Renewable and Sustainable Energy Reviews 142 (2021) 110841

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: http://www.elsevier.com/locate/rser

Energy and maintenance management systems in the context of industry 4.0. Implementation in a real case

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ARTICLE INFO

Keywords:
Energy efficiency
Energy management system
Maintenance management system
Industry 4.0
Network analyzer

ABSTRACT

Industry 4.0 facilities and organization structures are used to improve energy efficiency and maintenance in industry. One of the challenges of Industry 4.0 is the urgent need to lower the consumption of energy, water and raw materials, as well as to ensure the safe and reliable running of a plant and reduce maintenance costs. The work presented herein proposes the low cost integration of Energy Management Systems (EMS) and Maintenance Management Systems (MMS) within the main management systems of a company, formed by organization appliances such as Enterprise Resource Planning (ERP), Distributed Control Systems (DCS) or Manufacturing Execution Systems (MES), The proposal has the virtue of introducing maintenance and energy saving in the company agenda. A central role in such integration is played by the generalized use of network analyzers in electric machinery; the information gained from these network analyzers is not only interesting for ascertaining energy consumption, but also for understanding the real operating conditions of the machinery, identifying premature failures or abnormal behavior. Dramatic reductions (about 50%) in energy consumption and required maintenance inspections, as well as the extension of piece replacement time, are achieved at a reasonable cost. The proposed measures have been implemented by a multinational corporation, owners of a chemical plant located in El Palmar (Murcia-Spain).

1. Introduction

The Fourth Industrial Revolution, also known as Industry 4.0 (I4.0), is based in the introduction of the digital technologies in the industry. An overview of the principles and practicalities of modern industrial automation systems was described by Mehta and Reddy [1]. Pérez et al. deep inside of the Industry 4.0 concept, on one hand analyzing its main features and on the other listing which technologies and concepts may be included under this term [2]. One of the main characteristics of the so-called smart or intelligent manufacturing is their ability to collect, process and evaluate data, communicate with other systems and even initiate actions [3].

Energy efficiency (EE) has for many years been seen one of the key strategies for improving the economic results of industry [4,5], as well as for reducing industrial pollution (IEA) [6]. These days, EE is also considered important in the context of climate change and the part played by the industrial [7] and building [8] sectors in global CO2 emissions. These are two of the most important sectors, and the emissions of industry alone are estimated to account for around 30% of the same [9]. The link between I4.0 and EE has been clearly established by the United Nations Industrial Development Organization (UNIDO) [9,10], and they have been identified as complementary actions to help achieve the objectives of the United Nations related with Sustainable Development Goals (SDG).

I4.0 is based on the use of cyber physical systems (CPS) that are able to connect different pieces of equipment and systems that coexist in an industrial facility and the cyber computational space [11]. Industry 4.0 (I4.0) is also based on what is commonly called the Internet of Things (IoT), or, when referring to the industrial environment, the Industrial Internet of Things (IIoT) [12,13], which deals with the difficulty of connecting these devices and systems and, more importantly, the sharing of information which allows the integration of different management systems in the company for correct decision-making.

Rather than revolution, industry is at present facing a time of evolution. It is becoming interconnected - internally, through the linking of all plant and department teams, as well as externally, connected with suppliers and customers through computer applications. The

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https://doi.org/10.1016/j.rser.2021.110841
Received 30 November 2019; Received in revised form 28 January 2021; Accepted 13 February 2021
Available online 1 March 2021
1364-0321/

Specific nomenclature

BI	Business Intelligence
DCS	Distributed Control Systems
EE	Energy Efficiency
ECS	Energy Control Systems
EMS	Energy Management Systems
ERP	Enterprise Resource Planning
I4.0	Industry 4.0
MES	Manufacturing Execution Systems
MMS	Maintenance Management Systems
MRP	Manufacturing Resource Planning
PLC	Programmable logic controller
SCADA	Supervisory Control and Data Acquisition

development of I4.0 is a challenge for most of world's factories, but management looks upon it as a powerful means to increase real-time performance measurement and production control, despite occasional organizational resistance at both employee and middle management levels [14].

Martínez-García [15] studied the integration of maintenance and energy management for the prevention of failures and the optimisation of maintenance inspections in process plant equipment in the scope of I4.0, set within the architectural pattern and infrastructure of a medium size plant.

Rajput and Singh [16] studied the hidden connection between Circular Economy (CE) and I4.0 in the context of supply chain, concluding that this integration generates greater efficiency in the usage of resources and energy, and also that I4.0 enables performance monitoring, predictive maintenance and service recovery.

Chen et al. [17] found that potential energy savings in plants, e.g. in machining workshops, lies not only in using energy efficient equipment, but in developing proper energy monitoring and management systems, such as those IoT based tools provide, able to simultaneously monitor energy consumption and production data.

Adenuga et al. [18] reported an important reduction in energy costs in a rail car manufacturing plant through the integration of energy efficiency software, "using information on energy cost as a baseline to allow centralisation and cloud hosting of data through a web-based interacting energy efficiency sustainability framework platform, to determine the economic impacts of energy measurement and verification on energy consumption and environment". They claimed that the use of sensors, data, software and analytics across the energy value chain increases efficiencies, improves business outcomes, and reduces downtime and maintenance costs.

Frank et al. [19] have studied the degree of implementation of Industry 4.0 technologies in a big group of Brazilian plants. Through the study of four front-end technologies (Smart Manufacturing, Smart Products, Smart Supply Chain and Smart Working), and four I4.0 base technologies (internet of things, cloud services, big data and analytics) they found that the implementation of base technologies is challenging companies, since big data and analytics are still little implemented. The authors recommended a layered structure with different levels of adoption on the part of the manufacturing companies. Smart Manufacturing, which plays a central role, comprises energy management (monitoring and improving energy efficiency), while Smart Working is significantly based on maintenance management.

Cupek et al. [20] implemented an agent-based Manufacturing Execution Systems (MES) for short-series production support based on the ANSI/ISA-95 standards, finding that results can be used to support the decision-making process.

