Original Research Article

Research on optimization of green hydrogen production based on wind, solar and energy storage complementarity

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Abstract: Green hydrogen production technology is an important way to achieve the goals of "carbon neutrality" and "carbon peak". Using wind, solar and energy storage to carry out green hydrogen production research can not only effectively solve the problem of high carbon emissions in the traditional hydrogen production process, but also greatly improve the utilization rate of renewable energy. This paper focuses on the complementary technology of wind, solar and energy storage, comprehensively analyzes its application in green hydrogen production, and discusses the key issues of wind and solar resource volatility, water electrolysis technology efficiency bottlenecks and energy storage system optimization. By proposing solutions for intelligent scheduling and multi-energy complementarity, the study shows that the optimization measures significantly improve the utilization efficiency of wind and solar power, reduce the cost of hydrogen production, and improve the environmental benefits of the hydrogen production process. The research in this paper provides an important theoretical basis and practical guidance for the promotion and application of green hydrogen production technology.

Keywords: Wind; Solar and energy storage synergy and complementary optimization; Multi-dimensional energy interaction; Adaptive load scheduling

1. Introduction

1.1. Research background and significance

Hydrogen energy is known as the "ultimate energy" of the 21st century. It is a clean, efficient and sustainable secondary energy. In the process of global energy transformation, the strategic position of hydrogen energy is becoming increasingly prominent. The International Energy Agency (IEA) pointed out that by 2050, hydrogen energy will account for 18% of global energy demand and the market value will reach 2.5 trillion US dollars. In particular, green hydrogen (green hydrogen) produced from renewable energy has important application prospects in the future energy system due to its carbon-free characteristics.

However, the way hydrogen is prepared directly determines its carbon emission level. At present, traditional fossil energy hydrogen production occupies a dominant position, accounting for more than 95%, but its high carbon emission characteristics limit the green development of hydrogen energy. In contrast, the use of renewable energy such as wind and solar energy to electrolyze water to produce hydrogen can not only effectively reduce carbon emissions, but also solve the problem of low utilization of wind and solar energy resources. However, due to the volatility and intermittent nature of wind and photovoltaic power generation, the efficiency of green hydrogen production has not yet reached the ideal level. Therefore, studying how to optimize the efficiency of wind, solar, and energy storage complementary hydrogen production systems is not only a hot topic in current research, but also the key to achieving the industrialization and promotion of hydrogen energy.

1.2. Current status of research outside China

Internationally, countries such as Germany and Japan have made certain breakthroughs in the field of green hydrogen production. For example, Germany has proposed a "national hydrogen strategy" and plans to achieve an annual production capacity of 5 million tons of green hydrogen by 2030. Japan has integrated hydrogen energy with renewable energy through hydrogen energy demonstration projects, verifying the feasibility of wind, solar, and energy storage complementarity.

China has also seen rapid growth in the field of green hydrogen production in recent years. Green hydrogen production technology based on renewable energy has gradually formed a large-scale development trend in areas with rich wind and solar resources, such as Northwest China and North China.

1.3. Research objectives and methods

This paper takes the wind, solar, and energy storage complementary green hydrogen production system as the research object, analyzes its key technical links and efficiency bottlenecks, and proposes an optimization plan based on intelligent scheduling and multi-energy complementarity.

2. Overview of the wind power, solar power and energy storage complementary green hydrogen production system

2.1. Theoretical basis of wind, solar and energy storage complementarity

The core of wind, solar and energy storage complementary technology is to optimize the resource utilization of wind and solar energy. Wind energy is stable at night, while solar energy exhibits peak characteristics during the day. By integrating and scheduling the resources of the two, the volatility of energy supply can be effectively smoothed, thereby providing continuous and reliable power support for the water electrolysis hydrogen production system.

2.2. Energy flow and transformation

Wind and solar power are converted into direct current through a rectifier and used in water electrolysis hydrogen production equipment. In the hydrogen production process, water is decomposed into hydrogen and oxygen in the electrolyzer, and the hydrogen is compressed or liquefied and stored for subsequent use in fuel cells, industrial energy or transportation.

2.3. System composition

A typical wind, solar, and energy storage complementary green hydrogen production system includes the following main parts:

1. **Wind and solar power generation devices** : provide green electricity;
2. **Water electrolysis hydrogen production equipment** : complete water electrolysis and hydrogen production;
3. **Energy storage device** : used to balance the fluctuations of wind and solar power;
4. **Hydrogen storage and transportation facilities** : including high-pressure hydrogen storage tanks and hydrogen pipeline transportation systems.

