Research on Dispatch Optimization of Self-owned Power Plant under High New Energy Penetration

Zhenhuan Chen¹, Zan Yang², *, Chunxiang Yang¹, Bolin Zhang¹, Tianrui Zhang², and Tianyu Zhang²

¹ State Grid Gansu Electric Power Company, Lanzhou, China
² Beijing Tsintergy Technology Co., Ltd., Beijing, China

*Corresponding author e-mail: yangzan@tsintergy.com

Abstract. Considering that self-owned power plant (SPP) can accommodate more new energy generation, this paper proposes a joint dispatch optimization method of SPP. First, two market patterns of SPP considering its load characteristics were established. Then, a self-optimization model of SPP was built with the goal of minimizing SPP operating costs, and a joint optimization model of both SPP and the grid was constructed with the goal of minimizing total system operating costs which comprehensively considered the constraints of SPP interests, unit generation capacity, new energy accommodation requirement and grid security in optimizing the output of SPP and grid-connected units. Next, the optimization models were solved by NSGA-II algorithm. Finally, a comparative case-study on the two models was carried out, and the results showed that SPP can help to accommodate more new energy and reduce system operating costs.

1. Introduction
On September 22nd, 2020, China announced that it will strive to achieve peak carbon emissions by 2030 and achieve carbon neutrality by 2060. The key to achieve this goal is to continuously increase the penetration of new energy in China's power system. The leaping development of new energy has also brought about a problem: Since it is hard to consume all the new energy through the grid, wind and photovoltaic power has been seriously curtailed.

Self-owned Power Plant (SPP) has the characteristics of small installed capacity, rapid response and high peak-regulation capacity. However, for a long time, there has been a lack of frequent and flexible power interaction between the SPP and the grid, while the potential of SPP in new energy consumption has not been exploited [1]. To improve new energy consumption and effectively integrate the peak-regulation capacity of SPP, new energy enterprises are encouraged to trade generation rights with SPP.

To trade generation rights, SPP signs a medium and-long-term contract with new energy enterprise and transfers part or all of the generation right to the new energy enterprise while providing certain peak-regulation auxiliary services. Then, SPP consumes the traded power on time and pays the fees in time. Scholars have studied generation right trading. Literature [2-4] analyzed the current situation of generation right trading in China, discussed the trading mode and key issues, and analyzed the typical cases of SPP participating in generation right trading; Literature [5-7] built the generation right trading model with the goal of maximizing social benefits and incorporated green certificate trading and carbon
trading into the model; Literature [8] established the organizational process of generation right transfer for SPP and built the trading model based on the constraints of network losses; Literature [9-11] established the inter-provincial absorption and trading mechanism of new energy, and analysed the economic benefits of both parties based on the field data in China. Literature [12], [13] constructed profit models for different market participants in generation right trading, and set up different bidding strategies. At present, the generation right trading of SPP participating in new energy consumption is still in the initial stage, and the corresponding market mechanism remains to be further studied.

In order to encourage SPP enterprises to consume new energy, this paper puts forward the participation mechanism of SPP enterprises in spot market. While guaranteeing the interests of all parties and the safe operation of grid, the joint bi-level optimization model of SPP enterprises and the grid is constructed with the goal of maximizing new energy consumption and minimizing total operating cost. Finally, the validity of the model is verified by case study. The conclusions of this paper provide helpful reference for enriching power regulation resources and improving new energy consumption.

2. Mechanism design of SPP enterprises participating in spot market

In this paper, the means of SPP enterprises participating in spot market are discussed in the centralized market mode. There are two ways for the power plants to participate in the spot market: Bidding with capacity but no price and Bidding with both quantity and price. In Bidding with quantity but no mode, the market participant reports its own supply curve and does not declare the price to act as the price receiver of the market; In Bidding with both quantity and price mode, the market participant reports its own supply-price curve and participates in the centralized market clearing. The power demand of SPP enterprises is satisfied by the grid while their surplus power output is transmitted through the grid. Under reasonable market mechanism, the system can fully tap the adjustment capacity of SPP enterprises and promote the consumption of new energy. This paper designs two stages of SPP enterprises participating in the spot market: (1) In the initial stage, due to the lack of experience in participating in the spot market and understanding of market risks, SPP enterprises are not able to declare a reasonable supply-price curve based on their own production cost characteristics. Therefore, it is suggested to adopt the method of Bidding with quantity but no price; (2) As the spot market becomes mature, SPP enterprises, after accumulating certain market operation experience and clearing price information, can comprehensively consider their own operation cost and spot market competition risk to formulate a reasonable bidding strategy. Therefore, they can consider the Bidding with both quantity and price mode.