One of the challenges of Industry 4.0 is to respond to the urgent need to reduce energy, water and raw materials consumption. In this respect, top management behavior and attitudes are crucial for implementing energy efficiency policies in firms [21]. Real-time acquisition facilities related with Energy Management Systems (EMS) can play a central role where trade-based solutions present two main problems: (i) they are usually conceived as islands, with no interaction with the supply chain, and consequently irrelevant in the decision-making process, and, (ii) they are usually developed under proprietary platforms, which means that connection interfaces need to be developed [15]. In fact, energy efficiency is considered as one of the eight most representative characterizing featuring of I4.0 [2]. Lin and Oliveira [22] propose Software Defined Networking (SDN), a flexible and agile technology, for communication networks in order to comply with the challenges of Energy Efficiency in Industry 4.0.

Another concern is safe and reliable plant operation in complex processes in which a large number of machines and devices take part. In this case the Maintenance Management Systems (MMS) has to deal with similar problems [23–26]. Maintenance scheduling is considered as one of the activities which, largely thanks to Industrial Internet of Things, can be seamlessly integrated into the information network [2].

Ordinary computer systems for the company management are formed by a complex network of computational applications (Fig. 1) such as Enterprise Resource Planning (ERP), Distributed Control Systems (DCS) or Manufacturing Execution Systems (MES), also called Manufacturing Operations Management (MOM). MES is an information and communication system operating across a manufacturing organization that integrates business and plant systems; it includes key areas such as Operations, Maintenance, and Quality [27]. Mantravadia and Møller made an overview of the features of present and future MES, and their relevance in Industry 4.0 [28].

ERP is the core of the company computer system, which connects and exchange information between the different applications needed in everyday company operations, such as purchases, sales, financial management, raw material stock, etc. ERP provides real time knowledge of the key parameters of the company and is present in most companies that have accepted a certain degree of modernization, not only in industry. The system acts as the centre of several specific applications for the different tasks and branches of the company, which are treated as satellites, sharing meaningful information between company departments: Finance, Purchases, Sales, Warehouse management, Stock, etc., which, otherwise would not be connected. As for DCS, it collects all operation parameters of the different devices and plants (PLC, SCADA …) throughout the factory. But in many cases this rich information remains accessible only to plant operators or technical staff, and only serves for production control.

For its part, MES is a data base which connects the both systems: it "reads and writes" information from DCS in ERP systems. MES is directly related with on-time operations [20].

Frequently, Energy Management Systems (EMS) and MMS (Maintenance Management Systems) are not included in the overall company management system. Present work proposes the integration of MMS and EMS in the overall company management system. The objective of such integration is to use the information recovered on the company supply and operation chain for the purpose of improving maintenance [29] and energy saving strategies and to include these topics in the company's agenda.

All the proposed measures have been implemented in the Spanish subsidiary of a multinational chemical corporation located in El Palmar (Murcia - Spain). The company produces commodity aromas and other chemical products by means of more than one hundred chemical synthesis and distillation units. The factory opened in 1965 and employs around one hundred permanent workers. In the present case, ERP role is carried out by the commercial software Microsoft Dynamics NAV ("ERP" in Fig. 1), formerly called Navision®, the DCS function is carried out by Plant Automation Wonderware® [30] and MES is an in-house development which uses SQL language [31]. Two other applications are involved in the usability of the whole system, Sharepoint® from

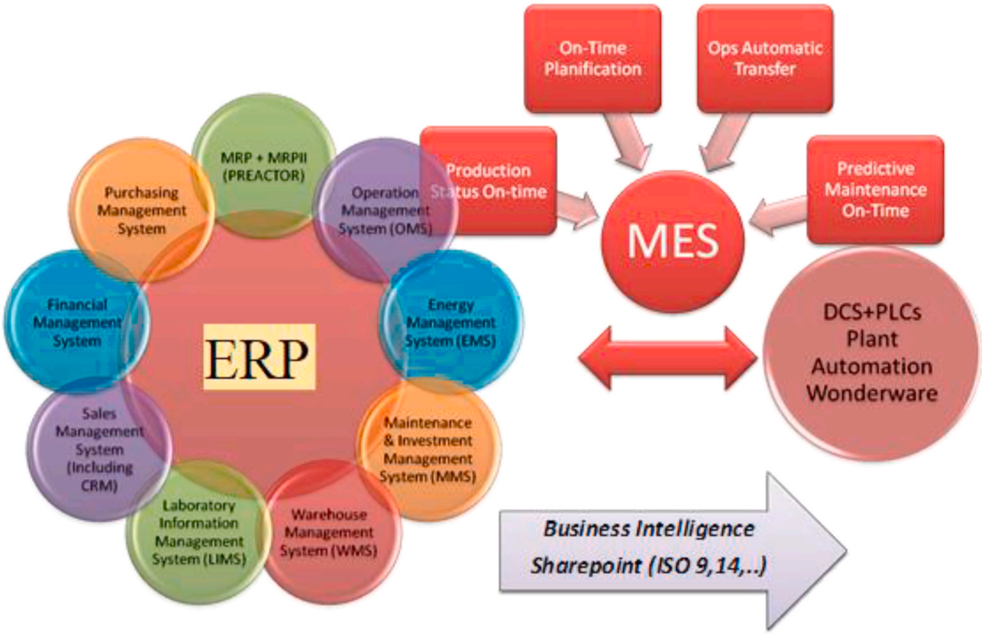


Fig. 1. Company management "eco-system" [15].

Microsoft® [32], a specific data sheet for industrial purposes, and Qlikview® [33], a business intelligence (BI) and visual analytics platform, which enables end-to-end data management.

All data and information about the company that are included in this work have been provided by it in the scope of PREBYA-2012 project (see Acknowledgements).

2. Energy and maintenance management systems in the main management system of the company

A huge variety of technologies have a role in Industry 4.0: Big Data, Cloud Computing, Robotics, System Integration, Augmented Reality, Additive Manufacturing, Internet of Things, Simulation, Cybersecurity, etc. Of course, not all companies can apply all these technologies. In the case of the El Palmar plant, efforts have been focused on the development of Industrial Internet of Things, Cloud Computing, Big Data and Systems Integration.

