Research on energy repetitive conversion of multi-micro grid system based on CVaR

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Abstract. the introduction of power to gas P2G (power to gas) equipment inside the micro grid strengthens the coupling between the power and natural gas network, reducing the phenomenon of wind and light abandoning, but also makes the renewable energy during the optimal scheduling of energy conversion, reducing energy efficiency, resulting in energy consumption. At the same time, with the aggregation of more and more microgrids in a certain region, a multi-microgrid system is formed, which has power interaction between microgrids. In this context, CVaR is introduced into the objective function of economic dispatching, and an optimal scheduling model considering the internal energy repeated conversion and power interaction between microgrids is established. This model takes into account the influence on the output of each equipment, and the optimal operation plan and optimal operating cost of the system are obtained. Finally, an example is given to verify the model, and the results show that the proposed optimal scheduling model can reduce the operating cost of the system, improve the energy efficiency and realize the energy optimization management of the whole system under the condition of improving the consumption of renewable energy.

Key words: Different types of energy; power interaction; economic dispatch; repeated energy conversion.

1. Introduction

As more and more micro grid connected to the power system, gradually formed closely linked to each other in some area of multiple piconets system, by using a variety of energy sources such as electricity, gas, heat, overall coordination and optimization of multiple piconets systems containing different types of energy to improve the efficiency of energy-using, promote clean production capacity, human sustainable development, provides an important way to solve, many developed countries of Europe as a key development strategy in the future[1-4].
The traditional multi-micro grid scheduling operation is the superposition of the economic operation of each micro grid in the single micro grid, that is, each micro grid operates independently, while the coordinated operation of the multi-micro grid takes into account the power interaction between the micro grid, strengthens the coupling of the multi-micro grid, and optimizes the output of the micro sources in each micro grid. In the multi-micro grid system, each micro grid has the situation of power shortage or power surplus: 1) each micro grid is short of power; 2) each micro grid has surplus power; 3) there are microgrids with power shortage and power surplus. In the first two cases, the micro grid can only obtain electric energy from online electricity distribution or electricity sales, and there is no power interaction between micro grids. Literature [5-9] fails to consider the influence of power interaction between microgrids on the output of microsources in the whole system. Therefore, it is necessary to study the internal energy repetitive conversion and power interaction of microgrids with different types of energy.

At present, scholars at home and abroad have made some achievements in the study of economic operation of micro-grid system. Literature [10-12] has studied the concept, planning and operation model of micro-grid system including electricity, gas, heat and other energy forms. Literature [13-14] fully considered the randomness and uncertainty of distributed power supply output, and realized real-time economic dispatch of micro-grid system by rolling optimization. Literature [15-16] proposed a micro-grid optimal scheduling model containing P2G equipment, taking wind power consumption into account. In reference [17], considering the battery loss, a multi-objective optimization model of micro-grid with the lowest battery loss, the lowest power generation cost and the best environmental benefit was established. All the above studies are to establish the economic optimal scheduling model for a single micro-grid system.

In view of the lack of literature mentioned above, this paper, based on the multi-micro grid system scheduling model, considers the repeated energy conversion within the micro grid and the power interaction between the micro grid, establishes an economic scheduling model based on CVaR to deal with the risks caused by uncertainty, and obtains the optimal operation cost of coordinating the scheduling operation plan of each equipment and the system. Finally, an example is given to verify that the model can make the distribution network and the multi-micro network achieve their respective economic optimization simultaneously, taking into account the consumption capacity of renewable energy and the economy of system operation.

