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Analysis of Power Generation Efficiency of Wind-Solar-Hydro Complementary Power System

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Abstract:

This article mainly explores the analysis of the power generation efficiency of the wind-solar-hydro complementary power generation system. As resources such as coal, oil, and natural gas decrease, the utilization of clean energy has become crucial. The wind-solar-hydro complementary power generation system is a power generation that combines wind power, photovoltaic power, and hydropower generation. The efficiency of this system plays a crucial role in the development of clean energy. Firstly, this article introduces the principle and composition of a wind-solar-hydro complementary power generation system. Then, it analyzes the impact of various factors in different wind-solar-hydro complementary power generation systems on power generation efficiency. Finally, this article proposes some suggestions to improve the power generation efficiency of wind-solar-hydro complementary power generation systems, making a contribution to the development of clean energy.

Keywords:

Wind-solar-hydro complementary power generation system

Power generation efficiency

Clean energy

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1. Overview

With the rapid development of the global economy and continuous population growth, the demand for energy is also increasing. However, traditional fossil fuel energy is facing growing pressure, not only because these energy sources are limited in supply but also due to the severe environmental issues associated with their use. Therefore, finding new, sustainable forms of clean energy has become a global priority. Against this backdrop, the wind-solar-hydro complementary power generation system, as a new, sustainable form of clean energy, has attracted considerable attention [1].

The wind-solar-hydro complementary power generation system combines wind, solar, and hydropower to generate electricity. By effectively utilizing the complementary nature of these different energy forms, the system can improve energy utilization efficiency and reduce energy waste. Additionally, it can significantly reduce environmental pollution and protect ecosystems. Therefore, studying the power generation efficiency

of wind-solar-hydro complementary systems holds substantial theoretical and practical significance.

This paper aims to conduct an in-depth study of the principles and structure of the wind-solar-hydro complementary system. Through analyzing the factors influencing its power generation efficiency, the paper proposes recommendations to enhance the system's efficiency. The study includes the following main areas:

(1) Principles and structure of the wind-solar-hydro complementary power generation system: This section will introduce the principles and structure of the wind-solar-hydro complementary power generation system, covering the three main components: wind power generation, solar photovoltaic generation, and hydropower generation. It will analyze the interactions among these components and their coordination within the overall system.

(2) Analysis of factors affecting power generation efficiency: This section will examine the factors that impact the power generation efficiency of wind-solar-hydro systems, such as the technologies used, meteorological conditions, and geographic location. Furthermore, it will analyze and compare the weight and influence of various factors.

(3) Recommendations for improving power generation efficiency: Based on the analysis results, this section will offer improvement measures to enhance the efficiency of the wind-solar-hydro complementary power generation system. These measures include advancing technological research, selecting appropriate sites, and optimizing equipment configuration.

2. Principles and structure of the wind-solar-hydro complementary power generation system

2.1. Principles of wind-solar-hydro complementary power generation system

The wind-solar-hydro complementary power generation system combines wind, solar, and hydro energy to generate electricity. This system leverages the complementary nature of different energy forms, enhancing energy efficiency and reducing energy waste. Specifically, the wind-solar-hydro complementary power generation system includes the following three components:

(1) Hydroelectric turbine generator: The hydroelectric turbine generator is the core of the wind-solar-hydro complementary power generation system, converting the potential energy of water into electrical energy. Based on the axis position, hydroelectric generators are categorized into vertical and horizontal types. Medium to large-sized units generally adopt a vertical layout, with the vertical hydroelectric generator further divided into suspended and umbrella types based on the bearing support method. Umbrella-type generators are further categorized into regular, half-umbrella, and full-umbrella types. Horizontal hydroelectric generators are typically used in small hydropower plants. For smaller turbines, especially impulse turbines with higher rotational speeds, horizontal-axis generators are commonly employed.

