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LORA NETWORK AND ESP32 MICROPROCESSOR APPLIED TO A PROTOTYPE ELECTRONIC ENERGY METER

Caio Luiz Jodas Nogueira[1*], Jandecy Cabral Leite[2*], Marcelo Maia do Nascimento[3], Marivan Silva Gomes[4], Juarez da Silva Ramos Junior[5], Railma Lima de Paula[6], Michael da Silva Caralho[7], Henrique Mark dos Santos Correa[8], Laís Freitas Bastos[9] and Luis Gabryel dos Santos Miranda[10]

[1]*(PostGraduate Master in Engineering, Process Management, Systems and Environmental (PPG.EPMSE), Institute of Technology and Education Galileo of the Amazon (ITEGAM), Manaus, Amazonas, Brasil)*
[2, 3, 5, 6]*(Institute of Technology and Education Galileo of the Amazon (ITEGAM), Manaus, Amazonas, Brasil)*
[4, 7, 8, 9, 10]*(University of Amazonas State (UEA), Manaus, Amazonas, Brasil.)*

ABSTRACT
The objective of this article was to discuss the application of LoRa network and ESP32 microprocessor in a prototype of a polyphase electronic electric energy meter. The application was developed for a company in the Manaus Industrial Complex. The article is considered exploratory, applied and qualitative under the aspects of bibliographic research and case study. Data collected through meetings, technical visits and research on the theme. The evolution of smart meters generates innovation to the energy network and optimizes the reading and data recorded by electronic meters. Results showed the capability of long-distance remote communication and efficiency in energy consumption data recording.

Keywords - LoRa Network, ESP32, Smart Meters, Remote Communication.

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I. INTRODUCTION

The Smart Grid is a technological innovation, an alternative for supplying electric power distribution needs. 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, reliable and sustainable [1].

The Smart Grid is a new, interactive model 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 [2].

In this system, it involves the application of processors, in order to perform tasks on the microsecond scale, intelligent applications, demand management, to optimize generation costs and energy utilization, sensors, to identify abnormalities in the system. In short, it is a modern and inter connected system [3].

LoRa is a communication protocol for LPWAN (Low Power Wide Area Network) networks, with low cost, security and bidirectional communication [4]. It has communication range of up to 20 km in rural areas and 4 km in urban areas and support for redundant operation technologies, free localization, low power consumption, and energy harvesting to support future network needs, enabling mobility of use features [5]. A LoRaWAN network uses unlicensed bands and open and free protocols, making it easy to deploy [6]. LoRaWAN has been used in REI applications mainly for remote metering infrastructure.

II. LITERATURE REVIEW

2.1 Electronic Meter

Electronic meters have distinct classes of accuracy that can reach levels of 0.2%, when active energy measurement is performed, besides having great facility in the implementation of new functionalities and lower production costs when compared to their predecessors [7][8].

The technological advance in embedded systems has made further improvements in measurement systems feasible, thus emerging smart meters [9], which not only have characteristics in performing readings of energy and electrical quantities, but also offer the possibility of local and remote communication, addition of power quality indicators, cut-off and reconnection via internal relay, alarms, and anti-fraud events [10].

2.2 Smart meters

Smart meters are increasingly being deployed in many global markets. New elements integrated into the meter give it the ability to capture, process, respond, and communicate new information [11][12]. The sharing of this information with other members of the electrical system, such as power generation units or even transmission and control system elements, provides, among other things, greater agility in identifying and solving 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 [12].

The Smart Grid is a technological innovation, an alternative to supply the needs of electric power distribution. 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 [13]. The term Smart Grid refers to an electric power system that uses information technology to make the system more efficient, reliable and sustainable [14].

2.3 Hall Effect Current Sensor

Linear current sensors based on the Hall Effect are devices capable of monitoring direct and alternating currents without the need for physical interaction between the monitoring circuit and the power circuit to be monitored, called galvanic isolation [15].

The Hall effect is about a potential difference in an electrical conductor, transverse to the current flow subjected to a perpendicular magnetic field [16] [17]. Its output voltage is proportional to the magnetic field to which the sensor is exposed. This voltage may be positive or negative according to the displacement in space of the magnetic field generator or the direction of the current if it is the generator of the magnetic field [18].

2.4 ESP32 LoRa

The name LoRa is short for the words Long Range. LoRa network is a wireless solution in networks below GHz, in frequencies that do not require licensing, such as 433, 868 and 915 MHz [19][20], for example. It is a type of network that is being used for connection between devices for low-power, long-distance applications, given that in open field it is possible to achieve up to 15 km of range [21][22]. In a simplified way, the LoRa system is a module placed in end devices and also in gateways, which are able to get data out of a LoRa network and through an IP connection reach local and/or remote servers [23]. The modules send and receive data from gateways in a similar way to Wi-Fi networks, but with much greater range. Their main applications are IoT systems such as remote sensors and monitors, especially those that are battery operated and in some cases in remote locations [24].

2.5 Raspberry Pi Pico

From the Raspberry Pi family of single board computers, Raspberry Pi Pico is the first high-performance, low-cost microcontroller board product built on RP2040 chip. The Pico features a Dual-core cortex M0+ processor with phase-controlled loop chip to adjust the core frequency. With a clock speed of 133 MHz, the Pico has a 264-byte SRAM and 16-byte on-chip cache. Sixteen PWM channels, real-time counter, 12-bit analog to digital converter, thirty multi-function I/Os, and an integrated USB 1.1 add to the Raspberry Pi Pico's features. Pi Pico runs on MicroPython, an implementation of Python Programming [25] [26].