2. Optimized operation architecture of multi-micro grid system

2.1. Description of repeated energy conversion and its causes

Due to the access of more and more devices, the diversity of energy coupling forms increases, and the number of paths for a load to obtain energy increases. Therefore, there are too many conversion devices that can flow, resulting in repeated energy flows. For example, in figure 1, in addition to path, there is also the situation that part of the electric energy supplies the power load through path. This path passes through many devices. Compared with path, the energy produces repeated conversion, resulting in more energy consumption, which reduces the economy and energy efficiency of micro-grid scheduling. Therefore, the operation cost of the system can be reduced by minimizing the amount of repeated conversion of this energy when the electric load obtains electric energy.
There are two main paths for repeated energy conversion in the micro-grid: 1) during the same period, the electricity generated by renewable energy may be converted into gas energy through P2G, and finally into electricity through micro-gas turbine, that is, the electricity produced by renewable energy through wind power and photovoltaic $\rightarrow$ P2G $\rightarrow$ micro-gas turbine. 2) in order to obtain heat energy, the same electric energy produced by renewable energy during the period should be converted into heat energy through the electric boiler, but some electric energy is converted into gas energy through P2G. Finally, it is converted into heat energy through the gas-fired boiler, that is, the heat energy generated by renewable energy through wind power and photovoltaic $\rightarrow$ P2G $\rightarrow$ gas-fired boiler. Where is less than or equal to the output of the micro-gas turbine in the same period, less than or equal to the output of the gas-fired boiler in the same period.

For the most part, micro-grid systems do not generate repeated energy flow. From the above description, it can be seen that the "repeated energy flow path" will all pass through P2G equipment, so the repeated energy flow will only be generated in some scenes where P2G is running. The main reason for the repeated conversion of multiple energy sources is the failure to coordinate the scheduling and operation plans of various conversion equipment.

Therefore, under the condition of the source - the Netherlands not harmonious, the system conversion equipment operation may produce repeat can flow, in order to reduce duplication of energy flow and energy efficiency, need to consider under the optimization model of repeated energy conversion for micro network system for the output of the energy storage equipment, gas turbines, gas boiler optimization scheduling.

2.2. Multi-micro grid system equipment model

2.2.1. Energy storage device. Energy storage equipment mainly includes electric energy storage, heat energy storage and gas energy storage. For this type of energy storage equipment, formula (1) modeling is uniformly adopted [14].

$$W_{s,t+1} = W_{s,t} + (P_{st}^e \eta_s^e - \frac{P_{st}^d}{\eta_s^d}) \Delta t$$  \hspace{1cm} (1)$$

In the formula: $W_{s,t}$, $P_{st}^e$ and $P_{st}^d$ are the energy storage, charging power and releasing power of the energy storage device $s$ in time period $t$; $\eta_s^e$ and $\eta_s^d$ are the charging efficiency and discharging efficiency of energy storage device $s$ respectively, and the relationship between them is $\eta_s^d = \eta_s^e$; $\Delta t$ is the length of the unit time period.
2.2.2. P2G equipment

\[ P_{G, t}^e = P_{P2G, j}^e \eta_p \]  \hspace{1cm} (2)

\[ 0 \leq P_{P2G}^e \leq P_{P2G, \text{max}}^e \]  \hspace{1cm} (3)

\[ P_{0,j}^e = P_{W,j}^e + P_{W,j}^h - P_{P2G,j}^e \]  \hspace{1cm} (4)

In the formula: \( P_{P2G,j}^e \) is the gas power generated by P2G equipment in time period \( t \); \( P_{P2G,j}^e \) is the electrical power consumed by P2G equipment during gas generation in time period \( t \); \( \eta_p \) is the energy conversion efficiency of P2G equipment; \( P_{P2G, \text{max}}^e \) is P2G device power limit; \( P_{W,j}^e \) is the power transmitted to the power grid by the new energy unit in time period \( t \); \( P_{W,j}^h \) is the electric power generated by the wind power in time period \( t \).

3. Multi-micro network optimal economic scheduling model

The local scheduling layer of the multi-micro grid system solves the minimum repetitive conversion energy flow inside a single micro grid, and reports the result to the micro grid of the regional scheduling layer. The economic scheduling model of the local scheduling layer and the regional scheduling layer is introduced below.

3.1. Local scheduling layer

The local scheduling layer sets the minimum energy flow through P2G repeated conversion in a single micro grid as the objective optimization objective function:

\[ \min \{P_{P2G,j}^e, P_{MT,j}^e + P_{GB,j}^e\} \]  \hspace{1cm} (5)

In the formula: \( P_{P2G,j}^e \) is the gas power obtained by P2G conversion of the \( l \) microgrid; \( P_{MT,j}^e \) and \( P_{GB,j}^e \) are respectively the gas power of the microgrid input microturbine and the gas-fired boiler.

