Social Development Studies, 2026, Volume 2, Issue 3
https://www.bbwpublisher.com/journal/SDS
Online ISSN: 3083-3868
Print ISSN: 3083-3876

Research on the Integration of Wind-Solar-Hydrogen-Energy Storage System for Oil-Gas Enterprises

Zhenjie Li

College of Management and Economics, Tianjin University, Tianjin 30000, China

Copyright: © 2026 Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), permitting distribution and reproduction in any medium, provided the original work is cited.

Abstract: In response to the large-scale energy consumption of oil-gas enterprises, the increasing demand for traditional energy structure adjustment, and the low efficiency of new energy utilization, this study conducts integrated research on the wind-solar-hydrogen-energy storage system. The system integrates wind power generation, hydrogen production, energy storage, and intelligent control to achieve coordinated operation of multiple energy sources. The analysis focuses on the multi-energy coupling architecture, key integration technologies, and engineering application paths. The system's operational effectiveness is evaluated based on actual cases. The results show that the integrated system can achieve efficient utilization of new energy, maintain stable operation of the wind power generation and hydrogen production units, control the response time of energy storage within 100 ms, and increase the energy utilization efficiency by approximately 15%, improving the system's operational stability. The wind-solar-hydrogen-energy storage system can promote the optimization of the energy structure of oil-gas enterprises, enhance the overall energy management level, and provide technical support for the green and low-carbon transformation.

Keywords: Oil-gas enterprises; Wind-solar-hydrogen-energy storage; System integration; Intelligent control; Energy transformation

Online publication: June 30, 2026

1. Introduction

With the continuous advancement of green energy transformation, oil-gas enterprises face the development demands of reducing carbon emissions, optimizing energy structure, and improving utilization efficiency. The traditional energy supply model faces certain pressures in terms of environmental impact and operational costs. The wind-solar-hydrogen-energy storage system integrates wind power generation, photovoltaic power generation, hydrogen production, energy storage, and intelligent control units to achieve coordinated operation of new energy production, storage, and utilization. It provides a technical path for oil-gas

enterprises to build an integrated energy system [1]. However, due to the volatility of wind and solar energy, the system operation still needs to address issues of multi-energy coordination and intelligent control. Therefore, conducting research on the architecture, key integration technologies, and application effects of the wind-solar-hydrogen-energy storage system is of great significance for promoting the low-carbon and intelligent development of oil-gas enterprises.

2. Wind-solar-hydrogen-energy storage system architecture for oil-gas enterprises

2.1. Composition and functional characteristics of the wind-solar-hydrogen-energy storage system

The wind-solar-hydrogen-energy storage system for oil-gas enterprises consists of wind power generation, photovoltaic power generation, hydrogen production, energy storage, and energy management control units. It achieves the coordinated utilization of electrical energy and hydrogen energy through multiple energy conversions. The wind and photovoltaic units supply renewable electricity, providing input for the hydrogen production and energy storage units. The electrolysis hydrogen production unit uses surplus electricity to convert electrical energy into hydrogen energy. The energy storage unit regulates energy supply and demand changes to ensure stable system operation. This system integrates multiple energy links to improve the efficiency of new energy utilization and reduce traditional energy consumption in the oil-gas production process [2]. In practical applications, the installed capacity of new energy and the scale of electrolytic cells are configured based on the load requirements of oil-gas stations, and energy regulation is carried out using energy storage equipment. The modular integration approach enhances the system's scalability, enabling it to adapt to the energy demands of different production areas and providing support for the green transformation of oil-gas enterprises.

2.2. Design of multi-energy coordinated operation architecture

The multi-energy coordinated operation architecture of the wind-solar-hydrogen-energy storage system is of great significance for the stable operation of the system. It uses coordinated control of energy input, conversion, storage, and utilization to achieve effective cooperation among different energy units. The system adopts a "source—storage—load—control" integrated architecture. Wind and photovoltaic units provide new energy supply; the hydrogen production unit is responsible for energy conversion; the energy storage equipment is used to stabilize power fluctuations; and the energy management platform completes status monitoring and operation scheduling. The multi-energy coordinated architecture of the wind-solar-hydrogen-energy storage system is shown in **Figure 1**. During the oil-gas production process, the system adjusts the operation mode based on the output of new energy and load changes. When the wind power generation is high, the hydrogen production equipment is driven first, and some energy is stored. When the supply of new energy is insufficient, energy is released through energy storage or hydrogen conversion to maintain production stability. The system collects parameters such as power, voltage, hydrogen flow rate, and energy storage status at a 100-500 ms cycle to adjust the energy flow direction.

