frontiers | Frontiers in Energy Research

TYPE Editorial
PUBLISHED 13 August 2025
DOI 10.3389/fenrg.2025.1670031

OPEN ACCESS

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RECEIVED 21 July 2025
ACCEPTED 01 August 2025
PUBLISHED 13 August 2025

CITATION
Zhang W, Yang Y, Zhang C and Zhou D (2025) Editorial: Modeling and control of power electronics for renewables.
Front. Energy Res. 13:1670031.
doi: 10.3389/fenrg.2025.1670031

Editorial: Modeling and control of power electronics for renewables

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KEYWORDS

power electronics, modeling, grid stability, inverter control, renewable power generation

Editorial on the Research Topic
Modeling and control of power electronics for renewables

Power electronics is used in a wide range of applications, including switched-mode power supplies, motor drives, active power filters, and renewable power generation (RPG). In recent years, power electronics has experienced a rapid increase in use as the grid interface of RPG systems. However, as the penetration level of renewable energy grows significantly, increasing challenges have emerged, e.g., weak grid stability issues, high-frequency circulations, active grid support function, and arc faults. As a result, further tasks have been brought to the table to enhance the modeling and control of power electronics, and in-depth discussions on these issues are urgently required to provide technical support for the global energy transition.

The main purpose of this Special Section is then to collect the recent advances in the modeling and control of power electronics converters, as well as to provide the researchers and engineers with how to analyze and model converter behaviors in order to improve their design and operation. A series of controls specifically designed for use with power converters to address emerging challenges like the weak grid stability issues, active grid support, arc detection, etc., are selectively archived in this Special Section. In general, this Research Topic provides an overview of the state-of-the-art in modeling and controlling power electronics for renewable energy power systems.

This Research Topic is divided into four thematic areas ("optimization and control of photovoltaic (PV) systems", "technologies for enhancing grid stability", "modeling for transient characteristics and electromagnetic interference (EMI) analysis", and "cutting-edge intelligent control algorithms"), and this Special Section has collected 12 articles.

The first area focuses on optimizing and controlling photovoltaic systems. Zhang et al. presented "*A ground current suppression method for systems with a large number of photovoltaic (PV) inverters*," in which a hardware-software approach is proposed. The hardware solution diverts ground current to the DC bus via filter capacitors, while the software-based mitigation strategy (carrier phase shifting and frequency shifting) is synthesized to mutually cancel zero-sequence currents across multiple inverters. This method addresses escalating ground current issues in large-scale PV plants, and it has been experimentally validated to reduce leakage currents and stabilize grid-connected operation without the need for grid neutral-point access. Moreover, in the paper "*An operating mode control method for photovoltaic (PV) battery hybrid systems*," Zhang et al. create a generalized control architecture for PV–battery hybrid systems that improves dynamic response performance by allowing smooth switching among six grid-connected and islanding modes without requiring control loop reconfiguration. In addition, a differential power processing (DPP) architecture with unit-power balancing control is designed by Ni et al. in their paper "*Unit Power Rating Balancing for Differential Power Processing-Based Distributed Photovoltaic Systems*." By coordinating maximum power point tracking (MPPT) and unit balance point tracking (UBPT) units, they successfully reduce the maximum processing power of each power-processing unit in distributed PV systems.

