energies

Editorial

Modeling, Control and Diagnosis of Electrical Machines and Devices

Moussa Boukhnifer [1,*] and Larbi Djilali [2]

[1] Université de Lorraine, LCOMS, F-57000 Metz, France
[2] Faculty of Technology, University of Ciudad del Carmen, Campeche 24130, Mexico; larbidjar@chihuahua.tecnm.mx
* Correspondence: moussa.boukhnifer@univ-lorraine.fr

1. Introduction

Nowadays, the increasing use of electrical machines and devices in more critical applications has driven the research in condition monitoring and fault tolerance. Condition monitoring of electrical machines has a very important impact in the field of electrical system maintenance, mainly because of its potential functions of failure prediction, fault identification, and dynamic reliability estimation. Fault diagnosis of electrical machines and devices has received a great deal of attention due to its benefits in reducing maintenance costs, preventing unplanned downtime, and, in many cases, preventing damage and failure. Fault-tolerant design offers a solution that combines fault occurrence conditions, fault detection and location tools, and the reconfiguration of control functions. On the other hand, recent advances in intelligent technology using artificial intelligence and advanced machine learning capabilities provide new perspectives for meaningful fault diagnosis and fault-tolerant control. These outstanding advances can improve the performance of condition monitoring and have significant potential for fault detection in electrical machines and equipment.

Based on the above premises, this Special Issue, titled "Modeling, Control and Diagnosis of Electrical Machines and Devices", aims to highlight the recent trends, research, development, applications, solutions, and challenges related to condition monitoring and fault diagnosis of electrical machines and devices. Topics of interest include the following:

- Modeling of electrical machines and devices.
- Robust control strategies of electrical machines and devices.
- Failure detection and diagnosis of electrical machines and devices.
- Fault-tolerant control of electrical machines and devices.
- Condition monitoring techniques and applications in electrical machines and devices.
- AI techniques for electrical machine fault diagnosis and fault-tolerant control.
- Machine learning techniques for electrical machine fault diagnosis and fault-tolerant control.

There are 10 scientific research articles published in this Special Issue. A summary of the articles published in this Special Issue is outlined in the following section.

2. Highlights of Published Papers

This section provides a summary of this Special Issue of *Energies*, which includes published articles [1–10] covering various topics related to the modeling, control, and diagnosis of electrical devices.

Saeed et al., in ref. [1], extensively studied the use of the common mode current for a stator winding insulation condition assessment. Two main approaches were followed. The first modeled the electric behavior of ground–wall insulation as an equivalent RC circuit; these methods have been successfully applied to high-voltage, high-power machines. The

check for updates

Citation: Boukhnifer, M.; Djilali, L. Modeling, Control and Diagnosis of Electrical Machines and Devices. *Energies* **2024**, *17*, 2250. https://doi.org/10.3390/en17102250

Received: 8 April 2024
Revised: 17 April 2024
Accepted: 28 April 2024
Published: 7 May 2024

second used the high frequency of the common mode current, which results from the voltage pulses applied by the inverter. This approach has mainly been studied for the case of low-voltage, inverter-fed machines and has not yet reached the level of maturity of the first one. One fact noticed after a literature review is that, in most cases, the faults detected were induced by connecting external elements between the winding and stator magnetic cores. The paper presented a case study on the use of the high-frequency common mode current to monitor the stator insulation condition. Insulation degradation occurred progressively with the machine operating normally; no exogenous elements were added.

Pietrzak et al. [2] proposed a low-cost embedded system based on a microcontroller with the ARM Cortex-M4 core for the extraction of stator winding faults (inter-turn short circuits) and an unbalanced supply voltage of the induction motor drive. The voltage induced in the measurement coil by the axial flux was used as a source of diagnostic information. The process of signal measurement, acquisition, and processing using a cost-optimized embedded system (NUCLEO-L476RG), with the potential for industrial deployment, was described in detail. In addition, the analysis of the possibility of distinguishing between inter-turn short circuits and unbalanced supply voltage was carried out. The effect of motor operating conditions and fault severity on the symptom extraction process was also studied. The results of the experimental research conducted on a 1.5 kW IM confirmed the effectiveness of the developed embedded system in the extraction of these types of faults.

