of the magnetic field and the direction of the vector IL in space. The construction principle of the electromechanical active energy meter consists in the coupling of the magnetic fields produced by 02 coils, current and voltage, of one phase, which has as a consequence an electromagnetic torque on an aluminum disk that rotates dragging a marker (21). The torque is proportional to the power flowing in the meter. The current coil conducts the line current and the voltage coil is powered by the line voltage. Both windings are made on a metal frame in order to create 02 magnetic circuits. A light aluminum diskis suspended in the region of the magnetic field created by the current in the current coil. Eddy currents (eddy current) are induced in the disk. The reaction of these currents and the magnetic field created by the other coil generates a torque, causing the disk to rotate. The torque developed is proportional to the field strength of the potential coil and the strength of the eddy currents. Eddy currents depend on the intensity of the field that produced them. This interaction produces 02(two) electromagnetic forces, and of the same direction. The force is produced by the eddy currents created by coil 1 and the magnetic field of coil 2. The force is produced by the eddy currentscreated by coil 2 and the magnetic field of coil 1. In this way, the number of revolutions on the disk is proportional to the energy consumed by the load in a given time interval. The measurement is made in kWh. The indication ismade by mechanical gears connected to the disk shaft (22-24).

Figure 3 shows the main elements responsible for the energy measurement of the electromechanical meter.

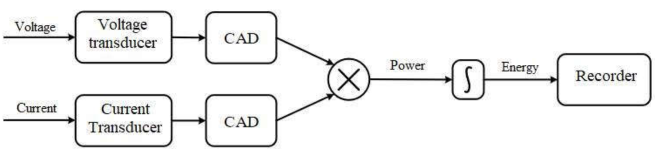


Source: (25).

Figure 3. Elements of the electromechanical meter.

As shown in Figure 3, the damping of the disk's motion is produced by two small diametrically opposed permanent magnets located on the edge of the disk. When the disc rotates, the magnets induce eddy currents in itthat react to the magnetic fields of these magnets. The result is a braking torque (26).

Electronic Meters: The electronic energy meters work with reference in the measurement made by sensors associated with transducers, which obtain current and potential values from input signals. The values obtained are multiplied, obtaining the instantaneous power, and then integrated to obtain the energy. Once the energy is integralized it is then recorded (27).



Source: Adapted from (28).

Figure 4. Principle of operation of the electronic meter.

According to the diagram in Figure 4, the transducers are of fundamental importance for the operation of theelectronic meter, the voltage and current transducers are responsible for receiving the input signals from the meter and adjusting them so that they can be multiplied. The power is obtained through the multiplier block, represented by the CAD box. The power is obtained through the integrator block, which receives the CAD, illustrated by the X, and finally this value is stored and recorded in the register block (28). Voltage transformers, also known as potential transformers (PT), are instruments designed to control and measure electrical potential. They are used in order to reduce the primary voltage of the system to acceptable levels for the measuring device, being highly accurate and usually referred to by its transformation ratio, for example, 60:1 indicating that every 60 volts in the primary has 1 volt in the secondary (29). Shunts, current transducers, are specially constructed resistors that allow voltages proportional to the currentflowing through them to be measured according to Ohm's law ($V=RI$). It is emphasized that shunt resistors provide no isolation between the primary and secondary systems (30).

To perform the reading of variables, electronic meters use samples at small time intervals through analog-to-digital (A/D) converters. The number of bits in the A/D converters and processing precision define the accuracy class of the equipment, enabling them to have higher accuracy than conventional electromechanical meters (31), (32). Differently from the electromechanical meters that measure only the active power consumption, the electronicmeters have characteristics to perform several tasks simultaneously in the same equipment. In addition to active power, electronic meters can measure reactive power, apparent power, maximum demand, power factor, voltageand current, and also use mass memory to record consumption with date and time information (33), (34).

Smart meters: Smart Grid (SG), is a system of intelligent energy supply, uses a communication platform for information exchange improving the efficiency, reliability and sustainability of electricity services. For this system to occur, it is necessary to have bilateral communication infrastructure of real-time information exchange betweenconsumers and suppliers (35). For (36), Smart Grid is defined as a set of networks and equipment of the power distribution system, in whichthe control and command is performed with the use of digital information technology, measurement, monitoring and telecommunications. Its implementation enables the provision of new services to consumers and theimprovement of existing services.

Traditional energy consumption meters, electromechanical or electronic, operate in isolation. They register the accumulated consumption of active electrical energy that is usually read manually once a month, making the information available through a rudimentary process that is costly and vulnerable to failure (37). Among the set of smart solutions for the SG system are the smart meters, Smart Meters (SM).

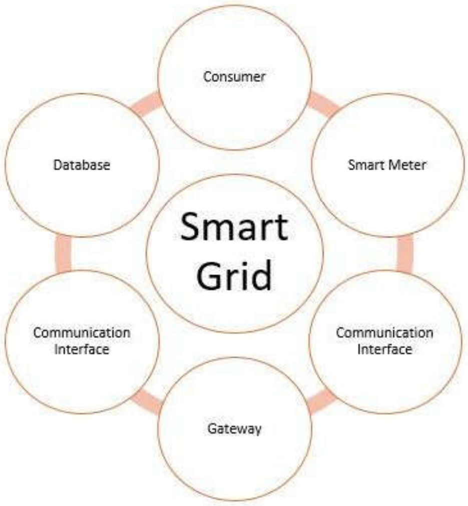
The elements that make up this meter model provide the capability to collect, process, respond, and communicate new data (38). The sharing of information with other elements of the electrical system, such as power generation units or even elements of the transmission and control system, enable, among other things, greater agility in the identification and solution of operational problems and more efficient management of the flow of energy, which starts to be directed through more reliable routes to the points that have demand to be met.

With the implementation of SG and use of SM in the power system, (39), states numerous benefits such as:

- Intelligent detection and correction of network failures in real time;
- Automatic network reconfiguration;
- Demand-side management;
- Real-time management of energy supply versus demand;
- Smart metering.

With the implementation of SG, the distribution networks and SM will play a key role with respect to monitoring the performance and characteristic of the network.

The SM can assist in detecting fraud and theft, optimizing efficiency and power quality (40). Figure 5 shows by means of the flow the exemplification of the smart metering infrastructure. According to Figure 5, the Smart Grid integrates remotely the consumer with smart meters, there is an interface for reading and communication between the utility and the meters. The integration occurs remotely, andcan be accessed directly from the power utility.



Source: Adapted from (40).

Figure 5. Smart metering infrastructure

Main tests and procedures: The manufacture of meters requires minimum conditions to be observed in the technical assessment of the model, in the initial verification, in the verification after repairs and in the verification by request of the user/owner, in electronic meters for active and/or reactive, single and polyphase electric power. The procedures for performing the tests are described in the Metrological Technical Regulation (RTM) (41).

- Annex A, refers to Model Technical Appreciation Tests on Meters;
- Annex B, refers to the Test Methodology for Initial Verification or After Repairs;
- Annex C, refers to the Test Methodology for Verification by Request of the User/Owner.

The tests described according to RTM, are followed for manufacturing and after repairs, the following testsare performed on the meters:

•**Visual inspection of approved mail**

Purpose: The inspection consists in verifying if the meter has the same constructive characteristics as the approved model.

•**General inspection of the meter:**

Purpose: its purpose is to investigate the possible existence of flaws in the various parts and assemblies that comprise the meter and that can cause physical damage to people and property, shorten the meter's useful life, orrequire increased maintenance.

•**Applied tension test:**

Purpose: To verify that the meter's insulation is satisfactory.

•**Accuracy test:**

Purpose: To verify if the meters have been properly adjusted.

•**Starting current test:**

Purpose: To verify the start of electric power logging with a certain percentage of the nominal current.

•**Control test of functions and magnitudes with temperature elevation:**

Purpose: To check that the meters are working correctly at elevated temperature.

•**Testing the peripheral outputs:**

Purpose: To verify the adequacy and functionality of all peripheral outputs.

•Test for verification of the lower limit of the supply voltage:

Purpose: To verify that the meter operates at the lower limit of the operating range.

•Testing the display:

Purpose: To verify if the measured energy indication corresponds to the energy consumed.

Electric Power: Electricity can be defined by a number of properties that distinguish it from other products (42), being:

- It is not susceptible in practice, to be stored or inventoried;
- It must be generated and transmitted as it is consumed, so there must be a balance between supply anddemand;
- Electricity systems are dynamic, complex and immense;
- Transmission is determined by Kirchhoff's laws, in which the current distribution depends on the impedancein the lines and other elements through which electricity flows.

According to (43), electrical energy is one of the forms of energy within a system. It corresponds to the product of the potential difference (Watts), by an electric current (Amperes), by the time (Seconds) in which it issupplied.

Power: For (44), power can be defined as a physical quantity with a directly proportional relationship between voltage and electric current. Equation 2 is used to calculate the instantaneous power, which is the power given at any instant of time considering V (Voltage) and I (Current) as sinusoidal signals in the steady state.

$$P = V \, x \, I \qquad (2)$$

Where:

P: Instantaneous power measured in W (Watts);
V: Voltage measured in V (Volts);
I: Electric current measured in A (Amperes).