Since equation (10) is a nonlinear problem and difficult to solve, its linearization can be described as the minimum value of the sum of repeated electric energy and thermal energy flows.

\[ \min \left( \sum_{t} P_{re,j}^e + \sum_{t} P_{re,j}^h \right) \]  \hspace{1cm} (6)

\[ \begin{align*}
0 &\leq \tau_1 \leq 10 \\
0 &\leq \tau_2 \leq 10 \\
0 &\leq \tau_1 + \tau_2 = \tau_3 \leq 10 \\
\frac{P_{P2G,j}^e \cdot \eta_p}{10} &\leq P_{re,j}^e \\
0 &\leq \frac{P_{re,j}^e}{P_{MT,j}^e} \leq \tau_4 P_{P2G,j}^e \\
0 &\leq \frac{P_{re,j}^e}{P_{GB,j}^h} \leq \tau_5 P_{P2G,j}^e \\
\frac{P_{P2G,j}^e}{P_{P2G,j}^e} \cdot \tau_1 + P_{P2G,j}^h &\leq \frac{P_{MT,j}^e}{\eta_{MT,j}} + P_{GB,j}^h / \eta_{GB,j} + P_{1}^h 
\end{align*} \]  \hspace{1cm} (7)

In the formula: \( P_{P2G,j}^e \) is the output gas power for P2G valve opening degree per gear; \( \tau_1 \) and \( \tau_2 \) are the valve integer variables controlling the repeated electricity and heat energy flow in the "repeated energy flow path" respectively; \( \tau_3 \) is the valve switch control volume for the entire P2G equipment.

The maximum atmospheric power that P2G may output is set to 10 according to the valve opening degree, so the valve opening degree of the whole P2G equipment is less than or equal to 10. As shown in the first three formulas in formula (6), the last equation constraint in formula (6) represents the node power balance constraint where P2G equipment output gas power is located.
3.2. Regional scheduling layer

\[
\min C = \beta C_{\text{EX}} + (1 - \beta) C_{\text{CVaR}}
\]  
(8)

\[
C_{\text{EX}} = \sum_j \rho_j C_j
\]  
(9)

\[
C_{\text{CVaR}} = \bar{\zeta} + \frac{1}{\beta} \sum_j \rho_j \left[ C_j - \bar{\zeta} \right]^{\frac{1}{\beta}}
\]  
(10)

In the formula: \( C \) is the Multi-micro grid system statistics and the total cost of CVaR; \( C_{\text{EX}} \) is the expected cost of economic dispatch for multi-micro network system; \( C_{\text{CVaR}} \) for economic dispatch of multi-micro-grid systems CVaR; \( \beta \in [0,1] \) is the weight coefficient; \( F \) and \( f \) are the scene number and the total number of scenes, respectively; \( f \) and \( C_j \) are the probability and cost corresponding to scenario \( f \); \( \bar{\zeta} \) is the auxiliary decision variables introduced for calculating CVaR, the optimal value \( \bar{\zeta}^* \) is VaR; \( \beta \) is the confidence level, whose size reflects the risk aversion level of the decision maker.

3.2.1. Multiple piconets

1) Target function.

The purchase cost of natural gas and the operating cost of equipment are considered in the \( l \) microgrid in the regional dispatching layer \( C_{l,o} \), power interaction costs between microgrids \( C_{lMG} \) and energy repetitive conversion penalty costs \( C_{l,r} \). The operating cost of equipment includes the cost of production and energy conversion of each equipment in the system; The penalty costs for energy duplication include the increased operating costs of equipment that passes through two "duplicate energy flow paths." The above constitutes the objective function of the total economic operating cost \( C_{\text{total}} \) of the microgrids in the region \( L \) within the operating cycle \( T \) of the multi-microgrids:

\[
\min C_{\text{EX}} = \sum_{l=1}^{L} \left[ C_{l,o} + C_{l,MG} + C_{l,r} \right]
\]  
(11)

