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Research on Synergistic Optimization of Wind, Solar, Hydrogen, and Storage Systems in Oil and Gas Enterprises

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Abstract: In response to the problems of high carbon emissions in the traditional energy supply mode of oil and gas enterprises, insufficient utilization of new energy, and insufficient energy supply stability in remote areas, this study explores the path of synergistic optimization of wind, solar, hydrogen, and storage systems. Considering the characteristics of energy consumption in oil and gas production, the composition relationship among wind power, photovoltaic power, hydrogen energy, and storage systems is analyzed. Synergistic optimization research is conducted from aspects such as capacity configuration, energy conversion, intelligent regulation, and digital management. By constructing a multi-energy complementary operation mode, the coordinated operation of new energy generation, energy storage regulation, and hydrogen utilization is achieved. The utilization rate of wind and solar resources can reach 85% to 95%, effectively improving energy utilization efficiency and reducing reliance on traditional energy. The wind, solar, hydrogen and storage system can enhance the energy security capability of oil and gas enterprises, promote the low-carbon and intelligent development of the production process, and provide technical support for the construction of a comprehensive energy system.

Keywords: Oil and gas enterprises; Wind, solar, hydrogen, and storage; Synergistic optimization; Energy management

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1. Introduction

In the context of energy structure transformation, oil and gas enterprises, as the main energy producers, are facing the dual pressures of adjusting traditional energy consumption methods and enhancing the requirements for low-carbon development. The production areas of oil and gas are widely distributed, and some well sites, gathering and transportation stations, etc. have the characteristics of long supply distances and strong load continuity. A single energy supply mode is difficult to meet the requirements for stable operation. The integration of wind power, photovoltaic power, hydrogen energy, and energy storage technologies can utilize new energy to replace some traditional energy sources and enhance the reliability

of energy supply through energy storage regulation. Currently, the wind-solar-hydro-storage system has become an important direction for oil and gas enterprises to build a comprehensive energy system. However, optimization research is still needed in aspects such as capacity configuration, coordinated control, and digital management to improve the economic efficiency and operational efficiency of the system.

2. Composition and operation requirements of the oil and gas enterprise's wind-solar-hydrogen-storage system

The production of oil and gas involves multiple links such as drilling and production, gathering and transportation, and processing. Some areas have the characteristics of long distances and strong load continuity. The traditional energy supply mode is difficult to meet the requirements of low-carbon development. The wind-solar-hydrogen-storage system integrates wind power, photovoltaic power, electrochemical energy storage, and hydrogen conversion equipment to establish a comprehensive energy model of "new energy generation–energy storage regulation–hydrogen utilization–production supply," as shown in **Figure 1**. This system uses the energy management center to coordinate the operation of wind power generation, battery storage, electrolysis hydrogen production, and hydrogen storage equipment to achieve multi-energy coordinated conversion [1]. Among them, the new energy installation can be configured according to the station's needs; the energy storage system is responsible for short-term regulation, and the hydrogen storage is used for long-term energy security. Through the multi-energy complementary operation mode, the energy supply stability of oil and gas enterprises can be improved, and traditional energy consumption can be reduced.