The instantaneous power can be represented by three constant powers, being:

- Active power;
- Reactive power;
- Apparent power.

In the following sections the other powers are discussed.

Active Power: The active power also called average or real power (45), is an electrical quantity that measures the average value of the instantaneous power in a given period that represents the portion of the power present in a circuit, converted into non-electrical forms of energy. Active power is the power that performs work, generating heat or motion (46), (47), states that active power is the portion of power that performs work on the load.

To calculate the active power is followed as equation 3:

$$P = U \, x \, I \, x \cos(\theta v - \theta i) \qquad (3)$$

Where:

P: Active power given in Watts;U: Voltage given in Volts;

I: Electric current given in Amperes;
55: Voltage phase angle;
55: Phase angle of the electric current.

Reactive power: Reactive power represents the amount of electrical power due to the portion of current that is offset from thevoltage. The average value of the reactive power calculated in a period of the line frequency is zero, showing thatit does not contribute to the transfer of energy from the source to the load (47). According to (44), reactive power is an electrical quantity that is not converted into non-electrical forms of energy. This power can be stored in the magnetic field of an inductor, as occurs in motors and inductive loads, or it can also be stored in the electric field of a capacitor. In other words, reactive power can be understood as the power that does not perform work, but has the purposeof forming magnetic fields necessary for the operation of components, such as inductive motors.
Its equation is given according to equation 4.

$$Q = U \, x \, I \, x \, sen \, (\theta v - \theta i) \quad (4)$$

Where:
P: Reactive power given in kVArh;U: Voltage given in Volts;
I: Electric current given in Amperes;
θv : Voltage phase angle;
θi : Phase angle of the electric current.

Apparent power: The unit of measurement of apparent power is the Volt-Ampère (VA). This apparent power quantifies the maximum power that could be generated or consumed if the voltage and current were sinusoidal and perfectly inphase. In other words, apparent power represents the maximum active power that would be achieved with unity power factor (47).

The apparent power is the modulus of the quadratic sum of active and reactive power, given in Volt-Ampere(VA), (44), describes equation 5.

$$|S| = \sqrt{P^2 + Q^2} \quad (5)$$

Where:
S: Apparent power, given in VA;P: Active power, given in W;
Q: Reactive power, given in kVArh.

Power Factor: Power Factor (PF) measures the fraction of maximum power that could be transferred, considering the given voltage and current magnitudes (48). The fraction ceases to be maximum when the reactive power is different from zero, i.e., it can be said that reactive power reduces the utilization factor of the line (49). In addition, the reactive power, being an oscillatory energy, with zero average, theoretically does not need a primary source of energy to exist (50). Several types of electromagnetic devices have windings, such as: motors, transformers, discharge lamps, induction furnaces, among others. To function, these devices magnetize the iron cores, storing reactive energy, energy that does not produce work and decreases the power factor of the installation (51). The power factor serves to indicate the efficiency of energy use and is defined mathematically as the ratio between two quantities represented by the same unit of power, the active power and the apparent power, it is a dimensionless number (52). The power factor provides the ratio between the active power actually delivered or consumed in a circuit and the apparent power at the same point. The closer the value of the power factor is to unity, the better the utilization of the circuit. The quantities described above and how they relate to each other can be represented graphically through the power triangle shown (47). To indicate whether the current is lagging or advancing relative to the voltage, the terms lagging and advancing are used in which indicate whether the difference 55 − 55 is positive or negative and therefore whether the load is inductive or capacitive. Equation 6 as follows:

$$FP = \cos(\theta v - \theta i) \quad (6)$$

Where:
P: Active power given in Watts; U: Voltage given in Volts;
I: Electric current given in Amperes;
θv : Voltage phase angle;
θi : Phase angle of the electric current.

Watt: Watt is a unit of power, whose symbol is W, which corresponds to one joule per second. Basically, it is the measure of power for the ability to do work. It is characterized by the amount of energy converted into joules being used or simply dissipated in one second. In solar energy, the watt would be the unit of power for a system with a current of one ampere under a voltage of one volt, as the product of voltage and intensity.

Kilowatt: Kilowatts or kilowatts (kW) are units of power that equal 10^3 watts, i.e. 7 kilowatts (7 kW) equals 7000 watts (7000 W). In addition, kW represents the size of a solar energy system. This means that the larger the kW measurement of a system, the greater its ability to produce energy on sunny days.

Kilowatt hour: In the case of kilowatt hours, or kWh, we are talking about the energy produced or consumed. This unit indicates the amount of energy that can be generated by a solar power system within a given hour. So if your panels produce 1 kW in a 60-minute period, 1,000 W of energy will be produced every hour.

Difference between kW and kWh: Let's first explain what each letter stands for:

k stands for kilo. k means thousand. W stands for Watt. Which is a measure of power. h means hour. Which is obviously a measure of time So kW stands for Kilowatt which is 1000 Watts. We are talking about a measure of power. Note that the correct way to write it is always with a lowercase k and an uppercase W. The size of a solar system is defined by its power. For example, a 1kW system can produce 1 kW of power on really sunny days. kWh stands for Kilowatt- hour. A kWh is a measure of energy (not power).

Converting kW into kWh: The formula for converting kW to kWh is: Consumption (kWh) = Power (kW) x time (h), a power of 10 kW (or 10,000 W) generated during 6 hours is equivalent to 60 kWh, so you have to multiply the power generated by the number of hours used.

Resistor Shunt: The shunt is a very low value resistor. It depends on the project, but usually around 0.01 Ohms. This is because it is connected in series with the load, and by means of the voltage drop over this resistor we can determine the current that circulates there and know when there is variation as shown in Figure 6.

Figure 6. Commercial shunt resistor.

Energy measurement units: A Hall Effect sensor is a transducer that, when under the application of a magnetic field, responds with a variation in its output voltage. A semiconductor under the application of a magnetic field, demonstrating the Hall Effect. If a potential difference is applied to a semiconductor material so that a current flows, and at the same time the semiconductor material is subjected to a magnetic field, as it moves through the material the charges will tend to deviate from their normal path, accumulate on one side, and a voltage will be detected, Figure 7.

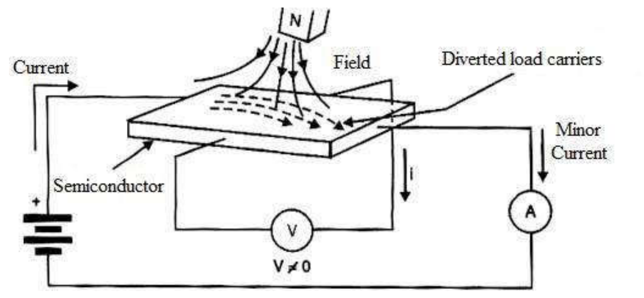


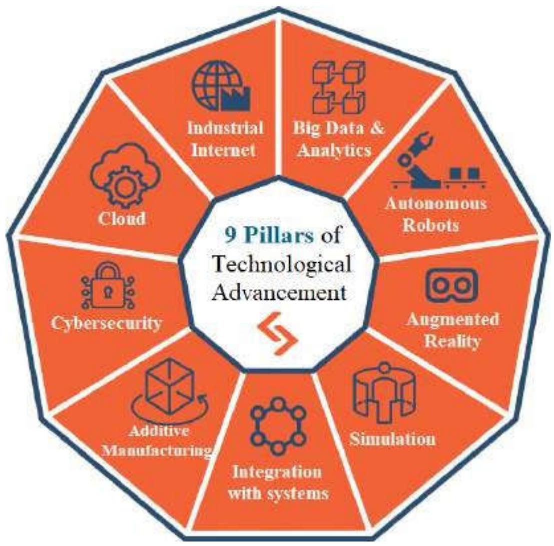
Figure 7. Hall Effect

Industry 4.0: In the context of technological development provided mainly by the integration of emerging technologies such as Smart (Electrical) Networks, Internet of Things, Mobile Internet, Big Data, Cloud Computing, Embedded Systems and other pillars, the industrial sector has entered the fourth revolution, called Industry 4.0 (53), (54). Companies immersed in the concept of Industry 4.0 make use of investments in research, technological development seeking modernization, which are essential to maintain the competitiveness of companies (55). It is relevant to highlight that the concept of Industry 4.0 can exist regardless of whether or not the industrial sector is inserted in a Smart Electric Network (IER), although their coexistence enhances the benefits and advantages for both.

According to (56) in the recommendations for the implementation of the strategic initiative 4.0, there are some key points for the success of the project, which are:

- Standardization and reference architecture;
- Communication infrastructure for the industrial sector;
- Information security;
- Work reorganization;
- Regulation;
- Efficient use of resources.

The pillars that make up Industry 4.0 are technologies, objects, and concepts. They are very well integratedwith each other, but are interdependent.



Source: (57).

Figure 8. Industry 4.0 pillars

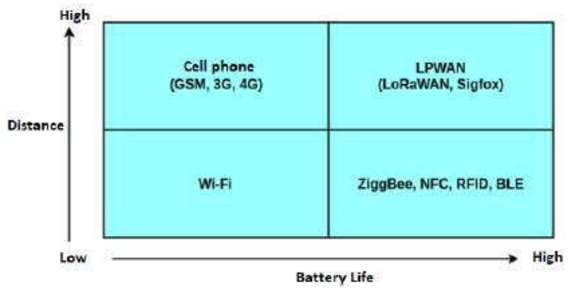
As shown in Figure 8, nine pillars are part of Industry 4.0, being Big Data and Analytics, Autonomous Robots, Augmented Reality, Simulation, Systems Integration, Additive Manufacturing, Cybersecurity, Cloud, and Industrial Internet. For this work and project application, IoT and Big Data (BD) concepts will be addressed, described in the next section.

