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TELEMETRY SYSTEM IN ELECTRIC MOTORS USING INDUSTRY 4.0 TECHNOLOGIES

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Abstract. *The Industry 4.0, potentially the fourth industrial revolution, has been driven by the need to provide real-time data and information on manufacturing processes in their entirety so that their equipment can operate with maximum efficiency and return on capital investments. These modern production systems are characterized by intense connectivity between the machines, endowed with ubiquitous and pervasive computational capacity. A group of technologies called Enablers has been the pillars of the development of Industry 4.0: Big Data, Artificial Intelligence, Additive Manufacturing, Internet of Things, Robotics, and Cyber-Physical Systems. By associating these technologies, it is possible to reduce costs without compromising quality and increasing productivity, creating the concept of smart manufacturing. This work aims to bring intelligence to the Edge, taking as a case study electric motors, fundamental equipment in industrial applications and whose efficient operation is essential. We simulate the instrumentation of an industrial electric motor, developing a verticalized architecture within the Industrial Internet of Things, and planning the design of components from the Edge to the Cloud when necessary. The paper features two distinct aspects: registration of tags via a web interface connected to PostgreSQL database, allowing easy equipment expansion without downtime or code changes, and a Python code structured as an object-oriented gateway, simplifying addition of new communication protocols without affecting existing ones. This system enables the motor to be an intelligent agent within the manufacturing system, actively sharing data and searching for information. Dynamically, the collected data can be stored locally or remotely in the Cloud, according to its criticality. With part of the intelligence at the Edge, industrial networks are unburdened, increasing their efficiency, security and robustness, besides facilitating the prevention of failures by the distribution of monitoring. The implementation of this system aims to increase the efficiency of engine operation and extend its useful life, reducing maintenance costs and unscheduled stops. Thus, companies can monitor engine performance in real-time and predict failures, collaborating with the compliance of regulations and safety standards in an industrial environment, achieving greater profitability and competitive advantages. As a result of this work, we have a modernization methodology for industrial electric motors, transforming them into active agents at higher manufacturing system levels.*

Keywords: *Industry 4.0; IIoT; Electric Motors; Telemetry; Monitoring*

1. Introduction

Currently, the significant transformations that have occurred in the industrial environment motivated by the high demand for production and the competition for markets are becoming increasingly clear, where it has been of fundamental importance to process and analyze the data generated on the production line in real-time and effectively. Linking the data obtained by industrial equipment to analysis and processing systems is one of the fundamentals of Industry 4.0, where process performance and agility are required, Xu et al. (2016).

According to a study published by the National Confederation of Industries (CNI, 2022), the Brazilian Industry is more digital than it was five years ago. In 2021, 69% of industrial companies already used at least one digital technology in a list that features 18 different applications. However, when looking at the detailed list of technologies, it can be seen that they are at an early stage of the digitization process. Technologies such as remote monitoring and control of production with MES (Manufacturing Execution System) and SCADA (Supervisory Control and Data Acquisition) systems, process simulation, Digital Twins and Big Data, adoption is still low, showing difficulties in integrating the various digital technologies, a necessary requirement of major value in Industry 4.0.

These numbers indicate that the lack of knowledge of technologies by the companies themselves is a problem to be addressed, and the restricted use of technologies reinforces the need for advancement and more integration to expand the benefits.

The high cost of adopting digital technologies is the obstacle cited by 66% of the companies interviewed by CNI when analyzing the progress of Industry 4.0 in the country. Next, come the lack of knowledge, clarity about the returns of the technologies adopted, and the structure and culture of the company, cited by 25% of the companies.

Manipulating so much information in a structured way in order to achieve increasingly better results, it is of fundamental importance to have access to updated information, because the world after digital transformation is accelerated and instantaneous, and it is necessary to anticipate having control over all levels of production. Thus, it will be possible to level up in terms of agility in decision-making to achieve competitiveness.

Because they are used in almost every industrial environment, electric motors have become increasingly complex and technical, and running them at maximum performance is a major challenge, Nandi et al. (2005). By monitoring the physical signals emitted by motors in the manufacturing process, it is possible to keep a close eye on their health. Temperature, vibration, oil, current, and voltage are among the signals that can reliably detect problems developing in a motor.

