Low carbon scheduling method of mine integrated energy system based on two-stage P2G technology

Haoran Chen, Chao Hu*

School of Electrical Engineering, China University of Mining and Technology, Xuzhou, China, 221116

* Corresponding Author Email: hc2416157@163.com

Abstract. Coal mines derive a large amount of various associated resources that can be used for production and living needs during the mining process. In order to realize the recycling of coal associated resources, a typical architecture of coal mine comprehensive energy system including the recycling of coal derived resources is proposed. Firstly, according to the coal mine resource endowment and its geological characteristics, the corresponding mine integrated energy system is constructed. Then, the refined two-stage P2G technology is combined with the mine integrated energy system to realize the complete consumption of wind and light and the efficient utilization of energy. Finally, the stepped carbon trading mechanism is used to further constrain the carbon emissions and realize the further reduction of carbon emissions in the mining area. The simulation model of the integrated mine energy system is established in MATLAB and the GUROBI solver is called to solve the results. The simulation results show that the method can effectively reduce carbon emissions, realize the complete consumption of wind and light and the efficient use of energy.

Keywords: Integrated Energy System, Stepped Carbon Trading Mechanism, Associated Resources.

1. Introduction

Coal as one of the world's major energy sources, the current coal energy use there are many problems, for mine production there are high energy consumption, high carbon emissions, and in the production of the accompanying surge of water, lack of wind and other resources have not been optimized use [1]. Therefore, the use of renewable energy resources to reduce carbon emissions in the coal mining process has become an important development trend [2]. However, the use of renewable energy for mine energy supply faces multiple problems such as complex resource endowment conditions and fluctuation of renewable energy. Therefore, there is an urgent need to propose a new type of integrated comprehensive energy system for mine area with high efficiency and cleanliness for sustainable development.

Currently, many experts and scholars have conducted research on comprehensive energy systems for coal mines. Deng Qianwen proposed an optimization method for the configuration of comprehensive energy systems considering the joint operation of multiple flexible resources[3]. This system effectively reduces carbon emissions but does not fully utilize various associated resources from coal mines. Huang Hongxu developed a multi-objective bi-level optimization model for coal mine comprehensive energy systems incorporating derived resources such as coalbed methane (CBM), groundwater (GW), and venting air methane (VAM)[4]. Although this model makes full use of associated resources, it does not sufficiently address the consumption of wind and solar energy, leading to resource waste. Lv Chaoxian introduced a robust optimization scheduling method for coal mine comprehensive energy systems (CMIES) based on information gap decision theory, incorporating power-to-gas (P2G) devices[5]. Despite comprehensive research, the utilization of renewable energy in mining areas remains low due to the differing resource endowments between mining regions and areas rich in renewable energy. Duan Xinhui proposed an optimization scheduling method for regional comprehensive energy systems considering P2G in a two-stage model to address wind and solar curtailment and resource optimization[6]. This method refines the two-stage P2G approach to achieve better resource utilization. Chen Jinpeng introduced a tiered carbon trading

mechanism to guide the control of carbon emissions in comprehensive energy systems[7]. While this approach improves energy efficiency, it does not analyze resources specific to mining areas.

Aiming at the shortcomings of existing methods, a new low carbon operation scheduling method of mine integrated energy system considering derived energy is proposed. The system first considers the associated resource utilization and landscape consumption needs, integrates new energy consumption and CBM utilization efficiently through P2G, and builds CMIES multi-resource recycling architecture with detailed two-stage P2G. Secondly, the CMIES deterministic scheduling model considering the utilization of associated resources and the absorption of the landscape is established through the cooperation and complementarity of P2G and the natural gas network on the basis of ensuring the reliable operation of the system. Finally, the cascade carbon trading is introduced to consider its benefits, resource utilization and environmental pollution.

