Research on an Optimization Method of Comprehensive Regulation of Energy Supply and Demand in Integrated Energy System

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Abstract: For an integrated energy system (IES) with demand-side response capabilities, both the production of chilled water, hot water, electricity, and steam can be changed by adjusting the output of various energy conversion equipment, and various energy products can be adjusted through the demand-side management. The change of energy conversion equipment operation and demand response measures implementation are all need costs. Integrated optimization of the production side and demand side of energy products such as cold, heat, electricity, and steam have the potential to reduce the total energy cost of IES. To this end, this article combines cases to establish a mathematical model for the various types of energy production and demand response costs of cold and heat electricity, with the goal of minimizing the overall cost of energy supply and use as a comprehensive control and optimization of energy supply and demand in IES. The results show that compared with simply adjusting the output of energy stations, the coordinated regulation of energy production and demand side of the integrated energy system has the potential to further reduce the cost of integrated energy supply and utilization system.

Keywords: Integrated Energy System, Comprehensive Adjust Of Supply And Demand, Synergic Optimization

1. Introduction

In the face of the increasing energy demand and the increasingly urgent situation of environmental protection, it has become an important and inevitable trend of energy transformation and social development to improve energy utilization efficiency and explore new energy. In general secretary xi jinping put forward the positive promotion of China's energy production and consumption revolution [1], should be provided by the supply side of the one-way, to provided by the supply side and demand side two-way coordinated security concept, namely to "scientific supply meet the demand of reasonable", to promote curb unreasonable demand to ensure our energy security strategy altitude, through the rationalization of energy demand, the supply of scientific, clean, low carbon, realize the sustainable energy security [2].With energy production and consumption revolution, the traditional energy services is gradually to take the customer as the center of comprehensive energy service transition, establishing comprehensive level of organic fusion zone can complementary
energy system, complement each other to achieve a variety of forms of energy optimization, respond to a nation "Internet +" wisdom energy initiative, is a hot spot in the current energy development trends [3, 4].

The park's integrated energy system has the potential to increase the consumption of renewable energy and reduce the energy supply cost. By modeling the comprehensive energy system of the park and solving the objective function by various optimization algorithms, the energy allocation, capacity and strategy of the park under the optimal goal scenario can be obtained [5]. Brandoni C. et al. [6] proposed the optimal configuration of hybrid distributed energy system suitable for residential buildings in specific areas based on energy price, energy demand, regional characteristics and other factors. Georgios Chalkiadakis et al. [7] believed that the creation of a virtual power plant could be used as an effective means to achieve the integration of distributed energy, and applied the game theory to propose a pricing mechanism as an alternative to the feed-in tariff to promote the planning, configuration and operation optimization of distributed energy. Alvarado C. et al. [8] combined with energy price and energy demand, considered the life-cycle cost and carbon emissions, and built a simulation model for the optimization of the park's integrated energy system configuration and operation.

For the matching problem of supply and demand of the park comprehensive energy system without considering the adjustable demand, the key points should be solved: 1) what kind of energy resources and energy conversion equipment should be adopted; 2) the installed capacity of the energy conversion equipment to be used; 3) what operation strategies should each equipment adopt to meet the energy demand [9]. ChenX et al. [10] studied considering the heat storage tank zone integrated energy system centralized scheduling problem of the supply side, set up a meet the demand of heat and electricity model of linear programming, this model considers the cogeneration systems (CHP), wind power generation, electric boiler and thermal storage tank, such as equipment, research results show that the electrical boiler with heat storage water tank can be improved CHP power flexibility. Based on the economic performance of the comprehensive energy system, YRuan et al. [11] established a linear comprehensive energy system model considering ice storage equipment, CHP and electric refrigeration equipment. The results show that the price of natural gas is the most important factor affecting the economic performance of the comprehensive energy system, followed by the market price of public power and the price of generators. LiGuo et al. [12] established a two-stage optimization planning and design model for cold, hot and electric micro-grid systems with the optimization objectives of the total net present value and the minimum carbon dioxide emissions in the whole life cycle. However, these models are generally static models. In actual operation, due to the partial load characteristics of the equipment, the price difference of energy sharing and the change of renewable energy output, the adjustment of output of each energy conversion equipment at different times will lead to the change of the production cost of terminal energy products such as cold, hot, electric and steam.

