RESEARCH ARTICLE OPEN ACCESS

Implementation of a Supervisory System in Electric Power Generating Units of Isolated Systems Installed In Municipalities of the Amazonas State

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ABSTRACT
This research consists of an exploratory research carried out by monitoring the maintenance activities carried out in the Thermoelectric Power Plants installed in the cities of the State of Amazonas, with the objective of implementing a monitoring system for electrical quantities coming from engines, also called Engenies Electric Power. This is a field research with qualitative approaches, taking into account the implementation of an automated system to capture the variations in electrical quantities (Voltage, Current, Power and Power Factor) of these energy generating units. The capture of these data, which are the variations of electrical quantities, occurs with the use of PLC, transducers, Modem, among other equipment, which are stored in a database (computer) that using a Supervisory System modeled for this purpose, providing the visualization of these data, in real time, in a friendly and interactive interface. From the monitoring of these data, via a Supervisory System, and with the use of data manipulation tools from the SCADA system, an interface for the generation of graphics was modeled, which significantly contributed to the interpretation of these data. And in addition, make it available remotely, to everyone involved in the activities of the plants, thus being able to access the Supervisory System from anywhere in the world, through the internet.

***Keywords*-**Supervisory System, Electric Power Generators, PLC, SCADA System, Thermoelectric Power Plants (TPP).

Date of Submission: 26-08-2021 Date of Acceptance: 10-09-2021

I. INTRODUCTION

It's not from today that we have processes with the need to be controlled, and to have this effective control it is necessary to have an adequate and specific monitoring of the related variables, according to their characteristics and peculiarities. And nowadays, their work routines that besides being optimized, no longer require their total dedication. To this end, supervisory systems have emerged, which allow the data from a process or physical installation to be monitored.

For [1], the first supervisory systems were basically telemetric systems, used to present at all times information or states of a process, in which this information was received without any action from the operator. And together with these systems are the electro-electronic devices that can be applied to computers and/or other devices capable of performing logical operations, such as programmable logic controllers - PLC, micro controllers, etc.

With the rise of automation in industrial processes there is a need for management of the information generated by the process. It is in this context that Supervisory Control and Data Acquisition (SCADA) systems are systems that use software to monitor and supervise the variables and devices of control systems connected through specific controllers (drivers) [2].

Considering that the north of the country, needs a specific management to perform activities related to the generation of electricity in the municipalities of Amazonas, taking into account the distance, access, logistics and the specificities that the state presents, caused by environmental conditions and other constraints of the seasonality of the region. In view of the fact that rivers are the main means of access that traverse the municipalities of the Amazonas territory, some of these municipalities are larger than many European countries.

The authors of this work seek to propose an implementation in the data collection system in electric power generation plants in the municipalities of the State of Amazonas with the use of a supervisory system capable of receiving, processing and displaying in numerical and graphic form the data/measurements, in real time, of the equipment installed in these plants. In addition, with the constant improvement of this implanted process and the use of more equipment that allows the installation and the capture of data from other equipment, it is possible to have a better data analysis that makes it possible to evaluate many more parts of the equipment for the use of maintenance, enabling the anticipation of possible failures that may occur.

However, the automation of the power generation system is essential to achieve high levels of efficiency, greater reliability, and process safety in the generation of thermal energy and in the transformation to electrical energy. Considering that the use of these automation techniques provides the repetitiveness of the operations, resulting, also, in higher quality, flexibility of the system, besides the reduction of production costs, considering that a precise control of the process, results in higher productivity and tends to the best use of the available resources.

On the other hand, it is necessary to evaluate other aspects for this implementation, taking into consideration the peculiarities of the Amazonas region, for example:

- Flooding and ebb and flow of the rivers during the year;
- It takes time to get to most of the locations (municipalities);
- The rivers are the access roads to the locations (municipalities);
- Defined" periods for transporting large loads;
- Disposition of logistics, because the lack of equipment, tools and/or parts has a huge impact on the execution of maintenance and operation services.

II. LITERATURE REVIEW

2.1 Electricity Sector History

The historical period of electricity in Brazil allows us to make different analyses of the various stages it has gone through since its origin until the present day. For this it is important to know that electricity was made available in its early days only to small population groups in the five regions of the country, with greater concentration in the south and southeast, due to the growth of the market. Electricity began to be produced in Brazil in the late years of the 19th Century, almost simultaneously with the beginning of its commercial use in Europe. Participating in this initial organization were small national private companies and companies from municipal governments in small localities that were prominent on the national scene [3].

With this, the Brazilian electricity sector presented a vertical structure involving a generating park at one end, transmission in the middle, and at the other end, distribution. Through a hierarchical structure (holding) the state controlled all phases of the process (generation, transmission, and distribution), however, with the new political-institutional arrangements of the 1990s for the electricity sector, this structure began to change to a model of horizontal integration, that is, there was a change from the hierarchical state structure to another structure based on private companies and free competition in the electricity market. This horizontal structure would have independent generators and distributors and a mixed transmission. During the reforms few transmission lines were privatized, most of them remaining in state hands [4], as shown in Figure 1.

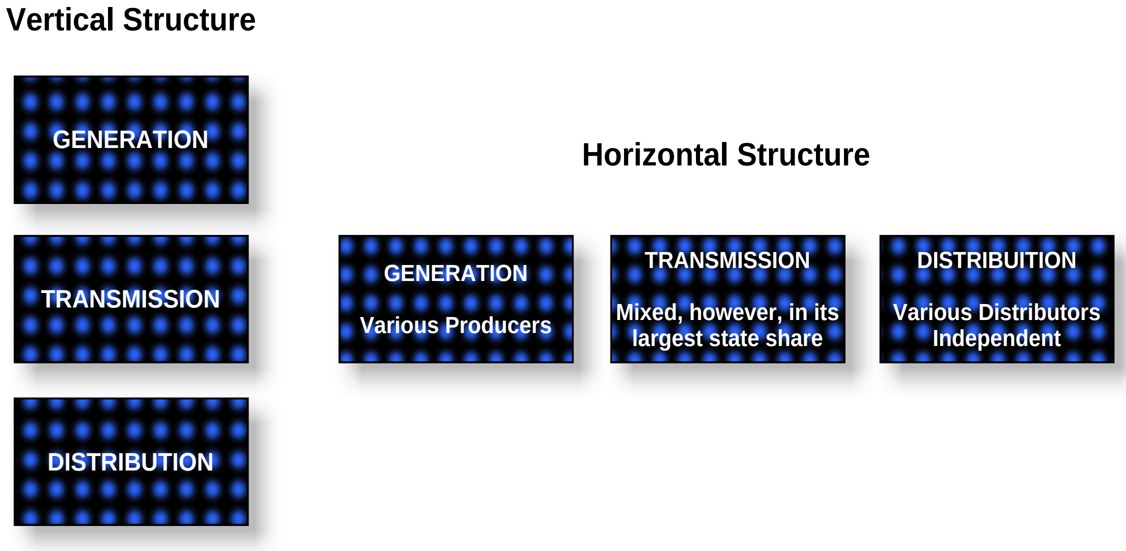

Figure 1 - Electric Sector Structuring Scheme.
Source: [4].

In 2001, the electricity sector suffered a serious supply crisis that culminated in a plan to ration electricity [5]. This event generated a series of questions about the directions that the electricity sector was taking. In order to adapt the model under implementation, the Committee for Revitalization of the Electricity Sector Model was established in 2002, whose work resulted in a set of proposals for changes in the Brazilian electricity sector. Thus, during 2003 and 2004 the Federal Government invested in a new model for the Brazilian electricity sector [6].

2.1.1 – Generation of Electric Energy

Electricity is the easiest way to transport energy for use in manufacturing processes. Electric power generation is the process of transforming any kind of mechanical energy into electrical energy, which occurs in two steps. In the first stage, the machine transforms any kind of energy into rotational kinetic energy. In the second stage, a generator attached to the primary machine transforms the kinetic energy of rotation into electrical energy [7].

Generation Information Bank-GIB of the National Electric Energy Agency (NEEA) is the best official source for the latest information on Brazil's generation park. One can find, for example, installed capacity by source, the number of generation plants by source and by region, and information on plants under construction.

2.1.2 - Electric Power Transmission

The electric power transmission system is responsible for the connection between large power plants and regions of high energy consumption [8]. Thus, the energy leaving the power plants and generators is transported via overhead cables suspended through poles, which are coated with insulating material. Transmission grids are long and cover large distances, at the end of 2014, there were 125,640 km (kilometers) of transmission lines in the National Interconnected System (SIN) [6], an extension equivalent to more than three circles around the Earth. These lines operate at extremely high electrical voltages of tens of thousands of volts. The electricity that is generated in power plants has high voltage and to reduce the losses of this energy during its transmission over long distances, the diameter of the cables is reduced and, therefore, their weight and cost. So lighter cabling also means lighter and less costly structures that support these extensive transmission lines.

The SIN is responsible for the supply of electrical energy to 96% of the national territory. The remaining 3.4% consists of isolated systems located in the northern region of the country that have local hydrothermal and/or thermal systems, as shown in Figure 2 [9].

Figure 2 - Map of the Electricity Sector.
Source: [10].

2.1.3 – Electric Power Distribution

The power distribution system blends with the very topography of cities, branched along streets and avenues to physically connect the transmission system, or even medium and small generating units, to the final consumers of electricity. Before reaching the consumers, the electric power goes through the distribution process, excluding in this case the industrial consumers of high voltages that are directly connected to the transmission systems [11].

Distribution networks are composed of high, medium, and low voltage lines. Although some transmission companies also own lines with voltage below 230 kV, the so-called Other Transmission Facilities (OTF), a large part of the transmission lines with voltage between 69 kV and 138 kV are the responsibility of distribution companies. These lines are also known in the sector as sub transmission lines. Besides the sub-transmission lines, the distribution companies operate medium and low voltage lines, also called primary and secondary networks, respectively. Medium voltage lines are those with electrical voltage between 2.3 kV and 44 kV, without the most common being 13.8 kV and are very easy to see in streets and avenues of large cities, often composed of three overhead conductor wires supported by wooden crosses on concrete posts [12].

Distributed energy, therefore, is the energy effectively delivered to consumers connected to the power grid of a particular utility, and may be aerial (supported by poles) or underground (with cables or wires located under the ground, inside underground ducts). As is the case with the transmission system, distribution is also composed of conductor wires, transformers and various measurement, control and protection equipment for the electrical networks. However, quite differently from the transmission system, the distribution system is much more extensive and branched, since it must reach the homes and addresses of all its consumers.

2.2 – Electric System in the State of Amazonas

The electrification of a region is essential to achieve sustainable development. In view of this development in the northern region, the federal government, through ELETRONORTE, invested in the expansion of the generation parks and the energy transmission systems in the Amazonas, building in this period the hydroelectric plants of Coaracy Nunes (AP), Tucuruí (PA), Balbina (AM), Samuel (RO) to the National Interconnected System (SIN). And as of 2013. And Manaus started the interconnection process, according to structural works, public policies, and also, through the use of Urucu natural gas deposits, for power generation, among others, starting to operate with its share of electricity made available by the SIN.

With the interconnection, the city starts to be supplied by electricity produced by natural gas (NG), diesel, fuel oil and hydroelectricity thermoelectric plants. It is also important to note that for each type of energy production there are environmental aspects involved, as well as social aspects [13].

In the Amazon region, on the other hand, the difficulties are great due to the territorial extension, low demographic density, sparse settlement, dense hydrographic network, numerous flooded areas, and compact forest. As these obstacles occur at different scales, the implementation of the PLpT (Light for All Program), where started by the locations with a possible extension of the distribution networks coming from already existing systems. For the other part, which represents more than half of the territory, the energy will come from isolated generation with a renewable primary energy source. Thus, making possible a positive impact on the improvement of the quality of life and the basic conditions for the exercise of citizenship for this population.

2.2.1 – Historical Survey of Manaus' Energy Matrix: From the Electric Motor to the National Interconnected System

Table 1 shows the historical evolution of the energy matrix over the years, in terms of generation, transmission, and distribution of electric power in the state of Amazonas, from hydrogen gas lighting in 1856, to natural gas (NG) in 2009, to the present day with the National Interconnected System (SIN).

Table 1 – Evolution of the energy matrix.

