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Induction motor diagnostics based on electrical signals analysis using cloud technologies

***Abstract**. The paper discusses implementation latest advanced in computational and data processing technologies to induction motors monitoring and diagnostics. As a diagnostic criterion, a Motor Current Signature Analysis was chosen. Typical frequencies related to most frequently caused damage types visible in stator current signal were described. A possible solution for implementation cloud computing to improve quality of induction motors health monitoring was proposed and its main components are described.*

***Streszczenie.** W artykule omówiono wdrażanie najnowszych zaawansowanych technologii obliczeniowych i przetwarzania danych do monitorowania i diagnostyki silników indukcyjnych. Jako kryterium diagnostyczne wybrano analizę sygnału prądu silnika. Opisano typowe częstotliwości związane z najczęściej powodowanymi uszkodzeniami widocznymi w sygnale prądowym stojana. Zaproponowano możliwe rozwiązanie wdrożenia chmury obliczeniowej w celu poprawy jakości monitorowania stanu silników indukcyjnych oraz opisano jego główne elementy.(**Diagnostyka silnika indukcyjnego oparta na analizie sygnałów elektrycznych przy wykorzystaniu technologii chmurowyc**)*

Keywords: Motor Current Signature Analysis, diagnostics, Cloud Computing.
Słowa kluczowe: analiza sygnału prądu silnika, diagnostyka, przetwarzanie w chmurze.

Introduction

Induction motors (IM) are extensively utilized in various industrial applications due to their inherent simplicity, reliability, and minimal maintenance requirements. Operating based on the principle of electromagnetic induction, these motors generate a rotating magnetic field in the stator, which induces rotor movement. They are integral components in pumps, compressors, fans, conveyors, and other machinery, thereby playing a vital role in industrial processes [1].

Induction motors are indispensable in driving machinery and equipment across industries such as manufacturing, mining, transportation, and agriculture. Their capability to function under varying load conditions renders them suitable for a broad spectrum of applications. The efficiency, durability, and cost-effectiveness of induction motors make them essential for contemporary industrial operations.

IM reliability is essential condition for ensuring uninterrupted operation in many industrial technologies. Thus, monitoring of its operational conditions, possibility to diagnose faults at incipient stages of their development and forecasting possible sever deterioration of their technical condition is a key component in modern industrial process management systems.

Motor diagnostics encompass the evaluation of the health and performance of induction motors to avert unexpected failures and downtime. Traditional diagnostic methods, including visual inspection and vibration analysis, are limited in their ability to detect early-stage faults. Analysing electrical signals offers a complementary approach, providing deeper insights into the motor's internal condition by examining voltage, current, and instantaneous power signals.

Electrical signals analysis is pivotal in diagnosing motor health as it facilitates the detection of abnormalities such as rotor bar defects, winding faults, airgap eccentricity and bearing wear. By analysing the characteristics of electrical signals, including harmonic components, asymmetry, and transients, engineers can identify potential issues before they escalate into significant failures. This proactive approach aids in the scheduling of maintenance activities, minimizing downtime, and optimizing operational efficiency.

Cloud technologies provide scalable and flexible solutions for the storage, processing, and analysis of data obtained from induction motors. By leveraging cloud platforms, organizations can centralize motor data from multiple locations, enabling real-time monitoring and analysis. Cloud-based analytics tools support predictive maintenance by identifying patterns and anomalies in motor performance data, allowing for timely interventions and the optimization of maintenance schedules. Additionally, cloud storage ensures data accessibility and security, facilitating collaboration and decision-making among multiple stakeholders.

Thus, employing could processing technologies to the task of IM diagnostics based on electrical signals analysis could improve diagnostics quality, especially, prediction of motor health trends analysis basing on historical data.

Diagnostic techniques for induction motors

Currently, several approaches are employed for online monitoring of induction motor operability. Traditional methods include following methods.

Vibration Analysis. This method involves monitoring the motor's vibration levels and analysing frequency spectra to detect mechanical faults such as misalignment, imbalance, and bearing wear. However, it is limited in its ability to detect early-stage electrical faults.

Temperature Monitoring. This method monitors the temperature of critical motor components to identify overheating issues caused by overload, poor ventilation, or bearing failure. Despite its effectiveness, it does not provide insights into internal electrical faults.

