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Low-carbon economic scheduling optimization of distribution network with hydrogen storage system

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ABSTRACT

Driven by the dual carbon target, renewable energy will be connected to the grid in a large-scale distributed way, and will be mainly concentrated in wind, photovoltaic and land resource-rich distribution network end areas. However, the weak distribution network architecture in these regions and the limited carrying and governance capacity of renewable energy make it difficult to effectively absorb the renewable energy output in peak periods, resulting in large-scale wind and light abandonment.

In response to this problem, this paper adopts a governance idea of using hydrogen energy storage to participate in the renewable energy consumption of the distribution network and meet the demand of users. The use of hydrogen energy storage can not only directly improve the absorption capacity of the distribution network, but also exchange energy with the outside world through the hydrogen network, reduce the dependence of electricity demand side on the distribution network, achieve the "soft off-grid" state, so as to reduce the burden of renewable energy governance of the distribution network, and improve the low-carbon operation economy of the end area of the distribution network.

Keywords: renewable energy consumption, hydrogen storage system, distribution network, low-carbon operation, energy systems

NONMENCLATURE

Abbreviations	
HSS	Hydrogen storage system
CDG	Controllable distributed generator
CCT	Cascade Carbon Trading
TOU	Time-of-use (Electricity Price)

1. INTRODUCTION

Energy transformation is the main path to achieve carbon neutrality, gradually reducing the proportion of fossil energy, and replacing fossil energy with renewable energy is one of the effective measures. However, the market consumption space has gradually become the biggest bottleneck of renewable energy consumption, and the problems of renewable energy consumption and grid-connected power fluctuation at the end of the distribution network need to be solved. At the same time, the large-scale deployment and large-scale access of distributed energy in the traditional distribution network have an impact on the distribution network, which needs to rely on energy storage for peak cutting and valley filling and local consumption of renewable energy, and hydrogen energy is green and clean, has high energy density, rich reserves, long life, easy transportation and storage, and has broad prospects, and has wide application in energy, automotive and other fields, and is of great research value in the future.

In view of this, this paper proposes a distribution network operation and scheduling solution with hydrogen energy storage, which is based on the "electric-hydrogen-electricity" conversion process, mainly including electrolyzer, hydrogen storage tank and fuel cell devices. Use the surplus renewable energy power in the low period to electrolyze water to produce hydrogen, and store it or supply it to the downstream industry; During the peak of electricity consumption, the stored hydrogen energy can be used to generate electricity and incorporated into the public grid by fuel cells. With the advantages of zero carbon emission, federal supply and flexible conversion, HSS has become one of the effective ways to solve the uncertainty of renewable energy[1]. The excess renewable energy is converted into hydrogen energy storage, and converted into electricity and heat energy when needed to release, which can improve the

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power imbalance problem of the integrated energy system and improve the revenue of operators.

Hydrogen energy storage has received more attention in the application of power systems, and many related studies have been carried out at home and abroad in recent years. Teng, Y et al. [2]proposes an electricity heat hydrogen multi-energy storage system (EHH-MESS) and its coordination and optimization operational model to reduce the curtailment of wind power and photovoltaic (PV) to the power grid and improve the flexibility of the power grid. Jia, KY et al. [3] indicate that the integration of gas turbine and hydrogen energy storage reduces carbon emissions and renewable curtailment but with high costs. Meanwhile, The collaborative hydrogen and electrochemical energy storage scheme improves the operating conditions of the gas turbine and significantly saves natural gas consumption, resulting in better system economy and carbon reduction. Based on the mobility characteristics of hydrogen energy storage, Zhu Junpeng et al. [4] proposed a novel optimal scheduling model of active distribution network with high-density RDG to promote the consumption of renewable distributed energy through various active and reactive flexible resources in active distribution network. Huang Yuehua et al. [5] proposed a comprehensive energy low-carbon economic scheduling model that takes into account the correlation of electric-carbon prices and the synergistic effect of hydrogen storage, and verified the effectiveness and rationality of the model to optimize emission reduction and improve comprehensive energy efficiency. Both the traditional carbon trading mechanism and the stepped carbon trading mechanism inhibit carbon dioxide emissions to a certain extent, but compared with the traditional carbon trading mechanism, the stepped carbon trading mechanism plays a more obvious role in reducing carbon [6].