Under the Bidding with quantity but no price mode, in the day-ahead spot market, SPP enterprises need to consider their load characteristics, generation cost, and price information of power exchanged with the grid to optimize the power flow of the tie line between themselves and the grid, and report it to the dispatch authority. The dispatch authority takes the tie line curve reported by SPP enterprises as the boundary condition of clearing the spot market, and combines with other boundary conditions of the spot market. The output curves of units in other markets are obtained through centralized optimization.

3. Construction of dispatch optimization model for SPP enterprises participating in spot market

Considering that the Chinese spot market is in trial operation, the way of SPP enterprises to participate in the spot market by Bidding with both quantity and price is immature. Thus, this paper constructs a bi-level dispatch optimization model of SPP enterprises in the spot market based on Bidding with quantity but no price. The lower model takes the lowest operation cost of the SPP enterprises as the goal in the unit output optimization, and outputs the power flow curve of the tie line between the SPP enterprise and the grid. The lower model interacts with the upper model through the optimized system load boundary.

3.1. Self-optimization model for SPP enterprises

Based on the minimum net cost, the optimization model of SPP enterprise is established. While the constraints are satisfied, the power supply reliability and economy of the SPP enterprise are realized.
3.1.1. Objective function. The power consumption cost of SPP enterprises includes the power generation cost of SPP thermal power units and the power purchase cost paid by SPP enterprises. In addition, when the SPP enterprises meet their own production load demand and still have surplus generation capacity, and the generating cost of the units is lower than the market price of the grid, they can sell electricity to the grid. Therefore, the optimization objective of SPP enterprises should be to minimize the balance between power consumption cost and sales revenue, and the objective function can be obtained as follows:

$$
\min F = \sum_{t=1}^{T} \left( \sum_{i=1}^{N_{spp}} P_{i,t}^{\text{pp}} \times C_{i,t}^{\text{pp}} + \sum_{j=1}^{N_{l}} P_{j,t}^{\text{down}} \times C_{j,t}^{\text{down}} - \sum_{j=1}^{N_{l}} P_{j,t}^{\text{up}} \times C_{j,t}^{\text{up}} \right)
$$

Where, $P_{i,t}^{\text{pp}}$ means the output of the No.$i$ thermal power unit in period $t$; $C_{i,t}^{\text{pp}}$ means marginal generation cost of the No.$i$ thermal power unit; $P_{j,t}^{\text{down}}$ means power on grid of the No.$j$ tie line in period $t$; $C_{j,t}^{\text{down}}$ means the power purchase price of the No.$j$ tie line in period $t$; $P_{j,t}^{\text{up}}$ means on-grid power of No.$j$ tie line in period $t$; $C_{j,t}^{\text{up}}$ means selling price of the No.$j$ tie line in period $t$. $N_{spp}$ means the number of thermal power units, $N_{l}$ means the number of tie lines between SPP enterprises and the grid.

3.1.2. Constraints. (1) Power balance constraints of SPP enterprises is shown in formula (2):

$$
\sum_{i=1}^{N_{spp}} P_{i,t}^{\text{pp}} + \sum_{j=1}^{N_{l}} P_{j,t}^{\text{down}} = \sum_{k=1}^{N_{sd}} L_{k,t} + \sum_{j=1}^{N_{l}} P_{j,t}^{\text{up}}, \forall t
$$

Where, $L_{k,t}^{\text{pp}}$ means the power demand of the No.$k$ production load of SPP enterprises in period $t$, $N_{sd}$ means the number of production loads of SPP enterprises.

Upper and lower limits of output of thermal power units in SPP enterprises are shown as:

$$
P_{i,t}^{\text{pp}} \leq P_{i,t}^{\text{pp max}}, \forall t
$$

(2) Ramping constraint of thermal power units in SPP enterprises is shown in formula (4):

$$
P_{i,t}^{\text{pp}} - R_{i,t}^{\text{down}} \leq P_{i,t}^{\text{pp max}} - P_{i,t-1}^{\text{pp max}} + R_{i,t}^{\text{up}}, \forall i, t
$$

Where, $R_{i,t}^{\text{down}}$ means the ramp-down rate of the No.$i$ thermal power unit in SPP enterprise, $R_{i,t}^{\text{up}}$ means the ramp-up rate of the No.$i$ thermal power unit in SPP enterprise.

