Power Electronics and Drives

Renewable Energy Conversion and Energy Storage Systems—Summary of the Special Section

Research Paper

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Received: 12 December, 2025; Received in the revised form: 12 December, 2025; Accepted: 12 December, 2025

Abstract: This short editorial provides a summary of the Special Section on Renewable Energy Conversion and Energy Storage Systems, published across the 2024–2025 issues of Power Electronics and Drives. The Section gathers ten research contributions addressing key challenges related to renewable energy integration, including maximum power point tracking, photovoltaic (PV) model optimisation, converter design and hybrid energy management strategies. Collectively, these works highlight significant progress in improving the efficiency, stability and reliability of renewable energy conversion and storage technologies.

Keywords: *renewable energy systems • energy storage systems • power electronics • MPPT • intelligent control*

Renewable energy sources (RES) have become indispensable in global strategies aimed at minimising fossil-fuel consumption and reducing greenhouse gas emissions. As emphasised in the Special Section announcement, the large-scale integration of photovoltaic (PV) systems, wind generators, hybrid energy systems and advanced energy storage systems requires continuous innovation in the fields of power electronics, control algorithms and system-level energy management. Variability in solar irradiance, wind velocity, load characteristics and grid disturbances presents persistent challenges to maintaining stability, efficiency and reliability. Power electronic converters—together with intelligent control, optimisation tools and robust protection mechanisms—play a transformative role in enabling stable energy conversion, maximum power extraction and secure power delivery.

This Special Section, published across the 2024 and 2025 volumes of *Power Electronics and Drives*, brings together ten research contributions that collectively address multiple layers of these challenges: from algorithmic maximum power point tracking (MPPT) innovation and PV modelling, through multiport converters for hybrid systems, to advanced energy storage utilisation and grid stability improvements. Each manuscript contributes unique insights aligned with the overarching goal of advancing renewable energy conversion and storage technologies.

1. Advanced MPPT Techniques and Optimisation Approaches in PV Systems

A substantial portion of the papers in this Special Section deals with the enhancement of MPPT algorithms—an essential requirement given the non-linear nature of PV systems and their susceptibility to shading, temperature fluctuations and dynamic atmospheric behaviour.

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The contribution by (Kechida et al., 2024) highlights the utilisation of artificial intelligence (AI) to increase the performance of a hybrid solar–wind–battery system. The authors propose fuzzy-logic-based MPPT controllers for both PV and wind subsystems, complemented by an adaptive neuro-fuzzy inference system (ANFIS)-driven bidirectional converter for battery energy storage regulation. Their simulation results show considerable improvement in the stability of the DC bus and enhancement of energy production efficiency. This work illustrates how soft computing approaches can simultaneously address MPPT efficiency and energy management reliability.

In a related but more specialised focus, (Khaterchi et al., 2024) introduce a hybrid optimisation-driven MPPT algorithm—WSO-IC—that merges the War Strategy Optimisation (WSO) metaheuristic with the well-established incremental conductance (IC) method. The resulting hybrid solution demonstrates high robustness under partial shading conditions, a scenario in which classical methods often fail to track the global maximum power point (MPP). With tracking efficiencies exceeding 99% and reduced steady-state oscillations, the proposed technique underscores the strong potential of hybridised MPPT approaches.

The accuracy of PV model parameter identification—often a prerequisite for MPPT performance evaluation—is addressed by (Jeridi et al., 2025) who propose a hybrid war strategy optimisation-hippopotamus optimization (WSO-HO) algorithm enhanced with the Newton–Raphson method. Their study evaluates both single-diode and double-diode models across multiple case studies. They demonstrate that the hybrid optimisation framework consistently achieves lower errors and superior convergence behaviour compared with classical and recently developed algorithms. Accurate modelling of PV cell behaviour is essential for system sizing, simulation and hybrid control design, making this contribution particularly valuable.

Extending the optimisation emphasis to bifacial PV systems, (Najdoska and Cvetkovski, 2025) examine maximum power point determination using the multi-verse optimisation (MVO) algorithm applied to three cell models (ideal single diode, real single diode and two-diode). Their research highlights the increased modelling complexity of bifacial modules due to rear-side irradiance variability, and demonstrates how nature-inspired optimisation can considerably improve MPPT accuracy in system design phases. This work supports the further expansion of bifacial technologies, which are increasingly used due to their higher energy yield and reduced land footprint.

Another notable MPPT enhancement comes from (Mahbouba et al., 2025), who propose a fuzzy model reference adaptive control (MRAC-Fuzzy) technique for PV systems. This approach achieves high tracking efficiencies—up to 99.98%—while reducing oscillations around the MPP and improving response times under variable irradiation. The authors address one of the fundamental challenges of adaptive MPPT methods: selecting adaptation gains that ensure both fast convergence and system stability. Their fuzzy-based gain adjustment mechanism offers a promising direction for designing reliable and computationally efficient MPPT controllers.

