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Editorial

Advances in Offshore Wind

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1. Introduction

Wind energy has emerged as one of the most effective solutions to address global energy crises and environmental degradation, owing to its clean and abundant resources [1]. In recent years, onshore wind power has experienced rapid growth and has been widely adopted in many countries, offering advantages such as easy installation and maintenance. However, onshore wind power requires large land areas and can result in significant noise pollution. On the other hand, offshore wind power provides benefits such as higher wind speeds, conservation of land resources, and the absence of noise pollution [2,3]. Consequently, offshore wind power has gained significant attention as a promising direction for development and has made substantial progress in recent years [4].

According to the "Global Wind Report 2022" published by the Global Wind Energy Council, data reveals that the global installed wind capacity reached 93.6 GW in 2021, representing only a 1.8% decrease from the 2020 record. The total installed capacity reached 837 GW, reflecting a 12.4% increase from 2020. Offshore wind power contributed 21.1 GW to the total, triple the amount in 2020, and set a new record with a cumulative installed capacity of 57.2 GW. Notably, China has played a significant role in offshore wind power generation, maintaining its position as the leader in offshore wind power installations for the fourth consecutive year. China achieved an annual installed capacity of nearly 17 GW and a cumulative installed capacity of 27.7 GW, which is comparable to Europe's development level over the past 30 years [5]. However, the high cost of offshore wind power remains a barrier to further development.

To address the cost challenges associated with offshore wind power, countries worldwide are striving to achieve cost parity in offshore wind development [6]. In March 2022, China launched its first cost-competitive offshore wind power project, marking the official entry of offshore wind power into a cost-competitive era and intensifying the demand for cost reduction and efficiency improvement [7]. Nonetheless, offshore wind power encounters various challenges. Compared to onshore wind power, offshore wind power entails higher construction and maintenance costs and involves greater technical complexities [8,9]. The harsh marine environment imposes greater demands on wind turbine design and operation [10–12]. Furthermore, the construction and operation of offshore wind farms require addressing intricate engineering and logistical challenges, including the installation, maintenance, and repair of offshore equipment, as well as the transmission of offshore wind power to the onshore grid [13–18]. These aspects pose technological and economic considerations.

This Special Issue aims to promote research and development in offshore wind power, encompassing a diverse range of studies comprising nine articles. These articles present research findings on offshore wind power technology, environmental impacts, economic feasibility, and other relevant aspects. Engaging with these articles will contribute to a

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deeper understanding of the current status, challenges, and potential of offshore wind power. Hence, we encourage readers to actively explore these articles to expand their knowledge in the field of offshore wind power.

2. An Overview of Published Articles

Zhenju Chuang's article (contribution 1) focuses on studying the impact of blade icing on the output power of a 15 MW wind turbine provided by NREL (American Renewable Energy Laboratory). The article proposes a multi-program coupled analysis method called CFD-WTIC-ILM (CFD: Computational Fluid Dynamics; WTIC: Wind Turbine Integrated Calculation; ILM: Ice Loss Method) to analyze the entire wind turbine. The icing of the wind turbine blades is simulated using Fensap-ice, and the icing results are then input into WTIC for integrated calculation and analysis. The WTIC calculation results are used to simulate SCADA (Supervisory Control and Data Acquisition) data, which are further input into ILM to calculate the power loss. The article comprehensively analyzes the influence of icing on the output power. The calculation results demonstrate that ice primarily accumulates on the windward side of the blade. Icing significantly affects the aerodynamic characteristics of the airfoil, leading to a considerable decrease in the power curve. The rated wind speed is pushed from 10.59 m/s to 13 m/s. The power loss of the wind turbine in the wind speed optimization stage reaches as high as 37.48%, and the annual power loss rate caused by icing can reach at least 22%.

Dongran Song's article (contribution 2) proposes a hybrid optimization method to optimize the topological structure of an offshore wind farm power collection system. The article focuses on designing the cable connection, cable selection, and substation location for optimal performance. The optimization model integrates cable investment, energy loss, and line construction. The Prim algorithm is used to initialize the population, and a novel hybrid optimization method called PSAO (Particle Swarm and Aquila Optimization) is introduced for topological structure optimization. The PSAO algorithm combines the strengths of particle swarm optimization (PSO) and aquila optimization (AO) algorithms to enhance the searching capability. The proposed PSAO method is validated with a real case, and the results demonstrate that it outperforms the GA, AO, and PSO algorithms, reducing the total cost by 4.8%, 3.3%, and 2.6%, respectively, while achieving better optimization efficiency.