To sum up, compared with the traditional distribution network scheduling based on energy storage batteries, the current research work has not well introduced hydrogen energy storage into the distribution network operation scheduling. At the same time, it is considered that carbon emission quota trading can realize low-carbon scheduling operation and meet the long-term operation goal of the system oriented to carbon neutrality. In view of this, this paper aims to study the dispatching operation of hydrogen-containing energy storage distribution network under distributed energy access, and realize the low-carbon operation optimization of the cascade carbon trading realization system under the condition of meeting the load demand of users.

The rest of this paper is organized as follows: section 2 compares the architecture of traditional distribution network and hydrogen energy storage distribution network, and analyzes the advantages of hydrogen energy storage distribution network architecture; In section 3, the power mathematical model of hydrogen energy storage distribution network system components is established, and the scheduling optimization model of hydrogen energy storage distribution network including cascade carbon trading is proposed with the goal of minimizing system cost. The rest part is the simulation result and conclusion of the case.

2. SYSTEM DESCRIPTION

2.1 Traditional distribution network

The traditional energy storage distribution network is mainly based on batteries, and its main functions include: short-term supplementary power supply, small-scale power peaking and valley filling, improving power quality, and improving the overall performance of the distribution network. In the context of the dual-carbon target era, the distribution network has put forward new demands for energy storage: the need for larger energy storage capacity, the need for diversified distribution of energy storage, the need for high-efficiency charge and discharge energy storage, and the need for long-term cross-quarter energy storage.

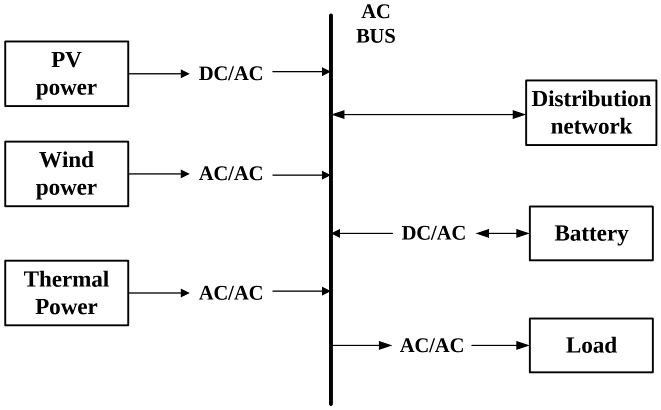


Fig.1. Traditional energy storage distribution network

At the same time, traditional battery energy storage is not enough to meet the above goals because of its own limitations. According to the characteristics of the battery, the larger the battery capacity, the more difficult the heat dissipation, the larger the footprint, the higher the maintenance cost, the more serious the self-discharge phenomenon, the greater the basic investment, and the battery energy density is low, the cycle life is short, the industrial chain has environmental pollution, is not suitable for large-capacity storage. At this time, there is an urgent need for a better energy storage method to undertake this task.

2.2 Hydrogen energy storage distribution network

2.2.1 Advantages of hydrogen energy storage

According to the characteristics of hydrogen energy, the advantages of hydrogen energy storage include: 1. Long discharge time and large capacity scale: hydrogen energy storage has obvious advantages over other energy storage in discharge time (hourly to quarterly) and capacity scale (gigawatt level); 2. High economy of scale: With the increase of energy storage time, the marginal value of hydrogen energy storage system decreases, and the total affordable cost will also decrease, and the cost of large-scale hydrogen storage is an order of magnitude lower than that of electricity storage; 3. Large storage and transportation flexibility: Hydrogen energy can be stored and transported according to actual needs in a variety of different ways, such as long tube trailers, pipeline hydrogen transport; 4. Eco-friendly: Compared with other large-scale energy storage technologies such as pumped storage and compressed air energy storage, hydrogen energy storage does not require specific geographical conditions and will not damage the ecological environment.

Hydrogen energy storage is not subject to regional restrictions, has the characteristics of large capacity, long storage time, easy decay, and flexible use, can effectively supplement the shortcomings of other energy storage, help the development of new power systems, or will become an important technical direction of large-scale energy storage. The storage time and capacity of various energy storage are shown in Fig. 2.