Internet of things: The Institute for Industrial Development Studies (58), defines IoT as the digital medium through which virtual versions of intelligent systems communicate, highlighting the growing number of objects connected to the Internet (Smart Objects). The concept is related to the predisposition to connect components that can perform activities such as information collection, monitoring and data exchange, through communication networks, wired or wireless, and without the permanent need for human presence (59), (53). The Internet of Energy (IoE) is an example of derivatives of the IoT concept, in which it transforms Distributed Energy Resources (DER) into Internet things to enable the management and control of electrical energy (60). Another example of IoT derivative is the Industrial Internet of Things (IIoT), which transforms industrial elements into Internet things to enable management and control of industry (61). Among the new technologies, the development and derivations of IoT along with the expansion of the use of EHRs emerge the concept of the Smart Electric Network (IER). This concept shaped itself with the need to make the operation of the electric grid more interactive, interconnected, reliable, secure, stable and flexible (62). In general, the characterization of smart power grid, is defined as the ability to integrate the actions of all agents connected to the grid, whether power generators or consumers. In view of this, REIs along with Industry 4.0 are growing worldwide.

Big data: Currently, in the business world having information at the right time can determine the success or failure of a business. Given this scenario, organizations seek information to ensure the survival and success of their operations and to achieve them the investment is being made in Big Data (BD). According to (63), Big Data refers to a large volume of structured or unstructured data that used in a precise manner can contribute knowledge that can assist in decision making and strategic planning for companies. Big data is commonly discussed in the context of completely new products and services as well as innovative business application systems (64). In general, it can be said that Big Data is essentially anything that is digitally collected or recorded by modern Information and Communication Technology (ICT), such as IoT, sensor networks, smart objects and devices, the internet, and social media (65). With use of DB, companies can process a stream of data in real time, and enable decision making with more agility, keep up with recent trends, repair misunderstandings quickly, and invest in new business (66). Given the characteristics of Industry 4.0 with the IoT and BD pillars the energy sector seeks to innovate the network, either in modern and smart meters or in the form of generation and distribution.

Lora network: According to (67), LoRa is a type of modulation for data transmission that is part of the physical layer of wireless communication technology. (68), this network was developed to be used for low data throughput, low power consumption, and long distance communications. For (69), LoRa (Long-Range) is a proprietary radio frequency technology that enables communication over long distances with low power consumption. The radio frequency waves in which the LoRa network is found are between the ranges of 10^2 and 106 Hz, commonly addressed by cycles per second. This technology uses modulation techniques for error correction, called Chirp Spread Spectrum (CSS), making it more robust to interference and noise, causing the receiver to receive the message with a low signal to noise ratio (70). For SM meters, in addition to the digital reading of energy consumption, it is possible to collect the information from each consumer remotely and send it to a central operation station. Thus, the set of these smart meters with digital communication make up an Advanced Metering Infrastructure (AMI) (71). The technologies with long battery life and long transmission range are those that present the best opportunities for the development of IoT applications, as per Figure 9. As per figure 2.9, it can be seen that LoRa networks are promising for long distance applications with high battery life.

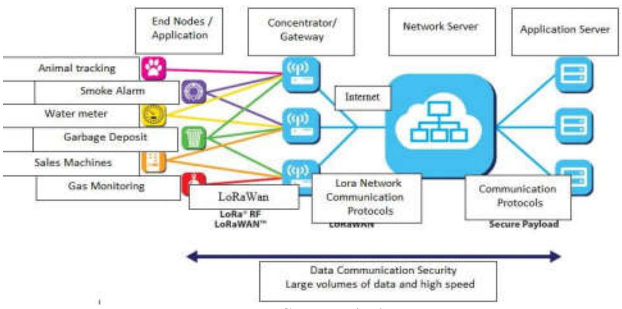
The Lora network architecture: LoRaWAN is an open specification of a wide area network protocol (Figure 10) that uses LoRa technology and provides two-way communication between devices, support for end-to-end encryption, mobility, and location services (72).



Source: (72).

Figure 9. Distance versus Battery Life

Thus, LoRa would be the physical layer for information transmission and LoRaWAN, the networking protocol to provide interoperability between devices. LoRa modulation allows a receiver sensitivity of up to -150dBm, making it possible to communicate over distances of up to 5 kilometers in urban environments and up to 10 kilometers in rural environments, allowing a variable data rate according to range, robustness and power consumption criteria (73). LoRaWAN is a network with its own signal modulation and open protocol sponsored by the LoRa Alliance for the purpose of implementing LoRa network operation. The LoRa network needs communication protocols with rules for how data will be handled to achieve a quality network. Joining the LoRa modulation and the technical specifications of LoRaWAN, a range of 2 to 5 km in urban areas and 15km in unsheltered areas was obtained and, because of the low power, a battery life of up to 10 years (74).



Source: (75).

Figure 10. LoRaWAN Architecture

As per Figure 2.10, the system consists of three main components, being:

- **End nodes:** These are sensors connected via LoRa radio interfaces to one or more Lora gateways.
- **Concentrator/Gateway:** They make the connection between end devices and the Network Server.
- **Network Serve:** The server that controls all stages of the network, such as security, integration, resource management.

In a LoRaWAN™ network, nodes are not associated with a specific gateway. Instead, the data transmitted by a node is usually received by multiple gateways. Each gateway forwards the packet received from the end node to the cloud-based network server via some backhaul (cellular, Ethernet, satellite, or Wi-Fi) (76). Intelligence andcomplexity is transferred to the network server, which manages the network and filters redundant received packets, performs security checks, schedules acknowledgements through the optimal gateway and performs adaptive datarate etc. If a node is mobile or on the move, there will not necessarily be gateway-to-gateway transfer, which is a critical feature for enabling asset tracking applications-a primary vertical target application for IoT (77).

Key Benefits for the Internet of Things: Basically, LoRa technology has revolutionized the IoT by allowing devices to accommodate a wide range of applications. Thus, it transmits multiple packets with important information. There are several important differentiators that should be mentioned for you to understand in practice this importance in the market such as:

•Low cost of implementation and operation:

It reduces infrastructure investment, battery replacement expenses, and ultimately operating expenses.

•Low power consumption:

It needs little power. Thus, the battery life is extended up to 10 years, which reduces your purchase costs.

•Long Range:

It connects devices over long distances in rural areas and infiltrates dense indoor or urban environments.

•Mobility:

It maintains communication with devices on the move without overloading power consumption.

•Standardized:

The emitted signals are robust, do not propagate noise, and do not suffer interference in their frequency range. So IoT applications can be deployed quickly anywhere.

MATERIALS AND METHODS

Materials: The technology of the work is the implementation of the LoRa network in a new model of electronic meter and the digital display, which in the current ones do not have both technologies. LoRa is a technology for sendingdata wirelessly (via radio frequency) to enable long-distance transmission and has low power consumption. It is one of the growing tools for IoT solutions. And the digital display refers to the accuracy of reading consumption information. The technology is based on a star topology network, similar to a cell phone. Its modules send and receive data from specific gateways - similar to WiFi networks, but with a wider range -, which forward them through an Internet Protocol (IP) connection to remote or local servers. Tools and software were used for the development of this work, which can be seen in the table below.

ACS712 Current Sensor Module: The ACS712 module is an invasive current sensor, where it is necessary to break the circuit for it to be installed. The 50A ACS712 module can read current values up to 50 Amperes, figure 11.

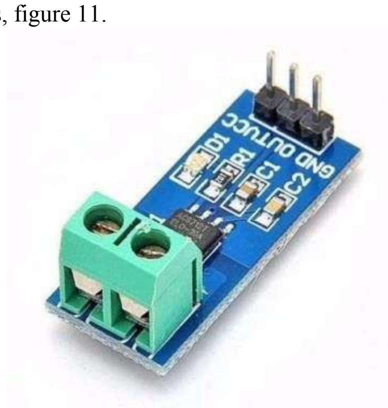


Figure 11. ACS712 current module.

The ACS712 uses the Hall effect to interface the real circuit current with the Arduino, in which, according to Thomazini in the book Industrial Sensors:

"The Hall effect is basically characterized by the appearance of a

Table 1. Tools used in the work.

Tool	Concept	Project Application
SolidWorks	Software designed to create three-dimensional virtual mechanical prototypes. It is also possible to simulate the operation of parts, assemblies.	In the project, software was used to model all mechanical parts and devices. From three- dimensional prototypes, 2D drawings were generated and forwarded to the machining/manufacturing process.
ProteusVSM	Software that allows the creation of electrical and electronic circuits to simulate and elaborate layouts for analog and digital applications, including microcontrollers.	It has been applied to the development ofelectronic boards and connections.

