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RESEARCH ARTICLE OPEN ACCESS

PROPOSED DEVELOPMENT OF A POLYPHASE ELECTRONIC POWER METER PROTOTYPE USING THE LORA NETWORK

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ABSTRACT

With the development of the electronics and mechanics prototype with a proposal for a new polyphase electronic electric energy meter aiming at subsequent manufacture, according to its manufacturing specifications as a product in the industrial environment. The objective of the article was to develop a prototype of a new polyphase electronic electric energy meter using LoRa network, for remote measurement of energy consumption. The prototype was developed for a company from the Industrial Pole of Manaus (PIM). An Experimental Methodology was used, presenting the model proposal, mechanical base, Terminal Block, Meter Cover, The Terminals, The Electronics, Transmission LoRa Interface, and the Reception LoRa Interface. Data collection was carried out through meetings with company professionals, technical visits, and research on the importance of the topic. The results showed that the main development phases were validated, and that the long-distance meter communication proved to be effective for energy consumption recording, and has potential manufacturing condition.

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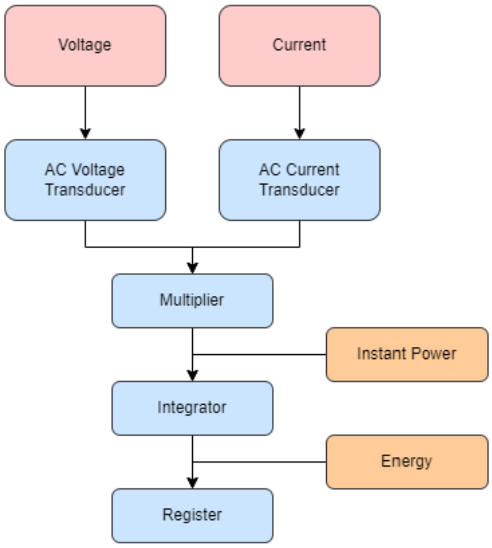
INTRODUCTION

The objective of this paper was to develop a solution for a prototype polyphase electronic meter with a digital display, using the LoRa network, in order to remotely read the real consumption of the consumer unit. The product's mechanical modeling was done, with the creation of plastic and metallic parts, as well as electronic and software development. The prototype was developed according to INMETRO's specifications, for Class B products. A LoRa device can offer optimal transmission power ratio, receiver sensitivity over long distances, low hardware cost, and a low inconsistency rate when reading the transmitted information [Vasconcelos, 2020]. In IoT applications in the field, these are features that assist in deploying connectivity in areas far from large centers [Kubisse, 2018]. In this way, sensors (that normally would have no network) can be arranged in several remote locations, with an efficient, 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 over large areas, consuming little power for transmission [Solagna, 2020; Harwahyu, 2018]. In the institutional and scientific aspect, this project is justified by the interest in innovation, based on the development of new technologies to be implemented in electronic meters, because it is a technological breakthrough of LoRa network in meters. The investigation was carried out through literature review and data collection in the company, whose activities supported the academic, scientific and technological development project, which can be better customized and introduced in companies in the electric energy measurement industry.

LITERATURE REVIEW

Electronicenergymeters: According to NBR 14519 [NBR, 2020], electronic electric energy meters are static meters in which the current and voltage act on solid-state elements (electronic components) to produce an output information proportional to the amount of electricity measured. These meters are basically composed of transducers, multipliers, integrators and recorders [Valle, 2018], the following diagram illustrates, as shown in Figure 1.



Source: Authors, (2022).

Figure 1. Diagram of an electronic meter.

Exemplified in Figure 1, voltage and current transducers do the acquisition and adjustment of the input signals to be multiplied. The multiplier in turn determines the instantaneous power by multiplying the voltage and current signals coming from the transducers. The power is obtained by integrating the instantaneous power that is performed by the integrator. Finally, the result is shown in the register [Oliveira, 2017; Godoi, 2018]. The power can be observed by means of equation (1).

$$p(t) = v(t) \,.\, i(t) \quad (1)$$

For analysis in alternating current (AC) circuits, equations (2) and (3) provide the instantaneous voltage (V) and current (A), respectively:

$$v(t) = Vmsen(wt + \alpha) \quad (2)$$

$$i(t) = Imsen(wt + \beta) \quad (3)$$

Where:

Vm and Im the peak values of voltage (V) and current (A), respectively; w the angular velocity, measured in (rad/s); α and β the angles (rad) of displacement of the voltage and current, respectively.

