DIGITAL SOLUTION CONSTRUCTION FOR ASSET MONITORING THE DUAL STRATEGY IMPORTANCE

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Abstract - In the last decade or so, the company has been working on the development of solutions for Industry 4.0, both for internal applications in its production lines, as well as for offering to the market. This dual strategy has generated operational efficiency gains and, more recently, increased business for the company. This paper intents to show some cases using a cloud-based solution for on-line monitoring and advanced management of equipment and industrial assets. Two special cases are presented, one 150kW electric motor bearing fault detection with artificial intelligence algorithm and other, a vibration analysis of a 375kW electric motor using a cloud-based software; in this case the analysis are based on ISO20816 standard. Some of the main benefits noted at wiring factory plant due to the 4.0 maintenance practice are the Total Cost of Ownership (TCO) reduction and 7% improvement of Overall Equipment Effectiveness (OEE), supporting savings in the order of US$ 4,15 million.

Index Terms - Industrial internet of things, proactive maintenance and total cost of ownership reduction.

I. INTRODUCTION - DUAL STRATEGY FOR INDUSTRY 4.0

Asset and equipment management is being significantly revolutionized by industrial digital solutions, Fig. 1, which use the combination of cloud computing, use of wireless sensors, the application of related standards for asset management and adoption of 4.0 maintenance practices.

Before the advent of digital technology, only large and critical assets were continually monitored. Now, such technology is allowing the high-level online monitoring of the entire fleet, with affordable cost and valuable deliverables, compared to tradition technology which is cabled, with local data processing units and limited integration. The results noted by the end-user are higher availability of machinery and plants, reduction of unexpected breakdowns and reduction of total cost of ownership (TCO) for the fleet.

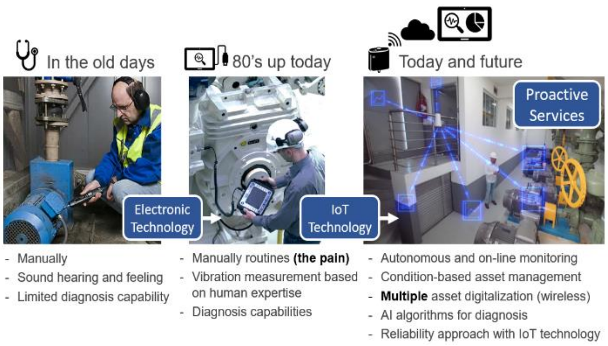

Fig. 1 Evolution of condition-based asset maintenance

As a highly verticalized company, with a wide portfolio of products and solutions, the company created the dual strategy approach to develop digital solutions and use such solutions internally during the last decade, the Motion Fleet Management (MFM) is one of them, that is briefly presented here. This approach helps the company to get the benefits but also create its own expertise to launch a mature solution world widely.

The pilot factory for Industry 4.0 at the company is the wiring factory, located at headquarters in Jaraguá do Sul, Santa Catarina state, Brazil. The main actions there were the adoption of:

- Motion Fleet Management (MFM) as online monitoring and asset management solution.
- Shop Floor Management (WSFM) as a MES system to optimize the production centers;
- Manufacturing System (WMS) methodology to detect and reduce losses;
- Maintenance 4.0 methodology and installation of the IoT sensors into the assets;

Currently, the wiring factory (Fig. 2) has 7.800 m², 107 workers, work time 24h/day for 7days/week, production of 1.100 tons copper and 300 tons aluminum per month. The MFM is applied to perform the online monitoring of 348 assets, providing relevant information to perform the condition-based maintenance, which is the base for predictive and proactive maintenance.

Fig. 2 Wiring factory with asset fleet online monitoring

II. ONLINE MONITORING WITH CLOUD SOLUTION

The MFM is based on cloud computing, operating on the company IoT platform. The MFM allows to check the operating status of low and medium voltage motors and generators, low and medium voltage variable frequency drives and soft-starters (drives), starting systems with smart relays, gearboxes, gearmotors, compressors and other assets installed in any type of industry or facility.

