Intelligent Calculation Model and Algorithm Optimization of Optimal Operation of Integrated Energy System

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Abstract. This paper analyzes the energy saving effect and optimal operation of the integrated park type energy system. The park type integrated energy system includes photovoltaic power generation system, ground source heat pump system, solar air conditioning system, regenerative electric boiler system and solar hot water system and so on. The energy saving benefit calculation model of each subsystem is established, and according to the operation history data of each subsystem, the calculation results of each subsystem are analyzed. It shows that: The energy saving income of photovoltaic power generation system is 734,200 yuan/year. The main revenue comes from the second and third quarters, during which it should pay attention to the maintenance of photovoltaic modules to ensure the maximum energy saving benefit. The energy saving income of ground source heat pump system in summer is 155,900 yuan/year, and the energy saving effect is not significant. It can cooperate with traditional units for cooling in summer. The heating in winter in the park is provided by ground source heat pump system, regenerative electric boiler system and solar energy air conditioning system. Its energy saving benefit is 3.995 million yuan/year which is the main source of energy saving income in the park, with remarkable energy saving effect.

Keywords: Integrated energy system, solar photovoltaic, ground source heat pump, energy-saving benefit, Operation optimization.

1. Introduction
In recent years, the integrated energy system with distributed energy as the main source of energy supply has been developed rapidly nationwide. In the integrated energy system planning and construction, load forecasting, scheduling and optimization operation, energy efficiency analysis, economic analysis and other aspects of the system are systematically studied. For example, distributed energy station equipment configuration and inter-station pipeline planning in an integrated energy system can realize the interconnection, coordination and complementation of energy resources between different regions [1]. The multi-load short-term prediction model or super-short-term load
prediction method of regional integrated energy system can effectively improve the load prediction accuracy of the integrated energy system [2-3]. The complementary characteristics of the electric and thermal power systems can be effectively utilized by establishing the scheduling model of the integrated electric and thermal energy systems [4]. Guo et al. systematically studied the energy efficiency assessment method of comprehensive energy system based on analytic hierarchy process, and verified the practicability and effectiveness of the energy efficiency assessment method [5].

However, the current research focuses on the theoretical research in the field of integrated energy system load forecasting and energy efficiency analysis, and there is no detailed and comprehensive analysis of the actual operation data of the integrated energy system. In this paper, according to the actual historical operation data of a comprehensive energy system, the overall energy saving benefit of the system is calculated, and according to the calculation results, a reasonable energy saving evaluation is made, and the operation characteristics are analyzed to guide the efficient and stable operation of the system.

2. Brief introduction of integrated energy system and energy-saving benefit algorithm

The park type integrated energy system includes photovoltaic power generation system, ground source heat pump system, solar air conditioning system, regenerative electric boiler system and solar hot water system, etc., and the corresponding energy-saving benefit calculation models are established.

2.1. Solar photovoltaic power generation system

The solar photovoltaic power generation system is distributed on the idle roofs of 8 buildings and corridors in the park. It adopts 4,180 pieces of 245Wp polysilicon photovoltaic modules with a total installed capacity of 1.024MWp. The calculation formula of energy saving benefit is as follows:

\[ X = 1.3141 E_f + 0.8686 E_p + 0.4431 E_g \]  

Where, \( X \) is the energy saving benefit of solar photovoltaic system, yuan/year. \( E_f \) is power generation in peak period, \( E_p \) is power generation in normal period, \( E_g \) is power generation in valley period, kW.h/year. 1.3141, 0.8686 and 0.4431 are respectively the electricity price of peak period, normal period and valley period, yuan/kW.h.

2.2. Solar hot water system

The solar hot water system is installed and coordinated with the regenerative electric boiler in the energy center to provide domestic hot water in the park. The specific calculation formula is as follows:

\[ X_{tr} = A \times N_{rs} \]  

Where, \( X_{tr} \) is the energy saving benefit of solar hot water system, yuan/year. \( A \) is the cost of domestic water heated by electricity, yuan/ton. \( N_{rs} \) is solar hot water accumulative flow, ton/year.