Resulting in equation (4), the instantaneous power (W):

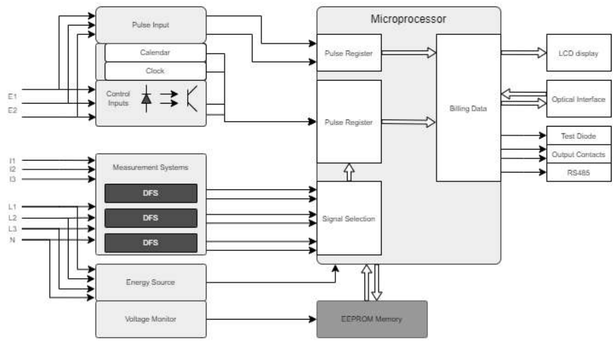
$$p(t) = VmImsen(wt + \alpha)sen(wt + \beta) \quad (4)$$

Then, according to [Linhares, 2017] the integrator sums all the instantaneous powers, which is presented by the following equation, (5), providing the energy consumed and that will be presented by the recorder.

$$e(t) = \int_0^t p(t)dt = \int_t^t v(t).i(t)dt \quad (5)$$

Electromechanical and electronic meters were designed to operate in linear systems, i.e., in pure sinusoidal conditions of the voltage and current signals [Suhett, 2008]. Measurements made by an electromechanical and an electronic meter gave similar results, showing good functioning of both. However, according to [Ferreira, 2013; Nóbrega Sobrinho, 2015; Ribeiro, 2015] when in presence of non-linear loads, meters show higher errors in the measurement mainly due to the low power factor. This is due to the fact that more and more non-linear loads are connected to the network such as air conditioners, computers, induction motors (elevators, pumps, compressors, among others) that cause harmonic distortions in the voltage and current signals.

Working Principle of the Electronic Meter: The measuring principle is briefly described by means of a block diagram as shown in Figure 2, below. The main inputs to the meter are shown on the left, identified the phase (L1, L2, L3) and neutral (N) connections for energy measurement and for power supply to the meter's power source, as well as, the control inputs (E1, E2) for switching the energy tariff [Frenzel, Silva, 2012].



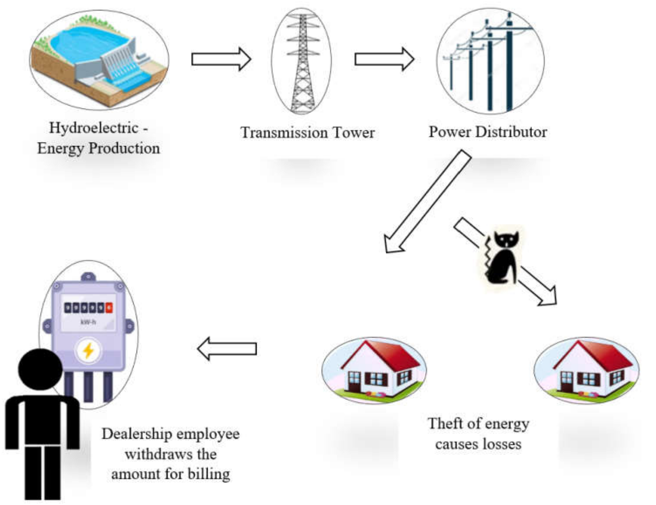
Source: Authrs, (2022).

Figure 2. Three-phase meter block diagram.

Shown in Figure 2, the meter's main output is shown on the right, as is the optical interface input, the LCD display, used to read the recorded value of power consumption, usually with 5 or 6 digits, additional information is used to indicate direction of power, presence of phase, phase sequence, applied power, and current tariffs. The power supply for the electronic meter comes from a 3-phase voltage circuit. The voltage monitoring circuit ensures efficient operation and data storage in case of power failure, as well as a proper reset when power is restored [Gentil, 2016; Silva, 2008]. The measurement system is based on integrated DFS technology (Direct Field Sensor, based on the "Hall" effect) and generates a signal proportional to the power per phase based on the applied voltage and the circulating current [Carvalho, 2015]. This signal is converted into a digital signal for further processing by the microprocessor. The current is usually detected by a Hall effect sensor and the voltage is detected by a resistive voltage divider [19].

The signal processing is performed by a microcontroller that sums the digital signals from the various phases and forms pulses of fixed energy. It divides these pulses into positive and negative ones based on the direction of power flow [Pereira Júnior] It then processes them according to the measurement constants and provides information to the corresponding registers according to the tariffs determined by the tariff controller. The microcontroller also controls the data communication with the display, the optical interface, and also ensures safe operation even in the event of a power outage [Ozelame; Nagamine, 2011]. A non-volatile memory (EEPROM) contains the parameters set in the meter and secures the billing data - energy data - against loss during a power outage [Santos, 2018].