(3) Power constraint of on and off grid:

$$
0 \leq P_{j,t}^{\text{pp}} \leq P_{j,t}^{\text{pp max}} \times U_{j,t}^{\text{up}},
0 \leq P_{j,t}^{\text{down}} \leq P_{j,t}^{\text{down max}} \times U_{j,t}^{\text{down}}, \forall j, t
$$

Where, $P_{j,t}^{\text{pp max}}$ and $P_{j,t}^{\text{down max}}$ means the upper/lower power limits of the No.$j$ tie line of SPP enterprises; $U_{j,t}^{\text{up}}$ and $U_{j,t}^{\text{down}}$ means the on/off-grid state of the No.$j$ tie line in period $t$, which are 0-1 variables.

(4) On/off-grid state constraints of tie line:

$$
u_{j,t}^{\text{down}} + u_{j,t}^{\text{up}} \leq 1, \forall j, t
$$

The No.$j$ tie line of SPP enterprise cannot be both on-grid and off-grid at the same time in period $t$.

3.2. Joint optimization model

To promote new energy consumption, thermal power plants bid with both quantity and price while new energy units bid with quantity but no price.

3.2.1. Objective function. Taking one hour as a dispatch period, this paper establishes a security-constrained economic dispatch model considering SPP enterprise to minimize the total operating cost, and incorporates new energy curtailment into the objective function as penalties. The objective function can be obtained as follows:

$$
\min F = \sum_{t=1}^{T} \left( \sum_{i=1}^{N_{spp}} P_{i,t}^{\text{pp}} \times C_{i,t}^{\text{pp}} + \sum_{j=1}^{N_{l}} \lambda_{w} \times (P_{w,j}^{\text{up}} - P_{w,j}^{\text{down}}) \right)
$$
Where, $P_{i,t}^e$ means the cleared power of the No.$i$ thermal power unit in period $t$, $C_{i}^e$ means the bidding price of the No.$i$ thermal power unit; $\lambda_w$ is the power curtailment penalty factor, $P_{w,t}^*$ means the forecast output of the No.$w$ new energy plant in period $t$, $P_{a,t}$ means the cleared output of the No.$w$ new energy unit in period $t$. $N_g$ means the number of thermal power units, $N_{re}$ is the number of new energy plants.

3.2.2. Constraints. (1) Power balance constraint is shown as:

$$\sum_{i=1}^{N_g} P_{i,t}^e + \sum_{w=1}^{N_{re}} P_{w,t} + \sum_{j=1}^{N_d} P_{j,t}^{up} = \sum_{d=1}^{D} L_{d,t} + \sum_{j=1}^{N_d} P_{j,t}^{down}, \forall t$$

Where, $L_{d,t}$ means the load demand of node $d$ in period $t$, $D$ is the number of load nodes.

(2) Upper and lower limit constraints:

$$P_{j,t}^{min} \leq P_{j,t}^e \leq P_{j,t}^{max}, \forall i, t$$

(3) Ramping constraint of thermal power units:

$$P_{i,t+1}^{g} - P_{i,t}^{g} \leq \Delta P_{i,t+1}^{g} \leq P_{i,t}^{g} + \Delta P_{i,t}^{g}, \forall i, t$$

Where, $R_{i,t}^{down}$ and $R_{i,t}^{up}$ means the ramp-down and ramp-up rate of the No.$i$ thermal power unit.

(4) New energy output constraint:

$$0 \leq P_{w,t}^* \leq P_{w,t}^*, \forall w, t$$

(5) Line power flow constraint:

$$P_{i,t}^{max} = \sum_{i=1}^{N_g} P_{i,t} G_{i,i} + \sum_{w=1}^{N_{re}} P_{w,t} G_{w,i} - \sum_{j=1}^{N_d} P_{j,t} G_{j,i} - \sum_{d=1}^{D} L_{d,t} G_{d,i} - \sum_{j=1}^{N_d} P_{j,t}^{down} G_{j,i} + \sum_{j=1}^{N_d} P_{j,t}^{up} G_{j,i}, \forall t$$

Where, $P_{i,t}^{max}$ means the power flow transmission limit of line $i$; $G_{i,i}$ and $G_{w,i}$ mean the d generation transfer distribution factor from the node of the No.$i$ thermal power unit and the No.$w$ new energy plant to line $i$; $G_{j,i}$ is the generation transfer distribution factor of the node of the No.$j$ tie line to the No.$i$ line; $G_{d,i}$ is the generation transfer distribution factor of the node of the No.$d$ tie line to the No.$i$ line.