Visual Inspection. This method involves visual examining the motor for signs of wear, damage, or contamination. Although it is a simple and cost-effective approach, it may not reveal hidden faults within the motor windings or rotor without IM disassembling.

Traditional methods are effective in detecting mechanical faults but it's hard to employ them to identify incipient electrical faults, which may lead to potential undetected issues and unpredicted failures.

More advanced diagnostics involve continuous monitoring of diagnostic parameters. The most easily implemented approaches are based on electrical signals analysis, such as Motor Current Signature Analysis (MCSA) [2] and Instantaneous Power Signature Analysis (IPSA) [3].

MCSA involves analysing the motor's current waveform to detect abnormalities related to bearings faults, airgap eccentricity, broken rotor bars, or stator winding faults. It relies on distinctive signatures present in the current spectrum to accurately diagnose motor health.

IPSA analyses the instantaneous power waveform to detect abnormalities caused by airgap eccentricity, shorted circuits in stator windings, rotor bar breaks or other unexpected harmonics in the motor's operation. By examining the instantaneous power signature, it provides insights into various electrical and mechanical issues affecting motor performance. In some cases, IPSA may be more efficient than MCSA for diagnosing incipient faults.

Both IPSA and MCSA could be used for adjusting IM operational modes in order to compensate the influence of faults presence, especially, at their incipient stage, and prolong IM operational lifetime [4–7].

The analysis of electrical signals, encompassing MCSA and IPSA, augments traditional diagnostic methods. This approach facilitates the early detection of faults within the motor's electrical system, thereby enhancing the overall accuracy of diagnostics and enabling proactive maintenance interventions. Moreover, it offers a non-invasive and cost-effective means of monitoring motor health, significantly contributing to the reliability and efficiency of industrial operations.

Fault-related frequencies

Both MCSA and IPSA operate with distinct frequencies related to certain fault type. According to statistics [1, 8–10] most typical induction motor fault types include bearings damage, stator windings faults, different types of rotor eccentricity and rotor bars break.

Current spectra frequencies appeared due to bearings faults could be calculated using the following equation [2, 11, 12]:

(1) $$f_{brg} = f_s \pm m \cdot f_{i,o},$$

where f_s is the supply mains frequency, $m = 1, 2, 3$ ..., and $f_{i,o}$ represents typical vibration frequencies caused by bearing inner or outer ring damage, and they could be calculated basing on bearing dimensions [2, 11, 13]:

(2) $$f_{i,o} = \frac{n}{2} f_v \left[1 \pm \frac{bd}{pd} \cos\beta\right],$$

where n is the number of bearing balls, f_v is mechanical rotor velocity represented in Hz, bd is the bearing ball diameter, pd is the bearing pitch diameter, β is the contact angle of the balls on the races.

Stator faults, such as stator windings interturn short circuits, typically leads to negative MMF which produces frequency components in the airgap flux waveform which reflects in the current waveforms as well and could be calculated basing on following function [2, 13, 14]:

(3) $$f_{\mathrm{st}} = f_s \left[\frac{n}{p}(1 - s) \pm k\right],$$

where f_s is the supply mains frequency; $n = 1, 2, 3$ ...; $k = 1, 3, 5$ ...; p is pole pairs number; s is the motor slip.

Different types of airgap eccentricity, static, dynamic and mixed, eventually produces current harmonics on following frequencies [2, 15–17,]:

(4) $$f_{\mathrm{ecc}} = f_s \left[1 \pm m\left(\frac{1-s}{p}\right)\right],$$

where f_s is the supply mains frequency; s is the motor slip; p is pole pairs number; $m = 1, 2, 3$ ...

Rotor bar break leads to symmetric sideband components around supply mains frequency calculated basing on following equation [2, 18-20]:

(5) $$f_{\mathrm{bb}} = f_s[1 \pm 2s],$$

where f_s is the supply mains frequency; s is the motor slip.

Modern measuring equipment and microprocessor-based data processing facilities provides easily sampling motor current instantaneous values with nearly online data processing. This, in turn, allows one to create nearly real-time motor health monitoring system. Additionally, collection of archived MCSA data could be used to analyse motor performance trends and predict its future behaviour, including possible critical faults. However, such analysis should involve more advanced processing techniques, such as cloud computing.