Given the benefits of real-time data access, the system will be able to reduce costs, minimize losses, better meet deadlines and, consequently, increase productivity. In addition, the use of data analysis and visualization will help create better revenue streams built around product quality in the manufacturing process, Arnold et al. (2016).

This paper aims to present a new alternative perspective of Industry 4.0 in Brazil with the purpose of democratizing, through the creation of software able to read and store industrial data from electric motors focusing on real-time visualization and data history, supporting decision-making and economy for the industry in the manufacturing processes.

2. Related work

The papers published from the problems cited in chapter 1, see Table 1, highlight the need for a solution that can contemplate the enabling technologies of Industry 4.0 and be of low cost, to facilitate the integration with the existing processes and disseminate the knowledge of the benefits that these technologies offer to improve the production and useful life of electric motors and industrial equipment. For the choice of papers, it was used as a criterion for those solutions that contemplate the possibility of connectivity with the equipment and telemetry in real-time using the tools of Industry 4.0.

The literature on the Internet of Industrial Things is relatively recent since the Industry 4.0 movement started a decade ago. The industry still needs standardized architectures and systems, presenting several variations in the organization of the systems, depending on the equipment manufacturers.

In Thu et al. (2019), an air quality monitoring system was developed using LoraWAN communication, one of the primary data communication platforms in the Internet of Things. With the capture of environmental parameters such as temperature, humidity, particulate matter and carbon dioxide, the platform consists of low-cost sensors using artificial intelligence for parameter prediction based on historical data.

Mudaliar et al. (2020) use low-cost and easily accessible elements to build an energy monitoring system, enabling analysis of energy consumption patterns and forecasting demand and faults, among other parameters. Ndukwe et al. (2020) follow the same line as the Smart Grid area, proposing a monitoring system for small solar power installations. With LoRa and SCADA technologies, their system presents diverse telemetry options, enabling the test of different elements.

In the scope of electric motor telemetry, we sought papers that discussed four main aspects: communication, data processing, data storage and information visualization.

Silva et al. (2016) propose an architecture for Internet of Things applications based on Cloud computing for remote monitoring and control of industrial systems. However, specifically, the work brings an example using an electric induction motor. The proposed architecture is based on sensor layers, gateways for protocol conversion, message management, and real-time data analysis, among other elements.

Magadan et al. (2019) also bring electric motor monitoring as a supporting application for developing a predictive maintenance system, using analysis in both the time and frequency domain. Data from various sensors are processed on free software platforms, enabling cost reduction and scalability.

Bastos (2021) presents a supervisory system for electric motors using open and low-cost platforms. The work presents a comparative chart of different edge computing devices, analyzing the advantages and disadvantages of each type of device.

Table 1. Telemetry solutions comparison.

Ref.	Year	Tag Register	Communication Protocol	Data Processing	Storage	Visualization
(Silva et al.)	2016	Indexed to code	MQTT	Node-RED (JavaScript)	Cloudant	IBM Watson IoT
(Thu et al.)	2019	Indexed to code	LoRaWAN	Node-RED	InfluxDB	Grafana

(Magadán et al.)	2019	Indexed to code	HTTP	Arduino (C++)	ThingSpeak	ThingSpeak
(Mudaliar and Sivakumar)	2020	Indexed to code	Modbus	Node.js JavaScript	InfluxDB	Grafana
(Ndukwe et al.)	2020	Indexed to code	LoRa	Node-RED (JavaScript)	InfluxDB	Grafana
(Bastos)	2021	Indexed to code	Modbus	Arduino (C++)	No Storage	ScadaBR
(Gonzalez et al.)	2021	Indexed to code	Modbus	Python	MariaDB	Grafana
Present Paper	2022	Scalable with PostgreSQL	Modbus	Python	TimescaleDB	Grafana / Power BI

The present paper has as differentials the registration of the tags that are made via a web interface connected to the PostgreSQL database, where the tags are not attached to the code, facilitating the expansion of monitored equipment, preventing unnecessary downtime and changes in the code that will be in operation. The other differential is the structure of the code in python which will work as a gateway that is object-oriented, making it easier to add new communication protocols without altering the reading operation of the existing ones.

3. Methodology

In order to proceed with the development of the next steps and understand their operation, this topic describes the methodology used for the development of this project and architecture. Figure 1 presents the general flowchart of the methodology and the tools used.