3.3. Model solving algorithm

The bi-level model of SPP enterprises is nonlinear. Since the upper level and the lower level of the model have the same solving characteristics, the same algorithm can be applied to solve the model.

NSGA-II algorithm was improved based on genetic algorithm [14]. First, a fast non-dominant sorting algorithm is presented. Second, using crowdedness and crowdedness comparison operators, we overcome the drawback in NSGA that the sharing parameters need to be artificially specified, so that the individuals in the quasi-Pareto domain can be uniformly extended to the whole Pareto domain, which guarantees the population diversity. Finally, elite strategies were introduced, expanding the sampling space. By hierarchical deposition of all individuals in the population such that the best individuals won’t lost. In addition, NSGA-II is a fast algorithm, which has been widely used in multi-objective problems [15].

The solution process using NSGA-II algorithm is as follows. The flow diagram is shown in Fig. 2.

1) System initialization. Input 24h load of the SPP enterprise and the grid, unit output constraints, ramping constraints, generation cost constraints, new energy output constraints, line flow constraints, etc.

2) Fill initialization. Generate initial population $P$; $\text{Algebra } N_{gen}=1, t=1$.

3) Simulations. Invoke a lower-level optimization strategy to calculate the net cost and system operating costs.

4) Gene selection: Perform selection, crossing, variation, and generation of sub-population $Q$.

5) Simulation and calculation. Calculate the individual suitability of the net cost of the SPP enterprise and the operating cost of the system.

6) Combination. Obtain population $Q_t$ by combining current population $P$ with sub-population $Q$. Calculate the dominance relationships and aggregation distances of each individual based on the fitness function values, and classify the individuals by Pareto.
7) Termination condition. If the termination condition is met, then output the best solution, the net cost of the SPP enterprise, the system operating cost, otherwise return to step 4).

![Figure 1. Flow chart of NSGA-II algorithm.](image)

4. Case study
This paper designs a self-optimization model and a joint optimization model. A case study is carried out to observe the unit output and cost of self-optimized SPP enterprises, as well as new energy consumption and cost indicators, and to verify the role of SPP enterprises in spot market.

4.1. Parameter input
The case study is based on the IEEE-39 node system shown in Fig. 3. The grid consists of 8 thermal power units (node 31 to node 38), 1 photovoltaic field station (node 14) and 1 wind field (node 17), with SPP enterprise connected to node 30 and two thermal power units inside. Load forecasting data, operation characteristics and unit cost parameters are shown in Table 1. The unit overview is shown in Table 2.
The bi-level model is a day-ahead optimization model. New energy output and node price are predicted based on the ten-day new energy output data and the clearing price of a spot market in China. This paper considers time series forecasting and trend forecasting, and uses multi-factor gray forecasting model to forecast the daily new energy output and node power price as shown in Fig. 4 and Fig. 5.
4.2. Optimization process

Based on the IEEE-39 Node System, this paper sets up three scenarios:

Basic scenario: The SPP enterprises are self-sufficient, and do not exchange power with the grid;

Scenario 1: The SPP enterprise optimizes the power exchange with the grid according to a fixed price. The on-grid price is set at 0.3yuan/kWh, and the off-grid price is set at 0.5yuan/kWh;

Scenario 2: The SPP enterprises optimizes the power exchange with the grid according to the prediction of the next day's node price. The prediction results of node price are shown in Fig. 5. The simulation cycle is 24 hours and the simulation step is one hour. NSGA-II is used to solve the model. The algorithm parameters are shown in Table 3, and the fitness iteration curve is shown in Fig. 6.

| Scenario 1 (Self-optimization) | Scenario 2 (Self-optimization) |
|--------------------------------|---------------------------------|
| Scenario 1 (Joint optimization) | Scenario 2 (Joint optimization) |