2. CMIES framework with P2G and laddered carbon trading mechanism

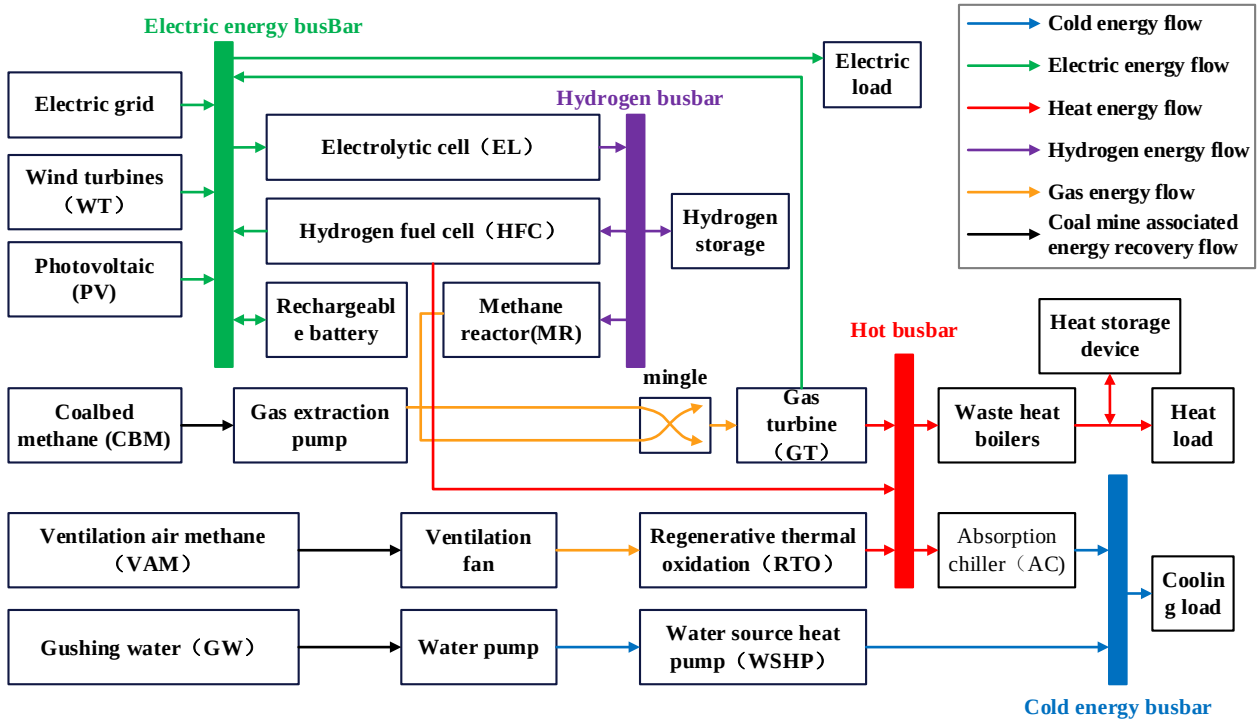


Figure 1. Architecture of Coal Mountain Integrated Energy System

In this paper, on the basis of the basic integrated energy system, considering the influence of external energy, refined two-stage P2G and stepped carbon trading mechanism, this paper adopts the layer-by-layer superposition scheme to continuously optimize the equipment configuration of the integrated energy system of coal mine, and builds the optimization model of the integrated energy system of coal mine, as shown in Figure 1. It mainly includes four parts: the basic framework of the integrated energy system, external energy supply, P2G two-stage operation process, and carbon trading mechanism.

2.1. P2G device and its refinement stage process

At times of peak renewable energy output, surplus electricity is used to generate hydrogen through electrolysis of water, which can be used directly or reacted with carbon dioxide to produce methane [8]. In addition, these gases can be stored for energy supply in case of power shortage. In this paper, compared to the conventional P2G plant, the P2G is replaced with a two-stage operation plant with a combination of EL, MR, and HFC, as shown in Fig. 2.

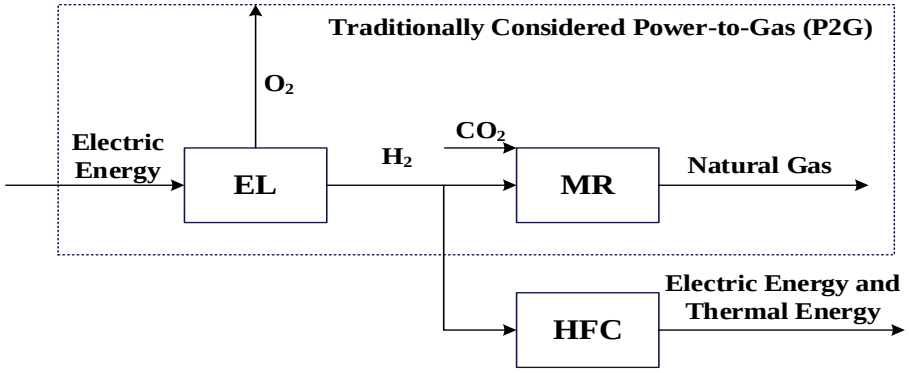


Figure 2. P2G two-stage process

Electricity is first converted into hydrogen and oxygen through EL, and hydrogen is divided into two parts of the role, one part and CO_2 together into the MR role synthesized into natural gas for the GB supply, reducing the cost of natural gas purchase, and the other part into the HFC converted into electric energy and heat energy. The above two-part conversion model is as follows:

(1) EL equipment

$$\begin{cases} P_{\mathrm{EL,H_2}}^{t} = \eta_{\mathrm{EL}} P_{\mathrm{e,EL}}^{t} \\ P_{\mathrm{e,EL}}^{down} \le P_{\mathrm{e,EL}}^{t} \le P_{\mathrm{e,EL}}^{up} \\ \Delta P_{\mathrm{e,EL}}^{down} \le P_{\mathrm{e,EL}}^{t} - P_{\mathrm{e,EL}}^{t-1} \le \Delta P_{\mathrm{e,EL}}^{up} \end{cases} \tag{1}$$

Where: $P_{\mathrm{e,EL}}^{t}$ is the electrical energy input to EL at time t; $P_{\mathrm{EL,H_2}}^{t}$ is the hydrogen energy output from EL at time t; η_{EL} is the energy conversion efficiency of EL; $P_{\mathrm{e,EL}}^{up}$, $P_{\mathrm{e,EL}}^{down}$ ask for the upper and lower limits of the electrical energy input to EL respectively.

(2) MR equipment

$$\begin{cases} P_{\mathrm{MR,g}}^{t} = \eta_{\mathrm{MR}} P_{\mathrm{H_2,MR}}^{t} \\ P_{\mathrm{H_2,MR}}^{\mathrm{down}} \le P_{\mathrm{H_2,MR}}^{t} \le P_{\mathrm{H_2,MR}}^{\mathrm{up}} \\ \Delta P_{\mathrm{H_2,MR}}^{\mathrm{down}} \le P_{\mathrm{H_2,MR}}^{t} - P_{\mathrm{H_2,MR}}^{t-1} \le \Delta P_{\mathrm{H_2,MR}}^{\mathrm{up}} \end{cases} \tag{2}$$

Where: $P_{\mathrm{H_2,MR}}^{t}$ is the hydrogen energy input to the MR at time t; $P_{\mathrm{MR,g}}^{t}$ is the natural gas power output from the MR at time t; η_{MR} is the energy conversion efficiency of the MR; $P_{\mathrm{H_2,MR}}^{\mathrm{up}}$, $P_{\mathrm{H_2,MR}}^{\mathrm{down}}$ are the upper and lower limits of hydrogen energy input to the MR respectively.

(3) HFC equipment

$$\begin{cases} P_{\mathrm{HFC,e}}^{t} = \eta_{\mathrm{HFC}}^{\mathrm{e}} P_{\mathrm{H_2,HFC}}^{t} \\ P_{\mathrm{HFC,h}}^{t} = \eta_{\mathrm{HFC}}^{\mathrm{h}} P_{\mathrm{H_2,HFC}}^{t} \\ P_{\mathrm{H_2,HFC}}^{\mathrm{down}} \le P_{\mathrm{H_2,HFC}}^{t} \le P_{\mathrm{H_2,HFC}}^{\mathrm{up}} \\ \Delta P_{\mathrm{H_2,HFC}}^{\mathrm{down}} \le P_{\mathrm{H_2,HFC}}^{t} - P_{\mathrm{H_2,HFC}}^{t-1} \le \Delta P_{\mathrm{H_2,HFC}}^{\mathrm{up}} \end{cases} \tag{3}$$

Where: $P_{\mathrm{H_2,HFC}}^{t}$ is the hydrogen energy inputted into HFC in time period t; $P_{\mathrm{HFC,e}}^{t}$, $P_{\mathrm{HFC,h}}^{t}$ are the electric and thermal energy outputted from HFC in time period t; $\eta_{\mathrm{HFC}}^{\mathrm{e}}$, $\eta_{\mathrm{HFC}}^{\mathrm{h}}$ are the efficiencies of converting HFC into electric and thermal energy; $P_{\mathrm{H_2,HFC}}^{\mathrm{up}}$, $P_{\mathrm{H_2,HFC}}^{\mathrm{down}}$ are the upper and lower limits of hydrogen energy inputted into HFC.

2.2. Stepped carbon trading mechanism model

The carbon laddering carbon trading mechanism model mainly contains carbon emission right quota model, actual carbon emission model, and laddering carbon emission trading model.

(1) Carbon emission allowance modeling

Carbon emission sources in IES are mainly grid, GB, GT, RTO, etc. At present, the main quota method used is gratuitous quota, and this paper considers that all power purchased by the grid comes from the generation of coal-fired units, which is modeled as follows[9]:

$$\begin{cases} E_{\mathrm{IES}} = E_{\mathrm{GT}} + E_{\mathrm{RTO}} + E_{\mathrm{GB}} + E_{\mathrm{gw}} + E_{\mathrm{buy}} \\ E_{\mathrm{GT}} = k_{\mathrm{GT_q}} \times (P_{\mathrm{GT}} + H_{\mathrm{GT}}) \\ E_{\mathrm{RTO}} = k_{\mathrm{RTO_q}} \times H_{\mathrm{RTO}} \\ E_{\mathrm{gw}} = k_{\mathrm{gw_q}} \times C_{\mathrm{wshp}} \\ E_{\mathrm{buy}} = k_{\mathrm{buy_q}} \times P_{\mathrm{buy_e}} \\ E_{\mathrm{GB}} = k_{\mathrm{GB_q}} \times H_{\mathrm{GB}} \end{cases} \tag{4}$$

