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Editorial

Modern Electrical Drives: Trends, Problems, and Challenges

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1. Introduction

Modern electrical drives possess many advantages. Electrical energy, compared to other sources, is easy to transport and can be environmentally friendly (if it comes from renewable sources). Electrical drives convert energy with high efficiency and have flexible control characteristics. They offer a wide range of speed, torque, and power operations. Furthermore, in general, they can serve as electrical generators.

With the growing demand for high-performance electrical drives, many universities and industrial researchers have focused on the problems surrounding the efficient, robust, precise, and fault-tolerant controls of these drives. In various industries, accurate control of electrical drives is crucial, from high-power drives evident in mining and petrochemical areas, to medium (automotive industries, robot arm drives, CNC machines) and small power drives (actuators), MEMS, etc.

In this Special Issue, the topics related to trends, problems, and challenges linked to the design and exploitation of modern electrical drives are presented. The submitted manuscripts, and those finally selected for publication in this Special Issue, focus on the trends, problems, and challenges in modern electrical drives. Very often, they are multidisciplinary works. In this Special Issue, 10 manuscripts were published that deal with the following topics: control strategies for different types of electrical motors [1–3], estimations of non-measurable states and parameters [3], sensorless control of electrical drives [1,2], the application of advanced control methodologies for high performance control of electrical drives [4–6], diagnoses, monitoring, and prognoses in electrical drives [7–10], and control of complex mechatronic systems, while taking the mechanical part of the system into account [3,4,6].

This publication is divided into two important sections: a short review of the contributions, where important contributions to the development of electric drives are presented, and a summary of the work.

2. A Short Review of the Contributions in This Issue

The main idea of the article [1] is to create a buffer power supply system for an asynchronous electrical drive, and to develop a strategy for a control system for this buffer power by using a bidirectional DC–DC converter. The article describes the process of creating a model of an electric drive, buffer source, control system, and frequency regulation based on MATLAB–Simulink. Simulations of the operations of this system were carried out together with a buffer source based on the supercapacitors. The adequacy and accuracy of the calculated mathematical expressions were proven. An algorithm for the operation of the control system for the buffer power source was proposed.

In [2], Bednarski et al. proposed and experimentally examined a family of generalized microstepping signal shapes for stepper motors. The authors provided the mathematical formula to derive the *p*-norm signals responsible for generation reference currents for stepper motors. The developed signals represent a middle ground between the smooth operation of sine–cosine and the high peak torque output of quadrature microstepping. Based on the numerous experimental tests, it can be concluded that the optimal signal shape (in the sense of positioning accuracy) is neither sin–cos nor quadrature. The best results in the considered test scenario are obtained for three-norm (*p*3) microstepping. The findings of this paper are valuable for developers of 3D printers, CNC machines, and other positioning devices, where a precise movement with a well-defined angular resolution is important.

The paper [3] presents an identification workflow of a multi-resonant mechanical part in a direct drive with up to three high-frequency mechanical resonances. The knowledge of a direct-drive model with a complex mechanical part is important in the syntheses of control algorithms and in the predictive maintenance of digital twins. The identification of two-mass drive systems with one low mechanical resonance frequency is often described in the literature. Previous research has focused on multi-mass drive systems with high mechanical resonance frequencies, in ranges up to 500 Hz. In the first approach, the author used only an output signal in frequency domains with a custom search algorithm. Anti-resonance frequencies were not identified by this algorithm, and a second drawback is its accuracy of around ±3 Hz. This algorithm was successfully tested and compared with manual identification used in control systems, with variable mechanical parameters with three resonance frequencies of 105, 251, and 417 Hz. Literature studies in the paper [3] showed that chirp signals give a smoother frequency response in comparison to PRBS, as the frequency range is banded and the magnitude is flat. The paper presents an identification workflow of a multi-resonant mechanical part in direct drive with up to three high-frequency mechanical resonances in a continuous-time (CT) representation. The usage of a nonlinear least-square algorithm with constraints, as a fitting algorithm, allows solving the issue of modeling multi-mass direct-drive systems in the frequency domain. The second finding in paper [3] is a comparison of different cost functions evaluated to choose the best complex number representation for the identification of multi-mass direct-drive systems.

The article by Szczepanski et al. [4] describes an application of a nature-inspired metaheuristic optimization algorithm in the controller's auto-tuning. To fulfill the requirements related to the precise control of a complex plant, the original objective function minimized during the automatic synthesis process of the controller has been proposed. An artificial bee colony algorithm for auto-tuning a two-mass system was explored. In the results, optimal coefficients of the state speed feedback controller has been obtained. These assure high-performance and robust operation of the drive with a complex mechanical structure. The proposed auto-tuning method may find application in many industrial machines, such as conveyor belts, servo systems, robot arms, and rolling-mill machines, to provide satisfactory product quality and extend the lifetime of the machine's mechanical part, due to the reduced coupling shaft stress.