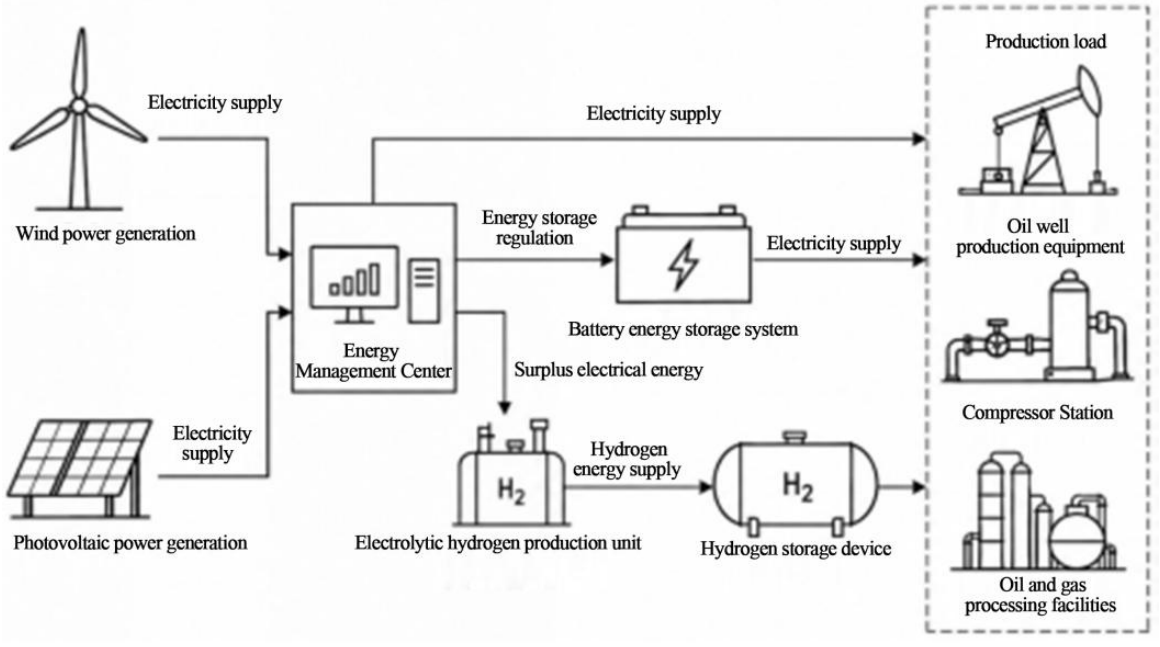


Figure 1. Schematic diagram of the comprehensive energy system of oil and gas enterprises combining wind, solar, hydrogen, and storage

3. Key technologies for synergistic optimization of the wind-solar-hydrogen-storage system in oil and gas enterprises

3.1. Capacity configuration of wind and solar energy and optimization of storage scale

The capacity configuration of wind and solar energy is the foundation for the stable operation of the wind-solar-hydrogen-storage system of oil and gas enterprises. It needs to comprehensively consider the production load, the conditions of new energy resources, and the regulation capacity of storage to achieve the matching of energy supply and consumption capacity. Due to the continuous and fluctuating characteristics of the production load in oil and gas enterprises, if the scale of new energy installations is simply expanded, it is very likely to cause power outages. An insufficient storage configuration makes it difficult to play a role in smoothing out the fluctuations of wind and solar power output. Therefore, it is necessary to conduct optimization configuration based on typical daily load curves, the changing characteristics of wind and solar resources, and the constraints faced by equipment operation. The capacity optimization objective can be expressed as follows:

$$C_{opt} = \min(C_{in\upsilon} + C_{\rho} + C_{loss})$$

In the formula: C_{opt} represents the overall system cost, $C_{in\upsilon}$ represents the equipment investment cost, C_{op} represents the operation and maintenance cost, C_{loss} and represents the energy loss cost. In actual engineering, the new energy systems of oil and gas enterprises usually adopt megawatt-level photovoltaic and wind power sources. The photovoltaic unit can be set within the range of 1 to 50 MW according to the power consumption scale of the station. The energy storage system is generally designed based on a 2- to 4-hour regulation capacity. For regions with more fluctuating new energy, the hydrogen energy storage capacity can be appropriately increased, and the surplus electricity can be absorbed through electrolysis to produce hydrogen. Currently, the power of a single alkaline electrolyzer unit can reach the MW level, and the hydrogen production efficiency generally remains within the range of 70% to 85%. Such a situation can meet the long-term energy regulation needs of oil and gas production [2]. By optimizing the proportion of photovoltaic and wind power installations and the scale of energy storage, the rate of wind and solar energy abandonment can be reduced, thereby improving the economic efficiency and operational stability of the system.

3.2. Synergistic control of hydrogen conversion process and energy storage regulation

The hydrogen conversion process is a crucial link connecting new energy power generation and oil and gas production loads. It mainly relies on surplus wind and solar power to drive the electrolyzer to produce hydrogen, and then achieves energy regulation across different time scales through hydrogen storage equipment. Due to the random fluctuations in the output of wind power and photovoltaic power, the system needs to coordinate the operating status of the electrolyzer, the charging and discharging of battery energy storage, and the release process of hydrogen based on real-time power changes. The operating parameters of different equipment directly affect the system's regulation capability. Typical configuration parameters are shown in **Table 1**.