Where: E_{IES}, E_{GT}, E_{RTO}, E_{GB}, E_{gw}, E_{buy} are IES, GT, RTO, GB, GW, and the carbon emission right quota of power purchased from the grid, respectively; $P_{\mathrm{buy_e}}$ denotes the amount of purchased power; C_{wshp} denotes the water-cooled power of the surge; $k_{\mathrm{GT_q}}$ denotes GT carbon quota, $k_{\mathrm{RTO_q}}$ denotes RTO carbon quota, $k_{\mathrm{gw_q}}$ denotes GW carbon quota, $k_{\mathrm{buy_q}}$ denotes power purchase carbon quota, and $k_{\mathrm{GB_q}}$ denotes GB carbon quota.

(2) Real carbon emissions modeling

The hydrogen to natural gas process in MR absorbs a portion of CO_2, so it needs to be taken into account. The actual carbon emissions are modeled as follows:

$$\begin{cases} E_{\mathrm{IES,a}} = E_{\mathrm{GT,a}} + E_{\mathrm{RTO,a}} + E_{\mathrm{GB,a}} + E_{\mathrm{gw,a}} \\ \qquad\qquad + E_{\mathrm{buy,a}} \\ E_{\mathrm{GT,a}} = k_{\mathrm{GT}} \times (P_{\mathrm{GT}} + H_{\mathrm{GT}}) \\ E_{\mathrm{RTO,a}} = k_{\mathrm{RTO}} \times H_{\mathrm{RTO}} \\ E_{\mathrm{gw,a}} = k_{\mathrm{gw}} \times C_{\mathrm{wshp}} \\ E_{\mathrm{buy,a}} = k_{\mathrm{buy}} \times P_{\mathrm{buy_e}} \\ E_{\mathrm{GB,a}} = k_{\mathrm{GB}} \times H_{\mathrm{GB}} \end{cases} \tag{5}$$

Where: $E_{\mathrm{IES,a}}$, $E_{\mathrm{GT,a}}$, $E_{\mathrm{RTO,a}}$, $E_{\mathrm{GB,a}}$, $E_{\mathrm{gw,a}}$, $E_{\mathrm{buy,a}}$ are the carbon emissions from IES, GT, RTO, GB, GW, and power purchased from the grid, respectively; $P_{\mathrm{buy_e}}$ denotes the amount of purchased electricity; k_{GT} denotes the intensity of GT carbon emissions, k_{RTO}denotes the intensity of RTO carbon emissions, k_{gw} denotes the intensity of GW carbon emissions, k_{buy} denotes the carbon intensity of power purchase, k_{GB} denotes the carbon intensity of GB.

(3) Stepped carbon emissions trading model

According to (1) and (2), we can get the carbon emission right quota and the actual carbon emission, that is, we can find the actual carbon emission right trading amount.

$$E_{\mathrm{IES,t}} = E_{\mathrm{IES,a}} - E_{\mathrm{IES}} \tag{6}$$

Where: $E_{\mathrm{IES,t}}$ is the carbon trading amount of CMIES.

Due to the large interval of purchased carbon emission allowances, different allowances correspond to different situations. To address this situation, this paper differs from the traditional carbon trading mechanism by adopting a laddering mechanism to save costs. Laddered carbon trading is:

$$f_{\mathrm{CO_2}}^{\mathrm{price}} = \begin{cases} \lambda E_{1\mathrm{ES,t}} & E_{1\mathrm{ES,t}} \leqslant l \\ \lambda(1+\alpha)\left(E_{1\mathrm{ES,t}} - l\right) + \lambda l & l \leqslant E_{1\mathrm{ES,t}} \leqslant 2l \\ \lambda(1+2\alpha)\left(E_{1\mathrm{ES,t}} - 2l\right) + \lambda(2+\alpha)l & 2l \leqslant E_{1\mathrm{ES,t}} \leqslant 3l \\ \lambda(1+3\alpha)\left(E_{1\mathrm{ES,t}} - 3l\right) + \lambda(3+3\alpha)l & 3l \leqslant E_{1\mathrm{ES,t}} \leqslant 4l \\ \lambda(1+4\alpha)\left(E_{1\mathrm{ES,t}} - 4l\right) + \lambda(4+6\alpha)l & E_{1\mathrm{ES,t}} \geqslant 4l \end{cases} \tag{7}$$

Where: $f_{CO_2}^{price}$ is the stepped carbon trading volume; λ is the carbon trading base volume; l is the length of the carbon emission interval; α is the volume growth rate [10].

