

# Research on Planning Model of Intelligent Energy System Based on Integrated Energy Stations

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**Abstract**—Traditional energy system planning mainly focuses on the energy system itself, featuring more serious fragmentation. The planning of intelligent energy systems needs to take full account of the system operation and coupling between different energy systems. In the present study, the planning model of intelligent energy systems based on integrated energy stations starts from the basic structure of energy stations, in which a double optimization model is established, including a planning level and an operation level, the economy, environmental protection and comprehensive energy utilization efficiency of the system considered, and the NSGA-II algorithm is used for optimization. Finally, a case in Hebei Province was used to solve the problem and verify the advantages of the model in the present, in terms of improving the comprehensive energy utilization efficiency, ensuring the economy of the system and reducing pollutant emissions.

**Keywords**—intelligent energy; integrated energy; energy station; multi-objective planning

## I. INTRODUCTION

In recent years, China's urban energy system planning has made considerable progress, especially in energy saving, emission reduction and renewable energy utilization. However, there are still some problems in the development of urban energy in China, such as large total energy consumption, unreasonable energy structure and low energy utilization efficiency. Traditional energy planning still suffers from some limitations and deficiencies. Fragmented energy planning and severe segmentation in energy categories has resulted in the repeated construction of energy facilities [1], which has long restricted the improvement of the comprehensive utilization level on each independent energy system. To date, research on integrated energy system planning has been conducted to improve the overall utilization efficiency of the energy system.

A literature [2] has introduced the characteristics of multi-energy systems and subsystems, and analyzed the optimal operation and planning of multi-energy systems. The comprehensive energy efficiency evaluation of multi-energy systems needs to consider the grade difference of different energy categories, and conduct a comprehensive evaluation based on the energy quality coefficient [3]. Another literature [4] proposed a model for the multi-objective optimization of integrated energy systems, and obtained the strategy for energy

optimization, aiming at maximizing the comprehensive energy efficiency level and improving the energy economy.

Considering economy, energy efficiency, environmental protection and many other objectives, the present study analyzed the advantages of integrated energy stations, proposed an optimization planning model, which included a planning level and operation level, and verified the model with examples.

## II. PLANNING THOUGHT OF INTEGRATED ENERGY STATIONS

The supply scheme of integrated energy stations belongs to long-term optimization, which can solve the development, construction and operation of energy facilities by combining long-term and short-term planning. Furthermore, the relationship is very complex between sub-energy networks in the system, the components and devices are great in number, and the energy demand significantly varies at the terminals. Hence, there are different methods for designing the supply schemes.

The double optimization model for the supply schemes of integrated energy stations can be optimized from two levels: operation level and planning level. At the planning level, optimization can be made on the types and quantities of supply and storage equipment for integrated energy stations. Based on the overall load level of integrated energy in the core area, in the alternative integrated energy supply and storage equipment, a portfolio scheme has been proposed for optimizing the refrigeration, heating, cold storage and heat storage devices in the area in view of the economy, environmental protection, energy efficiency and other optimization planning objectives, with the optimal operating conditions of the whole life cycle taken into consideration. At the operation level, based on the typical hourly load demand curve in different energy demand periods, the output of each energy supply and storage facility can be obtained according to different operation strategies already formulated, in consideration of the system operation and supply-demand balance constraints of the energy supply and storage equipment. The operation control, which serves as the second level, can be planned and optimized at the integrated energy stations of the first level.

As observed from the results of the operation level, the cost of the system operation under a certain planning scheme acts as part of the economic indicators and an important part of the

planning indicators of the integrated energy system. Hence, the operation level control of the integrated energy station is a sub-process of planning and optimization.

### III. PLANNING MODEL FOR INTEGRATED ENERGY STATIONS

#### A. Energy Station Framework

An energy station, mainly inside, has demands for cold, heat and electrical load, and the electrical load is supplied by the external power grid, photovoltaic, garbage combustion and other renewable energy generation, CCHP units and storage devices. The heat load of the park is supplied by CCHP units, gas boilers, electric boilers, ground/water source heat pumps and heat storage devices. The cold load of the park is supplied by normal refrigerators, ground source/water source heat pumps, lithium bromide refrigerators and cold storage equipment.