Different from the way of controlling the output of comprehensive energy equipment or the demand response measures, this paper discusses the optimal supply and use energy regulation strategy from the perspective of the economic cost that causes the change of energy supply and the economic cost that causes the demand transfer.

2. Dynamic Cost Modeling of Various Energy Supply Systems
The source of energy in the energy system are diverse, mainly including gas, coal, fuel, power grid, solar energy, wind energy, geothermal, water, air source and the means and so on, through a variety of energy conversion technology (ECT) to form the area available to the user of electricity, heat and cold, this article selects the energy conversion technology (ECT) mainly includes the gas generator set (ICS), lithium bromide absorption units (ARU), electric refrigeration unit, heat pump, boiler, energy storage device (storage heat storage), the power grid, photovoltaic (PV), sunlight (PT), wind and geothermal, different j value corresponding to the energy conversion technology (Energy Conversion Technology, ECT) as shown in table 1. Current methods of electricity storage mainly include battery
energy storage, pumping energy storage, super capacitor energy storage, compressed air energy storage and superconducting power storage. Due to the high input cost, low efficiency and poor economic benefit of electricity storage, it is less in the general comprehensive energy system of the park [13]. This paper only considers the cold and heat storage of the comprehensive energy system of the park.

Table 1 Different j corresponding ECT

| j | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|----|----|
| ECT | gas generator set (ICS) | lithium bromide absorption units (ARU) | electric refrigeration unit | heat pump | boiler | energy storage device | power grid | photovoltaic (PV) | sunlight (PT) | Wind power generation | geothermal |

Define the technology level of the supply $S\text{Cost}_{t_r, total}$ used to describe the park integrated energy system in all the supply side of moment $\tau$, initial investment, operating cost and maintenance level. Generally, the ECT equipment investment on the supply side generally occurs in the construction phase of the park’s integrated energy system project, while the operation cost usually occurs in the operation phase of the project. However, in this paper, the initial investment of ECT on the supply side of the integrated energy system in the park is converted into the initial investment of the project in the whole life cycle by using the equal annual value method (UAVM). On this basis, the annual equivalent running hours (AEOH) is used to convert the initial investment of equal annual value into the initial investment of each running time.

Then add the hourly running cost and maintenance cost to the hourly initial investment to obtain the technical cost level of the supply $S\text{Cost}_{t_r, total}$ represents the total technical cost of all supply side ECT, as shown in formula (1). $S\text{Cost}_{t_r, j}$ mainly includes the supply side of the first $j$ a ECT of the initial investment, operating and maintenance costs, as shown in formula (2).

The initial investment in ECT depends on the configured capacity of each ECT, and the maximum configured capacity is limited by local natural resources and the surrounding environment, so the configured capacity of each ECT has an upper limit.

$$S\text{Cost}_{t_r, total} = \sum_j S\text{Cost}_{t_r, j}$$  \hspace{1cm} (1)

$$S\text{Cost}_{t_r, j} = C_{in,j} + C_{o,j} + C_{m,j}$$  \hspace{1cm} (2)

Where, $C_{in,j}$ said technology investment of $\tau$ in the early moments $j$ can be calculated by UAVM and AEOH, as shown in the formula (3); $C_{o,j}$ presentation technology $j$ at time $\tau$ operating cost, the basic electricity and the electricity charge by transformer (gas fee, etc.), as shown in the formula (4); $C_{m,j}$ presentation technology $j$ maintenance in time $\tau$, is composed of fixed maintenance cost and change maintenance cost [14], as shown in the formula (5).