Among others the problems Industry 4.0 aim to deal with are the efficient use of energy and material and human resources. Within this field specific systems such as Energy Management Systems (EMS) and Maintenance Management Systems (MMS) have been developed. These systems provide energy and asset management in real time, which are focussed on the achievement of energy savings and availability of the production equipment.

Even today it is very common to find that both systems not integrated in the management of the supply and operation chain of industries and, therefore, in the main management systems of the company (ERP, DCS and MES), even though the information collected by means of the systems regarding the reliability, maintainability and energy consumption of the equipment should be key element in decision making. The aim of this work is to describe the integration of the information generated through the EMS and MMS systems in DCS, MES and Manufacturing Resource Planning (MRP II), which is another part of the ERP, and whose functions are performed by software Preactor® of Siemens® [34] to provide real-time information about the status of the dynamic equipment and therefore be able to act accordingly.

This information would allow the management system to forecast anomalous situations, significantly reduce unplanned stops and the costs involved, as well as those resulting from the continuous malfunctioning of machinery, especially in terms of energy expenditure. Generally speaking, the safety of the plant increases as long as unplanned stoppages are reduced (corrective maintenance). Typical situations are leakages in pipes, valves or devices that contain dangerous substances. In the case of dynamic equipment an unplanned stoppage or malfunction is a potentially dangerous situation, since, for example, if the shutdown affected a refrigeration group, the cooling capacity would be drastically reduced. Another example is an unexpected stoppage of the vacuum pump, which would lead to a rise of the pressure inside the reactors. Both situations could well generate an emergency situation. Moreover, if all this knowledge were shared, the safety of the plant would be significantly increased both from an environmental and industrial point of view. In this sense, Gómez de León et al. [35] describe a system that automatically assesses the functional condition of the equipment and immediately sends and shares that information with the plant's computer system, making it accessible in real-time to all staff.

But there are problems involved when integrating information [36]. Most current industrial equipment is provided with monitoring systems, such as SCADA, which provide on time information about all the relevant operational variables of the plant. But, as has been said before, they are intended to control and operate processes rather than to register and transmit information to a higher information level. Of course, solutions are available in order to implement both commercial modules, but two main problems then arise [37]:

- Monitoring systems are usually conceived as islands within the factories, that is without or very little interaction with supply chain management systems, so they do not provide relevant information for decision-making.
- They are usually developed under their own codes and platforms, forcing the company to maintain and operate different systems and create interfaces for their interconnection in addition to having to depend on external resources.

For these reasons, we carried out a search for suitable equipment that could overcome such difficulties, bearing in mind that any selected devices should not be excessively expensive. Therefore, to implement this proposal, a degree of technical ability (mentioned throughout this work) is necessary, which is in line with the requirements of the Industry 4.0 paradigm, or, at least be willing to take the appropriate steps in that direction. However, most of today's large and medium-sized industries are involved - even competing - in this process of technical integration of all hardware and software platforms. That is why the method proposed in this work can be easily implemented in a large number of companies.

3. Monitoring equipment: network analyzers

In all industries there is a set of machines which needs continuous supervision of its functional status because it is critical for the production process, its economic value or for safety reasons. Such continuous supervision is very difficult and expensive to perform by traditional methods (maintenance technicians continuously collecting information on the functional status of the equipment through off-line means). It would obviously be much better to use parameter measuring equipment that sends information of a machine's status in real-time (especially the level of vibration and temperature).

As mentioned above, the commercial solutions existing on the market are limited and expensive due to the high cost of the sensors and devices that make up the entire architecture of the monitoring; the cost of the associated software is also high.

The cost of the investment necessary for this implementation is only acceptable in cases where the cost of the machine to be monitored is very high, the repair cost is also very high or the downtime occasioned by the failure is very long and therefore generates important losses. This is particularly true in the case of large turbines in power plants, large units for the continuous distillation of crude oil or other type of large rotating equipment linked to continuous production, all of which are good candidates for the implementation of these commercial systems.

Therefore, there is a need for more accessible alternative monitoring techniques, which directly or indirectly, through the measurement of other variables, can give information in real time on the state of the equipment.

As an appropriate solution for equipment monitoring, individual electric network analyzers, or simple network analyzers, have been chosen (Fig. 2). This is a mature affordable technology, which provides real time information about the individual electric parameters of the items of equipment of the plant. Network analyzer information is interesting not only for measuring energy consumption, but also the parameters related with the actual operating conditions of devices and plants [38], which also reveal premature failures or abnormal behavior of the machinery.

Most dynamic equipment uses electric motors. A failure or loss of the properties of any of the elements of the rotating equipment affects the proper functioning of the electric motor. Consequently, monitoring the motor through its electrical parameters detects the possibility of premature failures or deviations from "normal" behavior. Analyzers are widely used in industry; it is a very mature technology, with a wide variety of suppliers that provide solutions at different economic and technological levels.

In addition, these devices are easily integrated in Energy Management Systems (EMS) and are already incorporated into most business management systems, because their information is frequently used for the calculation of production costs (the cost of energy is a direct production cost).

EMS is a module integrated in Enterprise Resource Planning (ERP), which recovers information concerning the energy used by several systems throughout the factory. The above mentioned characteristics make network analysers good candidates for forming a fundamental part in the implementation of the EMS.

The EMS module feeds on information supplied by the following systems [19]:

- **Energy Control System** (ECS). This system is specifically related to the Energy Management System (EMS) and is mainly composed of a set of network analyzers and flowmeters distributed throughout the factory and basically provide information about electrical and steam parameters, such as current, voltage, power, steam flow, etc. Fig. 3 depicts energy consumption (3a) and power (3 b) from units (buildings) and utilities obtained by the ECS at the Spanish plant over the course of one week. As can be seen, lightning (surprisingly), boiler (pumps) and compressed air are the most energy-consuming utilities (3a). Fig. 3b shows that boiler power predominates during the day and lightning power during the night, as expected. The graphs show the large difference between the working week and weekends in the case of the units, which is not so pronounced for the utilities.