Year	Energetic	Source	Modal	Installed Power	Finality
1856	Hydrogen gas Lighting	Services sold by undeclared company	The company itself imported the M.P and produced the gas	25 lamps	Illuminate the main points of the city
1870	Lighting kerosene	Services sold by the company Thury & Brother	Import performed by the Service Provider Company	90 lamp0s and candles mounted on wooden poles palms high	Illuminate the most populated and frequented streets in the city
1879	Globe gas lighting (naphtha oil)	Services sold by Manoel Joaquim Pereira de Sá	The entrepreneur himself imported and produced the gas	122 lamps	Illuminate the most populated streets in the city
1896	Thermoelectric plant	The State Government took charge of energy production, supervision f the system	Overhead Transmission Line on Wooden Poles	327 lamps arc voltaic 2.000 candle	The entire urban area of the Municipal Headquarters
1899	Thermoelectric Wood-fired	Services sold by *Manaós Railway Company*	Overhead Transmission Line on Iron Poles	-	Electrically supply electric tram lines
1989	Hydroelectricity	Balbina at the city of Presidente Figueiredo - AM	Overhead Transmission Line of 230 Kv	250 MW	Expand installed generation capacity
2009	Gas Natural (GN)	Urucu at the city of Coari-AM	Pipeline Urucu-Coari-Manaus	5,5 million the m³/day initially, but can be increased if there is demand	Replace fuel oil consumption with natural gas
2013	Hydroelectricity	Tucuruí-PA by the SIN	Overhead Transmission Line of 500 kV	Designated power fluctuates by seasonality	Interconnect the State of Amazonas to the SIN

Source: [14].

The system applied for the production of electricity in the city of Manaus, used the raw material to produce the gas for lighting, which was imported from the United States by sea, the firewood that was extracted on the outskirts of the city and transported by animal traction to the place of consumption. And the fuel oil that fed the thermoelectric system was imported from other states by sea.

2.2.2 – Configuration of the Electric System in Amazonia

In the Amazonas, due to its specific characteristics, the electrical system can be classified as:

• *Interconnected system;*

The State of Amazonas has recently ceased to be the largest isolated power system in the country, with the connection of Manaus to the substations, Figure 3, along the route of the Tucuruí-Manaus lignin, which is designed to transport up to 2,500 MW on its completion. Currently, the electric power system of Manaus and metropolitan regions are supplied with part of this energy generated by the Tucuruí Hydro-Power Complex, while the other part, equivalent to 50% of this energy comes from the recently inaugurated Mauá 3 Thermoelectric Plant, with a nominal generating capacity of 583 MW, in a combined cycle (gas and steam) using natural gas from the Urucu platform, located in the municipality of Coari in the State of Amazonas, 363 km from the capital city of Manaus.

It is worth noting that the Mauá 3 thermoelectric plant is considered strategic by the Federal Government, for ensuring increased reliability in energy supply, acting as a kind of insurance in the recompositing of the Amazon capital's system, in situations of failure in the

National Interconnected System (SIN), besides ensuring the efficient consumption of natural gas from Urucu [10].

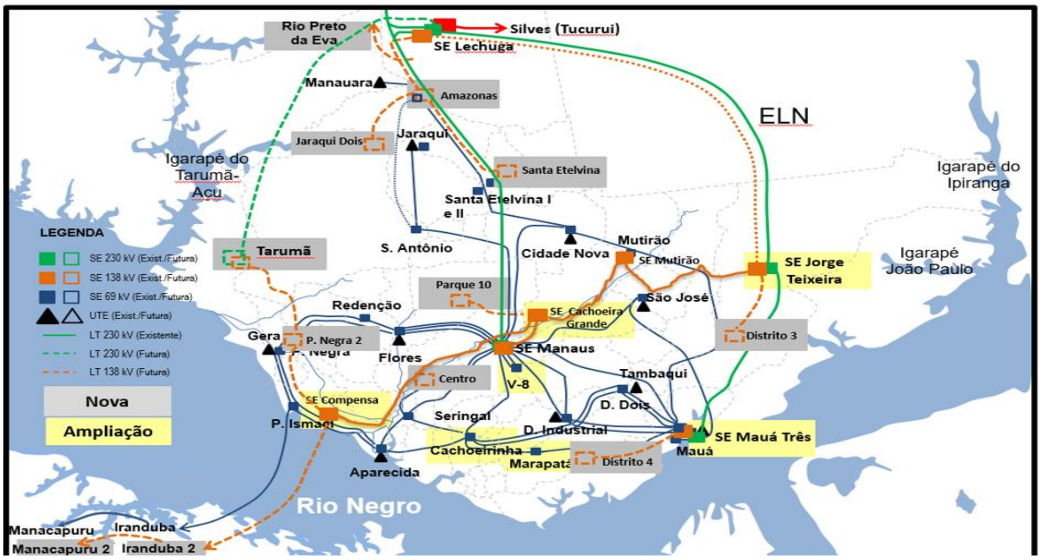

Figure 3 – Interconnected System of the State of Amazonas
Source: Authors, (2020).

• *Isolated System*

In the state of Amazonas there are 89 isolated systems, 1 being supplied by Manaus Energia S.A, and 88 responsibility of the Energy Company of the Amazonas S.A. - CEAM. Figure 4, shows the map of the isolated system of the Caapiranga municipality located 133 km from the capital Manaus.

Figure 4 – Isolated System cities of Caapiranga in the interior of the State.
Source: Authors, (2020).

2.3 – Generator Group

A motor generator set (GMG) is a mix that aggregates a diesel engine with a synchronous generator, also known as alternator, which generates alternating currents and voltages. Its purpose is to provide electrical energy to operate autonomously or in parallel connection with the utility's conventional power grid, through the use of diesel oil as fuel [15][16]. The generation systems with generators can be classified as standby, continuous or prime, depending on how it will be intended to deliver the energy produced and how the applied load will behave, being essential to have the total consumption survey to be met. When a load is connected, immediately a voltage drop occurs, the stabilization of the generator, at this time, occurs by the action of the voltage regulator that increases the field current and the return of the nominal voltage between 1 and 10 seconds [17]. The main difference between the energy consumed from a genset and that coming from the utility is when a load is suddenly connected. The electric grid of the distributor normally does not occur frequency variation, but when connected to a generator, there is a reduction in the speed of rotation of the shaft and, subsequently, the frequency of the GMG is reduced. Figure 5 shows a device designed by the manufacturer Guascor.

Figure 5 - Diesel Generator Set Manufacturer Guascor.
Source: [18].

2.4 – Maintenance

They are necessary measures for the conservation or permanence of something or of a situation. The Norm NBR5462-1994 from ABNT (Brazilian Association of Technical Norms), clarifies that maintenance is a combination of technical procedures, including those of supervision, with the objective of maintaining or replacing an item in a state in which it can perform a required function.

The term "maintenance" has its origin in military vocabulary, where the meaning was to "maintain" combat units at a constant level. It became known around the year 1950 in the United States of America. Due to the fierce international economic competition and the search for increased productivity, maintenance is no longer considered a cost center, but a profit generator, in the countries of the so-called First World. The growth and development of the industry showed the great concern in eliminating failures, identifying them, being indispensable the knowledge of professionals for this analysis and the due orientations of the production maintenance guidelines. Thus, the "Maintenance Engineering" started, which had as attributions the planning and control of maintenance.

2.4.1 – Classification of Maintenance

As the interventions are performed in equipment, systems or facilities can characterize different types of maintenance, being important that the definitions are clear and specific so that there are no misunderstandings about their types, as defined by[19] below:

• *Corrective maintenance*

Performed in an unscheduled way (emergency or urgent) to correct "failures" or "serious defects" in components, equipment, or systems, aiming to restore them to their required function.

• *Preventive Maintenance*

Performed with the purpose of preventing or detecting anomalies, aiming to avoid or reduce the probability of failures and defects in components, equipment or systems, whether main or auxiliary.

• *Non-Systematic (Scheduled) Preventive Maintenance*

It is a type of maintenance aimed at acting on equipment abnormalities even before defects or losses occur. Its main goal is the development of a chain of operations and an elaborate routine system that meets the most diverse activities, including those unscheduled maintenances. Taking into account the period of time that equipment that is part of the production of energy or not (auxiliary systems) is in operation, as determined by the manufacturers' manuals.

• *Predictive Maintenance*

It is defined by the actions that are taken in the machines according to changes in control parameters. Its purpose is to indicate, by means of software and equipment, the working conditions and performance of a machine in real time. Through this control of parameters and metrics it is possible for those responsible for maintenance to monitor the degradation of the equipment. All this will avoid losses for the company. For [19][20]. The main function of a maintenance program is to control the condition and ensure availability in an equipment or system. Thus, it is understood that it is necessary to identify the period for performing maintenance, exchanges and inspections of machinery and other tools used in the maintenance process.

2.5 – Programmable Logic Controllers (PLC)

The Programmable Logic Controller (PLC) emerged due to the needs of the automotive industry. The electromechanical panels for logic control previously used made it difficult to change and adjust their operating logic, making automakers spend more time and money on each change in the production line. For the Brazilian Association of Technical Standards (ABNT), PLC is an electronic digital equipment, with hardware and software that has compatibility with industrial applications. A programmable logic controller, or simply PLC is an electronic system developed especially for industrial use, although today it has other applications such as home automation. It is a computer capable of storing instructions for implementing control functions (logical sequence, timer, and counting), in addition to performing logical and arithmetic operations and data manipulation through network communication, and is used in the control of automated systems [21].

2.5.1 – Advantages of PLC Use

- Cost reduction: due to the large number of relays and the need for maintenance, PLC's are the most viable option;
- Easily configurable: through modular racks, it is possible to exchange input and output modules for each specific need;
- Greater control: because it is a microprocessor-based equipment, it provides the user with the facility to interact with the hardware via software, making it very practical and facilitating the identification of faults;
- Online monitoring: you can have several controllers connected and communicating, and with this connection monitor the processes in real time;
- Resources for real-time processing and multitasking: real-time control that allows greater accuracy in task execution.

2.5.2 – PLC Functional Principle - Block Diagram

The programs of a PLC are always executed in a loop, automatically restarting execution from the first program line. The complete execution of the lines that make up a program is called a scan cycle, as described [22] Figure 6.

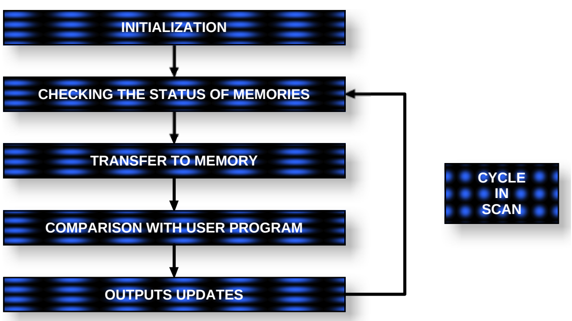

Figure 6 - PLC Operation Structure.
Source: [22].

Figure 6 shows the working principle of a programmable logic controller, with each of the steps being described below:

1. *Scan Cycle*

During its operation the PLC performs sequences of operations called scan cycle. The time it takes to complete a cycle is called Scan Time, manufacturers generally provide the scan time to execute 1024 (1K) Boolean logic instructions. All tasks that are performed by the processor are executed sequentially and cyclically while being powered.

2. *Initializing*

At the time the PLC is running it performs a series of pre-programmed operations, which are recorded in its Monitor Program:

- Checks the operation of the CPU, memories and auxiliary circuits;
- Checks the internal configuration and compares it with the installed circuits;
- Checks the status of the main switches (RUN/STOP, PROG, etc.);
- Checks for the existence of a user program;
- Issues an error beep, if any of the above items fail.

3. *Checking the State of the Inputs*

The PLC reads the states of each input, checking to see if any of them have been triggered. The reading process is called a Scan Cycle and is performed in microseconds (Scan Time).

4. *Transfer to Memory*

After the Scan Cycle, the PLC stores the results obtained in the memory called Image Memory of Inputs and Outputs [23]. It gets this name because of the mirror of the input and output states that will later be consulted by the PLC during user program processing.

5. *Compare with User Program*

The PLC, when executing the user's program, queries the Image Memory of the Inputs, according to the instructions defined by the user in his program.

6. *Update the Output Status*

The PLC writes the value that is in the output memory, updating the output modules, that is, it turns on or off according to its program, until a new scan cycle is started.

2.5.3 – Internal Structure of the PLC

The PLC is a microprocessor system, that is, it consists of a microprocessor (or microcontroller), a Monitor Program, a Program Memory, a Data Memory, one or more Input Interfaces, one or more Output Interfaces, and Auxiliary Circuits, as shown in figure 7.

