BX08 - IOT Vibration Monitoring System Interfacing with PI System

Pedro Costa[1], Marcos Branco[2], Gilmar Rios[3] and Glayson Habr[4]
1. Automation Engineer
2. Electrical Engineer
3. Electrical Engineer
4. Automation Engineer
Hydro Paragominas, Paragominas, Brazil
Corresponding author: pedro.costa@hydro.com

Abstract

Of Norwegian origin, Hydro currently has 13,000 employees involved in activities in more than 50 countries and on all continents. In the state of Pará it has two operations of Bauxite & Alumina Business Area: a bauxite mine (Mineração Paragominas) and an alumina refinery (Alunorte). In Hydro, the PI System, besides fulfilling the function of historian the process data and performance of the areas, was also adopted as the official concentrator solution to interface with initiatives related to Industry 4.0. Hydro Paragominas stands out as the first mining company in Brazil to obtain the ISO 55001 certification that evaluates the asset management systems and thus, reconciling its pioneering spirit in asset management, with its constant technological investment towards Industry 4.0. A system was implemented that consists in the quick installation (magnetic fixation) of vibration sensors of the VSE100 family in critical assets that are difficult to read manually by the predictive maintenance team, providing screens through the PI Vision interface easily accessible by the corporate network. The project explores connectivity, integration and functionalities of the Aveva PI System wa ith focus on predictive maintenance, either through CBM (Condition Based Maintenance), or using prediction rules through vibration profile signature. The integration developed in the PI System made it possible to automatically perform the process of opening maintenance notifications in the ERP software (SAP). Several gains were obtained mainly in relation to continuous monitoring, where although some operational conditions do not generate immediate damage to the equipment, they can cumulatively generate wear and premature failures. Thus it is possible to correct operational vices and easily expand the installation to other assets, creating a safer environment, with less exposure of the predictive team and automated notification of events.

Keywords: PI System, vibration sensor, predictive

1. Introduction

According to the strategic planning of the Brazilian Aluminum Association (ABAL) by 2030 companies in the aluminum chain need to reinvent themselves in the technology ecosystem and be sustainable. It is not easy to imagine a modern society without aluminum, in beverage cans, smartphones, automobiles, buildings, and energy in our homes, from mining to recycling, so aluminum drives the growth of the economy, being a strategic metal for Brazil [1].

From 2019 to 2020, bauxite demand showed a growth of 10.8 % for the processing of final products used in domestic consumption. Bauxite mining companies in the state of Pará are responsible for 82.8 % of Brazil's total production and grew 5.9% in the same period, showing that demand is growing more than production, requiring a strategic plan to sustain the aluminum chain [1].

From Norwey, Norsk Hydro currently has 13,000 employees involved in activities in more than 50 countries and on all continents. In 2011, the relationship that already existed with Brazil since the 1970s, due to the 5 % shareholding in Mineração Rio do Norte (MRN), became stronger. This was when the company acquired bauxite, alumina and aluminum activities from VALE S.A. in the northeastern region of Pará, becoming the owner of the bauxite mine in Paragominas/PA, the Hydro Alunorte alumina refinery in Barcarena/PA and the majority shareholder of Albras, a primary aluminum plant in the same municipality [2]. Figure 1 shows a macro flow of the aluminum production chain.

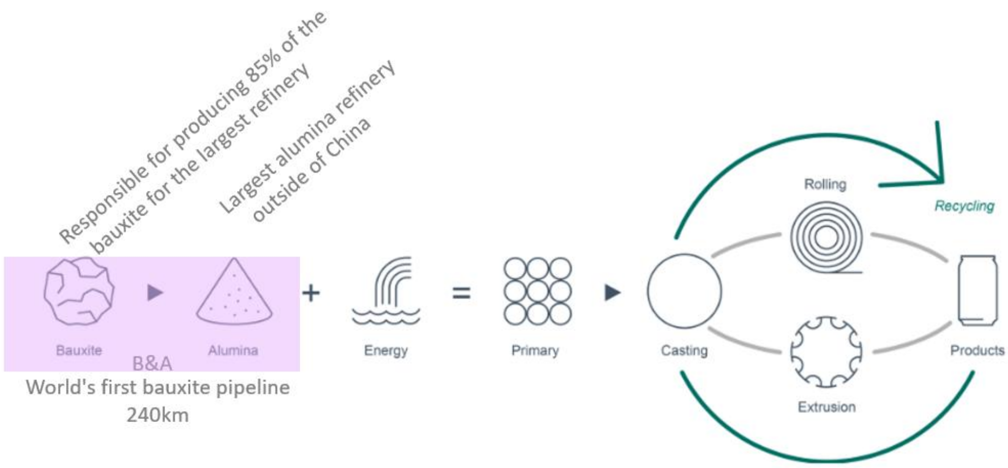

Figure 1. Aluminum production chain.

