Energy Storage Planning of Park Energy System Based On Multi-Dimensional Digital Twin Technology

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Abstract—The existing energy storage planning methods have the problem of imperfect equipment mathematical model, resulting in small installed capacity of renewable energy. An energy storage planning method of Park energy system based on multi-dimensional digital twin technology is designed. This article explains the basic connotation of multi-dimensional digital twin technology and park energy system, and obtains feedback information. Combined with the energy consumption of industrial users, the park's electricity load is predicted. We used the multi-dimensional digital twin technology to construct the mathematical model of the equipment, extracted the energy conversion law, optimized the energy storage mode of the energy system, and achieved zero heat emission. Case analysis results: the average installed capacity of renewable energy after optimization is 2349.6 kW, 626.6 kW higher than that before optimization, indicating that the energy storage planning method integrating multi-dimensional digital twin technology has a broader application prospect.

1. Introduction
The energy system of the park refers to the integrated system composed of power supply, district heating, cooling and various energy conversion equipment. The energy system of the industrial park is composed of energy station and cold / heat / electricity / gas energy supply pipe network, in which the energy station is the core of the regional comprehensive energy system. According to the energy stations are distributed on the user side or distributed in the park by users, the park can be divided into distributed energy stations and centralized energy stations [1-3]. For the centralized energy station, it is generally required to meet the cooling, heating, power supply and other load requirements in the park at the same time. It is the hub of the energy supply system of the park. The centralized energy station in the regional integrated energy system is called the integrated energy station. From the perspective of energy supply, the energy station mainly carries out energy supply and energy storage. The energy system consists of many different types of energy, energy production equipment, energy conversion equipment and energy storage equipment [4]. Energy forms include cold, heat, electricity, gas, etc. terminal energy load demand includes electricity demand, heating demand, hot water demand and cooling demand. At the input end of the system, its energy can be wind energy, natural gas, diesel, solar energy, geothermal energy, etc. Through different energy conversion equipment, the energy of these energy sources is finally transformed into electricity, heat and cold for end users through utilization and conversion at all levels. Existing studies at home and abroad have proposed the physical model level of the integrated energy system, including all kinds of energy forms such as electricity, cold, heat and gas in all links from production, conversion, storage to consumption [5-6]. The development of energy system in foreign countries started earlier, its research on energy system
planning considers more factors, and the construction of model is relatively complex. A stochastic programming method for comprehensive energy system is proposed. The uncertainty of different energy prices is described in the form of stochastic normal. Taking energy system investment planning as the first stage optimization problem and energy system operation as the second stage optimization problem, a two-stage model for energy system optimization is constructed. The development of domestic integrated energy system started later than that of foreign countries, but it has also achieved fruitful results. The factors considered in the research of integrated energy system planning are relatively simple. At present, the research data on the application of multi-dimensional digital twin technology to the park energy system is not very rich, which needs to be further discussed.

2. Energy storage planning of park energy system based on multi-dimensional digital twin technology

2.1. Forecast the power load of the park

When planning the equipment capacity of the comprehensive energy station in the industrial park, it is first necessary to analyze the power consumption characteristics of users and obtain the energy load curve of users\(^7\). Then, according to the user's economic development level and battery power storage capacity, the user's energy load in a certain period in the future is predicted, and the user's load prediction results are obtained\(^8\). When adopting the load forecasting method based on index method, for typical industrial enterprises, it should be composed of two parts: building envelope environmental heat exchange and equipment processing and production heat dissipation, which are usually dominated by building cooling/heating load. The calculation formula of total building cooling load is:

\[
L = \sum_{n=1}^{m} H_n \times W_\gamma \tag{1}
\]

In formula (1), \(H\) represents the sample building area, \(W\) represents the heat load, \(m\) represents the building type, and \(\gamma\) represents the comprehensive heat index. The thermal steam load and electric load of industrial users are highly related to product types, so they need to be analyzed and predicted according to the production plan of the enterprise. It is generally believed that the steam load/electric load is approximately proportional to the output. Therefore, the output value unit consumption method is used for analysis and prediction. The expression formula of industrial electric load is:

\[
Fr = \sum_{g=1}^{c_2} E \times r \tag{2}
\]

In formula (2), \(E\) represents steam load, \(r\) represents steam consumed per unit product, \(t\) represents product output, and \(g\) represents power consumption. In general, in engineering practice, if there is a lack of sufficient analysis data, the proportional growth method is often used for simple load forecasting according to the existing historical data and combined with engineering experience. The load forecasting formula is as follows:

\[
P' = P' \times (1 + d)^j \tag{3}
\]

In formula (3), \(P\) represents historical load, \(d\) represents load forecasting results, and \(j\) represents annual load growth rate. Combined with formulas (1) ~ (3), and after obtaining the load curve of park users according to collection or analysis, further analyze the load change trend and obtain the load prediction results. Based on this, complete the steps of predicting the power load of the park.