Table 1. Operational parameters of key equipment in the wind-solar-hydrogen storage system

Device type	Main parameters	Typical range
Photovoltaic power generation system	Individual installation capacity	1–50 MW
Wind power generation system	Single-unit capacity	1.5–6 MW

Device type	Main parameters	Typical range
Lithium battery energy storage	Adjust the time	0.5–4 h
Alkaline electrolyzer	Rated power	1–10 MW
PEM electrolyzer	Load regulation range	10–100%
Hydrogen storage device	Work stress	0.2–5.0 MPa

From **Table 1**, it can be seen that battery energy storage is mainly used for minute-level and hour-level power regulation, while hydrogen energy storage is more suitable for long-term energy storage. During actual operation, if the power output of wind and solar energy exceeds the demand of oil and gas production, the system can increase the load of the electrolyzer and convert the remaining electrical energy into hydrogen. When the output of new energy is insufficient, the hydrogen storage system or fuel cells can be relied on to supplement the energy [3]. Some PEM electrolysis equipment has a response time within minutes, which can adapt to the rapid fluctuations of new energy.

3.3. Intelligent operation optimization method driven by multi-source data

The multi-source data-driven optimization method integrates the output of new energy, production load, energy storage status, and equipment operation parameters to achieve dynamic regulation of the wind-solar-hydrogen-storage system. As shown in **Figure 2**, the digital energy management platform collects data on wind power, photovoltaic power, energy storage, and oil and gas production. It uses state prediction and intelligent scheduling to coordinate the operation of battery energy storage, hydrogen electrolysis, and hydrogen storage equipment. In response to the prominent problem of the influence of weather on new energy, the system needs to establish data collection, trend prediction, and collaborative control modes, which include:

(1) Collecting data such as wind speed, irradiation intensity, energy storage state of charge (SOC), and hydrogen storage volume;
(2) Adjusting the hydrogen production power and energy storage strategy based on the prediction results;
(3) Achieving the collaborative operation of equipment through the energy management system.

In practical applications, the data collection cycle of the platform is generally 1 to 60 seconds, and the scheduling optimization cycle is 5 to 60 minutes. This can improve the system's response capability and energy utilization efficiency. The system optimization goal can be expressed as:

$$F = \alpha E + \beta R + \gamma S$$

In the formula: F represents the comprehensive optimization objective, E represents energy utilization efficiency, R represents operational economy, S represents system stability, and α, β, γ are the corresponding weight coefficients. Through the integration of multi-source data and the application of intelligent algorithms, dynamic matching between wind and solar power generation, energy storage regulation, and oil and gas production load can be achieved.

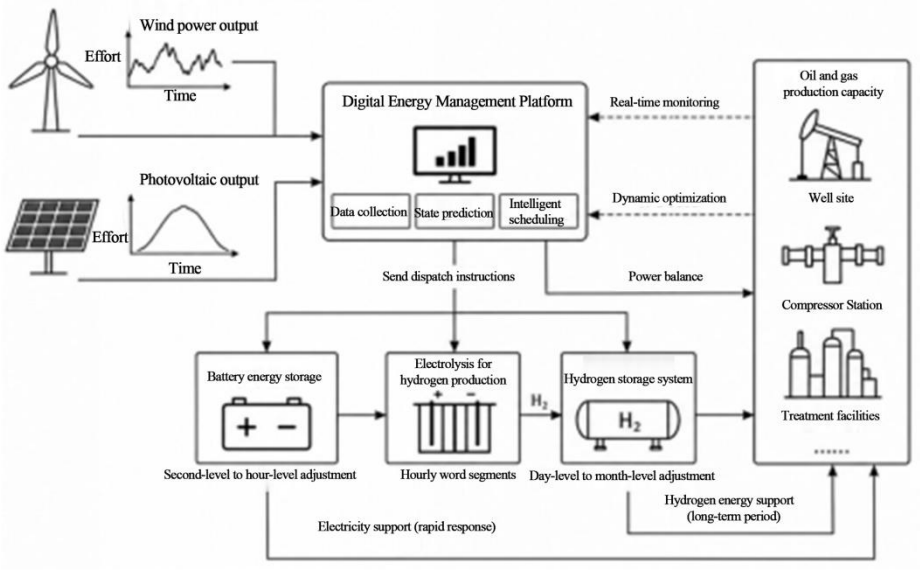


Figure 2. Schematic diagram of multi-time scale synergistic regulation of wind, solar, and hydrogen storage system