Using periodic data acquisition and advanced data processing, both on the edge and in the cloud, valuable insights are obtained. Thus, it is possible to establish predictive and proactive maintenance plans, considering the fleet operational condition.

The MFM has the layer concept (Fig. 3), the first layer comprises industrial assets that can be monitored with the MFM. The second layer is intended for asset digitalization and cloud connectivity through scans and Gateways. Both layers are hardware layers.

The third one is a software layer, which is the main application, named as Management layer where the data is stored and presented through dashboards, reports, notifications via App or e-mail and others. Some of the features of this layer are: dashboard for vibration analysis, module for maintenance management with CMMS features (computerized maintenance management system), backup of electronic drive parameters, notification and maintenance management application via Digital Notify APP, optimized data processing on the edge and cloud, view of asset events in the timeline, etc.

The Specialist and Exchange modules belong to the fourth layer. The Specialist module has advanced features for each asset monitored by the MFM, enabling autonomous failure diagnostics and energy consumption analysis, applying advanced data analysis with artificial intelligence algorithms based on the company expertise.

The Exchange module is used for data integration, via REST API or MQTT, with third-party systems as automation systems (SCADA), corporative management systems (ERP), maintenance management systems (CMMS), manufacturing execution and scheduling systems (MES) or other proprietary software.

The cyber security elements are briefly presented in Fig. 4, ensuring that information is safe, as it makes use of vanguard security standards, mechanisms and tools, such as: encryption of transported and stored data, security tokens for each device, controlled and segmented access, load balancing and redundancy features, enabling the application to meet the security goals.

The MFM solution operates on the company IoT platform, based on the architecture presented in Fig. 5. Authentications with access tokens generated by the application itself are used for connecting gateways, edge devices or Mobile APP to the MFM, which guarantee that only the devices with such token can consume and publish data in the MFM solution.

Digital hardware (wireless sensors and gateways) and software solutions for online monitoring are currently offered as a ready to use solution. Therefore, the implementation time and cost are drastically reduced and the gains can be quickly noticed. Adopting this technology, the company maintenance team reduces the number of unplanned stops, optimizes repair actions and speeds up decision making. Fig. 6 shows the screen (dashboard) of the MFM cloud solution for the wiring factory plant, which shows the factory layout with the position and status of each asset: green for healthy, yellow for alert and red for critical level for maintenance actions.