\[
C_{l,o} = \sum_t \lambda_{\text{buy},t} P_{\text{buy},t} + \sum_t \lambda_{\text{gas},t} P_{\text{gas},t} + \sum_n c_n P_{\text{out},n,t}
\]  
(12)

\[
C_{l,MG} = \sum_t \lambda_{\text{buy},t} P_{\text{MG},t} + \sum_t \lambda_{\text{sell},t} P_{\text{sell},t}
\]  
(13)

\[
C_{l,r} = \sum_t (c_{\text{P2G}} + c_{\text{MT}}) P_{\text{re},t} + \sum_t (c_{\text{P2G}} + c_{\text{Gth}}) P_{\text{b},t}
\]  
(14)

In the formula: \( \lambda_{\text{buy},t} \) is the purchase price of natural gas; \( P_{\text{buy},t} \) is the natural gas power purchased; \( \lambda_{\text{gas},t} \) is the purchase price of natural gas; \( P_{\text{gas},t} \) is the natural gas power purchased; \( c_n \) is the operating and maintenance cost of unit energy output of equipment \( n \); \( P_{\text{out},n,t} \) is the output power of energy conversion device \( n \) at time period \( t \); \( \lambda_{\text{sell},t} \) is the electricity price of electricity purchase and sale in time period \( t \); \( P_{\text{MG},t} \) is the interaction power of the \( l \) microgrid and the \( m \) microgrid in time period \( t \), the positive value is power purchase, and the negative value is power sales.

2) Constraints.

1) Power balance constraints.

In any period of time, the \( l \) microgrid satisfies the balance constraint of electricity, gas and heat power, where \( I_{l,t}^{\text{el}} \), \( I_{l,t}^{\text{g}} \) and \( I_{l,t}^{\text{h}} \) are the electricity, gas and heat loads in the microgrid \( l \), then

\[
P_{\text{MT},t}^{\text{el}} + P_{\text{PV},t}^{\text{el}} + P_{\text{W},t}^{\text{el}} + P_{\text{L},t}^{\text{el}} + P_{\text{D},t}^{\text{el}} + P_{\text{P},t}^{\text{el}} + P_{\text{D},t}^{\text{el}} = P_{\text{P},t}^{\text{el}} + P_{\text{E},t}^{\text{el}} + P_{\text{G},t}^{\text{el}} + P_{\text{P},t}^{\text{el}} + \Delta P_{\text{P},t} + L_{l,t}^{\text{el}}
\]  
(15)
In the formula: \( P_{MT,t}^g \) is the gas power of the microturbine; \( P_{MT,t}^e \) is the electric power output of the micro-gas turbine in time period \( t \); \( P_{GB,t}^e \) is the gas power of the gas-fired boiler; \( P_{GB,t}^h \) and \( L_{1,t}^h \) is the thermal power output of the gas-fired boiler in time period \( t \); \( P_{EB,t}^e \) is the electrical power consumed for heating of an electric boiler.

(2) Energy storage device constraints.

The energy storage device needs to meet the energy storage state constraint, and in order to ensure the continuity of scheduling, \( W_{s,T} \) is the state at the end time \( T \) of a given energy storage device scheduling is consistent with the state at the initial time \( W_{s,1} \).

\[
W_{s}^{min} \leq W_{s,t} \leq W_{s}^{max}
\]

(18)

\[
W_{s,1} = W_{s,T}
\]

(19)

In the formula: \( W_{s}^{min} \) and \( W_{s}^{max} \) are the minimum and maximum energy storage capacity of the energy storage device respectively.

The energy storage device shall also meet the constraint of charging and discharging power, which is related to the energy storage capacity and cannot be charged and discharging at the same time.

\[
\begin{align*}
0 &\leq P_{t}^{e} \leq \epsilon_{t,n}^{c} P_{\text{max}}^{e}
\end{align*}
\]

(20)

\[
\begin{align*}
0 &\leq P_{t}^{d} \leq \epsilon_{t,n}^{d} P_{\text{max}}^{d}
\end{align*}
\]

\[
0 \leq \epsilon_{t,n}^{c} + \epsilon_{t,n}^{d} \leq 1
\]

In the formula: \( \epsilon_{t,n}^{c} \) and \( \epsilon_{t,n}^{d} \) are the 0-1 state variables of the energy storage device at time \( t \) when it is charged and released; \( \epsilon_{t,n}^{c} = 1 \) represents charge, \( \epsilon_{t,n}^{d} = 1 \) That means energy.

