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Planning Model for Integrated Energy Supply System in Park Level Regions Under the Energy Internet

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Abstract. With the reduction of traditional fossil fuels and the increasing severity of environmental issues, it is of great significance to study energy system planning and optimization models that complement and integrate multiple energy utilization methods in the context of the energy internet for building an integrated energy supply system. Firstly, this article divides the planning indicators of the regional integrated energy supply system into four categories based on the goal of "two highs and three lows"; Secondly, analyze the three key issues of exergy efficiency, economy, and multi energy coupling in regional integrated energy planning; Finally, a multi-objective planning model for regional integrated energy systems that takes into account equipment capacity planning and operation scheduling optimization is proposed, with the optimization objectives of minimizing the annual value of full life cycle cost and maximizing efficiency, and a double-layer optimization structure is designed for efficient solution.

1. Introduction

With the reduction of traditional fossil fuels and the increasingly serious environmental problems it brings, it is particularly important to absorb diverse energy cultures and technologies, improve the utilization efficiency of various energy sources, strengthen coordination and optimization between energy systems, and achieve complementary and mutually beneficial multiple energy sources. In this context, regional integrated energy supply systems have emerged[1]. In addition, with the energy revolution, the proposal of the "Internet plus" strategy and the development of renewable energy, the energy Internet, as a new energy industry, has begun to emerge [2]. Guided by the dual carbon goals and policies related to the new power system, achieving a clean, low-carbon, safe, and efficient energy supply and consumption system has become an important task during the 14th Five Year Plan period[3]. Therefore, under the energy internet, establishing an energy system planning model that complements multiple energy sources and integrates multiple energy utilization methods can help build an integrated energy supply system, promote the large-scale utilization of renewable energy, and play a leading role in the development of integrated energy supply system planning theories and methods during the important transition period of energy development.

At present, research on the planning of integrated energy supply systems mainly focuses on optimizing the configuration of equipment capacity with the main objective of economy, supplemented by environmental protection and reliability. Reference [4] proposes a two-stage multi-objective planning method for an electrothermal coupled integrated energy system with the goal of optimizing investment and environment. On the basis of achieving the goal, it considers the operational characteristics of equipment to achieve optimal planning for system operation. Reference [5] provides a reference for the planning of site selection and capacity determination of park level integrated energy systems by constructing a fixed capacity planning model with minimal upper layer network loss and optimal lower layer economic efficiency. Reference [6] adopts multiple objectives such as minimizing investment costs to characterize the reliability and economy of the system, and establishes a coupling model for the integrated energy system of gas electricity interconnection. Reference [7] divides the optimization of integrated energy systems into two layers: energy allocation and comprehensive economy. The two-layer optimization method of second-order cone algorithm is used to reasonably optimize the comprehensive planning of multiple energy systems coupling. Reference [8] proposes an optimized configuration scheme for a park level integrated energy system with the goal of minimizing the annual cost of the entire life cycle, and quantitatively analyzes the external and internal main factors that affect the planning of the integrated energy system.

On the basis of existing research literature, this article considers renewable energy access, energy storage equipment, and distributed energy applications, and constructs a regional integrated energy supply system planning model centered on electricity, with the overall goal of improving system efficiency, and constrained by the total cost, pollutant emissions, and total energy consumption of the regional integrated energy supply system.

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2. Connotation and basic architecture of regional integrated energy supply system

The purpose of a regional integrated energy supply system is to improve integrated energy efficiency and promote sustainable energy development. Its connotation is the "multi energy complementarity, coordination and optimization" among various energy subsystems. "Multi energy complementation" refers to the complementation and coordination among various energy subsystems such as power system, coal, oil system, heating system, natural gas supply system, etc., highlighting the equality and "substitutability/complementarity" among various energy sources. Coordination and optimization "refers to the mutual coordination of various energy subsystems in energy development, energy transmission, energy conversion, comprehensive utilization, and other aspects. Although each link within the system is separated and there are many terminal energy self balancing units, to ensure system efficiency, it is necessary to ensure that the system chain is "separated but not dispersed", that is, to ensure the coordination of various links in the regional integrated energy supply system. This coordination is more reflected in the conversion and utilization of physical energy, as well as the interaction and response of energy information.