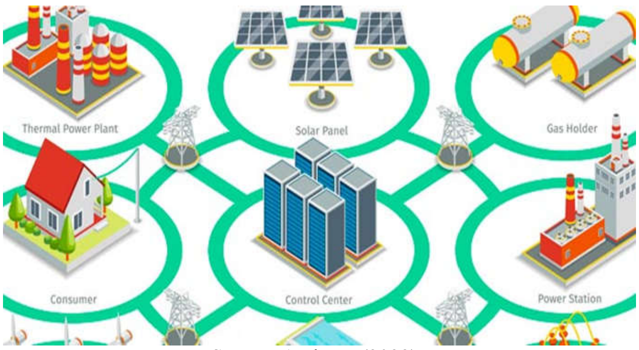
Technological advances: The Smart Grid, smart meter, is a technological innovation, an alternative used to supply electric power distribution needs [Oliveira, 2017]. It has been acquiring space in other countries as well as in Brazil, in view of events in the electrical sector with constant failures and surges. The term Smart Grid refers to an electric power system that uses information technology to make the system more efficient (economically and energetically) reliable and sustainable [Oliveira, 2017; Toledo, 2012]. In Brazil, many power utilities tend to adhere to the Smart Grid system, as it is a system that automates not only the monitoring, but also the entire management of electricity use. This internal implementation requires the adoption of a system that integrates the operation of Operational Technology with Information Technology [Toledo, 2012]. Smart Grid is interactive for both power generation sources and loads. The old central and vertical model is replaced by a distributed and disaggregated one in which different customers emphasize different aspects of the new power grid according to their perspective. Figure 3, shows the representation of the electric grid system usually used in Brazil.



Source: Authors, (2022).

Figure 3. Model of the electric grid used in Brazil.

As Figure 3 shows, initially the energy is generated by means of hydroelectric plants, and is transmitted by distribution towers to the distributor. On the way between the distributor and the customer, power deviations often occur, causing irreparable damage. Finally, an employee of the utility company measures the consumption for billing directly at the consumer unit. Smart Grid has the potential to modernize the electrical grid using IoT.



Source: Authors, (2022).

Figure 4. Smart Grid System.

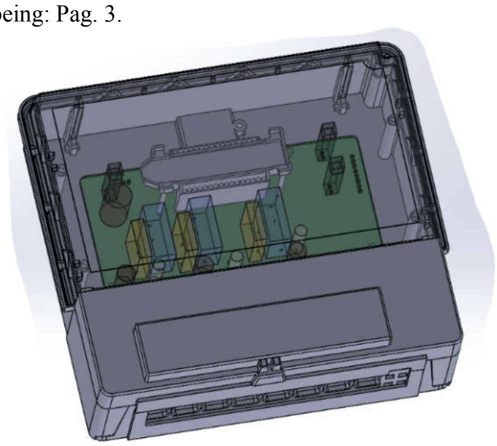
Figure 4, shows the diagram of the Smart Grid system in Brazil. The Smart Grid system involves the application of processors, with the objective of performing tasks on the microsecond scale, intelligent applications, demand management, to optimize generation costs and energy use, and sensors, to identify abnormalities in the system. In short, it is a modern and interconnected system. According to [Oliveira, 2022], in this new model, there is high speed with advanced measurement and control technologies, a bidirectional communication infrastructure capable of supporting the networks. Through interconnection between the transmission and distribution structure, consumers and generators are interconnected with new network components of intermittent nature - energy storage units and renewable sources. In smart meters, the data provided to the utility occurs through remote collection in real time, at predetermined time intervals, without the need for an employee to travel to the homes [Dias, 2020].

LoRa: According to [28], LoRa is a physical layer specification (PHY), architected for long range, low power networks. Thus, this technology is designed to enable connectivity of smart objects over distances on the order of kilometers with low power consumption, an essential requirement of Internet of Things networks. The physical layer (PHY) of LoRa technology modulates signals in radio sub-bands of the unlicensed ISM (Industrial, Scientific and Medical) frequency band in the order of MHz. For Brazil, according to the National Telecommunications Agency (ANATEL), the regulated frequency band for ISM is between 915 and 928 MHz (AU915-928MHz). LoRa PHY uses Forward Error Correction (FEC) and a proprietary spectral spreading modulation technique, which is a variant of chirp spectral spreading, that modulates pulses of chirps in frequency in order to encode the information [Ferreira, 2019].

MATERIALS E METHODS

Experimental Methodology: The present study is exploratory, for providing more knowledge on the subject, of applied nature, establishing the practice of specific problems in the organization aiming to solve them, and seeking qualitatively to understand its concepts under the aspect of bibliographic research to identify the authors' approach through books, theses, articles, electronic sites, company documents. And the case study aspect to analyze test validation on the developed meter. The research was based on the application of new technologies to be implemented in electronic electric erengy meters. For the development of the prototype, data collection was performed through meetings, technical visits in the manufacturing environment, and bibliographic references were researched to establish the theoretical foundation of new applications in the development of electronic meters using LoRa. This paper aims to present the development of a prototype of a polyphase electric energy electronic meter using LoRa network.