$$C_{in,j} = \frac{PR_j * RC_j * \frac{r^\tau}{1-(1+r)^\frac{r}{j}}}{T_j}$$  \hspace{1cm} (3)

$$C_{o,j} = \epsilon_j Q_{r,j} + C_{\text{trans},j}$$  \hspace{1cm} (4)

$$C_{m,j} = \frac{\alpha_j}{T_j} RC_j + \beta_j Q_{r,j}$$  \hspace{1cm} (5)
Where, \( PR_j \) said technology \( j \) unit configuration capacity price, RMB/kW. \( RC_j \) represents the configured capacity of technology \( j \), as shown in formula (6). \( r \) is the discount rate; \( n_j \) is the service life of technology \( j \), years; \( T_j \) represents the AEOH of technology \( j \), as shown in formula (7). \( \varepsilon_j \) represents the running cost coefficient of technology \( j \), RMB/kW; \( Q_{t,j} \) represents the output of technology \( j \) at time \( t \), kW; \( \alpha_j \) represents the fixed maintenance cost coefficient of technology \( j \), RMB/kW; \( \beta_j \) represents the variable maintenance cost coefficient of technology \( j \), RMB/kW; \( C_{\text{trans},j} \) represents the basic electricity cost of technology \( j \), as shown in formula (8).

\[
RC_j = \max(Q_{t,j}) \quad (6)
\]
\[
T_j = \frac{\sum_{n=1}^{8760} Q_{t,j}}{RC_j} \quad (7)
\]
\[
C_{\text{trans},j} = a_j \frac{RC_j}{T_j} \quad (8)
\]

Where, \( Q_{t,j} \) represents the output of technology \( j \) at the moment \( t \), \( t = 1, 2, ..., 8760 \); \( a_j \) represents the basic electricity charge coefficient of technology \( j \), RMB /kVA, whose form is shown in formula (9, 10):

\[
C_{\text{trans},j}^{\text{annual}} = Tr_{p,j} * m * RC_j \quad (9)
\]
\[
a_j = Tr_{p,j} * m \quad (10)
\]

Where, \( Tr_{p,j} \) represents the basic electricity charge of transformer capacity of technology \( j \), RMB / (kVA · month); \( m \) is the number of monthly copies used, and this paper takes 12.

\[
SCost_{t, \text{total}} = \sum_j [(a_j + \alpha_j + \varphi_j)\frac{\max(Q_{t,j})}{\sum_{n=1}^{8760} Q_{t,j}} + (\beta_j + \varepsilon_j)Q_{t,j}] \quad (11)
\]

Substitute equation (2) - (8) into equation (1) to obtain:

Where, \( t \) and \( \tau \) on behalf of the physical meaning is different, \( t = 1, 2, ..., 8760 \) represents each hour of the year, and \( \tau \) represents the moment when formula (11) calculates the level of technical cost of supply; \( \varphi_j \) means technology \( j \) equal to the value of the initial investment coefficient, formula \( \varphi_j = PR_j / (1 - 1/(1 + r)^n_j) \) RMB/kW; each coefficient \( a_j, \alpha_j, \beta_j, \varphi_j, \beta_j, \varepsilon_j \) see table 2 for the value. It is worth noting that energy storage equipment is different from other ECT capacity configuration methods. The capacity of energy storage is the accumulated value of energy storage or energy release in the energy storage and release cycle. The unit of construction cost is RMB/m³, while the capacity of other ECT is the maximum annual output, and the unit of cost is RMB /kW. In this paper, the cycle of energy storage and energy release is assumed to be 24 hours, that is, energy storage at night and energy release during the day, so the capacity of the energy storage equipment on day 1 is shown in equation (12). the configured capacity of energy storage equipment should be the maximum annual energy storage daily usage, as shown in equation (13). Therefore, the initial investment of energy storage equipment can be derived, as shown in equation (14).

**Table 2** Value of key parameters of supply technology cost level

| \( j \)          | \( \varphi_j \) (RMB/kW) | \( \alpha_j \) (RMB/kW) | \( \beta_j \) (RMB/kW) | \( \varepsilon_j \) (RMB/kWh) | \( \beta_j \) (RMB/kWh) | \( \alpha_j \) (RMB/kW) |
|------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Gas-fired generating set | 111.04 | 13.5 | 0.10 | 0.81 | 0.00 |
| Lithium bromide absorption unit | 49.25 | 12.4 | 0.03 | 0.00 | 0.00 |
| The electric machine | 36.88 | 12.4 | 0.02 | 0.16 | 28.00 |
| Heat pump | 45.32 | 12.4 | 0.02 | 0.26 | 28.00 |
The boiler 15.87 9.8 0.02 0.50 0.00
Energy storage device 12.70 11 0.02 0.17 0.00
Power grid 7.04 8.6 0.02 0.90 28.00
Photovoltaic power generation 394.02 14.5 0.09 0.00 0.00
Heat 267.37 14.5 0.09 0.00 0.00
Wind power generation 457.35 14.5 0.09 0.00 0.00
Geothermal 77.40 14.5 0.05 0.00 0.00

\[
\frac{1}{2} \sum_{i=1}^{24t} = 24(t-1) + 1 |Q_{i,6}|
\]  