Table 2. Technologies used in the work

Technologies	Concept	Project Application
C Language	It is a general-purpose, structured, imperative, procedural, compiled programming language.	In this project, it was used for the development of the firmware and system module.
Technologies	Concept	Project Application
Internet of things	It refers to the integration of physical and virtual objects in networks connected to the Internet, allowing the objects to collect, exchange, and store data that have been processed and analyzed, generating large- scale information and services.	The implementation of the Internet of Things in this project was for real-time data collection, sensor status data, productivity, alerts, errors. Situations that occur in the equipment were informed to the operator through a monitor.
Big Data	It is the area of knowledge that studies how to handle, analyze, and obtain information from data sets that are too large to be analyzed by traditional systems.	In this project, it was used to measure, collect, and report real-time energy consumption data to the user.
LoRa	Low-power wide area network (LPWAN) technology. It is based on spread spectrum modulation techniques derived from chirp spread spectrum (CSS) technology.	Applied as the main technology to read consumption data in the prototype electricity meter.

transverse electric field in a conductor traversed by an electric current, when it is immersed in a magnetic field." Hall effect sensors consist of semiconductor devices that are influenced by a magnetic field. When we put this semiconductor device in series with the source and the load, electrons pass through it. When electric current flows through a semiconductor material. When we add a magnetic field perpendicularto the motion of the electrons, a magnetic force, called the Lorentz force, is created. Under the influence of this force, the free electrons will no longer move in a rectilinear fashion, but will concentrate in the direction of the magnetic force.

Experimental methodology: The present study can be considered of exploratory form for providing more knowledge about the theme, of applied nature establishing the practice of specific problems of the organization in the intention of solving them and qualitative seeking to understand its concepts, under two aspects, bibliographic research with the purpose ofidentifying the authors' approaches through books, theses, articles, electronic sites and, case study, with the purpose of analyzing the development of a prototype of electric energy meter using LoRa network in Wasion company. The development was carried out in a company from the Industrial Pole of Manaus, located in the IndustrialDistrict II. The steps were performed according to the flowchart below, Figure 12.

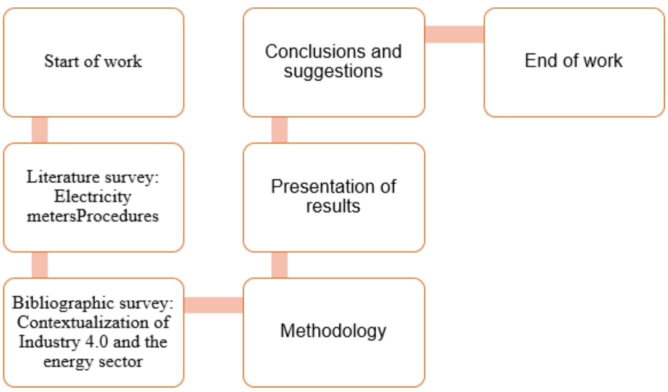


Figure 12. Flowchart of the project development.

Experimental development

The development of the prototype of the new meter was divided into three stages, being:

- Development of pneumatic and mechanical hardware;
- Electrical and electronic hardware development;
- Software development.

The three development subsets mentioned above were relevant for obtaining the prototype of the new meter. The following will describe how each step was accomplished. For the development of this work, the following components are required:

- 1 Arduino Nano ATmega328p board;
- 1 Shunt resistor of 100A;
- 1 ACS712 50A current sensor module;
- LCD 12864;
- DHT module (Temperature and Humidity Sensor);
- 1 Lora transmitter module;
- Jumpers and wires for electrical connection;
- 1 Lora receiver module;
- 1 ESP8266 Web interface module.

Figure 13 and 14 show the link architecture of the items mentioned. The function of each item and its purposein the project has been described.

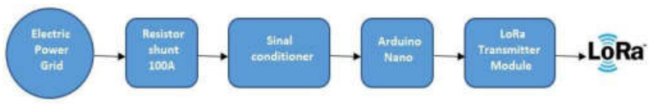


Figure 13. Proposed transmitter architecture: energy meter

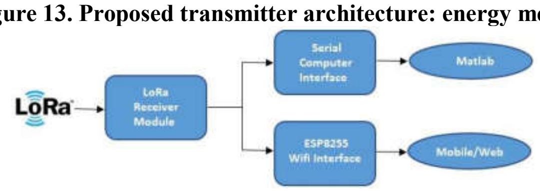


Figure 14. Proposed architecture of the energy meter receiver module

The LoRa network allows communication over long distances with minimal power consumption. For example, its range is 3 to 4 km in urban areas, but this depends on the installation conditions, such as blockage bybuildings or the topology of the terrain. In rural areas the same range is up to 20 km or more. LoRa technology is a solution for data transmission, especially in hard-to-reach places. For this operation, anexample of application would be in the IoT system, such as sensors. Initially, the Brainstorming tool was used to describe the need for the acquisition of machinery, equipment, tools, consumables, and services. Using Brainstorming the work was divided into pneumatic, mechanical, electrical, electronic and software. Figure 15 shows the Brainstorming.

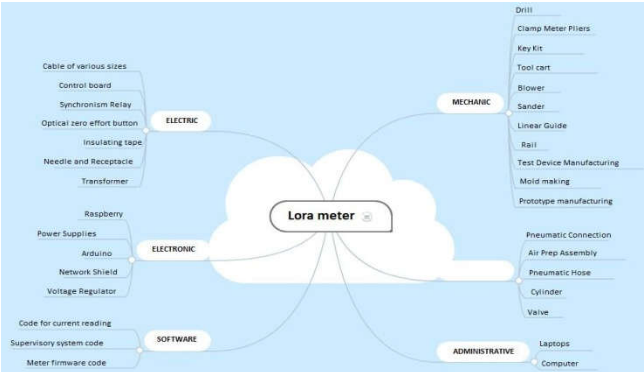


Figure 15. Brainstorming the project development

Mechanical and pneumatic hardware development: The pneumatic and mechanical hardware development contemplated the mechanical modeling of the prototype, SolidWorks 2018 software was used for this modeling. All the components of the new product were modeled:

- Meter base; Base cover; Meter terminal block; Terminal block cover; Screw; Neutral circuit; Shunt circuit and Display.

Each modeling was necessary to evaluate mechanical aspects, functionality, and the assembly of thecomponents. The new meter was developed with a view to avoiding danger when in use, so as to ensure especially personal safety against electric shocks and the effects of excessive temperatures, protection against the spread of fire, and protection against the penetration of solid objects, dust, and water. The parts that contain steel-type material in their manufacture have received a protective coating to prevent corrosion, the outer parts have been made of plastic and have received protection to prevent significant degradation when exposed to solar radiation. Besides the general manufacturing aspect, it was followed according to INMETRO's recommendations the manufacturing of the meter's base had a rigid construction, i.e., no screws, rivets, or fixation devices were inserted in the internal parts of the meter that could be removed without violating the meter's cover seals. In the base, a non-passing hole was designed to support the meter, as can be seen in Figure 16. As shown in Figure 16, the base was designed to be manufactured in black plastic material. It has the characteristic of being anti-flame, to not propagate possible fires in the product, its mechanical characteristics involve towers for fixing the terminal block, grooves and extrusion of materials to fit the cover of the base, and ahole for fixing the seal. The base is 111.20mm long, 103.80mm wide, and 47.70mm high. The device was designed to optimize physical space to minimize plastic injection costs and associated with electronic development.

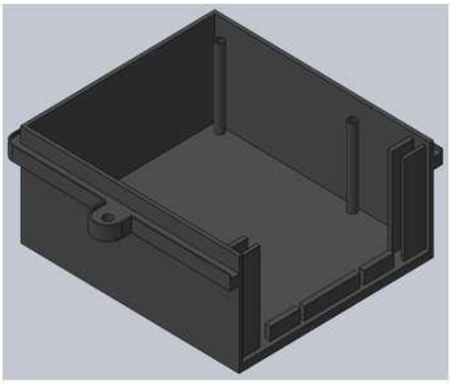


Figure 16. Perspective view of the meter base

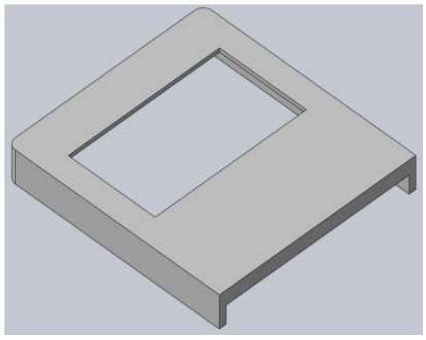


Figure 17. Perspective view of the meter cover

Once the modeling of the base was completed, the modeling of the base cover began. The meter's base cover, Figure 17, was designed with non-transparent material, and following the INMETRO standard, a display was placed for reading the display and observing the operation indicator. The display was designed in a way that it will not be possible to remove it without damaging the base cover. When modeling the item, it was designed that the display would be mounted on the cover and then the covercould be snapped onto the base. The meter's terminal block, Figure 18, was designed with an insulating material that will not deform after the meter has been subjected to the maximum current heating test. It was attached to thebase of the meter and when soldered can only be removed by breaking the seals of the cover.