These data, which are integrated in the company ERP by means of MES, allow the energy consumption related with the different processes to be differentiated and accounted for, which not only encourages the implementation of energy efficiency measures, but also has maintenance implications.

Many production plants only register overall plant parameters (i.e., overall electric or gas consumption). In this case, the biggest problem is that monitoring is more oriented towards the evaluation of production costs, the detection of anomalous situations in the production process or situations that could affect the performance and safety of the same, but not at the detection of anomalies. Consequently, this information alone is not suitable for detecting faults in dynamic equipment, which is of consummate interest, since they could lead to so-called "false positives" faults. For example, if a situation arises whereby the indicator of active pumps shows there are more pumps active than is necessary, this could be because one of the pumps in not working properly, because one of the pipes is obstructed or other problems. The first cause is a "positive" fault, i.e., the problem comes from the dynamic equipment; by contrast, in the second case, the problem is not in the pump, and, if only the pump indicator is taken into account, may be regarded as a "false positive".

What we found is that when the overall process data are combined with the information generated by the individual network analyzers, the system is much more robust in terms of energy control and equipment diagnosis.

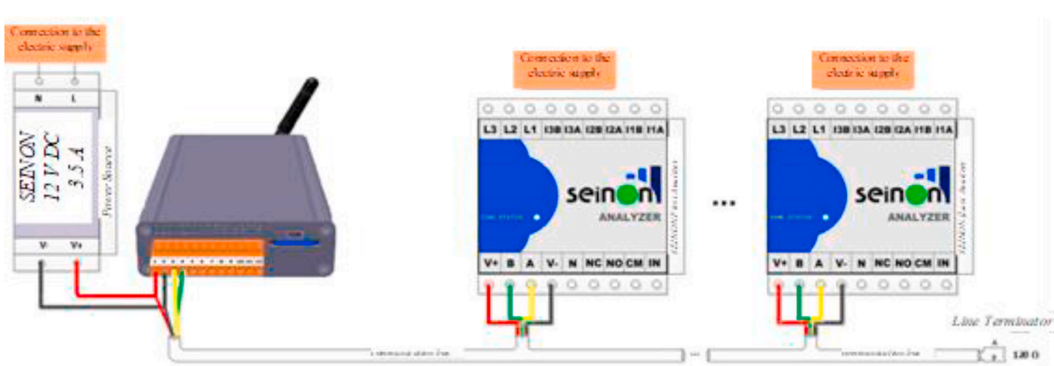


Fig. 2. Electric network analyzer.

- **Distributed Control System** (DCS). This system recovers process parameters from throughout the plant: pressures, temperatures, fluid flows, pH, etc. Fig. 4 shows how the different operative magnitudes in the plant change as the day progresses. When the curves are matched with the consumption curves of the corresponding building or utilities of Fig. 3, "positive" or "false positive" faults can be discriminated. The information provided by Fig. 4 can be used jointly with energy measurements of the Energy Control System and those of the Manufacturing Execution System to provide mixed indicators, which will also help in the detection of real faults. The mixed indicators are defined in the following section.
- **Manufacturing Execution System (MES)**, which provides process operational variables: amount of production, active equipment, hours worked, etc.

The integration of data collected through the Energy Control System (ECS) with those of the DCS or MES system is done through the BI software of Qlikview® [33]. The interest of dealing with data of different nature is studied in the following section.

4. Application: electrical and mixed indicators for fault detection in dynamic equipment

As we have seen, direct energy indicators (e.g., energy consumption) can be directly obtained from ECS, DCS and EMS. Also, mixed indicators, including technical and process parameters, are yielded from this information.

4.1. Energy indicators

Network analyzers provide energy indicators, of course, but also relevant information about the equipment status. There is a close relationship between maintenance and energy consumption. As an example, an electrical imbalance greater than 5%, detected through a deviation of