(12)

\[
\max_{1 \leq t \leq 365} \frac{1}{2} \sum_{i=1}^{24t} = 24(t-1) + 1 |Q_{i,6}| / \eta_6
\]

(13)

\[
C_6 = \frac{\max_{1 \leq t \leq 365} \frac{1}{2} \sum_{i=1}^{24t} = 24(t-1) + 1 |Q_{i,6}| + k}{\Delta t \cdot C_p \cdot \rho_w \cdot \eta_6} \cdot \frac{PR_6}{6 \Delta t \eta_6} = \frac{\max_{1 \leq t \leq 365} \frac{1}{2} \sum_{i=1}^{24t} = 24(t-1) + 1 |Q_{i,6}|}{\Delta t \eta_6}
\]

(14)

\[
C_{in,6} = \frac{PR_6}{6 \Delta t \eta_6} \cdot \frac{\max_{1 \leq t \leq 365} \frac{1}{2} \sum_{i=1}^{24t} = 24(t-1) + 1 |Q_{i,6}|}{\Delta t \eta_6}
\]

(15)

Where, \(Q_{i,6}\) represents the output of the energy storage equipment at day \(l\) and time \(i\), when during the said release can, negative energy storage; \(\eta_6\) represents the energy storage efficiency of the energy storage equipment; \(k\) is the conversion coefficient between one degree electricity and joule, J/kWh; \(PR_6\) represents unit capacity price of energy storage equipment, RMB/m³; \(\Delta t\) shall be energy storage temperature difference, °C; \(C_p\) is the specific heat capacity of the energy storage medium, usually water, J/(kg·°C); \(\rho_w\) is the density of the energy storage medium, usually water, kg/m³. Substitute equation (14) into equation (3) to get:

Where, \(n_6\) is the service life of the energy storage equipment in years. In order to unify equation (15) with other ECT calculation formulas in the form of equation (11), two assumptions are made in this paper: 1) energy storage equipment only appears in the comprehensive energy system of the park with time-of-use electricity price and low valley price lower than 0.4 RMB/kWh.2) in a storage period, the storage energy is equal to the sum of the released energy and the storage energy loss, that is, the energy cannot be stored across the storage period. Under the above two assumptions, equation (15) is converted into the form of equation (16).

The initial investment coefficient \(\varphi_6\) of equiannual value of energy storage equipment is shown in

\[
C_{in,6} = \frac{12 \times 16}{7 \Delta t \eta_6} \cdot \frac{PR_6}{\frac{1}{(1 + \varphi)^6}} \cdot \frac{\max_{1 \leq t \leq 365} \frac{1}{2} \sum_{i=1}^{24t} = 24(t-1) + 1 |Q_{i,6}|}{\sum_{0}^{365} |Q_{i,6}|}
\]

(16)

equation (17).

\[
\varphi_6 = \frac{12 \times 16}{7 \Delta t \eta_6} \cdot \frac{PR_6}{\frac{1}{(1 + \varphi)^6}}
\]

(17)

From equation (17), it can be seen that the initial investment coefficient of equiannual value of energy storage equipment is affected by the energy storage efficiency, energy storage temperature difference and the cost level of unit energy storage equipment. Equation (17) is substituted into equation (11) to
obtain the technical cost level of the energy supply of the park integrated energy system at time \( \tau \), as shown in equation (18).

\[
SCost_{\tau,\text{total}} = \sum_j \left( \left(b_j + \varphi_j\right) \sum_{t=0}^{Q_{t,j}} + c_j Q_{t,j} \right), \ t = 1,2,\ldots,8760
\] (18)