(3) Power interaction constraints.

\[
P_{DN,t}^{e,\text{min}} \leq P_{DN,t}^{e} \leq P_{DN,t}^{e,\text{max}}
\]

(21)

In the formula: \( P_{DN,t}^{e,\text{max}} \), \( P_{DN,t}^{e,\text{min}} \) are the upper and lower limits of power interaction between micro grid \( l \) and distribution network respectively.

(4) Minimum start and stop time constraints for micro - gas turbine.

\[
\begin{align*}
S_{\text{off},t,i} &= (S_{\text{off},t,i-1} + u_{t,i}) h_{t,i} \\
S_{\text{on},t,i} &= (S_{\text{on},t,i-1} + u_{t,i}) (1 - u_{t,i}) \\
(1 - u_{t,i} - u_{t,i}) (T_{i,\text{on}} - S_{\text{on},t,i}) &\geq 0 \\
(1 - u_{t,i} - u_{t,i-1}) (S_{\text{off},t,i-1} - T_{i,\text{off}}) &\geq 0
\end{align*}
\]

(22)

In the formula: \( S_{\text{on},t,i} \), \( S_{\text{off},t,i} \) is the continuous interruption state and the continuous stop interruption state, and represents the duration of the load continuous interruption and the duration of the continuous stop interruption; \( u_{t,i} \) is a Boolean variable, which represents the interrupt state of interruptible load at time period \( t \); \( T_{i,\text{on}} \) Is the minimum continuous interruption time; \( T_{i,\text{off}} \) is the minimum continuous stop interruption time.

The minimum start-stop time constraint can be equivalently transformed into the following linear constraint by linearization [15].
In the formula: \( \delta(t, 1) \) is the unit impulse function; parameter \( \theta(\omega, t), \eta(\omega, t), \theta_{i,0} \) and \( \eta_{i,0} \) each is determined by the following expression.

\[
\begin{align*}
\sum_{t=1}^{T} u_{i,t} & \geq (u_{i,t-1} - u_{i,t}) \eta(T_{i,\text{on}} - t) + \delta(t - 1) \theta_{i,0} \\
\sum_{t=1}^{T} (1 - u_{i,t}) & \geq (u_{i,t-1} - u_{i,t}) \eta(T_{i,\text{off}} - t) + \delta(t - 1) \eta_{i,0}
\end{align*}
\]  

(23)

In the formula: \( \delta(t, 1) \) is the unit impulse function; parameter \( \theta(\omega, t), \eta(\omega, t), \theta_{i,0} \) and \( \eta_{i,0} \) each is determined by the following expression.

\[
\begin{align*}
\theta(\omega, t) &= \min\{t + \omega, T\} \\
\eta(\omega, t) &= \min\{\omega, T - t + 1\} \\
\theta_{i,0} &= u_{i,0} \max\{0, T_{i,\text{on}} - T_{i,\text{on0}}\} \\
\eta_{i,0} &= (1 - u_{i,0})(1 - u_{i,0}) \max\{0, T_{i,\text{off}} + T_{i,\text{off0}}\}
\end{align*}
\]  

(24)

In the formula: \( u_{i,0} \in \{0, 1\} \), \( T_{i,\text{on0}}, T_{i,\text{off0}} \) are known constants.

4. The example analysis

4.1. The basic example

In order to verify the effectiveness of the proposed model, this paper adopted the power, gas and heat load analysis in a region of Sichuan province, and connected different types of micro grid in the distribution network, MG1 being the residential micro grid and MG2 being the industrial micro grid. There is no heat energy transmission channel between microgrids, and relevant parameters of each device are cited in literature [16]. The peak, plateau and valley transaction price of electricity purchased and sold by micro grid [17] is shown in table 1. Running period \( T \) and interval \( \Delta T \) 24 h and 1 h, respectively. The electrical, gas and thermal load curves in the system are shown in figure 3-4.