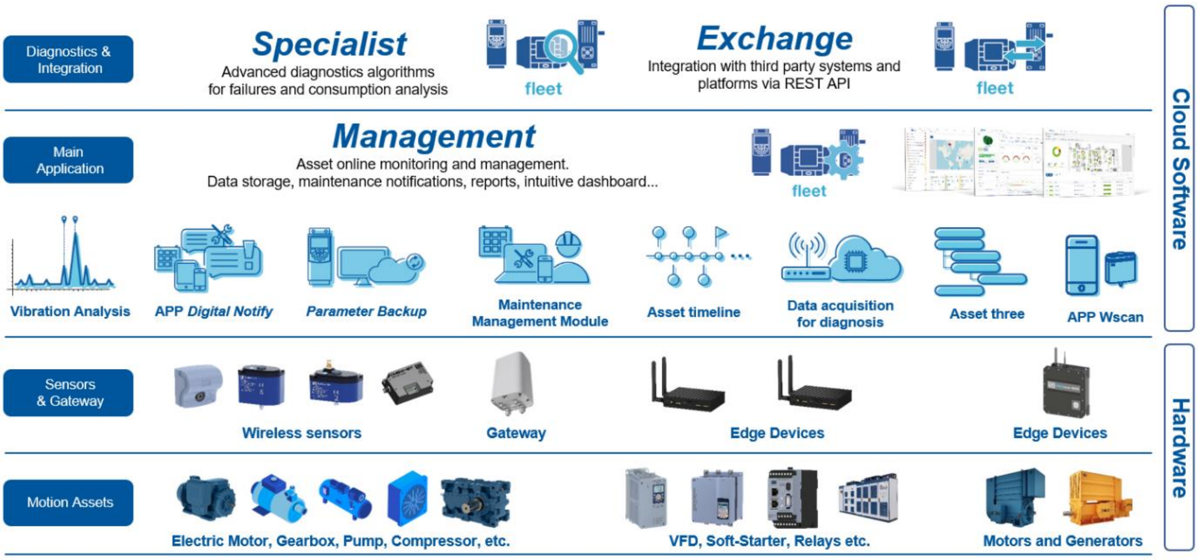

Fig. 3 Layer concept of digital solution for asset online monitoring

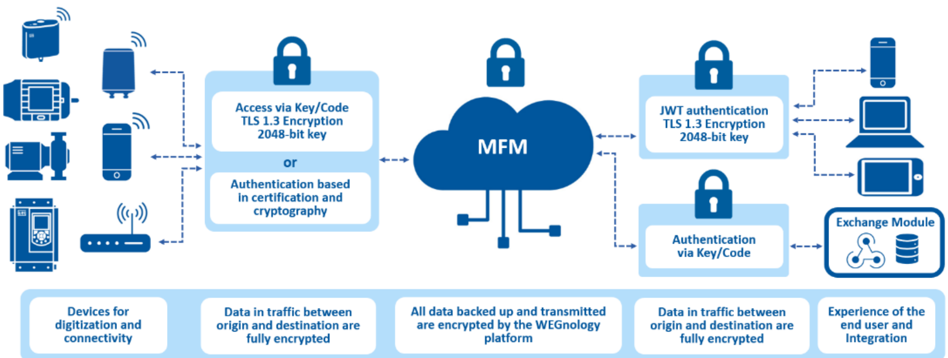

Fig. 4 Cyber security elements of a digital solution

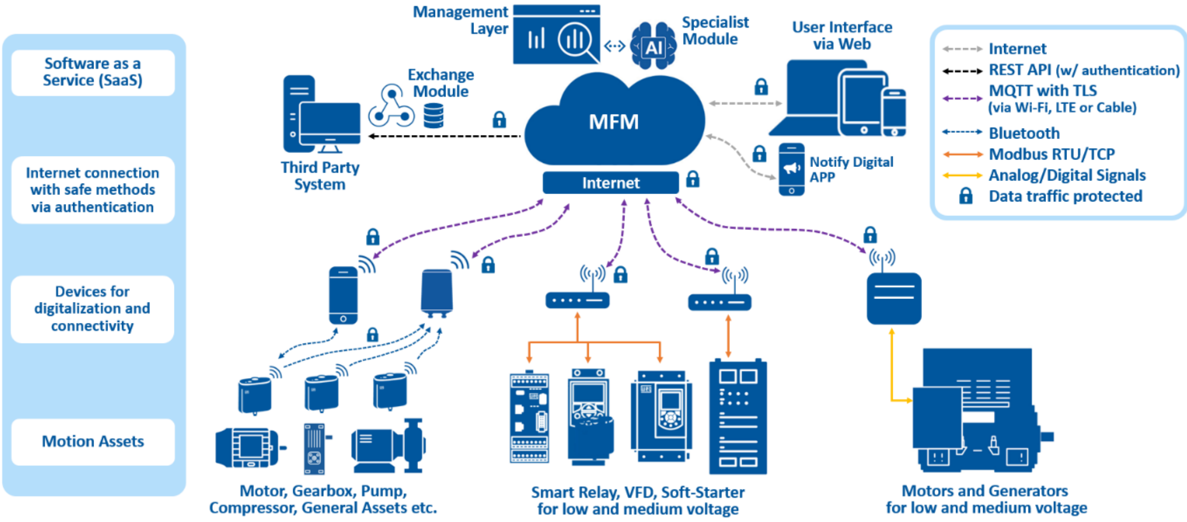

Fig. 5 Simplified Architecture of the solution

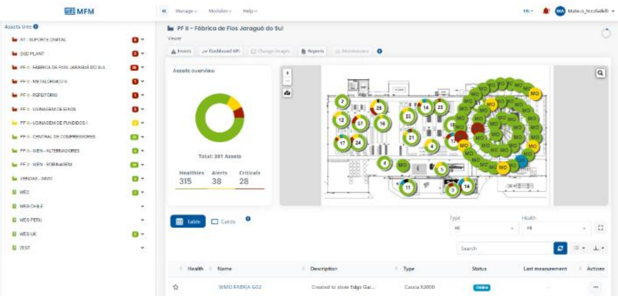

Fig. 6 Real plant digitalized for fleet management

III. REAL CASE WITH TEMPERATURE AND VIBRATION ANALYSIS

In a real case, using such solution the maintenance team prevented an overheating condition on a 3600RPM three-phase motor. In this instance, the maintenance team received an email notification, checked the data history (Fig. 7) and performed a fan cover cleaning and removed a small object that was obstructing the air ventilation. Without this action the motor could get the components damaged by temperature in such manner that the motor replacement becomes inevitable.

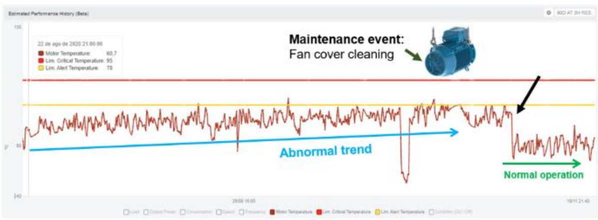

Fig. 7 Overheating occurrence and detection

In another case, the vibration raised values over the limits, as Fig. 8, which generated a notification. In this occurrence, the planned maintenance action prevented an unexpected production downtime, avoiding losses in production and maintenance.