Where, \( b_j = a_j + \alpha_j, c_j = \beta_j + \epsilon_j \). Type (18) describes the technology of \( \tau \) time energy supply. \( SCost_{\tau,j} \) with \( \max (Q_{t,j}) \), the relationship between \( \sum_{t=0}^{8760} Q_{t,j} \) and \( Q_{t,j} \). In the existing park integrated energy system, do not break in general, the value of \( Q_{t,j} \) is far less than \( \sum_{t=0}^{8760} Q_{t,j} \), that is to say, \( Q_{t,j} \), the influence of the change of the corresponding almost can be ignored. At time \( \tau \), therefore, when \( Q_{t,j} \) changes, can think \( \sum_{t=0}^{8760} Q_{t,j} \) remains the same, the \( SCost_{\tau,j} \) is only \( Q_{t,j} \) function.

### 3. Modeling the Demand Side Response Cost of Energy Products

According to the quantization method of energy storage technology in the model of technical cost level of energy supply, the technical cost level of distributed energy storage is derived, as shown in equation (19). \( DCost_{t,12} \) is used to quantify the demand changes of microcooling network and microheating network.

\[
DCost_{t,12} = (a_{12} + \alpha_{12} + \varphi_{12}) \frac{\sum_{t=0}^{8760} |\Delta D_{t,12}|}{\sum_{t=0}^{8760} |\Delta D_{t,12}|} + (\beta_{12} + \epsilon_{12}) |\Delta D_{t,12}|
\] (19)

Where, \( t = (1,\ldots,8760) \); \( \Delta D_{t,12} = D_{t,12} - D_{t,0} \) represents the demand change caused by distributed energy storage at the corresponding time; \( D_{t,0} \) is the initial energy demand at time \( t \); \( \Delta D_{t,12} = D_{t,12} - D_{t,0} \), unlike \( \Delta D_{t,12} \), represents the change in demand caused by distributed energy storage at time \( \tau \).

According to the existing research on demand response quantification, four commonly used functional relations between energy demand and energy price are linear equation relation, potential equation relation, logarithmic equation relation and exponential equation relation. Among them, the linear demand equation is the simplest and most widely applied energy demand and price model. Therefore, this paper selects the linear demand equation as the quantization equation of demand response, and then:

\[
D_{t,13} = l + hp_{t,13}
\] (20)

According to the price elasticity coefficient, \( E_{t,13} = \frac{p_{t,13} \partial D_{t,13}}{D_{t,13} \partial p_{t,13}} \) is introduced into equation (20), the equation of energy price \( p_{t,13} \) is obtained by taking the extreme value of the first derivative:

\[
D_{t,13} = D_{t,13}^0 \left[ 1 + E_{t,13} \frac{p_{t,13} - p_{t,13}^0}{p_{t,13}^0} \right]
\] (21)

According to the quantization method of energy storage technology in the model of technical cost level of energy supply, the technical cost level of distributed energy storage is derived, as shown in equation (19). \( DCost_{t,12} \) is used to quantify the demand changes of microcooling network and microheating network.

Therefore, the running cost of the demand response can be expressed as:

\[
p_{t,13}^0 D_{t,13}^0 - p_{t,13} D_{t,13}
\] (22)

Where, \( p_{t,13}^0 \) and \( D_{t,13}^0 \) are the initial energy price and initial energy load demand at time \( t \). Equation (21) and equation (22) are substituted into \( DCost_{t,13} \) to obtain:
$$DCost_{τ,13} = \left( \alpha_{13} + \varphi_{13} \right) \frac{\max^2(\Delta D_{τ,13})}{\sum_{0}^{8760} |\Delta D_{τ,13}|} + p^{0}_{τ,13}D_{τ,13}^{0} + \frac{D_{τ,13}(D_{τ,13} - L - hp^{0}_{τ,13})}{h}, t$$

$$= (1,\ldots,8760)$$

$$DCost_{τ, total} = DCost_{τ,12} + DCost_{τ,13} \quad (23)$$

Based on the technical cost water model of energy supply and demand established above, the change of energy supply and energy demand can be analyzed uniformly on the same quantitative index.