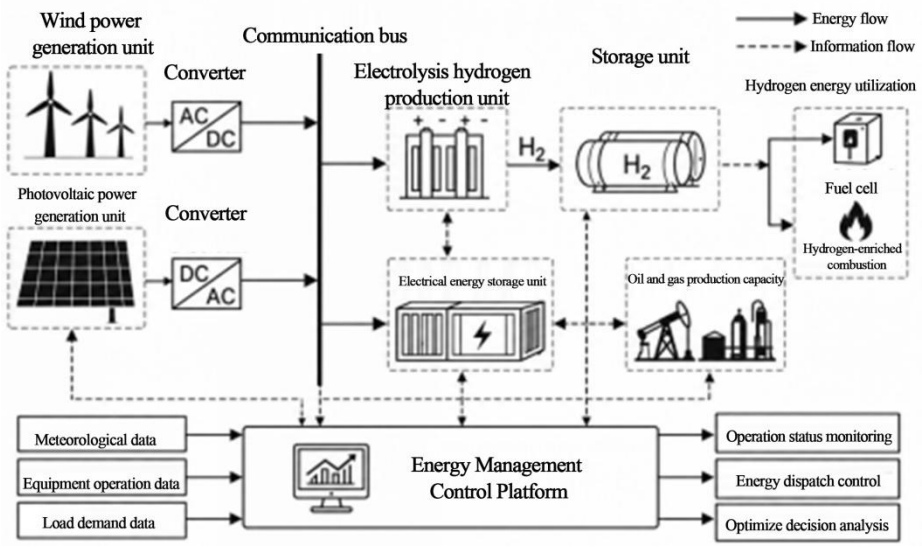


Figure 1. Schematic diagram of multi-energy synergistic architecture for wind-solar-hydrogen storage system.

3. Key integrated technologies of wind-solar-hydrogen storage system

3.1. Coupling method of wind-solar energy access and hydrogen production

The coupling of wind-solar energy access and hydrogen production is a key point for achieving energy conversion in the wind-solar-hydrogen storage system. The core lies in coordinating the output of wind power and photovoltaic power with the load of electrolytic hydrogen production. When applied by oil and gas enterprises, a collaborative connection structure for the wind power generation side, power conversion side, and hydrogen production side should be established based on the situation of new energy resources in the production area and energy demand. The electricity generated by wind power and photovoltaic power is regulated by the converter, providing a stable input to the electrolytic cell. When the output of new energy exceeds the production load, the hydrogen production equipment is used to consume the surplus electricity, improving the utilization rate of new energy. When the output is insufficient, it is compensated by the power system [3]. During the system design process, the operating power range of the electrolytic cell, the start-stop frequency, and the load response speed should be focused on controlling. Generally, the operating load of the electrolytic cell is controlled within the range of 20% to 100% of the rated capacity to improve equipment operation efficiency. By establishing a power prediction and dynamic matching mechanism, the influence of wind-solar fluctuations on the hydrogen production process can be reduced, achieving stable connection between new energy power generation and hydrogen production, and laying the foundation for oil and gas enterprises to establish a green energy supply model.

3.2. Synergy of hydrogen storage, conversion, and multi-energy supply

The synergy of hydrogen storage, conversion, and multi-energy supply plays a key role in achieving continuous operation of the wind-solar-hydrogen storage system. It is mainly used to solve the contradiction between the intermittency of new energy and the continuous energy demand of oil and gas production. This system establishes a multi-level energy regulation structure through hydrogen storage equipment, electrical energy storage devices, and hydrogen conversion equipment. When new energy is abundant, the excess

energy is stored, and when energy is insufficient, hydrogen or electricity is released for supplementation [4]. The storage capacity and conversion efficiency of hydrogen directly affect the stability of system operation. Therefore, the scale of energy storage should be reasonably configured according to load changes. The following formula can calculate the hydrogen storage quantity:

$$M_H = \int_0^t Q_H(t)dt \tag{1}$$

In the formula, MH represents the hydrogen storage quantity, in kilograms; QH(t) is the hydrogen generation flow rate per unit time, in kilograms per hour; t is the operating time, in hours.