Using the advanced module for vibration analysis, the vibration signal (spectrum) is analyzed in depth, based on the standard ISO 20816, thus allowing to diagnose the fault. Using such approach, it is possible to determine the best action to solve the problem.

The Fig. 11 shows the alerts using such spectrum zones, which is adjusted at MFM software, with health zone, alert zone, and critical zone for specific frequencies, up to 10 bands. The advanced vibration analysis module has other important features as circular waveform and multiple spectrum chart, as presented in Fig. 13 and Fig. 14, respectively.

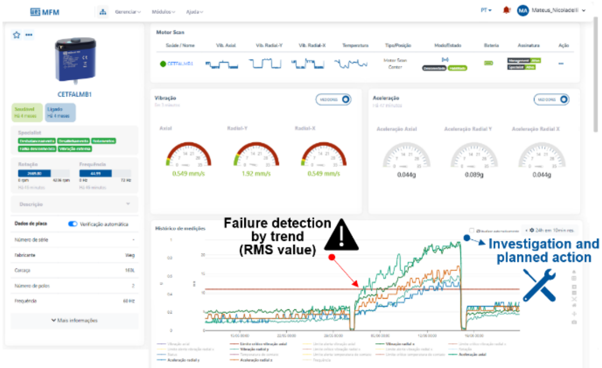

Fig. 8 Occurrence of high vibration (global) and detection

The use of ISO 20816 and such features are useful for experts and technical personal to analyze the asset issues in order to perform the failure diagnosis. Some failures possible to be detected using such approach are:

- Bearing failure
- Misalignment
- External vibration
- Unbalance
- Lubrication failure
- Broken bars
- Cavitation
- Lack of rigidity
- Eccentricity
- Friction (dragging)
- Defective belts
- Defective gears and others

Such diagnosis is performed using the asset failure frequencies. Taking a bearing as example, it is possible to observe four failure frequencies, which is calculated based on the bearing geometry and shaft speed, as presented by Silva, H. P (2019).