3. Objective function

In this paper, we consider the energy amount of IES f_{buy}^{price}, the amount of wind and light abandonment $f_{DG,DS}^{price}$, and the stepped carbon trading $f_{CO_2}^{price}$, and construct the low-carbon scheduling objective that minimizes the total operating F as follows:

$$F = \min (f_{buy}^{price} + f_{DG,DS}^{price} + f_{CO_2}^{price}) \tag{8}$$

3.1. Quantity of energy

$$f_{buy}^{price} = \sum_{t=1}^{T} (\alpha_t P_{e,buy}^t + \beta_t P_{g,buy}^t) \tag{9}$$

Where: $P_{e,buy}^t$, $P_{g,buy}^t$ are the amount of electricity and gas at moment t; α_t, β_t are the base amount at moment t, respectively; and f_{buy}^{price} is the amount of energy.

3.2. Amount of wind and light abandoned

$$f_{DG,DS}^{price} = \sum_{t=1}^{T} (k_{PV}(P_{PVout}^t - P_{PV}^t) + k_{WT}(P_{WT_{out}}^t - P_{WT}^t)) \tag{10}$$

Where: $f_{DG,DS}^{price}$ is the amount of wind and light discarded; k_{PV} and k_{WT} are the amount of wind and light discarded units, respectively.

4. Calculus analysis

In order to verify the effectiveness of the provided strategy, an arithmetic example is set up for verification. The optimized scheduling is performed in a cycle of 24h a day.

The benefits of CMIES integrated low-carbon economic scheduling model considering energy storage device, P2G and stepped carbon trading mechanism were verified respectively. Four typical scenarios were selected for typical winter scenarios, as shown in Table 1.

Table 1. Scene analysis for Scene 1-5

Scene Arrangement	Energy Storage Devices	P2G	Stepped Carbon Trading Mechanism	Refinement of the P2G Two-stage Process
Scene 1	×	×	×	×
Scene 2	√	×	×	×
Scene 3	√	√	×	×
Scene 4	√	√	√	×
Scene 5	√	√	√	√

The following table was obtained by solving the correlation coefficients for the five Scenes:

Table 2. Optimization results for scene 1-5

Parameters	Parameter Value				
	Scene 1	Scene 2	Scene 3	Scene 4	Scene 5
Carbon Footprint /kg	978895	982596	815270	760971	726134
Quantity of Electricity Purchased /kWh	11585.8	2436.20	2436.20	42796.4	60208.2
Quantity of Gas Purchased /kWh	159590	145954	85303.8	190338	52098.6
Rate of Abandoned Light	0.511	0.510	0	0	0
Wind Abandonment Rate	0.349	0.326	0	0	0
Carbon transaction cost/yuan	63408.4	64618.8	52535.5	69568.0	27928.7
Total cost/yuan	220509	208089	83415.7	153279	71468.7

Table 3. Comparison of the cogeneration energy utilization rates for scene 1-4

Associated Energy	Scene 1	Scene 2	Scene 3	Scene 4
Lack of Wind Utilization	10.20%	7.05%	7.05%	7.46%
Surge Water Utilization Rate	94.13%	100%	100%	100%
Coalbed Methane Utilization Rate	91.17%	92.91%	72.82%	60.96%

(1) Comparison of scene 1 and scene 2

In scene 2, an energy storage battery and a cold storage tank are added compared with scene 1. Through the flexible discharge of the battery, the absorption of the fan and the absorption of the photovoltaic are effectively realized, so that the light abandonment rate of scene 2 is reduced by 0.1%, the wind abandonment rate is reduced by 2.3%, and the purchase of electricity is greatly reduced, reducing the cost of electricity purchase. In addition the application of cold storage tank, associated energy surge water resources to achieve 100% utilization, coordinated with water source heat pumps and absorption chillers to meet the demand for cold loads in the mining area, the utilization rate of the spent wind resources to improve will reduce the carbon emissions of the spent wind utilization module to reduce carbon emissions. The wind and light abandonment rate in scenario 2 is somewhat reduced compared with that in scenario 1, and the daily wind and light abandonment situation is shown in Figure 3.

Compared to Table 3, the utilization rate of exhaust wind has experienced a slight decrease, while the utilization rate of coalbed gas has seen a slight increase. Simultaneously, as the utilization rate of coalbed methane improves, the carbon emissions from gas turbines are calculated based on the combined output thermal power and electric power, resulting in an overall increase in carbon emissions. As indicated in Table 2, compared to scene 1, carbon emissions have increased by 3700.92kg. Consequently, there is an overall rise in carbon emission costs by 310.4 yuan compared to scene 1. However, due to the implementation of energy storage devices, electricity and gas procurement costs have decreased significantly leading to a total cost reduction of 12,420 yuan.