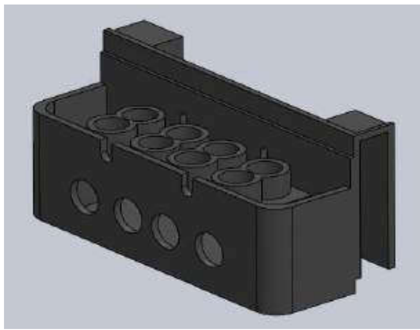


Figure 18. Terminal block perspective view

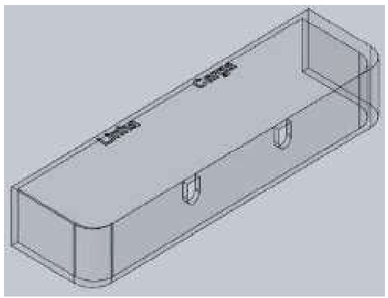


Figure 19. Perspective view of the terminal block cover

According to Figure 18, the block has eight holes for the positioning of the screws, has four entrances for cable connection and physical space to accommodate the shunt and neutral circuits. The cover of the terminal block, Figure 19, was designed to be manufactured in plastic and has the LINE and LOAD markings, indicating to the installer the position of the cables. The cover has the purpose of avoiding the access of the end customer to the screws to make energy deviations, and to preserve the mechanical integrity of the screws. The prototype also included the screws, because it is a single-phase meter, eight screws were used per meter and applied to the shunt and neutral circuits, which were fixed to the terminal block. The circuits make a jumper so that there can be the connection of cables coming fromthe electrical network (Line) and distributed to the customer's switchboard (Load).

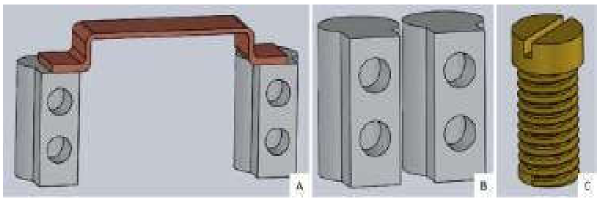


Figure 20 A, B, C - Shunt, neutral, and paraffin circuit

Figure 20A shows the 3D design of the shunt circuit, it has two terminals with 4 holes for placing the screwsand a plate in manganin material to connect the two terminals. In Figure 20B is illustrated the neutral circuit, designed to be manufactured in 1020 steel also has 4 holes for the screws and Figure 20C shows the representation of the M6x16 screw. All parts were designed to receive surface treatment. The surface treatment is a procedure that considerably improves the characteristics and properties of a part and offers an excellent cost-benefit that cannot be obtained by other procedures. The bolt received the bichromated zinc, which is a post-process passivation procedure of alkaline zinc or zinc bath with a layer determined by the Standard or customer specification. The treatment offers high resistance to white corrosion and red corrosion. These heat treatments contain IV chrome and are used with specific characteristics on a given metal surface.

This bichromated zinc protection exists in two different shades,white zinc (white zincating) and yellow zinc (bichromated zinc). For this screw, the bichromated zinc was chosen,and for the shunt and neutral circuits the white zincating was used. There are several ways to zinc parts, but the application was designed in an electrolytic way, one of the most efficient and economical metals to protect iron and steel against corrosion.

Through the various zinc baths the iron or steel is coated with a protective zinc layer, which acts as an insulating barrier for the base metal, protecting it against corrosion (cathodic protection). The process consists in the deposition of zinc through the passage of electric current, transformed from alternating to continuous by means of rectifiers, dividing the current into positive (cathode) and negative (anode) as shown in Figure 21.

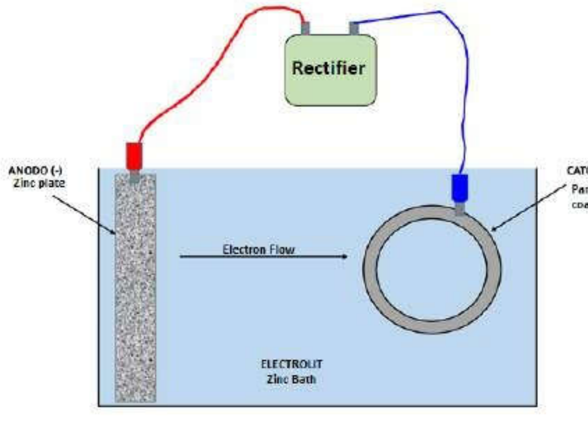


Figure 21 - Electrolytic Zinc Plating

The zinc is placed next to the anode and through the bath (electrolyte) will be conducted to the cathode, where the material to be coated (iron/steel) is, being deposited on its surface. The immersion time will vary depending on the type of bath, the geometry of the material, and the desired layer thickness. To define the thickness of the zinc layer applied and the type of finish, three main factors should be taken into consideration: Material exposure environment; Functionality; Durability. After finishing the modeling of the entire mechanical assembly, the product was assembled into a single piece, as shown in Figure 22.

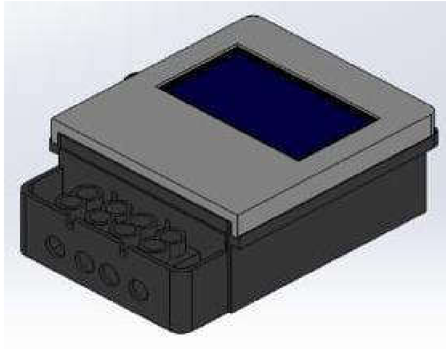


Figure 22. Mechanical assembly of the meter

With the modeling completed, the 2D technical drawings were created, and in these drawings all the specifications of the items to be manufactured were included. The mechanical technical drawing is the basis of any mechanical project. It is the highly detailed graphic representation of parts, parts and assemblies of productsand devices in general, aiming to represent all the shapes, dimensions, positions, materials and the manufacturing process for a good understanding of the part regarding its details, proportions and operation. Technical drawings, Figure 23, are extremely important for the documentation, disclosure, standardization, and the manufacturing process of parts, machines, and mechanisms, because they help maximize the efficiency of the processes, facilitating the operator's understanding and avoiding waste of material and time, as well as reducing irregularitiesin the generated product.

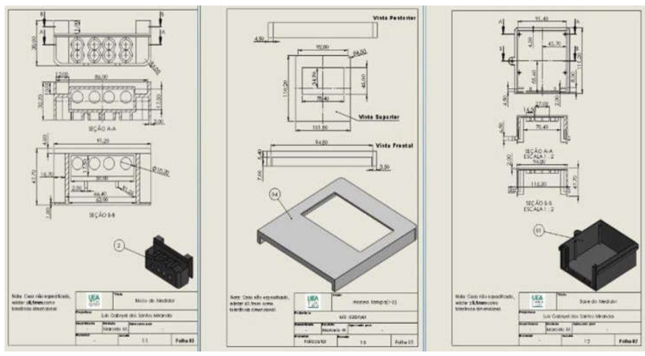


Figure 23. 2D drawings

The 2D drawings helped the manufacturing of the product items, and after this activity, the meter was assembled. Figure 23 shows the final assembly of the prototype, the product in this phase was ready to be validated the mechanical assembly and also evaluate possible violations, internal access, among others. It was observed that the construction of the new meter, Figure 24, remained within the parameters specified by INMETRO, not exceeding the external measures. The terminal block accommodates the shunt and neutral circuits, it is through these that the connection to theelectrical network will be made.

With the use of shunt current, it is possible to perform active and reactive powermeasurement. The development of this product aims at the remote measurement of energy consumption for low voltage residential and commercial customers. The bidirectional register presents the consumer with the consumption obtained from the network and the surplus exported to the distributor. The neutral circuit is a circuit or system element that permanently presents zero electric current and electric potential difference, regardless of its shape or nature. And even with these characteristics, it can be used as an active conductor. Still dealing with the shunt and neutral circuits, it was important for the application in the prototype the understanding of active andreactive power.

Figure 24. Mounting the new meter

The active energy refers to tangible energy, which generates the operation of electrical and electronic equipment. It is the energy that is effectively consumed and paid for by the utility customers. Reactive power does not produce direct work, but is important for creating magnetic flux in coils, transformers, generators, and related equipment. There are 2 subtypes of reactive energy, which are inductive reactive and capacitive reactive. The first, the inductive, is consumed by the customer, as was written, through the generation of magneticfield to run certain equipment. The second type is returned to the external power grid. Both inductive and capacitive reactive energy are harmful to the customer and to the national electrical system. In electrical installations, they generate overheating, voltage drops, increased consumption of active energy, and can generateunnecessary fines for the excessive use of reactive energy. The Reactive, when returning to the network, it "takesspace" in the electrical cables and ends up disturbing the national electrical system, because according to some studies, 85% of the large companies are not adequate to use and control this energy. The shunt circuit was manufactured in 1020 steel with a manganin bridge, an alloy composed of copper, manganese, and nickel. It has the characteristic of not being influenced by electromagnetic fields due to its resistive characteristics. Figure 25 below shows the shunt circuit.

