DEVELOPING A MAINTENANCE PLAN FOR AN AUTOMATED LINE BY INTEGRATING AN INDUSTRIAL ENERGY MANAGEMENT SYSTEM (IMES)

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Abstract: *The increase in automation in modern production systems requires an integrated approach to maintenance and energy management, in order to maximize operational efficiency and reduce environmental impact. In this context, the article presents the development of a maintenance plan for an automated line, analyzed from the perspective of an Industrial Energy Management System (IMES). The paper highlights the role of energy-oriented maintenance, the typologies of interventions (preventive, predictive and condition-based), as well as the relevant energy performance indicators. An application case study on an automated final assembly line is presented, including concrete maintenance recommendations for electronic assemblies and critical equipment. The results demonstrate that the integration of IMES in maintenance planning leads to the optimization of energy consumption, increased equipment reliability and supports the transition to sustainable industrial production.*

Keywords: EMI, industrial maintenance, energy efficiency, automated production, preventive maintenance, ISO 50001

1. INTRODUCTION

Modern industry faces major challenges related to rising energy costs, reducing greenhouse gas emissions, and increasing requirements for reliability and productivity. In this context, simply optimizing production processes is no longer enough; An integrated approach linking operation, maintenance and energy management is needed. An Industrial Energy Management System (IMES) is an advanced solution for monitoring, controlling and optimizing energy consumption in the industrial environment. However, in practice, maintenance plans are often defined separately from the energy strategy, which limits the real potential for optimisation. Traditional maintenance, based on fixed time intervals, does not capitalize on the available energy data and does not allow the prediction of degradation in equipment performance. The purpose of this article is to demonstrate the importance of integration between maintenance and EMI, by developing an energy-oriented maintenance plan for an automated line. The paper proposes a systemic approach, aligned with the ISO 50001 standard, and aims to highlight the technical, economic and sustainability benefits.

2. INDUSTRIAL MAINTENANCE FROM THE PERSPECTIVE OF ENERGY MANAGEMENT

2.1 The role of maintenance in energy efficiency

Industrial maintenance can no longer be regarded exclusively as a failure prevention activity. The technical condition of the equipment has a direct impact on energy consumption: mechanical wear, incorrect alignment, pneumatic losses or electrical problems invariably lead to an increase in energy consumption.

By integrating maintenance into IMES, the premise of energy-oriented maintenance is created, in which decisions are not only made on the basis of operating time, but also on the basis of energy deviations. Thus, abnormal increases in consumption can indicate early defects, allowing for proactive interventions.

2.2 Types of maintenance in the IMES context

In an integrated system, industrial maintenance can be classified as follows:

- Preventive maintenance, planned according to the actual operating cycles and energy consumption.
- Predictive maintenance, based on the analysis of IMES data, energy trends and functional parameters;
- Maintenance based on energy conditions, triggered by exceeding the defined thresholds of the performance indicators.

This approach allows maintenance to be aligned with energy efficiency goals and the reduction of unplanned production stoppages.

3. LACK OF INTEGRATION BETWEEN MAINTENANCE AND ENERGY MONITORING

One of the main problems identified in industrial environments is the lack of integration between maintenance plans and the data provided by IMES systems. In the absence of this correlation, multiple shortcomings arise.

Maintenance planning is often carried out exclusively on time criteria, without taking into account actual demands or energy consumption. As a result, unnecessary interventions can be carried out or, on the contrary, too late, which leads to significant energy losses.

Also, equipment with low energy efficiency is not systematically identified, and the lack of historical analysis of energy consumption makes it impossible to assess the impact of maintenance works on energy performance. Uncontrolled stand-by and auxiliary systems not included in maintenance plans further contribute to increased consumption.

4. PERFORMANCE INDICATORS FOR IMES-ORIENTED MAINTENANCE

An effective maintenance plan, from an EMSI perspective, must include clearly defined performance indicators. They make it possible to quantify the impact of maintenance activities on energy consumption and system reliability.

Among the most relevant indicators are:

- specific consumption (kWh/unit produced);
- power factor and electrical stability;
- efficiency of compressors and pneumatic systems;
- mean time between defects (MTBF);
- production line availability.

The continuous monitoring of these indicators allows for the rapid detection of anomalies and the optimization of the maintenance process.

5. CASE STUDY – MAINTENANCE PLAN FOR AN AUTOMATED ASSEMBLY LINE

5.1 Description of the analyzed line

The case study is carried out on an automated RLS final assembly line, used in an industrial process with high reliability and quality requirements. The line includes motorized conveyors, assembly robots, air compressors, PLC systems, HMIs, and smart sensors, all integrated into an IMES system.