2.3. Ground source heat pump system

The source heat pump system in the park is equipped with three screw-type ground source heat pump units. Under the refrigeration condition, the cooling capacity of the single-platform ground source heat pump unit is 1195kW. Under the heating condition, the heat produced by a single ground source heat pump unit is 1267kW. The specific calculation formula is as follows:

(1) Energy saving benefit in summer refrigeration condition

\[ X_{LD} = A_i \times E_{LD} \]  

Where, \( X_{LD} \) is the energy saving benefit of ground source heat pump system, yuan/year. \( A_i \) is the unit cost of electricity, yuan/kW.h. \( E_{LD} \) is the electric energy consumed by the ground source heat pump system, kW.h/year.
Where, $X_{LD}$ is the refrigeration cost of ground source heat pump unit, yuan/year. $A_1$ is the weighted electricity price during refrigeration of the ground source heat pump unit, yuan/kWh. $E_{LD}$ is the refrigeration power consumption of a ground source heat pump unit, kW.h/year.

$$E_{LJ} = \frac{Q_L}{COP_L}$$

(4)

Where, $Q_L$ is the cooling capacity of ground source heat pump unit, kW.h/year. $COP_L$ is the energy efficiency ratio of traditional refrigerating unit. $E_{LJ}$ is the theoretical power consumption of traditional refrigeration unit, kW.h/year.

$$X_{LJ} = A_1 \times E_{LJ}$$

(5)

$$X_L = X_{LJ} - X_{LD}$$

(6)

Where, $X_{LJ}$ is the refrigeration cost of the traditional refrigeration unit, yuan/year. $X_L$ is the energy-saving benefit of working condition in summer, yuan/year.

(2) Energy saving benefit in winter heating condition

$$X_{RD} = A_2 \times E_{RD}$$

(7)

Where, $X_{RD}$ is the heat consumption cost of the ground source heat pump unit, yuan/year. $A_2$ is the weighted electricity price during the heating period of the unit, yuan/kWh. $E_{RD}$ is the unit heating power consumption, kW.h/year.

2.4. Regenerative electric boiler system

In winter, the heating system of regenerative electric boiler is also adopted, which is equipped with 6 pieces of 2070kW electric boilers and 4 sets of heat storage tanks. The specific calculation formula is as follows:

$$X_{XR} = 0.4431 \times E_G$$

(8)

Where, $X_{XR}$ is the heating cost of regenerative electric boiler, yuan/year. $E_G$ is the valley electricity consumption of the electricity price of regenerative electric boiler, kW.h/year. 0.4431 is the electricity price during the grain period.

2.5. Solar air conditioning system

The solar air conditioning system is equipped with a solar collector covering an area of about 1,350 square meters, which obtains energy from sunlight. The specific calculation formula is as follows:

$$X_{RRT} = A \times E_{RRT}$$

(9)

Where, $X_{RRT}$ is the heating cost of solar air conditioning in winter, yuan/year. $E_{RRT}$ is the heating power consumption of solar air conditioning in winter, kW.h/year. $A$ is the weighted electricity price during the solar air conditioning operation, yuan/kWh.

2.6. Comprehensive economic benefit of heating in winter

In the winter heating period of the park, the ground source heat pump system, regenerative electric boiler system and solar energy air conditioning system provide heating comprehensively. Therefore,
the overall calculation method is adopted in this report, the energy saving benefit of the whole heating period is calculated.

\[ X_{ZXY} = A_{SZ} \times S - X_{RD} - X_{XR} - X_{RTT} \]  

(10)

Where, \( X_{ZXY} \) is the comprehensive economic benefit of winter heating in the park, yuan/year. \( A_{SZ} \) is the price of municipal central heating, yuan/(square meter*year). \( S \) is equivalent area of municipal heating, square meters.

3. Calculation results and analysis of energy saving benefit

3.1. Solar photovoltaic power generation system

The data used for calculation is select form the first quarter of 2018 to the second quarter of 2019. The calculated results are shown in Table 1. It can be seen that the total revenue of the solar photovoltaic power generation system is 734,238.11 yuan in one measurement period, among which, the revenue of valley period is 2,412.64 yuan/year, that of normal period is 447,833.22 yuan/year and peak period is 283,992.25 yuan/year. It can be seen that the solar photovoltaic power generation system has the highest income in the normal period.

