energies

Editorial

Sliding Mode Controllers in Energy Systems and Other Applications

Pawel Latosinski and Andrzej Bartoszewicz *

Institute of Automatic Control, Lodz University of Technology, 90-924 Lodz, Poland; pawel.latosinski@p.lodz.pl
* Correspondence: andrzej.bartoszewicz@p.lodz.pl

Citation: Latosinski, P.; Bartoszewicz, A. Sliding Mode Controllers in Energy Systems and Other Applications. *Energies* **2023**, *16*, 1049. https://doi.org/10.3390/en16031049

Received: 30 September 2022
Accepted: 10 October 2022
Published: 18 January 2023

The process of obtaining the necessary electrical energy to satisfy the needs of society is becoming an increasingly difficult issue in current times. Facing this problem, the scientific community has made advances in such areas as renewable energy, pollution reduction, and the more efficient use of available power. In particular, this Special Issue of *Energies* presents several findings in the field of control theory, which are intended to increase the effectiveness of many widely used energy systems. The included works are concerned with sliding mode control strategies, which are widely known for their exceptional performance in systems affected by disturbance or model uncertainties. This is a valuable property in various energy systems such as wind turbines, synchronous motors, and photovoltaic systems. At the same time, most energy systems operate with very fast sampling times. As such, the effective control of such systems demands high computational efficiency, which is also provided by sliding mode control strategies.

This Special Issue, entitled "Sliding Mode Controllers in Energy Systems and Other Applications", includes sixteen research papers on various applications of sliding mode control, tackling several typical issues in the practical application of such strategies. A short summary of all papers included in this Special Issue is given here.

The work by Sami et al. [1] considers wind turbines, a type of energy system that is especially vulnerable to nonlinearities and strong external disturbance. In particular, the authors propose the use of a fractional order terminal SMC based on the super-twisting algorithm. Furthermore, they apply a cascaded control scheme for regulating both the mechanical subsystem of the wind turbine as well as the electrical one, as they have significantly different response times. The proposed scheme is shown to ensure a fast and mostly chatter-free response of the system, which is translated into high energy efficiency.

Another study on the control of wind turbines is presented by Benbouhenni and Bizon [2], in which the authors propose a novel scheme combining the advantages of sliding mode control and synergistic control. When applied to a dual-rotor wind turbine, the proposed method results in significantly more accurate tracking of the maximum power point than a widely used PI control strategy.

A super-twisting sliding mode control algorithm is used by Ahmed et al. [3] for maximum power point tracking in a photovoltaic system. To generate the reference peak power voltage for the considered controller, the authors use an appropriately trained neural network. The satisfactory performance of the plant is demonstrated under changing irradiance as well as changing temperature.

A further study on sliding mode control of photovoltaic systems is demonstrated by Zeb et al. [4]. The authors use a super-twisting algorithm to inject both active and reactive power into a three-phase grid-connected system. They investigate system performance under various abnormal conditions, such as voltage swell or DC-link variation, and demonstrate the efficiency of the proposed algorithm.

The study of Silaa et al. [5] concerns proton exchange membrane fuel cells, which are one of the most promising means of producing electrical energy. Typically, sliding mode control strategies are inappropriate for such systems, since the chattering phenomenon would cause non-negligible energy loss. With this in mind, the authors introduce a higher-order sliding mode control strategy specifically meant to mitigate this phenomenon. The experimental results show that this strategy reduces unwanted oscillations by 84% compared with conventional sliding mode control, thus reducing energy loss in the fuel cell.

Shtessel et al. [6] further consider the topic of hydrogen fuel cells in the context of electric vehicles. Specifically, the authors consider a multi-part power system consisting of the fuel cell, ultracapacitor, and DC–DC power converters. The current in the fuel cell is controlled using a second-order sliding mode control strategy with adaptive gains while the remaining parts of the system are subject to a more conventional sliding mode control strategy.