During the energy conversion process, it is necessary to combine the operating status of the hydrogen generation equipment and the energy loss situation to conduct a comprehensive evaluation of the hydrogen energy conversion effect. At the same time, the utilization efficiency of hydrogen energy should be considered. The calculation model is as follows:

$$\eta_H = \frac{E_0}{E_i} \times 100\% \tag{2}$$

In the formula, ηH represents the hydrogen energy conversion efficiency, expressed as a percentage; Eo indicates the effective energy output of hydrogen, measured in kWh; Ei represents the input electrical energy, also measured in kWh.

By optimizing the hydrogen storage capacity, conversion efficiency, and supply strategy, it is possible to achieve a dynamic balance among the wind and solar power, hydrogen storage, and oil and gas production loads, enhancing the system's adaptability to fluctuations in new energy sources and improving the continuity and operational stability of energy supply. **Table 1** shows the configuration parameters of a wind-solar-hydrogen storage system for an oil and gas station. It can be seen that each energy unit forms a complementary operational relationship.

Table 1. Main configuration parameters of wind, solar, hydrogen and storage systems in oil and gas enterprises

System unit	Configuration parameters	Performance indicators
Photovoltaic power generation unit	Installed capacity: 5 MW	The annual utilization rate is approximately 85%.
Wind power generation unit	Installed capacity: 8 MW	Power fluctuation: ±10%
Electrolysis hydrogen production unit	Capacity: 2 MW	The hydrogen production efficiency is approximately 75%.
Storage unit	Hydrogen storage capacity: 500 kg	Adjustment period: 24 hours
Electrical energy storage unit	Capacity: 1 MWh	Response time ≤ 100 ms

From **Table 1**, it can be seen that by reasonably configuring different energy modules, the stability of the system's energy supply can be improved, and the adaptability of the wind-solar-hydrogen-storage system to the oil and gas production scenarios can be enhanced.

3.3. Integrated operation mechanism of wind-solar-hydrogen storage system

The integrated operation mechanism of the wind-solar-hydrogen storage system achieves its goal through a unified energy management platform. This platform enables information exchange and coordinated control among wind power, photovoltaic power, hydrogen production, energy storage, and the load side. During the system operation process, based on the output status of new energy, equipment operating parameters,

and changes in oil and gas production loads, the energy flow should be dynamically adjusted to ensure the stability and coordination of each subsystem. The integrated operation mechanism generally covers four links: data collection, status analysis, energy distribution, and feedback control. By obtaining real-time information such as power, voltage, hydrogen flow rate, and energy storage status, the energy supply and demand balance is achieved.

To evaluate the level of system collaborative operation, an energy matching evaluation model can be established. Through comprehensive analysis of the operating status of each energy unit, energy conversion efficiency, and the degree of supply-demand matching, the overall coordination ability of the wind-solar-hydrogen storage system can be quantitatively reflected:

$$C = \sum_{i=1}^{n} w_i x_i \tag{3}$$

In the formula, C represents the evaluation value of system collaborative operation; wi is the weight of the i-th indicator; xi is the standardized value of the i-th indicator; n is the number of evaluation indicators. In actual operation, the system data collection cycle can be controlled within 100 to 500 ms, and the control response time should be less than 2 seconds, enabling the energy dispatch to quickly adapt to load changes. Through the integrated operation mechanism, the phenomenon of renewable energy abandonment can be reduced, energy utilization efficiency can be improved, and the coordination and unity between the energy supply of oil and gas enterprises and the supply of new energy can be achieved [5].

3.4. Intelligent regulation method driven by multi-source data

The intelligent regulation method driven by multi-source data is of great significance for improving the operational accuracy and automation level of the wind-solar-hydro-storage system. This method mainly relies on sensors, communication networks, and intelligent algorithms to conduct real-time analysis and optimization control of the system operation status. The wind-solar-hydro-storage system of oil and gas enterprises involves various data such as electricity, hydrogen energy, energy storage, and production load. It is necessary to establish a unified data collection and processing platform to achieve information sharing among different energy units. The control system will collect parameters such as wind power generation, electrolyzer load, hydrogen storage pressure, and energy storage capacity, and based on this, determine the current operating status and adjust the equipment operation strategy according to the predicted results. The intelligent regulation operation process of the wind-solar-hydro-storage system is shown in **Figure 2**.

