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# Research on optimal configuration of natural gas electric hybrid energy system

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**Abstract.** Natural gas resources are crucial for the development of the international community, which has the advantages of energy conservation, economy, and environmental protection. By optimizing the allocation of natural gas energy storage resources, the negative impact of randomness and volatility on the energy system can be effectively suppressed. Therefore, this article proposes a research on optimal configuration of natural gas electric hybrid energy system. Using the investment payback period as the economic evaluation indicator, analyze the influencing factors of the economic performance of the natural gas electricity hybrid energy system from a technical and economic perspective. By using historical data of actual natural gas electricity hybrid energy systems for example calculation and analysis, the configuration method under the proposed strategy was verified to meet the multi time scale requirements of the system while considering equipment characteristics, effectively improving system economy.

**Keywords:** Natural gas, Energy system, Economic analysis, Optimization configuration method

## 1. Introduction

The volatility and randomness of new energy make their large-scale integration complex the structure and operational characteristics of power systems [1-3]. Therefore, the allocation of renewable energy storage is particularly important for improving resource utilization and meeting the requirements of renewable energy station planning [4].

However, a single energy storage technology cannot simultaneously meet the various requirements of the power system at different time scales, while hybrid energy storage technology can achieve complementary advantages of different energy storage technologies and compensate for the shortcomings of a single energy storage [5]. The natural gas distributed cogeneration system is a solution for energy storage. The new structure of natural gas electric hybrid energy systems is increasingly favored.

Many experts and scholars have conducted research on hybrid energy storage systems. Reference [6] proposes a hybrid energy storage system consisting of natural gas storage and batteries, which can effectively cope with complex wind power fluctuations. Reference [7] fully utilizes the different characteristics of lithium battery energy storage using natural gas, and proposes a method for frequency deviation adaptive allocation. Reference [8] constructed a hybrid energy storage system consisting of electrochemical energy storage and natural gas storage. When the battery SOC reaches the upper limit, the excess power is transferred to the electrolytic cell. Reference [9] couples hydrogen storage in new energy power plants and uses a hybrid algorithm to predict power generation using natural gas resources

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and neural networks. Reference [10] proposes an electric hydrogen hybrid energy storage scheme that takes into account the operating characteristics of electrolytic cells.

In summary, existing literature research mainly focuses on traditional power energy systems or natural gas combustion power generation systems. There is not much research on the hybrid energy system of natural gas and electricity. Or simply propose a simple architecture or idea. No optimization configuration and simulation verification were carried out. Therefore, the research focus of this article is on the optimization configuration of natural gas electricity hybrid systems, which is very important.

## 2. Natural gas electricity energy system

### *2.1. Overall architecture of the system*

The overall architecture of the natural gas electricity energy system is shown in Figure 1. The overall architecture is divided into two parts, one is information flow and the other is energy flow. In the energy flow, the new energy station is integrated into the power grid through AC/AC conversion, electrochemical energy storage, and hydrogen energy storage, which are coordinated and output through AC/DC conversion. In the information flow, the energy management system collects real-time output of new energy and the status of each energy storage through smart meters and BMS systems, and calculates the charging and discharging power of each energy storage and sends it to the energy storage converter.

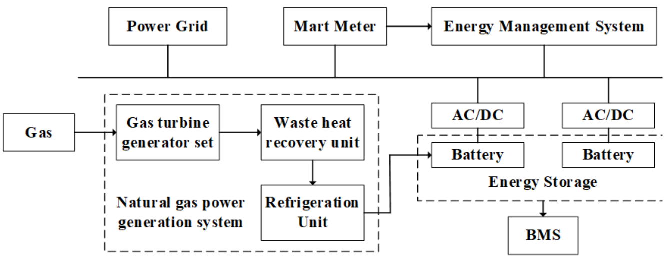


**Figure 1.** The overall architecture of the natural gas electricity energy system

The energy conservation and investment payback period model of the natural gas electricity energy system is as follows.

$$Q_P + Q_a + Q_f = P_e + Q_{eg} + \Delta Q_L \tag{1}$$

In the formula, $Q_P$represents the heat released by the combustion of natural gas. $Q_a$represents the sensible heat value of the air. $Q_f$ represents the sensible heat value of the fuel. $P_e$ represents shaft power. $Q_{eg}$ represents the residual heat from the exhaust gas of the gas turbine. $\Delta Q_L$ represents the heat loss of the gas turbine.

System multifunctional operation strategy

The natural gas electricity energy system, as an important high elasticity resource, can not only reduce the impact of new energy output volatility and randomness on the power grid, but also improve the revenue of wind farms by actively participating in grid frequency regulation, power prediction compensation, and other methods.