3. Key factors affecting green hydrogen production efficiency

3.1. Volatility of wind and solar resources

Wind and solar resources have significant temporal and spatial fluctuations. Wind power usually reaches its peak at night, while photovoltaic power generation is stable during the day. The complementarity of wind and solar power can significantly improve the stability of the overall energy supply.

3.2. Energy storage and energy regulation

The configuration of energy storage system is an indispensable part of green hydrogen production system. Lithium batteries, flow batteries and hydrogen energy storage systems can all be used for energy regulation of wind and solar power. Energy storage system can not only absorb excess electricity, but also release energy when power is insufficient to ensure the stability of hydrogen production process by electrolysis of water.

3.3. Bottlenecks in water electrolysis technology

Among the existing water electrolysis technologies, alkaline electrolyzers (AEL) have low costs but low efficiency, while proton exchange membrane electrolyzers (PEMEL) have high efficiency but high costs. The current research focus is to rationally select the type of electrolyzer for different scenarios and further improve its efficiency through technical optimization.

4. Green hydrogen production efficiency optimization plan

In order to cope with the volatility of wind and solar resources, the technical bottleneck of hydrogen production by electrolysis of water, and the cost of energy storage systems, this paper proposes a set of green hydrogen production efficiency optimization solutions, including three core strategies: intelligent scheduling, energy storage system optimization, and multi-energy complementarity. These optimization measures solve the main difficulties in the existing green hydrogen production process from the technical and system levels, and provide a feasible path for building an efficient and stable hydrogen production system.

4.1. Intelligent scheduling and energy management

The green hydrogen production system with complementary wind, solar and energy storage requires real-time scheduling of energy supply and demand to ensure that the electrolyzer operates at the optimal power point and reduce energy waste and equipment loss. To this end, the following measures are proposed:

1. **The prediction and optimization model**

   Uses the wind and solar resource prediction model, combined with historical meteorological data and real-time power generation data, to establish a dynamic energy supply and demand balance model. The model can predict the fluctuation of wind and solar power storage and output in the next few hours or days , providing a reliable scheduling basis for the hydrogen production process.

2. **The energy management system (ECMS)**

   Introduces an intelligent energy management system to dynamically adjust power distribution by real-time monitoring of wind and solar power generation, energy storage status, and hydrogen production equipment operation. For example:

   o When the storage of wind and solar power exceeds the demand for hydrogen production, the energy storage system will be charged first;

- o When electricity is insufficient, the stored energy is released to maintain stable operation of the hydrogen production equipment.

3. **The priority scheduling strategy**
   Sets task priorities according to different hydrogen production tasks and energy supply conditions. High-efficiency hydrogen production equipment is prioritized during peak power periods, and hydrogen production power is reduced or excess power is directed to the energy storage system during off-peak periods.

4.2. Optimal design of energy storage system

The energy storage system is one of the core components of wind-solar hybrid hydrogen production, and its performance directly affects the efficiency and economy of hydrogen production. Optimizing the design of energy storage systems requires starting from three aspects: capacity, type, and scheduling:

1. **Capacity optimization**
   reasonably configures the capacity of the energy storage system based on the day and night fluctuation characteristics of wind and solar resources. For example:
   - o Lithium-ion batteries can be used for short-term energy storage to meet the needs of daily fluctuation regulation;
   - o For long-term energy storage, flow batteries or hydrogen storage can be selected to balance seasonal fluctuations.
2. **Technology Selection**
   Different energy storage technologies have their own advantages in terms of efficiency, cost and life. Based on system requirements, the following energy storage technology combinations are recommended:
   - o **Lithium-ion batteries** : high energy density, suitable for short-term energy regulation;
   - o **Liquid hydrogen storage** : suitable for long-term energy storage during peak periods of wind and solar power generation, and can be directly coupled with the hydrogen production process to reduce intermediate conversion losses;
   - o **Pumped storage:** Pumped storage systems are suitable for storing large amounts of surplus wind and solar power to balance diurnal or seasonal fluctuations. In areas where seasonal wind and solar resources vary significantly, pumped storage can be used to achieve cross-seasonal regulation.

4.3. Multi-energy complementation and flexibility improvement

Multi-energy complementary technology achieves efficient cascade utilization of resources by integrating hydrogen production systems with other energy systems. The following are several ways to optimize the multi-energy complementary system:

1. **The coupling of water electrolysis to hydrogen production and fuel cell power generation**
   uses the byproducts of water electrolysis to produce hydrogen (such as oxygen) for fuel cell power generation. Fuel cells can not only provide additional electricity, but also provide heat through the combined heat and power (CHP) system to improve energy utilization.
2. **System**
   can be used for district heating. This method not only improves energy efficiency, but also reduces the overall operating cost of the hydrogen production system.