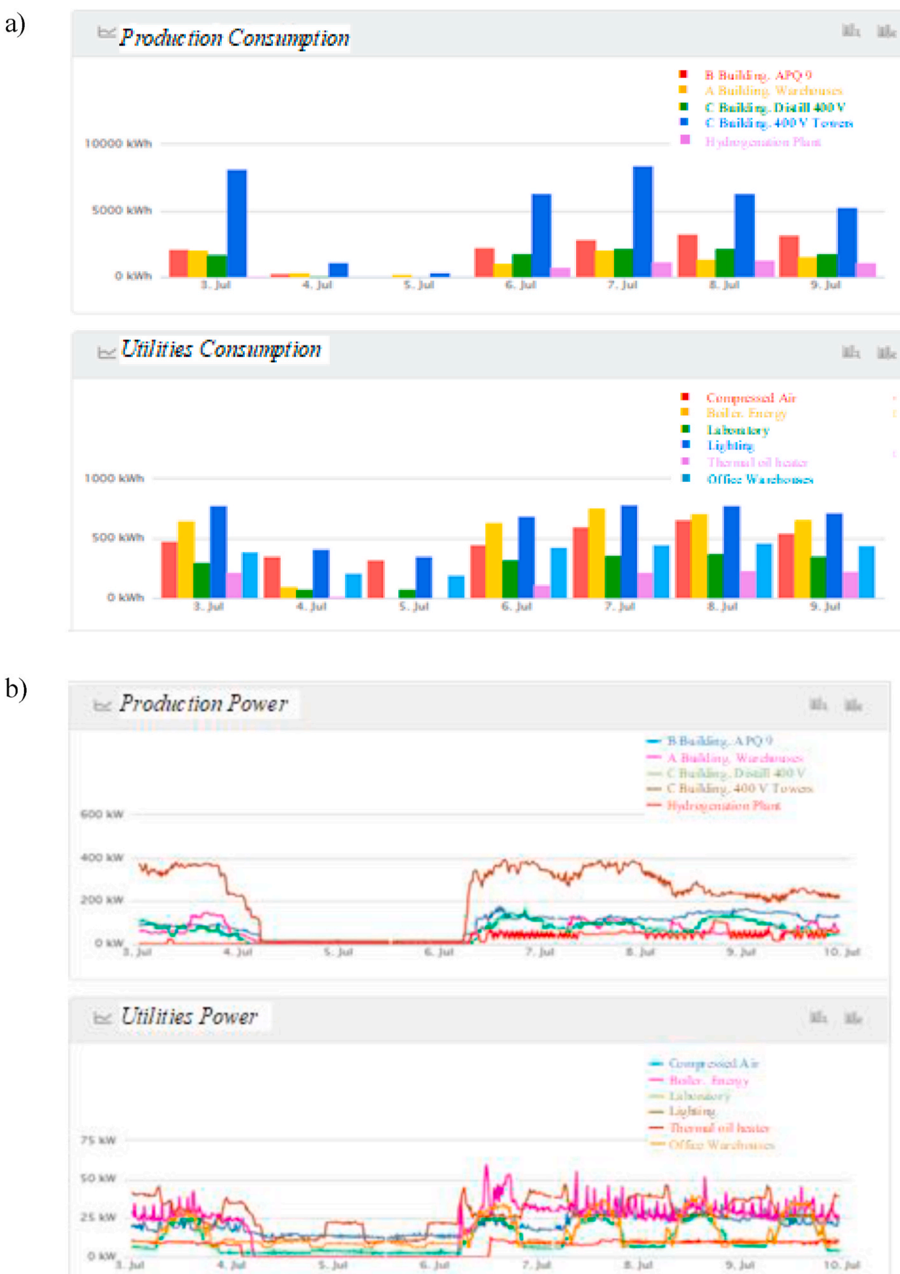


Fig. 3. Energy consumption and power of units and utilities at the Spanish plant yielded from EMS.

the average intensity per phase, can be caused by a significant increase in the mechanical unbalance or by a shaft misalignment [39]. In the case of a pump, if material has been detached from the impeller, either by the effect of cavitation or corrosion, the rotor imbalance will normally increase, initially causing an increase in the average diameter of the rotor orbit and, consequently, of the induced currents. Fig. 5 depicts measurements in a particular pump. In this case an electrical imbalance greater than recommended occurs (Fig. 5a). At the same time, vertical vibration (measured in units of velocity, according to ISO 20816 [40]) in this pump reflects a gradual but substantial increase in the main harmonic (1x) of the rotational speed, typical of an imbalance, in only 45 days (Fig. 5b).

4.2. Mixed indicators

These indicators combine information on energy consumption and plant operational or economic parameters. They indicate possible loss of properties of rotating equipment through ratios that relate operation (workload, hours worked, production volume …) or process variables (flow rate, temperature, pressure), with electrical data (energy consumption, power …). Two mixed indicators have been used in this work:

1. Mean Unitary Power (MUP) or Overall consumed power (kW)/ Number of running devices and
2. Power per Unit Flow (PFU) or Overall consumed power (kW)/ Nominal flow (m^3/h).

4.3. Application 1: group of centrifugal pumps

These ratios are used, as an example, in order to establish warning points for a group of centrifugal pumps that alert maintenance staff to correct the situation. Two case studies have been proposed:

- A water pumping system consisting of six centrifugal pumps (4 main pumps + 2 redundant), which supplies cooling water to the head condensers of 12 distillers located in two -differentiated production units. In this case, the MUP ratio has been used (Fig. 6) and is seen to be within the range of 18–22 kW per operating pump.
- A group of centrifugal pumps (1 main +1 redundant) belonging to a refrigerating unit used to control an exothermic reaction. The refrigeration circuit is a closed ring, where the reactors are connected in parallel to form a battery. The Power per Unit Flow (PFU) ratio of the refrigerating unit was considered suitable for studying this group, the nominal pump flow being obtained from the pump characteristic curve.

Fig. 6a shows the overall power of the 4 BP + 2R pump group over the course of four weeks. The power consumption range is approximately 150 kW up to 200 kW during the work week and zero from Friday night until Monday morning. Fig. 6b depicts the Mean Unitary Power ratio (left axis) as well as the number of pumps in operation (right axis) during one day. In this case, as can be seen, the ratio is within the range of 18–22 kW per operating pump at the beginning, but clearly increases when one more pump is started. This abnormal deviation may be an indicator of pump malfunction.

In both cases the detection of machinery malfunctions has the drawback of misleading the monitoring indicators, including the "expertise" of the plant operator. This comprises the condition of the pipes, which can generate additional hydraulic losses and equipment or unit fouling, etc. All these situations could mask the real status of the equipment. Therefore, the use of indicators is used as an alert of anomalous situations in the equipment or system, which must be confirmed by means of predictive techniques. Consequently, operation limit values of the analyzed systems were identified and an alarm system has been implemented so that if the value of the indicator exceeds its limit value during two consecutive measurements or three non-successive measurements within a period of 24 h, emails are sent to maintenance and production personnel, as well as an alert message through the MES to the PLC that "orders" the affected equipment to notify this to the maintenance operator in charge of the plant.

4.4. Application 2: dynamic predictive maintenance in steam traps. Effect on energy expenditure

Not only rotating machinery – electricity-consuming equipment - has been treated in the scope of EMS, but also steam traps (Fig. 7a), which are distributed along the steam network of the plant. In this case vibration and, more frequently, ultrasounds analyses are used in order to detect faults in traps [41].

Fig. 7b shows several ultrasonic registers of steam traps representing different functional conditions. From top to bottom we can see: a steam trap in good conditions (upper signal), a trap with total leakage from the inner valve (valve permanently open) (second signal), partial leakage, due to badly fitting seal in the valve (third signal) and, finally, a steam leakage through the body of the trap (bottom signal).

Fig. 8 depicts availability of steam trap as well as the amount of steam leaked by these devices over the last 7 years in the Spanish chemical plant in question. In the left column it can be observed how the availability has increased from 46% to almost 100% in this period, that has been accompanied by an almost 90% drop in steam leakage (red line), which are now almost negligible. On the other hand, this reduction means important economic savings. Table 1 illustrates the dramatic decrease in steam leakage costs considering a unitary cost of 30 € per steam tonne.