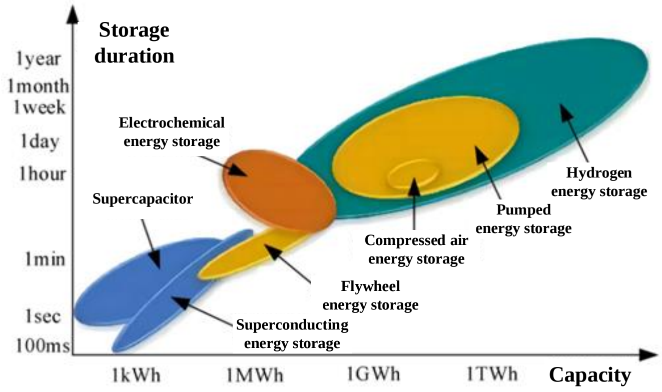


Fig.2. The applicable scope of various energy storage

2.2.2 HSS Distribution network

The structure of hydrogen energy storage distribution network is improved according to the structure of traditional energy storage distribution network, and hydrogen energy storage related equipment is added on the basis of the traditional structure. It mainly includes PV, wind power, CDG (composed of gas turbines), distribution network, hydrogen energy storage system and user load, etc., and according to the characteristics of the equipment, the DC bus is expanded, making the system more flexible operation. In addition to the distribution network, the system can also exchange energy with the outside world through the transportation of hydrogen.

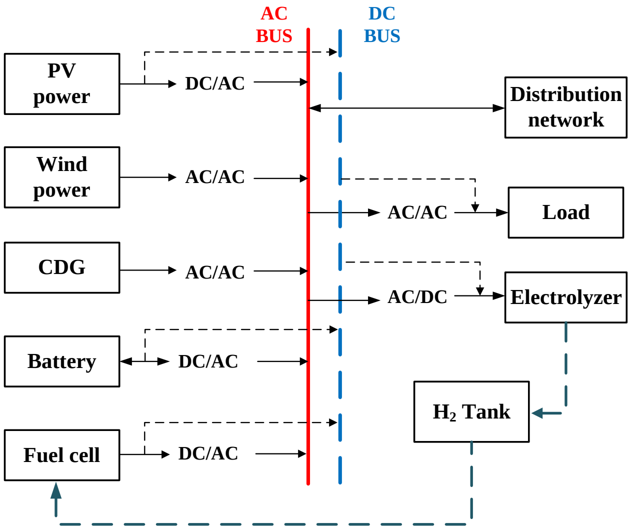


Fig.3. HSS distribution network structure

HSS distribution network has two main advantages over the traditional energy storage distribution network: First, it can solve the problem of "light abandonment" caused by the inability of the distribution network to absorb large-scale photovoltaic output when it is connected to the grid, and increase the installed photovoltaic capacity of the end distribution network. Based on the superiority of hydrogen energy storage in energy storage capacity and energy storage time, hydrogen energy storage can be used to achieve cross-quarter storage and solve the problem of difficult absorption of photovoltaic energy during the summer peak. Second, hydrogen networks can be used to reduce the dependence of photovoltaic power stations on the grid, achieve "soft off-grid" power plants, and further solve renewable energy governance problems such as frequency regulation and voltage regulation.

Renewable energy hydrogen production lacks market competitiveness, and the income from selling electricity is still generally greater than that from selling hydrogen. The root of the problem lies in the high cost of renewable energy electricity. This paper selects the scenario limitations of large capacity generation, small power load and limited carrying capacity of distribution network to ensure the feasibility of the scheme. At the same time, a stepped carbon trading mechanism is used to study the economy and feasibility of dispatching operation of hydrogen energy storage distribution network under the condition of fuel cost.

3. OPTIMAL DISPATCHING MODEL

3.1 The mathematical model of PV

The factors that affect the output of photovoltaic power generation are solar panel temperature, ambient temperature and solar radiation intensity. The output power$P_{\mathrm{pv},t}$ of the photovoltaic system is calculated as follows:

$$P_{\mathrm{pv},t} = P_{\mathrm{pvN}}\left(\frac{G_t}{G_{\mathrm{ref}}}\right)\left[1+\alpha(T_t - T_{\mathrm{ref}})\right] \tag{1}$$

$$T_t = T + 30\frac{G_t}{1000} \tag{2}$$

where P_{pvN} is the rated capacity of photovoltaic power generation, $G_t$is the solar irradiation intensity during the period t, $G_{\mathrm{ref}}$is the reference irradiation intensity, $\alpha$is the temperature coefficient, T_t is the operating temperature of photovoltaic cells during the period t, T_{ref} is the operating reference temperature of photovoltaic cells, and $T$is the ambient temperature at the time t.

