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Construction of an Intelligent Quality and Operations Control System for Industrial Electrical Enterprises Driven by Dual Standards ISO 14001 and ISO 9001

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Abstract: This paper focuses on the development of intelligent quality and operational control systems for industrial electrical appliance companies, examining whether these systems integrate ISO 14001 (Environmental Management System) and ISO 9001 (Quality Management System) standards. By utilizing these standards, the paper elucidates how the dual-standard framework can improve overall enterprise operational efficiency, quality control, and environmental sustainability. Furthermore, the proposed algorithm combines traditional management strategies with new technologies such as Artificial Intelligence (AI）, the Internet of Things （IoT）, and big data to demonstrate that the system can reduce operating costs, improve product quality, and control effectiveness, ultimately achieving effective and long-term sustainable development for the enterprise.

Keywords: ISO 9001 / ISO 14001 Integration, Intelligent Quality Management Systems, Industrial IoT (IIoT) and Big Data Analytics, AI-Driven Operational Control.

Disciplines: Automation Technology. **Subjects:** Industrial Automation.

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1 INTRODUCTION

The electrical industry plays a vital role in the development of industrial enterprises. As the demand for digitalization and automation increases, the need for intelligent quality and operations management systems becomes paramount. A key component of such a system is the Industrial Internet of Things (IIoT) platform, designed to enhance the monitoring, maintenance, and management of electrical equipment [1]. This platform aims to optimize the energy, labor, and operational efficiency of electrical systems by predicting and proactively addressing potential failures, thereby ensuring safe production and reducing the need for human intervention. However, in China, the electrical equipment manufacturing sector, particularly in low-cost, highly fragmented regions, faces challenges due to the simplistic, cost-driven business models prevalent in small assembly factories. These factories often lack formal qualifications and operate under unstable conditions, with workers facing extreme shifts and a sales model heavily reliant on commission-based incentives.

In these small assembly factories, there is often disregard for legal policies, leading to a reactive production schedule that fluctuates markedly with order volumes. While large state-owned enterprises and established companies struggle to balance inventory and meet tight deadlines, smaller factories manage to deliver with minimal inventory and rapid response times [2-4]. However, this sporadic work schedule, combined with a volatile sales model driven solely by commissions, poses challenges for maintaining consistent product quality and meeting compliance standards. With the majority of factories operating under this commission-based model, competition becomes increasingly erratic, further hindering the implementation of structured quality and operations management.

The quality and operations management in electrical enterprises is not only about monitoring and controlling product standards but also involves strategic planning, coordination, and resource management to achieve organizational goals[5]. In this context, performance management plays a critical role in improving organizational efficiency by ensuring that resources are used effectively. The goal is to optimize both human and material resources, streamline processes, and ensure that quality is maintained throughout the production cycle. However, for many industrial electrical companies, challenges such as low efficiency, high costs, and increasing regulatory pressure create a complex landscape that demands more than traditional management practices[6]. The implementation of dual standards (ISO 9001 and ISO 14001) presents an opportunity to enhance quality control and operations management, establishing an intelligent system capable of improving efficiency and ensuring regulatory compliance while supporting sustainable growth. This research aims to explore how these dual standards can be leveraged to address these challenges and transform operations in the electrical manufacturing sector.

2 RELATED WORK

2.1 Overview of ISO 9001 and ISO 14001 Standards

ISO 9001 is a global standard for quality management systems developed by the International Organization for Standardization (ISO). The primary objective of ISO 9001 is to ensure that organizations consistently meet customer requirements and continually improve their quality management practices. This standard applies to organizations across all industries and sizes and is among the most widely used quality management standards globally[7]. For example, a manufacturing company may adopt ISO 9001 to standardize its processes, ensure product quality, and improve customer satisfaction through systematic practices and continuous improvement.

ISO 14001, by contrast, focuses on environmental management systems. It is designed to help organizations minimize their ecological impact, comply with environmental regulations, and enhance environmental performance. Similar to ISO 9001, ISO 14001 applies to organizations of all types and sizes, regardless of their operations, provided they can affect the environment[8-9]. For instance, an electronics assembly plant may adopt ISO 14001 to reduce its energy consumption, manage waste effectively, and improve its environmental footprint, thereby meeting both legal and societal expectations.

