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Application of New Energy Technologies in Aero Engines and Gas Turbines

Xinxiong Lv

College of Pipeline Engineering, Xi'an Shiyou University, Xi'an, Shaanxi, 710065, China

Abstract

The intensification of global climate change and environmental pollution has made achieving carbon peaking and carbon neutrality a core strategy for global development. With the continuous advancement of new energy technologies, the utilization of clean energy sources such as wind, solar, and hydrogen has brought profound transformations to the traditional energy structure. In this context, the fields of aero engines and gas turbines are also facing both pressure and opportunities for low-carbon transition. This paper analyzes new energy power generation technologies under the "dual carbon" strategy, and, in conjunction with the working principles and development trends of aero engines and gas turbines, explores the application prospects and challenges of these technologies in the aviation and energy sectors. It further proposes a technological integration pathway for low-carbon and high-efficiency power systems. The results indicate that the integration of new energy generation technologies with aero engines and gas turbines provides a feasible technical route for advancing the green energy transition; however, numerous technical challenges remain to be addressed in practical applications.

Keywords

Dual Carbon Strategy; New Energy; Hydrogen Energy; Aero Engine; Gas Turbine.

1. Introduction

With the intensification of global climate change, the demand for sustainable development has become increasingly urgent worldwide. The proposal of carbon peaking and carbon neutrality strategies marks an accelerated transition in the global energy system [1]. In this context, the rapid development of new energy sources such as wind, solar, and hydrogen not only provides new approaches to addressing the energy crisis, but also serves as a key means of reducing carbon emissions and promoting green, low-carbon development [2]. However, despite the broad application prospects of new energy technologies in sectors such as power generation and transportation, their integrated application in high-efficiency power systems (e.g., aero engines and gas turbines) still faces numerous challenges [3]. Effectively integrating these new energy technologies with traditional energy systems has become a critical issue for achieving green and low-carbon aviation and energy systems [4].

As core equipment with high energy consumption, aero engines and gas turbines directly influence energy utilization efficiency and carbon emission levels [5]. To meet increasingly stringent emission standards and the growing market demand for high-efficiency, low-carbon power systems, traditional gas turbines and aero engines are actively exploring the application potential of new energy technologies. Based on an analysis of the current status of wind, solar, and hydrogen energy technologies, this paper investigates their integrated application in aero engines and gas turbines, and evaluates their technical feasibility and development trends.

2. Current Status and Development of New Energy Technologies

2.1. Wind Energy Technology

As a renewable energy source, wind energy has gradually become an important component of the global energy structure transition in recent years due to its abundant resources and low-carbon, environmentally friendly characteristics. The principle of wind power generation is to use wind to drive turbine blades, converting mechanical energy into electrical energy [6]. In recent years, with advances in materials science and manufacturing processes, the capacity of individual wind turbines has continuously increased, and the efficiency of wind energy conversion has steadily improved. In particular, in the field of offshore wind power, higher and more stable wind speeds result in significantly greater power generation efficiency compared to onshore wind power.

However, the intermittency and variability of wind power generation remain major technical challenges for its large-scale application. To balance grid loads and avoid power fluctuations, wind power systems typically rely on technologies such as smart grids and energy storage systems to achieve stable grid integration. Breakthroughs and improvements in these technologies will greatly promote the application of wind energy in various high-efficiency power systems.

2.2. Solar Energy Technology

Solar energy is one of the most abundant and clean energy sources on Earth. Solar power generation technologies mainly include photovoltaic (PV) power generation and solar thermal power generation. Photovoltaic systems use semiconductor materials to absorb sunlight and convert it into electricity. In recent years, continuous innovations in photovoltaic technology—especially improvements in cell efficiency and reductions in production costs—have enabled PV power generation to reach a mature stage of commercial application. In contrast, solar thermal power generation uses a heat collection system to convert solar energy into thermal energy, which then drives a heat engine to generate electricity.

Despite its significant potential in resource-rich regions, solar energy still faces challenges in efficient utilization and stable output. Photovoltaic power generation is influenced by factors such as weather, time, and geographic location, resulting in considerable fluctuations in output [7], while solar thermal power generation requires large land areas and efficient thermal storage systems, leading to relatively high costs. In the future, through improvements in cell efficiency, the development of large-scale energy storage technologies, and the construction of intelligent power grids, the technical bottlenecks of solar energy generation are expected to be overcome.