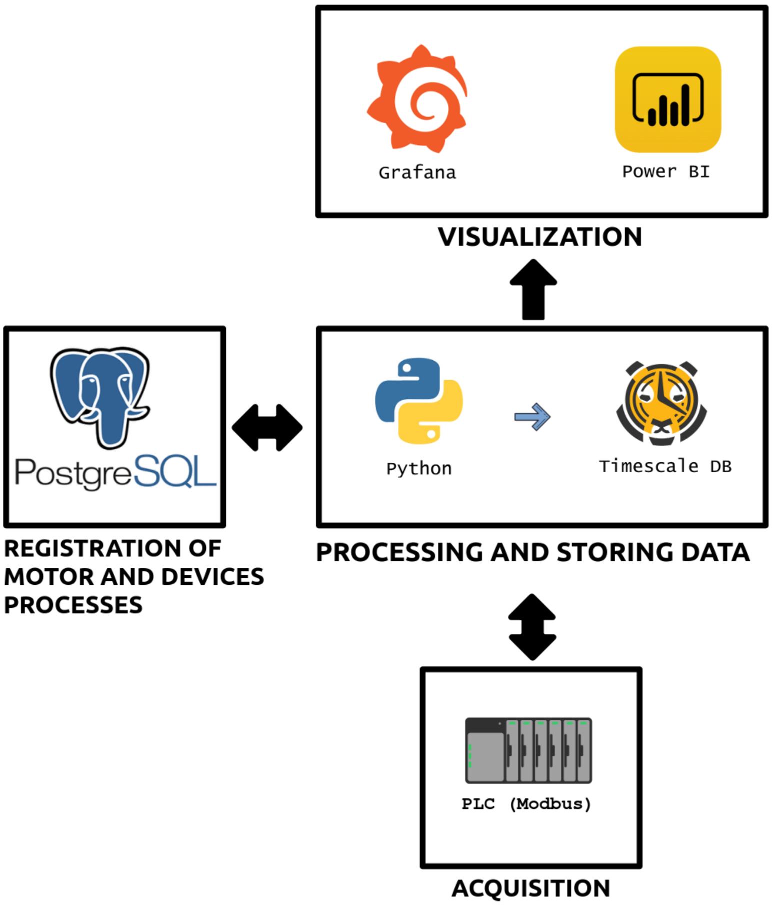

Figure 1. General flowchart of the methodology

The system is composed as follows: a web interface where the information about the process is registered and saved in a relational database, a program where this database information is read and communication is made with the Programmable Logic Controller (PLC) and addresses of the registered tags, the read values are stored in a time series database. These data are displayed in dashboards at the real-time visualization level for engine process control and at the managerial report level.

3.1 Modbus TCP

To exemplify an electric motor in an industrial environment, the communication protocol used was Modbus TCP. Used in different types of equipment, Modbus TCP integrates devices installed in the field and allows the exchange of information between them without authentication restrictions. In other words, each user can connect directly to the servers, forming a 1x1 (one-to-one) connection, in which the server waits for requests from the clients to answer them (Goldenberg and Wool, 2013). In addition, Modbus can be used in control devices, such as PLCs, and supervisory devices, such as HMIs. it is an open protocol, so it can be freely implemented on any device. Simulating the instrumentation of an engine, the following tags were created:

- TT01: Temperature sensor
- RH01: Humidity sensor
- HR01: Hour meter
- TE01: Electric voltage
- CA01: AC Current
- MT01: Motor status (0 = Off, 1 = On, 2 = Fault)

3.2 PostgreSQL and TimescaleDB

PostgreSQL is a software library that provides a relational database management system (PostgreSQL, 2022). It was used to perform the registration of the motor tags created in the PLC, as well as the entire relational structure for reading the devices. Figure 2 shows the entity-relationship diagram (ER) with the database tables and relations.