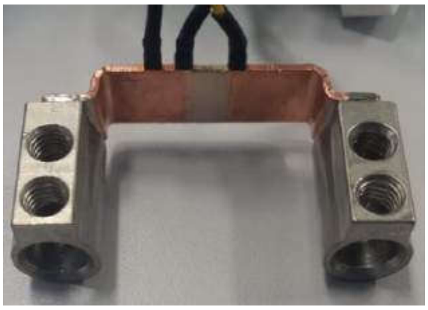


Figure 25. Shunt Circuit

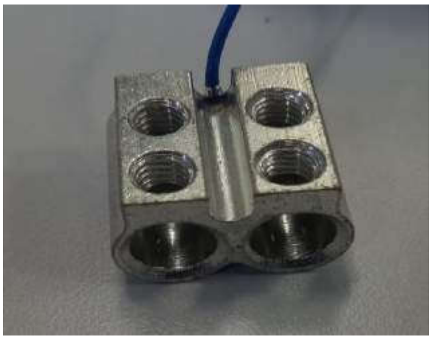


Figure 26. Neutral Circuit

The circuit has two pieces, called terminals, each piece has two holes for fixing M6 screws. According to Figure 25, the terminal on the left side receives the Line cable, coming from the electric network, according to INMETRO's regulation, this type of meter can receive cables of up to 35mm, the screws are for fixing and tightening the cable. On the right side, of this same circuit, the load cable is connected, which will be fixed fromthe meter to the client's circuit breaker box. The joining of the terminals was done by a manganin piece, by soldering the end. The neutral circuit, Figure 26, was also manufactured with 1020 steel, with four holes for fixingthe screws and two entries for fixing the cables. One solid piece was used and machined. It follows the same connection principle of the shunt circuit, holes on the left side receives the Line cable from the utility and on the right side the Load cable will be connected to the customer's circuit breaker box.

Figure 27. Terminal block assembly

Figure 28. Meter base

In Figure 27, the assembled terminal block is shown. During the manufacturing process of this new product, a sub-assembly can be performed, with the fitting of the shunt and neutral circuits and tightening of eight screws. Another component manufactured was the meter's base, Figure 28, manufactured in black plastic, the base serves to accommodate the electronic board and the display with digital display, as well as the terminal block fitting. The meter's base has parts that serve for the correct positioning of the terminal block and base cover, besides small towers for fixing the electronic board and positioning the display. It has an anti-flame characteristic, meeting INMETRO specifications. The new product's cover was manufactured in white polyacetal, Figure 29, according to 2D drawings, it was foreseen the accommodation of a graphic LCD 128x64 blue backlight type display, according to the Figure below.

Figure 29. Base cover with display

The cover of the base has space around the display for silk-screen printing according to INMETRO standards,where it will be possible to record the data via a laser engraver, equipment commonly used by companies that manufacture electronic energy meters.

Electrical and Electronic Hardware Development: The electronic development counted initially with the development of the interface, this step had the objectiveof presenting data to the user of the product, such as current, voltage, and consumption.

- **LoRa Interface**: The interface served to facilitate the relationship between two systems or between the user and the system to be used. In the case of the LoRa system, to facilitate the communication process between machine and user, the interface was developed so that the data reading was transmitted with more clarity and objectivity, facilitating the data monitoring inspection.
- **Electronic Circuit**: The development of this interface required the use of a 128x64 graphic LCD and a 30A current sensor (ACS712). The sensor captures the measurement data and transfers it to the LCD, informing the parameters measured in the equipment. The purpose of the LCD, on the other hand, is to inform the user of the data captured by the current sensor, in order to facilitate data inspection.

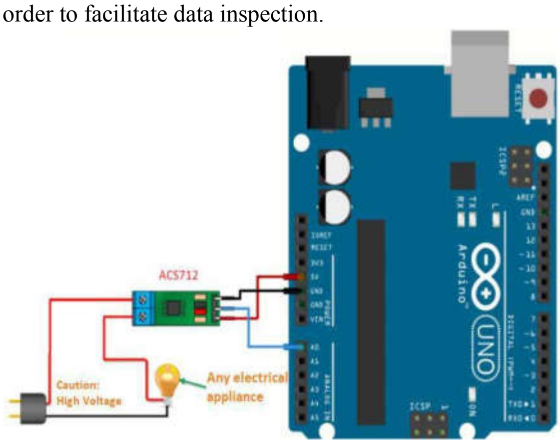


Figure 30. Electronic connection of the current sensor (ACS712).

The connection shown in Figure 30 is the electronic connection for the ACS712 current sensor:

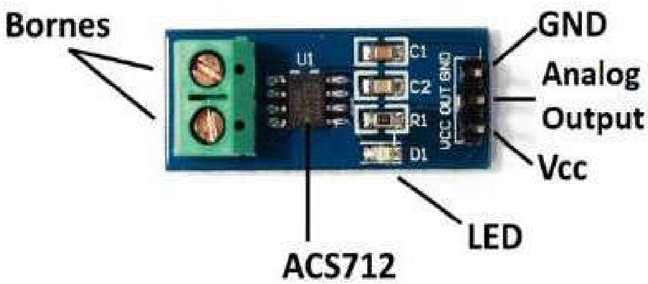


Figure 31. Datasheet of the ACS712 current sensor

The table below shows the current sensor pinouts to be connected to the ARROW pinouts shown in Table 3:

Table 3. Sensor and Arduino pinouts

ACS712	ARDUINO
GND	GND
ANALOG OUTPUT	A3
VCC	5V

The terminal pins were connected to the object that needs to be measured, in the case of the LoRa, the terminalpins were connected to the power input of the electronic meter. Then the electronic connection for the communication with the 168x64 graphic LCD, were made as follows, Figure 32.

Table 4 shows the 128x64 graphic LCD pinouts that were connected to the Arduino's pinouts:

Table 4. Display and Arduino pinouts

LCD 128x64	ARDUINO
VCC	5V
GND	GND
PSB	GND
BLA	5V
BLK	GND
RST	D9
ENABLE	D8
R/W	D7
R/S	D6

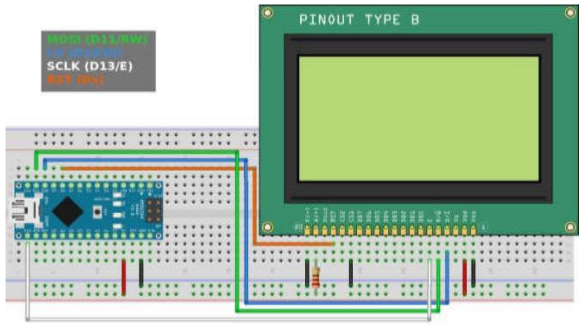


Figure 32. Electronic circuit for 128x64 LCD connection

Software Development

• **Source Code:** In the process of creating the interface, communication with the machine was of utmost importance, for it is through this communication that one can inform what is expected of the machine, what needs to be tested or not, and what needs to be transmitted to the user. The challenge was to parameterize these issues in a simple, clear, objective, and intuitive way for the operator, because the less complex the information is transmitted, the more productive is the data inspection process. The source code establishes the measurement orders, that is, it parameterizes how each variable should act at certain points, for example, the measurement of the power is the multiplication of the voltage with the current, that is, P = V x I. As with the other sensor measurement orders, thecalculations for each variable were made according to NBR 5410, which deals with "Low Voltage Electrical Installations". The graphic parameters were developed so that the interface could be interactive with the user, thus, the data transmission and communication with him becomes simple, clear, and objective. With this development,it was possible to create the version of the interface with the parameters for measuring current, voltage, power, and consumption in real time. The first version of the interface was as shown in Figure 33 below.

Figure 33. LoRa system interface for measurement control

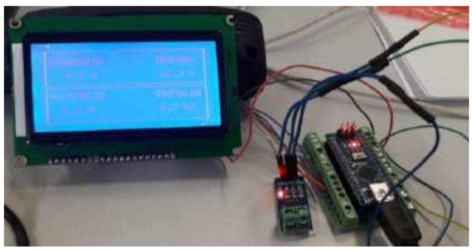


Figure 34. Electronic circuit with the aid of the ACS712 current sensor

Four parameters were used in this development phase, being: Current; Voltage; Power; Energy. For the development of the electronic circuit, the ACS712 current module, Arduino Nano, LoRa Esp32 and display to inform the user of the collected data were used.

Project Assembly Analysis: Because it is an invasive current sensor, it is necessary to interrupt the circuit so that the ACS712 can be connected to the circuit, as shown below. After this, the power (5V and GND) of the ACS712 is connected to theArduino, and the OUT pin is connected to the analog pin A0, according to the diagram in figures 35 and 37. TheShunt Resistor is connected in series with the lamp for connection to the current sensor.

Arduino Nano ATmega 328P: The Arduino ATMega328P Nano Board can be programmed with Arduino software. The ATmega168 on the Nano Board comes with a pre-recorded bootloader and makes it possible to send new code without using an external hardware programmer.

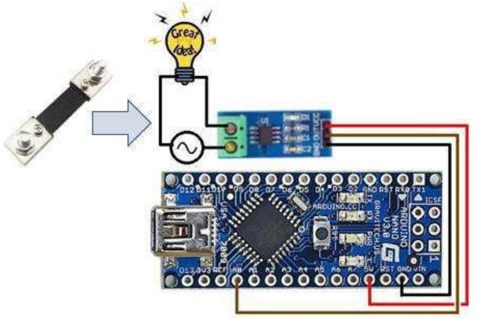


Figure 35. Connecting the Arduino nano with the current sensor

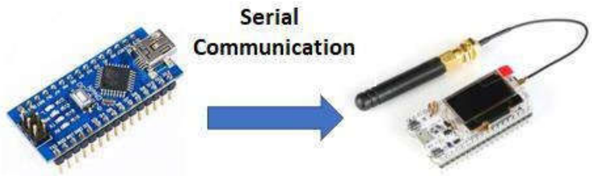


Figure 36. Arduino Nano connection to the Arduino LoRa

It communicates using the original STK500 protocol, you can also bypass the bootloader and program the microcontroller. Figure 37 shows the diagram of the Arduino Nano.