Maintenance work can only be carried out by appropriately qualified personnel, who have trainings done on that line. Dangerous areas are known and possible hazards are eliminated by appropriate means.

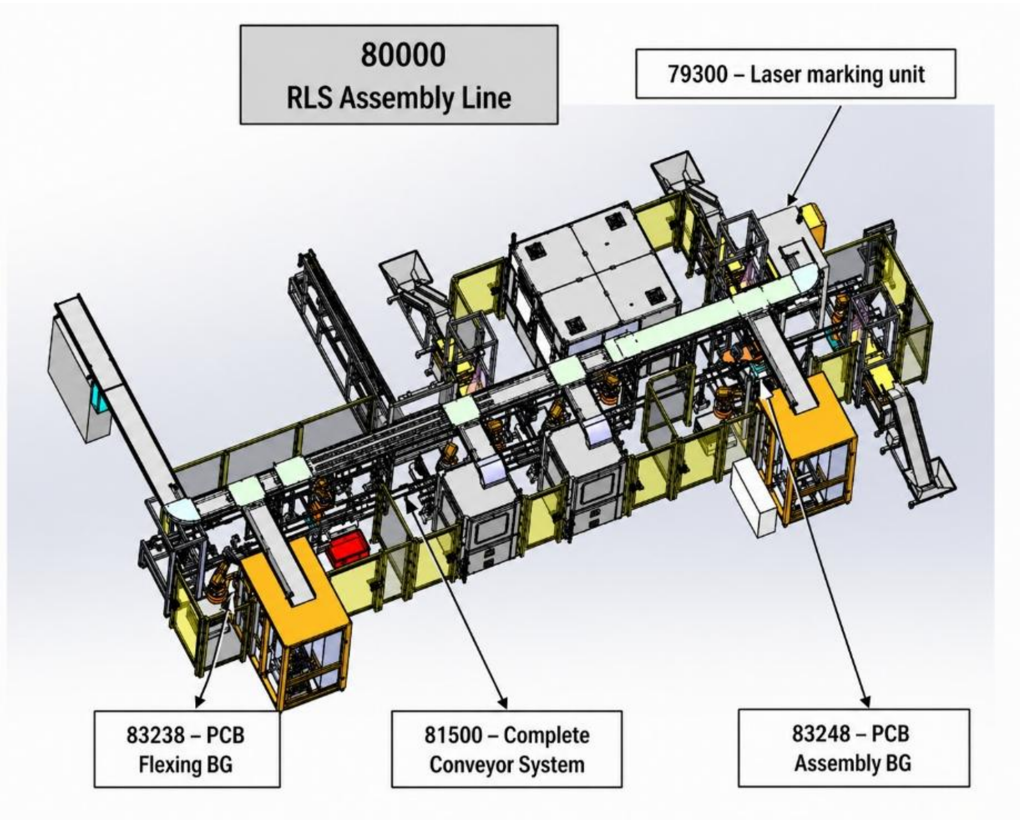

Figure 1. RLS Assembly Line

Maintenance intervals are designed as guides and refer only to the basic maintenance of the system or machine. If components or assemblies are subjected to test loads (e.g. sensors or cameras), adjustments or calibrations must, of course, be carried out on an exchange-by-exchange basis, using appropriate calibration means to ensure reliable test results. For components subjected to particularly high stresses or high levels of contamination, the maintenance interval can also be significantly shortened depending on the application to maintain reliable system production. The experience and technical knowledge of the operator in charge of the system are required here and should be used with caution.

Maintenance recommendations in the image below:

Component / Assembly	Work / Cycle	daily	weekly	monthly	quarterly	semi-annually	annual
Bearings	Clean the components sensitive to wear. Clean them.	X					
Assembly area	Clean the interior and around the cells. Check.		X				
Connections with bolts	If firmly fixed.			X			
	Tighten the deformed bolts. Check the position.	X					
	Correct and tighten if necessary.				X		
Safety devices and Light curtains	Check proper operation.	X					
	Check if they are intact. Tighten if they are loose.		X				
Machine parts / assemblies	Check for wear or faulty operation.	X					
System pressure	Check if there are 6 bar. Adjust if necessary.		X				
Compressed air filter	If necessary. Check if there is condensate accumulation.			X			
Compressed air treatment	Check if necessary, drain the filter bowl.		X				
Pneumatics Energy supply	If necessary. Check the tightness of the pneumatic fittings, tighten if necessary.					X	
Connections with bolts for compressed air	Check if there are leaks and if it operates properly.			X			
Conveyor belts	Clean the conveyor belt, check if there is tension and signs of wear, tighten if necessary.				X		

Figure 2. Maintenance interval recommendations

5.2 Maintenance planning based on IMES

The maintenance plan is structured on several levels, including daily, periodic and energy-performance-dependent activities. Daily consumption monitoring through IMES allows for quick identification of deviations, and automatic reports facilitate trend analysis.