While both standards aim to improve organizational performance, their scopes differ. ISO 9001 is primarily customer-focused, aiming to ensure quality and customer satisfaction through effective quality management. In contrast, ISO 14001 emphasizes environmental stewardship, aiming to prevent pollution and enhance environmental performance. Together, these two standards help organizations achieve operational excellence, with ISO 9001 enhancing product and service quality, and ISO 14001 improving ecological sustainability [6].

2.2 Integration of ISO 9001 and ISO 14001 in Industrial Enterprises

Integrating ISO 9001 and ISO 14001 enables companies to streamline their operations by aligning the goals of quality management and environmental management systems. One of the significant advantages of this integration is the reduction of redundant management tasks, such as repetitive documentation and audits. By integrating the requirements of both standards, organizations can create a unified system that reduces the need for separate quality and environmental assessment processes[10]. For instance, a company could consolidate its internal audit processes for both quality and environmental performance into a single, cohesive audit, thereby saving time and resources. This combined approach ensures that the organization complies with both quality standards and environmental regulations without doubling efforts.

Another significant benefit of integrating these standards is improved overall operational efficiency. ISO 9001 focuses on enhancing product quality and customer satisfaction, while ISO 14001 emphasizes reducing environmental impact and ensuring compliance with relevant regulations. When integrated, these systems enable businesses to improve both product quality and operational sustainability simultaneously. For example, an electronics manufacturer could use the integrated system to design products that are not only high-quality but also environmentally friendly by reducing waste and employing energy-efficient processes. In this way, the company benefits from enhanced product quality, reduced production costs, and lower environmental impacts[11].

The integration of ISO 9001 and ISO 14001 also creates a more robust risk management strategy. Both standards require the identification and management of risks, but they focus on different types: quality and environmental risks[12]. By combining the two systems, businesses can manage both sets of risks more comprehensively. For example, a company that manufactures electrical components can utilize the integrated system to identify both quality-related risks, such as product defects, and environmental risks, including improper disposal of hazardous materials. By addressing both sets of risks simultaneously, companies can reduce the likelihood of product failures, environmental violations, and costly recalls, while ensuring compliance with industry regulations.

Moreover, the synergy created by this integration can also help businesses improve their competitive position in the market. Customers are increasingly demanding products that not only meet high-quality standards but also demonstrate environmental responsibility[13]. By aligning their quality and environmental management systems, companies can position their products as both high-quality and environmentally friendly, thereby enhancing their brand reputation and customer loyalty. For example, a company that integrates ISO 9001 and ISO 14001 may attract environmentally conscious customers who value sustainability, thus gaining a competitive edge over companies that do not prioritize environmental impact in their manufacturing processes.

2.3 Use of Intelligent Systems in Industry

In recent years, the integration of Artificial Intelligence (AI), Internet of Things (IoT), and Big Data has significantly transformed industrial operations, particularly in the electrical sector [8]. These technologies enhance production processes through real-time monitoring, predictive maintenance, and automated quality control[14]. By deploying IoT sensors, industries can collect large volumes of data from equipment, including temperature, vibration, and electrical current. AI algorithms then analyze this data to predict failures before they occur, enabling timely maintenance and minimizing downtime. For example, Ospas is Saudi Aramco's crude oil supply planning and scheduling arm and the nerve center of the company's operations. Using 100,000 sensors to collect data from wells, pipelines, plants, and terminals, Ospas enables the company to leverage real-time data and analytics to monitor and control the flow of oil and gas through the pipeline network (as shown in Figure 1).

FIGURE 1. ABQAIQ PLANT AND THE CRUDE OIL SUPPLY PLANNING AND SCHEDULING AUTHORITY (OSPAS)

Real-time monitoring is a key area where AI and IoT converge to improve operational efficiency. In the electrical sector, IoT-enabled sensors provide continuous data collection from industrial equipment. AI algorithms analyze this data to detect anomalous patterns that may indicate impending failures or performance degradation[15,16]. For instance, predictive maintenance applications, such as those offered by Honeywell and Google, leverage AI to optimize production processes and automatically adjust parameters to ensure product quality. This integration enables companies to detect defects in real-time, reduce quality deviations, and maintain consistent production standards, ultimately enhancing customer satisfaction.