III. MATERIALS AND METHODS

3.1 Solution Architecture

For the development process of the polyphase LoRa meter, the embedded software was separated into 3 distinct parts, which act on different microcontrollers and different platforms:

1. LoRa Transmission Interface;
2. Arduino Nano;
3. Receiving LoRa Interface.

Each of these parts has a specific function to not overload the processing, and to improve the performance of the consumption measurement in (kWh) by the prototype meter. This division of function alities can be seen in Figure 1.

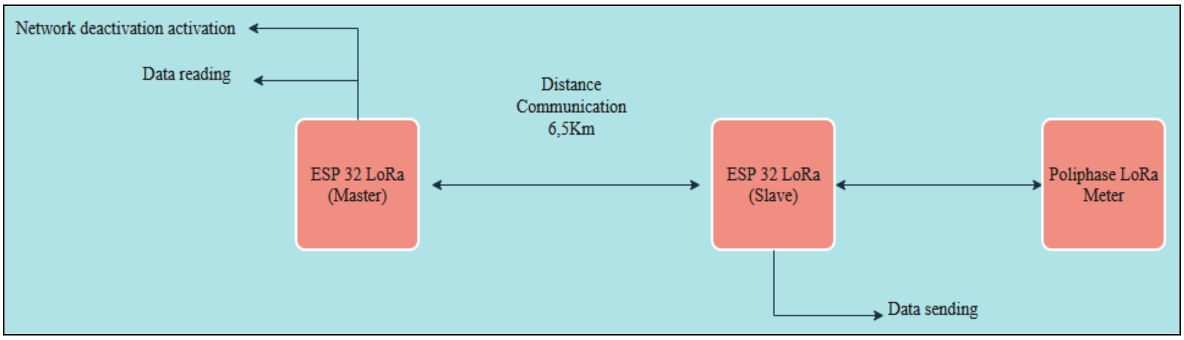

Figure 1 - ESP32 LoRa communication scheme.
Source: Authors, (2022).

3.2 LoRa Transmission Interface

Inside the meter, to send the information over long distance through the LoRa network, the ESP32 LoRa was used, which acted as a Slave, where in its source code it waits for a request from the ESP32 Master to send the requested information package, being these the consumption, phase A current, phase B current and phase C current.

This network is 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
- amplifierFromPower - Enables the power amplifier.

With the initial configuration of the Heltec library, we started to configure the LoRa network itself, 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 was done using the function "setupLoRa()", which changes settings such as the spreadingFactor which changes the amount of encoded data per second, increasing or decreasing the speed of transmission, SignalBandwidthn which 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 strength 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 will only send the 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 using the Heltec library, with the Write function, similar to using the Serial UART communication. This transmission was done through the "sendPackage()" function.

3.3 Arduino Nano

In order to separate the functions of the polyphase LoRa meter, instead of using only the ESP32 to perform all the functions, an Arduino Nano microcontroller was used together to perform all the commands and data reception, being these respectively, command of the relay modules that control the passage or not of current, and the reception of the current sensors of the 3 phases, as described in the diagram of the.

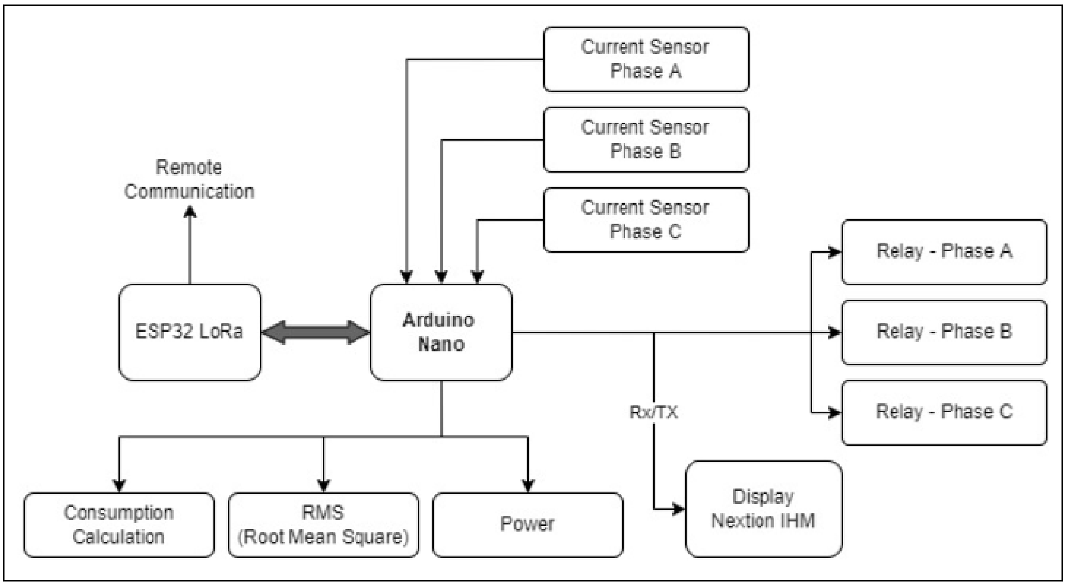

Figure 2 - Diagram of the Arduino Nano functions.
Source: Authors, (2022).