3.2 The mathematical model of WIND

Without considering the delay effect and wake effect of wind farm, the theoretical output expression is as follows:

$$\begin{cases} P_{\mathrm{w},t} = 0, & V_{\mathrm{w},t} < V_{\mathrm{in}} \\ P_{\mathrm{w},t} = P_{w\_rated} \times \frac{V_{\mathrm{w},t}^3 - V_{\mathrm{in}}{}^3}{V_{\mathrm{rated}}{}^3 - V_{\mathrm{in}}^3}, & V_{\mathrm{in}} \leq V_{\mathrm{w},t} < V_{rated} \\ P_{\mathrm{w},t} = P_{w\_rated}, & V_{\mathrm{rated}} \leq V_{\mathrm{w},t} < V_{\mathrm{out}} \\ P_{\mathrm{w},t} = 0, & V_{\mathrm{out}} \leq V_{\mathrm{w},t} \end{cases} \tag{3}$$

where, $P_{\mathrm{w},t}$is the output power of the wind farm during the t period, N is the number of grid-connected wind turbines of the wind farm, $P_{\mathrm{w},rated}$ is the rated power of the wind turbine, $V_{\mathrm{w},t}$ is the operating wind speed of the wind turbine during the t period, V_{rated} is the rated wind speed of the wind turbine, and V_{in} is the input-wind speed of the wind turbine. V_{out} cuts out the wind speed for the wind turbine.

3.3 The mathematical model of CDG

Traditional distribution networks usually have CDGs such as thermal power generation, which will emit a lot of carbon dioxide during operation, which is directly related to the carbon emission quota trading of the system. C_{CDG} consists of gas turbines, including fuel costs, maintenance costs, etc. In system optimization, its model can be expressed as a quadratic function:

$$C_{CDG} = \sum_{t=1}^{T}\left(\rho_{on/off} M_{CDG,t} + \gamma_{CDG} P_{CDG,t}\right) \tag{4}$$

where, $P_{CDG,t}$ is the power generation of the gas turbine at time t; $\rho_{on/off}$ is the CDG operating state fixed cost, with a value of 200; $M_{CDG,t}$ is the running state of the CDG (variable 0-1); γ_{CDG} is the cost coefficient after piecewise linearization of the second-order cost function during CDG operation, and the value is 300 yuan /kw.

3.4 *The mathematical model of Battery*

As a stable energy storage device, the battery can simultaneously store excess energy and release the balance of energy. The expression of the relationship between power and charge state is as follows:

$$\begin{aligned} \mathrm{SOC}_t = \mathrm{SOC}_{t0} + \big[&n_{\mathrm{ch}} P_{\mathrm{ch,t}}/P_{\mathrm{bat,rated}} - \\ &n_{\mathrm{dis}} P_{\mathrm{dis,t}}/P_{\mathrm{bat,rated}}\big]\Delta t \end{aligned} \tag{5}$$

SOC_{t0}indicates the charged state of the battery at t_0. $P_{\mathrm{ch,t}}$ and $P_{\mathrm{dis,t}}$ are the charging and discharging power of the battery at time t, respectively. n_{ch} for battery charging efficiency; n_{dis} is the discharge efficiency, which is 90% in this paper. $P_{\mathrm{bat,rated}}$ is its rated capacity; Δt represents the time step.

3.5 The mathematical model of HSS

The HSS selected in this paper has two processes of hydrogen production in electrolytic cell and hydrogen fuel cell power generation, and also has the service of selling excess hydrogen. The HSS model is as follows:

$$H_{2,el,t} = \xi_{el} \cdot P_{el,t} \tag{6}$$

$$P_{fc,t} = \xi_{fc} \cdot H_{2,fc,t} \tag{7}$$

$$S_{H,t} = S_{H,t-1} + \left(H_{2,\mathrm{el},t}\right)\Delta t - \left(H_{2,\mathrm{fc},t} + H_{2,\,\mathrm{sell}\,,t}\right)\Delta t \tag{8}$$

$$S_H^{min} \leq S_{H,t} \leq S_H^{max} \tag{9}$$

Equations (6) and (7) are constraints of hydrogen production and fuel cell power generation. Equations (8) and (9) are the constraints of hydrogen state of hydrogen tank. $P_{el,t}$ and $P_{fc,t}$ are the power of hydrogen production and fuel cell power generation during the period t, respectively; ξ_{el} is the loss coefficient of hydrogen production, and the unit is 0.23Nm^3/MW; ξ_{fc}

is the loss coefficient of fuel cell power generation, and the unit is 0.295MW/ $Nm^{3\cdot}$ $S_{H,t}$ is the hydrogen state of hydrogen storage tank.