2.3. Solar Energy Technology

Hydrogen energy has been widely studied in recent years as a clean energy source, with the primary advantage that its only by-product during combustion is water, producing no harmful emissions. Hydrogen energy applications are mainly based on hydrogen fuel cells, which generate electricity through the reaction between hydrogen and oxygen. Hydrogen has significant application potential in the aviation and energy sectors [8], particularly in aero engines and gas turbines, where it can serve as an alternative fuel to substantially reduce carbon emissions and improve combustion efficiency.

At present, hydrogen storage and transportation technologies still face considerable challenges. Technologies for low-temperature liquefaction, compression, and gaseous storage are not yet fully mature, and the cost of hydrogen production remains relatively high. Nevertheless, with the gradual advancement of hydrogen production technologies, hydrogen continues to be

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widely regarded as a promising clean energy source, especially in high-energy-demand sectors such as aerospace, heavy transportation, and gas turbines.

3. Application Prospects of New Energy Technologies in Aero Engines and Gas Turbines

With the increasing global demand for low-carbon environmental protection and efficient energy utilization, the low-carbon transformation of high energy-consuming equipment such as aero engines and gas turbines has become a key research focus in the energy sector. The integrated application of new energy technologies—particularly wind, solar, and hydrogen energy—is emerging as a major development trend in aviation and energy fields [9].

Through the comprehensive application of these new energy technologies, it is possible to effectively reduce the consumption of traditional energy, improve energy utilization efficiency, and significantly decrease greenhouse gas emissions. In this process, innovation in new energy technologies involves not only the replacement of traditional fuels, but also the integration of sustainable energy solutions into existing power systems. Specifically, wind, solar, and hydrogen energy can be integrated with aero engine and gas turbine technologies in various ways, thereby promoting the development of cleaner and more efficient power systems.

3.1. Indirect Integration of Wind Energy with Aero Engines

Wind energy is currently one of the most mature renewable energy sources, primarily converting the kinetic energy of wind into electricity through wind turbines. In the context of aero engines, the direct application of wind energy is relatively limited due to its variability, intermittency, and instability, which make it difficult to provide a stable power supply. However, wind energy can indirectly reduce the reliance of aircraft on traditional fuels by supplying clean electricity to airport ground facilities, thereby lowering carbon emissions from airport operations.

With the advancement of wind power generation technologies, an increasing number of airports are utilizing wind energy to supply electricity for ground facilities. Wind turbines can provide clean power for airport terminals, lighting systems, takeoff and landing facilities, and navigation equipment. In this way, airports can reduce their dependence on fossil fuels during operation, thereby lowering overall carbon emissions. In this model, wind energy does not directly power aircraft propulsion, but instead supports the electricity demand of ground infrastructure [10]. Particularly in regions with abundant wind resources, using wind energy to support airport operations aligns with the development of green airports while achieving both cost savings and environmental benefits.

To maximize the efficient utilization of wind energy, airports should consider integrating wind energy with other renewable sources such as solar energy. Some airports have already adopted hybrid wind–solar power systems to ensure a stable electricity supply. In such systems, wind and solar energy complement each other, mitigating the intermittency of single energy sources. Wind turbines can be installed in open areas around airports, especially in locations distant from flight paths and densely populated zones. By establishing small-scale wind farms, airports can effectively harness local wind resources, reduce conventional energy consumption, and support the sustainable development of the aviation industry.

3.2. Integration of Solar Energy with Gas Turbines

TSolar energy is one of the most promising clean energy sources globally, primarily utilized through photovoltaic and solar thermal power generation. In gas turbine applications, solar energy is mainly integrated via solar thermal technologies to improve energy efficiency and reduce carbon emissions.

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Solar thermal power generation converts solar radiation into thermal energy using collectors, which is then used to drive gas turbines or steam turbines for electricity generation. The primary advantage of this approach lies in its ability to use solar energy as a supplementary heat source, thereby enhancing the overall efficiency of the power generation system. For example, solar thermal collectors can provide heat to preheaters in gas turbines, reducing fuel consumption and improving energy conversion efficiency. Especially in regions with abundant sunlight, the integration of solar energy with gas turbines can significantly reduce fossil fuel consumption and promote the adoption of clean energy in industrial power generation.