4.2. Analysis of optimization results

As can be seen from figure 2-7, during the period of 0:00 to 6:00, the MG1 of the whole system is at a low level of electric load.

| Period of time | Electricity price/yuan / (kW·h) | Electricity price/yuan/ (kW·h) |
|---------------|---------------------------------|--------------------------------|
| peak          | 7:00-09:00                      | 0.83                           | 0.65                           |
|               | 18:00-23:00                     |                                |                                |
| flat          | 9:00-18:00                      | 0.49                           | 0.38                           |
| valley        | 23:00-07:00                     | 0.17                           | 0.13                           |

![Fig.2 Load of MG1](image-url)
At this point, the power generation output of the wind turbine unit produces surplus electric energy. P2G and the electric energy storage unit absorb the electric energy, and the internal micro-gas turbine is in a state of shutdown. The thermal load is gentle, which is provided by the waste heat of the electric boiler, the...
Gas-fired boiler and the micro-gas turbine. At the same time, the electricity load of MG2 gradually increases, and the real-time transaction price is at a low point. MG2 buys electricity from MG1 to meet the demand of electricity load, and the output of its internal micro-gas turbine increases slowly.

During the period from 7:00 to 12:00, the MG1 electric load increases, and the wind turbine and photovoltaic output cannot meet the demand of electric load, so the micro-gas turbine and the electric energy storage unit are started to generate electricity.

During the period from 12:00 to 18:00, the electric load of MG1 and MG2 is at a low point, and the output of renewable energy reaches a peak. All the devices in these two microgrids are in the same operating state. The output of the micro-gas turbine is decreasing. The heat load is rising and the heat supply of the electric boiler exceeds that of the gas boiler. At this time, micro grid power is in surplus and the electricity price is in normal period. In order to ensure economy, the system meets the electricity load demand of micro grid electricity.

At 18:00-24:00 hours, MG1 in electricity peak load, magnesium 2 electricity load down, each equipment running status is the same in the two piconets, renewable energy were decreased, the output of the electric energy storage unit is in a state of power, increase the micro gas turbine output to meet the demand of electric load, thermal load rise at the same time, in view of the peak period of electricity price is too high, mainly by gas boiler and micro gas turbine waste heat energy.

As shown in figure 8, under the condition of consuming the same size of renewable energy, compared with P2G outputs before and after considering the repeated energy conversion, it can be found that the optimal scheduling considering the repeated energy conversion can coordinate the operation plans of each equipment, reduce P2G outputs, reduce the repeated conversion energy flow, and improve the utilization efficiency of energy.

5. Conclusion
In view of the multiple piconets system, this paper constructs the piconets repeated internal energy conversion and power optimization scheduling model of interaction between piconets, the results show that compared with the traditional separate operation mode, this paper proposed the coordinated optimal operation model, through each device in the coordinate system of the operation plan, optimize the system energy flow, can effectively reduce the system cost and reduce the micro repeated energy conversion in the grid. Therefore, this model can improve the energy utilization efficiency, optimize the system...
operation state, make the multi-micro grid system reach the economic optimum, realize the energy optimization management of the whole system, and has a broad application prospect.

