Optimal scheduling of wind-electricity-gas energy system considering ladder carbon trading

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ABSTRACT

The integrated energy system(IES) contributes to the target of " double carbon". In the wind-electricity-gas energy optimization, a scheduling model is proposed in this paper considering the minimum sum of the three costs of energy purchased, carbon transaction and abandoned wind as the objective function with the ladder carbon trading. Then compare the results of scheduling in scenarios which set up differently, and analyze the data of carbon emissions and different type cost in scenarios which is set up four. Finally, the environmental protection coefficient 'a' and the economic coefficient 'b' of the four scenarios are compared. It is concluded that the IES with P2G equipment under the stepped carbon trading in scenario 4 achieve the optimal balance on 'a' and 'b', which verifies the superiority of the model.

Keywords: Integrated energy system, Ladder carbon Trading, Electric hydrogen production equipment

1. INTRODUCTION

At the time of the 75th United Nations General Assembly, Xijinping puts forward the development goal of "China's carbon dioxide emissions will strive to reach the peak by 2030, and strive to achieve carbon neutrality by 2060[1]".

At the development and progress of times, the era needs more types of energy. It becomes the focus of supplying energy efficiently and economically, the integrated energy system came into being[2].

In a certain area, the IES can integrate and utilize different energy by means of different coupling equipment in the system. The IES not only improves the utilization rate of primary energy, but also promotes the consumption capacity of renewable energy [3].

In the era of the "carbon neutral", there are also studies on low-carbon operations in the literature on optimal scheduling of IES. Literature [4] studied the effect of setting carbon trading coefficient to reduce emission; Literature [5] studied set a ladder carbon price to reduce carbon emissions under the ladder carbon trading mechanism; Literature [6-7] had introduced carbon trading mechanism and compared different carbon trading to limit carbon emissions. Although the carbon emission reduces on the ladder carbon trading, the cost increase significantly. Therefore, this paper introduces P2G.

A model was posed, which considers economic and environment protecting under the carbon trading mechanism. This model can balance the economy and environment protecting of optimal scheduling. The model takes the cost of energy purchased, carbon transaction and wind abandonment as the objective function. With the comparison of different scenarios, the model is proved to be superior in operation by comparing the environmental protection coefficient 'a' and the economic coefficient 'b' to verify that with P2G reach the optimal balance under the ladder carbon trading.

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2. STRUCTURE OF IES

The IES enables synergy of different energy, improves energy efficiency, and meets the needs of users with a variety of energy sources while ensuring continuous and reliable functions[8]. The energy established mainly comes from power、gas grid and wind power. The energy conversion mainly includes CHP, P2G and GB (Gas Boiler). The CHP, P2G and gas boiler (GB) are all energy coupling devices. The IES also includes electric and thermal energy storage devices to store energy, and there are two kinds of user loads on the demand side. Power-to-gas technology enhances electrical coupling and flexible scheduling of wind power in low-cost periods, which is an important technology for accommodating wind curtailment and optimizing wind power scheduling[9].

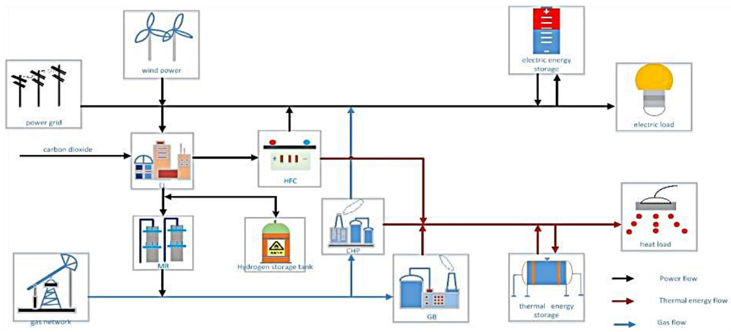

Figure 1. Structure of IES.

3. IES OPTIMAL SCHEDUALING MODEL

3.1 Carbon trading cost

3.1.1 Carbon trading

Carbon emission rights be referred as economically schedulable resources by introducing carbon trading mechanism [10]. Therefore, the actual amount of emissions participating in the market is:

$$E_{IES,\mathrm{t}} = E_{IES,\ \mathrm{a}} - E_{IES} \tag{1}$$

In the equations: $E_{IES,\ \mathrm{t}}$ is IES's carbon emissions trading volume; $E_{IES,\ \mathrm{a}}$ is the actual carbon emissions; E_{IES} is the quota of system.