Proposed Model: For the proposed model, this paper aimed to present the development of a prototype polyphase electronic electricity meter using LoRa network, as shown in Figure 5. The SolidWorks software was used for the 3D modeling of the prototype, considering INMETRO standards with aspects of dimensions and parameters according to the class of the meter model. The development had three subsets, being: Pag. 3.

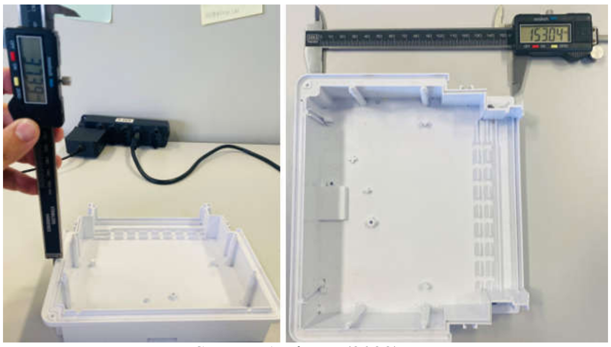


Source: Authors, (2022).

Figure 5. 3D model polyphase electronic meter.

Mechanical: The mechanical aspect of the prototype basically involved two components, plastic solution and metal parts. Plastics were applied to the base, terminal block, block cover, and meter cover, and metals were used for terminal blocks, screws, and phase A, B, and C circuits. It is emphasized that the plastics, meeting regulatory standards, were chosen to be flame retardant material and resistant enough to prevent fraud.

Base: The purpose of developing the base was to store all the electronic components in such a way that there are no loose parts and/or objects inside the closed prototype. The design of the base, as for every meter, was based on the maximum dimensions, described in the RTM as shown in Figure 5.

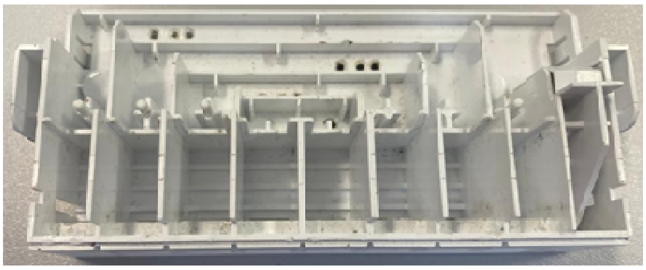


Source: Authors, (2022).

Figure 5. Prototype base.

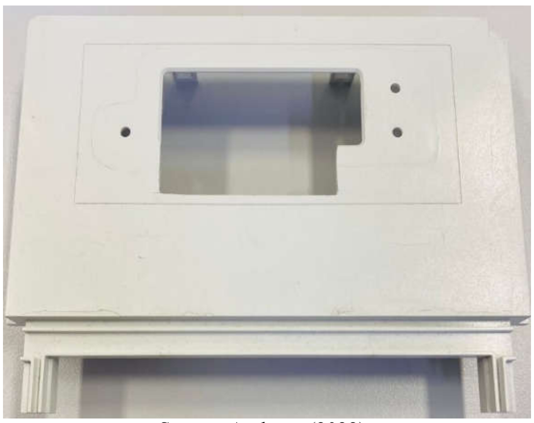
The base has several fitting points for the terminal block, the base cover, and the board. The material used to make this part was white polycarbonate.

Terminal Block: This part is a support in insulating material, grouping the meter's terminals. The terminal block was designed with insulating material capable of not deforming after the meter has been submitted to the heating test with the maximum current. It was fixed to the base in such a way that it could only be removed by breaking the seals of the prototype meter's cover. The position of the neutral terminals was identified by the blue color, on the front face of the terminal block for direct connection polyphase meters according to Figure 6.



Source: Authors, (2022).

Figure 6. Terminal Block.



Source: Authors, (2022).

Figure 7. Base cover.

The terminal block is designed to accommodate the circuit parts for phases A, B, and C, are insulated by the plastic itself, and have interlocking points to fit the base cover.

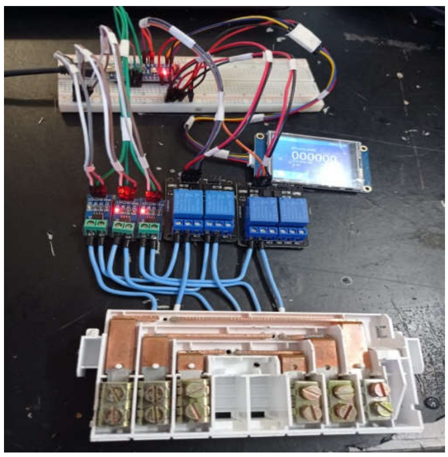
Meter Cover: It was a piece made to be overlaid on the base to cover and protect the internal parts of the meter. The cover was constructed and adjusted to ensure the perfect functioning of the meter, even in case of non-permanent deformation. A polycarbonate material cover was chosen, for this a digital display was placed for reading the display and observing the operation indicator. The model of the base cover is shown in Figure 7. As shown in Figure 7, the cover has an opening for the installation of the digital display and three holes for the insertion of leds that will signal the energized meter and the active and reactive power pulses.