#### B. Object Function

##### (1) Economy

The economic optimization criterion takes the total cost in the life cycle of an integrated energy system as its objective function. The total cost covers the initial cost (equipment purchase and installation), as well as the maintenance and operation costs of the integrated energy equipment. The annual construction investment and operation/maintenance costs respectively refer to the equal annual purchase cost of the equipment, and the operation and maintenance costs of the equipment during operation. The annual operation cost refers to the cost of equipment due to the purchase of fuel in the process of its operation. The operation cost mainly refers to the cost of the main supply and gas purchased for system operation. The objective function for the economic optimum criterion is as follows:

$$F^{Eco} = \sum_i (B_i + Y \cdot M_i) + Y \sum_f D_f \cdot O_f^{Eco} \quad (1)$$

Where,  $B_i$  is the initial investment cost of the  $i$ th energy equipment;  $M_i$  is the annual operation and maintenance cost of the  $i$ th energy equipment;  $Y$  is the engineering life (years) of the whole system;  $D_f$  is the number of days for the  $f$ th type of the energy demand period within one year;  $O_f^{Eco}$  is the typical daily operation cost of the system under the economic criterion of the  $f$ th type of energy demand period, which is subject to the following mathematical expression:

$$O_f^{Eco} = \sum_{t=1}^T (C_t^e \cdot P_t^e + C_t^g \cdot P_t^g) \cdot H \quad (2)$$

Where,  $T$  is the total number of optimal daily control intervals of the integrated energy system, which is generally set  $T = 24$ ;  $H$  is the number of hours in each control interval, and at this time  $H = 1$ ;  $P_t^e$ ,  $P_t^g$ ,  $C_t^e$  and  $C_t^g$  refers to the purchase of electricity in the  $t$  period, the purchase of gas in the  $t$  period, the hourly main supply price, and the price of gas, respectively.

##### (2) Environmental protection

The environmental objectives usually consider the fuel emissions, including greenhouse gas emission.  $CO_2$  is usually representative, as well as the main gas causing the greenhouse effect. Therefore, at present,  $CO_2$  emission ( $CO_2$  – eq greenhouse gas, GHG) is mostly used as the objective for optimization. That is, other pollutants are converted into  $CO_2$  emissions during calculation, and the objective function is as follows:

$$F^{EMI} = \sum_f \sum_t (P_t^e \cdot \gamma_e + P_t^g \cdot \gamma_g) \cdot D_f \quad (3)$$

Where,  $\gamma_e$  and  $\gamma_g$  represent the carbon emission factors of electricity and natural gas, respectively.

##### (3) Energy efficiency

Compared with the traditional energy distribution system, the integrated energy system can realize the scientific dispatch of multiple energy sources and the cascade utilization of energy. The index of the energy utilization efficiency can quantify this advantage and realize the accurate evaluation of the low-carbon and high-efficiency core value of the multi-energy system.

In the multi-energy system, the process of conversion between different energy sources has the ‘quantity’ conservativeness and ‘quality’ difference. In the traditional energy efficiency calculation, the energy sources that differ in quality are simply superimposed. However, merely the ‘quantity’ conservativeness can be analyzed, while the ‘quality’ difference cannot be analyzed or reveal the devaluation and loss of the energy quality that exist in the system, or scientifically characterize the utilization degree of energy. Therefore, different energy sources need to be converted to the same energy level for grade difference measurement. This project regards energy utilization efficiency as an optimization objective, and its objective function is as follows:

$$F^{EFF} = \frac{\sum_f \sum_{t=1}^T (L_t^e \cdot \lambda_e + L_t^h \cdot \lambda_h + L_t^c \cdot \lambda_c) \cdot D_f}{\sum_f \sum_{t=1}^T (P_t^e \cdot \lambda_e + P_t^g \cdot \lambda_g) \cdot D_f} \quad (4)$$

Where,  $\lambda_e$ ,  $\lambda_g$ ,  $\lambda_h$  and  $\lambda_c$  indicates the energy quality coefficients of the electricity, natural gas, heat and cold source.

#### C. Constraint Conditions

##### (1) Constraints of Load Supply and Demand Balance

a. Electric balance constraints: The total supply of electric energy is the sum of the purchased electricity, generated energy of the triple generation units, generated energy from renewable energy sources, and discharge of storage devices, while the total demand of electric energy is the demand of the pure electric load, namely, the sum of the refrigeration and heat equipment power consumption and storage capacity of the storage devices, which can be expressed, as follows:

$$P_t^e + \sum_{n=1}^N E_t^n + E_t^{CHP} = L_t^e + \sum_j E_t^j + S_t^e \quad (5)$$