Gnaciński et al. [3] described the effect of RC on low-voltage induction motors through the use of experimental and finite element methods. One method for the remote management of electrical equipment is ripple control (RC), based on the injection of voltage inter-harmonics into the power network to transmit information. The disadvantage of this method is its negative impact on energy consumers, such as light sources, speakers, and devices counting zero crossings. The results showed that the provisions concerning RC included in the European Standard EN 50160 Voltage Characteristics of Electricity Supplied by Public Distribution Network are imprecise, failing to protect induction motors against excessive vibrations.

Sun et al. [4] investigated the torque generation mechanism and its improved design in Double Permanent Magnet Vernier (DPMV) machines for hub propulsion based on the field modulation principle. Firstly, the topology of the proposed DPMV machine was introduced, and a commercial PM machine was used as a benchmark. Secondly, the rotor PM, stator PM, and armature magnetic fields were derived and analyzed considering the modulation effect. Meanwhile, the contribution of each harmonic to average torque was pointed out. It can be concluded that the 7th-, 12th-, 19th- and 24th-order flux density harmonics are the main source of average torque. Thanks to the multi-working harmonic characteristics, the average torque of DPMV machines has significantly increased by 31.8% compared to the commercial PM machine while also reducing the PM weight by 75%. Thirdly, the auxiliary barrier structure and dual three-phase winding configuration were proposed from the perspective of optimizing the phase and amplitude of working harmonics, respectively.

Li et al. [5] analyzed the fault characteristics of inter-turn short circuits in the excitation windings of synchronous condensers under unbalanced grid voltage. Mathematical models were developed to represent the air gap flux density and stator parallel currents for four operating conditions: normal operation and inter-turn short-circuit fault under balanced voltage, as well as a process without a fault and with an inter-turn short-circuit fault under unbalanced voltage. By comparing the harmonic contents and amplitudes, various aspects of the fault mechanism of synchronous condensers were revealed, and the operating characteristics under different conditions were analyzed. Considering the four aforementioned operating conditions, finite element simulation models were created for the TTS-300-2 synchronous condenser in a specific substation as a case study. The results demonstrate that the inter-turn short-circuit fault in the excitation windings under unbalanced voltage leads to an increase in even harmonic currents in the stator parallel currents, particularly in the second and fourth harmonics.

Alharkan, in ref. [6], developed a novel reinforcement neural network learning approach based on machine learning to find the best solution for the tracking problem of the switched reluctance motor (SRM) device in real time. The reference signal model, which minimizes torque pulsations, was combined with a tracking error to construct the augmented structure of the SRM device. A discounted cost function for the augmented SRM model was described to assess the tracking performance of the signal. To track the optimal trajectory, a neural network (NN)-based RL approach was developed. This method achieved the optimal tracking response to the Hamilton–Jacobi–Bellman (HJB) equation for a nonlinear tracking system. Simulation findings were undertaken for SRM to confirm the viability of the suggested control strategy.

Belkhadir et al. [7] presented an analytical model of the stator winding unbalance fault represented by lack of turns. Here, mathematical approaches were used by introducing a stator winding parameter for the analytical modeling of the faulty machine. This model can be employed to determine the various quantities of the machine under different fault levels, including the magnetomotive force, the flux density in the air-gap, the flux generated by the stator winding, the stator inductances, and the electromagnetic torque. On this basis, a corresponding link between the fault level and its signature was established. The feasibility and efficiency of the analytical approach were validated by finite element analysis and experimental implementation.

Aladetola et al. [8] developed a control approach to minimize the issue of torque ripple effects in synchronous reluctance machines (SynRMs). This work was performed in two steps: Initially, the reference current calculation bloc was modified to reduce the torque ripple of the machine. A method for calculating the optimal reference currents based on the stator joule loss was proposed. The proposed method was compared to two methods used in the literature, the FOC and MTPA methods. A comparative study between the three methods based on the torque ripple rate showed that the proposed method allowed for a significant reduction in the torque ripple. The second contribution to the minimization of the torque ripple was to propose a sliding mode control. This control suffers from the phenomenon of "Chattering", which affects the torque ripple. To solve this problem, a second-order sliding mode control was proposed.

Damine et al. [9] introduced a robust process for extracting rolling bearing defect information based on combined mode ensemble empirical mode decomposition (CMEEMD) and an enhanced deconvolution technique. Firstly, the proposed CMEEMD extracts all combined modes (CMs) from adjoining intrinsic mode functions (IMFs) decomposed from the raw fault signal via ensemble empirical mode decomposition (EEMD). Then, a selection indicator known as kurtosis median absolute deviation (KMAD) was created in this research to identify the combination of the appropriate IMFs. Finally, the enhanced deconvolution process minimized noise and improved defect identification in the identified CM. Analyzing real and simulated bearing signals demonstrated that the developed method showed excellent performance in extracting defect information. Comparing the results between selecting the sensitive IMF using kurtosis and selecting the sensitive CM using the proposed KMAD showed that the identified CM contained rich fault information in many cases.

