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Editorial

Novel Approaches to Electrical Machine Fault Diagnosis

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1. Introduction

The increasing demand for intelligent machines, coupled with the drive for the more efficient utilization of these machines in various industries, and the emergence of Industry 4.0 and 5.0 ideologies have accelerated the progress of machine fault diagnosis. As a result, a considerable amount of attention is paid to researching this field in both academia and industry due to the critical importance of identifying the root causes of machine faults. The goal of various machine fault diagnosis methods is to develop effective diagnostic procedures. Recent methodological advancements have enabled the achievement of comprehensive machine fault diagnosis, providing crucial information necessary for preventing future machine failures.

Several highly promising approaches are advancing fault detection and diagnosis technologies, such as advanced digital signal processing, vibration-based condition monitoring, modal and operational mode analysis, neural network analysis, and machine learning. Furthermore, these methods are often combined and used in conjunction. With the continuous development of various IT solutions, the number and usability of these methods are rapidly expanding. Even older methods that had one been discarded due to automation-related challenges or the need for extensive computational resources have been revitalized and are yielding promising results due to advances in measurement technologies and computational power. The advent of the Internet of Things (IoT) and cloud-computing services is creating new possibilities and reshaping the paradigms in this field.

Artificial intelligence (AI) constitutes a transformative technological revolution much like the invention of steam or electric engines. AI possesses attributes like robustness, precise automated (online) learning, and the ability to handle complex data, demonstrating its immense potential for machine fault diagnosis. Together with IoT and cloud computing, AI-based diagnostic methods are proving to be powerful tools for the future.

The primary objective of this Special Issue (SI) was to compile cutting-edge research contributing advancements in machine fault diagnosis and, ideally, outline potential future research directions in this field.

2. Review of Issue Contents

This SI compiles eight papers from authors and research groups active in the field of machine fault diagnosis. As the topic itself is interdisciplinary, the papers presented in this SI present different viewpoints. Some examine the electrical side of machines, while others concentrate on mechanical issues. However, most of the papers cover integral aspects of measurement technology and the corresponding signal-processing procedures, which are essential for ensuring successful prognostic and diagnostic procedures. One of the papers is a comprehensive review paper, while the other seven focus on research aspects of machine fault diagnosis.

The only review paper included in this SI [1] provides an overview of condition-monitoring and fault detection methods applied to electrical machines. The significant

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impact of electric machines on industry, various industrial sectors, and everyday human life underscores the importance of condition monitoring and timely fault diagnosis. This review article explores various diagnostic techniques that can be employed for algorithm training and implementing predictive maintenance. The authors emphasize the advantages and limitations of intelligent diagnostic methods. Additionally, this article delves into the most common faults found in electrical machines and introduces techniques for monitoring their parameters.

The author of [2] analyzed the broken rotor bar fault diagnosis method using the sum of weighted squared Fourier series coefficients. This study presents a fault diagnosis method for induction motors with broken rotor bars (BRBs). In this method, the sum of the squared Fourier series coefficients of a complex current are used as the diagnosis signal, which is filtered to capture the BRB fault signal within a limited frequency range. A proposed weighting factor eliminates the influence of slip frequency and load conditions, thereby rendering the diagnosis independent of these parameters. Experimental validation using a 55 kW induction motor with and without BRB faults demonstrated the method's effectiveness in distinguishing healthy from faulty motors under various load conditions. The proposed fault diagnosis method shows promising results regarding BRB fault detection.

A novel machine-learning-based approach for an induction machine fault classifier was developed and analyzed in [3]. The aim of this machine-learning-based approach was to develop a rotor bar fault identification classifier for induction machines. The authors utilized sequential model-based optimization and nested cross-validation, resulting in a reliable estimation of the classifiers' generalization performance. The study compared logistic regression and CatBoost models using fast-Fourier-transformed signals or extracted statistical features as input data. The authors determined that feature-based models exhibit similar accuracy to signal-based models with simulated current and measured vibration acceleration data but are faster to develop and run. With measured vibration acceleration data, raw fast-Fourier-transformed signals yield better accuracy.

Induction motor inter-turn faults (ITFs), which are common but challenging to accurately diagnose, were outlined in [4]. Previous studies simplified this type of fault's specific distorted flux distribution, limiting their applicability to pretested motors and sensitivity to fault signal distortion. However, in thus study, the authors present an advanced ITF model in the stationary DQ frame, considering rotor flux linkages for each pole and mutual flux linkages among the rotor, stator, and ITF windings. The proposed model accommodates high pole number motors, and a simplified version is provided for easier usage in diagnosis, particularly for light ITF cases. Simulation and experiments were conducted to validate the effectiveness of the presented induction motor ITF fault models.

