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Optimized Scheduling of Energy Systems for Meter and Distribution Network Flexibility

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Abstract. A two-tier distributed optimization system framework, consisting of an integrated energy system and a distribution network, is constructed with the aim of minimizing energy costs and distribution network losses. By adjusting the access location of the energy park and the topology of the distribution network, the co-optimization of energy flows is achieved. The simulation results verify that the distributed optimization and scheduling method can effectively reduce the number of interacting variable dimensions, simplify the data transmission requirements, and ensure that the algorithm can converge to the optimal solution.

Keywords. Integrated Energy Systems; Energy Hubs; Distributed Optimization

1. Introduction

In recent years, the world has entered a period of rapid economic and social development, which has brought the energy crisis and environmental pollution problems more and more prominent. In order to actively respond to climate change, it is imperative to change the traditional path of energy construction and promote a revolution in energy production and consumption. Countries around the world have actively responded to the call for the development of a low-carbon economy, vigorously promote the diversification of energy supply and demand structure, and continue to promote the transformation of energy into a highly efficient, low-carbon, intelligent and environmentally friendly energy source. Under the active efforts of all countries, the global primary energy consumption has been steadily reduced, and the proportion of renewable energy has increased significantly [1].

The Chinese government has actively responded to energy issues, promulgated a number of development policies and provisions, actively promoted low-carbon, safe and efficient use of energy, accelerated the adjustment of energy structure, and ensured China's energy security [2]. The white paper of China's Energy Development in the New Era in 2020 pointed out that clean and low-carbon energy should be the leading direction of energy development, energy production layout and consumption structure should be optimized, and carbon emissions should be significantly reduced; In the 14th Five Year

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Plan of 2021 and the 2035 Vision, it is proposed to promote the green transformation of key industries and fields, make the energy allocation more reasonable, and build a modern energy system with new energy as the main body [3]. As a responsible major developing country, China actively participates in global climate governance. made a commitment to the world at the 2020 UN Climate Summit, proposing the great strategic goal of achieving "carbon peak" by 2030 and "carbon neutrality" by 2060. However, the problems of the traditional energy system, such as single form of energy supply, poor coordination, low energy utilization rate, and separate operation of energy suppliers, are increasingly prominent, which cannot meet the requirements of China's energy development, and the energy system is in urgent need of transformation [4]. The Integrated Energy System (IES), through advanced multi energy complementary technology, has strengthened the coupling of power, heat, gas and other heterogeneous energies in the system, realized the flexible use and conversion of energy, and is a powerful means to promote pollution reduction, carbon reduction, synergy and efficiency increase, and realize energy transformation [5].

2. Literature review

At present, most studies on power system flexibility are based on the definition of flexibility given by the International Energy Agency and the North American Power Reliability Commission. This definition pays more attention to the role of coordination of flexible resources in improving the operational flexibility of power systems. With the deepening of research on power system flexibility, the definition of power system flexibility has been further expanded and extended. Vahidinasab, V. et al. considered the flexible adjustment ability of the power system to respond to power fluctuations and maintain reliable operation of the system under different time scales [6]. Riaz, S., et al. emphasized the exploration of the flexibility of the power system itself, and met the flexibility demand generated by renewable energy and load by coordinating the output of flexible resources in the system [7]. Zhou, B. and others further refined the definition of power system flexibility, that is, under economic constraints and operational constraints, within a certain time scale, the power system can quickly and effectively optimize the allocation of existing resources, quickly respond to grid power changes, and control the power grid's key operating parameters [8]. Li, Y. et al. believed that the definition of power system flexibility should include four elements: time scale, flexibility resources, system uncertainty and cost constraints, and that flexibility is not only limited to dealing with random fluctuations of power at the source and load sides, but also applicable to dealing with system power changes caused by simple fault conditions such as generator and line faults [9].

This paper establishes a two-layer distribution network-integrated energy system cooperative optimization framework by taking into account the interaction between the integrated energy system and the distribution network, and the topology of the distribution network. The scheduling layer of the integrated energy system in the park coordinates the optimized scheduling of the equipment output of multiple parks and the energy interaction between parks; the park-distribution network scheduling layer gives the operation strategies of the parks and the distribution network, and the access scheme of the parks in the distribution network to achieve the economy of the integrated energy system of the parks while taking into account the flexible and stable operation of the distribution network. A distributed algorithm based on the alternating direction multiplier method is used to solve this framework, and only part of the necessary information needs to be exchanged between the subjects in the two-layer optimization scheduling to realize the overall coordination and optimization.

3. The research methodology

3.1 System architecture and modeling

In actual operation, the management of multi-park integrated energy systems and distribution grids usually belongs to different operating entities, and most of the parks also belong to different management entities, and there are information barriers between them. At the same time, the parks are interconnected to realize the complementary and mutual aid of various energies, and in line with the principle of economic optimization of the parks and the balance of energy supply and demand, the energy they interact with and the amount of electricity they purchase from the grid are affected by the tariff of the power grid. At the same time, the distribution network's current distribution state is affected by the size of the load accessed by each node, specifically in the optimal trend calculation, the location of the parks accessing the grid will directly affect the power load of certain nodes in the grid, which in turn affects the distribution network's all-day network loss.

