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Editorial

Special Issue "Applications of Advanced Control and Optimization Paradigms in Renewable Energy Systems"

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The increasing environmental damage caused by adversarial factors, a growing need for energy, the continued reliance on fossil fuels, which comes with rising costs, and the global push for net-zero emissions targets have drawn significant focus on the global promotion of renewable energy sources [1]. The potential of renewable energy to transform our energy landscape is immense, but it is essential to recognize that it comes with its own set of intricate challenges. The variable, uncontrollable, and often unpredictable nature of renewable energy generation can create concerns regarding power quality, grid stability, and consistency in power supply. Yet, within these challenges lies an opportunity. Control and optimization approaches have emerged as powerful tools to address and overcome these complexities, and in doing so, they can elevate the performance of renewable energy systems. It is crucial to delve into the intricacies of these methods and their pivotal role in realizing the full potential of renewable energy. Control methods such as fuzzy logic, artificial intelligence, sliding-mode control, adaptive and predictive control, and data-driven control have proven to be indispensable in managing power generation [2]. These methods offer precision and adaptability, essential for handling the dynamic nature of renewable energy sources.

Furthermore, optimization methods play a vital role in fine-tuning renewable energy systems. Techniques like swarm optimization, genetic algorithms, Newton–Raphson, simulated annealing, linear programming, and hybrid optimization methods contribute to optimizing resource allocation, enhancing energy conversion efficiency, and facilitating the integration of renewable sources into the existing power infrastructure. As a collective effort, these strategies and methods aim to unlock the true potential of renewable energy sources, advancing the global mission toward sustainability and zero emissions. It's also worth noting that the relevance of this topic extends to various applications within renewable energy systems. From grid-tied solar and wind farms to off-grid microgrids and energy storage systems, the use of these control and optimization methods spans across the entire renewable energy spectrum. They not only enhance the efficiency and reliability of power generation but also support the integration of renewable energy into the broader energy infrastructure, ensuring a seamless transition toward a more sustainable and environmentally friendly future. The application topics in this domain are vast and ever-expanding, encompassing not only advanced control and optimization methods but also system-level solutions, demand-side management, and grid integration strategies. This Special Issue aims to be a conduit for the exchange of state-of-the-art research, fostering collaboration, and encouraging new ideas and approaches in the field of renewable energy systems. By exploring these control and optimization paradigms and their diverse applications, we take a significant step forward in the pursuit of a sustainable and environmentally conscious future.

The material of this special issue is organized into the following nine articles. All the articles have been included in this special issue after a rigorous review process. The topics in this issue are arranged in a sequence, starting with a focus on system design and optimization before moving into predictive modeling and advanced control systems, and finally, addressing broader energy supply and commercialization aspects. The expansion of horizons in power control, design, and optimization was fostered by the positive response from researchers worldwide, bolstered by the significant quantity and outstanding quality of articles featured in this Special Issue. Malozyomov et al. [3] explored the efficient design of a power system for a Siberian weather station. It begins with detailed data on insolation and focuses on renewable energy sources. The study considers climatic conditions and system components and conducts simulations to find optimal configurations at varying diesel prices. A technical and economic analysis results in a more than 60% cost reduction and a 5.5-year payback period. This research emphasizes resource-efficient design and renewable energy utilization for improving power system reliability, crucial for northern weather stations. Following this, Paaren et al. [4] address the optimization of conductive fins to reduce temperature gradients in UO_2 fuel, emphasizing the importance of thermal management in nuclear power systems. This research is particularly relevant in the context of developing low-enriched uranium fuels, where the goal is to maintain power output while lowering fuel temperature and radial temperature gradients. To achieve this objective, the study involves the modeling of a novel design that incorporates conductive fins with varying thermal conductivities and geometries within the fuel matrix. Significantly, these conductive inserts are restricted to occupy no more than 6% of the original fuel volume, in contrast to other designs that displace 10% of the fuel volume. A parametric study was conducted, consisting of 2.56 million BISON simulations, which explored different fin characteristics (such as fin thermal conductivity, number, and geometry) to identify the optimal geometric configuration while keeping the desired fuel volume displacement in mind. The study shows that the thickness and length of fins significantly influence fuel temperature and gradients more than the number and thermal conductivity of the fins. This research led to an optimized design that minimizes peak fuel temperature, reduced temperature gradients, and achieved maximum temperature reduction while displacing minimal original fuel volume. These simulations are part of an ongoing project and will be compared with irradiation experiments at the Idaho National Laboratory's Advanced Test Reactor. Pinello et al. [5] designed a framework for structurally optimizing secondary mirrors in Concentrated Solar Power (CSP) plants, including both the mirror and its mounting brackets. The framework utilizes Python code to adjust the structural model created in Abaqus for various configurations and perform Finite Element Method (FEM) analysis under four different loading conditions. Subsequently, the simulation outcomes are evaluated in MATLAB to ensure compliance with structural and optical efficiency constraints.