Ladder carbon trading model:

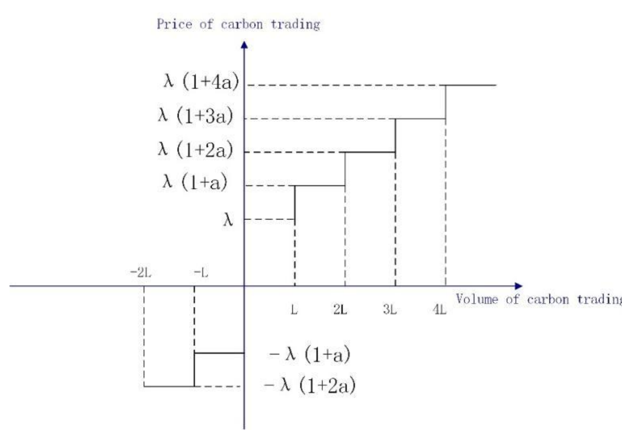

Figure 2. Price of carbon trading.

3.1.2 Mode of carbon emission quota

Emission sources mainly come from CHP, GB (gas boiler) and electricity and gas energy. The carbon emission quota model is:

$$E_{IES} = E_{e,buy} + E_{GT} + E_{GB} \tag{2}$$

In the equations: E_{IES}、$E_{e,buy}$、E_{CHP}、E_{GB} is the emission quota of IES、Purchased electricity、CHP and GB.

3.1.3 Mode of actual carbon emission

$$E_{IES,a} = E_{e,buy,a} + E_{total,a} - E_{MR,a} \tag{3}$$

In the equations: $E_{IES,a}$、$E_{e,buy,a}$ are actual carbon emissions for electricity purchased and IES ; $E_{total,a}$ is the actual amount of CO_2 for GHP and GB; $E_{MR,a}$ is actual CO_2 absorbed by MR.

3.2 Objective Function

The economic maximization of the IES is realized in the condition of satisfying the constraints. The optimization of IES scheduling model is constructed by the objective function of the cost of wind abandonment、energy purchased and carbon trading .

$$C = \min(C_{DG,cut} + C_{buy} + C_{CO_2}^{price}) \tag{4}$$

Energy purchase cost:

$$C_{buy} = \sum_{t=1}^{T} \alpha_t P_{e,buy(t)} + \sum_{t=1}^{T} \beta_t P_{g,buy}(t) \tag{5}$$

Cost of wind abandonment:

$$C_{DG,cut} = \omega_{DG} \sum_{t=1}^{T} P_{DG,cut}(t) \tag{6}$$

Carbon trading cost:

see Figure 2 above.

3.3 Constraint condition

CHP constraint:

$$\begin{cases} P_{g,CHP}^{min} \le P_{g,CHP}(t) \le P_{g,CHP}^{max} \\ \Delta P_{g,CHP}^{min} \le P_{g,CHP}(t+1) - P_{g,CHP}(t) \le \Delta P_{g,CHP}^{max} \end{cases} \tag{7}$$

In the equations: $P_{g,CHP}(t)$ is the gas power into CHP; $P_{g,CHP}^{max}$、$P_{g,CHP}^{min}$ are the range boundary of natural gas inputting CHP; $\Delta P_{g,CHP}^{max}$、$\Delta P_{g,CHP}^{min}$ are limits of climbing power.

Wind power output constraints:

$$0 \le P_{DG}(t) \le P_{DG}^{max}(t) \tag{8}$$

In the equations: $P_{DG}(t)$ is the wind power; $P_{DG}^{max}(t)$ is maximum that wind power can output power.

Power balance constraints:

$$P_{CHP,h}(t) + P_{GB,h}(t) = P_{h,CHP}(t) + P_{ES}^{h}(t) \tag{9}$$

$$P_{g,buy}(t) = P_{g,GB}(t) + P_{g,GT}(t) - P_{P2G,g}(t) \tag{10}$$

$$P_{e,buy}(t) = P_{e,Load}(t) + P_{e,P2G}(t) + P_{ES}^{e}(t) - P_{DG}(t) - P_{GT,e}(t) \tag{11}$$

In the equations: $P_{h,Load}(t)$ 、 $P_{e,Load}(t)$ indicates heat and electrical load; $P_{ES}^{h}(t)$ 、 $P_{ES}^{e}(t)$ indicate the thermal and electrical power which inputs storage device ; $P_{e,P2G}(t)$ Indicates the power input to P2G device; $P_{e,buy}(t)$ indicates the power purchased from power grid.

4. RESULT ANALYSIS

4.1 Operation results

Take 24 hours in a day as a cycle. The electricity 、natural gas price as Fig. 3. Fig.3 also shows the prediction results of various load demands and wind power output in one day. Four scenarios were set up as Table 3.Set up $L = 2t; a = 25\%; \lambda = 50$ yuan / t on trading. Using cplex solver in MATLAB operate the model.