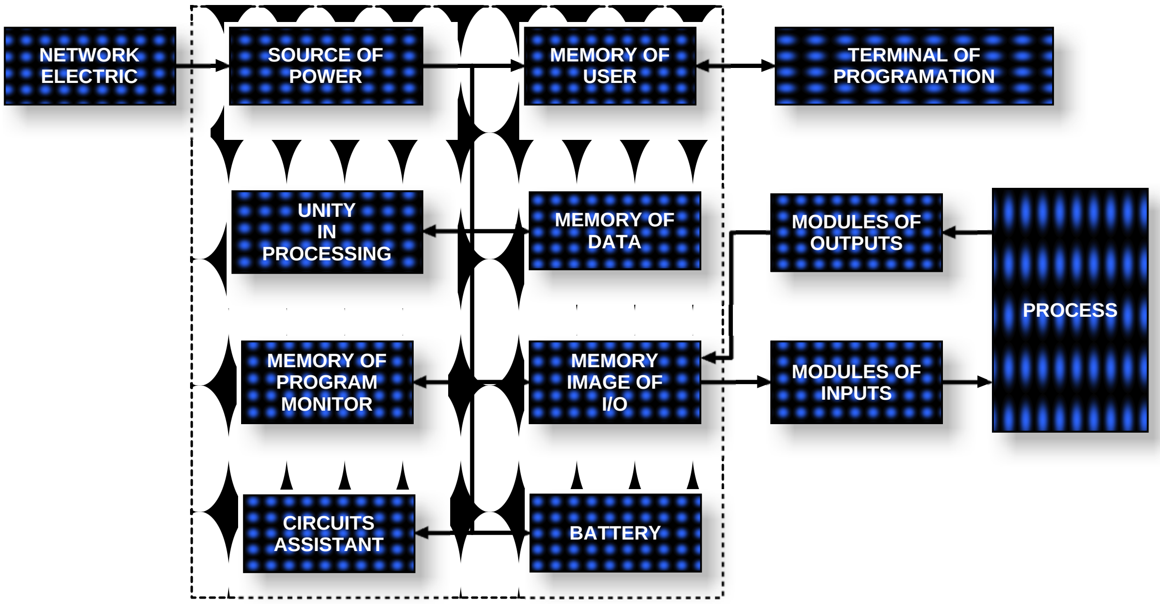

Figure 7 - Internal Structure of the PLC.
Source: [24].

Figure 7 shows the internal structure of the PLC, made up of modules that can easily be replaced if any of them are defective. They are described below:

1. *Power Supply*

Its function is to provide the proper voltages for CPU operation (usually connected to 220 VAC from the mains or 24VDC isolated source) [24]. They are normally designed to provide various supply voltages for the modules and the processor usually requires a 5 VDC supply. Digital input and output modules require auxiliary power for the switching and conversion elements which have the following basic functions:

- Converts the mains voltage (127 or 220 VAC) to the supply voltage of the electronic circuits, (+ 5 VDC for the microprocessor, memories, and auxiliary circuits, and +/- 12 VDC for communication with the programmer or computer);
- Provides voltage for powering inputs and outputs (12 or 24 VDC).

2. *Processing Unit*

The processor's main task is the execution of the program made by the user, as well as others such as communication management and the execution of self-diagnostics programs. To be able to perform all these tasks, the processor needs a program written by the manufacturer, called the operating system. This is not accessible by the user and is stored in the non-volatile memory that is part of the CPU. There are currently PLC's that use more than one processor, being able to divide tasks and thus gain greater processing speed and ease of programming.

3. *Battery*

Batteries are used to maintain the Real Time Clock circuitry, retain parameters or programs (in RAM memories), even in the event of a power failure, and store equipment settings. Usually Ni-Ca or Li rechargeable batteries are used. In these cases, charger circuits are incorporated.

4. *Monitor Program Memory*

The operating system, the input and output modules, and the internal registers are associated with different types of memory. The storage capacity of a memory is quantified in bits, bytes, or words. The operating system is written by the manufacturer and must remain unchanged so that the user cannot access it. It is stored in a memory such as ROM, EPROM or EEPROM, memories whose contents remain unchanged even in the absence of a power supply. The program built by the user and remain stable during the operation of the equipment with easy reading, writing and with the possibility of deletion. That is why RAM or EEPROM type memories are used for storage. In the case of using RAM memories, the use of batteries will also be necessary, because this type of memory goes out in the absence of a power supply. Speed also plays an important role in PLC operation, so RAM memories are used. In this process, the memory is responsible for storing all the information needed for the PLC to operate.

5. *User Memory*

Stores the application program developed by the user, and can be changed, since one of the many advantages of using PLC's is programming flexibility. Initially it was made up of EPROM-type memories, and today RAM-type memories (whose program is maintained by using batteries), EEPROM and FLASH-EPROM are used, and the use of memory cartridges is also common, allowing the program to be changed with the change of the memory cartridge. The capacity of this memory varies greatly according to the PLC brand/model, and is normally sized in Program Steps.

6. Memory Image of Inputs/Outputs

Whenever the CPU performs a cycle of reading inputs or making a change to outputs, it stores the states of each of the inputs or outputs in a region of memory called Input/Output Image Memory. This memory region functions as a kind of "table" where the CPU will get information from the inputs or outputs in order to make decisions during the processing of the user's program.

7. Auxiliary Circuits

They are responsible for acting on PLC failures. Some of them are:

POWER ON RESET: When a digital equipment is energized, it is not possible to predict the logical state of the internal circuits, so that an improper activation of an output does not occur, which may cause an accident. There is a circuit in charge of performing the shutdown the instant the equipment is energized, and as soon as the microprocessor takes control of the equipment, this circuit is disabled.

POWER-DOWN: The inverse case occurs when an equipment is suddenly de-energized, the content of the memories can be lost. For this there is a circuit responsible for monitoring the power supply voltage, and in case it falls below a predetermined limit, the circuit is activated interrupting the processing to warn the microprocessor and store the content of the memories in a timely manner.

WATCH-DOG-TIMER: To ensure that in case of a microprocessor failure, the program does not go into a "loop", thus considered a disaster, for this there is a circuit called "Watchdog", which is activated in pre-determined time intervals, and if not activated, takes control of the circuit signaling a general failure.

8. Input Modules or Interface

These are circuits used to electrically adapt the input signals to be processed by the PLC's CPU (or microprocessor), with two basic types of input: digital and analog.

- Digital Inputs;

They have only two states, on or off, so let's look at some examples of devices that can be connected to them:

- Push buttons;
- Inductive or capacitive proximity sensors;
- Switches;
- Thermostats;
- Etc.

The digital inputs can be programmed to operate in direct current (24 VDC) or alternating current (127 or 220 VAC). They can be type N (NPN) or type P (PNP), which refers to the internal construction of the sensor. In the case of type N, it needs to supply the negative potential (ground or neutral) of the power supply for it to be activated. In the case of type P it is necessary to supply the positive potential (phase). In either type it is customary to have a galvanic isolation between the input circuit and the CPU. This isolation is normally achieved by means of opto-couplers. 24 VDC inputs are used when the identified distance between the input devices and the PLC does not exceed 50 m. Otherwise, the noise level may cause accidental tripping. As shown in figure 8 and 9 with examples of digital input circuits 24VDC and 127/220VAC:

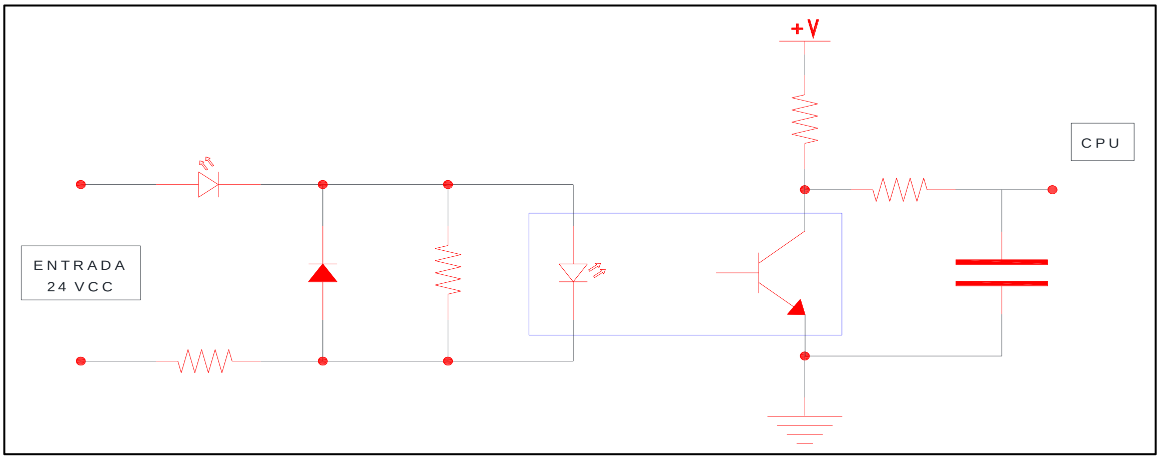

Figure 8 – 24VCC Digital Input Circuit.
Source: Authors, (2020).

- *Analog Inputs:*

The Analog Input Interfaces, allow the PLC to manipulate analog quantities, usually sent through electronic sensors. The analog electrical quantities handled by these modules are usually voltage and current. In the case of voltage the ranges used are: 0 to 10 VDC, 0 to 5 VDC, 1 to 5 VDC, -5 to +5 VDC, -10 to +10 VDC (for the case of interfaces that allow positive and negative inputs they are called Differential Inputs), and in the case of current the ranges used are: 0 to 20mA or 4 to 20mA.

The main devices are:

- Manometric pressure sensor;
- Mechanical pressure sensors (strain gauges - used in load cells);
- Cue - generators for measuring shaft rotation;
- Temperature transmitter;

An important piece of information about analog inputs is their resolution. This is usually measured in Bits. An analog input with a higher number of bits allows a better representation of analog quantities. For example: a 0 to 10 VDC analog input board with an 8-bit resolution allows a sensitivity of 39.2mV, while the same range on a 12-bit input allows a sensitivity of 2.4mV and a 16-bit input allows a sensitivity of 0.2mV. Thus, the higher the bit the lower the mV sensitivity (Figure 10) [25].

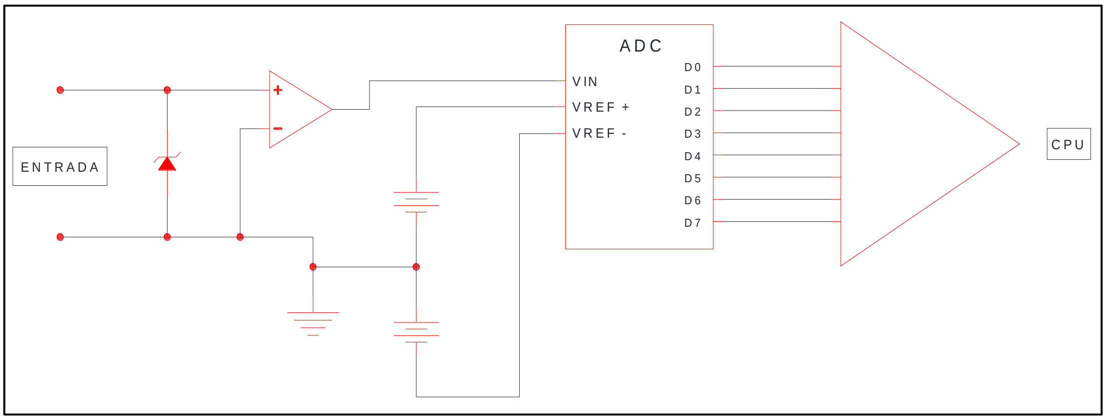

Figure 9 – Analogic Input Circuit
Source: Authors, (2020).

9. Special Input Modules

There are special input modules with very specialized functions. Some examples are:

- Single Phase Counter Modules;
- Dual Phase Counter Modules;
- Modules for Thermocouples (Type J, K, L, S, etc.);
- Modules for Thermoresistors (PT-100, Ni-100, Cu-25, etc);
- Modules for reading electrical quantities (kWh, kW, kVA, kVAr, power factor (cosφ), electric current (I), voltage (V), etc).

10. Special Output Modules

The Output Modules or Interfaces electrically adapt the signals coming out of the microprocessor so that it can act on the controlled circuits. There are two basic types of output interfaces: digital and analog outputs.

- Digital Outputs:

Digital outputs admit only two states: on and off. With them we can control devices, like:

- Relay
- Contactors;
- Solenoids;
- Frequency Inverters, etc.

Digital outputs can be constructed in three basic ways: Relay Digital Output, 24 VDC Digital Output and Triac Digital Output. In all three cases it is also customary to provide the circuit with galvanic isolation, usually opto-coupled as shown in Figure 10 and 11.