Terminals: The meter current terminals for direct measurement have holes for fastening two screws, in order to guarantee safe and permanent fastening of conductors from 4 mm² to 50 mm² in polyphase meters of up to 120 A. They are designed to be able to support the meter's maximum current. In the design of the prototype meter, eight terminal blocks were applied, as shown in Figure 8. The terminals are not subject to displacement inside the meter, regardless of the fixing screws of the connection cables, to avoid possible displacement, the cavities of the terminal block also help this fixation.

Fonte: Authors, (2022).

Figure 8. Borne.

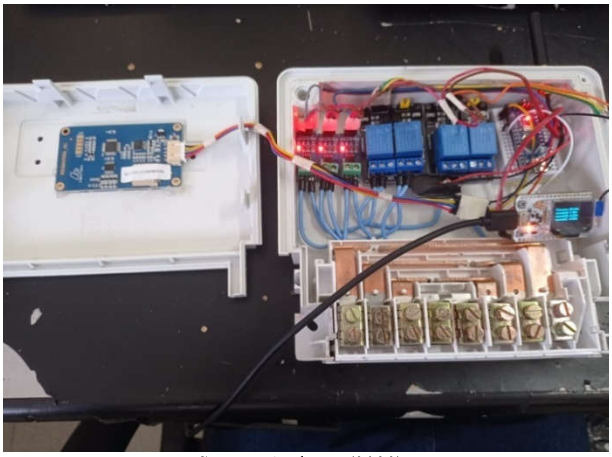
Electronics: As part of the electronics development, to measure the current in polyphase form, three current sensors were used, one in each phase of the meter, each connected to a channel of the relay module. The wiring diagram of the current measurement can be seen below, indicating all the sensors and the control through the switches with relay, being necessary 2 modules of 2 channels due to the necessity of the control of the 3 phases as shown in Figure 9.



Fonte: Authors, (2022).

Figure 9. Electronic development.

In addition to the ESP32's high performance, it features semtech's LoRa chip, which is characterized by a LoRa network connection with an SMA antenna (U. FL 2 mm). This is one of the newest radio frequency technologies, characterized by low power consumption and communication over long distances, and is suitable for a wide variety of projects involving WiFi and IoT networks. In the research, the ESP32 LoRa microcontrollers were used to communicate the information collected from the meter through the Arduino Nano and trigger commands over long distances, this through a division between a LoRa Master (Master) meter which sends requests and commands, and a LoRa Slave (Slave) meter which returns the requested information and carries out the requested commands. This idea was conceived so that the ESP32 LoRa (Master) could connect to several electronic meters serving as a Gateway, and in this way could collect the consumption measurements, monitored currents of each phase and store this in a database, or in a local disk. Figure 10 shows the entire circuit of the LoRa polyphase electronic meter, as well as a short distance simulation of the sending and capturing of data, the visualization through the Nextion display, and the connections of the current sensors and relays.



Source: Authors, (2022).

Figure 10. Network communication tests.

In order to send the information from the electronic polyphase LoRa meter, as well as receive commands in places with low internet connectivity, over long distances, the ESP32 LoRa SX1276 868/915 Mhz module with 0.92" V2 OLED was used. The ESP has a high performance for applications involving WiFi, relying on very low power consumption.

LoRa Transmission Interface: In the prototype meter, to send information over long distances through the LoRa network, we used the ESP32 LoRa, which acted as a slave, where in its source code awaits a request from the ESP32 Master to send the requested information package, which are the consumption, phase A current, phase B current and phase C current. This network was programmed from the library "heltec.h", which has the objects, classes and methods needed to use the LoRa network, as well as the OLED display, and has the following variables as settings:

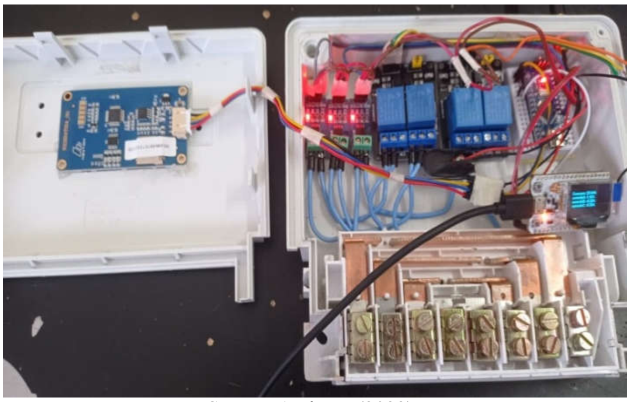
- displayState - Enables the display
- loraState - Enables the LoRa network
- serialState - Enables the transmission of network information via Serial
- bandadeTransmissionBand - Sets the network transmission band 868/915 MHz
- amplifierFrom Power - Enables the power amplifier