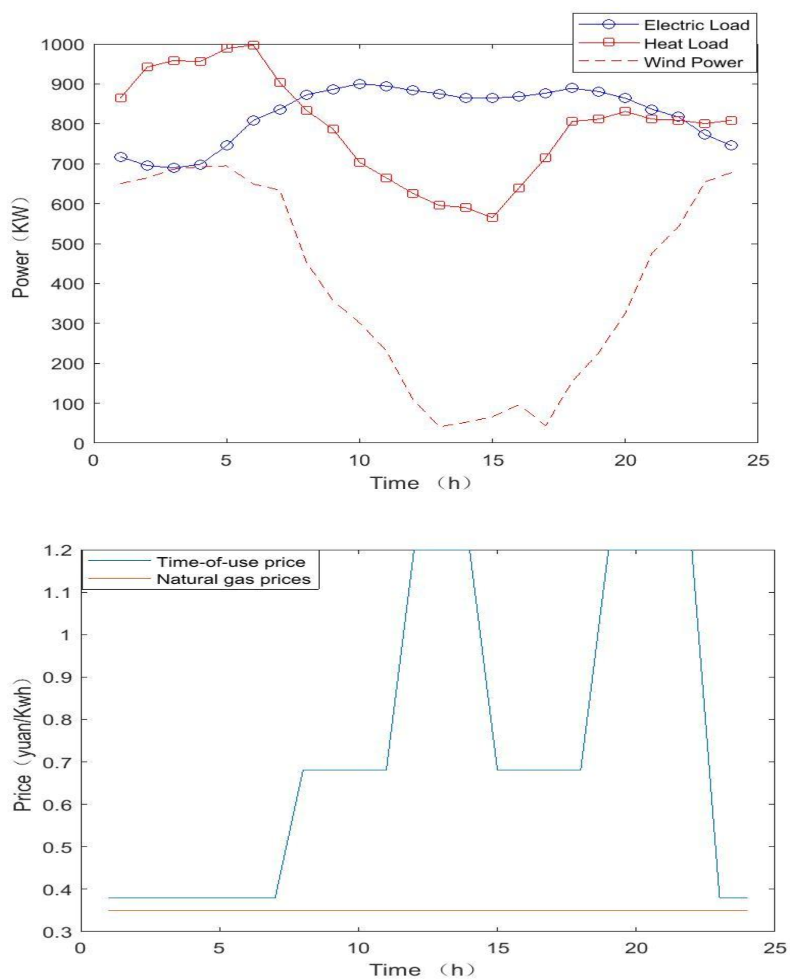

Figure 3. Load curve, wind power forecast and time-of use electricity 、 gas price

Table 1. Set up scenarios

Scenario	Scenario1	Scenario2	Scenario3	Scenario4
Ordinary carbon trade	√	√		
Ladder carbon trading			√	√
P2G		√		√

Table 2. Cost comparison under different scenarios

Parameter value	Scenario1	Scenario2	Scenario3	Scenario4
Carbon emission /kg	10678	8877.5	10233	8039.7
Carbon trading cost /yuan	-221.5	187.9	817.3	602.3
Electricity purchase cost /yuan	1405.6	1391.2	1405.6	1388.8
Gas purchase cost/yuan	6605.4	5781.2	6605.4	5784.5
Abandon wind cost/yuan	482.9	0	482.9	0
Total cost/yuan	8272.3	7361.3	9311.2	7775.6
Cost reduction rate	12.38%		19.75%	

On ordinary carbon trading, the carbon emissions in Scenario 2 are significantly reduced by 16.86 % compared with Scenario 1. Because P2G contains the MR, the device is capable of absorbing CO2 and synthesizing natural gas supply gas loads. It can be seen that the P2G devices in Scenario 2 can reduce CO2 emissions, and the cost of Scenario 2 is significantly lower than the cost of Scenario 1 on the condition of satisfying the gas load.

In addition, P2G devices can convert electrical energy to avoid waste. Therefore, the cost of wind abandonment in scenario 2 with P2G equipment is zero with the ordinary carbon trading, reducing wind abandonment and improving environmental protection. And compared to Scenario 1, the cost in Scenario 2 with P2G devices is also decrease 12.38 %.

P2G is not included in the comparison scenario: Compared with Scenario 1, Scenario 3 reduces emissions by 445Kg and increases the total cost by 1038.9 yuan; P2G is included in the comparison scenario: Compared with Scenario 2, Scenario 4 has reduced carbon emissions by 837.8kg and only increased total cost by 1038.9 yuan.

