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EDITORIAL

SPECIAL SECTION

Adaptive, predictive and neural approaches in drive automation and control of power converters

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1. Introduction

Motion control, electric drive automation, and power converters are among the most rapidly developing areas of advanced engineering. The importance of research in these fields for the global economy, industry, and social well-being is unquestionable. Contemporary power electronics, motion control, and drive automation constitute multidisciplinary research creatively absorbing the recent achievements of control theory, artificial intelligence, signal processing, and microprocessor technique. At the same time, the demanding challenges of drives and power converters provide an important impulse for the development of new theoretical results, especially new control methods.

The Polish research community interested in the control of drives and power converters remains among the world leaders in this area. Several important monographs published recently were created on the initiative of this community [1–3].

Editors of the **Bulletin of The Polish Academy of Sciences: Technical Sciences** constantly appreciate the importance and fast development of drive automation, motion control, and power electronics. Therefore, it is not surprising that among numerous research papers devoted to drive automation, several special sections and issues dedicated to this area had been published in the **Bulletin of The Polish Academy of Sciences: Technical Sciences** over previous decades. Let us mention "Control in Power Electronics and Drives", *Bull. Pol. Ac.: Tech.* 54 (3), 2006, "Power Electronics in Renewable Energy Systems", *Bull. Pol. Ac.: Tech.* 57(4), 2009, "Power Electronics for Smart Grids", *Bull. Pol. Ac.: Tech.* 59(4), 2011, and the recent one: "Multilevel Converters", *Bull. Pol. Ac.: Tech.* 65(5), 563–564, 2017 [4].

The latest Special Section presented here is devoted to three control approaches which we find the most promising for the further development of energy conversion systems: adaptive, neural, and predictive control. Twelve research papers, included after careful selection, provide an important contribution to the theory, as well as great application potential and possibilities.

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2. Adaptive approach in motion control and drive automation

It is well known that the parameters of the load, of the motor and of the converter are not known exactly and may vary during the drive system operation. Therefore, adaptive control seems to be a natural choice for drive automation. Unfortunately, the complexity of adaptive controllers forces us to constantly seek balance between the universal theoretical soundness and the ability of practical implementation of the designed control algorithm.

A nonlinear approach to adaptive motion control is presented in [5]. It is one of the first contributions using a nonlinear state transformation and backstepping. Its practical importance results from the fact that it allows us to impose hard constraints on the state variables directly and to achieve asymptotic tracking of any reference trajectory satisfying the constraints, despite unknown parameters of a drive.

An interesting cooperation of adaptive and algebraic speed estimation laws is proposed in [6] for induction machines. This approach improves stable operation in the considered range of changes of rotor speed and load torque.

Although the permanent magnet synchronous motor drive presented in [7] is not an adaptive control system literally, it possesses an important ability to reduce velocity ripples due to periodic disturbances. The disturbances are estimated by an extended Kalman filter and a state feedback controller with feedforward action regulates and compensates for disturbance.

Adaptive control is not the only methodology to obtain proper drive operation in the presence of parameter variations. A similar result may be achieved ensuring the system robustness by proper tuning of the state controller parameters. This technique is demonstrated in [8], where coefficients of the controller of PMSM servo-drive are tuned by an artificial bee colony optimization algorithm. Hence, the readers of the Special Section get an interesting opportunity to compare adaptive and robust approaches to the same type of drive with a permanent magnet synchronous motor.

The same type of motor is considered in [9]. Smart modification of a classical linear, model-reference adaptive control is presented with the Widrow-Hoff rule used to adjust controller's coefficients. Originally, the Widrow-Hoff rule was proposed in

1960 to train an adaptive pattern classification neural machine called Adaline. In addition to presenting an important application, the authors of [9] demonstrate close links between adaptive and neural approaches.

3. Artificial neural networks in drive automation

Artificial neural networks are widely applied in motion control, drive automation, and control of power converters. Due to still surprising and not fully investigated ability to approximate complex dependencies, neural networks are used as controllers, state observers, fault detectors and classifiers. Three papers presented in the Special Section concern the first and the third case.

Paper [10] presents a strong link between adaptive and neural control. An adaptive controller, focusing on the change of object parameters, is designed as a neural speed controller with the use of Reinforcement Learning. It ensures long term performance stability without the need to switch off the adaptation algorithm.

The next two papers [11, 12] describe the powerful application of neural networks in induction motor fault diagnosis. The first one presents the opportunity of detecting shorted turns and the broken rotor bars with the use of convolutional, deep neural networks based on an axial flux signal. The same networks are used in the second paper to diagnose inter-turn short circuits of induction motor stator windings operating under the Direct Field Oriented Control. It should be noted that the developed convolutional networks were based on the raw measurement signals, which eliminated the need for initial signal processing. This significantly facilitated the reduction of time of measuring the diagnostic signal as well as considerably accelerated the fault detection and localization process, which is particularly important due to the nature of the discussed motor winding damages.