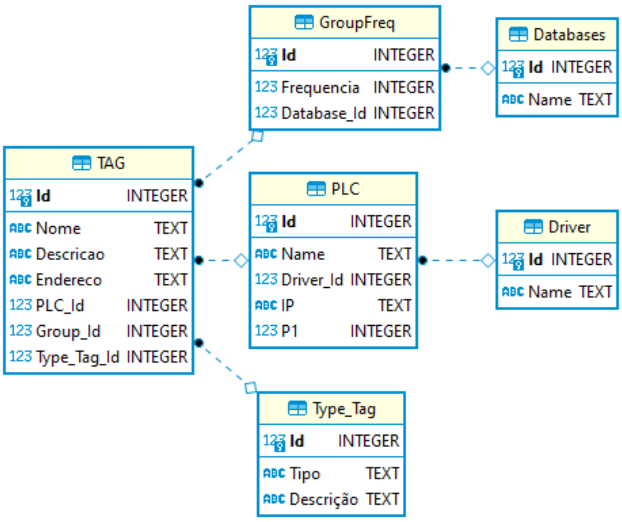

Figure 2. Entity Relationship Diagram

TimescaleDB is an open-source database designed to make SQL scalable for time series data. TimescaleDB is packaged as an extension to PostgreSQL. As a time series database, it provides automatic partitioning between date and key values (Timescale, 2020). The local TimescaleDB server setup for this project is required and consists of installing the server, client, the database where the information read by the python program will be stored and creating the user and password to perform the data writing and display in Grafana and Power BI.

3.3 Python

This topic explains and presents the used libraries and the structure of the object-oriented program created to read and store PLC information. It is important to note that all chosen libraries are receiving updates and support from their developers in addition to being open-source.

3.3.1 Psycopg library

The psycopg library allows you to read and write the data saved in the Postgres database and consequently, the TimescaleDB (Psycopg, 2021). Through it, it was possible to read the tables created that will later be used to perform the reading following the relations created. To perform the configuration process for storing the data in TimescaleDB it is necessary to configure the PostgreSQL IP address, the name of the database, and the user and password. The data is written in SQL format where the table and the fields with the tag name, value, and time of writing are sent.

3.3.2 PyModbus library

The pyModbus library has features to work as a Modbus client and server. It has a full read/write protocol in words and bits (PyModbus, 2022), but in this case, only the read characteristics will be needed, since the memory registers will be from the PLC. To connect to the PLC you need the IP address and the port created, to read the registers the read_holding_registers function was used. Figure 3 shows the data being read in real-time from the PLC.

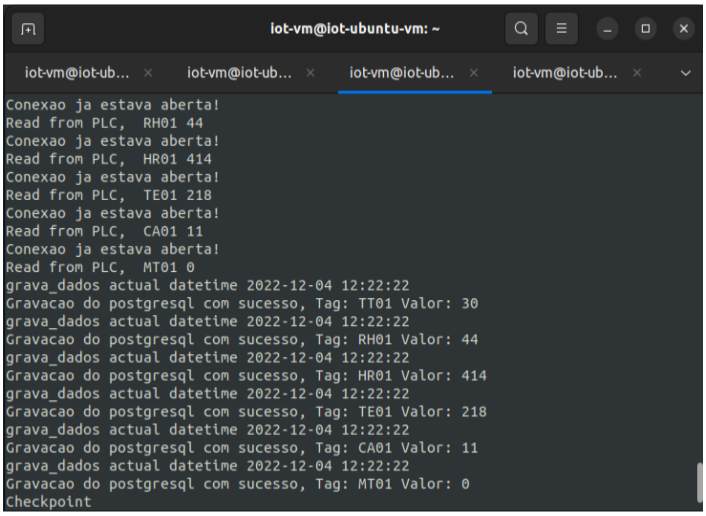

Figure 3. Program response to data read from the Modbus TCP simulator

3.3.3 Flask library

Flask is a framework designed mainly for small applications with simpler requirements. It has a simple and expandable core that allows a project to have only the necessary resources for its execution (Projects, 2022). In this case, the interface responsible for registering the information in PostgreSQL was developed, and also for viewing the data saved in TimescaleDB. Figure 4 shows the interface with the tags registered in PostgreSQL and Fig. 5 the interface with the tags read from the PLC saved in TimescaleDB.