3.6 *Cascade Carbon Trading (CCT) model*

In this paper, the power purchased by the system from the power network is generated by thermal power units. Therefore, there are two carbon emission sources in the system: purchased power and CDG. The amount of unpaid carbon emission is determined by equation (14) :

$$E_L = \delta \sum_{t=1}^{T} \left(P_{grid,t}\Delta t + P_{CDG,t}\Delta t\right) \tag{10}$$

where E_L is the gratuitous carbon emission amount of the system; T is the total number of one-day periods, which is 24 hours; t indicates the unit period length, which is 1 h. δ is the emission share of unit electricity. In this paper, the weighted average value of marginal emission factor and marginal capacity factor of regional electricity is 0.648. $P_{grid,t}$ is the purchased power in unit period t; $P_{CDG,t}$ is the internal combustion turbine output per unit period t.

The actual carbon emission of the system is determined by equation (15) :

$$E_P = \sum_{t=1}^{T} \left(\chi_e P_{grid,t} + \chi_f P_{CDG,t}\right) \tag{11}$$

where E_P is the actual carbon emission; χ_e is the amount of carbon emitted by the system when a unit of electricity is purchased from the grid, and χ_f is the carbon emission factor of CDG operation. $P_{CDG,t}$ is the internal combustion turbine output per unit period t.

In order to further control the total amount of carbon emissions, this paper constructs a step carbon trading cost calculation model. Based on the allocated free carbon emission amount, a number of emission ranges are specified, and the higher the emission range, the higher the corresponding carbon trading price. The formula for calculating the carbon trading cost of ladder type is as follows:

$$F_C = \begin{cases} \lambda(E_P - E_L) & E_P \leqslant E_L + d \\ \lambda d + (1+\sigma)\lambda(E_P - E_L - d) & \\ & E_L + d < E_P \leqslant E_L + 2d \\ (2+\sigma)\lambda d + (1+2\sigma)\lambda(E_P - E_L - 2d) & \\ & E_L + 2d < E_P \leqslant E_L + 3d \\ (3+3\sigma)\lambda d + (1+3\sigma)\lambda(E_P - E_L - 3d) & \\ & E_L + 3d < E_P \leqslant E_L + 4d \\ (4+6\sigma)\lambda d + (1+4\sigma)\lambda(E_P - E_L - 4d) & \\ & E_P > E_L + 4d \end{cases} \tag{12}$$

where F_C is the system carbon trading cost; λ is the carbon trading price of market soil; d is the length of carbon emission interval; σ is the increase in the carbon price of each ladder, and for each step up, the carbon price increases by $\sigma\lambda$. When $E_P < E_L$, F_C will be negative, indicating that the actual carbon emission of the system is lower than the unpaid carbon emission amount, and the carbon trading income can be obtained from the excess share at the initial carbon trading price.

3.7 *Low-carbon dispatch optimization model*

3.7.1 *Objective function*

In the case of system power balance, the minimum daily operating cost is taken as the objective function, and its expression is

$$\min C_{total} = C_t + C_y + C_{CDG} + F_C + R_{Hsell} \tag{13}$$

$$C_t = \sum_{i} c_{i,t} P_{i,rated} \tag{14}$$

where: $c_{i,t}$ is the construction cost factor of the i system unit; $P_{i,rated}$ is the rated capacity of the i system unit; irepresents wind turbine, photovoltaic cell, gas turbines, battery, electrolytic cell, fuel cell, hydrogen storage tank ,$i = \{wind, pv, CDG, bat, el, fc, Ht\}$。

$$C_{OM} = \sum_{t=1}^{T} \left(\sum_{i} k_i P_i + k_{Ht} E_{Ht} + C_{Grid}\right) \tag{15}$$

where k_i is the unit operation and maintenance cost of the component [ten thousand yuan /(kW-h)]; P_i is the daily operating power of energy storage components; $E_{Ht}$is the hydrogen storage capacity. C_{CDG}, F_C are the cost of construction and operation of controllable distributed generator and the cost of stepped carbon trading mechanism respectively. C_{Grid} is the cost of buying and selling electricity for system operation.