Hydro Paragominas' production starts with the bauxite mining operations which delivers a certain mass of ROM (Run of Mine) to the bauxite beneficiation operations. The beneficiated bauxite separated from the tailings is delivered to the Pipeline operations which transports and delivers it to the dewatering operations in Alunorte plant. Figure 2 shows a macro flow of the bauxite process from ore mining to dewatering at the Alunorte plant in Barcarena/PA.

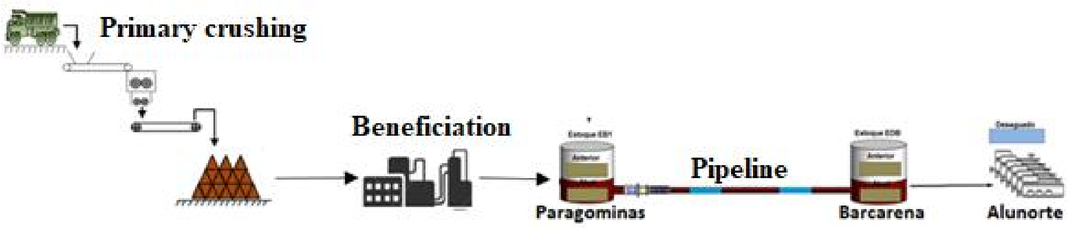

Figure 2. Macro flow of the bauxite process.

The competitiveness of a company depends on the application of best practices evidenced through results selected by a systematic process consolidated over the years. It is also observed that the tools to be applied depend on the stage in which the maintenance is and that traditional techniques for effective problem solving are recommended, such as Reliability Centered Maintenance (RCM) and Failure Mode and Effect Analysis (FMEA) [3].

RCM is a methodology that studies a system so that it fulfills the desired functions and directs insights supporting managerial actions and the best maintenance strategy in order to avoid failure or reduce losses due to failures. RCM analyzes historical data with the record of these failures of a maintenance system, generating indicators related to asset reliability [3]. FMEA, in turn, allows to identify and prioritize potential failures in physical assets, and to evaluate systems and processes, aiming to predict or anticipate failures based on known modes and recommend corrective actions to block or compensate for the effects of these failures. FMEA consists of applying methods for analyzing failures in processes and equipment, enabling specialists and managers to have arguments for decision-making in advance, in order to propose actions that block production line stops [4]. These techniques should be applied in the maintenance of assets with strategy in maintenance management [5]. The joint use of these two techniques allows understanding the process and identifying causes of failure and their effects, as well as establishing a structured improvement plan, with the expectation of increasing the reliability of the process and ensuring continuity in the aluminum production chain.

The RCM methodology aims to bring together the best maintenance practices, always focusing on the safety and reliability of items considered critical for the continuity of a system's operation. For this, there are indicators to measure the results and their controls. With the arrival of the 4th industrial generation, maintenance needs to be inserted in an innovative context of development in its management, from signal monitoring with the "Internet of Things" (IoT) to cloud databases, known as "Big Data". The thought of launching a journey in search of "zero breakage" as a strategy of modern industry, using maintenance technologies to ensure the planning of operations without failures, guarantees the delivery of the product as agreed with the customer.

The choice to apply RCM implies seven questions, each under review or critical analysis, which are: 1. what are the functions and performance standards of a piece of equipment in its present operating context? 2. in what ways does the equipment fail to fulfill its functions? 3. what causes each functional failure? 4. what is the perceived effect of the occurrence of each failure? 5. in what way does each failure matter? 6. what can be done to predict or prevent each failure? 7. what should be done if no appropriate proactive action is found? [6].