(2) Wind turbine generator: The wind turbine generator is a crucial component of the wind-solar-hydro complementary power generation system, converting wind energy into electrical energy. Currently, two types of wind turbine generators are commonly used: horizontal-axis and vertical-axis wind turbines. Broadly speaking, it is a form of engine that uses atmospheric air as the working medium for thermal conversion, driven by solar heat. The operating principle involves wind driving the rotation of blades, and a speed-increasing mechanism further elevating the rotational speed to enable electricity generation [2].

(3) Solar panels: Solar panels are an essential part of the wind-solar-hydro complementary system, converting solar radiation into electrical energy through the photovoltaic or photochemical effect, either directly or indirectly. Most solar panels are made of "silicon," and commonly used types include monocrystalline silicon, polycrystalline silicon, and thin-film solar panels [3].

2.2. Advantages and challenges of wind-solar-hydro complementary power generation system

The wind-solar-hydro complementary power generation system offers several advantages:

(1) Abundant resources: Wind, solar, and hydro energies are renewable and widely distributed, making them less restricted by factors such as location or climate.

(2) Environmentally friendly and energy-saving: Compared to traditional fossil fuels, the wind-solar-hydro complementary power generation system produces minimal carbon dioxide and other pollutants, effectively reducing environmental impact.

(3) High efficiency: The system can optimize the combination of different energy forms to improve energy utilization and reduce waste.

However, the wind-solar-hydro complementary power generation system also faces several challenges:

(1) High cost: The construction and operation costs of the wind-solar-hydro complementary system are high, requiring substantial investment and technical support.

(2) Low stability: Due to the fluctuations in wind and solar energy, the system's stability is relatively low, necessitating measures to ensure stable operation.

(3) Technical complexity: Building the wind-solar-hydro complementary system requires expertise in multiple fields, including mechanical, electronic, and materials engineering, making the technology demanding.

3. Analysis of the impact of different factors on the power generation efficiency of the wind-solar-hydro complementary power generation system

Power generation efficiency is a key indicator for evaluating the performance of a power generation system. For the wind-solar-hydro complementary power generation system, its efficiency is influenced by multiple factors, including meteorological conditions, technological level, and site location. This section analyzes the impact of these factors on the system's power generation efficiency.

3.1. Impact of meteorological conditions

Meteorological conditions are critical for both wind and solar photovoltaic power generation. In terms of wind power generation, wind speed is a primary determinant of wind power output, and variations in weather conditions significantly impact wind energy output. For solar photovoltaic power generation, factors such as weather, season, and geographic location affect solar radiation levels. Therefore, it is essential to select locations that match local meteorological conditions for optimal performance.

3.2. Impact of technological level

The level of technology is a crucial factor directly impacting the efficiency of the wind-solar-hydro complementary power generation system. Currently, the system uses advanced technologies, such as optimized wind turbine blade designs, efficient inverters, advanced wind rotor blade design, and optimized solar panel design, which effectively enhance the system's overall power generation efficiency.

3.3. Impact of site location

Choosing the right location is another significant factor influencing power generation efficiency. When selecting a site, it is essential to consider the characteristics of the surrounding environment, including valley depth, rock types, and nearby buildings, to ensure optimal power generation efficiency.

3.4. Distribution ratio of energy resources

The wind-solar-hydro complementary system achieves energy complementarity through the reasonable distribution of different energy resources. However, the distribution ratio of these resources also affects the system's power generation efficiency. For example, in certain situations, increasing the proportion of wind power might decrease the efficiency of photovoltaic power generation, thus reducing the overall system efficiency.

3.5. Operating conditions of equipment

The system involves multiple types of equipment, such

as wind turbines, photovoltaic modules, and hydro turbines. The operating condition of this equipment plays an important role in determining the system's power generation efficiency. For instance, in wind power generation, the turbine's speed and blade angle settings directly affect the efficiency.

3.6. System operation scheduling

Through appropriate system scheduling and control, it is possible to maximize the complementary utilization of various energy resources. This requires sophisticated algorithms and intelligent control systems to achieve higher power generation efficiency [4].