3.7.2 *Constraint conditions*

i. Power balance constraints

$$P_{el,t} + P_{load,t} = P_{wt,t} + P_{pv,t} + P_{gt,t} + P_{fc,t} + P_{bat,t} + P_{grid,t} \tag{16}$$

In formula (16), $P_{wt,t}$, $P_{pv,t}$, $P_{gt,t}$, $P_{fc,t}$, $P_{bat,t}$, $P_{el,t}$, $P_{load,t}$ are the power of wind power, photovoltaic power, gas turbine, fuel cell, battery, electrolytic cell and load at time t, respectively. When $P_{bat,t} < 0$, the battery is in charge state, when $P_{bat,t} > 0$ the battery is in discharge state; $P_{grid,t} < 0$ indicates power supply to the grid, $P_{grid,t} > 0$ indicates power purchase from the grid.

ii. Battery constraint condition

$$P_{bat}^{min} < P_{bat,t} < P_{bat}^{max} \tag{17}$$

$$SOC_{min} < SOC_t < SOC_{max} \tag{18}$$

In the formula (17)-(18), P_{bat}^{min} is the lower limit of battery charging and discharging; P_{bat}^{max} is the upper limit of charge and discharge power; SOC_{min} and $SOC_{max}$are the lower limit and upper limit of the battery charging state respectively.

iii. HSS constraint condition

Equations (19)-(22) are constraints of hydrogen storage and hydrogen selling.

$$P_{el}^{min} \cdot D_{el} \le P_{el,t} \le P_{el}^{max} \cdot D_{el} \tag{19}$$

$$P_{fc}^{min} \cdot D_{fc} \le P_{fc,t} \le P_{fc}^{max} \cdot D_{fc} \tag{20}$$

$$H_{2,\text{ sell}}^{min} \le H_{2,\text{ sell },t} \le H_{2,\text{ sell}}^{max} \tag{21}$$

$$D_{el} + D_{fc} \le 1 \tag{22}$$

$H_{2,el,t}$, $H_{2,fc,t}$ and $H_{2,\text{ sell },t}$ are the hydrogen of hydrogen production, fuel cell power generation and hydrogen selling, respectively; D_{el} and D_{fc} are binary variables and represent the status of hydrogen production and fuel cell power generation. P_{el}^{max} and P_{el}^{min} are the upper and lower bounds of the power of hydrogen production, respectively; P_{fc}^{max} and P_{fc}^{min} are the upper and lower bounds of the power of fuel cell power generation, respectively; $H_{2,\text{ sell}}^{max}$ and $H_{2,\text{ sell}}^{min}$ are the upper and lower bounds of hydrogen selling, respectively.

4. SIMULATION AND RESULTS

In order to understand the impact of Time-of-use electricity price (TOU) and increased hydrogen selling function on the system, this paper carries out technical and economic analysis under TOU/ Fixed electricity price form and whether hydrogen is sold or not. A comparative analysis is made on the combination of hydrogen-electric hybrid energy storage and only hydrogen energy storage to verify the research idea of using hydrogen storage to participate in the consumption of renewable energy in the distribution network to meet the needs of users.

4.1 System parameter setting

Wind power and photovoltaic power were obtained by selecting wind speed, light intensity and temperature data self-measured in a self-sustaining wind power photovoltaic field of a new energy enterprise in Chongqing and inputting 1MW WIND +1MW PV array system. In this paper, the fixed power purchase price is set at 0.65 yuan /kWh and the fixed power sale price is 0.42 yuan /kWh. Table 1 shows the TOU value. In order to simulate the conditions of the interaction between the distribution network and the grid in remote areas, the maximum purchased and sold electricity is set at 300kw.

Table 1. Time-of-use electricity price

Period	Time period	Purchase(¥/kwh)	Selling (¥/kwh)
Trough	00:00-08:00	0.37	0.28
Peak	08:00-12:00 17:00-21:00	0.87	0.72
Ordinary	21:00-24:00	0.69	0.53

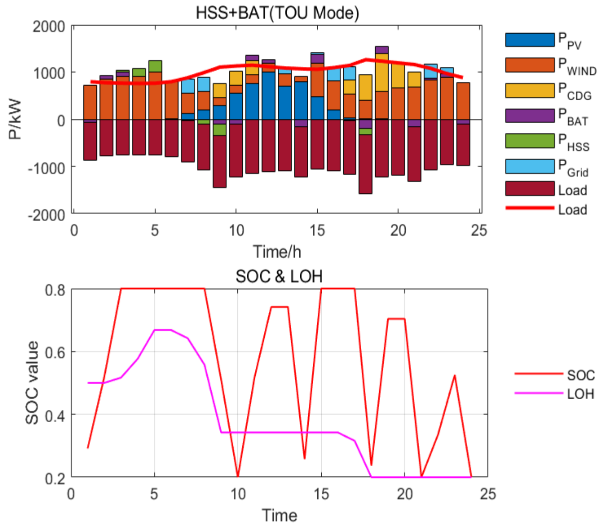
When the system runs under the condition of TOU mode, the system does not purchase power at the peak of the power purchase price and does not sell power at the trough of the power sale price. The hydrogen sale price is 22 yuan/kg and 40kg of gas demand will be generated when the system is equipped with the hydrogen sale function.