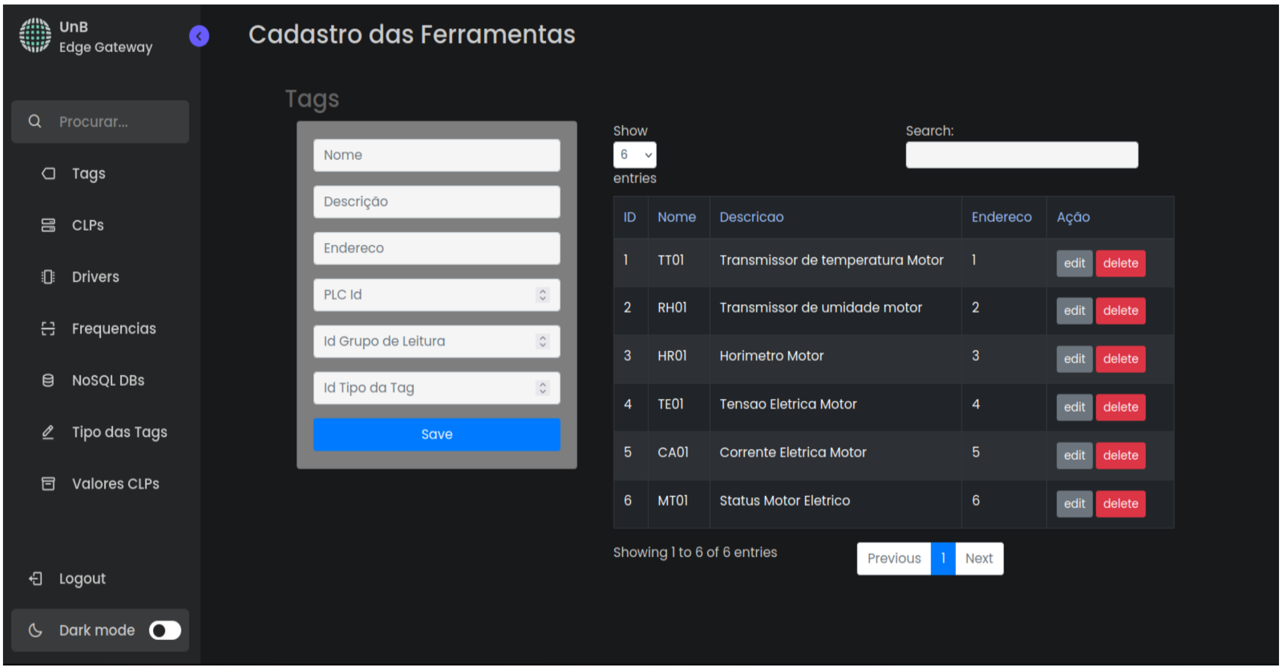

Figure 4. Web interface with the tags registered in the PostgreSQL database

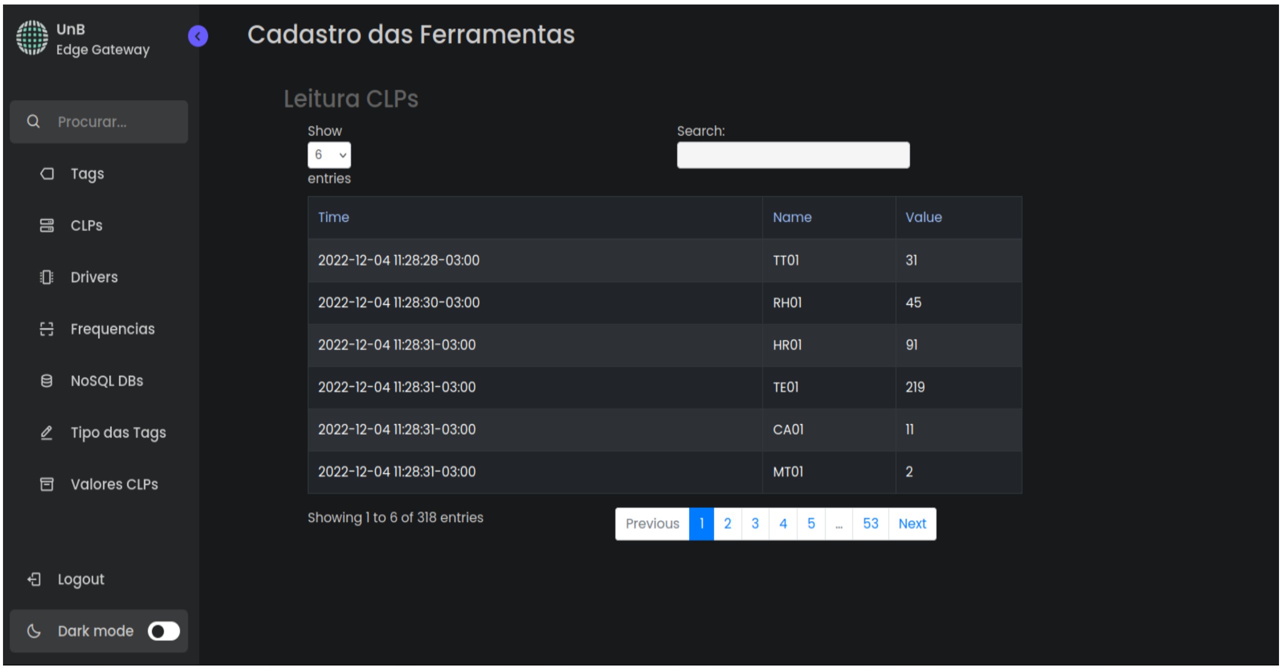

Figure 5. Web interface with the tags read by the PLC saved in the TimescaleDB database.

3.4 Grafana and Power BI

Grafana was used to build the real-time dashboard, it is an open-source visualization and analysis software, it provides tools to transform time series database data into graphs and visualizations (Labs, 2022.). For configuration, it is necessary to add the database that stores the information, for this project TimescaleDB was the database to interact with Grafana. To connect you need to identify the URL with the IP address and port used, add the database name and authenticate with the user and password.

For the management-level dashboard, Power BI was used, which is already being used in the context of business analysis. Using it to gain insights into processes in an industry becomes quite viable since it is practical to organize your data in one place, for greater accessibility, organization, and visibility in the reports (Becker and Gould, 2019). Its configuration for building dashboards is intuitive, just select where the database will come from, which in the case of this project is being used the TimescaleDB. Then it is necessary to configure the server and the name of the database created, followed by user authentication.

4. Results and Discussion

In this topic the results of the project are presented, contemplating the visualization of the data read by the Python program in Grafana and Power BI. Through this system, the health and working conditions of the motors are monitored against historical data. This involves the analysis of past failures and their criticality. The data comes from the telemetry of the devices that are collected by sensors and in the future can be used to create the digital twin model of the physical equipment. All the data is then aggregated and compiled to generate relevant information.

With regular telemetry of the equipment, it is possible to get an idea of the potential degradation of the engines, have the ability to calculate maintenance-related Key Performance Indicators (KPIs) by combining historical data related to risk factors, failures, and operational scenarios, allowing continuous intelligence and estimated time for the next required maintenance, which the maintenance system can use to schedule at the optimal time, Bressanelli et al. (2018).

4.1 Grafana Dashboard

Figure 6 shows the real-time dashboard made in Grafana. For the production of this dashboard, the 6 tags simulated in the PLC were used. In the upper right corner, it is possible to adjust the data display interval and the refresh frequency.