5. Energy costs

Electric energy consumption in the factory as a whole has registered

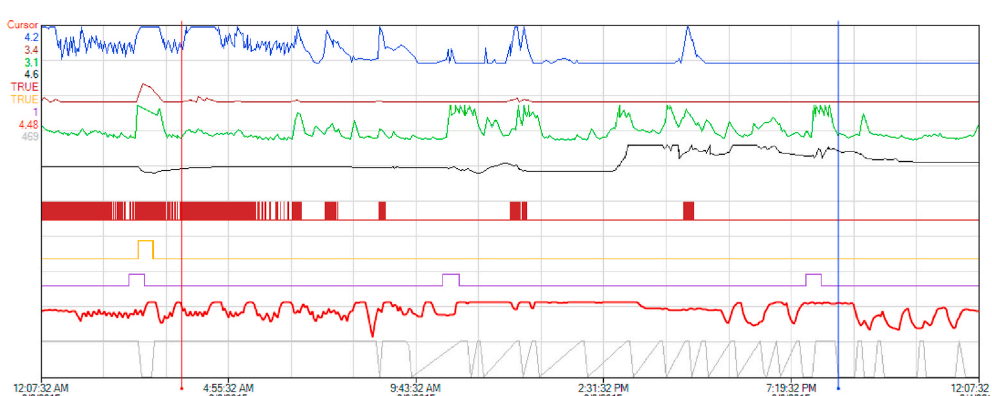
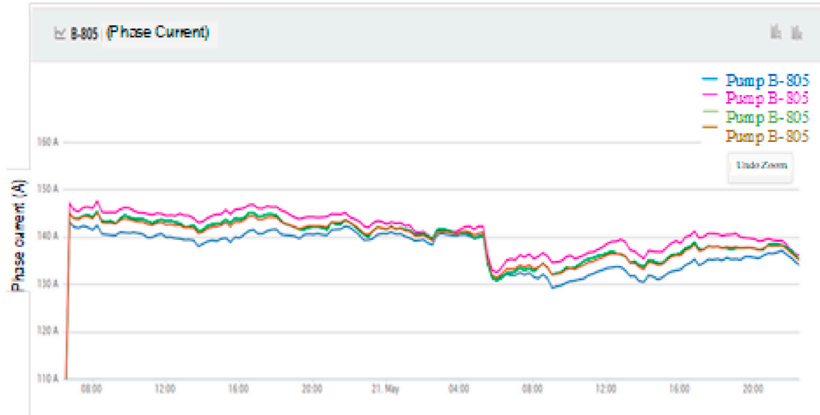


Fig. 4. Screenshot of process unit parameters and utilities at the Spanish plant provided by DCS.

a)



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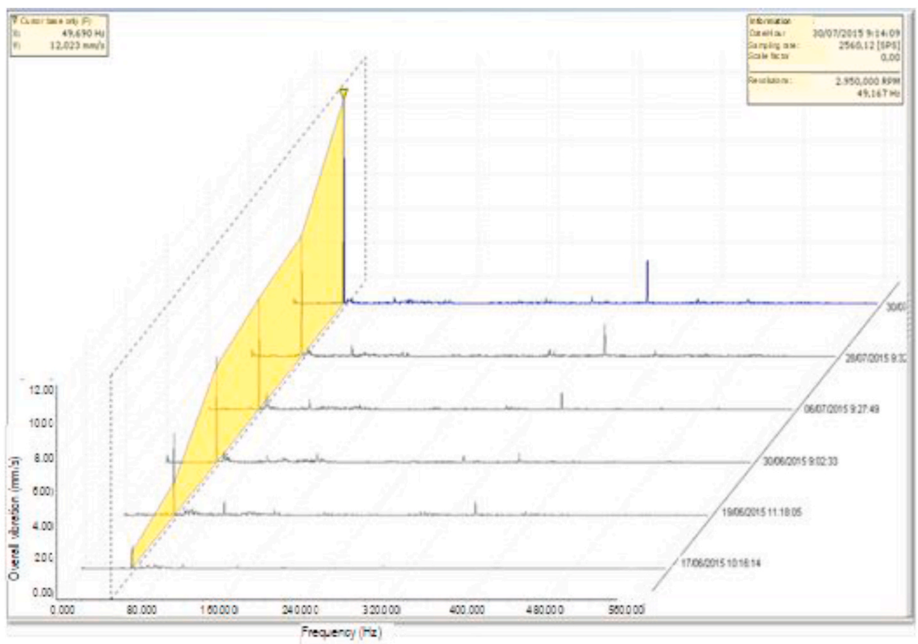

Fig. 5. Measurements in pumps at the Spanish plant; a) Phase currents; b) Rotor vibrations featuring 1x harmonic at different dates.

an impressive fall since the measures and strategies described in this work began to be implemented in 2009. Fig. 9a shows the overall electrical consumption in the most recent years. Although production has increased in these years, total energy consumption has registered a constant decrease as different measures have been put into practice.

More impressive still is the reduction in specific consumption. Fig. 9b depicts the specific electricity consumption (kWh/kg) and the specific electricity costs (€/kg), both of which show a decreasing, almost parallel, trend in the period under study due to the relative small variation in electricity prices in Spain in recent years. The reduction of 45% shows how the implemented measures have effectively contributed to the energy efficiency of the plant and the effect on the company's economic results.

It is important to remark that this outstanding achievement is the result of a set of measures, sometimes guided by maintenance requirements, sometimes by sustainability targets, which have been implemented, gradually but with determination. The Spanish chemical plant in question is a more than 50 years old, and, in less than 10 years, has reduced its energy consumption per kg of material produced by almost one half, without undergoing substantial changes in the productive structure, but implementing organization and management changes, where energy and maintenance management systems have taken on a central role.

6. Conclusions

Energy Management System (EMS) and Maintenance Management System (MMS) have been integrated in the supply chain management system (DCS, MES and MRP) and hence in the overall company management systems (ERP, DCS and MES) of a chemical plant. The information collected through both systems has become key element in the company decision making process.