With the use of Data Science and Analytics, it is expected to answer some of these seven questions, for this it will be necessary to test models and methods of Machine Learning and Deep Learning more suitable to achieve the expected results and deliver failure prognoses, helping in the application of the RCM methodology in the mining industry.

2. Challenges

At Hydro Paragominas, classical techniques were recognized through the title obtained as "The first mining company in Brazil certified by ISO 55001 Asset Management System" which is an internationally known standard that focuses on specifying the requirements for establishing, implementing, maintaining and improving an organization's asset management system.

Figure 3 shows the PF curve that relates the asset performance as a function of time, the application of different maintenance techniques, makes it possible to identify potential failures and correct there through the effects that precede a functional failure. Level 2 identifies the classic techniques where it is possible to anticipate the diagnosis of a functional failure up to 12 weeks in advance, for example in the identification of a hot spot with a low growth trend observed in the inspection route of the predictive team.

The project applied in this study provides for online vibration monitoring with real-time analysis and diagnosis of critical assets of a bauxite processing plant, a prediction capacity of up to 9 months is expected as observed in level 3 of figure 3. This study presents the application of an IoT product (Internet of Things) online vibration monitoring through high-precision sensors and diagnostics electronics connected directly to the AVEVA PI System [7] and which has application with a several tools, functions and connections with other systems, enabling correction of possible potential failures before a functional failure through the automatic creation of Analytics, notification and opening of maintenance order in ERP (SAP-PM).

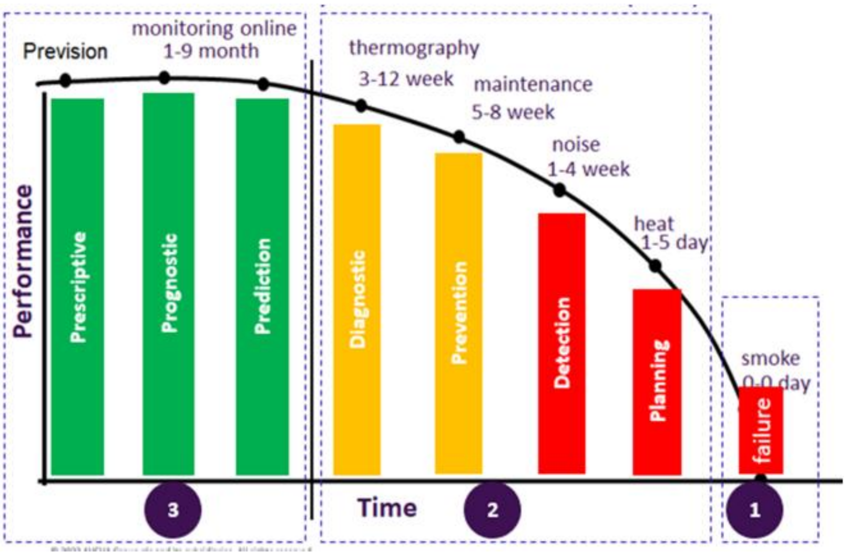

Figure 3. PF curve - Reliability Centered Maintenance (RCM).

It is observed in Hydro Paragominas, the use of classical predictive maintenance techniques, through the collection of vibration data in the field, which is performed every 15 days, exposing the maintainer to the risk of accident with rotating parts of the drive of the mills, generating results obtained after processing the data collected in a specific software with closed architecture. After this data compilation, fully manual reports are assembled that point out possible risks to the equipment, as illustrated in Figure 4.