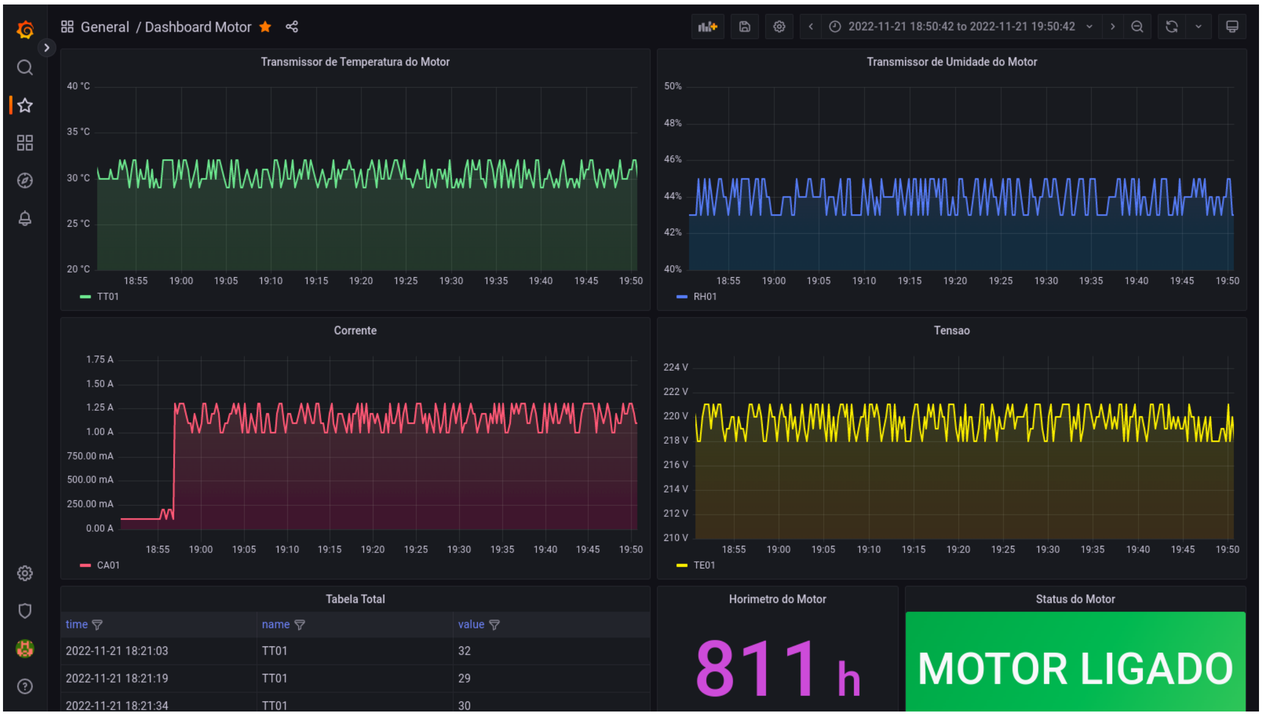

Figure 6. Dashboard in Grafana with motor tags

Grafana allows a generation of alarms for the created devices, where it is possible to delimit for each tag an alarm value. The alarms can be displayed on the screen together with the dashboards and also sent by email. It is also possible to export the data to a CSV file and generate a PDF report with dashboard data at the selected interval.

4.2 Power BI Dashboard

Figure 7 shows the management-level dashboard made in Power BI. The main objective for most managers is to improve productivity and calculate the equipment's performance. Through Power BI it is possible to perform several operations with the data read in order to add value to the process and assist in the decision-making process.

Figure 7. Dashboard in Power BI with motor tags

The process for generating alarms is similar to that of Grafana, where it is possible to define the limits in the tags individually and the alarms are displayed on the screen, sent by e-mail, and other solutions that the tool presents, but since there are many resources available, it was decided to standardize this process.

5. Conclusions

This paper presented a synthesis of the state of the art of Industry 4.0 in Brazil and developed a proposed solution through the creation of software for industrial data telemetry, focusing on electric motors with open-source technologies.

Importantly, regardless of the monitoring system, the need to ensure that the conditions to which the electric motors are subjected will not impair the achievement of their specific function, such as correct installation of the electric motor, which includes: mechanical alignment, the power consumption protection system, and handling by a qualified workforce.

External characteristics must also be considered by the maintenance plan since they decrease the engine's lifetime. Another factor that deserves attention is the engine's mode of operation: it can have a variable or fixed speed, and it can be continuous or with several starts during the day. All this will influence the calculation of the criticality of the engine and, consequently, the need for maintenance.

Analyzing engine conditions with real-time data also helps the manager define the frequency and severity of preventive inspections. They must vary according to the criticality of the engine, its operation, its time in activity, and the environment where it is inserted, among other indicators.

It is worth noting the benefits to be gained by using such a system, as the industry generates a substantial amount of unprocessed data every day about its equipment, or it is often written manually by the operator. To make decisions properly, data-based insights are needed. With access to real-time data analysis, the decision-making process becomes more efficient for managers and emerges as a solution to fix operational problems and correct inefficiencies for better performance of electric motors, decreasing unscheduled downtime and reducing maintenance costs, besides being able to analyze the life of the equipment.

Therefore, based on the results presented in this paper, it is concluded that it is of considerable importance that there is more effort to instruct managers about the benefits of implementing real-time data analysis tools and better integration with open-source software, in order to make the costs viable for a greater immersion of industries in this solution in the monitoring of electric motors.

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