With the initial configuration of the Heltec library, the configuration of the LoRa network was performed, since several factors can be changed to improve performance, transmission speed, transmission distance, as well as the encryption of this data in order to have security in this confidential data transport. This is done using the function "setupLoRa()", which changes settings such as the spreadingFactor that changes the amount of encoded data per second, increasing or decreasing the speed of transmission, Signal Band widthn that changes the bandwidth space around the transmission band, and SyncWord, which defines a word in hexadecimal that indicates the beginning and the end of the transmitted message, making each transmission unique. Other settings such as TxPower indicate the power of the transmitted signal, something that directly impacts the power used and the transmission range radius. In addition, this system has a real-time check, because the measurement of power consumption and other variables is done every second, and the ESP32 LoRa only sends data after this time, so the "Received()" function checks every time if there has been a request to send data, and only continues the program if there is. Finally, this data is received from the Arduino Nano and sent over the LoRa network with the use of the Heltec library, with the Write function, similar to using the Serial UART communication. This transmission was done through the "send Package ()" function.

Receive LoRa Interface: Similar to the transmitting ESP32 LoRa, the receiving one has the same way of configuration, as both must have the same specifications in order for communication to be established. The difference between these is the reading of the data from the LoRa network. This reading was done through the "receivePacket()" function, which checked every cycle the "parsePacket()" refers to a function that checks the packet size, if any, and if so, starts assigning the received values to the variables that will be shown on the OLED display.

RESULTS AND DISCUSSION

Application of the Results: To validate the full operation of the prototype meter, the mechanical and electronic assembly was performed, as shown in Figure 11.



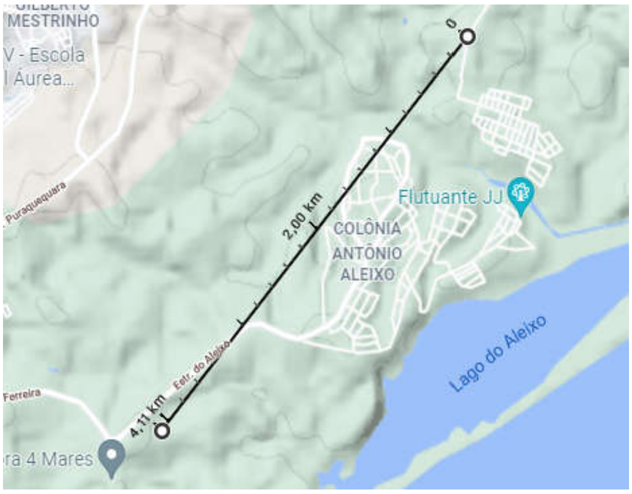
Source: Authors, (2022).

Figure 11. Assembling the prototype.

Finally, with the finishing of the mechanical structure and accommodation of the electronic components it was possible to visualize, as shown in Figure 12, a final view of the prototype of the LoRa polyphase electronic meter. The operation of the prototype, in relation to transmission over long distances, a fixed position was identified for the receiving ESP32 LoRa to read the data, which was in the company itself, and the electronic meter connected to an external artificial power supply was moved away until the interruption of the data transfer was noticed, which was verified at the location shown in Figure 13 and was obtained through Google Maps, using the "Measure distances" tool. This distance was captured in an industrial region, where there are no large buildings, facilitating data transmission. However, in a deeper analysis of the route between emission and reception, it was noted the various characteristics of the relief and obstacles, such as the existence of a small neighborhood in the stretch between the locations. In addition, the altitude of the two locations was also different, as according to the topographical map, seen in Figure 14, it indicates that the data reception site is approximately 85 meters above sea level, and the transmission site is approximately 66 meters above sea level.

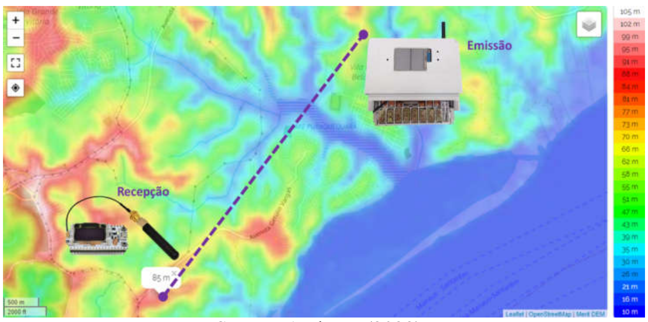
Source: Authors, (2022).

Figure 12. Prototype of the LoRa polyphase electronic meter.



Source: Authors, (2022).

Figure 13 - Maximum distance between emission and reception.



Source: Authors, (2022).