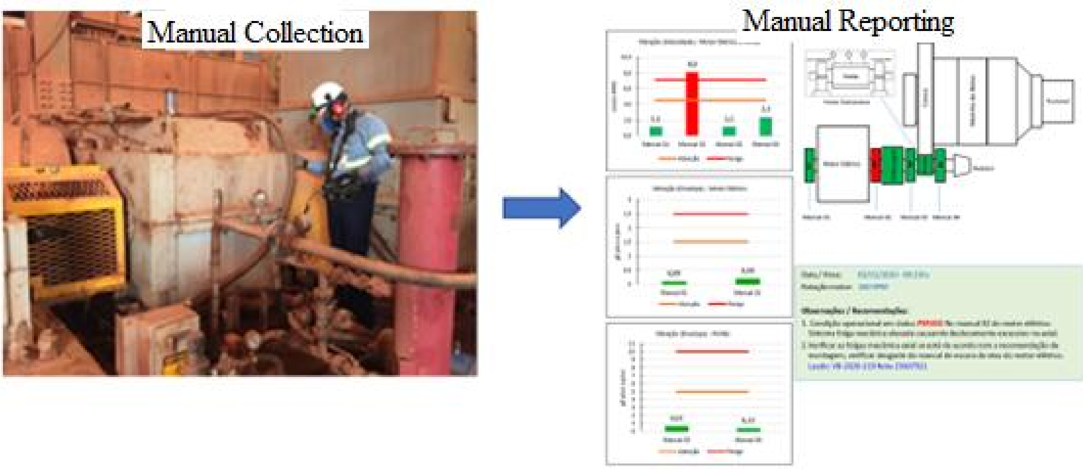

Figure 4. Manual collection and reporting.

3. Objective

In view of the difficulties presented in this article, tireless searches were made for technological alternatives that could bring greater security to the maintainer, as well as eliminate the need to generate manual reports with low productivity, reconciled with the fulfillment of the premises of continuous vibration measurement, real-time FFT diagnosis, and interface with AVEVA PI System that is easily scalable. In this way, the ball mill with a 13.8kV and 9600HP motor was used as a POC (proof of Concept), to later scale to the other mills of the bauxite processing plant.

Thus, this work consists of the implementation of an online vibration system that collects axial and radial vibration signals from the bearings of a 9600 HP synchronous machine that drives a ball mill. The framework used for IoT products helped to format the methodology of operation of the IoT monitoring addressed in this article. This framework has 5 layers in the IoT technology stack, where decisions need to be made in each of the layers: 1) Device Hardware; 2) Device Software; 3) Communications; 4) Cloud Platform; 5) Cloud Applications as Figureure 5 illustrates the relationship between the layers.

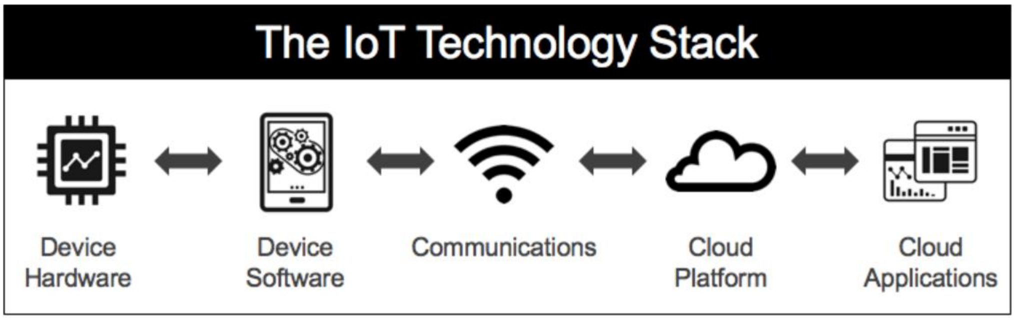

Figure 5. Framework for IoT technology.

In the first two layers, the Ifm vibration system was used which contains high-sensitivity vibration sensors from the VSA family, integrated with diagnostic electronics from the VSE100 family that provides failure modes in the time domain. In the last two layers, the AVEVA system was used for storage and application of Analytics and Machine Learning, finally, to perform the interface between the Ifm and AVEVA systems, an IoT server was used to perform the interface. an IoT server was used to install the OPC Server service of the vibration signals of the Ifm system and make the data available for reading through the OPC Client of the Aveva PI System.

3.1 Acquisition of the Vibration Signal

A simple signal can be represented graphically by a sinusoidal function (sinusoid or cosinusoid) and can be written in general form as in the equation in Figure 6, this signal is collected by the vibration sensor fixed on the engine bearing monitoring the radial and axial oscillations caused by the engine rotation.

$$S(t) = A_0 + C_1 \cos(Wt + \Theta)$$

A_0 is the average height of the signal with respect to the abscissa axis.
C_1 is the amplitude of the signal which is the height of the oscillation.
W is the angular frequency [rad/sec] indicating the measurement of one full turn in the period T of the signal.