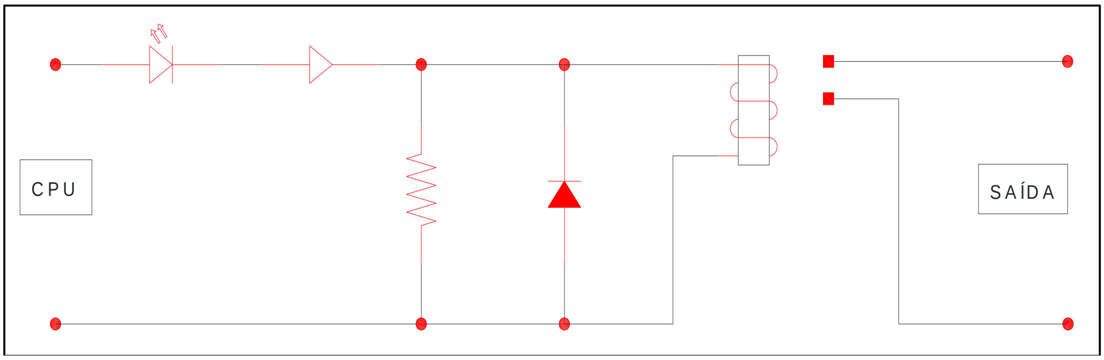

Figure 10 – Relay Output Circuit.
Source: Authors, (2020).

Analog Outputs: The analog output modules or interfaces convert numerical values into voltage or current output signals. In the case of voltage typically 0 to 10 VDC or 0 to 5 VDC, and in the case of current 0 to 20mA or 4 to 20mA.

These signals are used to control actuator devices of the type:

- Proportional valves;
- Direct Current (DC) Motors;
- DC Servo Motors;
- Frequency Inverters;
- Etc.

Figure 11 shows an example of an analog output circuit:

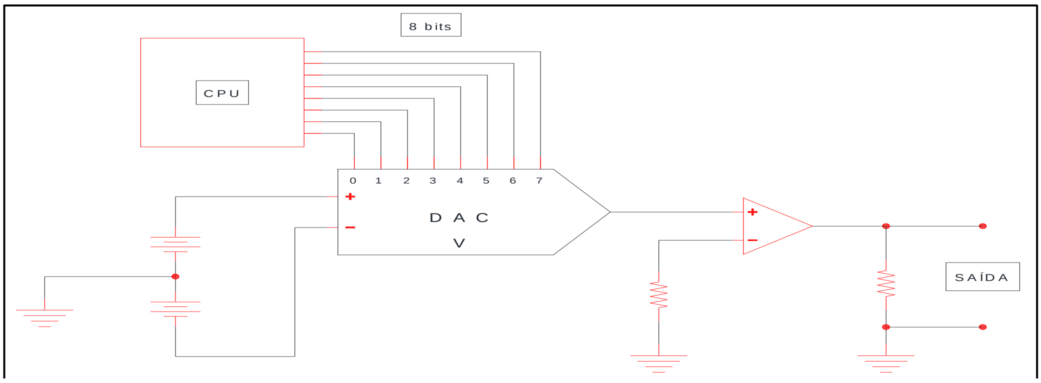

Figure 11 – Analogic Output Circuit.
Source: Authors, (2020).

There are also special output modules. Some examples are:

- PWM Modules for DC Motor Control;
- Modules for Servomotor control;
- Modules for Step Motor control;
- Modules for I.H.M. (Man Machine Interface), and etc.

Analog PLC`s are employed where more precise control with proportional variations is desired, where human presence is only to enter the values to be programmed [26][27].

2.6 – Modbus Protocol

Developed by Modicon Industrial Automation Systems, MODBUS is a network protocol used in PLC systems for signal acquisition and actuator control. Modicon, part of the Schneider Electric group, put the specifications and standards that define Modbus in the public domain, to be used in various existing equipment in order to obtain real-time data [28].

The request informs the addressed device what type of action should be performed. The data field must inform which register should be started and how many registers should be read.

In the check the errors receive a method to validate the integrity of the message content and in the response the code of this function is replicated in the query request. Thus, the data bytes contain the collected data as record values or statuses. If an error occurs, the function code is modified to indicate that there is an error-checking response that allows the master that the message content is valid. At the message level, the Modbus protocol is realized in the point-to-point network communication method [29][30].

2.7 – Supervisory Systems

A supervisory system is responsible for monitoring the variables sampled from the control process of a system. Its main objective is to provide subsidies to the operator to control and monitor an automated process more quickly, thus allowing the reading of variables in real time and the management and control of the process [31].

For [32], supervisory systems enable the integration of various devices and equipment controlling the process. Most of these systems have in common, the need for good knowledge of the industrial process working as operators, because they are the ones who provide the inputs to the systems, such as dosages, recipes and parameters, in addition to analyzing alarms, operating commands remotely and so on. The supervisory systems are located on the third level of the automation pyramid, where it makes a connectivity between the field control (PLCs, frequency inverters, relays) with the process and production management, as shown in Figure 3 [33].

According to [1], there are four basic elements that are part of the architecture of a supervisory system, they are: sensors and actuators, remote acquisition and/or control stations, communication networks and central monitoring. "Supervisory systems are digital plant monitoring and operation systems that manage process variables, these are updated continuously and can be stored in local or remote databases for historical record purposes" [34].

Currently the industrial automation systems use computing and communication technologies to perform the acquisition of data from processes, usually located geographically distant, the respective presentation of these data to the operator is made in a friendly way by a graphical interface with resources which help the interpretation of these.

2.7.1 – Planning a supervisory system

According to [34] essential steps are recommended for the development of a supervisory system, among them are:

- Understanding the Process
- Process Variables
- Planning the database
- Planning the navigation hierarchy between screens.

The understanding of the process is an essential step, where it is necessary to gather a lot of information about how the process will happen, for this talking to operators and experts helps to understand the needs, minimum requirements. After forming a solid idea about the process, separate it into parts and create a block diagram in order to understand all the interactions between the parts and get an idea of the amount of information exchanged between them. And to obtain a more efficient and secure data transfer between remote and central station, an identification process known as "tagging" is applied [35]. Next must be done the planning of the database, an essential part of a supervisory system, in view that the history of process information will be stored in this, and this should be made thinking about presenting only the essential data of the process so that the supervisory becomes concise, because a large traffic of information can harm the overall performance of the system.

"The database preparation should take into account that no matter how fast your system is, an optimized database represents greater efficiency of data exchange, allowing for shorter update times and less chance of future problems" [34].

III.MATERIALS AND METHODS

3.1 – Research Methodology

According to [36] methodology is the discipline that enables the methods available for a given research, i.e., it is the execution of work based on techniques and processes aiming at the construction of a given knowledge.

To didactically substantiate the Figure 12 shows the flowchart of the methodology, starting with a literature review based on authors in the areas corresponding to the theme, as well as the exploratory research that allowed interviews with experienced operators in loco during the maintenance performed on this equipment.

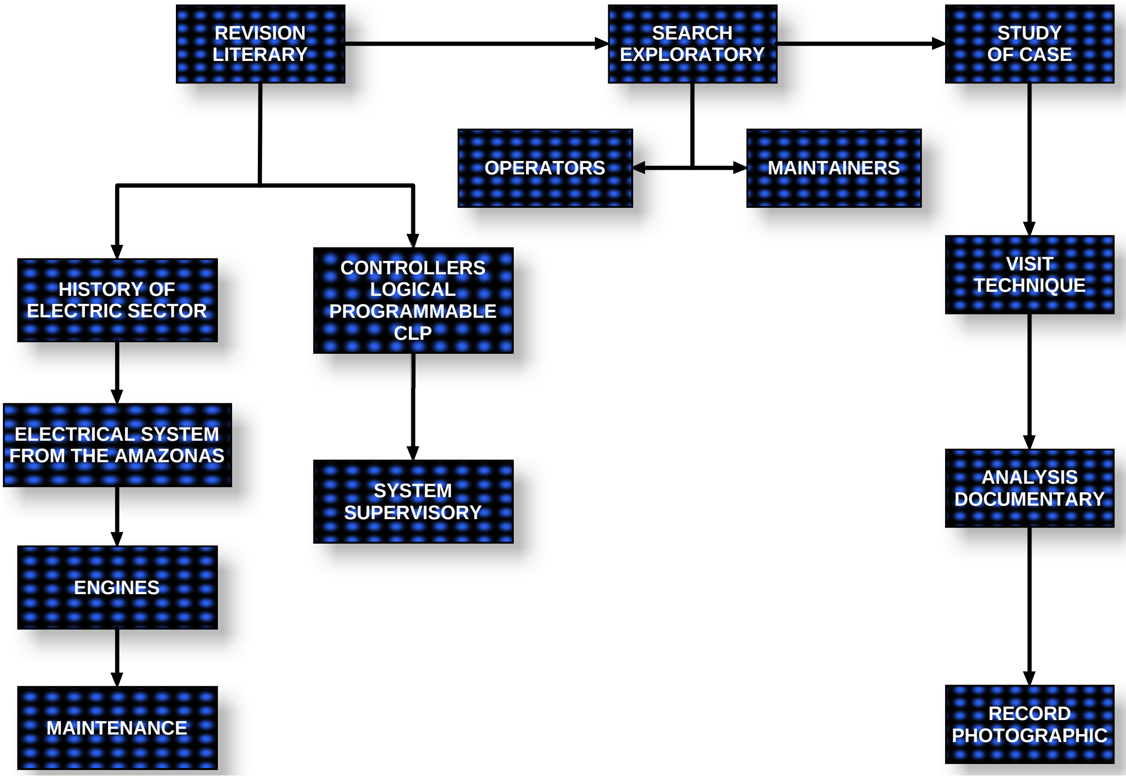

Figure 12 – Flowchart the Methodology.
Source: Authors, (2020).

3.1.1 – Bibliographic Research

In the teachings of [37], "the bibliographical research is prepared from previously published material, consisting mainly of: books, publications, scientific articles, monographs, dissertations, aiming to put the researcher in direct contact with all the material already written on the subject of research, [...]" and based the necessary information about the Energy; The history of the Brazilian Electric Sector; The configuration of the Electric System in the Amazon; Generating Units; Maintenance; Programmable Logic Controllers; Supervisory Systems, and other topics belonging to the structuring of this monograph.

3.1.2 – Exploratory Research

According to [38], it is configured with the preliminary phase, aiming to provide more information on the subject that will be investigated in a panoramic way, providing greater familiarity in the processes involved and with the systematic problem, and moreover, enabling the delimitation of the subject researched. Associated with this line of research, we adopted the model of part of the processes inherent to the generation of electricity from a thermoelectric power plant installed in a municipality in the state of Amazonas related to data collection.

3.1.3 – Case Study

For [37] case study "involves the deep study of one or a few objects in a way that allows its broad and detailed knowledge, has research methodology classified as Applied, in which it seeks the practical application of knowledge to solve problems, [...]".

For this case study, it was chosen the Thermoelectric Power Plant of Barreirinha municipality located in the interior of the state of Amazonas, located about 331 kilometers from the capital Manaus, where visits were made in order to "raise" information that would meet the realization of this work, taking into account the daily activities performed by maintainers, operators and other employees who work at the plant, as well as information from the equipment installed in this environment as: engines, generators, boilers, electrical systems, mechanical, pneumatic and logic systems (PLC). And in the context of this case study, the specific activities of reading and measuring electrical quantities used for the implementation of a supervisory system.

3.1.3.1 – Characteristic of the Plant's Generating Unit

Five (5) Guascor engines, model SFGLD360, OTTO cycle, with 16 "V" cylinders, internal combustion, nominal rotation of 1,200 rpm, are installed in the plant of this power plant in the municipality of Barreirinha. Coupled to the motor shaft is an electric generator manufactured by Leroy Samer, model LSA 50.2, six-pole self-excited, brushless, with apparent power of 594 kVA, three-phase 440 V supply voltage, power factor 0.8, and frequency adjusted to 60 Hz. These generating units are fed by natural gas, via the city gate of the company Petrobras, located next to the plant of this plant, providing the use of this fuel at pressures, volumes and temperatures ideal for the operation of these engines. Figure 13 shows the equipment installed in the plant.

Figure 13 – Generator Set the UTE.
Source: Authors, (2020).

3.1.3.2 – Operation and Maintenance

The operation in a thermoelectric power plant is performed at different levels of responsibility. This operation between two hierarchical levels such as: the operators of a local plant, being the first instance of operation and who receive the name of maintenance operators, because they perform the activities in the main systems and in the auxiliary equipment of the systems that generate electricity. In addition, they also read and interpret data, measure flows, read, measure and write down electricity quantities, check equipment and indicators to detect evidence of operational problems, and, if necessary, can make commands locally or remotely on the equipment. In the immediate operation level are the maintainers, who have a technical education and qualification that differentiates them from the operator. Besides this, they are capable of evaluating the availability of equipment to recompose the system, as well as ensuring the physical integrity and good operation of the installed equipment, following the procedures and operation instructions specified for this equipment, from small actions of opening miniature circuit breakers in panels, to lack of voltage alarms in motors, problems in auxiliary services, communication failures with field equipment, among other activities pertinent to the full operation of the plant's equipment.