(1) Primary frequency modulation scenario

GB/T19963.1-2021 require the wind farms should have the ability to quickly control their own active power, provide inertia response, and perform primary frequency regulation. Reasonable allocation of energy storage in wind farms can provide primary frequency regulation capability.

The participation of energy storage systems in primary frequency regulation often adopts two control methods: droop control of simulated generator sets and virtual inertial control. Based on the above two control methods, the frequency modulation power expression can be obtained.

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$$\Delta P = K_f\left(f_N - f_{pll}\right) + T_j\frac{\Delta f}{\Delta t} \quad (2)$$

In the formula, the first term is the primary frequency regulation of the analog synchronous generator. $K_f$ is the primary frequency regulation coefficient. $f_N$ is the rated frequency of the system. $f_{pll}$ is the real-time frequency of the system. The second item is to simulate the inertial frequency regulation of synchronous generators, where $T_j$ is the inertia coefficient, is the frequency change, and is the time change.

The frequency of the power system fluctuates in real-time and is in dynamic equilibrium. In order to avoid excessive losses caused by frequent charging and discharging of the energy storage system due to its participation in frequency regulation, a frequency regulation dead zone needs to be set, as shown in Figure 2.

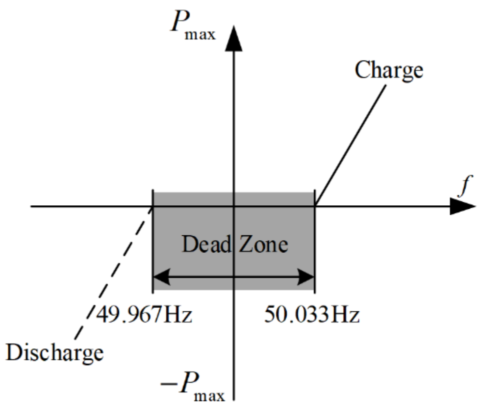


**Figure 2.** Energy storage participation in setting the primary frequency modulation dead band

(2) Power prediction compensation scenario

To prevent frequent switching of charging and discharging states of energy storage batteries, set the upper and lower limits of error bands; When the actual power of the wind farm is greater than the upper limit of the error band, energy storage is charged. As shown in equation:

$$P_{HESS} = \begin{cases} P_t - P_{daiup} & P_t > P_{daiup} \\ 0 & P_{dailow} \le P_t \le P_{daiup} \\ P_t - P_{dailow} & P_t \le P_{dailow} \end{cases} \quad (3)$$

In the formula, $P_t$ represents the real-time output of the power system. $P_{daiup}$ is the upper limit of power prediction error. $P_{dailow}$ is the lower limit of power prediction error.

(3) Consumption scenario

Due to structural contradictions in power sources, limited cross regional channel capabilities, and mismatched source load curves, wind farm output has been restricted to a certain extent. By configuring energy storage, it can cooperate with the large power grid to achieve functions such as peak shaving and valley filling, thereby reducing the curtailment rate of wind farms. The operation mode of the consumption scenario is shown in equation.

$$\begin{cases} P_{HESS}^{ch} = (1 - x\%)P_t & x\% < 100\% \\ P_{HESS}^{disch} = (1 - x\%)P_t & x\% > 100\% \end{cases} \quad (4)$$

In the formula, $P_{HESS}^{ch}$ and $P_{HESS}^{disch}$ respectively represent the charging and discharging power requirements for hybrid energy storage. $x\%$ is the scheduling instruction.

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## 3. Capacity configuration of hybrid energy storage system

### *3.1. Objective function model*

This article aims to achieve the optimal annual comprehensive net income based on the operational characteristics of energy storage systems. The objective functions include electrochemical energy storage costs, natural gas energy storage costs, auxiliary frequency regulation benefits, power prediction compensation benefits, electricity sales benefits, and natural gas sales benefits, as shown in equation.

$$f_1 = \max\left( S_x + S_y + S_f - C_{bess} - C_q \right) \tag{5}$$

In the formula, $S_x$, $S_y$, and $S_f$ respectively represent the benefits generated by new energy consumption, power prediction compensation, and frequency modulation. $C_{bess}$ and $C_q$ represent the costs of electrochemical energy storage systems and natural gas energy storage systems, respectively.

Life Cycle Cost (LCC) refers to the total sum of all direct or indirect expenses that occur or may occur during the entire life cycle of a system, including investment, procurement, operation, maintenance, and recovery. This article constructs an economic model of energy storage systems based on LCC theory.