BPFI - Ball Pass Frequency Inner Race
BPFO - Ball Pass Frequency Outer Race
BSF - Ball Spin Frequency
FTF - Fundamental Train Frequency

$Nb - Number\ of\ rolling\ elements$
$Bp - Diameter\ of\ rolling\ element$
$Pd - Diameter\ between\ rolling\ elements$
$\alpha - \ Contact\ angle\ of\ rolling\ element\ at\ race$

$$BPFI = \frac{Nb}{2} \cdot \left(1 + \frac{Bd}{Pd} \cdot \cos(\alpha)\right) \cdot Shaft\_Speed \quad (1)$$

$$BPFO = \frac{Nb}{2} \cdot \left(1 - \frac{Bd}{Pd} \cdot \cos(\alpha)\right) \cdot Shaft\_Speed \quad (2)$$

$$BSF = \frac{Pd}{2.Bd} \cdot \left[1 - \left(\frac{Bd}{Pd}\right)^2 \cdot (\cos(\alpha))^2\right] \cdot Shaft\_Speed \quad (3)$$

$$FTF = \frac{1}{2} \cdot \left[1 - \frac{Bd}{Pd} \cdot \cos(\alpha)\right] \cdot Shaft\_Speed \quad (4)$$

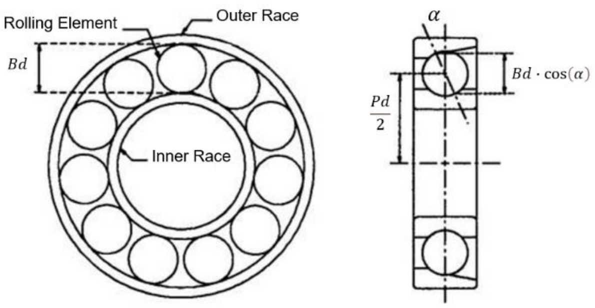

Fig. 9 Bearing geometry for failure frequencies calculation

These specific frequencies from the bearing are automatically loaded at software during the asset registration process, obtained from the solution data base with 70 thousand bearing models. This procedure is also applied into other assets types as gears, pumps and fans, informing the number of teeth, blades, vanes, shovels or impeller elements, which are used to calculate that failure frequencies.

The Fig. 10 shows the wireless sensor applied into a 315kW electric motor fan. The three-axis vibration analysis is performed as presented in Fig. 11, spectrum vibration detection based on ISO 20816, automatically.

The Fig. 12 shows the vibration signal in frequency domain but also in time domain, with some features to support the human analysis as autocorrelation, filters, envelope, sideband markers, harmonic markers and failure frequencies markers, taking a bearing as an example: BPFI, BPFO, BSF and FTF, and other functions.

In some cases, the analysis is can be complemented by the circular waveform analysis, as presented in Fig. 13, which is plotted observing the shaft speed and is very useful for gearboxes, fans and other assets.

As the solution gets automatically and periodically the spectrum measurement, the multiple spectrum chart is very useful, to track the evolution of the asset vibration profile.

Using such features, the failures can be automatically detected by the digital solution, from the early stages, providing relevant information for proactive maintenance.

