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Editorial

Optimization and Control of New Power Systems under the Dual Carbon Goals: Key Issues, Advanced Techniques, and Perspectives

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Production and consumption as a result of human demand for energy are increasing with each passing day as populations grow [1]. Nevertheless, the unsustainable use of natural resources, such as the immense consumption of traditional fossil fuel energy, will not only cause a crisis in their reserves but also lead to environmental pollution, climate change, and other problems [2,3].

In light of these issues, countries and governments around the world have committed themselves to fundamentally transforming the global energy structure, and they have released a series of relevant policies and guiding ideas in response. For instance, in the Sustainable Development Goals Report 2020, the United Nations recognized "Taking urban action to combat climate change and its impacts" as a crucial element among the 17 Sustainable Development Goals. This recommendation guides governments and enterprises in reducing greenhouse gas emissions, thus accelerating progress toward the Paris Agreement's ultimate goal of limiting global temperature rise to within 1.5 °C [4]. In addition, in September 2020, China proposed to achieve the dual carbon goals of reaching its "carbon peak" by 2030 and achieving "carbon neutrality" by 2060 [5]. However, Shi C F et al. [6] employed an interdisciplinary approach based on economics and artificial intelligence to analyze and predict China's carbon peak process and although the results suggest that China stands a good chance of reaching this carbon peak by 2030, the results state that achieving carbon neutrality by 2060 seems to be unlikely at present. Meanwhile, the aforementioned study further notes that only by utilizing technological means can carbon emissions be effectively suppressed, while the formulation of China's carbon emission reduction policy should be oriented to adjusting the country's industrial and energy structure.

To comply with the development trend of clean and low-carbon energy patterns driven by the dual carbon goals, numerous in-depth studies and analyses have been conducted by relevant academics on the corresponding implementation paths in various fields such as building [7,8], transportation [9,10], and electricity [11,12]. Among them, electricity has transformed from secondary energy to basic energy in other industries [13]. In January 2023, the National Energy Administration of China released the "Blue Book for the Development of New Power Systems (Draft for Soliciting Opinions)", which elaborates on the connotations, characteristics, development path, overall architecture, and key tasks of the new power system [14,15]. In general, the new power system is the inevitable product for building a low-carbon, safe, and efficient energy system based on renewable energy and supplemented by fossil energy, and it is also essential for achieving carbon neutrality.

The development process of the power system can be divided into three stages: a traditional power system dominated by coal power, a power system characterized by a high proportion of new energy and a high proportion of power electronics, as well as a new power system dominated by new energy [16]. Although the proportion of new energy (e.g., wind power, solar power generation, hydropower, etc.) in the power structure of the system constantly increases, their inherent characteristics such as their intermittency, randomness, and volatility seriously threaten the power system's safety and stability. Therefore, to meet the basic premise of safety and efficiency in the new power system, in addition to using energy storage technology to suppress the supply–demand gap in the system, coal-fired power is still an important guarantee for supporting the safe and stable operation of the system [17]. Specifically, in 2010, thermal power accounted for 73% of China's power structure, while wind and hydropower accounted for 25%. In 2021, thermal power accounted for 53% of China's power structure, while solar power, wind power, and hydropower accounted for 44% [15]. Moreover, using meteorological information to predict the output of new energy systems can also lessen uncertainty for various new energy sources and improve unified management capabilities for them [18,19].

In practice, during the development of the power system, key elements (for example, the source, grid, load, storage, etc.) and the system architecture will undergo incremental changes, ranging from simple to complex changes, and the complexity of the grid form and the diversity of operation modes make its intrinsic stability mechanism and dynamic characteristics more and more complicated. Consequently, the new power system will not only need to face the stability problems (for example, voltage stability, power angle stability, frequency stability, etc.) of the traditional power system (both the operation mode and the power tide are relatively fixed) but it will also suffer from new stability problems (e.g., broadband oscillation) [13] under the superposition of multiple factors, which requires the establishment of a perfect risk assessment and control mechanism. Meanwhile, in the face of the new power system, the traditional relay protection technology utilizing electrical principles evidently cannot meet the requirements; thus, a more refined and intelligent digital relay protection system can be introduced. However, the latter may be subject to cyber-attacks. Moreover, as new energy sources, distributed power sources, new types of energy storage, and electric vehicles are connected to the grid, the traditional planning and dispatching mechanism will no longer be suitable for realizing the demand for multi-directional interaction in a diversified power market environment, which requires interaction and management of various energy sources, changing the traditional energy production and distribution model and strengthening cooperation and coordination among all parties. Accordingly, it is extremely critical to optimize and control the highly integrated new power system using advanced technologies, i.e., converter control strategy design, planning, and dispatching, power and load forecasting, etc., to achieve safe and efficient system operation.

A suitable model for a new energy system can be used to predict and analyze the system's operational state, as well as to optimize and control it. Guo Z M et al. [20] proposed a parameter extraction technique based on a metaheuristic algorithm (i.e., the artificial rabbits optimization algorithm) for the double diode model of photovoltaic cells and the electrochemical model of solid oxide fuel cells to establish an accurate model of photovoltaic cells and fuel cells, and the established model can highly simulate the static output characteristics of the above hybrid power generation system under various operating scenarios. To address the problem that the traditional equivalent model of PV plants cannot reflect the discrepancy of fault currents of different PV power units, Liu S M et al. [21] used the activation state of the current limiter of PV inverters to quantify the fault current contribution of different PV units and classified the PV units accordingly. This has important practical significance for the design and optimization of relay protection for large-scale low-inertia photovoltaic power plants. Additionally, the new energy access power system and outgoing consumption are supported by a high-voltage DC (HVDC) transmission system, and it is important to identify and diagnose faults and to provide technical guidance for rapid disposal after faults, thus guaranteeing the stability of the power grid [22]. Knowledge Graph, which integrates the advantages of artificial intelligence technology and traditional databases, can integrate the fragmented knowledge in the transmission field and can comprehensively and methodically display the intricate relationships between the information of each fault element, thus providing technical support for rapid diagnosis and online warning of transmission line faults. Wu J Y et al. [23] conducted a comprehensive review of fault types, fault effects, and fault diagnosis on HVDC transmission systems and constructed a fault diagnosis framework for high-voltage DC transmission systems using Knowledge Graph and artificial intelligence techniques. Meanwhile, Li Q et al. [24] utilized a machine learning model, i.e., XGBoost, to investigate multiple fault diagnosis in HVDC transmission systems and obtained an accuracy level of more than 87 %. As mentioned above, dispatching is a key issue in the optimization and control of new power systems, ensuring that the system operates safely and efficiently. Therefore, Ni P C et al. [25] developed a wide-area distributed energy model based on digital twin technology and used a cooperative game to decide the optimal power output scheme of each new energy unit, which can satisfy the power support demand to the maximum extent.

In general, although a large number of new devices and technologies with advantages such as high intelligence and high programmability have been developed for new power systems, there are still many potential and evident challenges that need to be actively addressed. Meanwhile, higher professionalism is required by professionals to face increasingly complex grid business forms; therefore, it is necessary to continuously cultivate talents in the field of power systems. However, one can still hope that the new power system will develop towards safety, efficiency, cleanliness, low-carbon status, sustainability, digitization, and intelligence.

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