References

[1] Jia Hongjie, Mu Yunfei, Yu Xiaodan. Thought about the integrated energy system in China[J]. Electric Power Construction, 2015, 36(1): 16-25(in Chinese).
[2] Ju Ping, Zhou Xiaoxin, Song Yunting, et al. Review and prospect of regional renewable energy planning models[J]. Power System Technology, 2013, 37(8): 2071-2079(in Chinese).
[3] Wu Jianzhong. Drivers and state-of-the-art of integrated energy system in Europe[J]. Automation of Electric Power Systems, 2016, 40(5): 1-7(in Chinese).
[4] Geidl M, Koeppel G, Favre-Perrod P, et al. Energy hubs for the future[J]. IEEE Power and Energy Magazine, 2007, 5(1): 24-30.
[5] Chen Jie, Chen Xin, Feng zhiyang, Gong Chunying, Yan Yangguang. A control strategy of seamless transfer between grid-connected and islanding operation for microgrid[J]. Proceedings of the CSEE, 2014, 34(19): 3089-3097(in Chinese).
[6] Yang Peipei, Ai Xin, Cui Mingyong, Lei Zhili. Particle swarm optimization based economic operation analysis of microgrid containing multi energy supply system[J]. Power System Technology, 2009, 33(20): 38-42(in Chinese).
[7] Chen Jie, Yang Xiu, Zhu Lan, Zhang Meixia. Comparison of microgrid economic operation among different dispatch modes [J]. Electric Power Automation Equipment, 2013, 33(8): 106-113(in Chinese).
[8] Liu Xiaoping, Ding Ming, Zhang Yinyuan, et al. Dynamic economic dispatch for microgrids[J]. Proceedings of the CSEE, 2011, 31(31): 77-84(in Chinese).
[9] Ai Xin, Xu Jiajia. Study on the microgrid and distribution network co-operation model based on interactive scheduling[J]. Power System Protection and Contorl, 2013, 41(1): 143-149(in Chinese).
[10] Krause T, Andersson G, Frohlich K, et al. Multiple-energy carriers: modeling of production, delivery, and consumption[J]. Proceeding of the IEEE, 2011, (1): 15-27.
[11] Wang Yi, Zhang Ning, Kang Chongqing. Review and prospect of optimal planning and operation of energy hub in energy internet [J]. Proceedings of the CSEE, 2015, 35(22): 5669-5681(in Chinese).
[12] Xiong Yan, Wu Jiekang, Wang Qiang, et al. An optimization coordination model and solution for combined cooling, heating and electric power systems with complimentary generation of wind, pv, gas and energy storage[J]. Proceedings of the CSEE, 2015, 35(14): 3616-3625(in Chinese).
[13] Du Yan, Pei Wei, Ge Xianjun, et al. Rolling optimization of economic dispatching for multi-energy micro-grid system[J]. Proceedings of the CSU-EPSA, 2017, 29(11): 20-25(in Chinese).
[14] Xiao Hao, Pei Wei, Kong Li, et al. Research on optimal operation method of integrated energy microgrid system[J]. Advanced Technology of Electrical Engineering and Energy, 2016, 35(12): 1-11 (in Chinese).
[15] Chen Zhaoyu, Wang Dan, Jia Hongjie, et al. Research on optimal day-ahead economic dispatching strategy for microgrid considering p2g and multi-source energy storage system[J]. Proceedings of the CSEE, 2017, 37(11): 3067-3077, 3362(in Chinese).
[16] Li Yang, Liu Weijia, Zhao Junhua, et al. Optimal Dispatch of Combined Electricity-Gas-Heat Energy Systems with Power-to-Gas Devices and Benefit Analysis of Wind Power Accommodation [J]. Power System Technology, 2016, 40(12): 3680-3689(in Chinese).
[17] Hu Xiaotong, Liu Tianqi, He Chuan, et al. Multi-objective optimal operation of microgrid considering the battery loss characteristics [J]. Proceedings of the CSEE, 2016, 36(10): 2674-2681(in Chinese).
[18] Wang Chengshan, Hong Bowen, Guo Li, et al. A general modeling method for optimal dispatch of combined cooling, heating and power microgrid[J]. Proceeding of the CSEE, 2013, 33(31): 26-33(in Chinese).
[19] Madrigal M, Quintana A D. Semidefinite programming relaxation for \{0, 1\}-power dispatch problems[C]/IEEE Power Engineering Society Summer Meeting. Edmonton, Alta, Canada: IEEE, 1999: 697-702.

[20] Xu, Qingshan, Zeng Aidong, Wang Kai, et al. Day-ahead optimized economic dispatching for combined cooling, heating and power in micro energy-grid based on hessian interior point method[J]. Power System Technology, 2016, 40(6): 1657-1665(in Chinese).

[21] Liu Tianqi, Jiang Donglin. Economic operation of microgrid based on operation mode optimization of energy storage unit[J]. Power System Technology, 2012, 36(1): 45-50(in Chinese).