4.2 Problem analysis

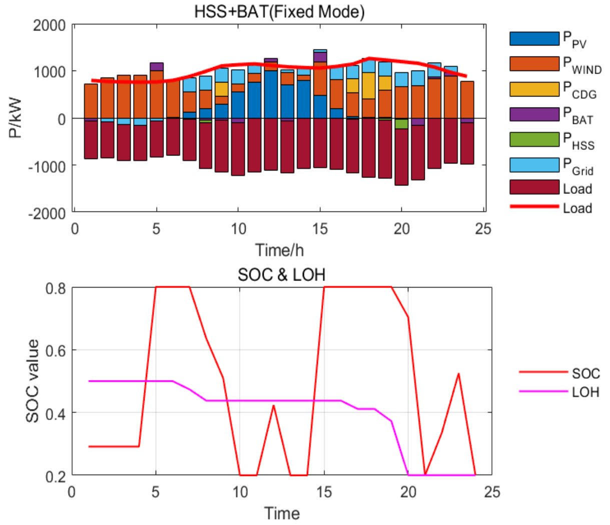
The mixed integer linear programming (MILP) problem of system scheduling in this paper is solved by using CPLEX solver of MATLAB. According to the system operation configuration conditions, it is divided into 8 system low-carbon operation scheduling case: ① HSS+BAT (TOU Mode); ② HSS+BAT (Fixed Mode); ③ HSS+BAT+H_2-selling(TOU Mode); ④ HSS+BAT+H_2-selling (Fixed Mode);⑤HSS(TOU Mode);⑥HSS(Fixed Mode);⑦ HSS+H_2-selling(TOU Mode); ⑧ HSS+H_2-selling (Fixed Mode);

4.3 Results

This paper shows the system scheduling results of HSS+BAT hybrid energy storage configuration and HSS+BAT+H_2-selling configuration under TOU/Fixed mode, as shown in Fig. 4-5. The scheduling trends of the remaining system configuration scenarios are similar to those of the following four configurations. Therefore, this document does not describe them.

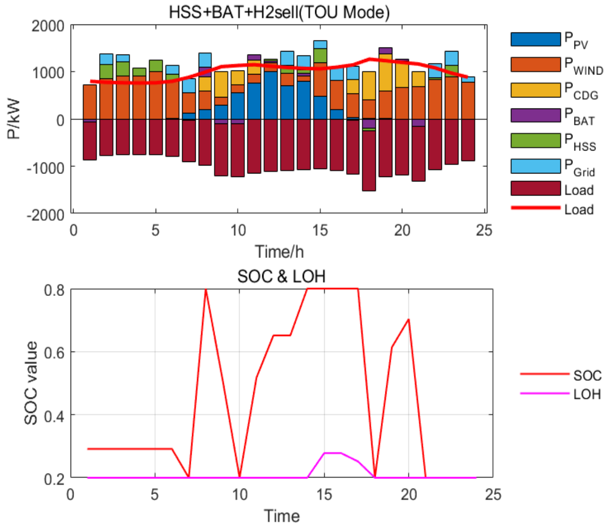


a. TOU Electricity Price Mode

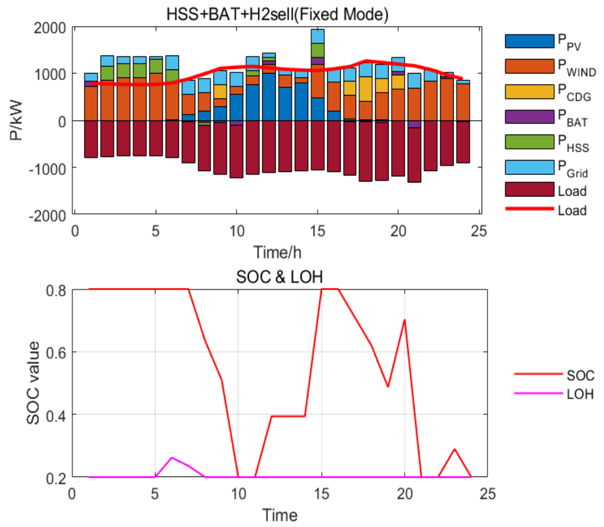


b.Fixed Electricity Price Mode

Fig.4. Scheduling result of HSS+BAT



a. TOU Electricity Price Mode



b. Fixed Electricity Price Mode

Fig.5. Scheduling result of HSS+BAT

Table2 -Table3 shows the comparative economic analysis of eight system configuration scenarios TOU_2 is the case where the strategy of "No electricity purchase at peak price and no electricity sale at low price" is not adopted under TOU price, while TOU_1 is the opposite.