Where,  $L_t^e$  indicates the demand of the pure electric load in the planned area at the  $t$  period;  $E_t^n$  is the electricity generated by renewable energy sources in the  $n^{\text{th}}$  period;  $E_t^{CHP}$  is the electricity generated by the triple generation unit in the  $n^{\text{th}}$  period;  $E_t^j$  is the electricity consumption of the  $j^{\text{th}}$  type of heating/cooling equipment in the  $t$  period;  $S_t^e$  is the storage capacity of the storage devices in the  $t$  period, and  $S_t^e$  is negative when the storage device is discharged.

b. Heat balance constraints: The total heat supply is the sum of the heat released by heat storage devices and heat produced by triple supply units, gas-fired boilers and electric boilers, as well as ground-source and water-source heat pumps; the total heat demand is the sum of the heat stored by heat storage devices and heat demands of lithium bromide refrigerators and pure heat loads, which can be expressed, as follows:

$$\sum_m H_t^m = L_t^h + S_t^h + H_t^c \quad (6)$$

Where,  $H_t^m$  is the heat production of the  $m^{\text{th}}$  type of heating equipment;  $L_t^h$  is the heat demand of pure heat loads in the planned area in the  $t$  period;  $H_t^c$  is the heat demand of lithium bromide refrigerators in the  $t$  period;  $S_t^h$  is the heat storage of the heat storage devices in the  $t$  period;  $S_t^h$  is negative when the heat storage device is discharged.

c. Cold balance constraints: The total cold supply is the sum of the cold released by cold storage devices and the cold produced by lithium bromide refrigerators, electric refrigerators and ground-source/water-source heat pumps, while the total cold demand is the sum of the demands of pure cooling loads and the cold storage capacity of storage devices, which can be expressed, as follows:

$$\sum_r C_t^r = L_t^c + S_t^c \quad (7)$$

Where,  $C_t^r$  is the refrigerating capacity of the  $r^{\text{th}}$  type of refrigeration equipment;  $L_t^c$  is the demand of pure cooling loads in the planned area in the  $t$  period;  $S_t^c$  is the cold storage capacity of the refrigeration equipment in the  $t$  period, and  $S_t^c$  is negative when the refrigeration devices discharge of heat.

## (2) Conventional equipment constraints

### a. Equipment operation constraints

$$Q_{\min}^j \leq Q_t^j \leq Q_{\max}^j \quad (8)$$

$$-\Delta Q_{\text{down}}^j \leq Q_t^j - Q_{t-1}^j \leq \Delta Q_{\text{up}}^j \quad (9)$$

Where,  $Q_{\min}^j$  and  $Q_{\max}^j$  indicate the maximum and minimum heating/cooling capacity of the  $j^{\text{th}}$  type of heating/cooling or heat/cold storage equipment, respectively;  $\Delta Q_{\text{down}}^j$  and  $\Delta Q_{\text{up}}^j$  shows the climbing speed for output reduction, and respectively increase of the  $j^{\text{th}}$  type of the equipment.

### b. Capacity constraints of the energy storage equipment

$$W_t^k = (1 - \varepsilon) W_{t-1}^k + \sum_k S_t^k \quad (10)$$

$$W_{\min}^k \leq W_t^k \leq W_{\max}^k \quad (11)$$

Where,  $W_t^k$  is the capacity of the  $k^{\text{th}}$  type of heat/cold storage equipment in the  $t$  period; if  $S_t^k > 0$ , it is the heat/cold storage capacity of the  $k^{\text{th}}$  type of heat/cold storage equipment; otherwise, it is the heat/cold discharge capacity of the  $k^{\text{th}}$  type of heat/cold storage equipment;  $W_{\min}^k$  and  $W_{\max}^k$  indicate the capacity upper and lower limits, respectively, of the  $k^{\text{th}}$  type of heat/cold storage equipment.

### c. Input upper constraints

The upper limit of the installed capacity exists in renewable energy sources. Hence, the renewable energy input has an upper limit in the integrated energy system, which can be specifically expressed as:

$$0 \leq E_t^n \leq E_{\max}^n \quad (12)$$

Where,  $E_{\max}^n$  is the output upper limit of the power generation from the  $n^{\text{th}}$  kind of renewable energy.

## D. Optimization Objectives and Solution Methods

In the above scenario of planning optimization, more than one optimization objective needs to be considered at the planning level. Hence, it is a multi-objective optimization problem, and there is a need to find a solution set called, a non-inferior solution set or a Pareto optimal solution set.

Therefore, the NSGA-II algorithm is used for optimization at the planning level.