4. Production and Supply Coordination Optimization

The energy demand and supply of the park’s comprehensive energy system change by the hour, and the regulation cost also changes by the hour. According to the aforementioned energy conversion cost $SCost_{τ, total}$ (supply technology cost at time $τ$) and demand regulation cost $DCost_{τ, total}$ (demand regulation cost at time $τ$), a new supply and demand matching model is established based on both. The simplified principle of the supply and demand matching process of the economically optimized comprehensive energy system that realizes the supply and demand matching through this model is shown in figure 1. Supply curve A and demand curve C are respectively the supply capacity and energy demand before the comprehensive energy system matching. Both can be converted to the final matching curve B by the change of ECT type, capacity and output, for example, the process of $A' \rightarrow B' \rightarrow C'$ at time $τ$.

![Figure 1. Supply and demand matching schematic diagram of integrated energy system](image)

5. Conclusion

Based on the technical and economic characteristics of the energy conversion technology of the park's comprehensive energy system, the technology cost level model of energy supply is established, which quantifies the dynamic energy supply cost of each energy conversion technology on the supply side of the park. Based on the analysis of the change technology of cold, heat and electricity demand in the park, the change description model of technology cost level of energy demand is established. Based on the quantification of the change of energy supply and energy demand regulation cost, the matching model of supply and demand is established.

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References
[1] Du Xiangwan. Revolutionary strategy of energy production and consumption [N]. China financial news, 2017-06-03 (002).
[2] Du Xiangwan. Frontier and future direction of energy science and technology development [J]. Chinese science bulletin, 2017,62 (08) : 780-784.
[3] Zhong Di, Li Qiming, Zhou Xian, Peng Shuo, Wang Baomin. Research status and development trend of key technologies for comprehensive utilization of multi-energy complementary energy [J]. Thermal power generation, 2008,47 (02) : 1-5 + 55.
[4] Ai Qian, Hao Run. Key technologies and challenges of multi-energy complementary and integrated energy system optimization [J]. Power system automation, 2008,42 (04) : 2-10 + 46.
[5] Huang Zishuo, He guixiong, Yan Huaguang, Tang Yanmei. Function review and prospect of optimization model of park level comprehensive energy system [J]. Power automation equipment, 2020,40 (01) : 10-18.
[6] Brandoni C, Renzi M. Optimal sizing of hybrid solar micro-CHP systems for the household sector. Applied Thermal Engineering. 2015;75:896-907.
[7] Chalkiadakis G, Robu V, Kota R, Rogers A, Jennings NR. Cooperatives of distributed energy resources for efficient virtual power plants. The 10th International Conference on Autonomous Agents and Multiagent Systems - Volume 2. Taipei, Taiwan: International Foundation for Autonomous Agents and Multiagent Systems; 2011. p. 787-94.
[8] Cedillos Alvarado D, Acha S, Shah N, Markides CN. A Technology Selection and Operation (TSO) optimisation model for distributed energy systems: Mathematical formulation and case study. Applied Energy. 2016;180:491-503.
[9] Huang Zishuo, Yu Hang, Peng Zhenwei. Urban energy system and its planning from the perspective of wan [J]. Chinese science bulletin, 2008,63 (Z2) : 3047-3058.
[10] Chen X, Kang C, Malley MO, Xia Q, Bai J, Liu C, et al. Increasing the Flexibility of Combined Heat and Power for Wind Power Integration in China: Modeling and Implications. IEEE Transactions on Power Systems. 2015;30:1848-57.
[11] Ruan Y, Liu Q, Li Z, Wu J. Optimization and analysis of Building Combined Cooling, Heating and Power (BCHP) plants with chilled ice thermal storage system. Applied Energy. 2016;179:738-54.
[12] Guo L, Liu W, Cai J, Hong B, Wang C. A two-stage optimal planning and design method for combined cooling, heat and power microgrid system. Energy Conversion and Management. 2013;74:433-45.
[13] Telaretti E, Dusonchet L. Battery storage systems for peak load shaving applications: Part 2: Economic feasibility and sensitivity analysis. 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC)2016. p. 1-6.
[14] Guo L, Liu W, Cai J, Hong B, Wang C. A two-stage optimal planning and design method for combined cooling, heat and power microgrid system. Energy Conversion and Management. 2013;74:433-45.