In practical applications, predictive control and intelligent optimization algorithms can be used to respond to changes in the output of new energy in advance, and the data refresh cycle can be controlled within 100 to 500 ms to improve the timeliness of regulation. Moreover, the abnormal identification mechanism can be used to monitor the operation status of the equipment. When the power deviation exceeds the set threshold, the hydrogen production power or energy storage output can be automatically adjusted to ensure the stable operation of the system. Multi-source data fusion can enhance the system's state perception ability, achieve the transformation from traditional passive control to active optimization regulation, and provide technical support for the long-term stable operation of the wind-solar-hydro-storage system of oil and gas enterprises.

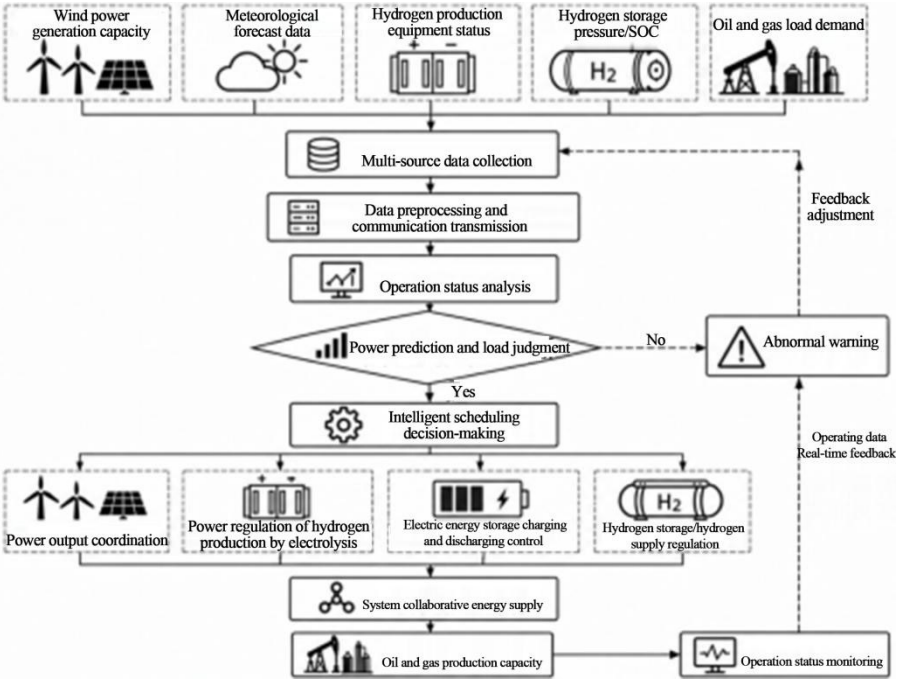


Figure 2. Intelligent control operating flowchart of the wind-solar-hydrogen storage system.

4. Application cases of wind-solar-hydrogen storage system in oil-gas enterprises

4.1. Project overview and system configuration

To verify the application effect of the wind-solar-hydrogen storage system in oil-gas enterprises, a comprehensive energy renovation project of a certain oil-gas production base was selected as a case for analysis. This project combined the regional wind energy and solar energy resource conditions and production energy demand, and constructed an integrated system of wind power generation, hydrogen production, energy storage, and intelligent control. The project was equipped with 5 MW photovoltaic power generation units, 8 MW wind power generation units, 2 MW electrolytic hydrogen production equipment and 500 kg hydrogen storage devices, and also set up a 1 MWh electrical energy storage system, in order to achieve the coordinated operation of new energy production, hydrogen conversion and energy regulation. The system utilized the energy management platform to uniformly monitor the power generation capacity, hydrogen production load, energy storage status and production energy, with the data collection period controlled within 100 to 500 ms. After the system is completed, it can meet the partial production energy demand of the oil-gas stations, reduce the dependence on traditional energy sources, improve the energy consumption absorption capacity, and lay the application foundation for oil-gas enterprises to establish a low-carbon energy supply model.