Collectively, these contributions demonstrate that MPPT continues to be a fertile research area, with new optimisation methods, hybrid intelligence and enhanced modelling techniques reshaping the way in which PV systems are controlled and integrated.

2. Converter Topologies and Energy Processing for Renewable and Storage Systems

Power converters serve as the backbone of energy interfaces between RES, storage systems and loads. Several papers in this Special Section tackle issues of converter design, modelling and performance optimisation.

A comprehensive tri-port DC–DC topology designed for bifacial PV modules is proposed by (Sahu et al., 2024) Unlike conventional systems requiring separate converters for PV and storage, the proposed three-switch tri-port converter uses a single inductor for simultaneous management of PV, battery and load ports. The topology provides enhanced power density, reduced semiconductor count and improved DC link voltage regulation. Experimental validation strengthens the practical significance of this design for standalone solar energy applications.

Addressing the high-power, fast-charging demands of storage systems, (Quintáns Graña et al., 2025) present a detailed model of a buck converter operating in continuous conduction mode (CCM) for supercapacitor charging. Their modelling strategy accounts for realistic parasitic resistances and switching behaviour, revealing how even small duty-cycle variations can lead to large current swings due to the low equivalent series resistance (ESR) of supercapacitors. The authors provide simulation and hardware results—including microcontroller-based implementation—demonstrating stable current regulation with millisecond-level settling times. This practical modelling approach is valuable for designing hybrid storage systems where supercapacitors capture transient peaks.

These works mark important advancements in converter efficiency, component reduction and enhanced control precision, all of which are increasingly essential for RES-powered systems.

3. Power Quality Enhancement and Converter Protection in Hybrid Renewable Systems

The variability of RES often leads not only to power fluctuations but also to power quality (PQ) disturbances such as voltage sag, harmonic distortion and frequency excursions. Two papers address critical PQ and protection concerns in hybrid networks.

(Singh and Singh, 2025) propose an integrated ANFIS-based firebug swarm optimization (FBSO) control framework in conjunction with a Unified Power Quality Conditioner (UPQC) to mitigate PQ issues in grid-connected hybrid renewable systems. By combining adaptive machine learning techniques with an optimisation-based controller, the study demonstrates visible improvements in current shaping, voltage regulation, harmonic mitigation and dynamic system stability. The multi-resolution PID control and shunt active filtering strategies ensure robust PQ compensation during disturbances such as voltage or current sag.

Complementing PQ improvement at the system level, (Strossa et al., 2025) focus on equipment protection by presenting a crowbar-based overvoltage protection mechanism featuring a fully passive power-supplied control unit. Their approach eliminates the dependency on auxiliary low-voltage supplies and offers precise control of the crowbar activation threshold. The work is especially relevant for H-bridge converters, which are increasingly deployed in renewable and grid-connected applications but remain vulnerable to transient overvoltage events caused by atmospheric or grid faults.

Together, these studies highlight how both smart control and robust protection are essential components of modern renewable grids.

4. Hybrid Renewable Generation and Multi-Layer Intelligent Energy Management

Beyond MPPT and converter-level optimisation, system-level coordination plays a crucial role in ensuring seamless and stable integration of multiple renewable sources.

In this context, (Marouani et al., 2025) introduce an advanced energy management and control framework for an on-grid hybrid system integrating PV, wind and flywheel energy storage. The authors develop a multi-layer control structure combining fuzzy logic control (FLC), PID regulation and sliding-mode control (SMC). Their seven-mode energy management strategy ensures optimal energy utilisation, grid support and stability under widely varying operating conditions. Notably, their simulations demonstrate high renewable utilisation (92.3%) and frequency deviation control within ±0.8%. This work exemplifies how intelligent hybrid control frameworks can help grids accommodate increasing shares of RES without compromising on performance.

From innovative MPPT strategies and hybrid optimisation algorithms, to advanced converter topologies, robust protection circuits and integrated supervisory control frameworks, the research presented here strengthens the foundations for future progress in RES technologies. As renewable penetration continues to rise globally, such contributions will remain essential for ensuring efficient, reliable and resilient power systems.

The Guest Editors would like to express their sincere appreciation to all authors for submitting high-quality contributions and to the reviewers for their careful evaluation and helpful insights. The ten papers collected in this Special Section provide a diverse and technically rich overview of current developments in renewable energy conversion, intelligent control, hybrid system optimisation, converter modelling and PQ enhancement.

The Guest Editors would also like to express their gratitude to the Editor-in-Chief of *PEAD* and the journal's editorial administration for their kind invitation and for their continuous support throughout the preparation of this Special Section. Their professional guidance and commitment were essential to ensuring the successful completion of this work.

As *Power Electronics and Drives* continues to grow as a promising platform for disseminating cutting-edge research, we warmly encourage both the authors of this Special Section and the broader research community to contribute to the newly established permanent section on 'Renewable Energy Systems and Smart Grid Technologies' We believe that sustained scholarly engagement in this area will further advance the impact of the journal and support the global transition towards clean, efficient and intelligent energy systems.

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