The scheduling of interventions is correlated with the energy impact of the equipment, and revisions are preferentially planned outside the maximum consumption ranges. A

The maintenance plan is very detailed explained in table no. 1 per stage, activities and recommended frequency.

Table 1. Maintenance plan

Activity	Description	Recommended frequency	Observations
PCB Cleaning	Cleaning with isopropyl alcohol (≥99%), antistatic brush and dry compressed air	6 months	Make sure the board is completely unplugged and discharged
Visual inspection	Check for dust, corrosion marks, cracked solder, faded components	Monthly	Use a magnifying glass or portable microscope

Checking connections	Tightening screws, checking busbars and sensing cables	3 months	Oxidation of contacts increases resistance and risk of overheating
Insulation Resistance Measurement	Test between power lines and ground	12 months	Use a megohmmeter according to the rated voltage
Thermal monitoring	Temperature measurement at critical points (MOSFETs, resistors, dissipation zones)	Monthly	Compare to the limits in the datasheet
BMS Functional Test	Verification of voltage/current measurements, cell balancing, protections	6 months	It can be done with a cell simulator or on a test bench
Firmware update	Installation of versions recommended by the manufacturer	When the update appears	May include protection and safety optimizations
Controlled storage	Dry, cool, conductive dust-free environment	Permanent	If the assembly contains cells, keep them at 40–60% SOC

6. PREVENTIVE MAINTENANCE OF ELECTRONIC ASSEMBLIES (PCBS)

A critical element of the analyzed line is the PCB assemblies used for control, monitoring, and safety. Their maintenance has a direct impact on the reliability and energy consumption of the system.

The preventive maintenance plan includes:

- periodic cleaning with suitable solutions and without power supply;
- visual inspections to identify oxidation or degradation of components;
- electrical checks of insulation and contact resistances;
- thermal monitoring in areas of high dissipation;
- firmware update and periodic calibration of sensors.

These measures help prevent defects, reduce energy losses and increase the life of the equipment.

7. RESULTS AND DISCUSSIONS

The application of an IMES-oriented maintenance plan leads to significant benefits. The comparative analysis indicates the reduction of specific energy consumption, the increase in the availability of the line and the decrease in the number of unplanned stops. In addition, the correlation between maintenance and energy data allows the justification of technical decisions and supports investments in the modernization of inefficient equipment.

The maintenance plan in an IMES is **multidisciplinary**, uniting mechanics, automation, energy and IT. The goal is not only to reduce breakdowns, but **to continuously optimize**

energy consumption through intelligent maintenance. This approach helps to reduce costs, increase the lifespan of equipment and comply with environmental regulations.

In the chapter on the maintenance plan, recommendations for the maintenance cycles for each component of the assembly line were presented in detail, so that in the future it can be studied in the long term what the implementation of an IMES system means at such a line and what the percentages of benefit will be if the recommended maintenance cycles and internals are respected on the entire line and its components.

An Energy Management System (IMES), according to the ISO 50001 standard, uses the **PDCA** (Plan-Do-Check-Act) cycle to monitor and continuously improve energy performance.

The issue of optimizing energy consumption in production systems has received attention with the increase in concern for sustainability. We believe that research related to energy optimization has a high applicative value and a vast research space. Through reasonable programming of O&M (operation and maintenance), energy savings can be achieved without changing the structures of the production system, which will pave the way for the progressive promotion of sustainable production paradigms. Research in this area is expected to receive increased attention and generate new procedures.

8. CONCLUSIONS AND DEVELOPMENT DIRECTIONS

Industrial maintenance integrated into an Industrial Energy Management System is an essential direction for the sustainable development of production systems. By using the PDCA principle, according to ISO 50001, the continuous improvement of the energy performance and reliability of the equipment is ensured.

Future research may aim at integrating artificial intelligence algorithms for advanced predictive maintenance, developing digital energy twins, and assessing the long-term impact of EMI implementation on industrial costs and emissions.

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