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Editorial

Recent Advances toward Carbon-Neutral Power System

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The pursuit of a carbon-neutral society has emerged as a global imperative in the face of escalating environmental challenges. The integration of renewable energy sources (RESs) and advanced storage systems into existing power grids has become a pivotal approach to achieving this ambitious goal. Renewable energy sources, such as solar, wind, and hydroelectric energy, present an unprecedented opportunity to decarbonize the power sector and mitigate the adverse effects of climate change. However, the variable and uncertain nature of most RESs complicates the operation of power systems, and thus innovative and transformative solutions are needed.

Power systems are traditionally engineered to accommodate for fluctuations in demand, but the introduction of several RESs has disrupted this equilibrium. This calls for the development of smart grids, as well as intelligent and digitized power systems capable of optimally distributing electricity among prosumers—consumers who can also produce energy. These future smart grids must have the key characteristics of security, reliability, resilience, cost-efficiency, and market-based structures, while concurrently facilitating the seamless integration between diverse energy sectors within a unified market framework. Furthermore, the active involvement of customers as central actors is essential for fostering sustainable and inclusive energy practices.

The challenges in transitioning to carbon-neutral, net-zero, power systems are multi-faceted, requiring comprehensive research and innovation. In this Special Issue, we present a collection of five comprehensive papers that shed light on some of the crucial aspects driving the development of these power systems. These papers encompass a diverse range of topics and methodologies, and each contributes unique insights to the complex puzzle of a carbon-neutral future. In the following, brief descriptions of the accepted articles are presented.

The first paper [1] presents a model to assess the reliability of a renewable electricity generation system with battery energy storage, using hourly wind speed and solar irradiance data. This case study examines the UK's electricity system, considering various generation combinations and storage capacities. The results demonstrate that optimizing the ratio of onshore wind, offshore wind, and solar PV increases a system's ability to meet demand profiles, while including Li-ion battery storage reduces overall generation needs and system costs. The study also reveals that high-solar systems use shorter-duration storage, but the most reliable systems have storage durations exceeding 20 h. These findings provide insights for designing a low-carbon electricity system and emphasize the importance of hourly simulations in system planning.

The feasibility of repowering a hybrid renewable system in the Galapagos Islands, with the aim of reducing diesel generator penetration and enhancing renewable energy utilization, is explored in [2]. This study, which uses a techno-economic analysis, indicates that increasing the capacity of current wind and photovoltaic systems can reduce annual energy costs by 10–20%. These repowering efforts can also lead to a significant reduction in CO_2 emissions, up to approximately 40%, due to decreased diesel generator usage. To achieve a 100% renewable system, in addition to a higher wind and photovoltaic capacity, a considerable energy storage capacity is required to handle the randomness of

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renewable sources. Therefore, a 100% renewable system in the Galapagos Islands would be very expensive. Consequently, an optimum solution might involve maintaining a certain capacity of diesel generators to provide a rolling reserve and minimize electricity surplus.

The integration of electric vehicles (EVs) in grid management to support green energy usage and enhance power management is investigated in [3]. The study explores the use of EVs as a storage system, allowing them to store excess solar energy for later use. The bi-directional off-board charger enables the grid to charge the EVs (G2V) and the EVs to send power back to the grid (V2G). This paper demonstrates the feasibility of the simultaneous charging and discharging of EVs, showcasing the grid's ability to compensate for surplus demand. Overall, integrating EVs in power management proves to be a promising solution for enhancing green power generation, promoting green transport, and reducing grid pressure due to increasing demand. Future research could address reactive power injection, load imbalance, and branch resistances in power management.

In [4], the authors focused on accurately estimating the energy consumption of EVs in different driving cycles. They highlight intrinsic characteristics in a theoretical study via a mathematical model using the forward method. The forward method, compared to the backward method, employs a driver model with various controllers, such as PID and LQR. The results show that the forward method can estimate energy consumption and losses in EV components. Future research may include developing computational models based on artificial neural networks to determine relationships between factors affecting EV energy consumption, as well as predicting driving behavior based on GPS data.

A comprehensive literature review on voltage stability analyses of renewable-dominated power systems, which involve a significant amount of inverter-based distributed generation is carried out in [5]. Various analytical methods and voltage stability indices (VSIs) are discussed, highlighting their advantages, limitations, and applicability to different microgrid configurations and distributed generators. The review emphasizes that static voltage stability analysis is crucial for accurately quantifying the voltage stability of the system and optimizing its stability. This paper suggests future research directions, including the development of dynamic voltage stability analysis methods, online real-time techniques for assessing system voltage, and strategies for coping with increasing asynchronous generation from renewable energy sources to ensure stable and efficient power systems.

The papers presented in this Special Issue collectively emphasize the pressing need for cutting-edge research in power system assessment, modelling, market design, and digitalization to facilitate a successful transition toward carbon-neutral power systems. It is our hope that these papers will inspire further exploration, collaboration, and innovation in shaping a sustainable and resilient future for generations to come.

Together, we embark on a journey to utilize recent advances in technology, policy, and knowledge to pave the way for a cleaner, greener, and more sustainable carbon-neutral power system. The path ahead may be challenging, but with determination and collective efforts, we can achieve a harmonious balance between energy security, environmental stewardship, and human prosperity.

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