The third article, by Hanwei Teng et al. (contribution 3), examines the current state of carbon fiber composites for wind turbine blades and the geographical distribution characteristics of wind resources in China. The article compares the economic revenues from increasing the length of wind turbine blades in four typical wind farms, including offshore wind farms. A mathematical model is used to evaluate the energy efficiency of carbon fiber composites in large wind turbine blades, considering cost, embedded energy, and carbon footprint. The article also analyzes the current supply–demand relationship for the industrial structure of carbon fiber in China, examines manufacturing technologies for carbon fiber composite wind turbine blades, and proposes corresponding countermeasures. It further explains the incentive policy for applying carbon fiber composites to wind turbine blades and explores the development prospects. The article provides a comprehensive analysis and evaluation of the economics and energy efficiency of using carbon fiber composite materials in large wind turbine blades, offering valuable insights for China's wind turbine blade industry.

The fourth article, by Sen Gong et al. (contribution 4), focuses on comparing the output power and wake velocity of small multi-rotor wind turbines with single-rotor wind turbines operating in the same swept area but at different blade tip distances. The study utilizes wind tunnel tests to examine single-rotor wind turbines with diameters of 0.4 m and 0.34 m, corresponding to triple-rotor and double-rotor wind turbines with a single rotor diameter of 0.24 m, respectively. The experimental results indicate that, without rotation speed control, the triple-rotor wind turbine generates more power than the single-rotor wind turbine with an equivalent swept area. The output power initially increases and then decreases as the distance between each rotor increases, reaching a maximum increase of 8.4% at the 0.4 D blade tip distance. Regarding wake measurement, triple-rotor wind turbines experience smaller wake losses and faster recovery rates compared to single-rotor wind turbines. The wake merging and fusion occur earlier, and the recovery rate is faster with smaller blade tip distances. These findings provide valuable guidance for the design of small multi-rotor wind turbines.

The article by Shigang Qin et al. (contribution 5) proposes a normal distribution modeling method based on relative volatility to extract wind-speed variation patterns from onsite SCADA (Supervisory Control and Data Acquisition) data. The study analyzes the correlation between wind-speed relative volatility and power relative volatility and establishes a wind-power volatility-curve model to evaluate wind turbine efficiency. The article defines relative volatility and probability vectors, designs a probability vector volatility-assessment function, and calculates the volatility-assessment index of the probability vector. The relative volatility and probability vectors of wind speed are modeled, and statistical analysis is conducted on characteristic parameters such as mean, standard deviation, and confidence interval of wind-speed relative volatility. The article also examines the correlation between wind-speed relative volatility, power relative volatility, and wind turbine characteristics. The conclusions provide a method reference for data processing, parameter variation patterns, and interrelationships of wind farm SCADA data, and evaluate power generation efficiency.

The sixth article is from Tengyuan Wang et al. (contribution 6). It investigates the wake characteristics of a yawed wind turbine using the actuator line method combined with URANS (unsteady Reynolds-averaged Navier–Stokes equations). Yawed wind turbines exhibit two main characteristics: deflection and deformation. As the yaw angle increases, the turbine wake shows increased deflection. The results indicate that the deflection varies at different heights, with the largest deflection occurring around the hub height and the smallest at the top and bottom of the yawed turbine's wake. The article visually demonstrates this through the evolution of a kidney-shaped velocity distribution in the vertical cross-section. Two-dimensional and three-dimensional presentations of velocity deficit distributions are provided, and the formation of an irregular kidney-shaped distribution is discussed, resulting from momentum exchange caused by the counter-rotating vortex pair. The study reveals that the counter-rotating vortex pair comprises the streamwise vortex flux brought by the tip vortex. Furthermore, when the wind turbine rotates clockwise and yaws clockwise, the negative vorticity of the counter-rotating vortex first appears in the upper left position.