The power generation capacity of the solar photovoltaic power generation system in each quarter in 2018 is counted, as shown in Figure 1. As can be seen, the photovoltaic power generation mainly concentrated in the second and third quarters, accounting for 65 percent of the annual power generation. Therefore, extra attention should be paid to the maintenance of photovoltaic modules in the second and third quarters of each year to ensure the maximum energy efficiency.

| Table 1. Calculation results of solar photovoltaic power generation system. |
|-------------------|--------|---------|---------|---------|--------|
|                   | unit   | valley period | normal period | peak period | total  |
| power generation  | kW.h   | 5,444.9  | 515,580.5 | 216,111.6 | 737,137.0 |
| electricity price | yuan/kW.h | 0.4431 | 0.8686 | 1.3141 | / |
| revenue           | yuan/year | 2,412.64 | 447,833.22 | 283,992.25 | 734,238.11 |

Figure 1. The quarterly power generation of Solar photovoltaic power generation system in 2018.

3.2. Solar hot water system

The data used for calculation is select form 2018/6/1 to 2019/5/31 as one measurement period. The calculated results are shown in Table 2. It can be seen that, compared with the use of electric heating domestic water, the use of solar hot water system has an energy saving benefit of 1,835,700 yuan/year in one period, with obvious energy saving effect.
### Table 2. Calculation results of energy saving benefit of solar hot water system.

| Parameter                                      | Symbol | Unit     | Result   |
|------------------------------------------------|--------|----------|----------|
| Cost of domestic water heated by electricity   | $A$    | yuan/ton | 73.2     |
| Solar hot water accumulative flow              | $N_{RS}$ | ton/year | 25,077   |
| Energy saving benefit of solar hot water system | $X_{tr}$ | yuan/year | 1,835,700 |

#### 3.3. Ground source heat pump system

In working condition of the summer, the data used for calculation is select form 2018/6/1 to 2019/9/30 as one measurement period. The calculated results are shown in Table 3. It can be seen that, the power consumption of the ground source heat pump system in a refrigeration cycle is 646,500 kW.h, and the power consumption of the traditional unit to prepare the same cooling capacity is 820,700 kW.h. Then, the power saving in summer is 174,200 kW.h, and the energy saving benefit is 153,900 yuan. We can see that, the energy saving benefit of the ground source heat pump system in summer is not significant compared with the traditional refrigeration unit, which can make the ground source heat pump unit and the traditional refrigeration unit work together to ensure sufficient cooling in the park.

### Table 3. Calculation results of ground source heat pump working conditions in summer.

| Parameter                                      | Symbol | Unit     | Result   |
|------------------------------------------------|--------|----------|----------|
| Heat pumps power consumption in summer         | $E_{LD}$ | kW.h/year | 646,500   |
| Weighted electricity prices                     | $A_1$  | yuan/kW.h | 0.8839    |
| Heat pump refrigeration cost                    | $X_{LD}$ | yuan/year | 571,500   |
| Refrigerating capacity                          | $Q_L$  | kW.h/year | 3,775,100 |
| Refrigeration energy efficiency ratio           | $COP_J$ | / | 4.6 |
| Conventional units power consumption (prepare the same amount of cold) | $E_{LJ}$ | kW.h/year | 820,700 |
| Conventional unit refrigeration cost            | $X_{LJ}$ | yuan/year | 725,400   |
| Energy saving in summer                         | $E_L$  | kW.h/yaer | 174,200   |
| Energy saving benefit in summer                 | $X_L$  | yuan/year | 153,900   |

In working condition of the winter, the data used for calculation is select form 2018/11/15 to 2019/3/31 as one measurement period. The calculated results are shown in Table 4. It can be seen that the power consumption of the ground source heat pump system in one winter operating cycle is 1,295,100 kw.h, and the power consumption cost is 1,116,300 yuan. The comprehensive economic benefits of winter heating can be seen at Section 3.6.

### Table 4. Calculation results of ground source heat pump working conditions in winter.

| Parameter                                      | Symbol | Unit     | Result   |
|------------------------------------------------|--------|----------|----------|
| Heat pumps power consumption in winter         | $E_{RD}$ | kW.h/year | 1,295,100 |
| Weighted electricity prices                     | $A_2$  | yuan/kW.h | 0.8620    |
| Ground source heat pump heating cost            | $X_{RD}$ | yuan/year | 1,116,300 |

In addition, the shutdown of the ground source heat pump system in summer and winter conditions is also counted, as shown in Figure 2-3. It can be seen that the ground source heat pump system in summer stopped the most times in June, for 13 times, and the ground source heat pump system in winter stopped the most times in November, for 11 times. The reason is that June and November are the first month of summer and winter working condition. Therefore, it is recommended that operators overhaul and maintain important equipment such as buried pipe heat exchanger and centrifugal chiller.
in May and October, which can avoid multiple downtime maintenance in June and October, prolong the safe and stable operation time of the system and improve economic benefits.