4.2 Electric power balance

Analyze Scenarios 1 and Scenarios 3. In the morning, there are mainly storage devices, wind power and CHP to meet demand; When wind power is insufficient at noon, system will purchase power to achieve demand; at night, wind power is sufficient, IES purchase electricity from the grid no longer. wind power, CHP power generation and storage device discharge can achieve power balance.

Analyze Scenario 2 and Scenario 4. When the system contains P2G equipment, the wind power consumption rate is 100 %. Analyze the operation of P2G, the IES system first transmits the surplus wind power to the EL equipment for hydrogen production, and consumes all wind power. It can be known that part of the hydrogen is stored inside the hydrogen storage and others are transported to the MR to synthesize natural gas. So when IES contains P2G, wind power which costs 0 can be fully utilized.

Optimal electrical load balancing as Figure 4.

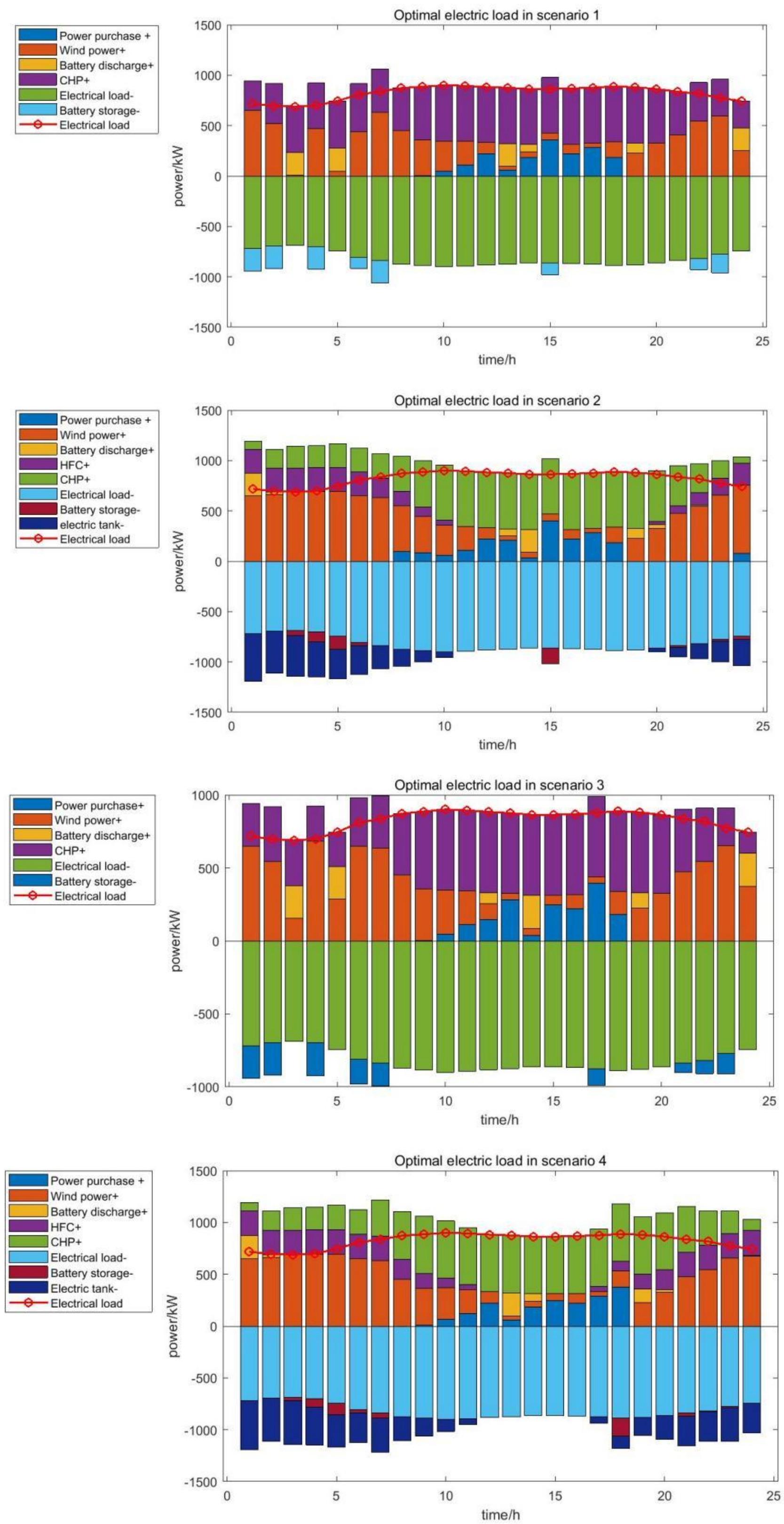

Figure 4. Optimal electrical load balancing

4.3 Economic and environment comparison

By analyzing, the economy and environmental protection in different scenarios are reflected respectively. Figure 5.can see that scenario 4 has the least carbon emissions, which indicates that scenario 4 has the best environmental protection; the total cost is the lowest in scenario 2, which indicates that the economy of scenario 2 is the best.