The basic architecture of a regional integrated energy supply system can be summarized as "loose on the outside and tight on the inside, separated but not dispersed". Outside the system, the regional integrated energy supply system has obvious openness, and multiple energy sources can be freely accessed according to certain rules, and internal and external information can be reasonably shared. Within the system, the vertical links are closely coordinated, the horizontal energy subsystems are interconnected, and the terminal self balancing units are closely interconnected at both the physical and information layers. For the entire system structure, seemingly dispersed structures have coordination mechanisms and optimization control measures at the system level, regional level, and component level, with each component, part, and link closely interconnected with their respective systems and interacting with information rather than isolated.

3. Planning index system for regional integrated energy supply system

Planning indicators can be divided into expected indicators and constraint indicators [9]. Among them, expected indicators refer to the goals that are expected to be achieved but need to be achieved through the autonomous behavior of the subject. Constrained indicators refer to certain requirements that must be met in the development of power planning and are mandatory tasks that must be completed. This article aims to improve the integrated energy efficiency of the system, improve the reliability of system operation, reduce user energy costs, reduce system carbon emissions, and reduce emissions of other pollutants based on the goals of "two highs and three lows" in the integrated energy system [10]. By decomposing it, the planning indicators for the regional integrated energy supply system are divided into four primary indicators - system energy efficiency, system cost, system pollutant emissions, total system energy consumption, and 15 secondary indicators. The specific content is shown in Table 1.

Table 1. Classification of regional integrated energy supply system planning indicator system.

Primary indicators	Secondary indicators	Notes
System energy efficiency	primary energy ratio	expected
	Energy conversion efficiency coefficient	expected
	Per capita energy consumption	constraint
System costs	Investment cost	constraint
	operating costs	expected
	income from investment	expected
System pollutant discharge	Annual emissions of smoke and dust	constraint
	Annual SO_2 emissions	constraint
	Annual CO_2 emissions	constraint
	Annual NO_x emissions	constraint
Total system energy consumption	Clean energy consumption ratio	constraint
	Renewable energy utilization rate	constraint
	Annual consumption of oil	constraint
	Annual coal consumption	constraint
	Annual consumption of natural gas	constraint

4. Planning model for park level integrated energy supply system

4.1 Analysis of key issues

Due to the traditional definition of energy efficiency only taking into account the changes in quantity of energy, but neglecting the differences in quality of energy, it is impossible to accurately measure the energy utilization level of a integrated energy system. This article uses exergy efficiency, which balances quantity and quality, as the standard for measuring the energy utilization level of a integrated energy system. So this section first provides a detailed analysis of the three key issues in the planning, namely exergy efficiency, economy, and multi energy coupling.

4.1.1 Exergy efficiency analysis of regional integrated energy system

Perform exergy efficiency analysis on the regional integrated energy system, and equate it to a black box model as shown in Figure 1 based on external characteristics. The supply side inputs exergy $E_{\text{x,in}}$ into the regional integrated energy system as payment, and through a series of processes such as transmission, conversion, storage, and distribution within the system, outputs exergy $E_{\text{x,out}}$ to the demand side as revenue to meet all forms of energy demand in the region. According to the exergy reduction principle of the second law of thermodynamics, in the process of internal energy changes in a regional integrated energy system, it is inevitable that a portion of the quantity will disappear into the natural environment, which is called exergy loss $E_{\text{x,loss}}$. Payment exergy $E_{\text{x,in}}$ is equal to the sum of gains and losses. Thus, the exergy efficiency of a regional integrated energy system can be defined as:

$$\eta_{\text{ex}} = \frac{E_{\text{x,out}}}{E_{\text{x,in}}} \tag{1}$$

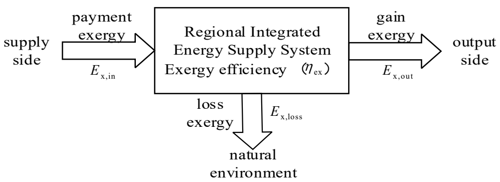

Figure 1. Black box model for efficiency analysis of regional integrated energy system.