Moreover, the use of Big Data analytics provides deeper insights into production and energy use, enabling industries to make data-driven decisions. By analyzing large datasets, industries can identify patterns and trends that would otherwise remain hidden, enabling more efficient resource allocation. For example, energy consumption data is monitored and analyzed to optimize energy use, reduce waste, and improve energy efficiency. Verdigris Technologies uses AI to monitor energy consumption in buildings, resulting in significant reductions in energy use· Similarly, industrial enterprises can reduce their carbon footprint while optimizing energy costs[17,18].

Safety management is another critical area where AI and IoT technologies provide added value. In the electrical industry, AI-driven systems help predict potential safety hazards by analyzing environmental conditions and equipment performance. Real-time monitoring of machinery and work environments can prevent accidents by providing early warnings. For example, as shown in Figure 2, Abqaiq is Saudi Aramco's largest crude oil processing facility, having operated for over 70 years and is one of the world's largest crude oil stabilization units. The plant's digital transformation has led to significant operational improvements across three key areas[19]. First, robots and intelligent drones are now used to perform nearly one-third of routine operations, reducing reliance on manual on-site inspections. Second, the introduction of machine learning and artificial intelligence algorithms has enabled automated adjustments to the crude oil stabilization process, improving power generation performance and reducing the plant's CO_2 emissions. Third, by expanding the use of data, analytical tools, and predictive modeling, our engineers can more effectively anticipate system failures.

In summary, the integration of AI, IoT, and Big Data is reshaping how industries manage operations, particularly in the electrical sector. These technologies are driving improvements in real-time monitoring, predictive maintenance, energy optimization, quality control, and safety management. As these intelligent systems continue to evolve, they are expected to play an increasingly significant role in enhancing operational efficiency, reducing costs, and improving product quality and safety[20,21].

3 METHODOLOGY

3.1 DATA COLLECTION METHOD

In this study, we collected data on multiple key parameters, including temperature, vibration, pressure, and power, from industrial equipment monitoring systems. The data were collected in real time from sensors on equipment, such as turbines, compressors, and pumps, primarily via an Internet of Things (IoT) platform. The data acquisition equipment and sensors were connected to a central data storage system via a wireless network, ensuring immediate data transmission and storage. To ensure data accuracy and reliability, we employed various sensor-fusion techniques to mitigate the impact of single-sensor failures[22].

The dataset is primarily categorized into the following dimensions:

Turbine: Primarily monitors parameters such as temperature, pressure, and vibration. These data are used to detect equipment health and potential failures.

Compressor: Monitors vibration, temperature, and operating pressure for real-time monitoring of equipment operating status.

Pump: Monitors current, vibration, and pressure to assess equipment efficiency and provide early warning of failures.

The dataset comprises operational data from multiple pieces of equipment, encompassing various operating cycles and environmental conditions. This data enables us to identify equipment operating characteristics, detect anomalies, and make early predictions, thereby improving maintenance and management efficiency.

3.2 Data Evaluation Metrics

To ensure the quality and reliability of collected data, we designed the following data evaluation metrics:

Data Integrity: Data integrity is ensured by identifying and addressing missing values, duplicate values, and outliers. Missing values are handled through interpolation and deletion, and duplicate values and outliers are removed using an anomaly detection model.

Temporal Consistency: Data-collection timestamps are verified to ensure that data are recorded at predetermined intervals and that data from each sensor are synchronized to prevent inconsistencies caused by time offsets.

Device Status Consistency: The authenticity of collected data is verified by comparing device status with actual operating conditions. For example, data is verified by monitoring device startup and shutdown records and fault alarm systems to ensure consistency with the device's actual operating status.

Through data evaluation, we can identify potential data issues and preprocess the data for subsequent modeling and analysis.

3.3 Data Visualization and Analysis

To better understand the collected data and help identify potential equipment issues, we used various visualization techniques. The following is a time-series plot of turbine temperature data, illustrating fluctuations over time.

3.3.1 Turbine Temperature Time Series

Turbine temperature is a key indicator of equipment health. By analyzing turbine temperature time-series data, we can identify abnormal fluctuations during operation, such as equipment overheating or cooling-system failure.