The previously cited authors further analyze ITFs in [5], proposing an online method for diagnosing inter-turn faults (ITFs) in induction motors by using negative sequence current as a fault signal based on the approach in [4]. This method is used to analyze the relationships between fault parameters, negative sequence current, and fault copper loss using the ITF model. It demonstrates that the fault severity index, which is dependent on fault parameters, is directly linked to negative sequences and copper loss. The proposed model-based fault diagnosis estimates the fault severity index from the negative sequence current to identify an ITF and calculates the fault's copper loss causing thermal degradation. The effectiveness of the proposed method was validated through experimental tests conducted under various fault conditions.

The authors of [6] present methods for detecting bearing defects, impeller clogging, and cracked impellers in variable speed drives (VSDs) used in industry. The first approach, load-point-dependent fault indicator analysis (LoPoFIA), is derived from motor current signature analysis (MCSA) and considers amplitudes at fault frequencies in the current spectrum based on the hydraulic load point. The second approach, advanced transient current signature analysis (ATCSA), involves a time-frequency analysis of the current signal during start-up. Both LoPoFIA and ATCSA were tested on a VSD-driven circulation pump using a pump test bench, and the results showed that these analyses improved the minimization of false alarms compared to MCSA. LoPoFIA simplifies the separation of bearing and impeller defects, while ATCSA is more efficient in terms of measurement effort. Overall, both methods provide valuable insights into faulty pump behavior and offer advantages over MCSA in terms of false alarms and fault separation.

The authors of [7] analyzed level-crossing barrier machine faults. Barrier machines play a crucial role in ensuring safety at railroad crossings. Their failure can lead to transportation delays and pose risks to human life. To enhance safety and enable predictive maintenance, fault and anomaly detection algorithms are recommended for automatic level-crossing systems. The authors propose fault models for barrier machine fault and anomaly detection based on current waveform observations. Various algorithms, including self-organizing maps (SOM), the autoencoder artificial neural network, local outlier factor (LOF), and isolation forest, were applied and assessed with respect to their detection accuracy. The proposed solution offers the advantage of using existing hardware and sensors, making it practical for test stage implementation with acceptable rates of detection accuracy for simulated faults.

Power quality issues related to electrical machine diagnostics are analyzed in [8]. In modern power systems, the low power factor of inductive loads poses a significant power quality issue, impacting the system's capacity and voltage level. Researchers are keen on improving the power factor to mitigate these effects. This article presents a case study analyzing real-time data from a frequency converter used in a ventilation system's motor. The converter output exhibits highly distorted current waves, necessitating a hybrid Fourier and wavelet-transform-based solution for diagnosing and identifying motor failure causes. The wavelet transform is employed for data denoising, thereby enhancing the accuracy of the subsequent Fourier analysis. A spectrum analysis revealed that noise generated by rapidly switching circuits in the frequency converter leads to motor failure.

3. Conclusions

Electrical machines, which are used to perform critical tasks in production, propulsion, power generation, and numerous other industrial processes, play a vital role in various industries. Therefore, ensuring the smooth operation of these machines by monitoring, prognosing, and diagnosing potential faults is of utmost importance. Such practices help minimize downtime, prevent financial losses, safeguard human lives, and protect the environment.

Although there are several traditional diagnostic techniques currently in use and under investigation, the ever-advancing world of technology is revealing new horizons in the field of diagnostics. By incorporating the Internet of Things, powerful artificial intelligence tools, virtual sensors, cloud computing, and other cutting-edge solutions associated with Industry 4.0, more sophisticated and precise diagnostic methods can be employed. This provides exciting possibilities for introducing novel approaches to electrical machine fault diagnosis. Additionally, older techniques that were once considered less promising may regain relevance and efficiency through advanced IT solutions, which offer increased computational resources and faster calculation and simulation times.

Considering the rapid proliferation of electrical machines across all sectors of life, embracing these novel approaches to fault diagnosis can lead to more efficient machine utilization, extended machine lifetimes, and the integration of intelligent technologies into engineering practices.

Conflicts of Interest: The authors declare no conflict of interest.

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