Based on the exergy theory, assign corresponding energy quality coefficients to each form of energy involved in a regional integrated energy system according to its essential attributes, thereby quantifying the quality level between different forms of energy. For a certain energy form i, based on its energy quality coefficient value λ_i, the relationship between its energy E_i and its quantity $E_{\text{x},i}$ can be simply established as:

$$E_{\text{x},i} = E_i \lambda_i \tag{2}$$

In the formula, i represents the form of energy, such as electric energy e, fossil fuel f, natural gas g, thermal energy h, cold energy c, renewable energy rn, etc. Therefore, according to the black box model shown in Figure 3-1, the overall exergy efficiency of the regional integrated energy system can be expressed as:

$$\eta_{\text{ex}} = \frac{E_{\text{x,out}}}{E_{\text{x,in}}} = \frac{\sum_{i\in\Omega_{\text{out}}} E_{\text{out},i}\lambda_i}{\sum_{i\in\Omega_{\text{in}}} E_{\text{in},i}\lambda_i} \tag{3}$$

In the formula, Ω_{in} is the set of input energy forms for the regional integrated energy system; Ω_{out} is the collection of energy output forms of the regional integrated energy system; $E_{\text{in},i}$ is the energy contained in the input energy form i; $E_{\text{out},i}$ is the energy contained in the form of output energy i.

4.1.2 Economic modeling of regional integrated energy system

This article establishes the annual value of life cycle cost C_{ATC} to describe the economic performance of a regional integrated energy system within the planning level year. The annual value of life cycle cost is composed of four parts: Annual value such as initial investment cost C_{inv}; Operation and maintenance costs C_{mat}; Energy consumption cost C_{csu}; Environmental costs C_{env}.

$$C_{\text{ATC}} = C_{\text{inv}} + C_{\text{mat}} + C_{\text{csu}} + C_{\text{env}} \tag{4}$$

Among them, C_{inv} takes into account the time value of funds and converts the one-time initial investment cost of equipment into an equal annual value through a discount rate, which can be compared with other costs. The calculation method is as follows:

$$C_{\text{inv}} = \sum_{i\in\Omega_{\text{out}}} \left[\sum_j C^{\text{sp}}_{\text{inv},i,j} Y^{\text{sp}}_{i,j} + \sum_k C^{\text{st}}_{\text{inv},i,k} Y^{\text{st}}_{i,k} \right] \frac{r(1+r)^N}{(1+r)^N - 1} \tag{5}$$

In the formula: j is the energy production equipment number; k is the number of the energy storage equipment; $C^{\text{sp}}_{\text{inv},i,j}$ and $Y^{\text{sp}}_{i,j}$ are the unit configuration cost and capacity of the j energy production equipment in energy form i, respectively; $C^{\text{st}}_{\text{inv},i,k}$ and $Y^{\text{st}}_{i,k}$ are the unit configuration cost and capacity of the k energy storage device in energy form i, respectively; r is the discount rate; N is the year.

C_{mat} is the annual operation and maintenance cost of the equipment, expressed as:

$$C_{\text{mat}} = \sum_{i\in\Omega_{\text{out}}} \left[\sum_j C^{\text{sp}}_{\text{mat},i,j} Y^{\text{sp}}_{i,j} + \sum_k C^{\text{st}}_{\text{max},i,k} X^{\text{st}}_{i,k} \right] \tag{6}$$

In the formula: $C^{\text{sp}}_{\text{mat},i,j}$ is the unit annual operation and maintenance cost of the j energy production equipment in the energy form i; $C^{\text{st}}_{\text{max},i,k}$ is the unit annual operation and maintenance cost of the k type of energy storage equipment in energy form i; $X^{\text{st}}_{i,k}$ is the rated power of the k energy storage device in the energy form i.