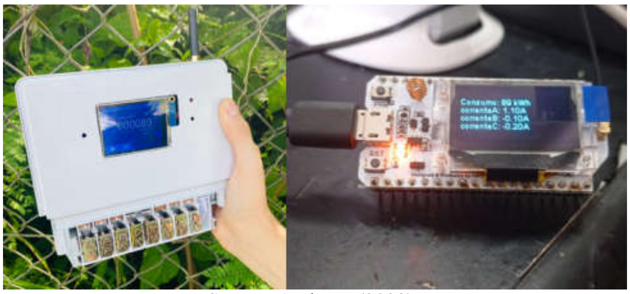
Figure 14. Topographic map of the measured distance.

To check the maximum distances for the communication to remain between sender and receiver, the meter was moved gradually away from the receiver until the signal was interrupted, as can be seen in Figure 15. At the maximum distance between the two microcontrollers, the consumption and current values were noted to validate the correct sending of the information, as can be seen in Figure 18, where the same value is seen in both screens of 89 (kWh), and 1.1 (A) in the current of phase A. This was possible by using an external source to simulate the current consumption. According to Figure 18, on the left side there is the prototype meter, the display shows the consumption of 89 kWh and on the side, there is the ESP32 receiving the prototype data.

Source: Authors, (2022).

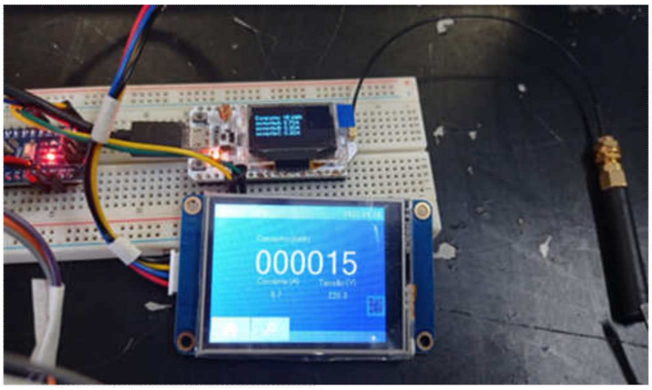
Figure 15. LoRa meter sending data over long distance.

On its display it is possible to identify the receipt of consumption, registering the same 89 kWh sent by the prototype, in addition to the data of the phases, being 1.1A in phase A, 0.10A in phase B and 0.20A in phase C. With the data sending and receiving test, it was possible to identify that the LoRa Network was effective for data transmission with the maximum distance 4.11Km, as shown in Figure 19. The demonstration of the display's operation and the measurement of the electric current, with these measurements being sent to the ESP32 LoRa, which sends remotely over long distances, were validated in the company, as shown in Figures 16 and 17.



Source: Authors, (2022).

Figure 16. Reception of information over long distances.



Source: Authors, (2022).

Figure 17. Sending meter data via LoRa.

CONCLUSION

With the advancement of technology, especially in the electric power distribution system, one can notice a modernization in the gauging of electric power consumption, which used to be done through manual readings by electromechanical meters. The electronic meters, on the other hand, are able to guarantee a more precise reading of consumption and in real time, which makes gauging more effective. Another relevant aspect is the fact that when the meter is connected to a network, it is possible to follow the consumption remotely, avoiding labor costs and displacement of employees to take the readings.

LoRa is a wireless communication technology that works via radio frequency. It is a spread spectrum modulation technique, this occurs when a radio wave is manipulated to encode information using a chirped CSS (Chirp Spread Spectrum) format. Therefore, this paper presents a proposal to develop a prototype polyphase electric power electronic meter using LoRa network, creating the possibility of smart power generation, distribution and utilization and integrated energy saving management solution. The development proposal is based on three main parts. The first refers to the mechanical solutions of the prototype, with the creation of 3D projects of each plastic part, and confection via additive manufacturing, using a 3D printer. The electronics is referred to the second part, with all the research for using the LoRa Network in polyphase electronic energy meters, as well as embedded boards to meet energy measurement specifications. And finally, the third part deals with the software development aspect, with firmware elaboration for emission and reception of data via network and all the prototype logic to register and inform the LCD screen about the consumption. In the future, the intention is to generate research so that the electronic solution found in this project can be optimized and a single board developed with all the necessary processors for the correct functioning of the meter. It is also noteworthy that it is relevant to make test devices with parameters defined by the Metrological Technical Regulation - RTM, for the validation of each step of the meter.

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REFERENCES

Carvalho, Marcos Civiletti de *et al*. Amperímetro sem contato baseado em sensores GMR. 2015.

Dias, Camila de Oliveira *et al*. Estudo e implementação computacional de sistema de armazenamento de energia com conexão direta ao sistema elétrico. 2020.

Domingues, Hingrid Tavares. Escola de Engenharia. 2020. Tese de Doutorado. Universidade Federal Fluminense (UFF). Rio de Janeiro. RJ. Brasil.