**Figure 3.** New energy output forecast. **Figure 4.** Node electricity price forecast.

**Table 3.** Algorithm parameter setting

| Simulation Environment | Matlab2016b |
|------------------------|-------------|
| Population Size        | 300         |
| Iteration Times        | 30          |
| Probability of         | 0.3         |

**Figure 5.** Iterative curve.
During self-optimization, if the marginal cost is higher than the cost of purchasing power, units 1 and 2 will not generate power; When the marginal cost is lower than the cost of purchasing power, units 1 and 2 should give priority to the generating units with low marginal cost; If the unit output is surplus and the predicted market price is higher than the marginal cost of the unit, the SPP enterprise can sell power to the grid. Table 4 shows the objective function values of the relative optimal solution in scenarios 1 and 2. When the regional new energy curtailment rate is high, and the off-grid price of the SPP is lower than the generation cost of the SPP, the SPP can benefit from power exchange with the grid. When the regional new energy curtailment rate is low, the SPP meets its production load, and the off-grid price of the SPP is higher than the generation cost, it is economical that the SPP does not exchange power with the grid.

**Table 4. Values of two objective functions (yuan)**

| Object                           | Values (×10^6) |
|----------------------------------|----------------|
| Fitness curve of scenario 1      | 3380.13        |
| Fitness curve of scenario 2      | 3362.35        |
| Fitness curve of scenario 1 (Joint optimization) | 29063.10        |
| Fitness curve of scenario 1 (Joint optimization) | 28648.00        |

### 4.3. Optimization results

#### 4.3.1. Self-optimization results of SPP enterprises

The generation of SPP enterprise is independently optimized as follows:

1. **Unit output**
   - According to the optimized output results of SPP units in Fig. 7,
     a. Under the basic scenario, the total output of SPP units 1 and 2 is 10651.6mwh;
     b. Under scenario 1, the optimized total output of SPP units 1 and 2 is 9918.91mwh, the purchased power is 988.73mwh, and the sold power is 63.63mwh;
     c. Under scenario 2, the optimized total output of SPP units 1 and 2 is 9986.61 MW h, the purchased power is 805.46 MWh, and the sold power is 77.83 MWh.

2. **Economic analysis**
   - According to the cost optimization results in Fig. 8, in the basic scenario, the total generation cost is 3544710 yuan, of which the generation cost of unit 1 is 2110550 yuan and that of unit 2 is 1434150 yuan;
     a. Under scenario 1, the generation cost is 3380130 yuan, including 1512029 yuan for unit 1, 1491300 yuan for unit 2, 418630 yuan for power purchase and 41830 yuan for power sales;
     b. Under scenario 2, the total generation cost of SPP unit is 3362350 yuan, including 1556820 yuan for SPP unit 1; 1450140 yuan for SPP unit 2; 416160 yuan for power purchase and 60770 yuan for power sales. It can be seen from the above results that the SPP enterprises can obtain the highest economic benefits by applying the price declaration according to the forecast of the next day's node power price and implementing the optimization of power exchange with the grid.

![Figure 6. Cost optimization results of SPP unit.](image-url)
4.3.2. **Joint optimization results.** According to the optimization results of the lower model, the system load boundary of the system is adjusted, and the joint optimization is carried out, the results are shown as follow:

(1) Analysis of thermal power unit

a. Under the basic scenario (Fig. 9), the total output of thermal power units in the grid is 122416.5mw;

b. In scenario 1, the output of thermal power units in the grid is 121669.8mw;

c. In scenario 2, the output of thermal power units in the grid is 120524.3mw.

In scenario 2, the output of thermal power unit is smaller. According to the different marginal costs of eight thermal power units under the three scenarios (Fig. 10):

a. Under the basic scenario, the generation cost of thermal power unit is 2960.9×10^4 yuan;

b. Scenario 1: the generation cost of thermal power unit is 2906.3×10^4 yuan;

In scenario 2, the generation cost of thermal power unit is 2864.8×10^4 yuan.

![Figure 7. Output optimization results of thermal power units in the grid.](image)

![Figure 8. Marginal cost of thermal power unit.](image)

Fig. 11 shows that under the basic scenario, the output of new energy units is 16428.7mw; under scenario 1, the output of new energy units is 16546.02mw; under scenario 2, the output of thermal power units in the grid is 16628.38mw. In scenario 2, the output of thermal power unit is smaller.