However, in this line of activities, it can be observed in Figure 14 the execution of electrical and mechanical services performed by the maintainers, following the procedures and regulatory standards for the performance of these services, both related to technical processes and especially the safety ones. For, unlike other thermoelectric plants installed in the interior of the Amazonas, this plant in question is far from the urban center of the city.

Figure 14 – Maintainers working in equipment maintenance.
Source: Authors, (2020).

Thus, most of the activities in a plant have the risk of accidents, whether electrical, mechanical, high altitude, burns, among others. However, and no less important, we have to take into consideration the plant's facilities, because as it is located in a municipality in the state of Amazonas, in this case study in Barreirinha, the proximity to the forest area is critical, because there are several types of risk, such as

- insect bites;
- stings from venomous animals;
- attacks from carnivorous animals, and etc.

And as reported by several employees, there have already been several incidents related to these animals (Figure 15).

Figure 15 – Access to the plant via river.
Source: Authors, (2020).

From another perspective, we have the proximity of these plants with the riverbed, because it is a matter of logistics of the plant the use of rivers, in view of the receipt of equipment, tools, lubricating oil, among others, and the employees themselves (employees) use to access the plant in situations when the rivers are full (downstream) shown in Figure 16. However, the period when the rivers rise also brings with it the proximity of reptiles in the plant's environment.

On the other hand, also, as a work routine of these maintainers who are fundamentally important in the processes of electric power generation of the plant is obtaining the measurements of electrical quantities of equipment, which initially occurred manually, i.e., the information was captured from the panels of equipment readings and transcribed the values of these quantities to a printed worksheet, as shown in Figure 16. However, it is worth mentioning that this manual activity was routine in the plant and that became the focus of this case study, which deals with the feasibility of implementing a system that could perform this activity in an automated way, and that transcribed in a digital and safe environment the data from the measurements of these electrical magnitudes in real time, and that in addition, could be treated and subsequently generate graphs of each of these magnitudes collected, enabling better analysis and decision-making.

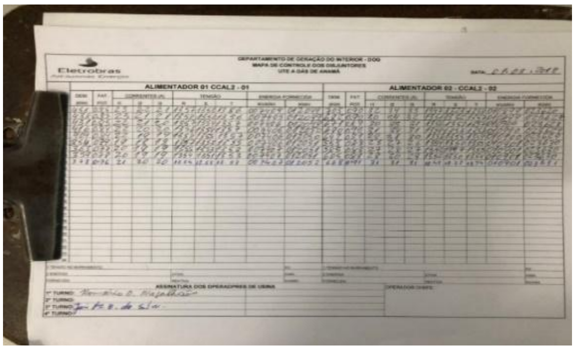

Figure 16 – Notes of Electrical Quantities of Feeders Collected by operators.
Source: Authors, (2020).

3.1.3.3 – Supervisory Control and Data Acquisition - SCADA

The SCADA system's generated interface uses communication to collect, monitor, and control data from the generating units via MODBUS communication and enables the respective interaction of these processes in an intuitive way for the operators/maintainers available on a computer, figure 17 (supervisory) [38].

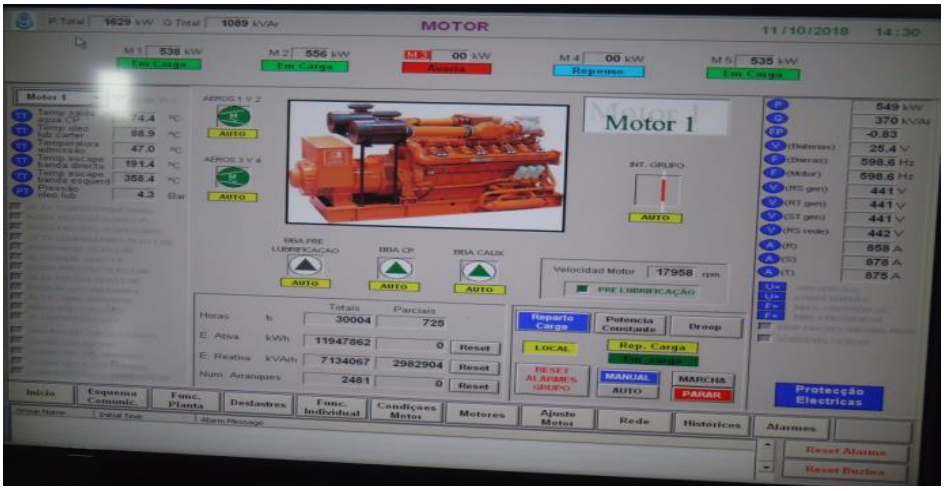

Figure 17 – Operational Command Panel.
Source: Authors, (2020).

From another point of view, in the generating units and in their auxiliary systems, several analog equipment's are installed, especially the pressure gauges, for example, highlighted in red, which during preventive maintenance, we sometimes find divergences, leading to a condition of doubt in the readings, when the comparison is made with the measurements of the supervisory system, figure 18. What makes for operators and maintainers a doubtful situation, because the activities of monitoring the readings of this equipment are of great importance for the proper functioning of the equipment and, moreover, influencing the decision making and especially the possibility of an aggravating accident occurring in the plant.

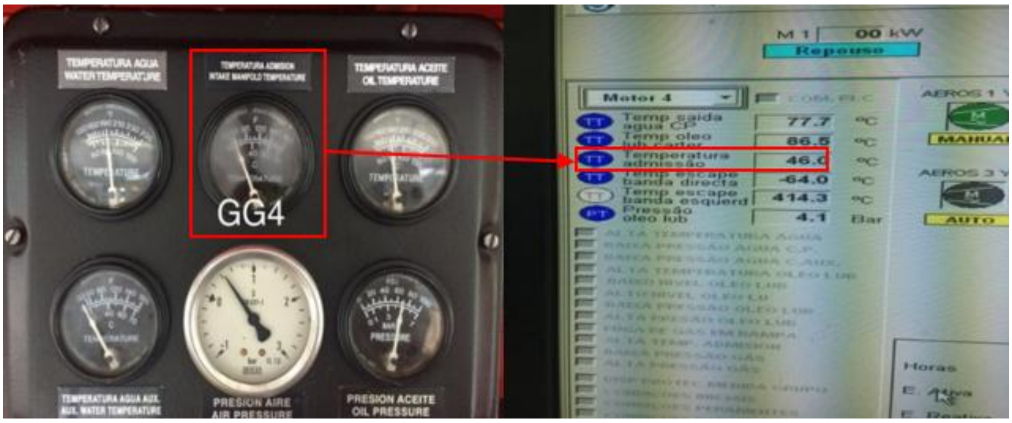

Figure 18 – Verification of Digital and Analog Measurements.
Source: Authors, (2020).

IV. STUDY APPLIED TO THE IMPLEMENTATION OF THE SUPERVISORY SYSTEM

During the technical visits to the city of Barreirinha to perform the maintenance of the generating units, information was analyzed and collected taking into account the characteristics and specificities of the generating units of that city, in view of the need to obtain information that directly impacted the rates and results of electricity generation (electrical magnitudes) of this plant in relation to the recurring activities of the maintenance of this equipment. Thus, these "captured", "modeled", "tabulated" and "graphed" data would be displayed in a supervisory, which in addition to this purpose, would be transmitted, enabling further analysis of performance, adverse or not, of the electrical quantities in question.

On the other hand, to make this supervisory activity possible, the tables and graphs became essential for these types of analysis. And for this, it was necessary the intervention of the Informatics Department, which, with technical knowledge and programming methodologies, developed activities in this environment that supported this data, enabling the operation of this implementation. Thus, the system's interface should display the system's information in a way that the end user could be familiar with the system, and the system's interface and the screens created for navigation were defined together with the operators, presenting the data in a clear and organized way.

4.1.1 – Initial Supervisory Interface

The access module to the supervisory system allows you to view the data from the database captured by the Programmable Logic Controller (PLC) which are available for import, thus enabling the flexibility of the use of such data by the user. And as a standard security mode of the company, access to the system starts with a login interface, as shown in Figure 19, where the user, in this case the operators and maintainers, has restricted permission to access this platform. Taking into account that this data is reserved and cannot be exposed to any other type of user, which could make this process vulnerable.

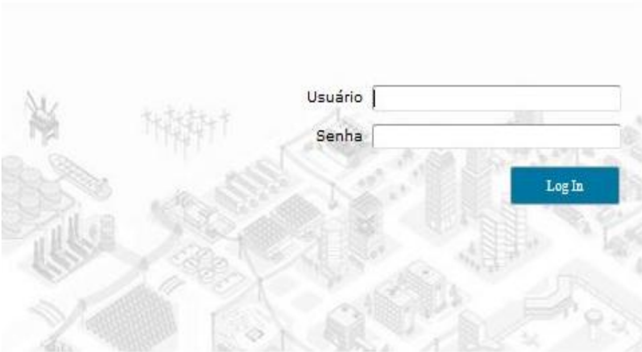

Figure 19 – Initial System Interface.
Source: Authors, (2020).

4.1.2 – Navigation Interface

The navigation interface shown in Figure 20, displays the geographic map of the State of Amazonas as the initial screen of the supervisory system, and through this map we used the river channels as divisions for the database environment, with distinct nomenclatures for each region. In this way, each channel is related to its respective municipalities, which, registered in the database, have their own organizational structure defined for the generation and distribution of electricity. For accessibility reasons, the implemented system enables the communication in several equipment's of various platforms, requiring only an internet connection.

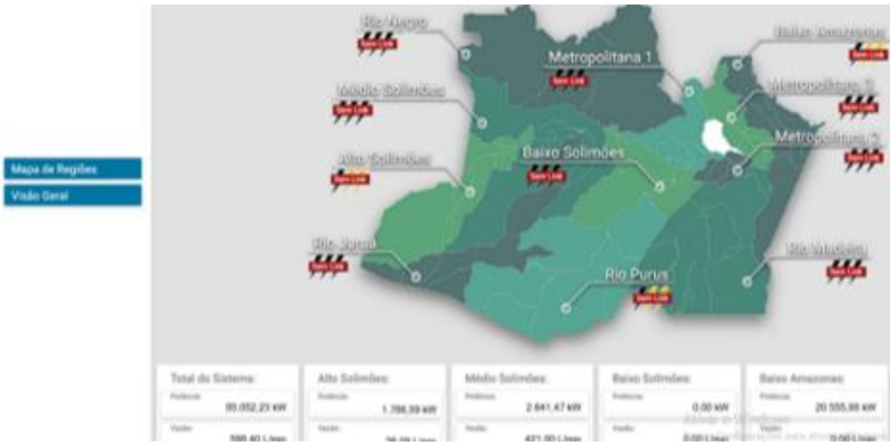

Figure 20 – Navigation Interface.
Source: Authors, (2020).

4.1.3 – Interface to Lower Amazonas River Channel

The access to the Lower Amazonas River Channel link, in figure 21, displays their respective municipalities related and organized in this interface, although some measurements are previously displayed, among them the measurements of the Total Active Power (KW) captured by each municipality, the Regional Total (KW) that represents the sum of the Active Power of each listed municipality, and, in some municipalities, the measurement of the specific consumption (L/kWh), in real time.

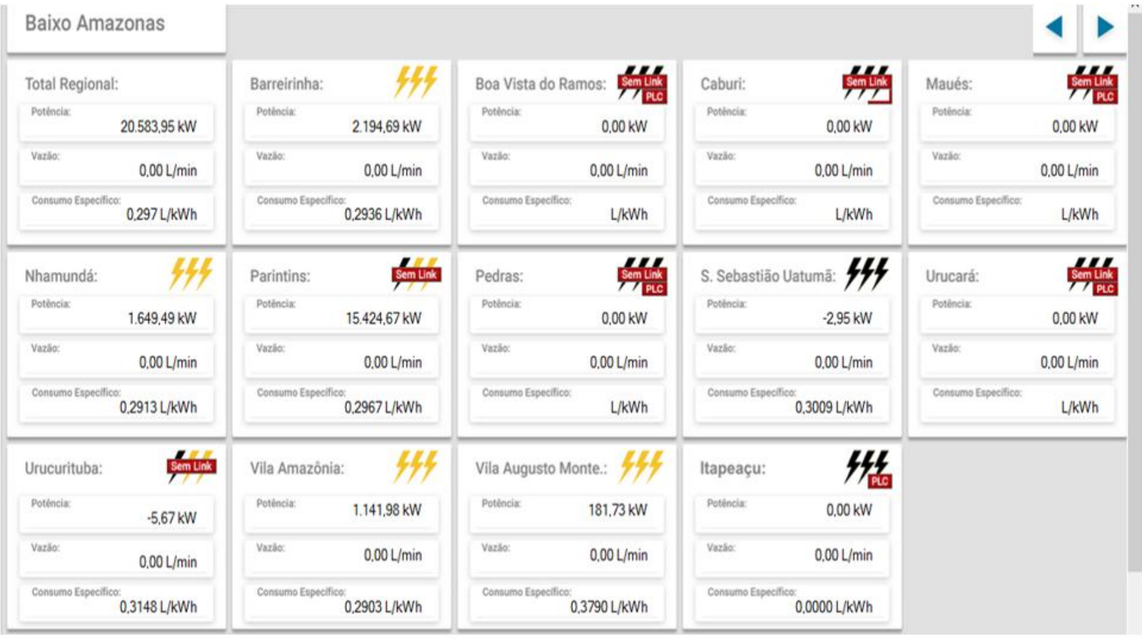

Figure 21 – Energy Measurements of the City of Lower Amazonas River Channel.
Source: Authors, (2020).