The use of cloud computing in induction motor health monitoring

Cloud platforms can be integrated with motor diagnostics systems to streamline data collection, storage, analysis, and visualization processes. Integration involves connecting motor sensors and diagnostic devices to cloud-based applications or platforms, allowing real-time data streaming and analysis [21, 22]. Such approach provides following benefits.

Real-time data collection and centralization. Cloud technologies enable the real-time collection and centralization of data from induction motors. Sensors attached to the motors continuously gather various parameters such as current, voltage, temperature, and vibration. This data then transmitted to cloud servers where it is stored in a centralized database. Centralized data storage ensures that information from multiple motors across different locations is consolidated, providing a comprehensive overview of the operational status of all monitored motors.

Advanced data analytics and machine learning. Cloud platforms offer powerful computational resources and advanced data analytics tools. By leveraging these tools, large volumes of data from IM can be processed and analysed to identify patterns and anomalies indicative of potential faults. Machine learning algorithms can be employed to develop predictive models that forecast motor failures based on historical data and real-time inputs. These models can continuously improve over time as more data is collected and analysed, enhancing the accuracy and reliability of motor health diagnostics.

Cloud technologies facilitate remote monitoring and diagnostics of induction motors. Maintenance engineers and managers can access real-time data and diagnostic reports from anywhere, using internet-connected devices such as smartphones, tablets, or computers. This remote accessibility enables prompt decision-making and intervention, reducing the time required to respond to potential issues and minimizing motor downtime.

Predictive Maintenance. By integrating cloud-based predictive maintenance systems, organizations can move from reactive to proactive maintenance strategies. Predictive maintenance relies on analysing trends and patterns in motor performance data to predict when maintenance should be performed. This approach minimizes unexpected failures and optimizes maintenance schedules, reducing operational costs and extending the lifespan of the motors.

Scalability and flexibility. Cloud platforms offer scalability and flexibility in managing data and computational resources. As the number of monitored motors increases or data volumes grow, cloud infrastructure can be scaled up without the need for significant upfront investments in hardware. This scalability ensures that the monitoring system can adapt to the evolving needs of the organization.

Data security and compliance. In case of using third-part cloud service providers, industry may use benefits of robust security measures under responsibility of cloud service provider. Cloud providers implement robust security measures to protect data against unauthorized access and breaches. Features such as data encryption, access controls, and regular security audits ensure the confidentiality and integrity of motor health data. Additionally, cloud services often comply with industry standards and regulations, providing organizations with assurance regarding data privacy and protection.

Cloud technologies can seamlessly integrate with Internet of Things (IoT) and Industrial Internet of Things (IIoT) ecosystems. This integration allows for the aggregation of data from various sources, including sensors, controllers, and other industrial equipment. The holistic view provided by such integration enhances the ability to diagnose and address issues that may affect the overall performance and efficiency of the industrial processes.

Also, cloud-based monitoring systems facilitate enhanced collaboration among stakeholders. Maintenance teams, engineers, and managers can share insights, reports, and diagnostic findings easily. Cloud platforms can generate detailed, customizable reports and dashboards that provide actionable insights, helping stakeholders to make informed decisions and improve overall operational efficiency.

In summary, the use of cloud technologies in induction motor health monitoring provides numerous benefits, including real-time data collection, advanced analytics, remote diagnostics, predictive maintenance, scalability, data security, IoT integration, and enhanced collaboration. These advantages contribute to improved reliability, efficiency, and cost-effectiveness in the management of induction motors within industrial operations.

Proposed solution

In this research, the authors propose an online monitoring system for induction motors, integrating both MCSA and IPSA methods, utilizing the mathematical framework described in [3]. The system is comprised of three primary components: field devices, the cloud computing section, and user clients.

Field devices component includes an array of current, voltage, temperature, and vibration sensors attached to the monitored motor or mechanism. These sensors collect raw data and transmit it to a microcontroller for pre-processing and preliminary analysis. In the event of detecting harmful motor faults, the system can trigger alert signals and ensure the emergency stoppage of equipment if necessary.

Cloud computing part is responsible for transmitting pre-processed data to a cloud server, where it is stored in a database. This data serves as input for the "intelligent analysis" module, which performs in-depth analysis using both real-time and historical data, with results stored in a separate database.

User client, the final component of the system, involves the dissemination of the processed data to end-users through various devices such as smartphones, laptops, and PCs. Users can access summaries of the current technical conditions of the monitored devices, receive forecasts for the next maintenance period, and obtain alerts in case of emergency situations.