Moving on, the article delves into predictive modeling, specifically focusing on deterministic and probabilistic wind power predictions and intelligent predictions of transformer loss in distribution networks. Zhang et al. [6] introduce a novel hybrid intelligent model that incorporates isolated forest, wavelet transform, categorical boosting, and quantile regression to improve wind power forecasting. The Isolated Forest method identifies anomalies, smoothing wind power data. Wavelet Transform breaks data into high and low-frequency signals. Categorical boosting extracts meaningful features, and Quantile Regression assesses uncertainty levels. Tested with real data from China, it outperforms standard methods in deterministic and probabilistic predictions. The hybrid model is a promising solution for wind power forecasting in power systems. The topics then transition to advanced energy management and control systems, exploring the integration of Internet of Things (IoT) and cloud computing for efficient demand-side management in smart grids, hybridization of Particle Swarm Optimization (PSO) for protective relays, and deep transfer learning for wind turbine fault diagnosis. Dai et al. [7] introduced an intelligent model for predicting transformer losses, aiming to address the issue of low accuracy in calculating transformer losses under three-phase unbalanced loads. They optimized the prediction model, resulting in a highly accurate transformer loss prediction model. When compared to other models like the BP network, GA-BP network, PSO-BP network, and SSA-BP network, the PCA-SSA-BP network-based model was validated as accurate using real data. Notably, it improved prediction accuracy by up to 1.12%, demonstrating its effectiveness and feasibility in predicting transformer losses under unbalanced loads.

The topics then transition to advanced energy management and control systems, exploring the integration of IoT and cloud computing for efficient demand-side management in smart grids, hybridization of PSO for protective relays, deep transfer learning for wind turbine fault diagnosis, and an experimental study of inverter control for reactive power compensation in grid-connected solar Photovoltaic (PV) systems. Saleem et al. [8] emphasize the integration of cloud computing and IoT into Demand-Side Management (DSM) for Smart Grids, enabling an efficient Smart Energy Management System (SEMS). This SEMS collects real-time data from IoT devices to optimize energy consumption in buildings, focusing on AC units. It provides real-time monitoring, load control, and energy savings (15% to 49%), offering applicability in various sectors and promoting sustainability. However, challenges like standardizing protocols and handling big data remain. Despite these, the research showcases SEMS's effectiveness and potential for wider adoption in DSM for Smart Grids, contributing to advancements in smart energy management and sustainability. Wang et al. [9] introduced metaheuristic algorithms, including PSO and a hybrid PSO with Simulated Annealing (SA) for global solutions. The problem, called DOPR, was formulated as a mixed-integer non-linear programming problem. PSO and HPSO algorithms were used to address DOPR in various test systems. Their HPSO algorithm was tested in IEEE single-line power distribution systems and proved superior to existing methods such as GA, SM, WOA, HWOA, TLBO, CGA, FA, MEFO, MILP, BBO-LP, and HGA-LP. The study demonstrated the effectiveness of their technique across three benchmark IEEE case studies (four-bus, six-bus, and eight-bus systems) compared to other state-of-the-art methods. Flota-Bañuelos et al. [10] introduced a control system, consisting of a Sliding Mode Control (SMC) and a Proportional-Integral (PI) voltage control loop, to ensure a disturbance-free energy injection from a photovoltaic (PV) system into the grid. This control system enables the PV inverter to enhance the power factor required by the connected loads, reducing the reactive current demand. It operates continuously, even during power generation gaps caused by shadows, clouds, or rain. The results confirm that the SMC control technique effectively improves the power factor and reduces the Total Harmonic Distortion (THD) of the grid current injected by the PV system.

Finally, this Special Issue focuses on a broader energy supply and commercialization, discussing the commercialization of smart rural energy in times of supply chain disruptions. Min et al. [11] offered user-friendly tools and metrics for boosting the commercial potential of Sustainable and Renewable Energy (SRE). These metrics, based on the Balanced Scorecard, provide valuable insights from various angles, aiding non-technical planners in making informed decisions. The study also pioneers supply chain maps to identify vulnerabilities and offers strategic action plans from diverse stakeholder perspectives, reflecting their varying viewpoints and interests.

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