4.2. Implementation process of system integration construction

The construction of the wind-solar-hydrogen storage system in oil-gas enterprises needs to be carried out in accordance with the production load characteristics and energy supply requirements, and in accordance with the equipment configuration, system joint debugging, and operation optimization process to ensure the stable connection of each subsystem. The specific implementation process is as follows:

(1) Construction of the new energy power supply unit, completing the layout of wind power and photovoltaic equipment based on the resource conditions of the project area, establishing a 5 MW photovoltaic array and 8 MW wind turbine group, and connecting them to the integrated energy control platform through converter equipment to achieve stable output of new energy power.
(2) Integration of a hydrogen production and energy storage system, equipped with 2 MW electrolytic hydrogen production equipment and a 500 kg hydrogen storage device, converting new energy power into hydrogen for storage, and connecting 1 MWh electrical energy storage equipment to achieve short-term power regulation and energy backup.
(3) Deployment of the intelligent control platform, establishing an energy management system to conduct real-time collection of wind power generation capacity, hydrogen production status, energy storage capacity and production load, and using control strategies to achieve automatic adjustment of energy flow, with the system response time controlled within 2 seconds.
(4) System debugging and operation optimization, completing equipment communication, control logic, and safety protection function tests, optimizing for changes in wind power output, hydrogen production load adjustment, and energy storage response capability, to ensure that each energy unit can operate in coordination.

4.3. Evaluation of system operating effect

To evaluate the integrated application effect of the wind-solar-hydrogen storage system, statistical analysis was conducted on the energy utilization efficiency, system response capability and operational stability during the project operation stage. As shown in **Table 2**, after the system was put into operation, the energy consumption absorption capacity was improved, and the energy regulation process was more stable. Among them, the new energy utilization rate reached 92.5%, the operation efficiency of the hydrogen production system reached 75.8%, and the system response time was controlled within 1.8 seconds, which had stronger energy coordination ability compared to the traditional energy supply mode. Moreover, the energy storage unit could effectively suppress the fluctuations of wind power generation and reduce the impact of unstable new energy output on oil-gas production. Through the coordinated operation of wind power generation, hydrogen conversion, energy storage regulation, and intelligent control, the system achieved simultaneous improvement in energy supply stability and utilization efficiency, providing an engineering reference basis for oil-gas enterprises to apply green energy.

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

Evaluation indicators	Before the renovation	After the integrated system is operational
Utilization rate of new energy sources	78.0%	92.5%
Hydrogen production system efficiency	—	75.8%
System response time	5.0 s	1.8 s
Power fluctuation range	±15%	±6%
Energy regulation stability	Generally	Good

As shown in **Table 2**, the wind-solar-hydrogen-storage system, through multi-energy integration and intelligent regulation, effectively improves the energy utilization level and operational stability of oil and gas enterprises, and verifies the feasibility of the system integration scheme.

5. Conclusion

Oil and gas enterprises integrating wind, solar, hydrogen and storage systems can effectively integrate various links such as new energy generation, hydrogen conversion, energy storage regulation, and intelligent control, thereby improving the overall operational efficiency of the energy system. By establishing a multi-energy collaborative framework and optimizing processes such as the integration of wind and solar energy, hydrogen production coupling, energy storage management, and intelligent control, the system can enhance its adaptability to fluctuations in new energy and improve the stability of energy supply. Case studies show that the integrated system has good application value in reducing energy consumption, improving operational reliability, and promoting green transformation. In the future, as new energy technologies and intelligent control technologies continue to develop, the wind, solar, hydrogen and storage system will play an increasingly important role in oil and gas production, base energy supply, and comprehensive energy management, providing continuous support for enterprises' low-carbon development.

Disclosure statement

The author declares no conflict of interest.

References

[1] Cheng S, Han F, Zhang C, et al., 2026, Economic Analysis of a Megawatt-Scale Integrated System of Wind, Solar, Hydrogen and Storage. Low-Carbon Chemistry and Chemical Industry, 51(8): 141–152.

[2] Meng L, Chen X, Hu YT, et al., 2026, Short-Term Supply and Demand Prediction Method for Coupled Application System of Wind, Solar, Hydrogen and Storage Considering Energy Storage Synergy. Automation and Instrumentation, (5): 287–291.

[3] Qian XY, Geng WN, Yuan J, et al., 2026, Modeling and Simulation Analysis of Integrated System of Wind, Solar, Hydrogen and Storage Based on RSOC. Nuclear Technology, 49(5): 137–154.

[4] Shi J, 2025, Capacity Matching and Economic Analysis of Distributed Wind, Solar and Storage System. Power Station Auxiliary Machinery, 46(4): 57–60.

[5] Shen Z, Dou Z, Zhang C, et al., 2022, Design and Integrated Optimization of Comprehensive Energy System of Wind, Solar and Hydrogen. Electric Power and Energy, 43(2): 117–123 + 177.

Publisher's note

Bio-Byword Scientific Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.