Considering the above factors, this paper proposes the following two-tier distributed optimization system architecture of distribution network and integrated energy system. The energy interconnection between the parks is realized through power and heat lines, and the optimal operation target of each park is achieved through the information interaction server, while the power quota scheduling center between each park and the distribution grid interacts with the distribution grid to formulate the necessary information for the optimal operation plan, thus realizing the two-tier distributed optimization scheduling. The two-tier distributed optimization structure is shown in Figure 1.

3.2 Distribution network modeling

The power flow model of the distribution network in this paper is established using the second-order cone programming (SOCP) method, as follows: (1) (2) (3) (4):

$$\tilde{V}_j = \tilde{V}_i - 2\left(P_{ij} r_{ij} + x_{ij} Q_{ij}\right) + \left(r_{ij}^2 + x_{ij}^2\right)\tilde{I}_{ij}, \tag{1}$$

$$p_j = \sum_{k \in \delta(j)} P_{jk} - \sum_{i \in \pi(j)} \left(P_{ij} - \tilde{I}_{ij} r_{ij}\right) + g_j \tilde{V}_j, \tag{2}$$

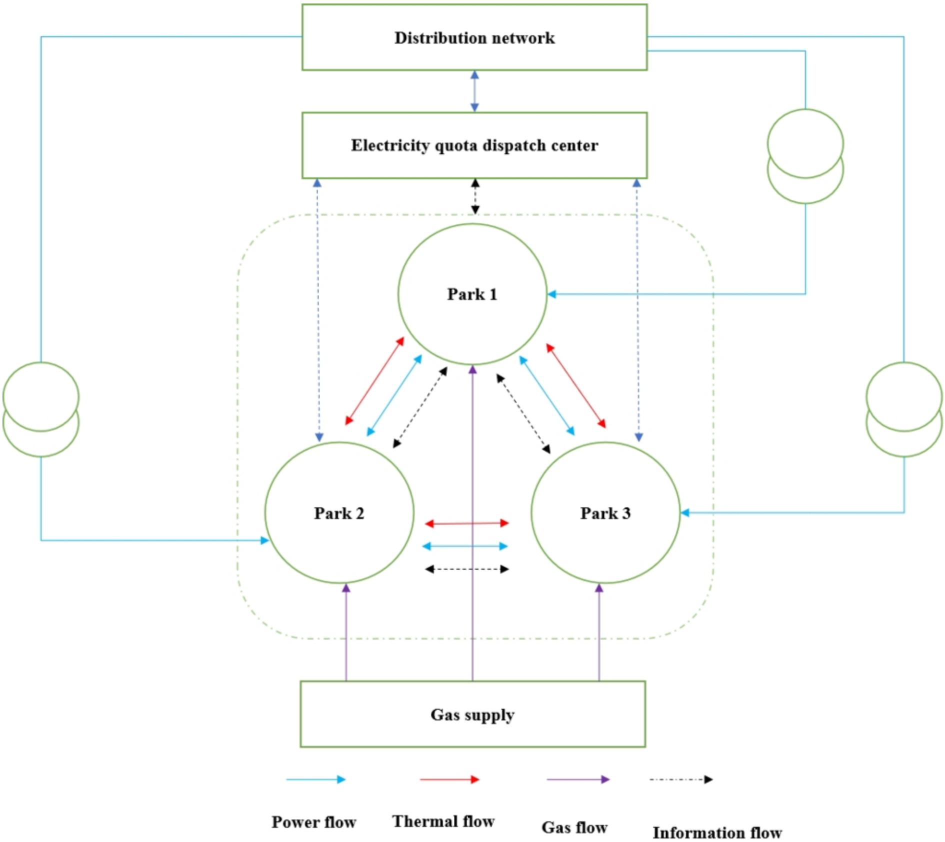

Figure 1. Overall system structure

$$q_j = \sum_{k\in\delta(j)} Q_{jk} - \sum_{i\in n(j)} \left(Q_{ij} - \tilde{I}_{ij}x_{ij}\right) + b_j\tilde{V}_j, \tag{3}$$

$$\tilde{I}_{ij}\tilde{V}_i \geqslant P_{ij}^2 + Q_{ij}^2 \Leftrightarrow \left\| \begin{matrix} 2P_{ij} \\ 2Q_{ij} \\ \tilde{I}_{ij} - \tilde{V}_{ij} \end{matrix} \right\|_2 \leqslant \tilde{I}_{ij} + \tilde{V}_i, \tag{4}$$

where: , and $\tilde{V}_i$ is a node i the square of the voltage amplitude; , the $\tilde{I}_{ij}$ for the line ij Square of current amplitude; Pij and Qij are the active power and reactive power on line ij respectively; Rij and xij are lines respectively ij Resistance and reactance; Pj and qj are nodes respectively j Active power and reactive power injected; Pjk and qjk are the active power and reactive power on the line jk between node k connected to node j respectively; Gj and bj are the conductance and susceptance of node j, respectively. The following general constraints shall also be met:

The node voltage is constrained as follows in equation (5).

$$\underline{V}_j^2 \leqslant \tilde{V}_j \leqslant \bar{V}_j^2, \tag{5}$$

The branch current is constrained as follows in equation (6).

$$\underline{I}_{ij}^2 \leqslant \tilde{I}_{ij} \leqslant \bar{I}_{ij}^2, \tag{6}$$

Distribution network reconfiguration is carried out through the switching of contact switches and sectionalized switches in the distribution network. In the process of network reconfiguration, in order to reduce short-circuit currents, the distribution network should be maintained as a radial network, and the existence of isolated nodes with zero injection should be prevented to ensure the connectivity and effectiveness of the network, therefore, the following constraints should be added on top of the tidal current model. The radial network is constrained as follows in equation (7).

$$\begin{cases} \sum\limits_{ij \in \Phi_l} z_{ij} = n_l - n_s, \\ z_{ij} \in \{0,1\}, \forall ij \in \Phi_l, \end{cases} \tag{7}$$

Where: nl is the total number of network nodes; Ns is the number of root nodes; Zij is a 0 – 1 variable used to represent the on-off state of line ij. 0 means disconnected, 1 means connected, Φ_l is the set of all lines in the distribution network.

4. Analysis of results

In this paper, an improved IEEE33 node distribution network system, a multi park integrated energy system composed of three parks with energy interaction through power tie lines and thermal tie lines, and a gas supply system are used to build a simulation example. The loads of three parks are typical loads of three different parks in the north in winter. Park 1, 2 and 3 are connected to 29 nodes, 23 nodes and 10 nodes respectively, and the original distribution network is reconstructed, which not only realizes the effective connection of all load nodes, but also ensures the minimum network loss of the distribution network throughout the day.

Using the optimized network loss of access combination 4 as a benchmark, the difference in network loss of other access combinations of the distribution network throughout the day is given. Combination 4 has the smallest all-day network loss, and combination 9 has the largest all-day network loss difference compared to combination 4.

The analysis and solution process of the example in this paper is based on MATLAB language. The MDCE framework is used to build a computing cluster. The cluster contains four computers with the same configuration. Some key configurations are: 8-core i7-9700CPU, 16 GB memory. All solutions involved in the process are solved by Gurubi+IPOPT solver. The distributed optimal scheduling method and the traditional centralized optimization algorithm proposed in this paper are used to solve the problem four times, and the indicators are shown in Table 1-3.

Table 1. Comparison of total operating costs for multiple parks

Methods	Total operating cost/$ for multi-campus 1	2	3	4
Two-tier distributed optimization	28015.51	28015.52	28014.93	28015.32
Traditional centralized optimization	28013.27	28014.44	28015.47	28015.48

Table 2. Comparison of distribution network losses throughout the day

Methods	Whole day network loss of distribution network/MWh 1	2	3	4
Two-tier distributed optimization	2.1546	2.1545	2.1543	2.1545
Traditional centralized optimization	2.1538	2.1539	2.1543	2.1545

Table 3. Optimization speed comparison

Methods	Solution time/s				interaction variable dimensions
	1	2	3	4	
Two-tier distributed optimization	61	63	61	62	96 × 3+72
Traditional centralized optimization	107	112	114	111	266 × 3+72

From Table 1-2, it can be seen that the distributed optimization scheduling method proposed in this paper and the traditional centralized optimization are repeated four times, and the solution results are consistent, so it can be seen that the distributed optimization solution method can also converge to the optimal solution. As can be seen from Table 3, using the distributed optimization algorithm proposed in this paper, the number of interacting variable dimensions in the solution process becomes significantly less, from 266×3+72 dimensions to 96×3+72 dimensions, which eliminates the transmission of detailed parameter data of all the equipment in the parks, and only needs to carry out the transmission of the expected switching power. The double-layer distributed optimization algorithm proposed in this paper can simultaneously carry out the interaction optimization problems between the parks and between the parks and the distribution network, avoiding the centralized optimization algorithm to be carried out step by step, and occupying a more advantageous position in problem solving and communication.

5. Conclusion

In this paper, the interaction between the integrated energy system and the distribution network is considered, and the economic and efficient operation of the system is realized by adjusting the access position of each park in the distribution network, the network topology of the distribution network, and the power output of each equipment within the integrated energy system of the park. Firstly, a cooperative optimization model of the distribution network and multi-park integrated energy system is established with the optimization objectives of minimizing the operating cost and minimizing the active network loss, respectively. Secondly, in order to ensure the privacy of system information interaction, the problem is solved by the alternating direction multiplier method with improved adaptive step size, and the operation control schemes of the distribution network and the integrated energy system in one dispatch cycle are given. Finally, the feasibility, efficiency and accuracy of the proposed method are verified through simulation and comparison with other traditional centralized optimal scheduling algorithms.

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