C_{csu} represents the total annual cost of various forms of energy consumed by the regional integrated energy system, generally including fossil fuels, electricity, and regional heating, expressed as:

$$C_{\text{csu}} = \sum_t (P_{\text{in,f},t} G_{\text{f},t} + P_{\text{in,e},t} G_{\text{e},t} + P_{\text{in,h},t} G_{\text{h},t}) \tag{7}$$

In the formula: t represents the time; $P_{\mathrm{in,f},t}$ and $G_{\mathrm{f},t}$ are the input power and unit price of fossil fuels at time t, respectively; $P_{\mathrm{in,e},t}$ and $G_{\mathrm{e},t}$ are the input power and unit price of electrical energy at time t, respectively; $P_{\mathrm{in,h},t}$ and $G_{\mathrm{h},t}$ are the input power and unit price of thermal energy at time t.

C_{env} represents the carbon emission cost generated by the regional integrated energy system in the process of consuming various forms of energy, expressed as:

$$C_{\mathrm{env}} = \sum_t (P_{\mathrm{in,f},t}\delta_{\mathrm{f}} + P_{\mathrm{in,e},t}\delta_{\mathrm{e}} + P_{\mathrm{in,h},t}\delta_{\mathrm{h}})D_{\mathrm{ctax}} \quad (8)$$

In the formula: D_{ctax} is the carbon tax price; δ_{f}, δ_{e} and δ_{h} are carbon emission factors for fossil fuels, electricity, and thermal energy, respectively.

4.1.3 Multi energy coupling modeling of regional integrated energy system

This article proposes an improved five level energy hub model. This model consists of allocation layer, conversion layer, integration layer, energy storage layer, and network layer, and can cover the entire process of energy production, transmission, conversion, storage, and allocation. The energy conversion process of each layer can be expressed in the form of transfer matrix $M_x(x=1,2,\cdots,s)$, and the relationship between the total input and total output of the regional integrated energy system can be expressed as:

$$\begin{bmatrix} P_{\mathrm{out,e},t} & P_{\mathrm{out,h},t} & P_{\mathrm{out,c},t} \end{bmatrix}^{\mathrm{T}} = \mathbf{M}\begin{bmatrix} P_{\mathrm{in,f},t} & P_{\mathrm{in,e},t} & P_{\mathrm{in,h},t} & P_{\mathrm{in,rn},t} \mid P_{\mathrm{st},t} \end{bmatrix}^{\mathrm{T}} \quad (9)$$

In the formula: $P_{\mathrm{in,rn},t}$ is the power input of renewable energy into the energy hub at time t; $P_{\mathrm{st},t}$ is the power of energy storage at time t; $P_{\mathrm{out,e},t}$, $P_{\mathrm{out,h},t}$, $P_{\mathrm{out,c},t}$ are the electrical power, thermal power, and cold power output by the energy hub at any time t; $\mathbf{M} = \mathbf{M}_5\left[\mathbf{M}_3\mathbf{M}_2\mathbf{M}_1 \mid \mathbf{M}_4\right]$ is the total transfer matrix of the energy hub, where $\mathbf{M}_1$ is the transfer matrix of the distribution layer, used to describe the distribution process of external input energy between multiple energy production equipment. If natural gas is partially supplied to gas turbines and partially supplied to gas boilers or kitchen utensils; $\mathbf{M}_2$ is the transfer matrix of the conversion layer, used to describe the energy conversion process, such as the conversion of natural gas into electricity and heat energy by a cogeneration unit; $\mathbf{M}_3$ is the transfer matrix of the integration layer, used to describe the summary of output power of multiple devices belonging to a certain form of energy, such as the total electricity in a certain area equal to the sum of renewable energy generation and external grid purchase electricity; $\mathbf{M}_4$ is the transfer matrix of the energy storage layer, used to describe the energy storage process in the regional integrated energy system, such as the impact of thermal energy storage on the supply and demand balance of thermal energy through heat storage or release; $\mathbf{M}_5$ is the network layer used to describe the energy loss generated during the transmission process of energy supply pipelines.

In equations (9), the specific values of $\mathbf{M}_1$ to $\mathbf{M}_5$ can be calculated from the structural parameters of the given system. Energy storage can be regarded as a type of energy production equipment with positive or negative output power. Its power $P_{\mathrm{st},t}$ at time t is listed in an augmented form after the energy production equipment, and the energy storage transfer matrix $\mathbf{M}_4$ is also listed in an augmented form in the total transfer matrix.