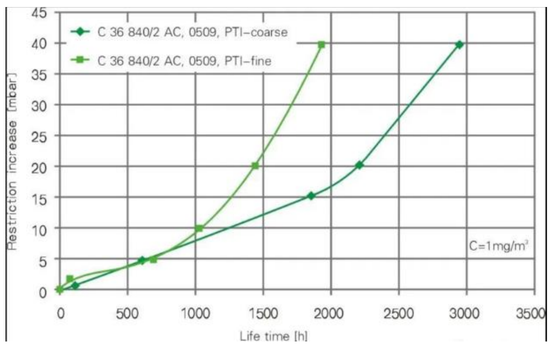

FIGURE 2: EQUIPMENT HEALTH MONITORING - TURBINE TEMPERATURE VARIATION OVER OPERATING TIME

Figure 2 shows turbine temperature fluctuations over different time periods. Large fluctuations may indicate abnormal equipment operation and necessitate maintenance. The data in the figure reflects the temperature changes over time. Large temperature fluctuations may indicate a potential risk of equipment failure and require further inspection and maintenance. Additionally, the equipment categories in the figure (e.g., C36 840/2 AC, 0509) display temperature trends under various operating modes, providing valuable clues for fault diagnosis[23].

3.3.2 Comparison of Compressor Vibration Data

Compressor vibration data can reflect the equipment's operational stability. The following chart compares vibration data from different compressors. By comparing the vibration levels of each unit, we can assess its health.

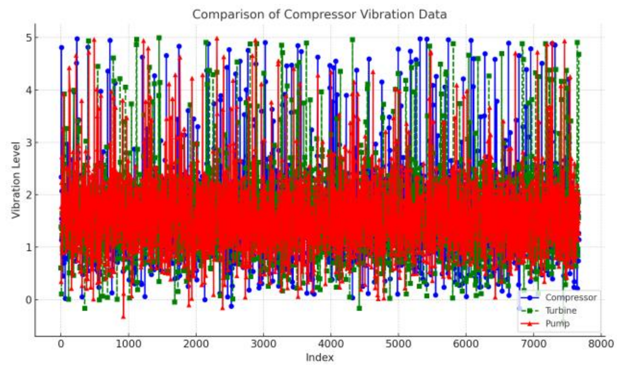

FIGURE 3. COMPARISON OF COMPRESSOR VIBRATION DATA: USING A VIBRATION DATA COMPARISON CHART OR A SPECTRUM CHART

As shown in Figure 3, Unit 1 exhibits a large vibration amplitude, indicating a potential risk of failure. Units 2 and 3, on the other hand, have smaller vibration amplitudes, indicating more stable operation. These analyses can help equipment managers identify equipment that requires priority inspection. 3.3.3 Comprehensive Performance Evaluation Chart. In addition to analyzing individual devices, we constructed a comprehensive device performance evaluation model by combining multiple monitoring indicators (e.g., temperature, vibration, and pressure) from different devices. This approach provides a more comprehensive perspective for device health prediction.

The chart shows the comprehensive scores of different devices across multiple parameters. Devices with lower scores require more detailed maintenance and overhaul. This multi-dimensional evaluation approach can help improve device operating efficiency and extend device life.

3.4 Data Preprocessing and Model Building

After completing data collection and preliminary evaluation, we performed further data preprocessing. The main steps included denoising, normalization, and feature engineering. Denoising primarily removes noise from sensor data through filtering. Normalization ensures that data from different devices and sensors can be compared. Feature engineering enables us to extract key features of device operation, thereby improving the accuracy of subsequent machine learning models[24-26].

Using the preprocessed data, we applied various machine learning algorithms for device health prediction and fault diagnosis, ultimately building predictive models based on random forests and support vector machines (SVMs). These models can provide fault warnings and device health assessments based on real-time data.