Application of the adaptive control structure for a drive system with an elastic connection is described in the paper [5]. The proposed algorithm is based on the direct adaptive control concept. As a speed controller, the recurrent neural network is applied. The model of the system is inspired by Elman nets. The properties of the system depend on the control coefficients significantly; therefore, a method based on the particle swarm optimization algorithm is proposed here. Additionally, the ADALINE model is used in order to filter the signal used in the control structure. The properties of the proposed control structure are tested under simulation and experimental studies.

In [6], an application of the D-decomposition method for a control structure of a drive system with a flexible connection is presented. The proposed method allows a detailed analysis of the closed-loop control structure properties. The stability regions for constant and changeable parameters of the drive can be specified. Furthermore, the additional delays caused by the torque control loop, as well as the torque and speed sensor, can be included in the analysis. Furthermore, the properties of the drive system with the controller, tuned with the help of classical pole placement methodology, is analyzed. The limitations of both approaches are pointed out. Then, a tuning algorithm based on the connection of D-decomposition and pole placement techniques is proposed. It allows reducing the oscillations in the state variable transients effectively. The theoretical considerations are supported by experimental studies.

Ewert [7] presents the effectiveness of a bispectrum analysis for the detection of the rotor unbalance of an induction motor supplied by the mains and a frequency converter. Two diagnostic signals, as well as the stator current and mechanical vibrations of the tested motors were analyzed. The experimental tests were conducted for two low-power induction motors with one and two pole pairs, respectively. The unbalance is modeled using a test mass mounted on a specially prepared disc and directly on the rotor, and the influence of this unbalance location was tested and discussed. On the basis of the conducted analyses, it can be stated that the vibration acceleration signal is a better information carrier in the case of rotor unbalance than the stator current signal. The changes in the amplitudes that are characteristic of the unbalance symptoms occurring in the mechanical vibration analysis are a few (or sometimes even more than a dozen) times higher than those observed in the stator current analysis. Therefore, the analysis of the mechanical vibration signal is a better solution in the detection of rotor unbalance.

Hajnrych et al. [8] propose the parameterized models of the yokeless axial flux (AF) machine with different rotor parameters using the advanced 3D finite element analysis. The impact of the number of rotor poles on the cogging torque amplitudes and their ripple factors is investigated. The results indicate that the best drive torque density with a low torque ripple and low back-EMF total harmonic distortion are obtained for the pole span of around 0.8 of full pole pitch. On the basis of the above-mentioned findings, efficient and smaller motors with permanent magnets can be designed, which is essential for application in electric vehicles. Finally, the authors recommend the yokeless AF machines for low-speed direct-drive applications requiring a low cogging torque and a high output torque density.

The article by Pajchrowski et al. [9] presents concepts of three-phase power rectifiers with improved quality of converted electrical power. This effect is obtained by modulating the currents in the DC output circuits of the rectifiers by means of current sources controlled by power electronics, working as so-called current modulators. For further quality improvement of the grid currents of the analyzed systems, using an additional controlled current source connected in parallel to the DC load was suggested (hereinafter referred to as a supporting system). The original elaborated method of controlling this source was presented. This solution is very attractive due to the ease of implementation in systems already in use, which significantly reduces investment costs. It should be noted that already in its basic version, this solution enables a significant reduction in undesirable harmonics in the grid current, which has a positive effect on the quality of the converted energy. It should also be emphasized that even a possible failure of these modules does not interrupt the energy supply to the DC load.

The use of the D-decomposition technique for an analysis of the work of a boost converter operating in continuous condition mode is described in [10]. The authors propose the application of the genetic algorithm to select the optimal gain of PI coefficients. The D-decomposition technique allows specifying the global stability region of the controlled plant. Additionally, the design requirements based on the specified desired gain and phase margin are introduced here. This problem is shown as a function that is further used in the generic algorithm. Three different performance indexes are tested in the paper. The delay evident in a controlled plant is taken into account. The identification procedure of the plant is describe in the paper. The simulation and experimental results are included in the paper.

3. Conclusions

After analyzing the contributions selected for publication in this Special Issue, the following conclusions were drawn. Modern control approaches (i.e., state feedback control, adaptive control) and identification techniques are applied to improve the overall performance of electrical drives with complex multi-mass systems. Advanced optimization techniques (including the meta-heuristic approach) and analysis tools (i.e., D-decomposition) play essential roles in developing complex control schemes, designing electrical machines with respect to the considered performance indexes (e.g., mitigation of torque ripples, efficiency maximization, dynamic property optimization), and investigating stability issues. An accurate and robust estimation of the non-measurable states and parameters is still of interest to researchers. Therefore, data-driven analyses supported by artificial neural networks and advanced spectral approaches are employed. As a result, more accurate models of the electrical drive (i.e., motor and power converter) are obtained, and further phenomena are investigated. The presented approaches lead to more efficient and high-performance electrical drives. Therefore, further development of intelligent control algorithms and tools responsible for optimal design and analysis will be observed in the near future.

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