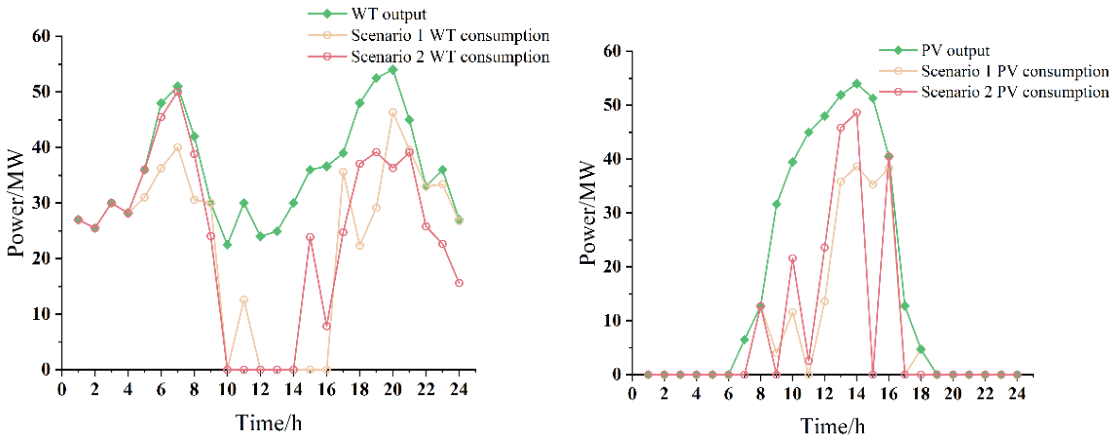


Figure 3. Comparison of fan absorption and photovoltaic absorption in Scene 1 and 2

In summary, Scene 2, with the addition of the energy storage device, sacrifices a small portion of carbon emissions and realizes an increase in the utilization rate of associated energy and a decrease in the rate of wind and light abandonment and the purchase of electricity and gas with the coordination of multiple systems.

(2) Comparison of scene 2 and scene 3

In Scenario 3, conventional P2G technology is added, which combines hydrogen with CO2 to synthesize methane, a process that reduces CO2 emissions and stores it. In this way, the CO2 originally emitted into the atmosphere can be converted into energy, realizing the reuse of resources and reducing greenhouse gas emissions. Through this process, carbon emissions can be reduced to some extent. Compared with the data, it is found that the carbon emission of scenario 3 is reduced by 167,326 kg compared with scenario 2. At the same time, its use can reduce the purchase of gas. In comparison with scenario 2 and scenario 3, the proportion of gas purchased in scenario 3 is reduced by 41.55%. At the same time, this self-contained supply does not need to artificially increase high concentration of gas, thus improving the utilization rate of coalbed gas, by contrast, the utilization rate of coalbed gas increased by 1.14%.The application of P2G can also solve the problem of renewable energy volatility. When wind and solar energy are sufficient, P2G can convert excess renewable electric energy into gas and store it for use when wind or solar energy is insufficient. Compared with the situation without P2G, it can be seen from Figure 4 that the abandonment rate of wind and light in scenario 3 is close to zero percent. Much higher than scenario 2.

From the comparison of data in Table 3, it is found that the utilization of coal bed methane is reduced, this is due to the work of the P2G, he himself can provide gas for the gas boiler, the gas boiler produces more heat, which makes the gas turbine to reduce the amount of heat provided to reduce the utilization of coal bed methane, so that the utilization of coal bed methane is reduced.

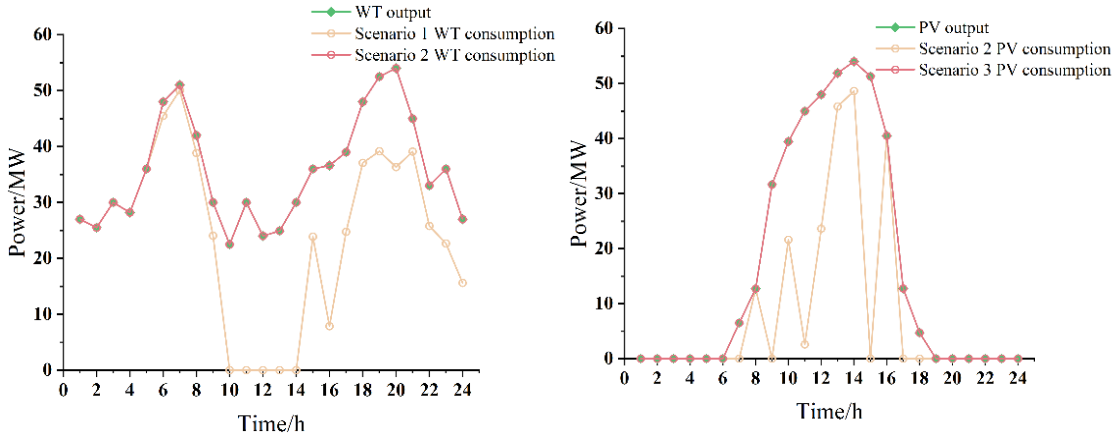


Figure 4. Comparison of fan absorption and photovoltaic absorption in Scene 2 and 3

