Research on hydrogen energy storage capacity model based on Genetic Algorithm in new power system

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Abstract. In order to promote China's energy revolution and realize China's energy transformation, green and low-carbon energy development and comprehensive green transformation of economic and social development are the keys. Among them, the development of hydrogen energy has great influence and significance on energy saving, emission reduction, deep decarbonization and improvement of utilization efficiency. For the power industry, it is necessary to build a new power system with new energy as the main body. Under this system, this paper establishes a hydrogen energy storage planning model by studying the application scenarios of new energy sources, and uses genetic algorithm to solve it. Finally, a case study proves the rationality of this planning model for hydrogen energy storage planning research, and provides theoretical support and decision-making basis for large-scale investment and operation of similar systems in the future.

1. Introduction
China's goal of "peak carbon dioxide emissions" and "carbon neutrality" will accelerate the evolution of power system to a high-proportion new energy power system based on wind and photovoltaic power generation, and ensuring the stable operation of power system is the core of the transformation of high-proportion new energy power system [1]. As a clean, zero-carbon, multifunctional secondary energy carrier, hydrogen can be exchanged with electric energy and stored efficiently for a long time, which will play an important role in the flexibility adjustment of high-proportion new energy power system [2-3]. The main path of low-carbon transformation of power system is to increase the proportion of new energy generation such as wind power and photovoltaic in primary power. In the application scenario of new energy consumption, the control system adjusts the power ratio of wind power, photovoltaic grid and hydrogen production, absorbs wind power abandoned wind and photovoltaic power grid to the maximum extent, and alleviates the "bottleneck" problem of large-scale wind power and photovoltaic power grid, electrolyzes water to produce hydrogen and secondary oxygen by using the abandoned wind and photovoltaic power grid, and increases the storage density of hydrogen through pressure hydrogen storage. Hydrogen can be used as multi-purpose and high-density clean energy to improve the power quality of wind power grid through FC or H2ICE feedback grid, and can also be used as energy carrier through vehicle or pipeline.
2. New energy consumption application scenarios

In the application scenario of new energy consumption, the control system adjusts the power ratio of wind power, photovoltaic power grid and hydrogen production, absorbs wind power abandoned wind and photovoltaic power grid to the maximum extent, and alleviates the "bottleneck" problem of large-scale wind power and photovoltaic power grid, electrolyzes water to produce hydrogen and secondary oxygen by using the abandoned wind and photovoltaic power grid, and increases the storage density of hydrogen through pressure hydrogen storage. Hydrogen can be used as multi-purpose and high-density clean energy to improve the power quality of wind power grid through FC or H2ICE feedback grid, and can also be used as energy carrier through vehicle or pipeline.

Using clean energy to generate electricity and hydrogen is called green hydrogen, which is an important direction of hydrogen energy development in the future [5]. Electric hydrogen production equipment can tolerate a large degree of input power fluctuation, and large-scale hydrogen production is an effective way to stabilize the fluctuation of new energy output. Under this path, we can give full play to the flexibility of hydrogen production load, deploy large-scale electric hydrogen production facilities through off-grid and grid connection, and track the fluctuating output of new energy power generation in real time at the source side and the grid side, effectively solving the problem of flexible regulation of power system with high proportion of new energy [6].

From the point of view of hydrogen energy preparation, storage and transportation, and terminal utilization, alkaline electrolyzed water and proton exchange membrane electrolyzed water can accept fluctuating power input, and are suitable as the main electric hydrogen production technologies to absorb new energy [7]. Storage and transportation is the key factor that restricts the large-scale development of hydrogen energy. Gas storage and transportation efficiency is low, liquid storage and transportation cost is high, and safe and economical storage and transportation technology needs to be broken through. At present, the key materials of domestic hydrogen storage tanks are imported, and there is a big gap between low-temperature liquid hydrogen technology and hydrogen storage material technology and foreign advanced level, and the industrialization is far away [8]. In terms of terminal utilization of hydrogen energy, hydrogen energy has a certain application prospect in terminal consumption market.