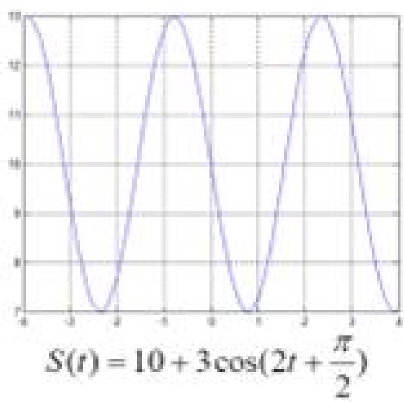

Figure 6. Sinusoidal signal.

3.2 Signal Processing

The complexity of the signal treatment is in the analysis of the frequency spectrum, needing to transform the original signal collected by the rotation of the motor shaft and which is in the time domain, needs to be converted to the frequency domain, for this the Fourier transform is used in the signal that is composed of several frequencies that it is possible to capture the frequency spectrum displaying the frequency components and their amplitudes which are present in a dynamic signal such as vibration, misalignment, unbalance, clearances etc. Figure 7 shows an example of 6 frequency bands extracted from a Fourier series and its transform.

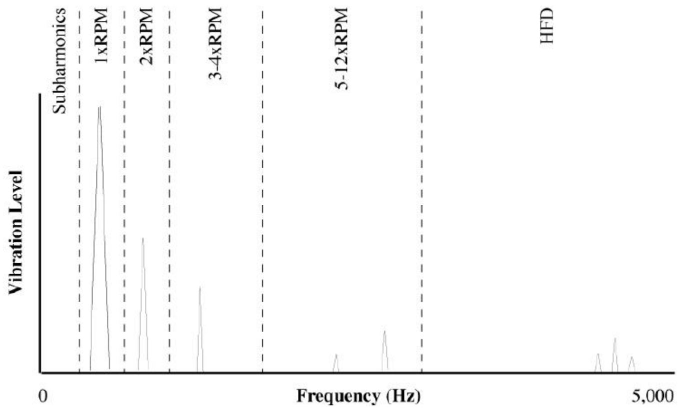

Figure 7. Frequency spectrum divided into 6 bands.

The frequency bands represent the multiples of the rotation of the mill that in the case studied is 180RPM, generally the mechanical failure modes are in these rotation bands, the failure modes of electrical origin, appear in the multiples of the rotation, and multiples of the network frequency.

3.3 Diagnosis of Failure Modes

It is known that vibration measurement brings 3 pairings, displacement, speed, and acceleration, displacement is often used as an indicator of imbalance in the rotating parts of a machine because relatively large displacements usually occur at the frequency of rotation of the shafts, which is also the frequency of greatest interest for balancing purposes, where it always occurs at the rotational frequency with amplitude always greater in the radial, the misalignment can be on the shaft or in the coupling, can occur up to 2 or 3 times the rotational frequency, its amplitude represents 50% or more in the axial direction, for mechanical clearances, the frequency occurs 1 or 2 times the rotational frequency, the phases differ in relation to the failure mode of the unbalance.

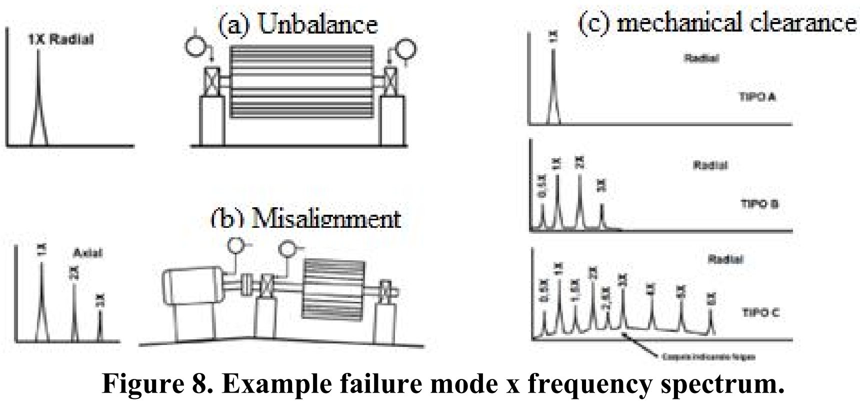

Figure 8. Example failure mode x frequency spectrum.

These failure modes presented, are few that the diagnostic electronics of the VSE100 family can deliver, if parameterized, applying filter and FFT analysis of easy configuration, can deliver on its communication port in the form of time series up to 8 failure modes per sensor of the possible failures captured by the vibration sensor.