The combination of solar energy and gas turbines, particularly in hybrid energy systems, is emerging as an innovative energy solution. In such systems, solar energy and conventional gas fuels can either substitute for or complement each other in power generation. When solar energy availability is high, it can be prioritized to provide thermal energy for gas turbines, reducing natural gas consumption. Conversely, when solar resources are insufficient, gas turbines can rely on natural gas or alternative fuels to meet power demand. In the United States, the "Almara" solar–gas hybrid power generation project integrates a solar thermal system with gas turbines as its core energy supply system [11]. This project uses solar collectors to provide a stable heat source for gas turbines, significantly reducing gas consumption. Through this integrated approach, the project achieves high energy conversion efficiency while reducing dependence on fossil fuels. This flexible power generation mode ensures energy supply stability and significantly lowers greenhouse gas emissions. Particularly in high-radiation regions, the abundant solar resource provides strong potential for widespread application of this technology.

3.3. Integration of Hydrogen Energy with Gas Turbines

Hydrogen energy, as a representative clean energy source, has attracted widespread attention due to its zero carbon emissions during combustion. Its high energy density and clean characteristics make it an ideal alternative to traditional fuels, particularly in gas turbine applications, where it represents a key pathway for achieving efficient and low-carbon power generation.

However, hydrogen combustion differs from natural gas in several aspects, particularly in its higher combustion temperature and faster reaction rate. Therefore, integrating hydrogen with gas turbines requires modifications to combustion chamber design to ensure efficient combustion while preventing damage to heat-resistant materials caused by excessive temperatures. Currently, some gas turbine manufacturers are exploring hydrogen–natural gas co-firing technologies, which can reduce emissions while maintaining power generation efficiency [12]. With continued technological advancements, fully hydrogen-fueled gas turbines may emerge in the future, potentially exerting a profound impact on the traditional energy industry.

In addition to direct combustion, hydrogen fuel cell technology can also be integrated with gas turbines, where fuel cells generate electricity to drive turbine operation. This combination not only leverages the clean characteristics of hydrogen but also enhances overall system efficiency. The coordinated operation of hydrogen fuel cells and gas turbines enables more efficient energy conversion while achieving high power output under low-carbon conditions [13].

Nevertheless, challenges related to hydrogen storage, transportation, and distribution remain key bottlenecks for large-scale application. Current storage methods include high-pressure gaseous storage, cryogenic liquid storage, and metal hydride storage, all of which face issues such as high cost and technical complexity. To address these challenges, ongoing research focuses on improving hydrogen storage materials, increasing storage density, and reducing costs, as well as developing more efficient hydrogen distribution systems to expand its application across industrial and transportation sectors.

4. Future Development Trends

In the future, wind, solar, and hydrogen energy will not exist as isolated systems but will be integrated through advanced energy integration technologies to achieve synergistic optimization. For example, wind and solar energy can be combined with smart grids and energy storage technologies to maximize power generation efficiency and supply stability; hydrogen can be integrated with gas turbines and fuel cells to enhance energy conversion efficiency and environmental performance. Such integrated energy systems not only improve overall energy utilization efficiency but also reduce energy waste, enhance the stability and economic viability of renewable energy, and provide sustainable green energy for high energy-consuming equipment such as aero engines and gas turbines.

To meet the demands of hydrogen and other new energy applications, future gas turbine designs will emphasize adaptability and flexibility. Researchers will further optimize combustion chambers and turbine systems to accommodate a wider range of fuels, particularly hydrogen and other low-carbon fuels. Additionally, the incorporation of intelligent control systems will significantly improve the operational efficiency and adaptability of gas turbines.

In the aviation sector, the development of hydrogen-powered aircraft is accelerating. With advancements in fuel cell and hydrogen combustion technologies, zero-emission aircraft are expected to become feasible in the future, further promoting the sustainable development of the aviation industry. Currently, several airlines and aircraft manufacturers have initiated the development of hydrogen-powered aircraft, with plans for commercial deployment in the coming decades.

5. Conclusion

As global attention to environmental protection and energy transition continues to grow, low-carbon, high-efficiency, and sustainable energy solutions have become a major research focus across industries, particularly in aviation and energy sectors. In this context, the integrated application of renewable energy sources such as wind, solar, and hydrogen is driving transformative changes in traditional aero engine and gas turbine technologies.

This paper analyzes the current application status and development potential of wind, solar, and hydrogen energy in aero engines and gas turbines. The findings indicate that these technologies can not only significantly reduce greenhouse gas emissions but also improve energy utilization efficiency. In particular, their application in aero engines and gas turbines provides new opportunities for achieving low-carbon transition, enhancing energy efficiency, and reducing dependence on conventional fuels.

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