In a didactic and intuitive way, a symbology was adopted to represent, in an interactive way, the communication via Internet or the absence of it and the communication of the equipment that performs the capture and measurement of electrical quantities via PLC. Beside each symbol there is the corresponding description of the legend for the understanding of the operation of this process.

All Feeders Energized;
All Feeder De-energized;
Partially Energized Feeders;
PLC No PLC Communication;
Sem Link No Internet Connection.

However, of the municipalities related to the Lower Amazon river channel, the functionality of the supervisory was used as a demonstration, with the reading of the measurements of electrical magnitudes captured at the site of electricity generation in the municipality of Barreirinha. It is worth noting that the same interface structure is used for the other municipalities of this and the other waterways.

4.1.2.1 – Lower Amazonas River Channel - Municipality Barreirinha

The interface of figure 22 shows the visualization of the measurements of electrical quantities such as active and reactive power, current, and voltage, based on the installed generating units, as well as the readings of the measurements of fuel oil levels and specific consumption in the supervisory system.

Figure 22 – Energy Measurements of the City of Barreirinha.
Source: Authors, (2020).

4.1.2.2 – Feeder Interface 01

Figure 23 illustrates the measurement readings of the electrical quantities specific to the circuit called feeder 01, which were captured and displayed in the supervisory interface 04BAM_01_Barra_ALP01.

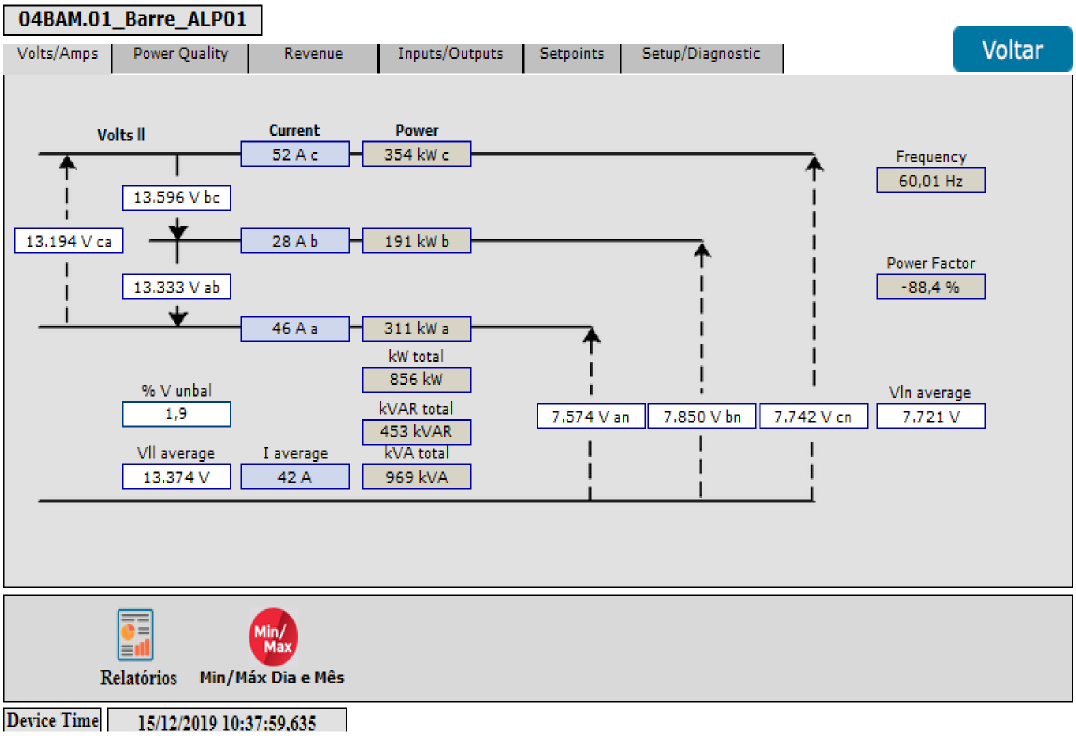

Figure 23 – Energy Measurements of the Feeder 01.
Source: Authors, (2020).

In this same interface, two buttons are also available for different accesses:

This icon enables the Data History Record interface, of the electrical quantities (Voltage, Current, Power/Energy and Frequency/Power Factor), captured from the PLC and available for navigation. However, in the next section the functionality of this interface will be discussed in detail;

This icon will enable the supervisory interface for Registering Maximum and Minimum Peaks of the measurements of the electric quantities, highlighted:

- - Active Power (kW);
- - Reactive Power (kVAr);
- - Average voltage - VII avg (V);
- - Frequency (Hz).

4.1.2.3 – Logs Interface Feeder Data History 01

As shown in Figure 24 of the interface 04BAM_01_Barra_ALP01, there are 5 search options for analyzing the measurements of the electrical quantities captured from feeder 01. However, due to system access limitations, 4 options of this interface will be analyzed:

- Voltage;
- Current;
- Power/Energy;
- Power Factor / Frequency.

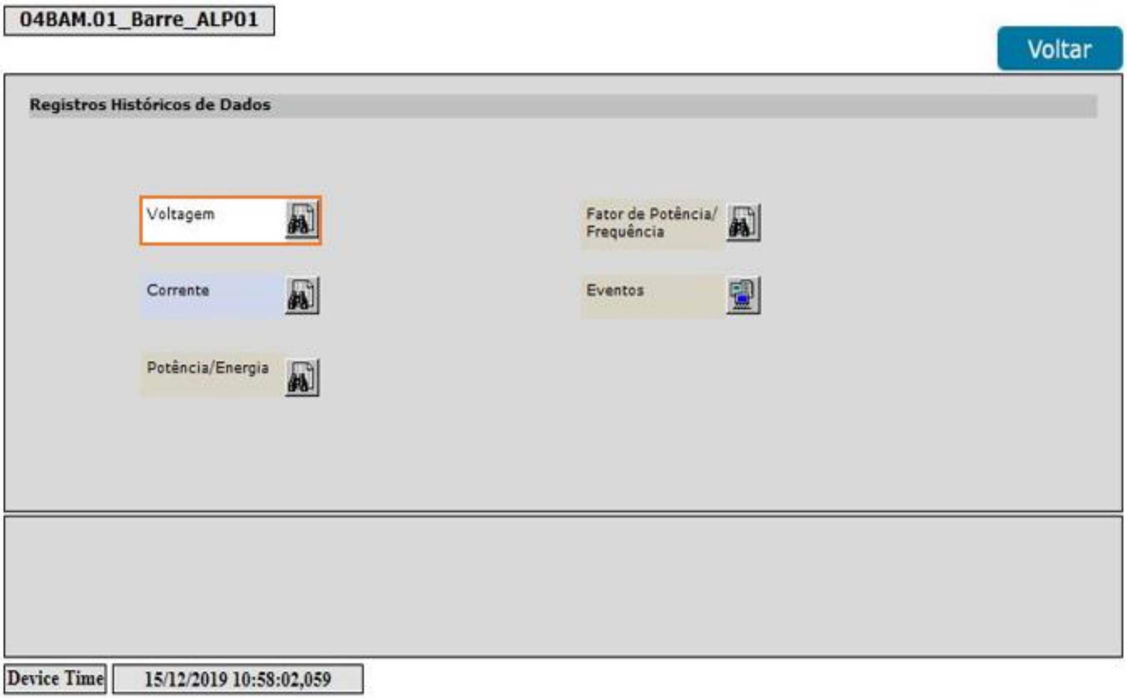

Figure 24 – Historical Data Records
Source: Authors, (2020).

After clicking on the Voltage option in red, you have access to the data from the measurements captured from one of the feeders of this power plant, represented in various scenarios, with the purpose of better visualizing these events.

4.1.2.4 – Feeder 01 Periodic Reporting Interface: Voltage, Current, Power and Frequency Factor

In this item, the interfaces of the options: Voltage, Current, Power and Frequency Factor will have the same structure in the interface **Report by Period** shown in Figure 25, obtaining results of great relevance, since in this interface there is the possibility to access the history of captured data to perform the analysis of these variations that occurred in this feeder over the course of the selected periods, or even customize the period to be analyzed. This theme brings a proposal, even if in a primary and limited way, a perspective on understanding the variations in the behavior of these previously mentioned electrical magnitudes, for possible causes of problems that occur in the generating unit itself, reflecting in small improvements that can improve the procedures in the interventions of the maintenance of the generating units and minimize the time in normalization of the generation system.

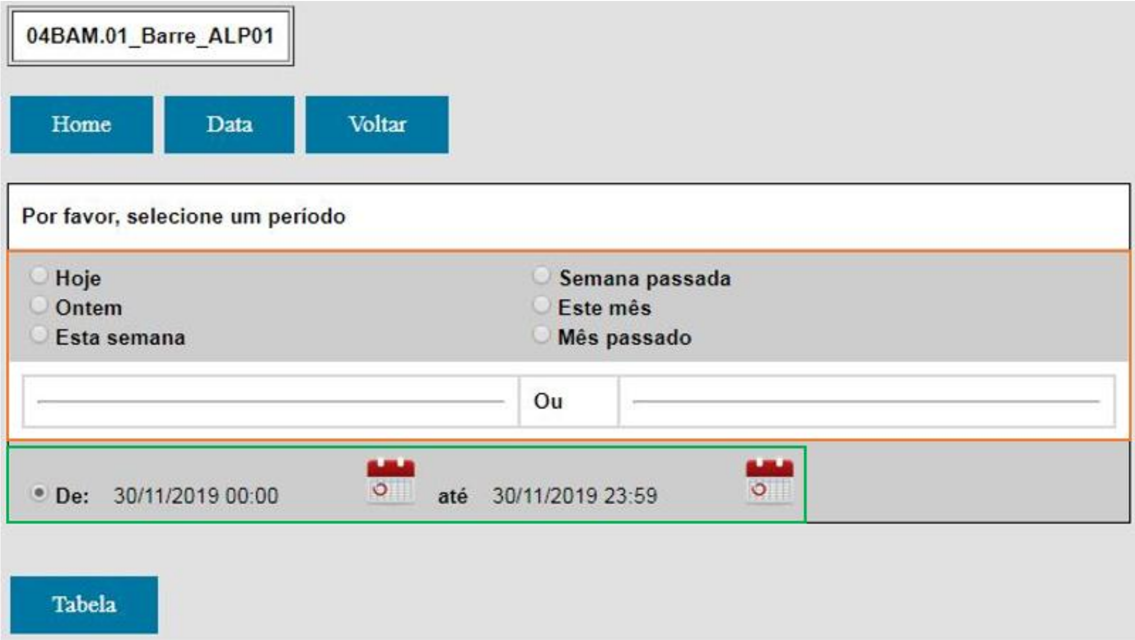

Figure 25 – Interface Report by Period.
Source: Authors, (2020).

Below is information about the periods in the ComboBox:

•Today: generates the feeder's measurement data displayed in a table during the research period, resulting in data for the period from 00h00m until the research time of the same day. Keep in mind that the maximum period for this search option is from 00h00m to 23h59m;

•Yesterday: generates the data from the measurements of the electrical quantities for this feeder shown in a table from the day before the surveyed day;

•This week: generates the measurement data displayed in a table for the week in which the survey will be carried out. Take into account that this period starts at 00:00 on Sunday of each week and ends at 23:59 on Saturday, or until the research time of that day of the week;

•Last week: generates the measurement data displayed in a table for the week prior to the week that the survey will be conducted. Take into account that this period starts at 00:00 on Sunday of the previous week and ends on Saturday of that same week at 23:59;

•This month: generates the measurement data displayed in a table for the month of the survey. Note that this period starts at 00:00 on the first day of the month in effect and ends with the time of the day of that month;

•Last Month: generates the measurement data displayed in a table for the month prior to the month that the survey will be performed. Taking into account that this period starts at 00h00m on the first day of the last month and ends at 23h59m on the last day of that month.