Such integration has been largely accomplished through the widespread use of electric network analyzers, particularly their application in rotating machinery. This is a mature technology that is available at an affordable price that provides real-time information about the status of the dynamic equipment, which can then be easily integrated in the supply chain management system.

As a result, the management system is provided with important information to forecast anomalous situations, significantly reducing unplanned stoppages, as well as the costs derived from the continued malfunction of the equipment, particularly energy expenditure. With this shared knowledge, too, the safety of the plant has been significantly increased, from an environmental and industrial point of view.

a)

b)

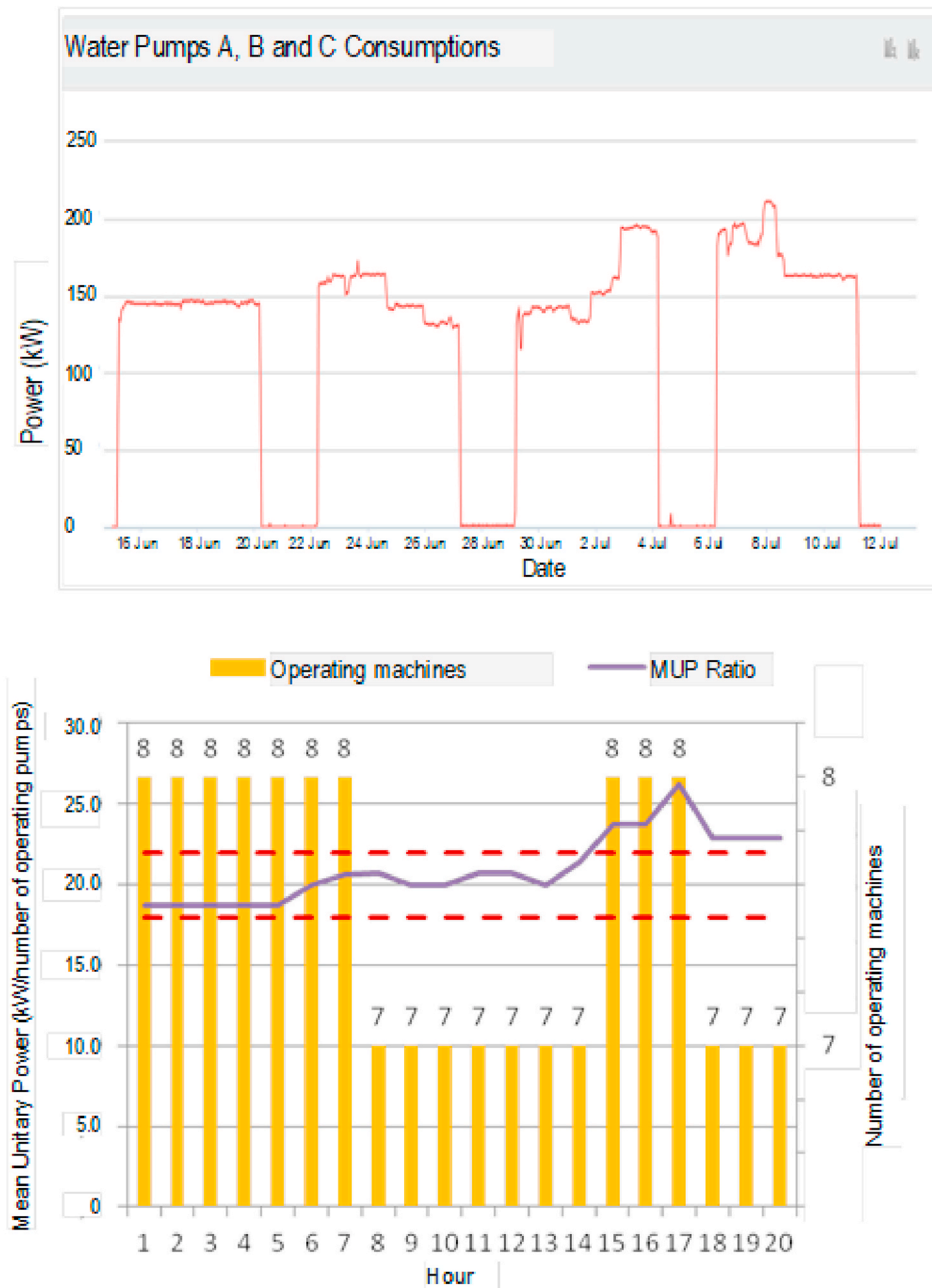

Fig. 6. Energy and Mixed indicators of a group of centrifugal pumps (screenshots); a) Overall power (kW); b) Right axis: Mean Unitary Power (kW/number of operating pumps); left axis: Number of operating pumps.

a) b)

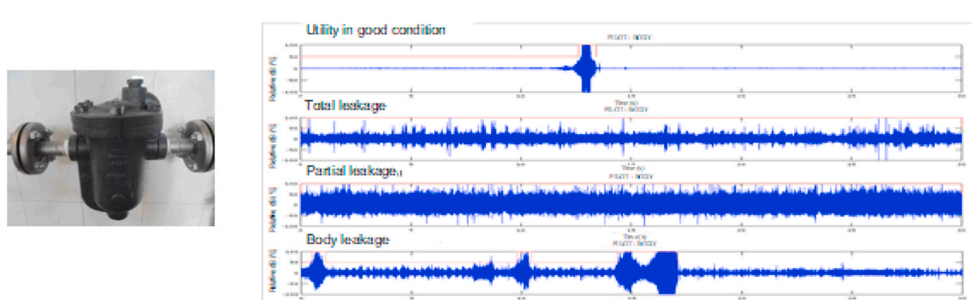

Fig. 7. Use of ultrasounds in leakage detection in steam traps. a) Seam trap; b) Different status and malfunctions in steam traps (screenshot).