A block diagram of the proposed system is presented in Fig. 1. This diagram illustrates the interaction between the field devices, the cloud-based analysis and storage, and the end-user interfaces, showcasing the comprehensive flow from data collection to actionable insights.

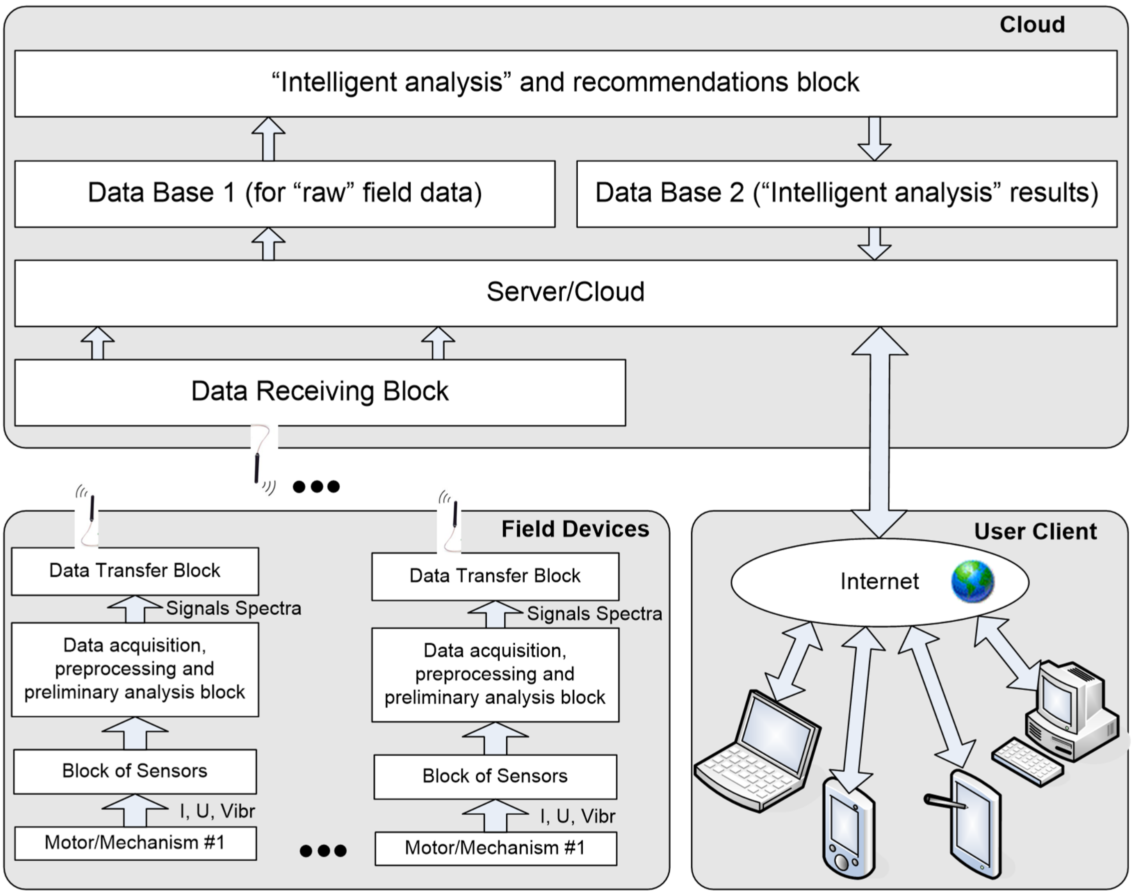

Fig.1. The block-diagram of cloud-based induction motors monitoring systems using electrical signals analysis methods

Conclusion

In this research, the authors presented a novel perspective on a cloud-based diagnostic system for induction motors utilizing electrical signal analysis. Motor current signature analysis was chosen as basic method in this research due to its simplicity for implementation and proved reliability in diagnostics results. This approach enables the development of a cost-effective system that performs online diagnostics without the need to halt the manufacturing process for fault diagnostic procedures via monitoring of stator phase currents. The continuous monitoring of diagnostic parameters, coupled with historical data analysis, facilitates the early detection of incipient faults and provides information to forecast fault development. Thus, this method supports the implementation of condition-based maintenance, providing real-time health condition summaries to end-users via mobile and internet technologies.

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