The Arduino Uno was responsible for treating the signal measured by the current sensor, as well as acting in relays to control the passage of current in the three phases, this through the digital ports of the Arduino. However, in addition to these functionalities, it was responsible for sending and receiving the commands from the Nextion display through the library of the same name "Nextion.h", which was done serially.

As the Arduino Nano has only one pair of UART ports (RX/TX), and this is used to communicate the microcontroller with the Nextion display, it was necessary to use a library called "SoftwareSerial.h", which emulates more pairs of UART ports through the Arduino's digital ports, to communicate with the ESP32 LoRa and send the collected information.

The current measurement made by the sensors is returned to the microcontroller through a voltage proportional to the measured current, and this is interpreted by the analog inputs of the Arduino through a 10-bit ADC (Analog-to-Digital-Converter), and this is treated to eliminate noise through a digital filter in the function "filtroDaMedia()", and a calculation of the ratio of the ADC from 0 to 1024 for current from -30 to 30 Amperes is made through the function "calculatesCurrent()".

The power consumption was calculated through the current and voltage measured according to the NBR 5410 that addresses the "Low Voltage Electrical Installations", calculating the power that is the relationship between voltage and current, P = V x I, and the consumption that is the calculation of power over time.

However, this measured current is in the form of a sinusoid, at 60Hz, and to calculate consumption the Root-Mean-Square (RMS) current was used. In order to perform this calculation we used the library Emonlib (energy measurement library), which is an Open Source library that receives the values from the ADC and calculates from several samples the RMS value of the current through the function "emon1.calcIrms(number of samples)".

3.4 Receiving LoRa Interface

Similar to the transmitting ESP32 LoRa, the receiving one has the same form 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()", which is nothing more than 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.

3.5 Analog Digital ADC - Raspberry Pi Pico

The Raspberry Pi Pico's internal ADC analog-to-digital converter has a 12-bit resolution, but it is possible through SARS technology to optimize the

ADC for a 16-bit readout, transforming a signal read from 0 to 3.3 V into a digital value between 0 and 65536. To read AC values at the microcontroller input it is necessary to condition the signal, and this is done through a coupling circuit that is shown in Figure 3.

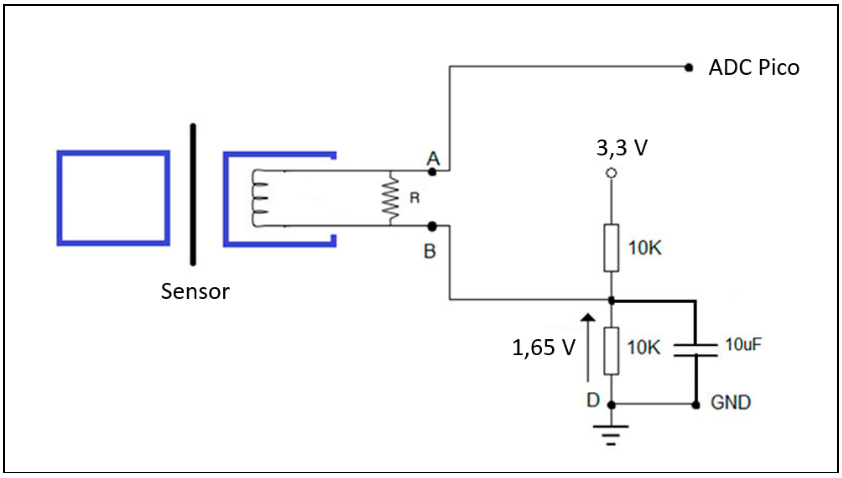

Figure 3 - Current Sensor Coupling Circuit.
Source: Authors, (2022).

With the voltage and current conditioned for reading in the ADC, C++ programming is used to perform the reading of the two magnitudes almost simultaneously, this is possible through the internal CLOCK of 48 MHz, where to perform a reading of a sample of the ADC it takes 96 cycles of CLOCK, indicating a maximum speed of 125 kHz for each of the four channels, but we used a default value of 61.55 kHz:

- Channel 1 (ADC0) = Voltage
- Channel 2 (ADC1) = Phase A current
- Channel 3 (ADC2) = Phase B current
- Channel 4 (ADC3) = C Phase current

For the development of the LoRa meter, the ACS712 current sensor was used, an integrated sensor that uses the Hall effect to obtain the measured current in a linear fashion. From this microchip, it was possible to use its module evidenced in Figure 4, to measure currents both in direct and alternating form, with an isolation of up to 2.1 kVRMS.

3.6 ACS712 Current Sensor

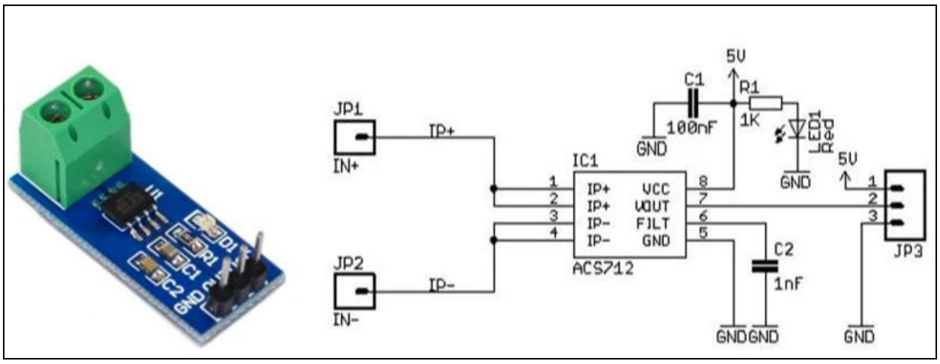

Figure 4 - ACS712 current sensor module.
Source: Adapted by authors, (2022).