The second part of this Special Section focuses on grid stability-enhancing technologies. The paper "*Megawatt-level converter grid-forming control technology by adopting MPC for medium voltage distribution network*," Liu et al. proposes an enhanced grid-forming control strategy that integrates virtual admittance with model predictive control to improve several key grid-integration performance metrics such as the power quality, fault ride-through capability, dynamic response, and transient overcurrent limitations in weak grid scenarios. The technique can support carbon reduction in DC industrial parks by demonstrating stable and efficient current restriction under different grid strengths. Moreover, in order to greatly increase the stability margin of AC/DC hybrid grids, Zhou et al. propose a multi-resource collaborative damping control strategy that combines energy storage and high voltage direct current (HVDC) into a multi-input multi-output control (MIMO) system. The proposal is presented in their paper "*Research on the multi-objective collaboration damping control strategy based on multi-resource*" (Zhou et al.). Gao et al. presented "*A Review of Dynamic Voltage Support for Power Grids with Large-Scale Penetration of Renewable Generation,*" analyzing dynamic voltage stabilization mechanisms, aggregation modeling approaches for renewable plants, and innovations in coordinated control of multi-type reactive power sources using autonomous decentralized strategies. The review highlights challenges in transient voltage stability while emphasizing converter-based reactive support capabilities and future research directions for renewable-dominated grids. Additionally, a grid-forming control is used to modify reactive-power droop coefficient, significantly raising the static voltage stability limit of renewable energy power plants Wentao et al. "*Research on static voltage stability enhancement for new energy station based on grid-forming control strategy*".

The third area focuses on modeling and analysis of transient behavior, EMI characteristics, and device reliability under extreme conditions. By creating a dynamic equivalent model of the current inner loop, the paper "*The impact of current-loop control parameters on the electromagnetic transient voltage performance of voltage-source converter*," by Ding et al. clarifies how control parameters affect transient-voltage behavior and proposes a bandwidth-optimization strategy to enhance high-frequency stability. In the paper of Liu et al. "*Time domain analysis of flyback EMI based on distributed parameters theory*," a distributed-parameter model for flyback converters is established, explaining how leakage inductance and parasitic capacitance shape the EMI spectrum and guiding EMI-suppression design for high-density power supplies. Furthermore, Wen et al., in "*Exploring the Performance of GaN Trench CAVETs from Cryogenic to Elevated Temperatures*," conduct extensive electrical characterization, demonstrating improved 2DEG mobility and reduced on-resistance at cryogenic temperatures, device survival up to 500°C, and severe degradation at 800°C, highlighting the potential of GaN CAVET for extreme-temperature power-electronics applications.

The last area focuses on cutting-edge intelligent control algorithms. Wang et al. "*Load frequency optimal control of the hydropower-photovoltaic hybrid microgrid system based on the off-policy integral reinforcement learning algorithm*," apply off-policy integral reinforcement learning to water-solar complementary microgrid frequency control, overcoming the "curse of dimensionality" in traditional dynamic programming and enabling disturbance-adaptive regulation. Fen et al. "*A Coordinated Power Quality Improvement Control Strategy for AC/DC Hybrid Distribution Networks based on Three-Phase Four-Leg Flexible Interconnection Converter*," propose a coordinated control strategy for a three-phase four-leg flexible interconnection converter that achieves full compensation of AC three-phase imbalance while also mitigating DC double-frequency ripples.

Oriented for addressing the emerging issues of RPG systems, i.e., from suppressing ground currents and managing grid-forming converter dynamics to analyzing high-frequency EMI, improving multi-resource damping, and ensuring static voltage stability, the contributions in this Research Topic present cutting-edge control, modeling, and optimization strategies. It is shown how advanced predictive, data-driven, and reinforcement-learning methods, combined with innovative hybrid converter designs, can improve PV-battery performance, coordinate AC/DC power quality, and streamline differential power processing. These works, which combine hardware-software co-design with flexible architectures, provide practical solutions for increasing efficiency, reliability, and stability across a variety of grid scenarios, and highlight the critical role of sophisticated power electronics control in advancing sustainable energy systems.

Author contributions

WZ: Writing – original draft, Writing – review and editing. YY: Writing – original draft, Writing – review and editing. CZ: Writing – original draft, Writing – review and editing. DZ: Writing – original draft, Writing – review and editing.

Funding

The author(s) declare that no financial support was received for the research and/or publication of this article.

Conflict of interest

Author WZ was employed by Ginlong Technologies Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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