•From: (date) to (date): is the possibility to generate data in a start and end period of the calendar, specified by the user. However, as described in the previous item, the search period will start at 00:00 of the start date and will end at 23:59 of the end date of this search. On the other hand, there is the possibility that the search dates are prior to the data capture dates of the system, and therefore, no data will be available.

For didactic purposes of the system functionality, the last option listed above **from: (date) to (date)** based on the period from **30/11/2019 00h:00m to 01/12/2019 23h:59m** as item selected in green in image 25 and the table generated after clicking this option, as illustrated in figure 26.

04BAM.01_Barre_ALP01

Voltar | Data | Gráfico

Timestamp	Tensão Fase A	Tensão Fase B	Tensão Fase C
30/11/2019 23:45:00,000	7.704,134	7.876,382	7.753,881
30/11/2019 23:30:00,000	7.703,193	7.874,735	7.752,711
30/11/2019 23:15:00,000	7.629,215	7.817,904	7.686,503
30/11/2019 23:00:00,000	7.617,036	7.792,596	7.668,730
30/11/2019 22:45:00,000	7.608,127	7.786,702	7.657,398
30/11/2019 22:30:00,000	7.604,987	7.786,654	7.656,873
30/11/2019 22:15:00,000	7.605,016	7.786,681	7.663,539
30/11/2019 22:00:00,000	7.622,893	7.798,665	7.675,226
30/11/2019 21:45:00,000	7.620,407	7.797,277	7.676,140
30/11/2019 21:30:00,000	7.613,540	7.796,817	7.675,979
30/11/2019 21:15:00,000	7.609,955	7.791,341	7.677,355

Figure 26 – Measurements Table Interface.
Source: Authors, (2020).

In the table generated by this search option, the data captured at this time and period of the voltage of each phase of the feeder 01 are displayed.

Figure 27 shows a graph highlighting the voltage options from the data in the table in Figure 34. As an example, the suppression of one of the phases, just by clicking on one of the boxes of the phases that are available (as the box highlighted in red in figure 26), allowing the user to perform the analysis of each phase in this period. Note that the user can skip any other phase that he/she wishes to suppress or visualize in this scenario.

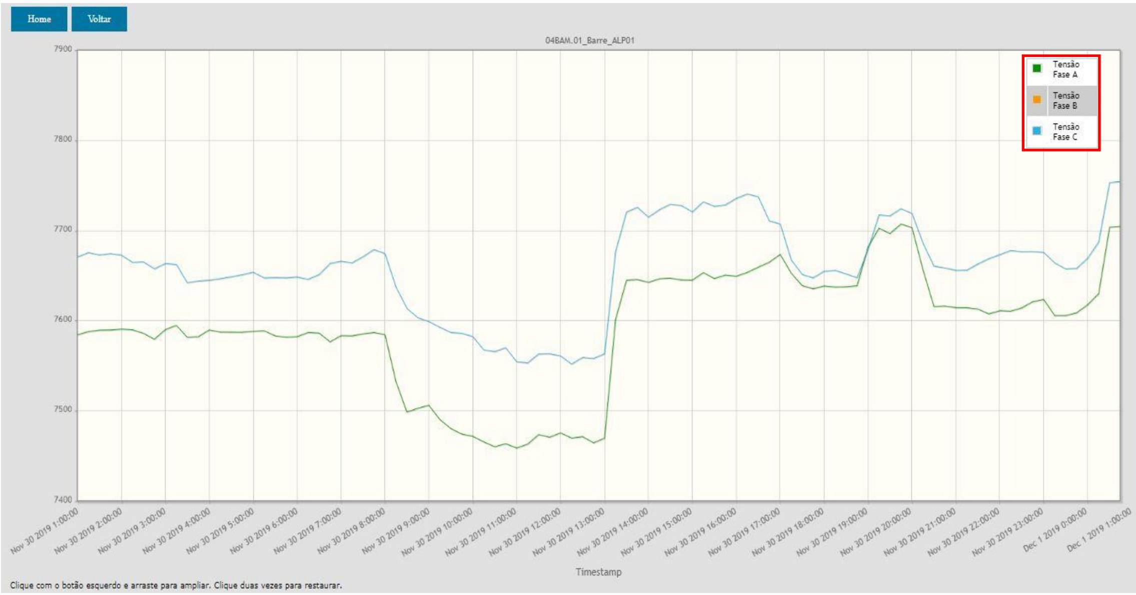

Figure 27 – Voltage Measurement Chart.
Source: Authors, (2020).

Consequently, the result shown to the user of the behavior of the captured data of the electric voltage, brings a better visualization of this variation, helping the operator, in this case, to relate possible events and/or failures in the system of electric power generation, with the behavior plotted on the interface. It is worth mentioning that all these visualized processes were previously performed manually by the operators, and noted in a table every day and every hour, as shown in Figure 27. However, not only this highlighted electrical measurement, but also other electrical magnitudes, which are of extreme importance for the analysis and preparation of technical reports.

Another scenario that can be seen in figure 28 is the possibility to zoom in on any area within the generated graph, which as highlighted in red, in the lower left area of figure 29, where it is described: **left click and drag to zoom. Double click to restore**.

Figure28–Bar Voltage Measurements Chart of thefeeder 01.
Source: Authors, (2020).

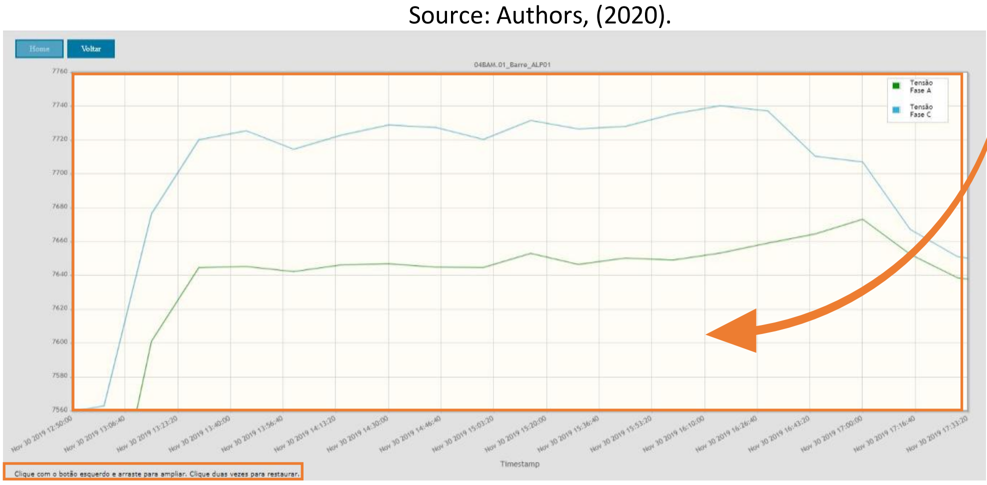

Figure29– Resized Chart of Voltage Measurements.
Source: Authors, (2020).

As a result of this graphical interface there is a positive point technically, since there is the prospect of analyzing accurately, the events that occurred in the selected period, in addition, to use the captured data, taking into account, the use of images from the interfaces of the supervisory system, in the composition of the preparation of technical reports of the events occurred for use of operators and maintainers of this system, when necessary. It is worth pointing out that the causes of voltage variation are diverse in this system.

Given the above, there is also the viability of performing the analysis of the other magnitudes such as the Current option, for example, where the user will have access through the interface Report by Period of Feeder 01. And for the purpose of demonstrating the system's functionality, the same interval used previously was also adopted, that is, the period from **11/30/2019 00h:00 to 12/01/2019 00h:00**, to generate a graph showing the behavior of the electric current data for each phase, as shown in figure 30.

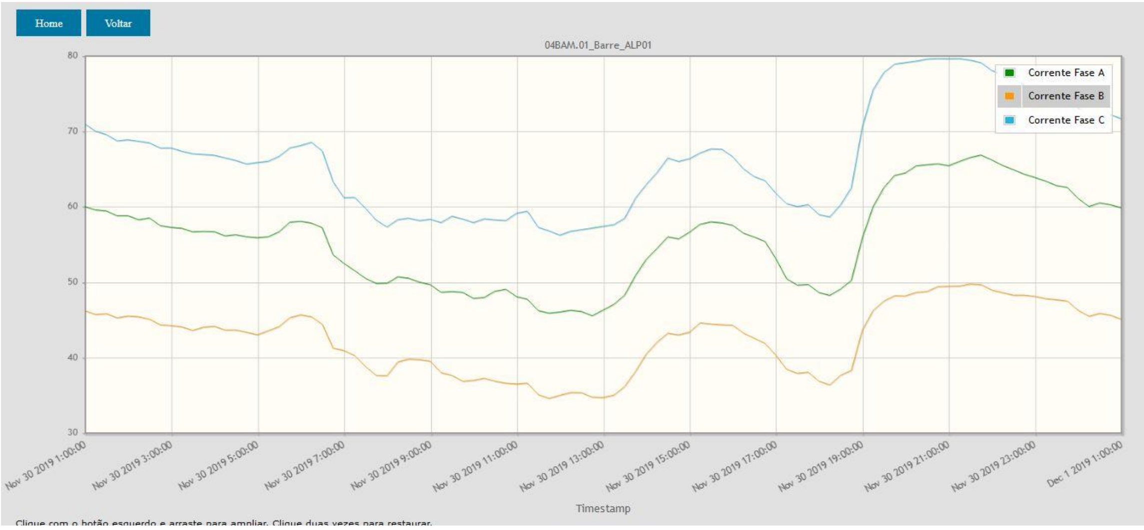

Figure 30 – Chain Measurement Chart
Source: Authors, (2020).

The generated graphic shows in a clear and easy to interpret way for users, the visualization of the behavior of the variations of the electric currents during the established period, in the three phases of the feeder 01, providing a dynamic view of the process. And with increments in the visualization processes, the implementations of expanding the graphics can be done, for a more detailed analysis and suppression of one or two phases of the electric current of the feeder.

Continuing with the options of the interface of figure 30 of Historic Data Records and following the previous steps of parameterization of the periods applied, there is access to the generation of graphs of Energy (Active and Reactive) as well as Power (Active and Reactive), figure 31. Which, as well as the other displayed graphics, can be enlarged, according to the user's needs.

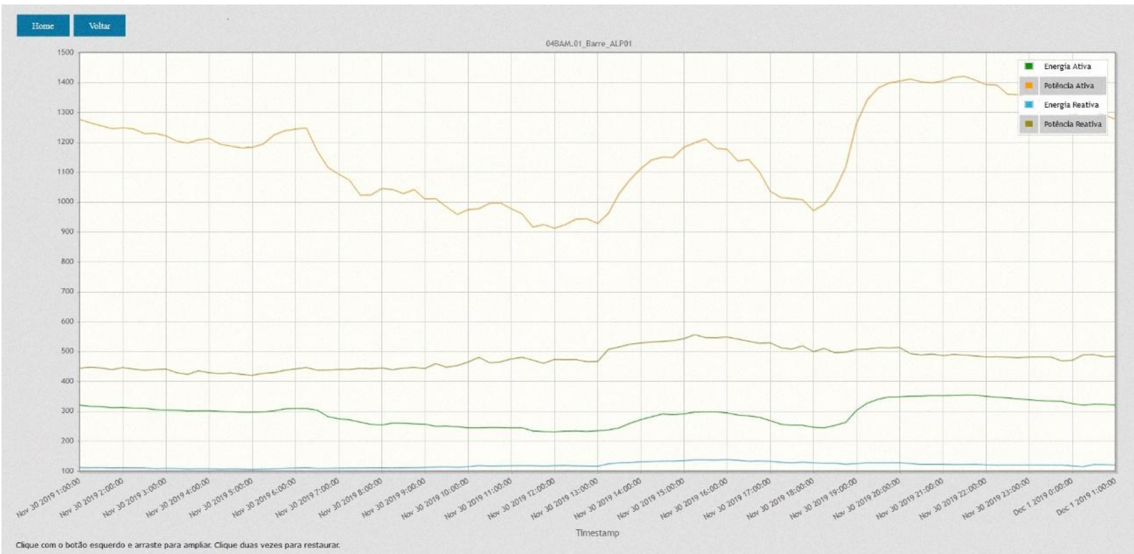

Figure 31 – Power/Energy Measurement Chart.
Source: Authors, (2020).

The inductive Power Factor, on the other hand, is also based on regulations for compliance established by Decree No. 62,724 of May 17, 1968 and with the new wording given by Decree No. 75,887 of June 20, 1975, and updates given by Technical Note No. 0083/2012-SRD/ANEEL, where the electric utilities adopted, since then, the power factor of 0.85 as a reference to limit the supply of reactive power. Thus, observing the graph in Figure

32, it can be seen that the measurements performed are adequate for these metrics.