In summary, in Scene 3, the traditional P2G technology is introduced to reduce the amount of purchased gas by converting electricity into gases such as hydrogen and methane, which are mixed with coalbed methane to supply energy. At the same time, the P2G technology improves the utilization of renewable energy, reduces carbon emissions, and improves system efficiency.

(3) Comparison of scene 3 and scene 4

Considering the stepped carbon trading mechanism benefit analysis. In order to verify the effectiveness of the stepped carbon trading mechanism proposed in this paper, the length of the interval $l = 2$ t, the price growth rate $\alpha = 25$ %, and the base price of carbon trading $\lambda = 250$ yuan/t. The proposed method is simulated and analyzed.As can be seen in Figures 5, Scene 4 is based on the P2G technology of Scene 3, so Scene 4 can realize the 100 percent consumption of wind and solar resources.

Compared with scheme 3, Scheme 4 considers the stepped carbon trading mechanism, and the stepped pricing mechanism divides multiple purchase intervals. As the more carbon emission permits need to be purchased, the higher the purchase price of the corresponding interval, so the consideration of the stepped carbon trading mechanism can limit carbon emission to the greatest extent and achieve the purpose of emission reduction. According to the simulation results, the total cost of scene 4 is

increased by 70,469.32 yuan compared with scene 3, but the carbon emission is reduced by 54741.2kg, which shows that under the stepped carbon trading mechanism, the system can reduce emissions while ensuring lower operating costs.

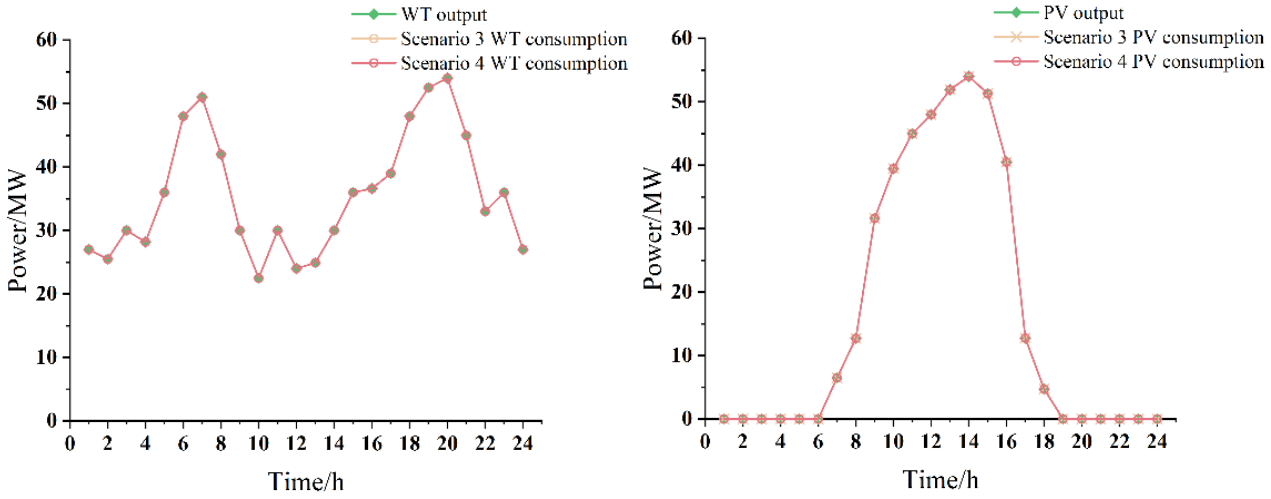


Figure 5. Comparison of fan absorption and photovoltaic absorption in Scene 3 and 4

In summary, compared with scene 3, scene 4 has an increase in total cost but a decrease in carbon emissions, which shows that under the cascade carbon trading mechanism, the system can achieve the goal of emission reduction at the expense of some benefits by reasonably setting the base price, interval length and price growth rate of carbon trading.

(4) Comparison of scene 4 and scene 5

In Scene 5, under the same parameters of the carbon trading mechanism as in scene 4, P2G is further refined into the combined operation of EL, MR And HFC. As can be seen from Table 2, Scene 5 has the lowest operating carbon emission, and Scene 5 reduces 30782.98kg compared with scene 4. Compared with scene 4 and Scene 5, the carbon trading cost is reduced by 41,639.36 yuan, and the total cost is reduced by 81,1810.3 yuan.