4. Synergistic operation application and optimization enhancement of wind, solar, and hydrogen storage system

4.1. Multi-energy complementary operation mode in oil and gas production scenarios

The application of the wind, solar, and hydrogen storage system in oil and gas production scenarios requires the establishment of a multi-energy complementary operation mode based on the different energy consumption characteristics of various facilities such as well sites, gathering and transportation stations, and processing plants. The oil and gas production areas generally have continuous operation requirements, and the single station's electricity load can reach several hundred kilowatts to several megawatts. Therefore, by leveraging wind power, photovoltaic power, energy storage, and hydrogen power equipment to achieve a stable power supply, in practical applications, the photovoltaic system can be configured with a scale of 1 to 50 MW; the single-unit capacity of wind power is generally 1.5 to 6 MW, and the energy storage system can provide a regulation capacity of 0.5 to 4 hours. During operation, priority is given to using wind and solar power to meet production loads, and the excess electricity is used for energy storage or hydrogen production. When new energy is insufficient, the power supply is supplemented through energy storage and hydrogen release [4]. This mode can enhance the energy security capabilities of oil and gas enterprises, reduce traditional energy consumption, and achieve multi-energy synergy utilization.

4.2. Evaluation of system operation efficiency and low-carbon benefits

The evaluation of the operation effect of the wind, solar, and hydrogen storage system should comprehensively consider multiple indicators such as energy utilization efficiency, equipment operation performance, and low-carbon benefits. Compared with the traditional oil and gas production power supply mode, this system, by means of new energy substitution and energy storage regulation, can reduce the consumption of fossil energy, thereby improving the energy utilization level. The energy utilization efficiency of the system can be evaluated using the following formula:

$$\eta = \frac{E_u}{E_t} \times 100\%$$

In the formula: η represents energy utilization efficiency, E_u represents the effective utilization of energy, E_t and represents the total input energy. In actual engineering, the comprehensive efficiency of photovoltaic systems is usually 75% to 85%, the round-trip efficiency of lithium battery energy storage can reach 85% to 95%, and the comprehensive efficiency of hydrogen energy storage is approximately 30% to 45%. The main evaluation indicators of the system under operating conditions are shown in **Table 2**.

Table 2. Evaluation indicators of operating benefits of wind-solar-hydrogen storage system

Evaluation indicators	Typical range	The significance of evaluation
New energy consumption rate	85–95%	Reflects the level of utilization of renewable energy resources
Energy storage regulation time	0.5–24 h	Characterizing the system's power balance capability
Battery energy storage efficiency	85–95%	Evaluate the short-term regulatory effect
Hydrogen energy storage comprehensive efficiency	30–45%	Evaluate the long-term energy storage capacity
Proportion of new energy substitution	20–50%	Measuring the level of low-carbon operation

From **Table 2**, it can be seen that the photovoltaic-hydrogen-storage system has certain energy loss during hydrogen conversion, but it has the advantages of large-scale and long-term energy storage. In the oil and gas production scenario, by optimizing the configuration of new energy and the storage scheduling strategy, the utilization ratio of green energy can be increased, and the use of traditional energy such as diesel power generation can be reduced, achieving a coordinated improvement of energy security and low-carbon development.

4.3. Dynamic optimization management supported by digital platform

The digital platform is an important support for the dynamic optimization operation of the photovoltaic-hydrogen-storage system. By integrating Internet of Things, data collection, and intelligent control technologies, real-time monitoring and coordinated scheduling of new energy generation, storage status, and oil and gas load can be achieved. The platform can collect various types of information such as wind speed, light intensity, battery state of charge (SOC), hydrogen storage pressure, and equipment operating parameters. The data collection cycle is generally controlled within the range of 1 to 60 seconds, while the scheduling optimization cycle can be set to 5 to 60 minutes. During the operation process, the prediction model is used to analyze the trend of new energy output, and then the charging and discharging of storage and hydrogen production strategies can be adjusted in advance [5]. In addition, through remote monitoring and fault diagnosis functions, the reliability of equipment operation can be improved, achieving dynamic matching of photovoltaic-hydrogen-storage and oil and gas production loads, and promoting energy management towards an intelligent and low-carbon direction.

5. Conclusion

The collaborative optimization of the wind-solar-hydrogen-storage system offers an effective pathway for oil and gas enterprises to adjust their energy mix and achieve a low-carbon transition. By integrating wind

power, photovoltaic power generation, energy storage regulation, and hydrogen conversion technologies, it is possible to achieve dynamic matching between new energy production, storage, and the load demand of oil and gas, thereby improving energy supply stability. Studies have shown that reasonable allocation of new energy capacity, optimizing the hydrogen storage collaborative control strategy, and conducting intelligent management through digital platforms can enhance energy utilization levels and reduce traditional energy consumption. In the future, oil and gas enterprises should further strengthen the application of multi-energy integration technologies to promote the development of integrated energy systems towards intelligence, efficiency, and greenness.

Disclosure statement

The author declares no conflict of interest.

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