Fig. 10 Online monitoring of 315kW fan electric motor

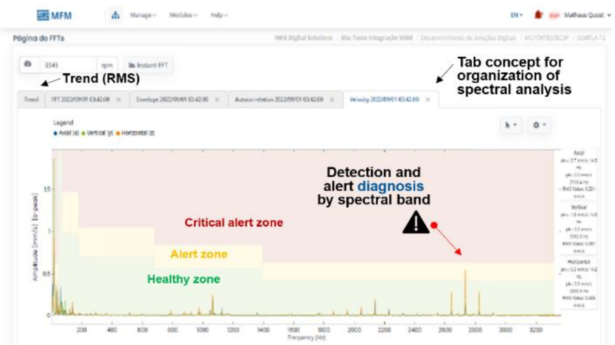

Fig. 11 Spectrum vibration detection based on ISO 20816

Fig. 12 BPFO failure detection & time domain analysis

Fig. 13 Circular waveform for vibration signal

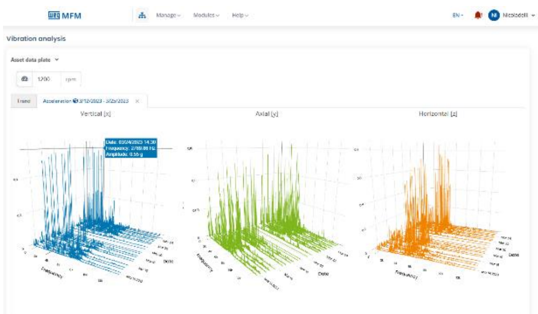

Fig. 14 Multiple spectrum chart for vibration analysis

IV. FAILURE DIAGNOSES WITH ARTIFICIAL INTELLIGENCE INTO ADVANCED MODULE

Another development driver for a digital solution is to incorporate the expert knowledge into the solution that provide high value for the user, converting data info insights automatically. The Fig. 15 shows the basic workflow used to construct the autonomous failure diagnostics algorithm, constructed by experts about vibration analysis, vibration sensing and data science.

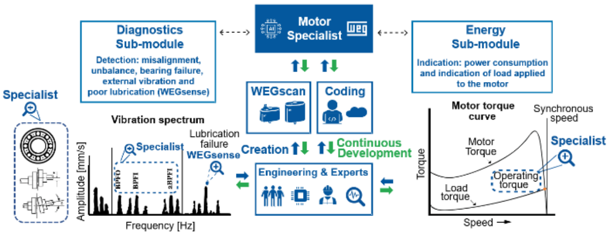

Fig. 15 Basic workflow to construct the advanced module with AI

In another real case, it was possible to prevent the unexpected stop of a 150kW air compressor (Fig. 16 and Fig. 17). In this case, the advanced data analysis algorithm (Motor Specialist module) detected a bearing failure even before the vibration levels raise.


Fig. 16 Air compressor with 150kW electric motor with online monitoring via four wireless sensors


Fig. 17 Detail of damaged bearing (inner race)

The Specialists modules applies AI and machine learning to support the troubleshooting, autonomously and early. This module uses the magnetic field measurements to infer motor energy consumption and three axis vibration data to indicate bearing failure, motor unbalance, misalignment, external vibration or lubrication problems.

Using such technology, the maintenance team knows what spare components must be requested for the service orders and how long the activities will take. The results are less unplanned stops and shorter maintenance periods.

The Fig. 18 shows the dashboard of AI module with such alert, a damaged bearing. As presented in Fig. 17, after disassembly the asset, the damaged was noted at bearing inner race.

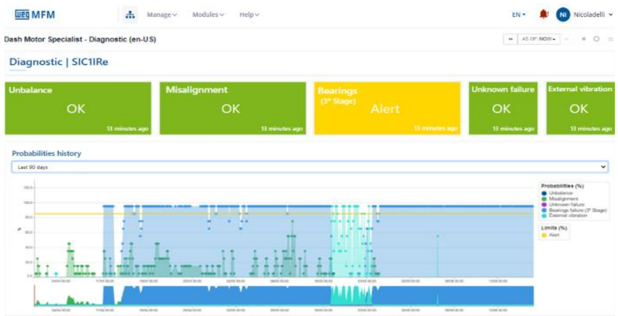

Fig. 18 AI module indicating bearing failure with automated diagnosis

V. LESSONS LEARNED

During this journey, which still on going, some lessons learned were raised by the engineering, application and commercial teams. Some of these learnings are presented below:

- Create a company mindset observing the Industry 4.0 as a journey, with strong support from top board;

- Adjust the mindset from maintenance and production team to adopt such solution, updating the procedures, to accelerates the adoption and creation of a new methodology of work;