4. Project Implementation

The project was divided into 3 steps to facilitate its understanding: the step of installation of the sensors and configuration of the electronics, the step of configuration of the communication between the two, systems and the step to storage and Analytics generations.

4.1 Installation of Devices in the Field and Parameterization

So that the system could have an MVP (Minimum Viable Product) in order to facilitate the understanding of methodologies, standards, interface In order to facilitate the understanding of methodologies, standards, communication interfaces, cyber security, and culture change, 3 VSA 001 sensors were installed in the bearings of the mill motor and 1 electronic was installed next to these sensors, figure 9 shows details of the installation.

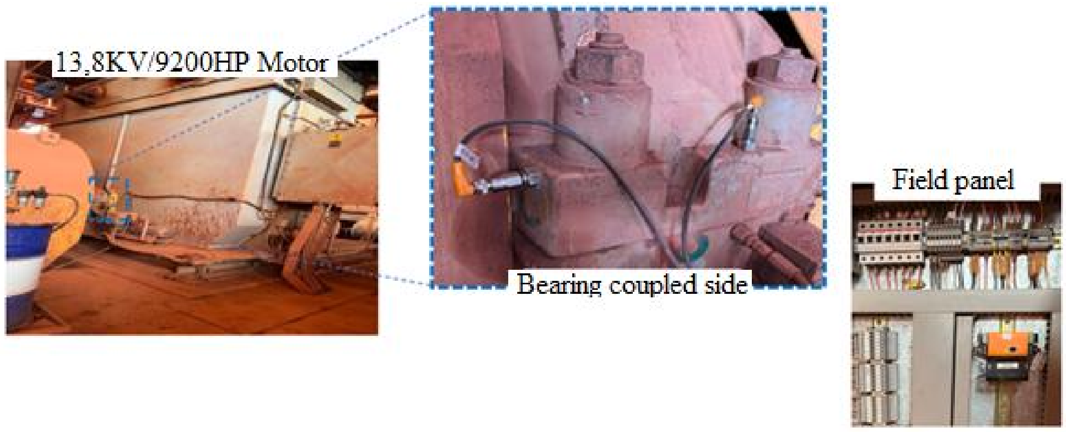

Figure 9. Monitoring synchronous ball mill machine.

Accessing the electronics remotely were parameterized 3 sensors and 18 failure modes, 6 failure modes for each sensor. The Figure 10 is seen the VSE004 interface configuration and diagnosis of the vibration system.

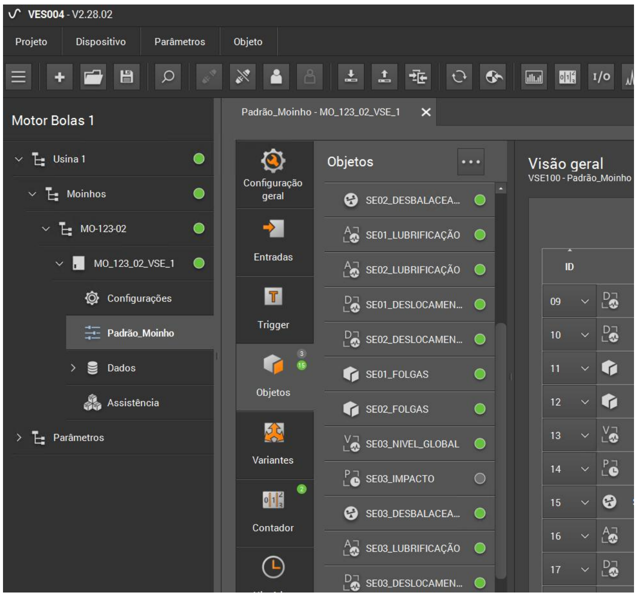

Figure 10. Parameterization of diagnostic electronics.

4.2 Setting Up Communication Between Systems

This project was only viable because the AVEVA PI System remote servers and the local IoT server were already installed in the plant reading the variables from the ABB 800xA control system. For plants that do not have this kind of data infrastructure, a better viability assessment should be made. Figure 11 summarizes the architecture used to communicate the IFM system with the AVEVA historian system.