In the seventh article, Bin Wang et al. (contribution 7) employ a two-way fluid–structure coupling method to investigate the NREL 5 MW wind turbine. The study considers blade coupling deformation and examines the distribution of equivalent stress and strain in blades with different internal structures under various operating conditions. The results indicate that the maximum equivalent stress and strain distribution in the beam-structured wind turbine blade occur near the leading edge. For the shell-structured wind turbine blade, the maximum equivalent stress and strain distribution is near the leading edge of the blade root, and although there is a noticeable dangerous area, it is smaller compared to the beam-type wind turbine. The coupled deformation of the wind turbine model with a shell-structured blade with a web is significantly reduced, and the equivalent stress and strain distribution of the skin are similar to that of the shell structure, but with significantly smaller numerical values and a smaller area of maximum equivalent stress distribution. The comparison among the three types of blades suggests that the shell structure blade with a web is the most favorable option.

The research conducted by Joo-Shin Park and Myung-Su Yi (contribution 8) focuses on investigating and analyzing cases of punch-through accidents. A WTIV (Wind Turbine Installation Vessel) model with six legs is employed to numerically examine the variation in maximum vertical reaction force when punch-through occurs in each leg. The findings reveal that the maximum vertical reaction force occurs in leg number three when a punch-through happens in leg number five and when the maximum stress exceeds the allowable criteria in both the hull and legs. Proper structural reinforcement, such as increasing the thickness and adjusting the high-yield stress, is required. The key results of this investigation can be utilized to determine the fundamental specifications of wind turbine installation vessels, and the distribution pattern of the reaction force can serve as fundamental data for the design of legs and hull structures.

Mohan Kumar Gajendran's work (contribution 9) introduces a machine learning-based symbolic regression approach to elucidate wake dynamics. The study utilizes WindSE's actuator line method (ALM) and Large Eddy Simulation (LES) to model an NREL 5-MW wind turbine under yaw conditions ranging from no yaw to 40 degrees. By leveraging a hold-out validation strategy, the model achieves robust hyper-parameter optimization, resulting in high predictive accuracy. The model demonstrates remarkable precision in predicting wake deflection and velocity deficit at both the wake center and hub height. However, there is a slight deviation observed at low downstream distances, which is of lesser importance in the context of large wind farm design. Nevertheless, the approach presented in this study paves the way for advancements in academic research and practical applications within the wind energy sector. It provides an accurate and computationally efficient tool for wind farm optimization. This study establishes a new standard in the field by addressing a significant gap in the literature, specifically the application of machine learning-based wake models for wind turbine yaw wake prediction. The findings contribute to the advancement of knowledge and have implications for enhancing the efficiency and performance of wind turbines in practical settings.

3. Conclusions

This compilation of articles provides a comprehensive overview of wind turbine research, covering a wide range of topics and emphasizing the diversity within the field. The articles delve into different aspects, including turbine blades, turbine structures, wind speed distribution, wake effects, and wind farm collection systems.

In terms of subject, research on turbine blades continues to make its mark in this Special Issue, with four articles focusing on this direction. Two of these articles concentrate on the materials and stability issues of the blades, summarizing the application of carbon fiber composites in wind turbine blades and analyzing the stability of blades in different structural models. In addition, numerous researchers have also focused on studying the lifespan of and damage to wind turbine blades [19]. The other two articles focus on the influence of blade parameters or operating conditions on the output power of wind turbines. Furthermore, in these two articles, the concept of aerodynamic characteristics of wind turbines is emphasized, which is of great importance for the design, optimization, and operation of wind turbines and has drawn extensive attention from numerous researchers [20–22].

In addition, research on the wind turbine wake effect under yawed conditions also plays an important role in this Special Issue. Among them, two articles focus on this field, but with different specific directions. One article delves into the wake characteristics of yawed wind turbines, utilizing the actuator line method that was also reflected in the research by Wang, T. et al. [23]. Another article focuses on the prediction methods of yawed wind turbine wakes, filling a significant gap in the literature regarding the application of machine learning-based wake models for predicting yawed wakes in wind turbines.

Additionally, three articles cover various areas of wind turbine research. One article investigates the structural strength of offshore wind turbine installation vessels under single-leg penetration, which differs from previous studies focusing on the bending strain direction at the base of offshore wind turbine towers [24]. This study fills a research gap in the structural aspects of offshore wind turbine systems. The other two articles examine wind speed distribution and its impact on output power, as well as the topology optimization of offshore wind farm collection systems. Research in these two directions has been gradually increasing in recent years [25–30].

The diversity of topics covered in these nine articles showcases the breadth of wind turbine research. From the current focus on blade and yaw research to the exploration of offshore wind turbine structures, this Special Issue highlights the relevance and importance of wind turbine research. It serves as an inspiration for readers to delve more comprehensively into the field of wind turbine research.

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

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