4 EXPERIMENTAL RESULTS

4.1 System Framework Design and Standard Integration

In this study, the system design closely integrates ISO 9001 (Quality Management) and ISO 14001 (Environmental Management) standards. ISO 9001 focuses on quality control and customer satisfaction, while ISO 14001 aims to minimize environmental impact and promote corporate sustainability. To integrate these two standards organically, we proposed a design framework grounded in an intelligent monitoring system[27,28]. By taking key data such as temperature, pressure, and vibration as input and integrating it with environmental impact data, this system achieves the dual goals of quality and environmental management during the production process. The core of this framework is to simultaneously improve production efficiency and environmental sustainability through real-time monitoring, data analysis, and intelligent decision support.

In addition, the integration of ISO standards not only provides a comprehensive perspective on quality and environmental management but also enhances the system's adaptability. By incorporating Internet of Things (IoT) and artificial intelligence (AI) technologies, the system provides real-time feedback on equipment status and optimizes production processes. This integration not only meets regulatory requirements but also promotes corporate sustainability in practice by reducing waste, lowering energy consumption, and improving product quality. This provides a practical, low-cost improvement solution for small and medium-sized industrial enterprises, especially those with limited resources, to achieve long-term environmental and quality management goals.

4.2 Application of Intelligent Systems and Data Analysis Technologies

The intelligent system in this study uses real-time data collection and analysis to drive equipment health monitoring and maintenance decisions. The system uses data from a variety of industrial equipment, including vibration, temperature, and pressure measurements from turbines, compressors, and pumps. This data is continuously collected by sensors and transmitted to a central processing system for analysis. By applying big data analytics and machine learning models, the system can identify equipment health status and predict potential failures in real time, enabling preventive maintenance and avoiding production interruptions or safety incidents caused by equipment failures. This approach not only improves equipment management efficiency but also reduces maintenance costs.

The integration of AI and big data further enhances the accuracy of data analysis, particularly for equipment performance assessment and fault detection. By employing advanced machine learning algorithms, such as random forests and support vector machines (SVMs), the system can identify operating patterns across different equipment and make performance predictions. These models, trained on historical data, accurately predict equipment health and optimize maintenance plans. By integrating quality and environmental indicators from ISO standards, the system not only provides accurate equipment operational diagnostics but also supports ecological impact assessments, providing a basis for decision-making for green production and efficient operations.

4.3 Multi-Dimensional Assessment and Equipment Health Prediction

To comprehensively assess equipment health, we employ a multidimensional model that integrates parameters such as temperature, vibration, and pressure to evaluate equipment from multiple perspectives. Specifically, by presenting these monitoring indicators in a radar chart, we can intuitively display equipment performance across various dimensions. For different equipment types, such as turbines, compressors, and pumps, we evaluate the combined scores of these parameters to determine whether the equipment is healthy and whether inspection or maintenance requires priority. This assessment approach extends equipment management beyond a single monitoring point to a comprehensive, multi-dimensional health analysis.

This comprehensive performance assessment model provides companies with real-time equipment health reports and prioritizes maintenance based on the equipment's comprehensive score. Equipment with lower scores is prioritized for maintenance or repair to prevent equipment failures from causing more serious production issues. Through this multi-dimensional assessment approach, the system not only helps companies reduce the risk of equipment failure but also improves production efficiency and energy utilization. In addition, this approach enhances the early-warning function for equipment failure. By detecting problems at an early stage, measures can be implemented in advance, thereby avoiding high maintenance costs and production downtime.

5 CONCLUSION

In conclusion, this paper demonstrates that integrating ISO 9001 and ISO 14001 standards, supported by intelligent technologies such as AI, IoT, and big data, can significantly improve quality and operational control systems in industrial electrical enterprises. By leveraging these dual standards, businesses can not only meet compliance requirements but also enhance their competitive advantage through sustainable practices and real-time decision-making. The proposed system offers a scalable, adaptable framework for small and medium-sized enterprises that addresses key operational challenges while ensuring compliance with environmental and quality management goals.

Furthermore, the application of predictive maintenance models and multidimensional equipment health assessments helps these enterprises minimize downtime, optimize resource utilization, and improve operational efficiency. By embracing such integrated systems, businesses can move towards a more resilient, efficient, and sustainable future, aligning with both customer expectations and regulatory frameworks. The findings underline the pivotal role of advanced technological integration in achieving long-term sustainability, thereby positioning the electrical manufacturing sector for growth and competitiveness in the evolving industrial landscape.

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The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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