Ferreira, Ana Elisa; Ortiz, Fernando M.; Costa, Luís Henrique MK. Avaliação de tecnologias de comunicação sem-fio para monitoramento em ambientes de floresta. In: Anais do XXXVII Simpósio Brasileiro de Redes de Computadores e Sistemas Distribuídos. SBC, 2019. p. 113-126.

Ferreira, Pedro Guilherme Costa. Prof. Dr. João Carlos de Oliveira Aires. 2013. Tese de Doutorado. PUC-Rio.

Frenzel JR, Louis E. Eletrônica Moderna. McGraw Hill Brasil.

Gentil, Murillo Garcia. Desenvolvimento de hardware dedicado para monitoramento online de máquinas elétricas via TCP/IP. 2016. Trabalho de Conclusão de Curso. Universidade Tecnológica Federal do Paraná.

Godoi, Leonardo Antônio. Simceel sistema informatizado de medição e monitoramento do consumo de energia elétrica. 2018.

Harwahyu, Ruki; Presekal, Alfan; Sari, Riri Fitri. LoRaWAN Performance Evaluation with Optimized Configuration. *International Journal of Future Generation Communication and Networking,* v. 11, n. 4, p. 51-68, 2018.

Kubisse, Larissa. 2018. Internet das coisas com enfase em telecom no Brasil.

Linhares, Marcelo Saraiva. Desenvolvimento de multimedidor eletrônico de energia elétrica. 2017.

Nagamine, Guilherme Key. Estudo das perdas não técnicas no sistema elétrico de distribuição e as tecnologias utilizadas para seu combate. 2011. Trabalho de Conclusão de Curso. Universidade Tecnológica Federal do Paraná.

NBR 14519 Medidores eletrônicos de energia elétrica (estáticos) - Especificação MAIO 2000. ABNT – Associação Brasileira de Normas Técnicas Sede: Rio de Janeiro Av. Treze de Maio, 13 28º andar CEP 20003-900 – Caixa Postal 1680 Rio de Janeiro – RJ Tel.: PABX (21) 210-3122 Fax: (21) 220-1762/220-6436 Endereço eletrônico: www.abnt.org.br.

Nóbrega Sobrinho, Carlos Alberto *et al*. Estudo comparativo de técnicas para Diagnóstico de falhas em motores de Indução trifásicos. 2015.

Oliveira, Bruno Alberto Soares. Desenvolvimento de um protótipo de sistema de monitoramento de energia elétrica via internet: um estudo de caso no IFMG-Campus Bambuí. Engenharia de Computação, n. 1, 2017.

Oliveira, Jhulia Maria Nogueira Rodrigues de. Utilização da tecnologia 5G nos avanços das redes elétricas inteligentes. 2022.

Oliveira, Tamires Giovanna de Paiva *et al*. Comunicação Ethernet para medidores de consumo de energia. 2017.

Ozelame, Jamenson Guilherme. Protótipo microcontrolado para telemetria de unidades consumidoras de baixa tensão.

Pereira Júnior, Francisco. Algoritmo para detecção de eventos por medidores eletrônicos de faturamento monofásicos de baixo custo. 2015. Tese de Doutorado. Universidade de São Paulo.

RIBEIRO, Daniela Rosa. A participação dos medidores eletrônicos na rede inteligente de energia elétrica. 2015.

Santos, Mauricio de Carvalho; Nunes, Rafael Policarpo. Redes inteligentes de energia. 2018.

Silva, Luiz Carlos Evangelista da. Efeitos das distorções harmônicas (tensões e correntes) e desequilíbrios (tensões) em medidores eletrônicos trifásicos de energia elétrica ativa. 2008.

Silva, PaullusTarsis Pinheiro da Rocha Cordeiro; MEDEIROS, Thayane. Utilização de medidores eletrônicos de energia na supervisão e controle do fator de potência. 2012. Trabalho de Conclusão de Curso. Universidade Tecnológica Federal do Paraná.

Solagna, Emanuele Araújo *et al*. Análise de perdas de pacotes de uma rede LoRaWAN. 2020.

Suhett, Marcos Riva. Análise de técnicas de medição de potência reativa em medidores eletrônicos. Rio de Janeiro, RJ-Brasil Março de, 2008.

Teixeira, Leandro Lettieri. Medidor de energia eletrônico: utilizando microprocessador. 2009.

Toledo, Fabio. Desvendando as Redes Elétricas Inteligentes-Smart Grid Handbook. Brasport, 2012.

Valle, Gustavo Ari *et al*. Desenvolvimento de dispositivo amostrador de sinais de tensão e corrente para cálculo das grandezas elétricas referentes à rede e do consumo de energia. 2018.

Vasconcelos, Alexandre Sales *et al*. 2020. Plataforma IoT para rastreamento e monitoramento para bovinos a pasto.

Vizzotto, William Dotto *et al*. Implantação e avaliação de infraestrutura avançada de medição de energia em uma instituição pública. 2020.

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