In the present study, the objective function encompasses the economic, environmental protection and energy efficiency in

dexes, and the decision variables are the allocation capacity of each equipment. Hence, in the NSGA-II algorithm, the species are set as the configuration capacity of each equipment, and the fitness function is the economic cost, the emission of polluting gases and the percentage of energy efficiency for selection, crossover and mutation. These would allow for the determination of the optimal solution set of the configuration capacity, in order to obtain the optimal planning and configuration scheme.

IV. EXAMPLE ANALYSIS

The electricity price follows the peak and valley periods and prices of industrial, commercial and other forms of electricity consumption in the southern power grid of Hebei province. The price of natural gas is 1.86 yuan/m<sup>3</sup> and the calorific value is 9,700 kcal/m<sup>3</sup>.

Based on the analysis of the energy consumption load in typical summer, transition season and winter days, the demand for heat and power mainly concentrates in the daytime, and this significantly decreases at night. In summer, the demand for cooling load is great. In winter, the demand for cooling load is significantly lower, while the demand for heat load is significantly higher.

The capacity configurations of the equipment in the energy stations of the core area are optimized, and all resources/equipment can be collected or used normally. Furthermore, the objective function includes three indicators: economic cost, emissions of polluting gases, and energy efficiency percentage. Hence, the NSGAI algorithm was used to optimize a series of non-inferior solutions, and form a Pareto frontier, thereby obtaining six groups of solutions that focus on economy, energy efficiency and environmental protection, respectively. The table below presents a set of configuration schemes with all indicators more balanced.

TABLE I. SCHEME FOR THE CONFIGURATION OPTIMIZATION, UNIT: MW

Equipment	Gas Engine	Lithium Bromide	Gas Boiler	Electric Refrigeration	Electric Heating	Ground Source Heat Pump
Capacity	15	15	0	11	0	22
Equipment	Water source heat pump	Steam generator	Photovoltaic	Storage battery	Water storage tank	Heat storage tank
Capacity	20	4	10	0	25	20

Efficiency Analysis	Composite Cost (10,000 Yuan)	CO2 Emissions (Tons)	Energy Efficiency
Scheme 4	2.6488*10 <sup>5</sup>	1.1451*10 <sup>5</sup>	95.70%

The power load supply mainly depends on the main supply, and the triple supply system, photovoltaic power generation and garbage combustion power generation in the energy station. In addition to the pure electric load in the functional area, the power supply should also meet the energy demand of electric refrigerators, ground source heat pumps and water source heat pumps.

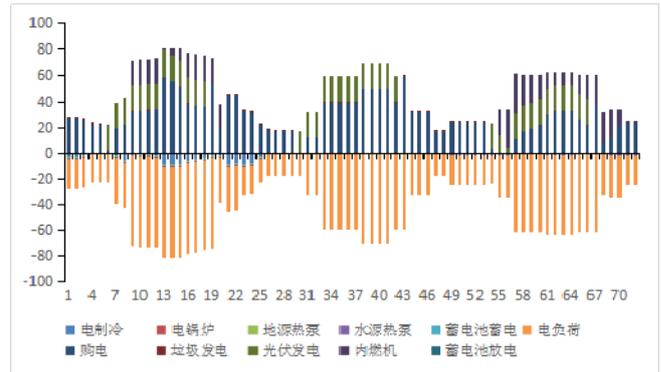


FIGURE I. TYPICAL DAILY ELECTRICITY SUPPLY AND DEMAND BALANCES

V. CONCLUSION

Spatially, the supply of the intelligent energy system has broken the traditional mode of separate energy supply. Different energy systems can realize relevant transformation and mutual support through typical energy conversion equipment, which has increased the energy supply paths of the system and improved the system reliability. At the same time, the cold, heat and power energy can be optimized in accordance with regional resource distribution, which has improved the economy of the energy supply.

In terms of the time distribution, the combined supply of cold/heat/electricity/gas energy sources can change the excessive demand for a single energy input during the load peak period. Peak-shaving and valley-filling within different energy systems can be realized through the coordinated utilization of energy resources, thereby improving the utilization rate of energy equipment. Simultaneously, the energy cost of the system can be lowered through the optimal regulation and control of multiple energy sources.

In terms of the scale, the intelligent energy system puts emphasis on achieving the cold, heat and power combined supply at the user side based on regional resources, which has changed the traditional mode of centralized energy supply, allowing it to achieve a decentralized, flexible, economic and selective combined energy supply.

In terms of the price, the intelligent energy system can realize comprehensive utilization of multiple energy sources, which has provided an opportunity to select cleaner, more efficient and cheaper energy sources for conversion and utilization, and thereby effectively reducing energy cost.

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