In this research, due to the requirement of measuring a high current, the model ACS712ELCTR-30A-T was chosen. This model, as shown in Table 1, is capable of measuring between -30A and +30A, and has a sensitivity of 66 mV/A.

Table 1 - ACS712 chip models.

Part Number	Packing	TA (ºC)	Optimized Range, Ip (A)	Sensitivity, Sens (Typ) (mV/A)
ACS712ELCTR-05B-T	Tape and reel, 3000 pieces/reel	-40 to 85	+/-5	185
ACS712ELCTR-20A-T	Tape and reel, 3000 pieces/reel	-40 to 85	+/-20	100
ACS712ELCTR-30A-T	Tape and reel, 3000 pieces/reel	-40 to 85	+/-30	66

Source: Adapted by authors, (2022).

The sensor datasheet indicates, from Figure 5, the definition of each pin of the module, and its operation is done by feeding the module through the VCC and GND ports, applying a voltage of 5V.

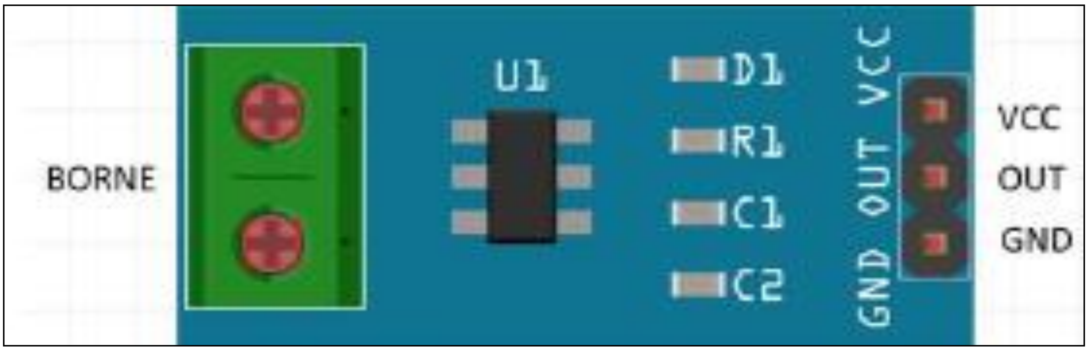

Figure 5 - ACS712 current sensor pins.
Source: Authors, (2022).

The sensor was then placed in series with the circuit where you want to measure the current, as pointed in Figure 6, passing through the internal resistor (Shunt) of 1.2 mΩ that generates a magnetic field measured by the chip through the Hall effect. With this connection, and being powered by the Arduino Nano, the module was connected to one of the microcontroller's analog outputs to perform the analog to digital conversion, using the Arduino's internal A/D that has a 10-bit resolution.

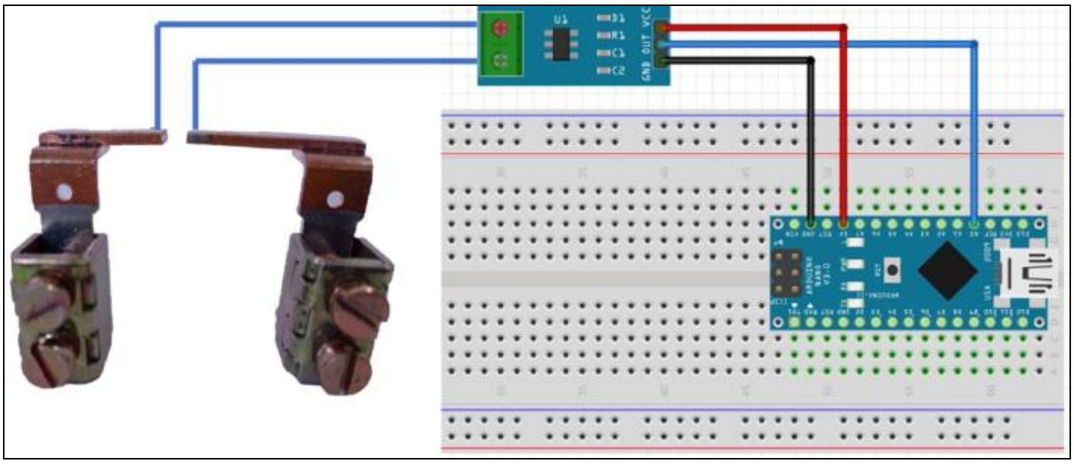

Figure 6 - Connecting the ACS712 with the Arduino Nano.
Source: Authors, (2022).

The shunt circuit is composed of two stirrups, made of steel and a mangaline plate, in which the wires were soldered and installed in the terminals of the current sensor. Through this connection, the circuit for simulating the current measurement was obtained. In order to control the operation of the phases and automatically turn the power grid on and off, a 30A relay module was used, which is controlled by the Arduino's digital ports.

The connection of this relay module, which has two channels and can be triggered either by logic level 5V or 3V3, connected to the digital ports of the Arduino, as shown in. 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 in Figure 7, 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.