On the other hand, Konieczny et al. [7] focus on the control of active vehicle suspension with the use of sliding modes. The main objective of the control process is to reduce the vehicle's roll and vibration for the sake of comfort, but without meaningfully increasing energy demand. This objective is fully achieved by the advanced sliding mode control strategy proposed by the authors.

Wang et al. [8] consider a somewhat different approach based on second-order sliding modes. This approach is applied to active magnetic bearings with the aim of minimizing rotor displacement. It is experimentally verified that the proposed scheme performs significantly better than a common equivalent based on the reaching law approach, while producing no noticeable chattering.

Another type of energy system, permanent magnet synchronous motors, is considered by Liu et al. [9]. In order to design a successful sensorless control scheme for such systems, the authors aim to reconstruct the full system state using a sliding mode observer. The particular observer proposed in that work is based on the super-twisting algorithm and is characterized by the adaptive estimation of system parameters. It is demonstrated via experiments that the proposed method successfully suppresses the influence of changing motor parameters on control quality.

A further study on the observer-based control of permanent magnet synchronous motors drives is conducted by Bao et al. [10]. The authors propose the use of a full-order sliding mode control strategy based on a synchronous frequency tracking filter as well as a Luenberger observer. The former is responsible for filtering out the harmonics of the electromotive force, while the latter serves to reduce position and speed errors in the controlled plant.

Sliding mode control of permanent magnet synchronous motors is also considered by Gao et al. [11]. Similarly to previously discussed works, the authors of this paper also propose the use of a second-order sliding mode control algorithm in conjunction with a state observer. However, the authors further introduce a new nonlinear sliding surface to improve the transient response of the system.

A comparative study on the control of permanent magnet synchronous motors was conducted by Dendouga [12]. In this work, the author discusses the design procedure of conventional sliding mode control strategies for such systems, as well as more sophisticated second-order strategies. It is demonstrated that, for the considered motor fed by a direct matrix converter, one can achieve a fast response of the system and good reference tracking regardless of uncertainties.

A well-known issue in sliding mode control is the existence of an initial reaching phase during which the controlled plant remains vulnerable to uncertainties. Thus, various authors aim to eliminate this phase using an appropriately designed sliding hyperplane. One such approach is presented by Mobayen et al. [13] and successfully applied to the control of DC–DC buck converters. Indeed, the authors show that the output voltage of the considered converter can be effectively regulated at all stages of the control process.

A more general sliding mode control strategy is proposed by Pietrala et al. [14]. In this work, the authors consider a second-order system with nonlinearities and aim to ensure its stability under velocity and input constraints. Such constraints are typical in a variety of electromechanical systems, which makes the proposed method widely applicable. To achieve their objective, the authors propose the use of a novel time-varying sliding surface, the parameters of which are adjusted to minimize settling time under given constraints.

In another work, Lesniewski and Bartoszewicz [15] consider the sliding mode control of sampled data systems. This is a highly relevant topic, as virtually all control algorithms are applied digitally with no continuous states in the controller. In particular, the authors propose a strategy based on the reaching law approach and apply it to a discrete-time representation of the system. It is demonstrated that the proposed scheme ensures the robustness of the plant with respect to disturbance even when typical assumptions about matching conditions are omitted.

Finally, Latosinski and Bartoszewicz [16] discuss the issue of quasi-sliding mode band width in the control of sampled data systems. Particularly, they propose a novel sliding hyperplane on which the width of this band can be effectively reduced to zero even in the presence of uncertainties. As a result, when the system is operating in sliding mode, the state error is reduced compared with conventional sliding mode control strategies.