V. RESULTS AND DISCUSSIONS

From studies carried out and with the proposal to demonstrate the applicability and functionality of the implementation of a data supervision system, parameters of electrical quantities were adopted as indicators of measurements from the electric power generators, which were collected manually during the routines performed by operators of this thermoelectric plant. This manual data collection and filling process ended at the end of each month, as an example of how to fill out this data, we have the spreadsheet model, as shown in figure 16, in the operation and maintenance section, mentioned in item 3.1.3.2. However, the cycle of this routine continued at the beginning of the next month in each successive month. At the end of each month, these documents were sent via courier to the company's headquarters, to be scanned, analyzed and, subsequently, sent to the inspection agencies. During the periods of maintenance performed in this generating unit, it was found that the reading of electrical data was, and continues to be performed by a supervisory itself, which is a normal process for these activities, as shown in Figure 33.

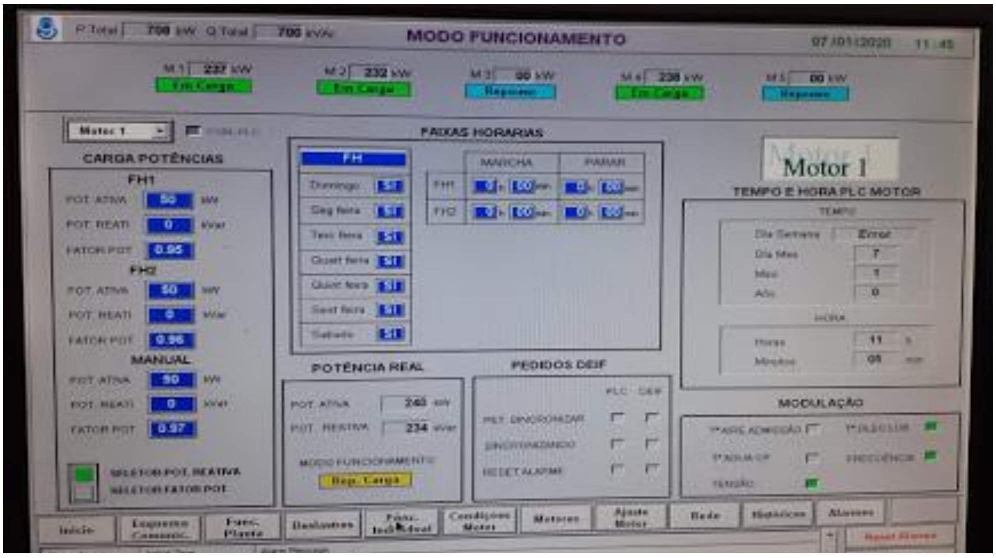

Figure 33 - Interface Operating Mode of the Local Supervisor.
Source: Authors, (2020).

Thus, the implementation of this supervisory system, allowed from the technical point of view, improvements in the analysis and interpretation of variations of electrical quantities captured in the supervisory implemented in the power generation system in the city of Barreirinha. To this end, we highlight some examples of activities directly related to the electric power distribution system, arising from the application of this improvement in the system as a result of the implementation of the supervisory system:

Actual Situation: In the city of Barreirinha, a study was conducted to verify, via this supervisory system, the considerable lag between the currents of the phases of feeder 01 (phase B), having as points of analysis, the distortion variations and the period. And according to the use of the supervisory graphing tool, analyses of possible causes attributed to the origins of this unbalance were made. With this, the technical analysis of the graphs conditioned the performance of several activities in the field to mitigate the resolution of this mismatch. Where maintenance technicians performed the adjustments, also known as "load balancing" of several distribution transformers installed in the electrical network of this municipality. In these activities, the load balancing of 8 transformers were performed, being: 3 of 150kVA and 5 of 112.5kVA, in a period of 5 weeks, approximately. The image in Figure 34, reflects the behavior of the variations of the three currents of feeder 01, before the activities performed by the technicians for the adequacy of the loads of this circuit.

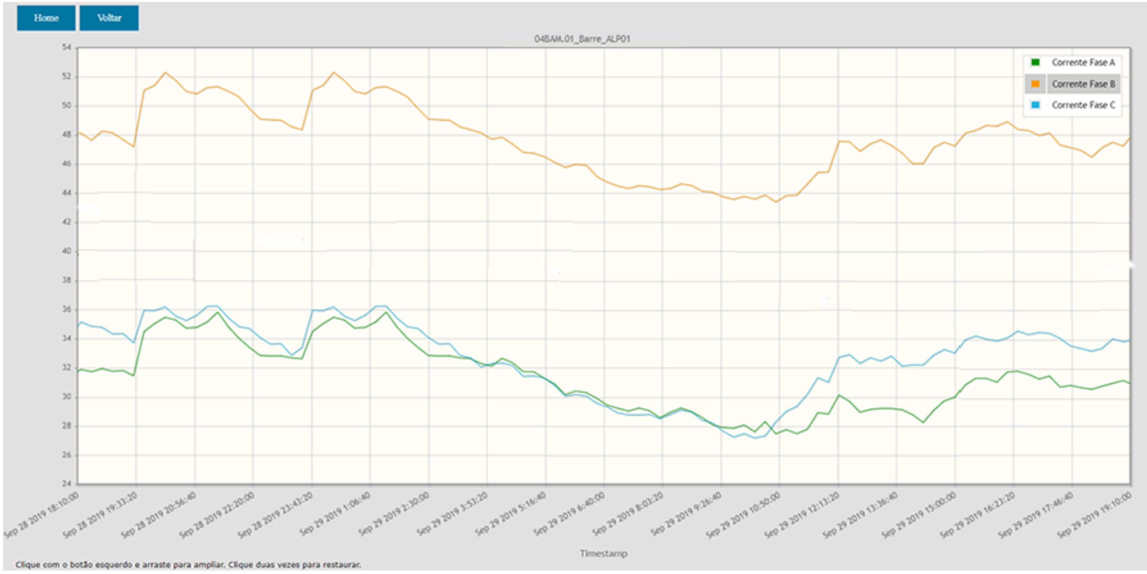

Figure 34 - Graph of the variations of the electric current of feeder 01.
Source: Authors, (2020).

As a result of these activities, according to Figure 35, there is the balance of currents of feeder 01, impacting directly on the life of the transformer, the minimization of voltage drops of this equipment (constant complaints from consumers fed by this network), due to the adequacy of loads and the balance of loads reflected in the generators of the plant. Thus, the use of supervisory tools for graph generation, provided analysis and mitigation in the performance of agents causing this disturbance in the system.

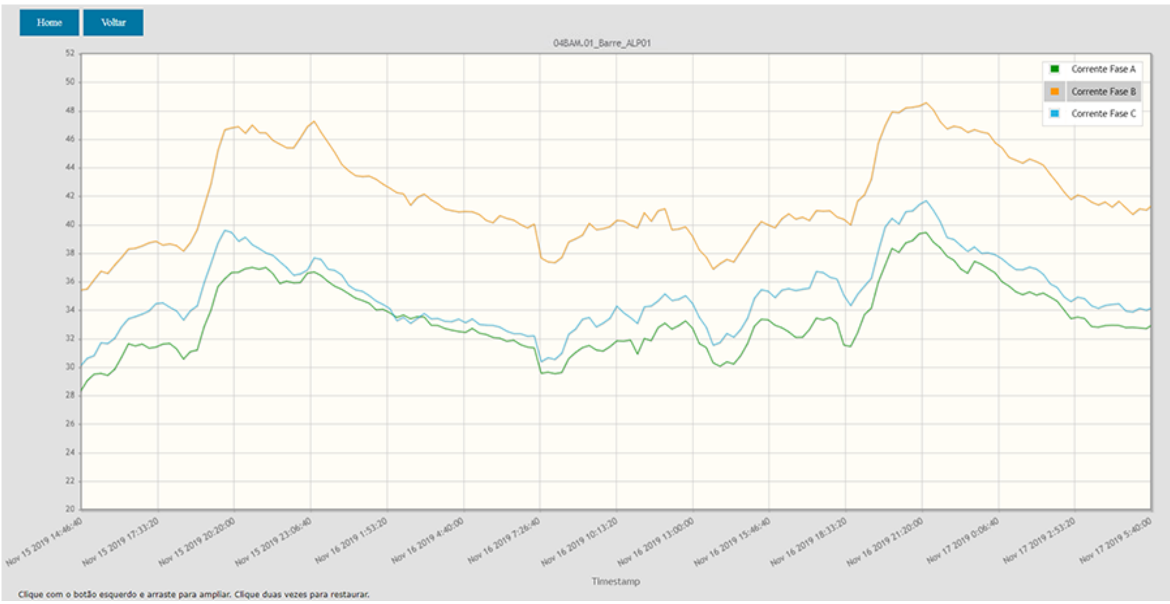

Figure 35 – Eletric Current correction chart of the feeder 01.
Source: Authors, (2020).

It is clear and evident that all the processes and results demonstrated need constant improvement and refinement, and this supervisory system implemented is no exception to the rule. However, the fact that there is the possibility of storing, structuring and monitoring, in real time, these data captured automatically, as in the case of the plant in the city of Barreirinha. And as a result of this capture, the possibility of performing analysis of these data about this process, making it possible, for example, to find patterns and trends results of variations in this system, possible failures, such as phase discrepancies, power factor variations and even possible power interruptions, already grants this implementation of the supervisory system a great ally in the development of process improvements for this system.

Emphasizing and taking into account that, previously, all the extracted data was performed manually by the plant operators, and without demeriting in any way, the performance of these activities in the collection of information in an organized way. However, with only these spreadsheets of annotated measurement data there were no conditions, in this circumstance, a clear perception and sensitivity in the behaviors of these electrical magnitudes between the electric power generation system and the distribution system loads. In this trend line, the monitoring of the behavior of these data compiled via the internet and in real time, allows, in addition to the easy visual understanding of these captured electrical magnitudes, an improvement in the performance of this data analysis, moreover, all these data can be viewed within the characteristic of each supervisory interface, at anytime and anywhere, having only the access to this supervisory system, via internet.

VI. CONCLUSIONS

From the studies performed and the understanding of the process of generating electricity it was observed the need for a supervisory system. Considering the huge number of records that are generated by the system, it is of utmost importance to have a tool that collects the readings of electrical quantities, making them available for monitoring and assisting in decision making, to minimize the impacts that can be caused by the lack of monitoring of the operation of the equipment arranged in the plants. By understanding the problem, a bibliographical survey was done that allowed us to understand the process of energy generation, to understand the stages of availability in the SCADA system and in the use of a qualitative way for data analysis. Thus, through the implementation it was possible to visually improve the information available to the operator, a factor that directly influences the quality of the electric system operation, contributing to maintenance performed in an active and efficient way, while maintaining familiarity with the original software from the equipment manufacturer.

With an intuitive, simple and direct work interface, the handling of the supervisory system was uncomplicated, collaborating with a fast-learning process by the user. It also met the proposal to be accessed by any device with internet access, the generation of the system graphics is made for statistical control, allowing the analysis of the equipment performance from the generated result, allowing the user to choose the magnitude to be evaluated and solving the problem of lack of concise information about the process of generation and distribution of electricity. But, at no time, does it fulfill the need of having an operator on site to make the decisions. This implementation provided an experience of teamwork, with engineers and technicians of great experience, as well as operators and maintainers who had no technical knowledge, but remained in constant learning and the responsibilities assigned also contributed to a great professional growth. In addition, the daily coexistence in a section with involvement in several areas with supervisory systems contributed to an increase in the perception of new project solutions.

As any system and/or process is susceptible to continuous improvement, it becomes necessary to study such needs, because, due to time limitations, financial viability, and studies of various auxiliary equipment and the engine itself, it was not possible to carry out other implementations. And as a suggestion for possible improvements in this process some proposals, as follows below:

- Provide data of thermal quantities captured by internal or external sensors, for monitoring and identification of temperature variations of the engines and certain auxiliary equipment of this system, such as: oil temperature in the crankcase, cooling water temperature, and other equipment where the variations need to be captured, recorded, visualized and analyzed, remotely, during the operation of these machines, when in operation;
- Include a GSM module, with a Machine to Machine (M2M) chip, which can be registered with greater signal coverage, thus avoiding being without communication with the supervisory or new technologies that enable adaptations of a stable communication system.

ACKNOWLEDGEMENTS

We would like to thank the Postgraduate Program in Process Engineering (PPGEP), the Institute of Technology of the Federal University of Pará (ITEC), the Federal University of Pará (UFPA) and the Institute of Technology and Education Galileo of the Amazon (ITEGAM), for supporting this research.

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Jefferson Emilio Maciel da Silva, et. al. “Implementation of a Supervisory System in Electric Power Generating Units of Isolated Systems Installed In Municipalities of the Amazonas State.” *International Journal of Engineering Research and Applications (IJERA)*, vol.11 (9), 2021, pp 25-54.