Analysis for the Hierarchical and Distributed Coordination Control Method of Integrated Energy Systems

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Abstract. Energy, as one of the important material foundations of economic development, has an immeasurable impact on the development of the national economy. However, it can be seen from the current situation of energy distribution in our country that there are problems such as unreasonable distribution and energy shortages. The above problems have severely restricted the development of my country's economy. In view of this, it is necessary to analyze the integrated energy system and analyze the corresponding coordinated control method according to the advantages and disadvantages of the equipment.

Keywords: Integrated energy systems; Hierarchical and distributed control; Coordination control; Optimized control.

1. Introduction
Traditional energy systems often operate independently and are difficult to coordinate with each other. In order to further improve the utilization efficiency of energy, this paper analyzes and studies the integrated energy system, aiming to alleviate the increasingly serious shortage of resources in our country through the effective control and coordination of energy.

Although there are few researches on the coordination control of integrated energy system in China, the control system has been gradually incorporated into the future development strategy of China.

1.1. Analysis of the Concept and Characteristics of the Integrated Energy System
Different from the traditional energy treatment system, the integrated energy system can be used to realize the all-round transmission of cold, heat, electricity, gas and other energies. In addition, the integrated energy reserve system can also allocate and store energy according to actual needs. Compared with a single energy processing system, the integrated energy system can not only greatly enhance the energy processing efficiency, but also improve the comprehensive utilization ratio of energy.

In general, the integrated energy system is a complex system which can allocate and couple multiple energy flows. Due to the volatility of renewable energy and load in the system, it’s very complicated to balance the supply and demand of the integrated energy as well as to allocate the integrated energy. In view of this, in order to achieve the full and effective control of the integrated energy system, we currently enable coordination control by frequently using distributed autonomy and centralized coordination. This paper mainly analyzes the hierarchical and distributed coordination control method of the integrated energy system.

During implementation of hierarchical and distributed coordination control, users can be divided into those at upper level and lower level. During control of the lower level users, it is necessary to first collect
the users’ power utilization capacity and the energy storage of the lower level system, and then conduct self-adaptive near-optimal control according to the collected information. During control of the upper-level park, it is necessary to collect and process the equipment in the upper-level park and the gateway power of each equipment. After that, it is necessary to analyze and predict the historical load data of all kinds of energies, and then dispatch and allocate the energy on that basis.

2. Brief Analysis of Distributed Coordination Control Method

2.1. Control Method of Distributed Autonomy for the Lower Level Users
During coordinating and controlling of the lower level users, the coordination subject is each user in the plant. The coordination process is shown in the figure below:

![Figure 1. User coordination process.](image)

2.2. Setup of Objective Function

\[
\min f = C_{grid} + C_{gas}
\]

Taking the minimal total energy purchase cost as the objective:
Wherein, \( f \) means the total cost of energy consumption of users, \( grid \) means the power consumption cost of users, and \( gas \) means the gas consumption cost of users.

In order to enable coordination control of the integrated distributed system of the integrated energy more truly and effectively, this paper is intended to take an industrial park in Guangdong Province as an actual case analysis.

The distribution structure of the integrated energy in the park is as follows: There are 12 lower-level-user plants and 1 upper-level-user plant in the park. For the convenience of information obtainment, this paper is intended to select three key parts of the park for analysis. Wherein, in the user plant ①, the PV peak capacity is 500 kW, and the electric energy storage capacity is 6 MW. Based on analysis of examples, it can be seen that only the electrical load demand exists in the plant; in the user plant ②, the PV peak capacity is about 500 kW, and ice storage capacity is 20MW·h. Thus, besides electrical load demand, there is also the thermal load demand in the plant. In the user plant ③, the power of micro-gas turbine is 100 kW, the maximum power of the steam-to-water conversion device is 120 kW, and the maximum power of the waste heat boiler is 120 kW. Therefore, there are both electrical load and thermal load demands in the plant.
Through the function calculation, we can obtain the daily load and PV forecast curve of the user plant ①-③, as shown in the following figure:

**Figure 2.** The daily load and photovoltaic forecast curve of the user plant area.

Based on local prices of the industry power consumption and gas consumption in Guangdong, we can make estimation to obtain the following parameters:

In the user plant ②, the efficiency of micro-gas turbine is $\eta_{MT} = 0.3$, the efficiency of the waste heat boiler at user side is $\eta_{GFB} = 0.75$, and the efficiency of gas turbine is 0.348. In addition, the maximum discharge rate of the battery is 0.4, the maximum charging efficiency is 0.95, the maximum energy storage of the ice storage equipment is 0.5, and the maximum natural heat release of the ice storage equipment is 0.03.

In the assumption that the dispatching cycle is one day and that the periodic dispatching time is 60min, the respective dispatching results of the three plants are shown as follows:

**Figure 3.** Optimized control results of user plant 1.
In order to achieve the optimal dispatching goal of each plant, the calculation and analysis of function show that the total operating cost of plant ① is 13,884.72 yuan, that of plant ② is 22,985.9 yuan and that of plant ③ is 3,791 yuan. Thus, the following control measures can be obtained:
Firstly, for the plant with battery discharging, charging operation can be carried out in case of valley power pricing, and discharging operation of battery can be carried out in case of peak power pricing. Compared with the original coordination control method, such kind of operation has two advantages: first, it can save a lot of electricity charge for the park, thus reducing the operation cost. Second, it can play the role of grid peak load shaving, thus reducing the electricity load.
Then, the cooling load inside plant is mostly supplied by refrigerating unit for base load and ice storage device. Compared with the battery, ice storage system has higher peak load shaving efficiency. In case of valley power pricing, the refrigerating unit in the plant operates in ice-making mode, where the cooling load is supplied by refrigerating unit for base load; and in case of peak power pricing, the
refrigerating unit in the plant operates in single melting ice mode, where considerable electricity price can be saved for the enterprise.

Finally, the thermal load in the plant is mainly provided by the micro-gas turbine equipment and gas boiler. In general, the micro-gas turbine can only be started in case of normal pricing. The insufficient power can be supplemented by the integrated energy suppliers in the park. Compared with the traditional unidirectional power supply, this mode can be used to not only help the park save a lot of electric energy, but also realize the supplement and transformation of gas, electricity and heat.

2.3. Several Coordination and Dispatching Measures for the Upper Level Users

Without changing the normal operation of upper-level control system, in order to achieve the supply and demand balance among cold, heat and electricity in the upper-level park, the management of industrial park has to conduct peak load shaving for the direct dispatching equipment and DemandResponse for lower demand, and give price subsidies to users involved in the response interaction. Moreover, in order to realize the maximization of the economic benefit, it’s required to minimize the compensation cost of the users as far as possible.

It’s known from the above content that, there is only one upper-level user plant in the park. Due to huge amount of gas used in the plant, enterprises can get a slight of optimization when purchasing gas. For example, the discounted gas purchase price is 2.66 yuan, which is converted into a thermal value 0.269 yuan/(kW·h) per unit.

In addition, during calculation, the national dividend measures for the industrial park shall be considered as well. The integrated energy supplier in the park may offer proper compensation prices for some users during energy supply. The regional compensation electricity price is shown below:

| TYPE            | USER  | The compensation price/[¥·(kw·h)^{-1}] |
|-----------------|-------|----------------------------------------|
| Mediatable load | user1 | 2.3                                    |
|                 | user2 | 2.5                                    |
|                 | user3 | 2.8                                    |
| Interruptible load | user1 | 100                                    |
|                 | user2 | 105                                    |
|                 | user3 | 108                                    |

**Figure 6.** Compensation Electricity Price Table.

In view of this, during coordinating and dispatching of the upper-level plant, adjustments should be made according to various scenarios:

Scenario ①: Realize the economic operation of integrated energy provider equipment. According to the actual cases, in order to realize the economic operation of the equipment, integrated energy suppliers need to conduct coordination control for CHP units and electrical energy storage unit simultaneously. Meanwhile, the energy suppliers can also achieve an effective balance of all kinds of power in the park without coordinating with the lower-level user plants a second time. The calculation results of energy consumption are as follows: the total operating cost of the integrated energy supplier is 452,474.8 yuan, and the possibly earned net profit is 180,848.7 yuan.
Scenario ②: Adjustable load users involved in response. According to the above-mentioned prediction diagram, it is known that, in the peak period of power consumption, the electrical load of plant users may rise to 350 kW. Supposing that, at the moment, the power consumption and heat consumption load for the rest periods keep unchanged basically, we know from calculation that, if all adjustable load users are involved in response, it’s required to perform cooperative control over the adjustable loads of CHP units, electrical energy storage units and users so as to realize energy-stored balance. In this case, the operating cost of the integrated energy supplier is 453,107 yuan, and the compensation cost to the users is 338,533.66 yuan. And, the net profit is 180,529.9996 yuan.

Scenario ③: Interruptible load users involved in response. Supposing that the electrical load of users in the prediction period rises to 700 kW, while the power consumption and heat consumption load for the rest periods keep unchanged basically, we know from calculation that, in order to realize power balance in the park, it’s required to perform cooperative control over the adjustable and interruptible loads of CHP units, electrical energy storage units and users. Hence, it’s known that, the total operating cost of the integrated energy supplier is 4,794,916 yuan, the compensation cost for adjustable load users is 720 yuan, the compensation cost for interruptible load users is 21,425 yuan, and the net profit is 159,036 yuan.

According to the calculated values under different circumstances, the following conclusions can be drawn:
1. When the thermal load of the plant is completely supplied by CHP unit operating in the mode of determining power by heating load, which can provide both electric energy and thermal energy for the park. If the power supply is insufficient, the integrated energy supplier of the park can obtain the power from the external grid.
2. Due to the impact from gateway load in the park, allocating electric energy in the industrial park can’t fully comply with the principle of storing electric energy in valley load period and generating in peak load period. The stored electrical energy in the park may be weakened when exceeding the maximum gateway value in the park. Only by this way can we achieve operative constraint for tieline power.
3. It is known from the above table that, due to relatively high compensated electricity price and during effective allocation for the upper-level control system, if users’ electrical loads are in a rising state for a long time, energy suppliers will be required to conduct effective interaction with the users to adjust the electrical load, and restrict the upstream and downstream power utilization effectively.

3. Summary
To sum up, this paper mainly analyzes the hierarchical and distributed coordination control strategy of the integrated energy system in the industrial park, and focuses on the analysis of the control strategy of upper and lower levels of energy. Based on the foregoing, the following conclusions can be drawn:
First, when controlling the lower-level users, we can adopt the control strategy of distributed autonomy to allocate and control the cold load, heat load and electric load resources of the lower-level users through the effective allocation of energy, so as to realize the effective utilization of energy. Second, when controlling the upper-level users, we can adopt the centralized coordination control method, by which we can realize effective peak load shaving in the industrial park, so as to greatly improve the safety of energy operation in the industrial park. In general, by the hierarchical and distributed coordination control method, we can realize the coordination of the integrated energy system to reduce the difficulty of energy dispatch effectively. In this way, we can not only guarantee the energy demand of the upper-level users but conduct reasonable distribution for the energy demand of the lower-level users. This paper mainly involves the effective coordination control of the upper and lower levels of energy in the industrial park, but does not involve the optimal control of energy allocation. As the current Chinese energy allocation technology is not yet mature, it is believed that in the near future, we can scientifically analyze the dynamic response characteristics of a variety of energy sources in different time periods, and develop a more perfect hierarchical and distributed emergency control strategy based on that.
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