Based on the operational characteristics of a natural gas electric hybrid energy storage system, this article aims to achieve optimal economic efficiency by using a time-series production simulation method to optimize the configuration of a multifunctional energy storage system in a wind farm. The time-series production simulation method can not only effectively solve the optimization configuration problem of wind farm energy storage systems, but also retain the temporal relationship between the charge state and charging and discharging power of the energy storage system. It is very convenient for analyzing the economic feasibility of configuration schemes.

### *3.2. Time series simulation software*

This article uses GOPT software for simulation. GOPT is a production simulation timing simulation software developed by Tsinghua University. It is an application developed based on the Windows x86 environment. The basic hardware configuration must meet the operational requirements of Windows 2000 and above operating systems.

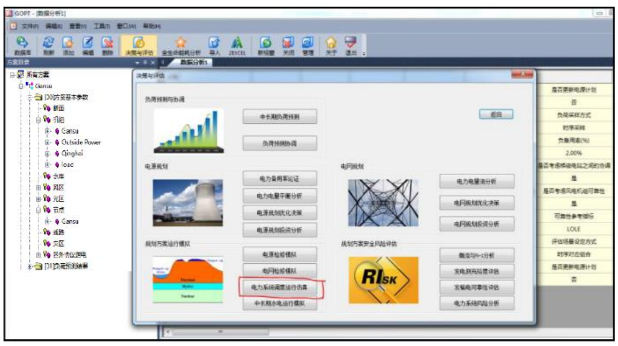

**Figure 3.** The interface of GOPT simulation software

The interface of GOPT simulation software is shown in Figure 3. The software is independently developed by Chinese universities. Therefore, the illustrated interfaces are all in Chinese. And there is no English version available. GOPT software has more advantages in integrating functions compared to other software. Integrate traditional power grids with new energy systems.

## 4. Simulation analysis

This article selects the output data of a 200MW wind farm and the annual frequency and power prediction data of the local power grid to analyze the energy storage configuration for multifunctional applications. The performance and economic parameters of the energy storage system are shown in table 1.

**Table 1.** Example parameter index

| Parameters/Units | Numerical value |
|---|---|
| Discount rate/% | 10 |
| Battery unit capacity price/(10000 yuan/MWh) | 108.5 |
| Battery unit power price/(10000 yuan/MW) | 206.4 |
| Auxiliary cost per unit charge of battery/(10000 yuan/MWh) | 4 |
| Auxiliary cost per unit power of battery/(10000 yuan/MW) | 2.06 |
| Fuel cell unit power auxiliary cost/(10000 yuan/MW) | 6 |
| Upper limit of energy storage SOC | 0.1 |
| Lower limit of energy storage SOC | 0.9 |
| Cost coefficient of natural gas storage tank investment (10000 yuan/m3) | 1.5 |
| Maximum pressure of storage tank/Mpa | 5 |
| Tank temperature/K | 288 |
| Fuel cell unit power price/(10000 yuan/MW) | 500 |

Solve the capacity allocation model through traversal optimization. The optimal capacity allocation results for multifunctional scenarios can be obtained by maximizing net income, as shown in Table 2.

**Table 2.** Capacity configuration results

| Parameters/Units | Natural gas electric hybrid energy storage Numerical value |
|---|---|
| Battery energy storage power/MW | 5 |
| Battery energy storage capacity/MWh | 5 |
| Natural gas storage tank capacity/MWh | 35 |
| Fuel cell power/MW | 1 |
| Cost/10000 yuan | 681.02 |
| Total income/10000 yuan | 1646.4 |
| Net income/10000 yuan | 1005.4 |
| Primary frequency modulation evaluation indicators | 0.02414 |

As shown in the table, compared to a single electrochemical energy storage system, the net profit of the natural gas electricity hybrid energy storage system has significantly increased. The cost was 6.8102 million yuan, and the net income was 10.054 million yuan, an increase of 47.41%. The significant increase in revenue from the consumption of new energy is mainly due to the fact that the consumption of new energy relies more on energy storage capacity. There has also been some improvement in the technical aspect, with the primary frequency modulation evaluation index raised to 0.02414. Verify that the natural gas electricity hybrid energy storage system proposed in this article can consider the annual time series simulation situation, resulting in more accurate capacity allocation results and better economic performance throughout the year.

## 5. Conclusions

This article proposes a research method for optimizing the configuration of natural gas electric hybrid energy systems based on economic analysis. Eliminate the drawbacks of traditional manual experience based configuration methods, and scientifically analyze the influencing factors of the economic

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performance of natural gas electricity hybrid energy systems from a technical and economic perspective. And using actual data for instance calculation and analysis, the correctness of the proposed method was verified, providing guidance for hybrid energy projects.

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