Ruz-Hernandez et al. [10] presented the development of a neural inverse optimal control (NIOC) for a regenerative braking system installed in electric vehicles (EVs), which is composed of a main energy system (MES), including a storage system and an auxiliary energy system (AES). The latter one is composed of a supercapacitor and a buck–boost converter. To build up the NIOC, a neural identifier was trained with an extended Kalman filter (EKF) to estimate the real dynamics of the buck–boost converter. The NIOC was implemented to regulate the voltage and current dynamics in the AES. For testing the drive system of the EV, a DC motor was considered, with speed controlled using a PID controller to regulate the tracking source in regenerative braking. Simulation results illustrated the efficiency of the proposed control scheme to (1) track time-varying references of the AES voltage and current dynamics measured at the buck–boost converter and (2) guarantee that charging and discharging operation modes of the supercapacitor would be initiated. In addition, it was demonstrated that the proposed control scheme enhances the EV storage system's efficacy and performance when the regenerative braking system is working.

Author Contributions: Investigation, M.B. and L.D.; Writing—original draft, M.B. and L.D.; Writing—review and editing, M.B. and L.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

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

References

1. Saeed, M.; Fernandez, D.; Guerrero, J.M.; Diaz, I.; Briz, F. Insulation Condition Assessment in Inverter-Fed Motors Using the High-Frequency Common Mode Current: A Case Study. *Energies* **2024**, *17*, 470. [CrossRef]
2. Pietrzak, P.; Pietrzak, P.; Wolkiewicz, M. Microcontroller-Based Embedded System for the Diagnosis of Stator Winding Faults and Unbalanced Supply Voltage of the Induction Motors. *Energies* **2024**, *17*, 387. [CrossRef]
3. Gnacinski, P.; Peplinski, M.; Muc, A.; Hallmann, D.; Jankowski, P. Effect of Ripple Control on Induction Motors. *Energies* **2023**, *16*, 7831. [CrossRef]
4. Sun, Y.; Bianchi, N.; Ji, J.; Zhao, W. Improving Torque Analysis and Design Using the Air-Gap Field Modulation Principle for Permanent-Magnet Hub Machines. *Energies* **2023**, *16*, 6214. [CrossRef]
5. Li, J.; Zhang, C.; He, Y.; Hu, X.; Geng, J.; Ma, Y. Impact of Inter-Turn Short Circuit in Excitation Windings on Magnetic Field and Stator Current of Synchronous Condenser under Unbalanced Voltage. *Energies* **2023**, *16*, 5695. [CrossRef]
6. Alharkan, H. Torque Ripple Minimization of Variable Reluctance Motor Using Reinforcement Dual NNs Learning Architecture. *Energies* **2023**, *16*, 4839. [CrossRef]
7. Belkhadir, A.; Pusca, R.; Belkhayat, D.; Romary, R.; Zidani, Y. Analytical Modeling, Analysis and Diagnosis of External Rotor PMSM with Stator Winding Unbalance Fault. *Energies* **2023**, *16*, 3198. [CrossRef]
8. Aladetola, O.D.; Ouari, M.; Saadi, Y.; Mesbahi, T.; Boukhnifer, M.; Adjallah, K.H. Advanced Torque Ripple Minimization of Synchronous Reluctance Machine for Electric Vehicle Application. *Energies* **2023**, *16*, 2701. [CrossRef]
9. Damine, Y.; Bessous, N.; Pusca, R.; Megherbi, A.C.; Romary, R.; Sbaa, S. A New Bearing Fault Detection Strategy Based on Combined Modes Ensemble Empirical Mode Decomposition, KMAD, and an Enhanced Deconvolution Process. *Energies* **2023**, *16*, 2604. [CrossRef]
10. Ruz-Hernandez, J.A.; Djilali, L.; Canul, M.A.R.; Boukhnifer, M.; Sanchez, E.N. Neural Inverse Optimal Control of a Regenerative Braking System for Electric Vehicles. *Energies* **2022**, *15*, 8975. [CrossRef]