Table 2. Economic analysis of HSS+BAT and HSS

Case		HSS+BAT		HSS	
Electricity price form		TOU	Fixed	TOU	Fixed
C_{Grid}/¥	TOU_1	653	2329	568	2107
	TOU_2	1308		1166	
C_{CDG}/¥		1011838	438510	1162615	611559
C_{MCT}/¥		37159	94461	36284	90748
C_{OM}/¥		5833663	5710744	5897251	5705327
C_{total}/¥	TOU_1	15277661	14638716	16286150	15597634
	TOU_2	14637695		15596693	
CO_2/t		3961	5065	4278	5312
Self-balancing rate /%		92.71	84.04	92.67	84.44

Table 3. Economic analysis of HSS+BAT and HSS with hydrogen sale function

Case		HSS+BAT+Hsell		HSS+Hsell	
Electricity price form		TOU	Fixed	TOU	Fixed
C_{Grid}/¥	TOU_1	1177	3519	1414	3510
	TOU_2	2003		1998	
C_{CDG}/¥		1197480	519738	1194525	632262
C_{MCT}/¥		71557	136991	87769	135499
C_{OM}/¥		6149508	6139452	6423298	6274474
C_{total}/¥	TOU_1	15812665	15190301	16895592	16232236
	TOU_2	15188785		16230724	
CO_2/t		5867	6902	6553	7115
Self-balancing rate /%		86.87	77.65	84.22	77.7

4.4 DISCUSSION

1. From the perspective of HSS+BAT/ HSS selection, the economic analysis results in Table 2 show that the total cost of the former is 1023067 yuan lower on average than that of the latter, and the carbon emission of HSS+BAT is 6.7% lower on average than that of HSS. Compared with HSS, the self-balancing rate of HSS+BAT is not much different, but among the four schemes that do not have the function of selling hydrogen, the power purchase cost of HSS+BAT is higher, and the power purchase cost of TOU electricity price mode is much lower than that of Fixed electricity price mode. Therefore, HSS+BAT has better economy.

2. From the perspective of whether the hydrogen selling function is configured, the constraint of 40kg hydrogen selling capacity must be met in 24h based on the paper, and the total cost of the HSS+BAT+H_2sell/ HSS+H_2sell scheduling scheme configured with hydrogen selling function increases by 582,658 yuan on average, carbon emissions increase by 1955t on average, and the self-balancing rate decreases by 6.85% on average.

As can be seen from the internal scheduling results in Fig. 5, the change of LOH in the state of charge of hydrogen energy storage decreases after hydrogen sale function is added, and more hydrogen sale is carried out instead of hydrogen storage after hydrogen production in the electrolyzer. In view of this, the overall cost and dependence on the power grid increase after hydrogen sale function is equipped, so the system configuration in this paper chooses not to add hydrogen sale function.

3. From the perspective of TOU/fixed price mode operation, under the TOU_1 mode of "No electricity purchase at peak price and no electricity sale at low price" strategy set in this paper, compared with the Fixed electricity price, the average cost of electricity purchase is reduced by 1913 yuan, the average carbon emission is reduced by 934 t, and the self-balance rate is increased by 8.16 %.

In TOU_2 mode, the average cost of electricity purchase is reduced by 1247 yuan. However, since there is no restriction prohibiting the purchase and sale of electricity in TOU_2 mode, compared with TOU_1 mode, which greatly increases the total cost of the system, TOU_2 can reduce the total cost of the system to a small extent. Therefore, according to the scheduling restriction in the paper, the electricity price required by TOU is more economical than the fixed price.

5. CONCLUSION

Aiming at the low-carbon scheduling problem of the distribution network with hydrogen storage system, this paper makes economic comparison and analysis from the aspects of the selection of hybrid energy storage/hydrogen storage system and whether the system chooses to sell hydrogen, and optimizes the selection of the distribution network scheduling scheme with hydrogen storage system: HSS+BAT (TOU Mode).

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