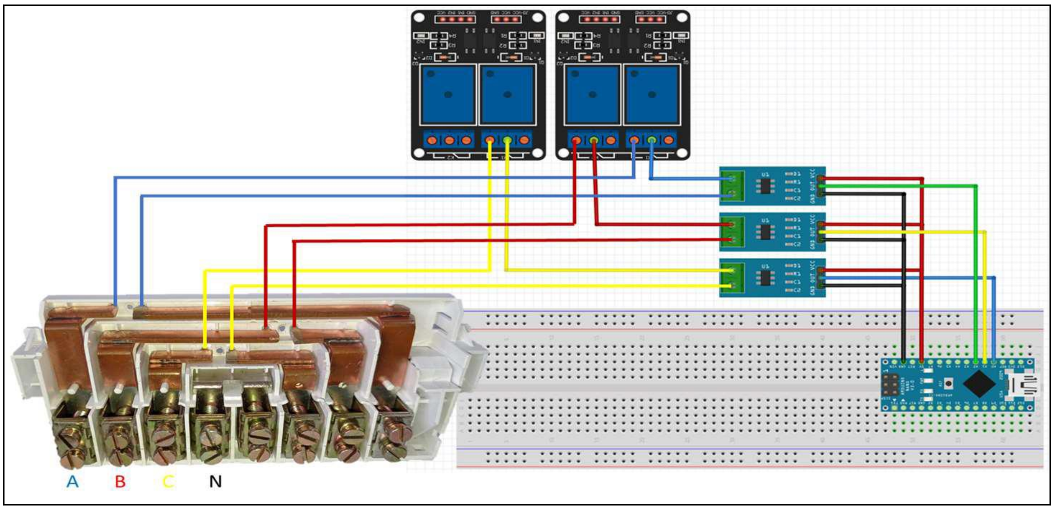

Figure 7 - Complete current measurement circuit.
Source: Authors, (2022).

This configuration was tested on a protoboard, evidenced in Figure 8, with the help of a mechanical part called the main terminal block, which is responsible for connecting the wires that come from the electric network concessionaire, and the output for feeding the phases of the residence or industry, having 3 phases, A, B, C, and the Neutral.

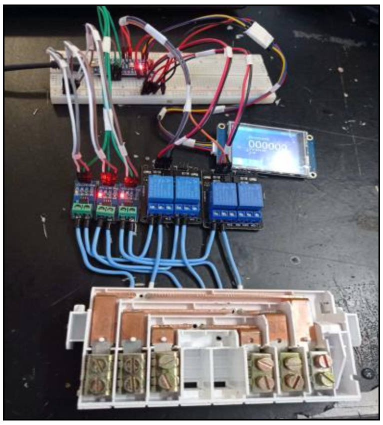

Figure 8 - Current measurement and control circuit tested on protoboard.
Source: Authors, (2022).

With the measurement and control circuitry complete, we started programming the Arduino

Nano, where the firmware responsible for output commands and sensor readings was embedded.

3.7 ESP32 LoRa

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, we used the ESP32 LoRa SX1276 868/915 Mhz module with OLED 0.92" V2, which has as microcontroller the ESP32 from Espressif, which has a high performance for applications involving WiFi, with very low power consumption.

In addition to the ESP32's high performance, it features the semtech LoRa chip, which is characterized by a connection through the LoRa network, with an SMA antenna (U. FL 2 mm), which is one of the newest radio frequency technologies, characterized by low power consumption and communication over long distances, thus being suitable for the most varied projects involving WiFi and IoT networks. It has a frequency of 868/915 MHz and can reach distances.

This project used the ESP32 LoRa microcontrollers 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 on a local disk. The first step was to perform a unit test and perform a communication between the two ESP32s through the LoRa network, initially using the Slave to send a standard data packet, in the form of a counter, as can be seen in Figure 9 and Figure 10.

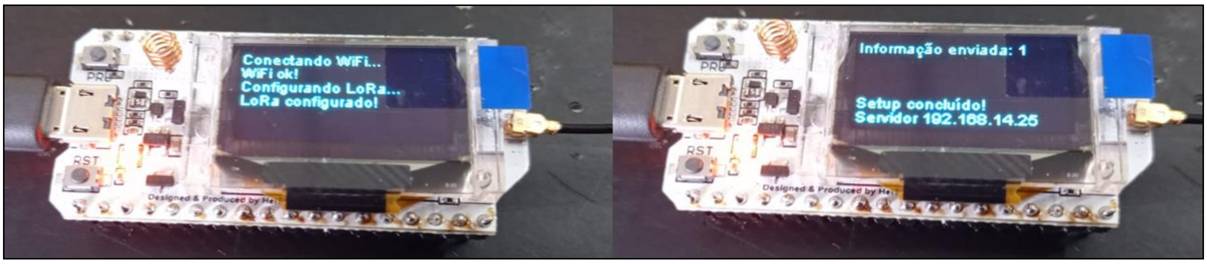

Figure 9 - Data transmission test with LoRa.
Source: Authors, (2022).

Figure 10 - Information being sent via LoRa.
Source: Authors, (2022).

To receive this packet of data sent, another ESP32 LoRa was used, with the sole function of receiving the data sent and showing it on the OLED display screen, and while no data was received, showing the text "Awaiting Data..." on the screen, as can be seen in Figure 11.

Figure 11 - Data reception test with LoRa.
Source: Authors, (2022).