3.7. Inverter efficiency

In the wind-solar-hydro complementary power generation system, both wind and solar power generation require inverters to convert direct current (DC) into alternating current (AC). Inverters are critical to the system's efficiency; high-efficiency inverters can enhance the system's power generation efficiency and reduce operating costs.

3.8. Transmission line loss

Generally, wind, solar, and hydro resources require transmission lines for power conveyance, which inevitably involves some energy loss. Therefore, in designing and constructing the wind-solar-hydro complementary system, it is important to consider the structure and scale of the transmission lines to minimize energy loss as much as possible [5].

3.9. System safety and reliability

Failures or abnormal conditions in the wind-solar-hydro complementary system may lead to system downtime and reduced power generation efficiency. Thus, ensuring the system's safety and reliability is a critical factor for achieving stable and efficient power generation in the wind-solar-hydro complementary system.

4. Recommendations to improve the power generation efficiency of the wind-solar-hydro complementary power generation system

Based on the above analysis, the following recommendations are proposed:

(1) Meteorological conditions: To enhance the accuracy and predictability of the energy allocation ratios in the wind-solar-hydro complementary system, high-precision meteorological detection technology and robust meteorological forecasting models should be employed. This will enable more intelligent and customized power generation.

(2) Strengthening R&D efforts: Improving the technological level of the wind-solar-hydro complementary system is crucial to increasing its efficiency. Therefore, research and development in this field must be intensified, and the latest technologies should be incorporated.

(3) Optimal site selection: Site selection should carefully consider meteorological conditions, geological environment, geographic location, and the characteristics of wind, solar, and hydro resources. A strategic layout will ensure system stability and optimal power generation efficiency.

(4) Energy resource allocation ratio: According to the local natural conditions and availability of resources, the energy allocation between wind, solar, and hydro should be adjusted to maximize energy utilization efficiency.

(5) Equipment operating conditions: Timely equipment maintenance and fault resolution are essential to ensure efficient and stable operation. Regular inspections, maintenance, and prompt equipment updates are also necessary.

(6) System operation scheduling: An intelligent scheduling system should be implemented to manage and monitor the wind-solar-hydro complementary system, optimizing power generation efficiency and system stability.

(7) Inverter efficiency: High-efficiency and reliable inverter equipment should be used to reduce energy losses in the conversion process, enhancing power generation efficiency and lowering operational costs.

(8) Transmission line loss: The choice of transmission method and construction scale

should suit the actual conditions, minimizing energy losses and reducing the environmental impact.

(9) System safety and reliability: The introduction of an intelligent monitoring system allows for real-time monitoring and assessment of system performance, ensuring safe and stable operation. Regular inspections and maintenance are essential for ensuring the system's long-term stability.

5. Conclusion

The study results indicate that the complementary use of different energy sources can improve power generation efficiency. Factors such as meteorological conditions, technological level, and site location also impact system efficiency, and their effects are interrelated. A comprehensive consideration of these factors mechanisms and interactions is necessary to achieve efficient and stable system operation. Additionally, this research, through analyzing the complementary relationship among various energy sources, provides several recommendations to improve the power generation efficiency of the wind-solar-hydro complementary system. These insights offer scientific guidance and management methods for the construction and operation of such systems.

As an emerging field, wind-solar-hydro complementary power generation systems are poised to become a major form of electricity supply aligned with national carbon neutrality goals. With continued technological advancement and decreasing costs, the scale of these systems will expand, potentially integrating with other renewable energy technologies to form a more complete energy system that supports sustainable development goals. However, the construction and management of wind-solar-hydro complementary systems will face new challenges and opportunities, necessitating stronger policy and regulatory frameworks, the promotion of technological innovation, industry upgrades, and enhanced market competitiveness and profitability.

In summary, the wind-solar-hydro complementary power generation system is a renewable energy system with significant potential and practical value. Its power generation efficiency depends on the combined influence of various factors. Through continuous technological improvements, rational site selection, and optimized equipment configuration, its efficiency can be greatly enhanced.

Disclosure statement

The authors declare no conflict of interest.

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