Generally, the energy forms required by the terminal can be classified into three categories, namely electricity, heat, and cold. To meet the total energy demand of users in the region, the various forms of energy output by the energy hub must be greater than or equal to the corresponding load demand in the region, namely $\begin{bmatrix} P_{\mathrm{out,e},t} & P_{\mathrm{out,h},t} & P_{\mathrm{out,c},t} \end{bmatrix}^{\mathrm{T}} \ge \begin{bmatrix} L_{\mathrm{e},t} & L_{\mathrm{h},t} & L_{\mathrm{c},t} \end{bmatrix}^{\mathrm{T}}$. Among them, $L_{\mathrm{e},t}$, $L_{\mathrm{h},t}$, and $L_{\mathrm{c},t}$ respectively represent the electrical load, heating load, and cooling load of the regional integrated energy system at the time t.

4.2 Analysis of key issues

Based on the indicator system established above, this article considers system cost and system energy efficiency indicators, with the optimization goal of minimizing the annual value of full life cycle cost and maximizing efficiency as expected indicators, and designs a double-layer optimization structure for efficient solution. The upper level model is a device selection and capacity optimization model, used to select the optimal device configuration combination from the set of selected devices; The lower level model is the operation scheduling optimization model, which is used to formulate the optimal plan for the output of each equipment while meeting the regional energy supply and demand balance.

4.2.1 Decision variables

The decision variables of the upper level model include three types of variables, namely the configuration capacity of energy production equipment ($Y_{i,j}^{\mathrm{sp}}$), the configuration capacity of energy storage equipment ($Y_{i,k}^{\mathrm{st}}$), and the rated power of energy storage equipment ($X_{i,k}^{\mathrm{st}}$).

The decision variables of the lower level model include three types of variables, namely energy input power ($P_{\mathrm{in,f},t}$, $P_{\mathrm{in,e},t}$, $P_{\mathrm{in,h},t}$, $P_{\mathrm{in,rn},t}$) energy storage equipment power ($P_{\mathrm{st},t}$), and energy allocation coefficient ($\upsilon_{i,j,t}^{\mathrm{sp}}$).

The energy distribution coefficient $\upsilon_{i,j,t}^{\mathrm{sp}}$ represents the proportion of a certain form of energy i allocated to the j energy production equipment at time t. For example, if the natural gas power rate inputted into the integrated energy system of a certain region at any time is 100MW, of which 60MW is supplied to the cogeneration unit, and the remaining 40MW is supplied to the gas boiler, then there are $\upsilon_{g,1,t}^{\text{sp}} = 0.6$ and $\upsilon_{g,2,t}^{\text{sp}} = 0.4$.

4.2.2 Objective function

(1) Upper level model

The upper level model is the main model of the entire planning model, with the objective function of minimizing the annual value of life cycle cost and maximizing efficiency, i.e

$$\begin{cases} f_{1,1} = \min C_{\text{ATC}} \\ f_{1,2} = \max \eta_{\text{ex}} \end{cases} \tag{10}$$

Bringing the decision variable into a yields the expression:

$$\begin{aligned} \eta_{\text{ex}} &= \frac{\sum_{i\in\Omega_{\text{out}}} E_{\text{out},i}\lambda_i}{\sum_{i\in\Omega_{\text{in}}} E_{\text{in},i}\lambda_i} \\ &= \frac{\sum_t (P_{\text{out,e},t}\lambda_{\text{e}} + P_{\text{out,h},t}\lambda_{\text{h}} + P_{\text{out,c},t}\lambda_{\text{c}})}{\sum_t (P_{\text{in,f},t}\lambda_{\text{f}} + P_{\text{in,e},t}\lambda_{\text{e}} + P_{\text{in,h},t}\lambda_{\text{h}} + P_{\text{in,rn},t}\lambda_{\text{rn}})} \end{aligned} \tag{11}$$

From equations (10) and (11), it can be seen that the values of $f_{1,1}$ and $f_{1,2}$ cannot be directly calculated solely based on the upper level decision variables $(Y_{i,j}^{\text{sp}}, Y_{i,k}^{\text{st}}, X_{i,k}^{\text{st}})$. Because the values of C_{csu}, C_{env}, and η_{ex} all depend on the operation scheduling plan of the equipment, which will be optimized by the lower level model and returned.