3. **Flexible load management**

Hydrogen production equipment can participate in grid frequency regulation as a flexible load. When there is an excess of wind and solar resources, the excess electricity can be absorbed by increasing the hydrogen production power; when the power demand is at a peak, the hydrogen production power can be reduced to free up electricity for other key loads.

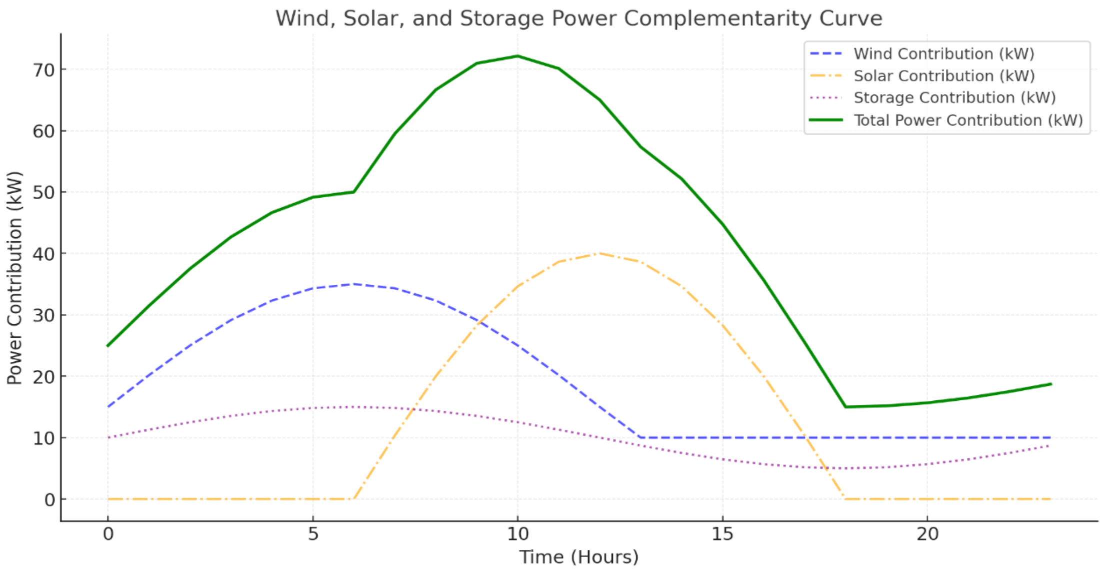

Figure 1. Wind power, solar energy and energy storage complementarity curve.

4.4. "Source-load interaction" model

By adopting the "source-load interaction" mode, the hydrogen production plant can achieve two-way regulation of load and power supply, improve the flexibility and stability of the system , and optimize and adjust each electrolyzer and storage tank in the plant through intelligent control algorithms to ensure the overall efficient operation of the hydrogen production and storage system. This "source-load interaction" mode not only improves the operating efficiency of the hydrogen production plant, but also enhances the stability of the power system and promotes the efficient use of energy and low-carbon transformation.

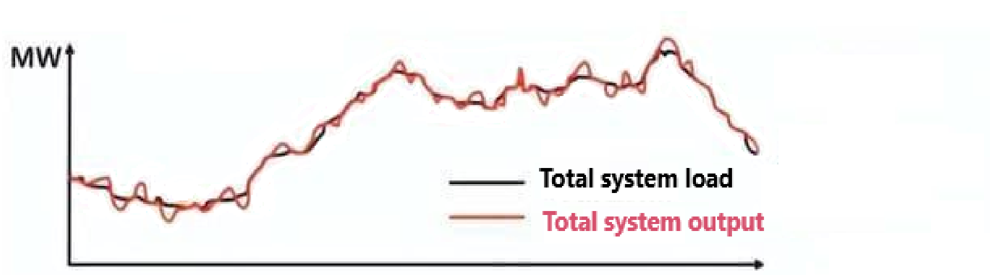

Figure 2. Source He Interactive Chart.

5. Conclusion and outlook

5.1. Main conclusions

This paper analyzes the key influencing factors of wind, solar, and energy storage complementary green hydrogen production technology, and proposes solutions for intelligent scheduling, energy storage optimization, and multi-energy complementarity. These measures significantly improve hydrogen production efficiency, reduce hydrogen production costs, and provide practical references for the promotion of green hydrogen production.

5.2. Future prospects

Future research should focus on:

1. Develop new electrolyzer technologies that are efficient and low-cost;
2. Promote the industrialization of large-scale energy storage technology;
3. Deepen regional energy coordinated optimization and realize the comprehensive application of multi-energy complementarity.

The innovation and development of green hydrogen production technology will provide solid technical support for the global energy transformation and lay the foundation for building a low-carbon energy system.

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