To complete this test, the microcontrollers were separated at various distances in order to verify that the information was being sent and received properly, and by sending a consecutive counter that increased the value every 1 second, it was possible to validate the operation of sending information over the LoRa network. Figure 12 evidences this data passage, but to facilitate the simultaneous visualization, the picture was taken with the two ESP32s close together, where it is possible to see the number 29 being transmitted.

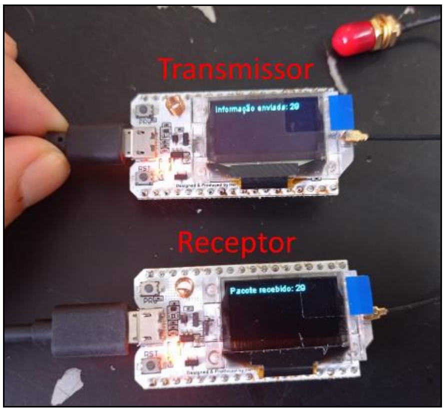

Figure 12 - Emission and reception via LoRa.
Source: Authors, (2022).

With the full operation of sending and receiving data via LoRa, we started to capture the data provided by the Arduino, since it is responsible for capturing the measurements of the current sensors, and calculate consumption, as well as the RMS value (Root Mean Square). This communication is made through a UART communication, i.e., RX/TX, but as the Arduino Nano has only one RX/TX serial input, the "Software Serial" library was used to emulate a UART output programmed in digital ports of the Nano, through ports D02 and D03, as shown in the diagram of Figure 13.

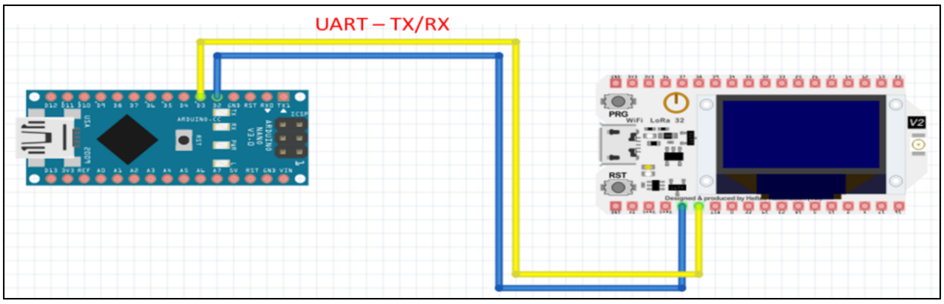

Figure 13 - Communication between Arduino and LoRa.
Source: Authors, (2022).

Putting together all the isolated connections from each part of the development, a large diagram was assembled to illustrate the electronic connections of the LoRa Polyphase meter, as can be seen in Figure 14. The main terminal block has been omitted (for better representation), where the phase currents are measured.

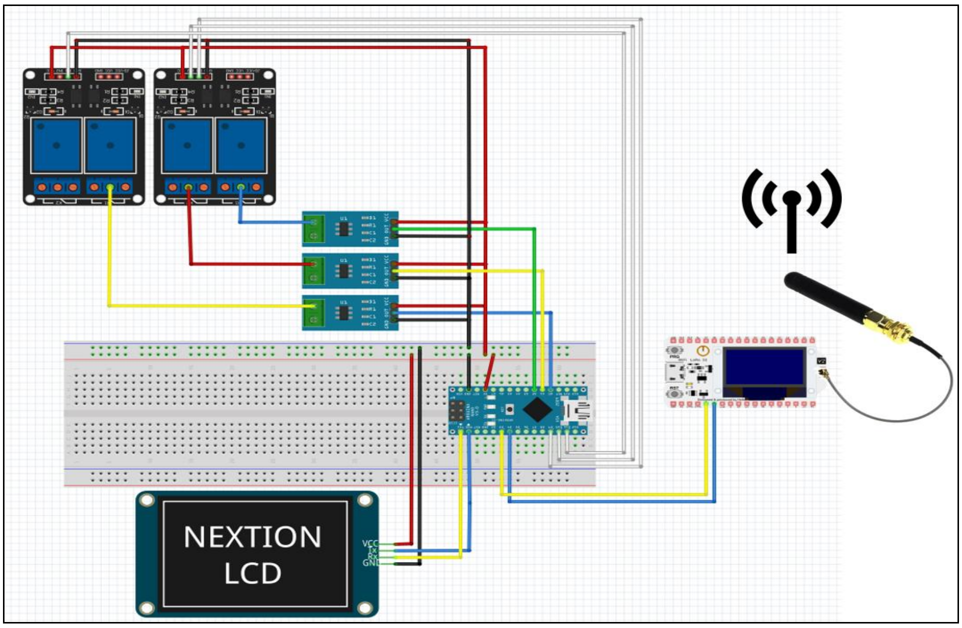

Figure 14 - Complete diagram of the LoRa Multiphase meter.
Source: Authors, (2022).

IV. RESULTS AND DISCUSSION

4.1 Signal Sampling (MATLAB)

To validate the operation of the microcontroller readout, and verify that the measurement is within an acceptable range where voltage and current control can be applied, a voltage and current sample storage program was developed. This is done through a mechanism called DMA (direct memory access), where a reading configuration is sent, and the microcontroller takes care of reading a sample from each of the channels, at a defined speed, and a defined sample size. This mechanism can be seen in Figure 15.