Figure 1. Schematic diagram of new energy consumption and application.
segments such as heavy trucks, and can be used as an important supplement of electric energy. It is estimated that hydrogen energy will account for about 10% of China’s terminal energy consumption in 2050.

3. Hydrogen energy storage planning model

3.1. Objective function

The carbon emission cost is included in the objective function, the economic goal and the low-carbon goal are unified by adding, and the low-carbon economic planning optimization model of electric coupling system based on carbon trading mechanism is established. The economic optimal operation of comprehensive energy system requires the minimum total cost of the system. Consider one-way power supply from power grid to microgrid. Wind turbines and photovoltaics use natural resources to generate electricity, so it can be considered that they have no power generation cost. Therefore, the total cost in the operation of integrated energy system mainly consists of five parts: power grid purchase cost, equipment purchase cost, operation and maintenance cost and total carbon cost. The objective function is:

\[
F = \min\left(f_e + f_{OM} + f_{inv} + f_{CO\text{-}2}\right)
\]

Where, \(F\) is the total cost of the system; \(f_e\) is the cost of purchasing electricity from the power grid; \(f_{OM}\) is the operation and maintenance cost of the system; \(f_{inv}\) is equal annual cost for the initial equipment investment of the system; \(f_{CO\text{-}2}\) is the sum of the purchase cost, capture cost and emission cost of carbon dioxide in the system.

3.2. Constraints

3.2.1. Energy balance constraint

(1) Power constraint. The specific formula is:

\[
P_{e-PV}(t) + P_{e-WT}(t) + P_{e-CHP}(t) + P_{e-grid}(t) = \sum\left(P_{e-load}(t) + P_{e-P2G}(t) + P_{e-Eb}(t)\right)
\]

Where: \(P_{e-grid}(t)\) is the power for the comprehensive energy system to purchase electricity from the power grid (kw); \(P_{e-WT}(t)\) is the output power of wind power generation (kw); \(P_{e-PV}(t)\) is the output power of distributed photovoltaics power generation (kw); \(P_{e-CHP}(t)\) is CHP electric output power (kw); \(P_{e-load}(t)\), \(P_{e-P2G}(t)\), \(P_{e-Eb}(t)\) are the power consumption of users, P2G equipment and electric boilers respectively.

(2) Thermal power constraint. The specific formula is:

\[
P_{h-CHP}(t) + P_{h-Eb}(t) = P_{h-load}(t)
\]

Where: \(P_{h-CHP}(t)\) is CHP heat output power (kw); \(P_{h-Eb}(t)\) is the output power of electric boiler (kw); \(P_{h-load}(t)\) is the heat load in the system (kw).

3.2.2. Energy network constraints

1. Power network constraints

(1) Upper and lower limits of generator set output:

\[
P_{i,max} \leq P_i \leq P_{i,max}
\]

\[
Q_{i,min} \leq Q_i \leq Q_{i,max}
\]

\(P_i\) and \(Q_i\) are the active and reactive output of the generator set at time t: \(P_{i,max}\), \(P_{i,min}\) are the upper and lower limit of the active output of the i generator, and \(Q_{i,max}\), \(Q_{i,min}\) are the upper and lower limit of the reactive output \(i = 1, 2, ..., N\).

(2) Node voltage constraint:

\[
U_{m,min} \leq U_{m,j} \leq U_{m,max}
\]
Where: $U_m$ is the voltage of node $m$ at the moment; $U_m, U_{m,\text{max}}, U_{m,\text{min}}$ are the upper and lower limits of the voltage amplitude of node $m$, $m = 1, 2, ..., Ne$.

(3) Line power constraint:

$$P_{l,\text{min}} \leq P_l \leq P_{l,\text{max}} \quad (6)$$

Where: $P_l$ is the line power flowing through the transmission line $L$, $P_{l,\text{max}}, P_{l,\text{min}}$ are the upper and lower limits of the line power respectively.

3.2.3. Equipment constraints

1. Existing equipment constraints

$$P_{\text{equipment},i,\text{min}} \leq P_{\text{equipment},i} \leq P_{\text{equipment},i,\text{max}} \quad (7)$$

Where: $P_{\text{equipment},i,\text{min}}$ and $P_{\text{equipment},i,\text{max}}$ are the maximum and minimum operating power of the $i$ existing equipment, respectively.