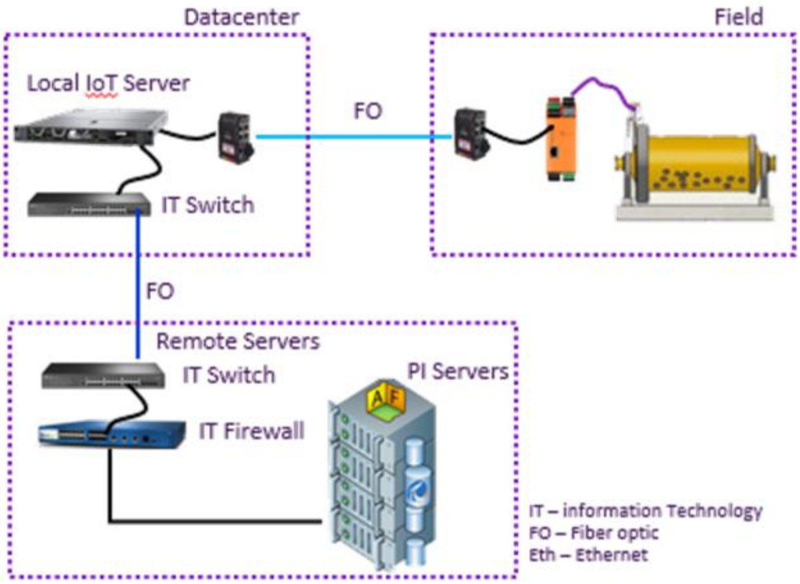

Figure 11: Communication architecture between systems

4.3 Historian Configuration and Analysis Rules

In the third step, the necessary configurations were made within the PI System servers, starting with the configuration of the attributes in the PI Asset Framework tree, passing through the event rules, notifications, and screen elaboration in PI Vision, in Figure 12 is shown some of these activities performed in the PI System.

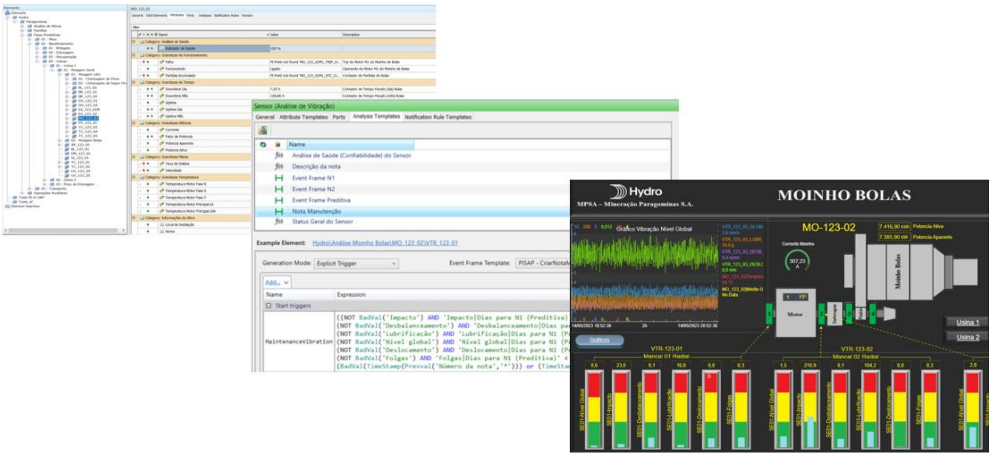

Figure 12. Asset tree architecture, rules and dashboards.

5. Results

The main result obtained with this whole project, is in the IoT product developed by the multidisciplinary team of Hydro Paragominas together with the corporate team of Norsk Hydro of Digital Transformation and Cyber Security, figure 13 is seen the architecture of the project that had as model the Framework for IoT technology previously shown in figure 5.