![Figure 9. New energy output optimization results.](image)

From the above results, SPP enterprises can effectively improve the new energy consumption and reduce the system generation cost by declaring the price according to the forecast of the next day's node price and exchanging power with the grid, and adjusting and optimizing the tie line power of the grid.
5. Conclusion
The wind and solar new energy consumption puts forward higher requirements for system flexibility and peak-regulation capacity, and the fixed consumption price limits the flexibility of generation right transfer between new energy and SPP enterprises. To further release the potential of SPP to consume new energy and improve the trading efficiency, this paper designs the mechanism of SPP enterprises to participate in the spot market, and constructs a bi-level model of joint optimization between SPP enterprises and the grid with the goal of maximum new energy consumption and minimum total operation cost. By setting different power prices between SPP enterprises and the grid, this paper analyzes the new energy consumption and cost of joint optimization of SPP enterprises and the grid in different scenarios of price mechanism. The case study results show that the incorporation of SPP enterprises into the spot market system can guide the SPP enterprises' energy consumption behavior through the time-of-use price signal and reflect the supply and demand situation of the system, effectively improving the new energy consumption level, reducing operation cost, and realizing incentive compatibility.

References
[1] Hua Xia, Luo Fan, Zhang Jianhua, Wang Weizhou, Liu Fuchao. Feasibility Analysis of Trade Mode Promoting New Energy Consumption Based on Generation Rights Trade of Self-generation Power Plants[J]. Power system automation, 2016, 40(12):200-206.
[2] Zhang Xian, Geng Jian, Pang Bo, et al. Application and analysis of generation rights trading in energy conservation and emission reduction in China[J]. Power system automation, 2014, 38(17):87-90, 129.
[3] Wang Dandong, Li Fengting, Li Yiyan, et al. Research on the Matchmaking Mode for Promoting Captive Power plant to Participate in Wind Power Substitution[J]. Hydropower generation, 2017, 43(12):68-70, 75.
[4] ZHAO D, YAO L. Analysis of generation rights trade comprehensive benefit[C]//International Conference on Systems and Informatics, Yantai, 2012: 628-632.
[5] Zhao Wenhui, Gao Jiaoqian, Yu Jinlong, et al. Generation rights trading model taking into account carbon trading and green certificate trading mechanisms[J]. Renewable energy, 2016, 34(8):1129-1137.
[6] YANG H, PENG J, CHEN H, et al. Research of generation right transaction scheduling model considering carbon emissions constraints blocking[C]//IEEE 20th International Conference on Computer Supported Cooperative Work in Design, Nanchang, 2016: 557-559.
[7] LIU Y, ZHANG N, KANG C, et al. Impact of Carbon market on China’s electricity market: An equilibrium analysis[C]//IEEE Power & Energy Society General Meeting, Chicago, 2017: 1-5.
[8] YANG Huping, YAN Feifei, ZHANG Li, et al. Optimization of low network loss generation right transaction considering steady state voltage stability constraint[J]. Power System Protection and Control, 2017, 45(4): 45-49.
[9] Zhang Lizi, Wang Rui, Jin Yunjian, et al. Research on "Xinjiang Power Delivery" Transaction Model Based on Inter-provincial Generation rights Transaction[J]. Power System Protection and Control, 2012, 40(5):69-74, 79.
[10] Zheng Xiangyu, Jia Rong, Wen Dong, et al. Research on the new transaction mode of inter-provincial and inter-regional generation rights considering new energy consumption[J]. High-voltage electrical appliances, 2017, 53(5):121-126.
[11] Li Feng, Zhang Lizi. Research on the mechanism of large-scale wind power consumption and transaction across provinces[J]. Power automation equipment, 2013, 33(8):119-124.
[12] Meng Wenchuan, Lin Changyong, Wen Fushuan, et al. Bidding strategy of generation companies in generation rights trading market with high low matching mechanism[J]. Power construction, 2016, 37(11):1-8.
[13] YU Q, ZHANG L. Research in bidding strategies under different price mechanisms in generation-
right trading[C]/2011 2nd International Conference on Artificial Intelligence, Management Science and Electronic Commerce, Deng Leng, 2011: 4197 — 4200.

[14] Ma T X, Wu J Y, Hao L L, et al. The optimal structure planning and energy management strategies of smart multi energy systems[J]. Energy, 2018, 160:122-141.

[15] Hassoun A, Dincer I. Development of power system designs for a net zero energy house[J]. Energy & Buildings, 2014, 73(2):120-12