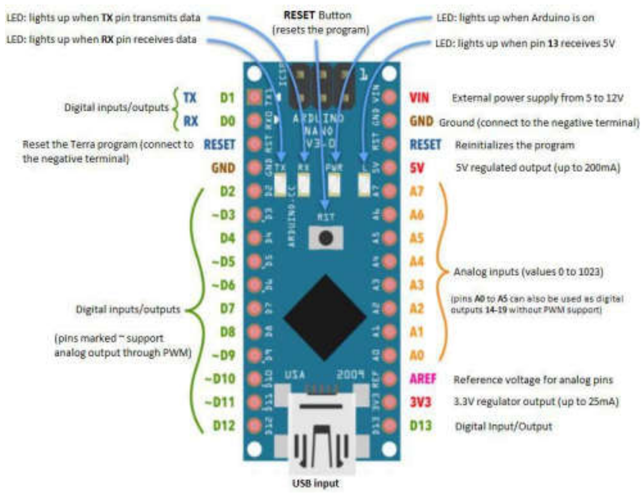


Figure 37. Arduino Nano diagram

According to Figure 37, the diagram was used as a reference for the electronic connections, through which it was possible to obtain the meter's electronic circuit.

LoRa ESP32: The ESP32 LoRa 868/915Mhz module with 0.96″ OLED is a compact and extremely connected board, as it features: Bluetooth, WiFi and Lora. In addition to connectivity, this module also ships with a 0.96 Oled display, an SMA antenna, and a battery connection. The ESP32 module is a high performance module that connects to WiFi 802.11 b/g/n networks, featuring as a module with low power consumption ideal for IoT applications. In addition, the module also enables Bluetooth connection. To top it off, you can program the ESP32 using LUA orthe Arduino IDE using a micro-usb cable. Offering communication over 20km (Figure 38).

Serial communication: Serial communication is widely used and has great importance in automation, because most equipment still use this technology for communication either through the RS-232 standard, as many others that transmit their data serially such as RS-485, Ethernet, USB, among several others. Certainly the most common use is for serial communication with microcontrollers. The communication is done through the transmission of information bit bybit sequentially, usually ASCII characters, through a single path (wire), in the vast majority of standards there aretransmission and reception paths called RX and TX.

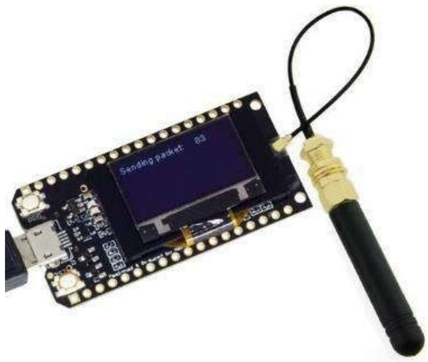


Figure 38. ESP32 LoRa

The most used standard for serial transmission is RS232, which uses differential voltages typically +12V, -12V, but others can be admitted, such as +-5 and +-15. In serialcommunication, the transmission can be synchronous or asynchronous.

Serial communication speed: The serial transmission speed is expressed as "bps" (bits-per-second) or "baud" (baud rate) this represents how many bits can be transmitted per second.

- 9600 bps or 9,6 kbps
- 19200 bps or 19,2 kbps
- 115200 bps or 115,2 kbps

Both devices that are to communicate must be configured exactly the same, with the same speed, parity andstop bit configuration, therwise communication will not be possible.

Three communication systems can be employed:

- **Simplex:** Onde apenas um terminal transmite e o outro recebe.
- **Half Duplex:** Também apenas um terminal transmite de cada vez, mas ambos podem fazê-lo.
- **Full Duplex:** É possível transmitir e receber ao mesmo tempo.

Interface between LCD12864 and Arduino nano: The LCD communicates with the Arduino through the ISP protocol. This 6-pin set follows a fixed pattern, usually called the ISP 6-pin header, and is usually indicated with the acronym ICSP on Arduino boards. ISP and ICSP are two acronyms that refer to the same general concept: the ability to transfer programs to a component while it is installed in a system (ICSP refers specifically to doing so via serial protocols). In the case of Arduinos,ICSP refers to the ability to directly program the microcontrollers on the board using the SPI serial protocol, which is why - besides the voltage and control pins (VCC, GND and RESET) - it also has the 3 pins required for a point- to-point connection using SPI: MOSI, MISO and SCK, which are, respectively, the pins through which the mastersends data to the peripheral, the master receives data from the peripheral and the master controls the pulse/clock of the connection. The pin configuration adopts the unified pattern as shown in Figure 3.29 below, where pin 1 isusually indicated by a stamped dot on the board:

Figure 39. Arduino's SPI bus pinout

Figure 40. LCD12864 ISP interface with the Arduino Nano

Interface entre LCD12864 com Arduino nano: For the Web and Mobile (cellular) interface, Blynk was used in conjunction with the ESP8266 ESP-01. Blynk combined with these platforms will make it possible to develop Mobile IoT projects using WiFi. To connect the ESP-01 to the computer it is necessary to use a USB Serial converter. I used the PL2303HX, however we can use any USB Serial converter that provides 3.3V to power the ESP-01.

DTH22 Module - Temperature and humidity sensor: Humidity is the amount of water vapor in the atmosphere. Relative humidity is an important measure used in weather forecasting, and indicates the possibility of rainfall. A high amount of water vapor in the atmosphere favors the occurrence of rain. Low humidity, on the other hand, makes rain difficult. High humidity during hot days makes the thermal sensation increase, that is, the person has the impression that it is hotter, due to the reduction in the effectiveness of skin perspiration, and thus reducing body cooling. According to the WHO (WorldHealth Organization), humidity values below 20% are a health risk, and can cause dehydration in people.

These are some applications for Humidity and Temperature Sensors:

- Weather station,
- Irrigation control for plants,
- Humidity and temperature control in controlled environments,
- Refrigerators,
- Data Centers,
- Data loggers, etc.

The DHT22, Figure 41 is a temperature and humidity sensor that can read temperatures between -40 to +80 degrees Celsius and humidity between 0 to 100%, and is very easy to use with Arduino and other microcontrollers because it has only 1 pin with digital output. The DHT22 is a temperature and humidity sensor that can measure temperature from -40 to +80 degrees Celsius and humidity from 0 to 100%. It is very easy to use with Arduino and other microcontrollers, as it has only 1 pin with digital output.

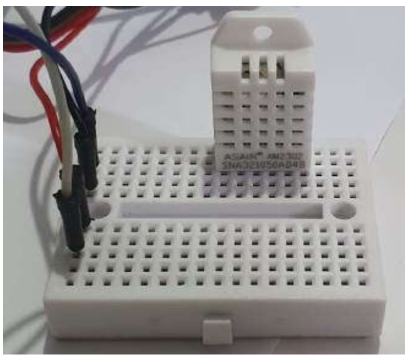


Figure 41. Temperature and humidity sensor DTH22

RESULTS AND DISCUSSION

Project Implementation: Before proceeding to the AC current meter sketch with ACS712 it was necessary to install the libraries used. For this the simplest way was to use the VsCode IDE utility itself. It was necessary to install the following libraries in VsCode.

- Adafruit GFX Library (graphic functions for the display).
- Adafruit SSD1306 (driver for the display).
- Emonlib (measurement library).

For safety, whenever working with a project involving the power grid it is interesting to keep the circuit disconnected from the grid while loading the code, after completely loading the source code in the Arduino you should connect the AC model to the power outlet. The Emonlib library was developed in a way that sensors/transducers for various ranges can be used. When you configure the library instance you indicate which ADC channel is being used and the calibration constant. For the ACS712-50A this constant was obtained empirically, that is, a multimeter was used as reference to calculate the constant that was used. The setup loop will basically initialize the display and the Emonlib library. Inside the loop the function "emon1.calcIrms(1996)" is called and a common question is where the values inside the parentheses come from. This number indicates the number of samples used in the RMS algorithm. An important point, for the measurement to have good accuracy it is necessary that the number of points is the equivalent of samples within N complete cycles of the network. With some modifications in the library (using the "micros()" function) it was found that the function starts a conversion of the ADC on average every 166.86us. Knowing that one cycle of the 60Hz network is 16.66 ms long, it is possible to calculate that 99.84 samples per cycle are needed. The more complete cycles sampled, the more stable the measurements will be. In this case 20 complete cycles have been chosen, i.e. approximately 1996 samples. The function "emon1.calcIrms( )" does all the work of sampling the signals, performs the calculations and returns the result. After that the data is presented on the display. Figure 42 shows the interface between the Arduino, LCD, DHT22 temperature sensor, and the LoRa transmitter. The graphical interface using the LCD is for the electric utility meter reader to read the customer's consumption. The consumption data is displayed on this interface, as well as the temperature and humidity data.

