The Planning Method of Township Regional Low-carbon Energy System Based on Demand Side Response

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Abstract: To solve the problem of environmental pollution caused by rising energy demand and explore the impact of demand-side resources on system optimal scheduling, based on the EH model, it is of great significance to study the integrated demand response strategy, carbon trading mechanism and low-carbon energy uncertainty for the operation of IES low-carbon economy. Compared with the traditional load response model, this model has better flexibility with the adjustment response. According to the thermal inertia and certain time delay characteristics of the heat load, the demand response model of heat load is established. Then, according to the application of the multi-energy price demand response theory in natural gas system, the optimization model of gas load response is constructed. Three different optimization scenarios are set for simulation and comparative analysis, which verifies that the township comprehensive demand response model considering electric and thermal gas load has a significant effect on improving the system economy and the absorption capacity of low-carbon energy.

1. Introduction

The new energy system is composed of distributed power supply, energy storage device, load, energy conversion equipment, monitoring and protection equipment, etc. On the premise of ensuring the stability of power, voltage and frequency, the autonomous power generation and distribution system uses some methods to achieve the optimal operation of the system, and has certain self adjustment and control functions[1]. The traditional energy system has a simple structure, a single type of energy, and its operation scheduling is limited to a single energy, lacking the coordination and management between different forms of energy, which leads to the low energy utilization rate of the system. In order to better explore China's low-carbon economic development path and reduce environmental pollution, researchers in China and abroad have done a lot of research on the structure of the energy system, multi-energy complementarity, carbon emission constraints and uncertainty considerations, and have achieved remarkable results. Therefore, the Integrated Energy System (IES) came into being. The introduction of ES breaks the independence of each energy system and realizes multi-energy coupling coordination optimization and cascade utilization [2].

Under the coupling effect of various energy sources in the energy Internet, the energy supply and demand tend to be stable. The joint planning of multiple energy systems using multi-energy systems can increase the absorptive capacity of wind power and other low-carbon energy sources, and can also effectively alleviate peak power consumption, making the operation of multi-energy systems more economical and safer. Through the planning and layout of multiple energy supply networks, it can meet the needs of different users for electricity, gas, heat, cold and other energy supply modes, thus improving the energy utilization rate and contributing to the coordinated optimization and rational utilization of energy. In addition, on the premise of meeting the power demand, reducing the construction cost and operation cost of a multi-energy supply network is an important direction of multi-energy system planning in the future [3].

In reference [4], Ben-Tal et al. proposed a modeling method that uncertain linear programming can be transformed through robust equivalence, and confirmed that linear programming of ellipsoidal uncertain sets can also be processed on RC. Bertsimas et al., based on the research of Ben-Tal et al., adjust the conservatism of robust solutions according to the probability limit of violating constraints, and can easily solve and calculate, and also extend this method to discrete optimization problems. In reference [5], the interval gap decision model is added to the robust model and solved after linearization. The results indicate that this method can reduce the conservatism and make the uncertainty results more reasonable and accurate.

This paper studies the collaborative optimization of the multi-energy micro-grid and the energy storage power station, and continues to tap the optimization method of regulation capacity on the basis of regulation capacity dispatching. Two-level optimal scheduling of micro-grid and energy storage is proposed. A bi-level optimization model of coordinated regulation capability of the multi-energy micro-grid and energy storage power station is constructed with the objective of maximizing the comprehensive operation income and maximizing the energy utilization rate of micro-grid and energy storage

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participating in grid regulation. The improved algorithm is adopted to solve the model. In the case simulation, the regulation ability of micro-grid and energy storage in the multi-scenario of renewable energy grid is analyzed, and the superiority of two-level optimization to the regulation ability optimization is verified.

2. Bi-level programming model for regional low-carbon energy

A large amount of surplus electric energy can not be consumed, resulting in energy waste. As a system for storing energy, the energy storage device stores surplus electric energy on the premise of meeting operational constraints, and releases the stored energy during periods of tight energy supply and demand, such as peak periods of power use, to ease the tension between supply and demand. At the same time, it plays the role of energy time shift, reducing the energy cost during peak periods of power use and improving the flexibility of energy supply of source side units.