- A low code IoT platform is crucial for digital solution, for developments and continuous evolution;

- Create a step-by-step implementation approach, getting fast the learnings to upgrade the solution;

- Create a collaborative environment between business units, involving the business and engineering teams;

- Algorithms are mandatory to convert data into insights, focus first into simple and reliable algorithms;

- Asset sensing/digitalization, connectivity and data visualization are key, without it, getting advanced features is challenging;

- Digital solution must be designed for multiple application (Fig. 19), with proper sensors and software's parameter settings;

- Improve the traditional products (motors, variable frequency drives, transformers, generators, electric panels, etc) to allow the proper asset digitalization and connection with cloud;

- Cyber security is mandatory;

- Promote the integration between the asset online monitoring solution with CMMS solution, is key to expand the proactive maintenance, systematically.

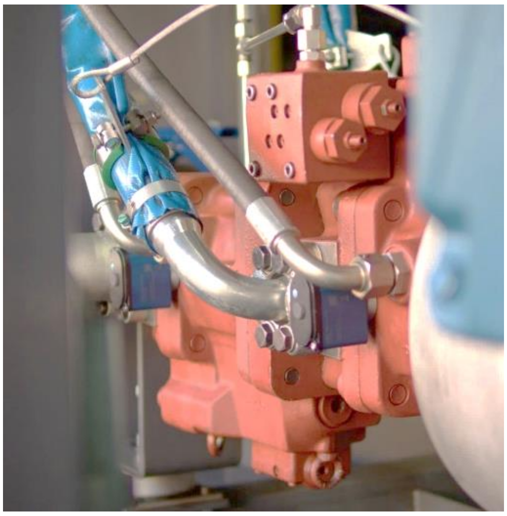

Fig. 19 Wireless sensors applied into an oil pump

VI. CONCLUSIONS – REAL GAINS

With the Industry 4.0 initiatives at the wiring factory, an increase of 7% in OEE was observed in this manufacturing department from 2019 to 2021. This gain eliminated the need to invest in new production lines, representing an investment in the order of US$ 4,15 million.

In 2020, the 4.0 maintenance and online monitoring approach avoided 49 unscheduled downtimes, a maintenance cost savings on the order of 6%. The number of man-hours on work orders for electrical and mechanical corrective action was reduced by around 10%.

The dual strategy has generated operational efficiency gains and good business for the company. The internal use of such technology allows company to improve also the features and robustness of the digital solution MFM. This digital solution has received continuous improvements, for hardware and software perspective. Such progresses are based on the product strategic roadmap and feedbacks from the internal and external customers, which some are from Oil & Gas segment.

VII. ACKNOWLEDGEMENTS

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IX. NOMENCLATURE

IIoT	- Industrial Internet of Things
MES	- Manufacturing Execution System
MFM	- Motion Fleet Management solution
TCO	- Total Cost of Ownership
OEE	- Overall Equipment Effectiveness
AI	- Artificial Intelligence
SCADA	- Supervisory Control & Data Acquisition
CMMS	- Computerized Maintenance Management System

X. VITA

Mateus Nicoladelli de Oliveira received the master of science degree in electrical engineering from Santa Catarina State University (UDESC), Joinville, Brazil, in 2020; the bachelor of science degree in electrical engineering from SATC, Criciúma, Brazil, in 2010; the electrical technician degree from SATC, in 2005 and pursuing the MBA in Digital Business from USP/Esalq, São Paulo, Brazil. Works at WEG Equipamentos Elétricos since 2010. He has five years with electronics, electric panels and automation systems (with WEG dealer in Criciúma-SC from 2005 up to 2010), five years global experience with service, commissioning & start-up of protection systems, excitations systems and medium voltage rotating electric machinery (synchronous and asynchronous), six years with engineering, research and development of rotating machinery and related systems for monitoring and digitalization. Since end of 2020, Mateus acts as Sales and Business Development at WEG Digital & Systems.
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