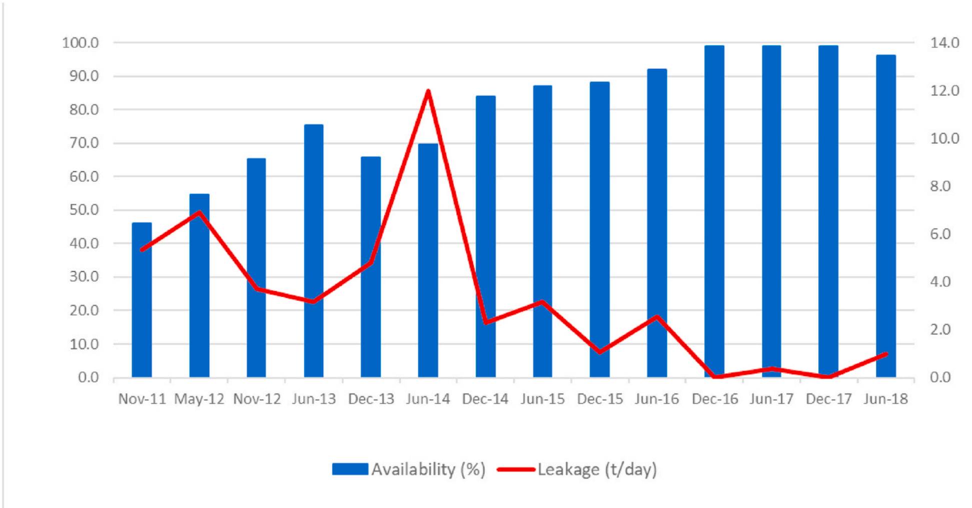

Fig. 8. Steam trap leakage in recent years.

Table 1
Costs of steam leakage in steam traps.

Year	Steam leakage (t/day)	Daily cost (€/day)
2012	6.9	207
2018	0.97	29.05

Through the monitoring of electrical parameters, individually (Energy Indicators) or combined with other characteristic parameters of the operation or process (Mixed Indicators), these devices provide information about the energy consumption, as well as machinery malfunction, helping in the early detection of possible failures of dynamic machinery.

Furthermore, important reductions in steam leakage have been achieved through the implementation of vibration and ultrasound analysis of steam traps, and maintenance revision periods have been optimised using the information provided by EMS.

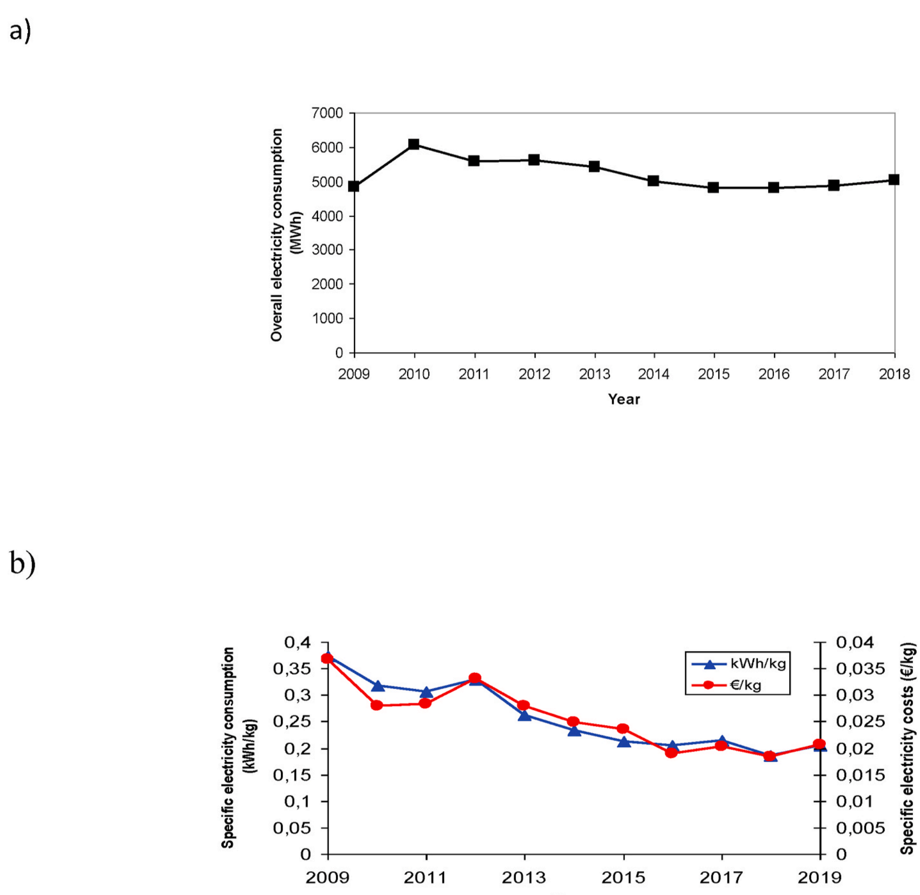

Fig. 9. Electricity consumption and costs in the factory. a) Overall consumption; b) Specific consumption and costs.

Dramatic reductions in energy consumption have been recorded in the past ten years, including a decrease of close to 50% in specific electricity consumption, which means that the implemented measures have reduced the energy needs by nearly one half for every kilogram of production. This achievement is not the sole result of this set of measures, but also, and above all, the consequence of an improvement in company policy to achieve safer plant operation, reduce unplanned stoppages and save energy, as expressed in the Energy and Maintenance Management Systems (EMS & MMS), whose integration in the overall company management system has amplified their impact. This illustrates how energy and maintenance management systems (EMS & MMS) can effectively contribute to the energy efficiency, safety and reliable operation of a plant and its effect on a company's financial results. The proposal formulated in this work is suitable for most of today's large and medium-sized industries worldwide involved in the process of technical integration of hardware and software management platforms.

Credit author statement

Alarcón: Conceptualization, Methodology, Writing, Reviewing and Editing, Funding acquisition. **Martínez-García**: Methodology, Software, Data curation, Validation, Original draft preparation, Reviewing, Funding acquisition. **Gómez-de-León**: Methodology, Visualization, Investigation, Supervision, Funding acquisition, Project administration, Reviewing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work has been developed in the framework of the research project "PREBYA-2012" (Ref. JUSTO-15634/2012–2018) of the University of Murcia. Also, this work has been partially supported by Plan PROPIO of the University of Murcia (2018).

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