3.3. Genetic algorithm

Conventional genetic algorithm is prone to premature convergence, but it can effectively avoid searching some unnecessary points. Simulated annealing algorithm has strong computational robustness but slow convergence speed. Therefore, the idea of Simulated Annealing (SA) is integrated into the conventional genetic algorithm, the fitness function and crossover operator are improved, and the improved genetic algorithm is adopted to solve the problem, which better solves the shortcomings of premature convergence and poor local search ability of the classical genetic algorithm, and improves the running efficiency and solving quality.

The flow chart of genetic algorithm is as follows.

![Flow chart of genetic algorithm](image-url)
4. Example Analysis of 4 New Energy Stations
Hydrogen production near the wind farm, wind power and hydrogen production plants adopt the mode of self-provided power plant, and use the abandoned wind power to produce electrolyzed water hydrogen. Schematic diagram of self-provided power plant and local utilization mode of hydrogen is shown in Figure 4-5:

![Figure 3. Schematic diagram of self-provided power plant and local utilization mode of hydrogen.](image)

In this basic scheme, hydrogen is produced by using the electricity quantity of 50,000 kW wind farm. Considering wind power abandonment, 14.8% can be used for hydrogen production, and all of them are concentrated in the heating season. It is equipped with three electrolytic hydrogen production equipment units. The first electrolytic cell has a service life of 15 years and can produce 3.6 million m3 of hydrogen annually. Under the constraint of objective function, the installed capacity of hydrogen energy storage is 2853.9KW. Among them, the electric load and heat load in this area are shown in the figure, and the cost composition table under this scheme is shown in the following table.

| project                   | Numerical value (ten thousand yuan) | Construction measurement                                                                 |
|---------------------------|-------------------------------------|------------------------------------------------------------------------------------------|
| Initial investment cost   | 3000                                | The investment of 800 m3/h hydrogen production plant is about 30 million yuan.            |
| running cost              | 130                                 | The annual total operating cost of hydrogen production by electrolysis of water without electricity charge is about 1.3 million yuan. |
| Electricity purchase cost | 7993.48                             |                                                                                          |
| Operation and maintenance cost | 683.76                         | Operation and maintenance fee is 0.42 yuan /m3.                                            |
| total cost                | 11123.48                            |                                                                                          |

![Figure 4. Electrical load](image)

![Figure 5. Thermal load](image)
When the price of hydrogen product is 3.65 yuan /m³, the cash flow at the end of the project life cycle is calculated and solved by the initial cash flow of the project with a life cycle of 15 years, and the internal rate of return is calculated by the equivalent annual income, among which the solution results are shown in the following table.

| Initial cash flow of project | Cash flow at the end of project life | Earnings | internal rate of return |
|-----------------------------|-------------------------------------|----------|-------------------------|
| 111.2348 million yuan       | 832.9119 million yuan               | 13.14 million yuan | 11%                     |

Among them, the internal rate of return is 11%, and the benchmark rate of return of the project is 10%. When the internal rate of return is greater than the benchmark rate of return, the project is feasible. Total cost is 11,123.48 yuan, available NPV 1 = 11,123.48 * (P/A, 10%, 15) - 1314 = 83,291.19 yuan, IRR1=11%, IRR 1 > IC, and the project is feasible.

5. Conclusion
With the rapid development of new energy generation technologies represented by wind power and photovoltaic power generation, the energy field is experiencing profound technological and consumption revolution. While realizing high efficiency, cleanliness and low carbon, it is necessary to solve the problem of power consumption caused by intermittence of new energy.

Hydrogen energy, as a secondary energy source, is a potential solution to this problem. However, by analyzing its basic principle, technical economy and future development potential, it can be clearly seen that hydrogen energy mode is difficult to play a key role in solving future energy and power development problems. At the same time, the establishment of the annual income model of hydrogen refueling station can effectively analyze the comprehensive utilization project of hydrogen energy, and provide theoretical support and decision-making basis for future large-scale investment and operation of similar systems.

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