Scene 5: The cost of wind and light abandonment is 0. At this time, wind and light abandonment in EL Xiaona mining area can generate hydrogen energy to realize 100% utilization of renewable energy. ES first input surplus wind power into EL equipment to produce hydrogen and absorb all wind power. Part of the hydrogen energy is stored in the hydrogen storage to play the role of low storage and high incidence arbitrage, part of it is transported to HFC for thermoelectric production, and part of it is transported to MR Synthetic natural gas. Since hydrogen energy is synthesized into natural gas by MR And then transported to GB for energy supply, it will undergo energy loss in several steps, and the thermoelectric production of hydrogen energy in HFC has high energy efficiency, while reducing an intermediate energy conversion link, so hydrogen energy is preferentially transported to HFC for thermoelectric production, so HFC is in full power state. The remaining hydrogen energy is then converted to natural gas by MR. Therefore, less gas is purchased compared to the traditional P2G system. Hydrogen energy, as a clean energy, can be used by HFC without producing carbon emissions. At the same time, it can minimize GT output and GT output is reduced. However, in order to meet the electricity load demand of mining area, the purchased electricity of mining area will eventually increase. GT output reduction can effectively reduce GT unit carbon emissions, while MR Device can absorb CO2 to further reduce carbon emissions in mining areas.

To sum up, Scene 5 can combine wind power, TOU, gas price and real-time load demand, adjust its own thermoelectric ratio to achieve energy supply balance, improve energy utilization and reduce carbon emissions.

5. Conclusions

In this paper, a comprehensive mine energy system based on associated energy utilization is constructed, and a method of dispatching based on P2G technology and low carbon economy is proposed. The analysis and verification are carried out with a practical coal mine example, and the results show that:

Through the two-stage P2G device, the wind absorption and mine energy are closely connected and mutually complementary, which significantly improves the utilization level of associated resources, enhances the system's wind absorption ability, and reduces the operation and dispatching cost.

Compared with the traditional carbon trading mechanism, the introduction of the stepped carbon trading mechanism can limit carbon emissions to the maximum extent and achieve the purpose of emission reduction.

This paper provides a new idea for considering the optimal operation of the typical architecture of coal mine integrated energy system. In the future, other devices such as P2G that can convert and store energy to improve resource utilization efficiency will be further studied, and the carbon trading mechanism will be continuously optimized to achieve further low-carbon optimization operation of the system.

References

[1] Zhang Gou. Low-carbon optimal operation of mine integrated energy system considering coal flow process and associated energy utilization[D]. China University of Mining and Technology, 2023.

[2] WANG Longfei,WANG Shuai,LI Qing,et al.Optimization study on the configuration of multi-energy complementary thermoelectric synergistic energy supply system for mines in western region[J/OL].Coal Journal,1-12[2024-08-06].

[3] Deng Qianwen,Li Qi,Qiu Yibin,et al.An optimal allocation method for integrated energy systems considering joint operation of multiple types of flexibility resources[J/OL].Journal of Shanghai Jiao Tong University,1-24[2024-08-06].

[4] HUANG Hongxu,LIANG Rui,ZHANG Xiaotong,et al.Multi-objective configuration two-layer optimization of coal mine integrated energy system under accounting and carbon constraints[J].Grid Technology,2022,46(05):1731-1742.

[5] Lv Chaoxian,Sun Wen,Liang Rui,et al.Robust scheduling of integrated energy system with electricity-to-gas coal mine based on information gap decision theory[J].High Voltage Technology,2023,49(10):4203-4212.

[6] Duan Xinhui,Cheng Zelong,Zhang Dongchao,et al.Optimal scheduling of integrated energy system considering demand response with two-stage P2G[J/OL].Journal of System Simulation,1-13[2024-08-06].

[7] CHEN Jinpeng,HU Zhijian,CHEN Yingguang,et al.Thermoelectric optimization of integrated energy system considering stepped carbon trading mechanism and electric hydrogen production[J].Power Automation Equipment,2021,41(09):48-55.

[8] CHEN Sheng,CHEN Mingjian,WEI Zhinong,et al.Flexibility mining-oriented unit combination study of electric-hydrogen hybrid integrated energy system[J/OL].Grid Technology,1-12[2024-08-08].

[9] Fang Siwei, Wu Shaohua, Song Xiayun. Evaluation of carbon emission rights of thermal power enterprises based on short-term carbon production model: A case study of Guodian Electric Power [J]. China Assets Evaluation,2024,(03):74-81.

[10] ZHOU Jianhua,LIANG Changyu,SHI Linjun,et al.Optimized scheduling of integrated energy systems taking into account the stepped carbon trading mechanism[J/OL].China Electric Power,1-12[2024-08-08].