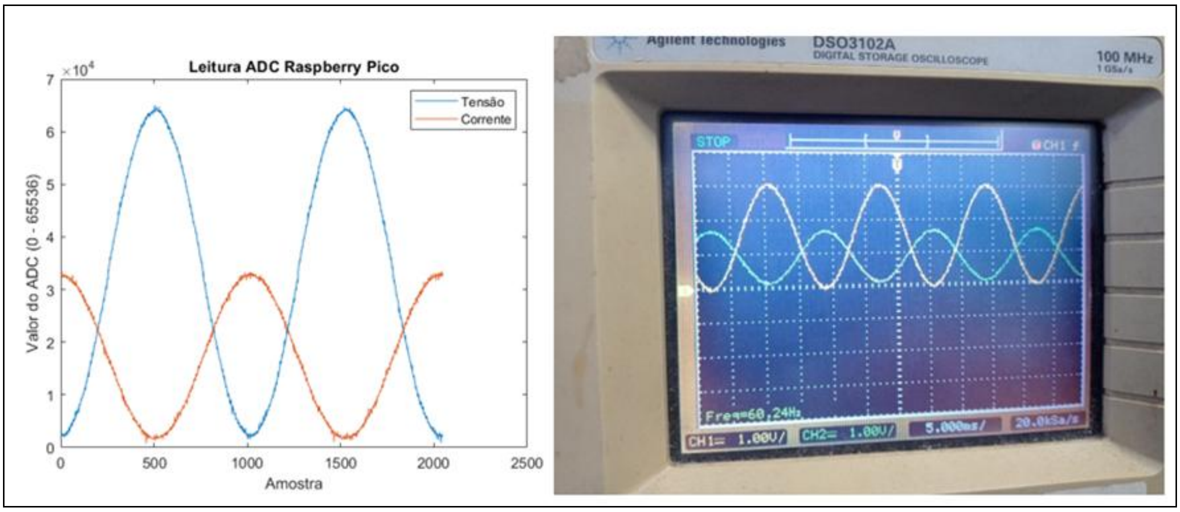

Figure 15 - Comparison of the ADC measurement with the oscilloscope.
Source: Authors, (2022).

This comparison measurement was performed with an Agilent DSO3102A oscilloscope (Digital Storage Oscilloscope), which performs measurements up to 100 MHz, with a sampling rate of 1 GSa/s, compared to the Raspberry Pi Pico which has a sampling rate of 61.44 kSa/s.

Figure 16 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.

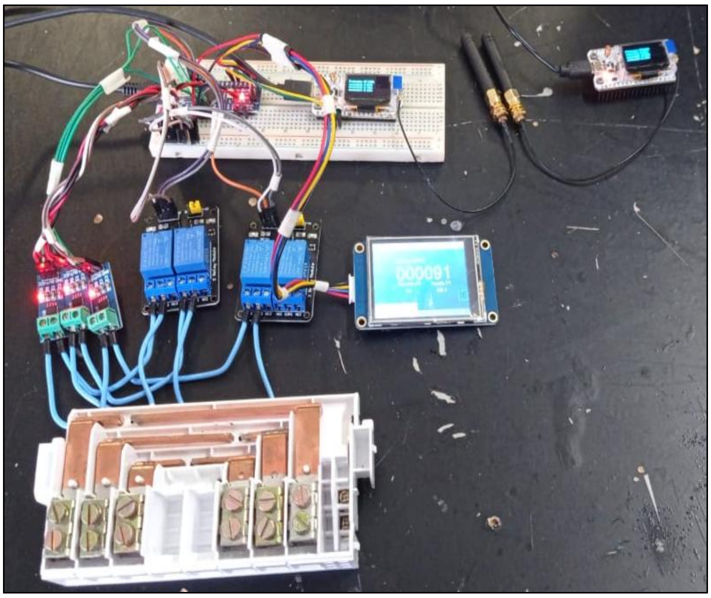

Figure 16 - A complete meter.
Source: Authors, (2022).

After the meter was fully operational, the mechanical assembly of the housing was used to fix the electronic components and modules. Using a small 170-hole protoboard to fix the Arduino Nano, as well as the other modules, all parts were attached inside, as shown in Figure 17.

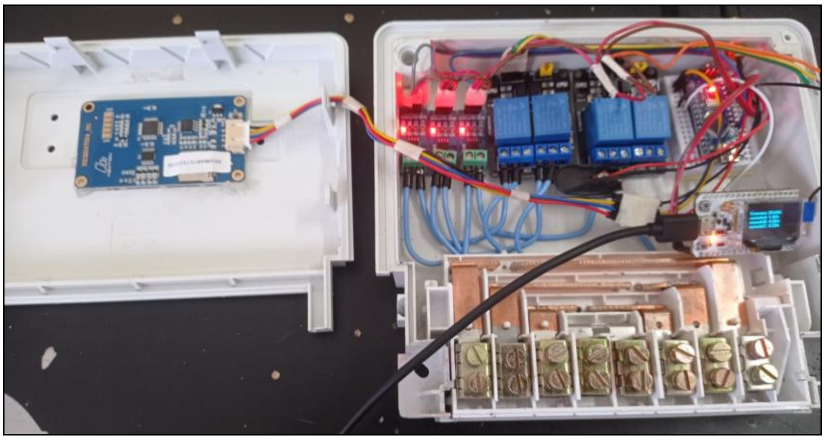

Figure 17 - Transmission and Reception via LoRa.
Source: Authors, (2022).

4.2 Simulation of long distance transmission

To validate the operation of the meter, in relation to transmission over long distances, a fixed position was identified for ESP32 LoRa reception to read the data, which was at the Wasion da Amazônia 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 indicated in Figure 18, and was obtained through Google Maps, using the "Measure distances" tool.