4. Predictive control of power converters

The constant increase in the computing power of digital signal processors (DSP) is closely related to the growing interest of scientists in predictive control methods. Two basic approaches can be distinguished among the predictive control methods: continuous control set model predictive control (CCS-MPC) and finite control set model predictive control (FCS-MPC). A characteristic feature of the methods from the CCS-MPC group is the generation of the desired converter voltage using a modulator, as in the case of deadbeat controllers. The main advantage of the voltage generation is a constant switching frequency. Moreover, the aforementioned algorithms show good results in both the steady state and the transient state. They combine the advantages of linear and nonlinear control. It is worth emphasizing that the constant switching frequency facilitates the design of appropriate EMI filters.

Paper [13] proposes the implementation of an infinite control set, model predictive control into a three-phase AC/DC converter connected to the grid through an LCL filter. The predictive algorithm is based on the look-up table Direct Power Control -3 Vectors method. The general principle of this algorithm is based on controlling sinusoidal voltage on the filter capacitance which is obtained by a sinusoidal grid current absorbed from the grid. The sinusoidal voltage is provided by appropriate control of the input converter current. The calculation of the duty cycles for the space vector modulator is based on the analysis of the current derivatives both in static and transient states. The proposed method allows damping the resonance frequencies of an LCL filter and to obtain smaller ripples of grid current, lower values of the THD coefficient, and maintain a constant switching frequency.

The discrete nature of voltage converters is directly used in the second group of converter control methods, i.e. FCS-MPC. The use of this feature allows us to limit the number of possible future behaviors of controlled variables, because of a finite number of switching possibilities of the converter. The analysis of the optimal switching of the converter to a specific voltage vector depends on the calculations performed at each sampling step. The choice of an exact vector depends on the result of minimizing the defined cost function, which allows for simultaneous control of multiple physical quantities in the system, such as voltage, current, flux, torque, rotational speed, and common-mode voltage. Due to the possibility of using very different cost functions, control methods from the FCS-MPC group have been developed for many types of converters, including current converters, matrix converters, and active filters.

The result of the research presented in [14] is an innovative, optimal-switching-sequence, model predictive flux control method which guarantees a constant switching frequency of the drive inverter. The applied cost function allows minimizing the stator flux errors in stationary coordinates. The control of the stator flux vector ensures satisfactory waveforms of the rotor flux vector and the torque. Moreover, the algorithm allows including the stator flux errors (resulting from the use of the three selected voltage vectors) in the cost function. In this way, the errors of the flux components are additionally minimized, and a constant switching frequency characteristic of the space-vector-modulation (SVM) methods is ensured. Speed and selected motor parameters are estimated online based on MRAS technique. The proposed solution is well illustrated by experimental results.

One of the essential ways in which an AC/DC converter should cooperate with the grid is that it should be immune to grid voltage distortions, both static and dynamic, under grid voltage asymmetry, distorted by higher harmonics and step change of the reference grid current.

In paper [15], the authors proposed a modification of the FCS-MPC technique with the specific cost function that controls the grid current, the converter current and the capacitor voltage. An additional controller of the grid current improves the robustness for higher harmonics and unbalanced grid voltage. Both simulation and experimental results are presented to verify the effectiveness of the proposed control strategy.

Interesting properties of the predictive FCS-MPC control for matrix converters are presented in [16]. The cost function is constructed to achieve sinusoidal currents at the input and output of the converter. In addition, two simulation-tested algorithms for achieving the input power factor equal to one by setting zero reactive power and the input current in phase with the grid voltage were proposed. The correctness of the strategies was confirmed by simulation tests.

5. Conclusions

The idea of the Special Section was born during the last, 24th Conference **Control in Power Electronics and Electric Drives** – "SENE 2019", organized every two years in Łódź, by Institute of Automatic Control, Lodz University of Technology (the next one is planned in November 2021). Over 100 researchers representing the majority of technical universities in Poland take part in each edition of this cyclical conference. It is undoubtedly the largest and most representative scientific conference in this thematic area in Poland. All participants create an exceptional, stimulating atmosphere by demonstrating a mutual interest in their findings. As an effect of this stimulation, the leading topics of the Special Section were proposed by Guest Editors and kindly accepted by the Editorial Board. We hope that the selected papers represent a high scientific level and strong practical applicability, will be interesting and inspiring for our readers and motivate them to participate in the next conference.

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