(2) Lower level model

The lower level model is a sub model of the upper level model, used to solve the operation scheduling optimization sub problem of various equipment in the regional integrated energy system. Receive the data $(Y_{i,j}^{\text{sp}}(n), Y_{i,k}^{\text{st}}(n), X_{i,k}^{\text{st}}(n))$ transmitted by the upper layer model in iteration n and use it as a boundary condition for scheduling optimization. The optimization objectives are:

$$f_2 = \min\left\{\mu_1(C_{\text{csu}} + C_{\text{env}}) - \mu_2\eta_{\text{ex}}\right\} \tag{12}$$

In the formula, μ_1 and μ_2 are the weight coefficients of economic indicators and exergy efficiency indicators, respectively. In the n iteration of the optimization process, the lower level model obtains the operation scheduling plan, i.e. $(P_{\text{in,f},t}(n), P_{\text{in,e},t}(n), P_{\text{in,h},t}(n), P_{\text{in,rn},t}(n), P_{\text{st},t}(n), \upsilon_{i,j,t}^{\text{sp}}(n))$. Then return to the upper level, so that the values of $C_{\text{ATC}}(n)$ and η_{ex} can be fully calculated and used as the initial values for the $(n+1)$ iteration.

4.2.3 Constraints

Based on the indicator system established above, considering the total energy consumption of the system and the equipment output of the system, the constraints of energy supply and demand balance, energy production equipment, and energy storage equipment are taken as the constraints of the park level integrated energy supply system planning model.

(1) Energy supply and demand balance constraints

When the regional integrated energy system reaches an energy balance between supply and demand, the energy output of the energy hub should be greater than or equal to the total energy demand of all users in the region, i.e. $\left[P_{\text{out,e},t} \quad P_{\text{out,h},t} \quad P_{\text{out,c},t}\right]^{\text{T}} \geq \left[L_{\text{e},t} \quad L_{\text{h},t} \quad L_{\text{c},t}\right]^{\text{T}}$. Therefore, the energy supply and demand balance constraints of a regional integrated energy system considering multi energy coupling can be expressed as:

$$\mathbf{M}\left[P_{\text{in,f},t} \quad P_{\text{in,e},t} \quad P_{\text{in,h},t} \quad P_{\text{in,rn},t} \mid P_{\text{st},t}\right]^{\text{T}} \geq \left[L_{\text{e},t} \quad L_{\text{h},t} \quad L_{\text{c},t}\right]^{\text{T}} \tag{13}$$

$\mathbf{M}_2$ to $\mathbf{M}_5$ can be directly obtained from the parameters of the regional integrated energy system, while $\mathbf{M}_1$ is composed of the decision variable $\upsilon_{i,j,t}^{\text{sp}}$.

(2) Energy production equipment constraints

Although the characteristics of various energy production equipment in regional integrated energy systems vary, there are still some common constraints: The upper and lower limit constraints on equipment configuration capacity are used to describe the funding and site limitations of equipment configuration, as shown in equations (14); The upper and lower limit constraints of equipment operation are used to limit the output of the equipment within its allowable range, as shown in equations (15) - (18).

$$0 \leq Y_{i,j}^{\text{sp}} \leq Y_{i,j,\text{limit}}^{\text{sp}} \tag{14}$$

$$P_{i,j,\min}^{\text{sp}} \leq P_{i,j,t}^{\text{sp}} \leq P_{i,j,\max}^{\text{sp}} \tag{15}$$

$$P_{i,j,\min}^{\text{sp}} = \rho_{i,j,\min}^{\text{sp}} Y_{i,j}^{\text{sp}} \tag{16}$$

$$P_{i,j,\max}^{\text{sp}} = \rho_{i,j,\max}^{\text{sp}} Y_{i,j}^{\text{sp}} \tag{17}$$

$$P_{i,j,t}^{\text{sp}} = \upsilon_{i,j,t}^{\text{sp}} P_{\text{in},i,t} \tag{18}$$