Based on the energy hub model, this paper models and analyzes the integrated energy system covering multiple energy forms of electrical heating, and divides the integrated energy system into three parts: energy supply side, energy conversion side, and energy demand side. The typical structure diagram is shown in Figure 1.

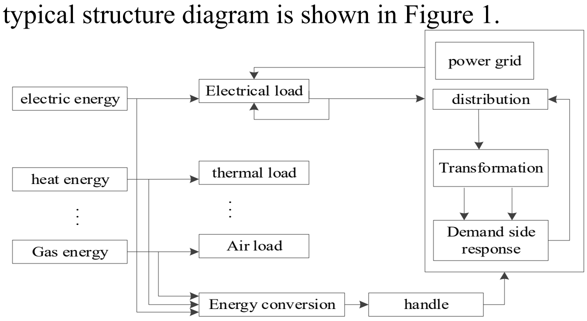

Figure 1 Structure of integrated energy system

The energy supply side includes: wind power, photovoltaic, the superior power grid representing the power of tie lines, the superior gas grid representing the input of natural gas, and the heat network representing the centralized heating of pipelines; Energy conversion side envelope: energy coupling conversion units such as electric to gas, air source heat pump, cogeneration, energy storage device, etc; The energy demand side includes: electric load, heat load, gas load representing the load demand of multi energy users, and schedulable resources of multi energy users such as interruptible load, transferable load, and convertible load.

By establishing an interrelated double-layer optimization model, because the upper lay and the lower layer respectively correspond to different objective functions and constraint conditions in the double-layer optimization model, an intermediate decision variable is introduced as a bridge connecting the upper layer and the lower layer to describe the relationship as follows:

$$\begin{cases} \min f(x,y) \\ S_0 \cdot G(x) \le 0 \\ H(x) = 0 \end{cases} \tag{1}$$

$$\begin{cases} \min f(x,y) \\ S_0 \cdot g(x,y) \le 0 \\ h(x,y) = 0 \end{cases} \tag{2}$$

Where, $f(x,y)$ is the load capacity that can participate in the excitation response; X and y are the decision variables of the upper level model that can participate in the incentive response; $G(x)$ and $H(x)$ are upper model constraints that can participate in the excitation response [6];

In the bi-level optimization model, the optimal solution obtained by optimizing the lower objective function is selected as the decision variable and fed back to the upper objective function. The specific process is displayed in the following equation.

$$\min f(x, y(x)) \tag{3}$$

$$y_i(x) = \arg\min_{j|_i(x)} f_i(x, y_i) \tag{4}$$

$$f_i : R^n \times R^{n_{yy}} \to R \tag{5}$$

Where, R^n is the total operating cost of incentive response.

The contract shall be signed with township users to encourage users to reduce or transfer load during power peak. The contract shall include the total transfer amount or reduction amount, the time period for participating in response, and the liquidated damages for refusing to participate in response.

A bilevel optimization problem is one in which both the upper and lower levels have their own optimization objectives and constraints. At the same time, for the system optimization problem with hierarchical structure, the decision variables of the upper level directly act on the lower level, resulting in the lower level being constrained by the upper level [7].

3. Multi-energy dispatching in villages and towns based on demand-side response

Operation and maintenance costs, startup and shutdown costs of energy conversion and storage equipment. Considering the comprehensive demand response of electric, heat and gas loads, an optimization model of comprehensive demand response taking into account electric, heat and gas loads is established by coordinating and optimizing the output of different energy conversion equipment in the system. The objective value of the model is to minimize the operating cost of the whole system.

The two-level scale optimal dispatching process of township multi-energy system considering demand-side response is displayed in Figure 2.