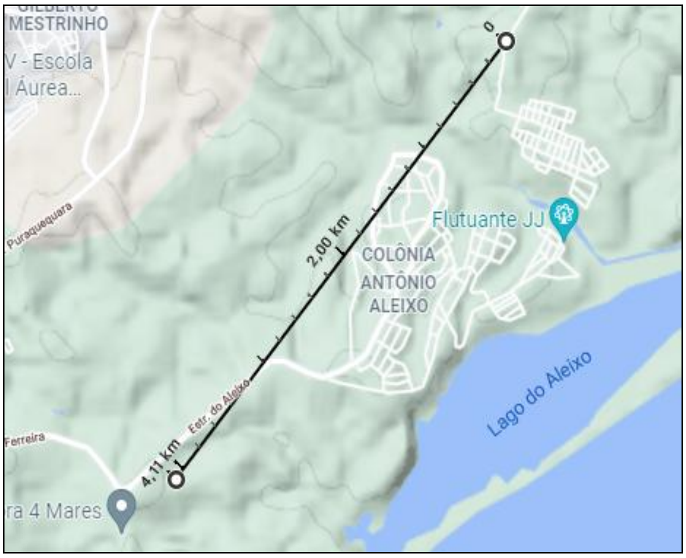

Figure 18 - Maximum distance between emission and reception.
Source: Authors, (2022).

This distance was captured in a sparsely populated region, it is 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 19, which indicates that the data reception location is approximately 85 meters above sea level, and the transmission location is approximately 66 meters above sea level.

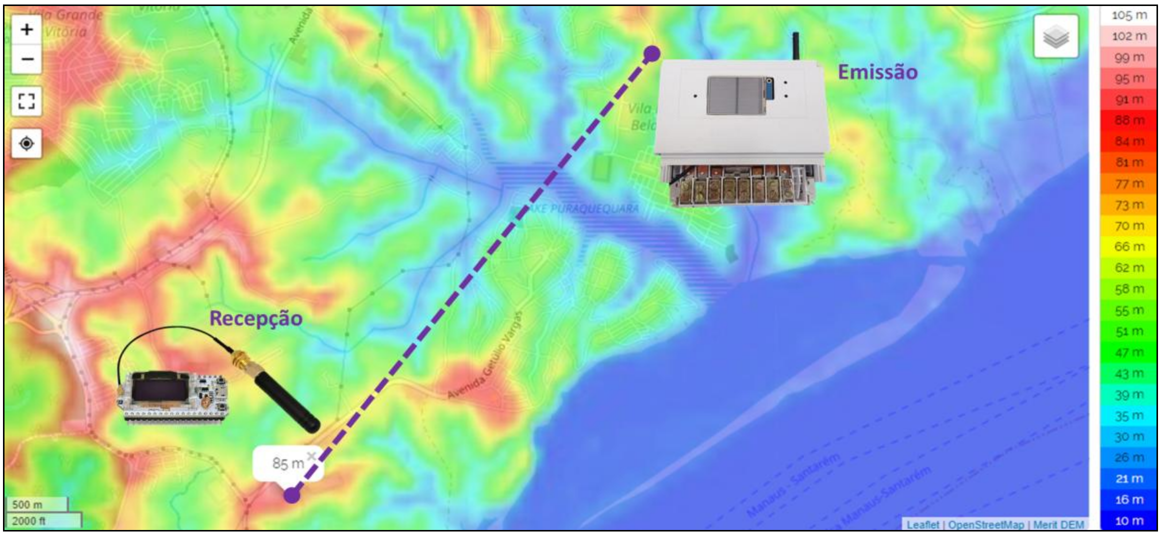

Figure 19 - Topographical map of the measured distance.
Source: Authors, (2022).

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 20.

Figure 20 - LoRa meter sending data over long distance.
Source: Authors, (2022).

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 21 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.

Figure 21 - LoRa receiver receiving information at a distance.
Source: Authors, (2022).

As shown in Figure 21, on the left side there is the prototype meter, the display shows the consumption of 89 kWh, and on the right side there is the ESP32 receiving data from the prototype. 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 1A in phase A, 0.10A in phase B, and 0.20A in phase C.

V. CONCLUSION

Electronic electrical energy meters, are static meters in which current and voltage act on solid state elements (Electronic Components) to produce an output information proportional to the amount of electrical energy measured. These meters are basically composed of transducers, multipliers, integrators, and recorders. With the evolution of the electrical grid, the so-called Smart Grids are emerging in large poles and have the potential to modernize the Electrical Grid, with the use of IoT. This system involves the application of processors, with the purpose 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, interconnected system.

LoRa refers to the communication protocol for LPWAN (Low Power Wide Area Network) networks, with low cost, security, and bidirectional communication. It has a communication range of up to 20 km in rural areas and 4 km in urban areas, and support for redundant operation technologies, free localization, low power consumption, and energy harvesting to support future network needs, while enabling mobility usage features. LoRaWAN has been used in Smart Grid applications mainly for remote metering infrastructure.

In view of this, this paper presented a proposal for the application of LoRaWAN and the ESP32 microprocessor in a prototype of an electric energy electronic meter, creating the possibility of communicating the consumption data of each user remotely. The electronic application was referenced using micro controllers, embedded systems, sensors and shunt circuits.

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