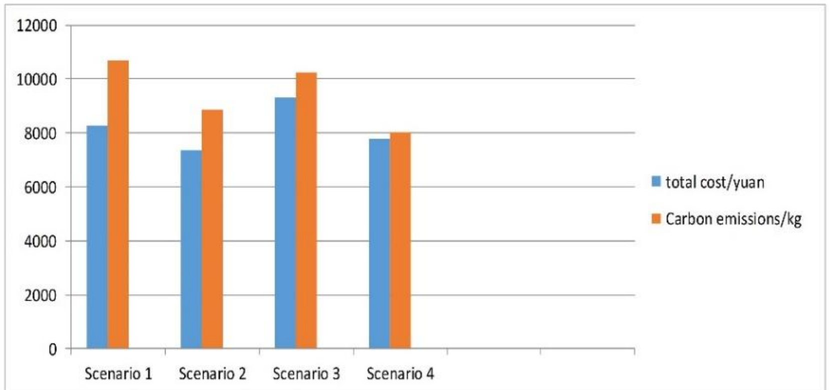

Figure 5. Total cost and emissions

Environmental protection is inversely proportional to carbon emissions, and the economy is inversely proportional to the total cost.

Environmental protection coefficient ‘a’ and Economic coefficient ‘b’ is:

$$a = \frac{1}{C\_CO_2} \tag{12}$$

$$b = \frac{1}{COST} \tag{13}$$

In the equations： COST represents the total cost of the system; C_CO_2 represents CO_2 emissions.

Figure 6. can be more intuitive and clear comparison of different scenarios of economic and environmental protection. From the data of scenarios, it can be seen that scenario 4 can achieve the optimization of economy and environmental protection and balance in ‘a’ and ‘b’.

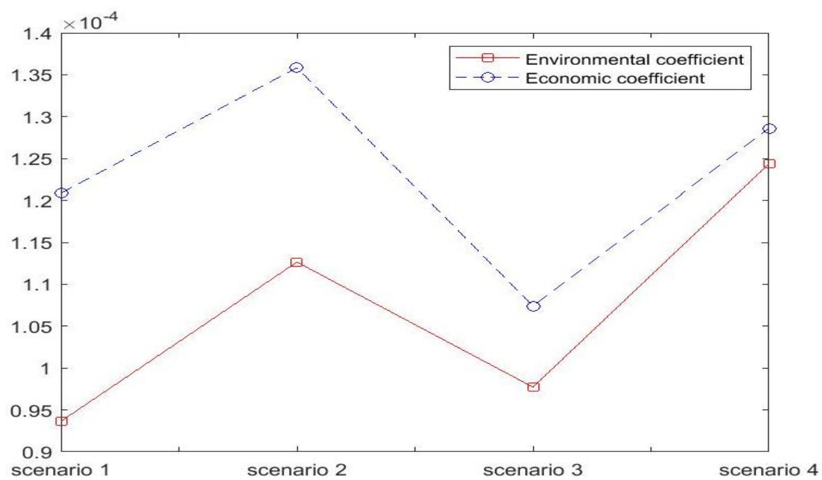

Figure 6. The comparison of economic and environment

5. CONCLUSION

This paper mainly establishes the IES on the ladder carbon trading. The IES established in the system takes into account P2G equipment and carbon trading mechanism on the model :

The P2G equipment in this paper adopts the P2G two stage operation mode, not only considering the process of P2G, but also considering that P2G generates electricity and heat energy, and supplies electricity-heat load. Compared with the IES without P2G, the carbon emission is reduced by 27.3 % and the cost is reduced by 19.75 %.

It can be seen that compared with ordinary carbon trading, the total cost with ladder carbon trading is lower and the carbon emissions are less from four different scenario. It shows that ladder carbon trading can further limit carbon emissions while constraining costs.

In order to compare the environmental protection and economy in different scenarios, this paper determines the economy and environmental protection in different scenarios through the environmental protection coefficient a and the economic coefficient b. With intuitive data performance, it can be seen that the coefficient 'a' and 'b' of the IES with P2G under ladder carbon trading have reached the optimal balance, which demonstrates the superiority of modeling.

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