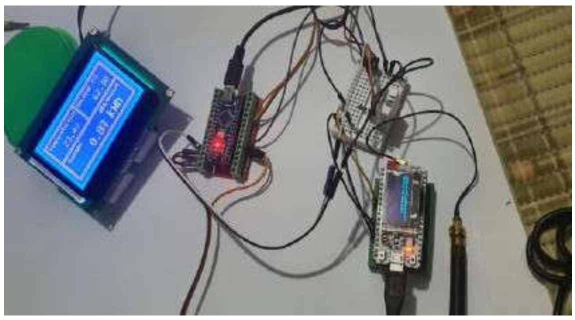


Figure 42. All devices connected and working

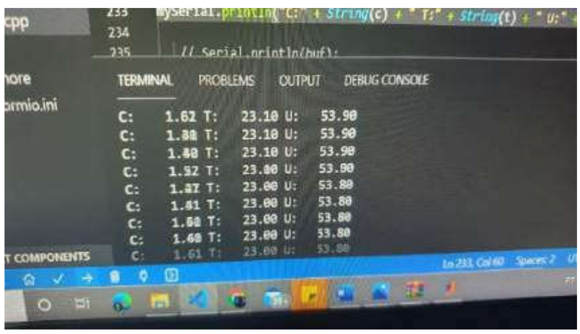


Figure 43 - Data received by the VsCode interface

Although it was not a requirement of the Wasion company for the development of this prototype, temperatureand humidity were put into this project because this information affects the life of the device. These variables affect the aging of the meter. Figure 43, shows the output of consumption, temperature and humidity informationsent by the meter to the LoRaWAN network. This information will be used by the energy utilities to monitor thecustomer's consumption, with the purpose of obtaining the consumption profile. Figures 44 and 45 show the capture of meter data by Matlab, this data is stored in a database, and in the future can be used to profile each user. In the Northern region, many communities in the interior of the state do not have access to the Internet. Due to the federal government's program "Light for All", meters have been installed in mostcommunities in the region. The utility does not have access to the meters due to the distance. Through the LoRa meter developed in this project the telemetry information from the meters will be able to reach an internet access point in the community and thus transmit the information to the utility.

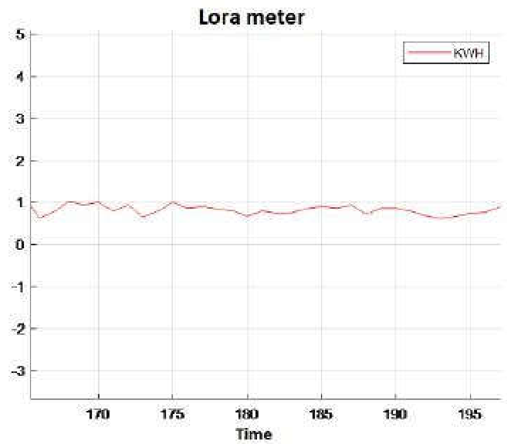


Figure 44. Graphical interface with Matlab, consumption reading.

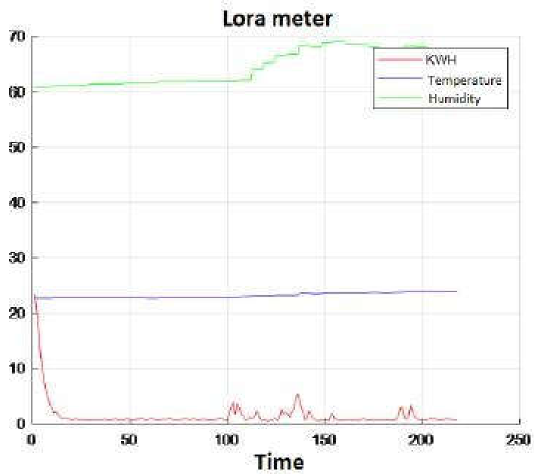


Figure 45. Graphical interface with Matlab, all collected information.

Figure 46 shows the mobile interface developed for the lora meter. Using this interface, the maintenance teamof the concessionaires will be able to visualize which of the clients are without electric energy in their residences,being able to act quickly in the reconnection.

This interface can also be made available to customers so that theycan follow their consumption in real time and thus reduce their monthly consumption, contributing to the monthly amount paid. Besides the development of software for measuring electricity consumption with a mobile interface, the design of the mechanical parts of the meter was developed from 3D modeling to the final assembled version. Among the modeled parts are the base cover, base, terminal block, terminal block cover, and the shunt and neutralcircuits.

Figure 47 shows the result of this development. The developed electronic circuit was accommodated inside the meter's base and the connections were made with connections between the boards and the shunt and neutral circuits, responsible for receiving the electric cables from the external network and distribution to the client's circuit breaker box. Figure 48 shows the result ofthis step.

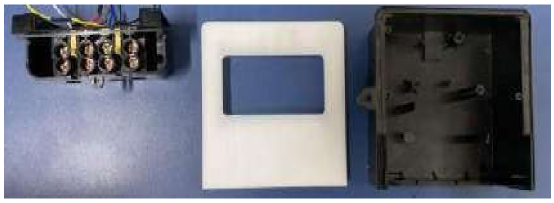


Figure 47. Mechanical parts of the meter

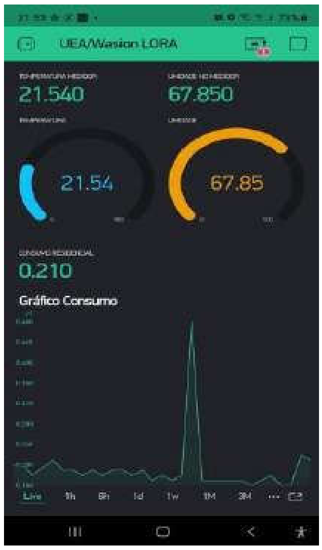


Figure 46. Mobile interface

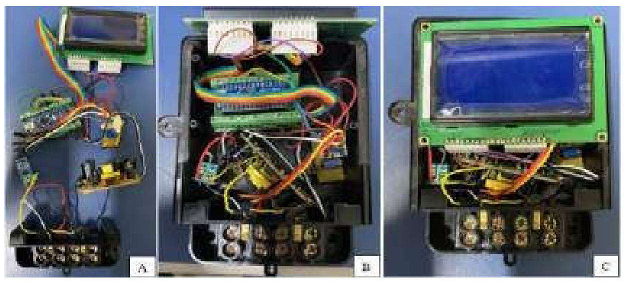


Figure 48. Mechanical parts of the meter

Figure 48A shows that the electronic circuits were developed using four boards, but it is intended in future work to develop a circuit that optimizes this solution. Figure 48B shows the electronics housing inside the meter base, and Figure 48C shows the positioning of the display. Figure 49, shows the final prototype of the LoRa meter in its prototype version.

According to Figure 49, it can be seen that the meter reads the temperature, humidity, and consumption, and shows the collected data through the digital display. The base cover, white in color, has a reserved area for marking the minimum information required by INMETRO and data used by the utility. To validate the concept and the electrical and mechanical tests of the new meter, a test jig (Fixture) was developed for this meter, Figure 50. As shown in Figure 49, it is possible to observe that the meter reads the temperature, humidity and consumption, and shows the test device as shown in Figure 50, which performs the test of the peripheral outputs, whose purpose is to verify the adequacy and functionality of all the peripheral outputs of the meter.

Figure 49. Final version of the prototype

Figure 50 . Meter test fixture.

The device has six cradles to accommodate the products, the test is performed by contacting the needles directly on the meter's peripheral outputs.

CONCLUSIONS

Manufacturers of electric energy meters have been investing in strategies to modernize their products, optimizing functionality and seeking new ways to communicate with meters. Smart meters using the LoRa network have as characteristics high range, low power consumption, and reduced data rate, and stand out due to the flexible network architecture, in which it is possible to send a larger amount of messages during the day, either to the meter server or to the meter server. In view of this, this dissertation presents a proposal for the development of a prototype of an electronic meter for the measurement of electric energy using the LoRa network, for a company from the Industrial Pole of Manaus, gaining, with this, modernization in its products, greater accuracy in the measurements and modernization in part of the electric network system in Brazil. The project had three main stages: the modeling and making of the new product's mechanical parts, and the development of the electronic circuit boards and firmware. The mechanical modeling was done using SolidWorks software and following INMETRO standards, such as maximum dimensions and providing areas for customer data insertion, manufacturer INMETRO. After modeling, the parts were made and assembled to evaluate the manufacturing process (in-line assembly). It was observed that for the assembly of the product the parts had satisfactory results, not generating difficulties during the fitting of the parts and the use of testing devices. The electronic development associated with the circuits of the current module, Arduino nano, LoRa Esp32 performed the reading of the energy consumption efficiently. The firmware development was done using Arduino libraries associated with the necessary requirements for reading energy consumption and monitoring external factors such as temperature and humidity. These measurements were chosen because they are two of the means used to measure the useful life of electric energy meters. The proposal was completed at the meter manufacturing company. All the parts that make up the proposed solution were tested in the laboratory through the development of prototypes.

It was observed the effectiveness ofthe energy consumption reading, satisfactory mechanical aspects of the product assembly, and communication through peripheral outputs in a test device with good performance.

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