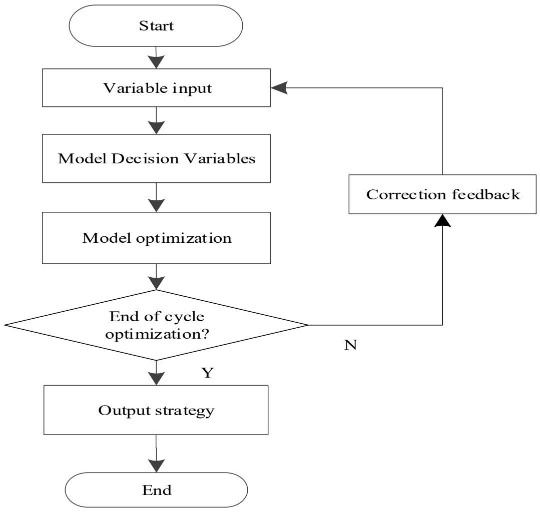

Figure 2 Energy planning process block for demand side response

Among them, the input data of dispatching shall include the wind and solar forecasting output data, the unit configuration parameters in the township multi-energy system, and the basic data of demand side load. Experimental analysis [8].

3.1. Simulation environment setting

The comprehensive operation cost of the multi-energy micro-grid is 122 yuan/ (MW. h), and the comprehensive operation cost of the energy storage power station is 126 yuan/ (MW. h). Considering that the participation of the multi-energy micro-grid and energy storage power station in grid regulation can reduce the emission of exhaust pollutants from conventional units, Table 1 shows the emission density and price of exhaust pollutants, which represents the environmental cost of reducing grid operation by participating in regulation [9].

Table 1 Emission intensity and price of exhaust pollutants

Type of pollutant	Emission density/kg/MW.h	Carbon trading price/yuan
Co2	875	0.19
So2	1.7	13.47
Nox	1.5	53.69

To facilitate the observation and analysis of the regulation capacity of the multi-energy micro-grid and the energy storage power station to the power grid, the effect of considering the multi-energy micro-grid and energy storage power station to participate in optimal dispatching is reflected. Therefore, in the operation mode, three different scenarios are selected for comparative analysis of low-carbon energy output prediction.

(1) The output power amplitude of low-carbon energy is small and basically consistent with the time sequence change of load, increasing and decreasing at the same time;

(2) Low-carbon energy output and load change show an opposite trend, one increase and one decrease;

(3) The output of low-carbon energy is consistent with the time sequence of load change, but the change range of low-carbon energy is larger.

3.2. Analysis of experimental results

Calculate the curve error E and volatility V index of the interactive power curve under different schemes, and the calculation results are displayed in Table 2. Because there are many kinds of power output units in the township multi-energy system, the output power fluctuates greatly, so the interaction degree between the power and the external network is greater than that of the heating network [10].

Table 2 Error and volatility indicator results

Model	Indicators	E	V
Correction after optimization	Grid interaction	2.7	0.048
	Heating network interaction	2.6	0.013
No correction	Grid interaction	13.4	0.935
	Heating network interaction	4.8	0.047
Not optimized	Grid interaction	114.77	0.825
	Heating network interaction	30.28	0.148

The day-ahead optimal dispatch model considering the price and substitutional demand response can effectively reduce the operation cost of the township multi-energy system. Adjust the output of different units to stabilize the fluctuation of both supply and demand sides according to the difference in dispatching time of different types of loads, so as to ensure the reliability of unit output optimization of the township multi-energy system under source-load supply and demand balance. Then, an intra-day real-time rolling optimization model based on the model predictive control algorithm is constructed. Through the simulation analysis and the comparison of operation schemes, the results verify that the optimal scheme proposed in this paper can optimize the interaction power with the grid and heating network through real-time rolling, follow the day-ahead reference trajectory to the greatest extent, and reduce the interaction error and volatility with the external network.

4. Conclusion

By studying the double-layer configuration of the model, the regulation capacity is further optimized on the basis of multi-energy dispatching in villages and towns. Therefore, a double-layer optimization model of micro-grid and energy storage is proposed in the intra-day stage. The goal is to maximize the comprehensive operation income and the goal is to maximize the energy efficiency. Through the upper decision quantity acting on the lower energy utilization rate, the output results of the lower optimization results also affect the upper operating income, so the regulation capacity optimization is realized by means of mutual decision-making. Finally, the simulation results of an example indicate that the comprehensive operation benefits of the multi-energy micro-grid and the energy storage power station are improved by using the bi-level optimization model.

For the demand-side response, although this paper considers the scheduling capacity of demand-side resources at different time scales, it does not consider the uncertainty of load participation in demand response and the uncertainty of flexible load response. In future work, the output and solution methods of uncertainty in complex models will be researched further.

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