Author Contributions: P.L.: Methodology, formal analysis, investigation, writing—original draft. A.B.: Conceptualization, supervision, validation, writing—reviewing and editing. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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

References

1. Sami, I.; Ullah, S.; Ali, Z.; Ullah, N.; Ro, J.S. A Super Twisting Fractional Order Terminal Sliding Mode Control for DFIG-Based Wind Energy Conversion System. *Energies* **2020**, *13*, 2158. [CrossRef]
2. Benbouhenni, H.; Bizon, N. A Synergetic Sliding Mode Controller Applied to Direct Field-Oriented Control of Induction Generator-Based Variable Speed Dual-Rotor Wind Turbines. *Energies* **2021**, *14*, 4437. [CrossRef]
3. Ahmed, S.; Muhammad Adil, H.M.; Ahmad, I.; Azeem, M.K.; e Huma, Z.; Abbas Khan, S. Supertwisting Sliding Mode Algorithm Based Nonlinear MPPT Control for a Solar PV System with Artificial Neural Networks Based Reference Generation. *Energies* **2020**, *13*, 3695. [CrossRef]
4. Zeb, K.; Busarello, T.D.C.; Ul Islam, S.; Uddin, W.; Raghavendra, K.V.G.; Khan, M.A.; Kim, H.J. Design of Super Twisting Sliding Mode Controller for a Three-Phase Grid-connected Photovoltaic System under Normal and Abnormal Conditions. *Energies* **2020**, *13*, 3773. [CrossRef]
5. Silaa, M.Y.; Derbeli, M.; Barambones, O.; Cheknane, A. Design and Implementation of High Order Sliding Mode Control for PEMFC Power System. *Energies* **2020**, *13*, 4317. [CrossRef]
6. Shtessel, Y.B.; Ghanes, M.; Ashok, R.S. Hydrogen Fuel Cell and Ultracapacitor Based Electric Power System Sliding Mode Control: Electric Vehicle Application. *Energies* **2020**, *13*, 2798. [CrossRef]
7. Konieczny, J.; Sibielak, M.; Rączka, W. Active Vehicle Suspension with Anti-Roll System Based on Advanced Sliding Mode Controller. *Energies* **2020**, *13*, 5560. [CrossRef]
8. Wang, X.; Zhang, Y.; Gao, P. Design and Analysis of Second-Order Sliding Mode Controller for Active Magnetic Bearing. *Energies* **2020**, *13*, 5965. [CrossRef]
9. Liu, Y.; Fang, J.; Tan, K.; Huang, B.; He, W. Sliding Mode Observer with Adaptive Parameter Estimation for Sensorless Control of IPMSM. *Energies* **2020**, *13*, 5991. [CrossRef]
10. Bao, D.; Wu, H.; Wang, R.; Zhao, F.; Pan, X. Full-Order Sliding Mode Observer Based on Synchronous Frequency Tracking Filter for High-Speed Interior PMSM Sensorless Drives. *Energies* **2020**, *13*, 6511. [CrossRef]
11. Gao, P.; Zhang, G.; Lv, X. Model-Free Control Using Improved Smoothing Extended State Observer and Super-Twisting Nonlinear Sliding Mode Control for PMSM Drives. *Energies* **2021**, *14*, 922. [CrossRef]
12. Dendouga, A. Conventional and Second Order Sliding Mode Control of Permanent Magnet Synchronous Motor Fed by Direct Matrix Converter: Comparative Study. *Energies* **2020**, *13*, 5093. [CrossRef]
13. Mobayen, S.; Bayat, F.; Lai, C.C.; Taheri, A.; Fekih, A. Adaptive Global Sliding Mode Controller Design for Perturbed DC-DC Buck Converters. *Energies* **2021**, *14*, 1249. [CrossRef]
14. Pietrala, M.; Leśniewski, P.; Bartoszewicz, A. Sliding Mode Control with Minimization of the Regulation Time in the Presence of Control Signal and Velocity Constraints. *Energies* **2021**, *14*, 2887. [CrossRef]

15. Leśniewski, P.; Bartoszewicz, A. Reaching Law Based Sliding Mode Control of Sampled Time Systems. *Energies* **2021**, *14*, 1882. [CrossRef]
16. Latosiński, P.; Bartoszewicz, A. Zero-Width Quasi-Sliding Mode Band in the Presence of Non-Matched Uncertainties. *Energies* **2021**, *14*, 3011. [CrossRef]