In the formula: $Y_{i,j,\text{limit}}^{\text{sp}}$ is the upper limit of the configured capacity of the j energy production equipment in the energy form i; $P_{i,j,\max}^{\text{sp}}$, $P_{i,j,\min}^{\text{sp}}$ and

$P_{i,j,t}^{sp}$ are the upper and lower power limits of the j energy production equipment in energy form i, and the output power at time t; $\rho_{i,j,\max}^{sp}$ and $\rho_{i,j,\min}^{sp}$ are the upper and lower power limit coefficients of the j energy production equipment in energy form i.

(3) Energy storage equipment constraints

In this model, three types of energy storage devices, namely battery energy storage, heat storage tank, and water cooling storage, are considered, all of which follow the following common constraints:

$$0 \le Y_{i,k}^{st} \le Y_{i,k,\text{limit}}^{st} \tag{19}$$

$$\psi_{\min} \le \frac{Y_{i,k}^{st}}{X_{i,k}^{st}} \le \psi_{\max} \tag{20}$$

$$-X_{i,k}^{st} \le P_{i,k,t}^{st} \le X_{i,k}^{st} \tag{21}$$

$$\rho_{i,k,\min}^{st} Y_{i,k}^{st} \le S_{i,k,t}^{st} \le \rho_{i,k,\max}^{st} Y_{i,k}^{st} \tag{22}$$

$$S_{i,k,t+1}^{st} = \eta_{i,k,\text{h}}^{st} S_{i,k,t}^{st} + \eta_{i,k,\text{in}}^{st} P_{i,k,t}^{st,+} - \frac{P_{i,k,t}^{st,-}}{\eta_{i,k,\text{out}}^{st}} \tag{23}$$

In the formula: $Y_{i,k,\text{limit}}^{st}$ is the upper limit of the configured capacity of the k energy storage device in the energy form i; $\psi_{\max}$ and $\psi_{\min}$ are the upper and lower limits of the energy storage capacity power ratio; $\rho_{i,k,\max}^{st}$ and $\rho_{i,k,\min}^{st}$ are the upper and lower limit coefficients of residual energy storage; $\eta_{i,k,\text{h}}^{st}$, $\eta_{i,k,\text{in}}^{st}$ and $\eta_{i,k,\text{out}}^{st}$ are the energy storage standby efficiency, charging efficiency, and discharging efficiency; $P_{i,k,t}^{st,+}$ and $P_{i,k,t}^{st,-}$ represent the charging and discharging power of energy storage. $P_{i,k,t}^{st,+}$ and $P_{i,k,t}^{st,-}$ represent the charging and discharging power of energy storage.

In addition to the common constraints mentioned above, heat storage tanks and water cooled storage tanks require a certain amount of electrical energy to be consumed during their operation, expressed as:

$$P_{i,k,t}^{loss} = \chi_{i,k} \mid P_{i,k,t}^{st} \mid \tag{24}$$

In the formula, $P_{i,k,t}^{loss}$ and $\chi_{i,k}$ are the power consumption and power consumption coefficient of the k energy storage device in energy form i.

5. Conclusion

The integrated energy system involves the interaction and coupling of multiple energy sources, and includes different equipment of single and multiple energy sources. How to coordinate, cooperate, and optimize different heating systems as a whole, meet the characteristics and energy needs of different regions under different energy consumption modes, achieve the optimal overall efficiency of the system, and minimize system costs is a key issue in the planning of the Integrated energy system. This article proposes a multi-objective planning model for regional integrated energy systems that combines equipment capacity planning and operation scheduling optimization, by establishing an indicator system, considering system costs and system energy efficiency indicators, with the optimization goal of minimizing the annual value of expected indicators such as full life cycle costs and maximizing efficiency. This model improves the overall economic efficiency of regional integrated energy systems.

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