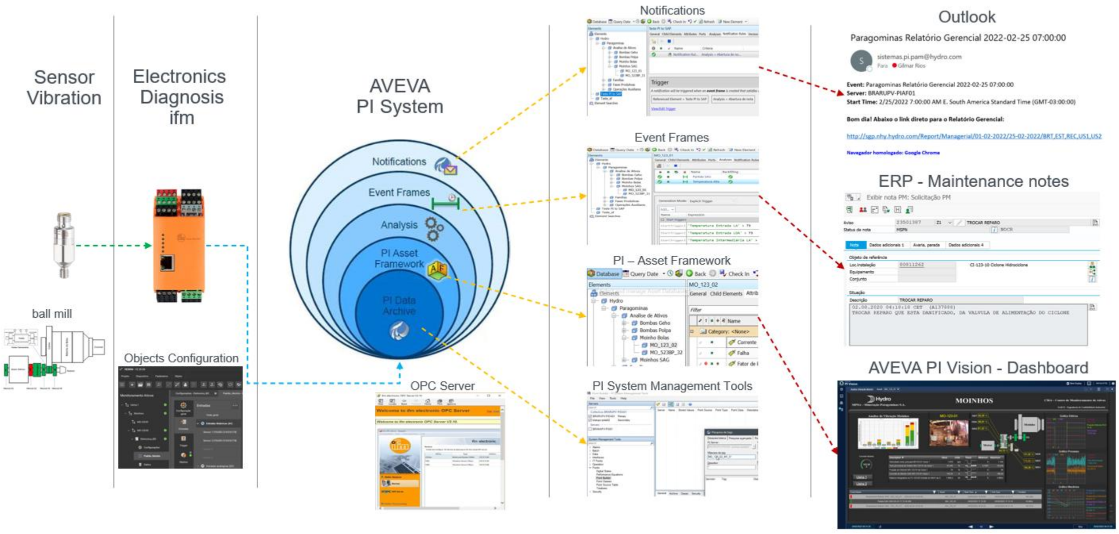

Figure 13. IoT architecture vibration monitoring with PI System.

The present vibration monitoring in real time, allows its failure modes to be stored in time series recording their amplitude every 1 second in the PI system database, with this data it was possible to create analyzes correlating with other process variables generated by the control system of the processing plant and creates insights when deviations between the variables are detected, these notifications can be directed to emails, opening maintenance notes directly in SAP-PM, all automatically, through PI Vision it was possible to configure the dashboard for online visualization of the 18 vibration variables of the 3 sensors configured in the system.

In the tests the system has already helped to identify a chronic problem of high vibrations, passing 9mm / s global level on the coupled side bearing of the engine, the difficulty of analyzing the classic way is in the manual and individual reading of the vibration points. With the system it was possible to confirm the value above 9 mm/s global level with strong correlation of the displacement level only in axial, proving the existence of error in the coupling clutch clearance.

6. Conclusions

Several gains were obtained mainly in relation to continuous monitoring, where although some operating conditions do not generate immediate damage to equipment, they can cumulatively generate wear and premature failures. Thus, it is possible to correct operational vices and easily expand the installation to other assets creating a safer work environment, with less exposure of the predictive team and automated event notifications, to know the effects and causes of potential failures, possibility to create reliability curves more easily, adjust maintenance plans with assertiveness, calibration of component levels in stock, without putting the business operation at risk, in short, the purpose of this work is to make Hydro Paragominas' bauxite processing plant more available, with greater reliability, within the planned costs and without harming the aluminum chain. The continuity of this work is being done with a Machine Learning tool for AVEVA prediction, in order to reduce operating costs and reduce operational risks, joining Data Science methodologies with RCM methodologies.

7. References

1. ABAL official website https://abal.org.br/estatisticas/nacionais/bauxita/
2. Hydro official website http://www.hydro.com
3. Kardek, A., NASCIF, J. 2012: *Manutenção Função Estratégica*. Qualitymark.
4. Lafraia, J.R., 2001: *Manual de Confiabilidade Mantenabilidade e Disponibilidade*. Qualitymark.
5. Viana, H.R. 2021. *Manual de Gestão da Manutenção*. Engeteles, Brazil.
6. Moubray, J. 1999. RCM II: *Realiability-centred Maintenance*. São Oxford: Butterworth-Heinemann.
7. Aveva official website https://www.aveva.com/pt-br/products/aveva-pi-system/
8. Rosa, R.N. 2016. *Aplicação da manutenção centrada em confiabilidade em um processo da indústria automobilística*, Professional Master's thesis in Production Engineering, Porto Alegre, Brazil.
9. Indicium. Machine learning: *Modelagem preditiva para prevenção de falhas*.
10. https://blog.indicium.tech/machine-learning-estudo-de-caso-manutencao-preditiva/.
11. Ifm. In accordance with ISO18436: Treinamento de análise de vibrações sistema on line Ifm. Edition August 04, 2017.