![Figure 2. Shut down times of ground source heat pump system in summer.](image)

![Figure 3. Shut down times of ground source heat pump system in winter.](image)

### 3.4. Regenerative electric boiler system

In working condition of the winter, the data used for calculation is select form 2018/11/15 to 2019/3/31 as one measurement period. The calculated results are shown in Table 5. It can be seen that the power consumption of regenerative electric boiler system in winter is 2,579,800 kw.h, and the heating cost is 1,143,100 yuan.

| Parameter                        | Symbol | Unit     | Result      |
|----------------------------------|--------|----------|-------------|
| Electricity consumption          | $E_g$  | kW.h/year| 2,579,800   |
| Electricity price during the grain period | $A_g$  | yuan/kW.h | 0.4431      |
| Heating cost of regenerative electric boiler | $X_{fr}$ | yuan/year | 1,143,100   |

### 3.5. Solar air conditioning system

In working condition of the winter, the data used for calculation is select form 2018/11/15 to 2019/3/31 as one measurement period. The calculated results are shown in Table 6. It can be seen that the heating cost of solar air conditioning in winter is 54,100 yuan. The comprehensive economic benefits of winter heating See section 3.6.
Table 6. Calculation results of solar air conditioning system in winter heating condition.

| parameter                                             | symbol | unit      | result  |
|-------------------------------------------------------|--------|-----------|---------|
| Solar air conditioning power consumption in winter    | $E_{RTT}$ | kW.h/year | 61,800  |
| weighted electricity prices                            | $A$    | yuan/kW.h | 0.875   |
| Solar air conditioning heating costs in winter         | $X_{RTT}$ | yuan/year | 54,100  |

3.6. Comprehensive economic benefit of heating in winter

In winter, the park is provided comprehensive heating by ground source heat pump system, regenerative electric boiler system and solar air conditioning system. Therefore, this paper adopts the method of overall calculation to calculate the energy saving benefit during the whole heating period, and the calculation results are shown in Table 7. It can be seen that if municipal central heating is used in the park, the cost is 6308000 yuan/year, and the comprehensive energy saving benefit of winter heating in the park is 3994500 yuan/year, which is the main source of energy saving benefit of the park.

Table 7. The comprehensive energy saving benefit calculation result of heating in winter in the park.

| parameter                                              | symbol | unit      | result  |
|--------------------------------------------------------|--------|-----------|---------|
| municipal central heating price                         | $A_{SZ}$ | yuan/m²  | 40      |
| equivalent area of municipal heating                    | $S$    | m²        | 157,700 |
| municipal heating costs                                 | $X_{SZ}$ | yuan/year | 6,308,000 |
| heating cost of ground source heat pump system          | $X_{RD}$ | yuan/year | 1,116,300 |
| heating cost of regenerative electric boiler system     | $X_{XR}$ | yuan/year | 1,143,100 |
| heating costs of solar air conditioning system          | $X_{RTT}$ | yuan/year | 54,100  |
| comprehensive economic benefits of winter heating       | $X_{ZXY}$ | yuan/year | 3,994,500 |

4. Conclusions

This paper studies energy saving effect analysis and optimal operation of park integrated energy system. The park type integrated energy system includes photovoltaic power generation system, ground source heat pump system, solar air conditioning system, regenerative electric boiler system and solar hot water system and so on. The calculation model of energy saving benefit of each subsystem is established. The calculation results of each subsystem are analyzed as follows:

1. Solar photovoltaic power generation system energy saving income is 734,200 yuan/year, and concentrated in the second and third quarter, special attention should be paid to the maintenance of photovoltaic modules, to ensure the maximum energy saving benefit.

2. The summer energy saving benefit of ground source heat pump system is 155,900 yuan/year, and the energy saving effect is not significant. In addition, it is recommended to carry out regular maintenance of the system in May and October each year to reduce the number of unit downtime.

3. Winter heating in the park is provided by the ground source heat pump system, regenerative electric boiler system and solar air conditioning system, and its energy saving benefit is 3,994,500 yuan/year, which is remarkable.

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