2.2. Construction of equipment mathematical model by multi-dimensional digital twin Technology

The operation principle of multi-dimensional digital twin system is: when the production system is running, the service system controls the physical production line to carry out real production activities
according to the production plan. In the future, the results of analysis and calculation can be fed back to the park energy system to realize the alarm, control optimization and energy storage planning of the production process. The power supply equipment in the energy system of the park mainly includes distributed renewable energy generation, energy storage battery, electric vehicle charging pile and distribution network. This kind of equipment can realize the production, transmission and storage of clean electric energy and is an important part of the comprehensive energy system of the industrial park. The power network power flow of the energy system in the park shall adopt the AC power flow of the distribution network to extract the energy conversion law\cite{9}. The expression formula of its physical and mathematical model is:

\[
\begin{align*}
T &= S_v \times (Q_v \cos \theta + l) \\
Y &= L_v \times (Q_v \sin \theta + l)
\end{align*}
\] (4)

In formula (4), \(S\) represents the active power on the distribution network line, \(L\) represents the amplitude of node voltage in the distribution network, \(V\) represents the power consumption of equipment, \(Q\) represents the number of equipment, \(\theta\) represents the simultaneous working coefficient of equipment, and \(l\) represents the active power on the distribution network line. Natural gas suppling includes natural gas source, pipeline, compressor and other equipment. Generally speaking, the relevant parameters will not change with time, such as pipeline pressure, fluid velocity, etc\cite{10}. The parameters in the dynamic power flow model will change with time. The expression formula of physical and mathematical model of transmission capacity of natural gas pipeline network is:

\[
Z = 67.86 \sqrt{\frac{K_0^2 - K_1^2}{M_0^2 \phi^2}} \frac{\phi^3}{B}
\] (5)

In formula (5), \(K_0\) represents the mass flow of natural gas, \(K_1\) represents the absolute pressure rating at the starting point of the natural gas pipeline, \(M_0\) represents the compression factor of natural gas at the starting point of the pipeline, \(M_1\) represents the natural gas potential energy factor function, \(\phi\) represents the absolute pressure rating of natural gas at the end of the pipeline, and \(B\) represents the resistance coefficient along the pipeline. At the same time, electricity to gas is to obtain hydrogen by water electrolysis, and further synthesize hydrogen and carbon dioxide into methane and other gases, so as to convert electric energy into relatively convenient gas for storage. With the rapid development of renewable energy and supply and demand, the current in the power grid flows to the battery after rectification, and the battery discharge flows back to the power grid through inverter, so as to realize the two-way flow of electric energy between the battery and the power grid. The structure of battery energy storage system includes energy storage unit, battery energy management system, filter, etc. Battery is the core of energy storage unit, which is composed of multiple batteries for electric energy storage and release. The battery management system monitors and controls the output voltage, current, temperature and state of charge of the energy storage system in real time to ensure the safe, efficient and economic operation of the energy storage system. Based on this, the steps of building the mathematical model of the equipment are completed.

### 2.3. Optimizing energy storage mode of energy system

The energy storage mode of the energy system must meet the dislocation distribution of the same energy in time and can adjust the mismatch between supply and demand of energy supply in time. Therefore, it can be used as a secondary regulation means of the comprehensive energy system in the functional area to make up for the mismatch between energy supply and demand caused by multi energy complementarity. During the operation of the energy system, electric energy storage mainly plays the role of stabilizing the output uncertainty of renewable energy and improving the economy of
system operation. It can store electric energy when the power grid load is low and release electric energy when the power grid load is high, which can be used to cut peak and fill Valley and reduce power grid fluctuation. At present, the electric energy storage equipment is mainly lithium-ion battery, lead-acid battery, sodium sulfur battery and liquid flow battery, and has realized megawatt demonstration applications in the fields of renewable energy grid connection, distributed generation and Microgrid. The electric boiler in the regenerative electric boiler is a coupling unit for energy form conversion. It generally uses new energy such as photovoltaic and wind power as the power supply, generates heat through electromagnetic induction or resistance, and outputs hot water or high-temperature steam. The installation of heat storage tank can break the conventional operation mode of "Determining electricity by heat", make the electric load of the electric boiler controllable, and increase the electric load during the low load period, Convert excess electricity into heat and store it. In the peak load period, the power load demand is reduced and the stored heat energy is used for heating. This will not only make more effective use of wind power in the trough period, but also play the role of peak shaving and valley filling. In extreme cases, it can even shut down the CHP unit and completely use the electric boiler for heating, so as to realize zero emission of heating. Among various cold energy storage methods, ice storage stores the cooling capacity by making water into ice. Compared with water storage, the volume of ice storage will be much smaller than that of water storage. Assuming that lead-acid battery, heat storage tank and cold storage tank are used as physical equipment for storing electric heat energy, the expression formula of the relationship between physical stored energy and charging / discharging power is as follows:

$$I = (1 - \varepsilon) \times D_{t-\Delta t} \quad (6)$$

In formula (6), $p$ represents the self loss coefficient of physical energy storage, $D$ represents the scheduling time interval, $t$ represents the discharge efficiency, and $\varepsilon$ represents the charging efficiency. Through the space-time coupling of cooling, heating and power and the complementarity of energy demand, the problem of users' comprehensive energy demand is solved, and the cold and hot electric energy is generated, transmitted, transformed and supplied in one system. At the same time, the cross complementarity of various energy sources and the flexible and reliable characteristics of thermoelectric units can efficiently absorb new energy sources such as photovoltaic and wind power with strong volatility. However, the energy storage planning of regional integrated energy system including multi-functional areas is no longer the capacity allocation of a single independent energy system. It is necessary to comprehensively consider the capacity requirements of energy supply, transmission, transformation and storage equipment of various energy forms. Considering that the functional area is equivalent to the whole as a decomposable state, the expression formula of electric quantity distribution characteristics in a certain area is obtained as follows:

$$U = \sum_{i=1}^{q} h^i \quad (7)$$

In formula (7), $h$ represents the power supply period, $q$ represents the initial power consumption of the functional area, and $i$ represents the re decomposition period. How to plan according to different user needs during multi-functional interval collaborative planning. Based on the above analysis, considering the differences and space-time complementarity of "source network load storage" of cooling, heating and power in different types of functional areas, this chapter proposes to optimize EV charge and discharge, room temperature and cold storage temperature by using the space-time distribution characteristics of EV, the flexibility of temperature load and the thermal inertia of heating system, so as to build an entity considering the differences of "source network load storage" in multi-functional areas, Multi entity energy storage equipment planning model of regional integrated energy system with coordinated virtual energy storage. Based on this, the steps of optimizing the energy storage mode of the energy system are completed.
3. Case description

3.1. Selecting the basic parameters of equipment in the park
This paper selects an industrial park in southern China as the research object. There are 13 industrial users in the industrial park, which can be equivalent to 13 load nodes in the whole park. The four load nodes include four load types: electricity, heat, cooling and gas. The three load nodes include three load types: electricity, heat and cooling. The three load nodes include electrical and thermal load types. In this case, the heat load refers to the hot water for industrial production with water supply temperature of 140-170 ℃ and return water temperature of 30-45 ℃, and the heat for building space, and the cooling load refers to the cold for building space. The basic parameters of equipment in the park are shown in Table 1:

| Equipment                  | Fan   | P2G   | Water storage tank | CCHP  |
|----------------------------|-------|-------|--------------------|-------|
| Cost (yuan/Kw)             | 19200 | 3700  | 35                 | 9700  |
| Maintenance Costs (yuan/Kw)| 2200  | 1800  | -                  | 2400  |
| Efficiency                 | -     | 0.5   | 0.9                | 0.42  |
| Life (year)                | 22    | 8     | 18                 | 14    |

Based on table 1, case analysis is carried out. In addition to the above conditions, the industrial park contains 24 road network nodes. According to the local resource conditions, geographical environment and policy factors, energy alternative stations are selected, including combined cooling and heating power supply, photovoltaic, electric heating boiler, gas boiler, absorption refrigerator, electric refrigerator, natural gas station and energy storage alternative station. For the cooling and heating load of buildings, this area is located in the subtropical climate zone. There is no heating demand all year round, which is cooling demand. Besides the Spring Festival, there is cooling load demand in all periods of the year. In summer, June, July, August and September are the peak period of cooling, and the cooling load demand in this period accounts for more than 55% of the total amount of the whole year.

3.2. Optimization results
Combined with the multi-dimensional digital twin technology, the energy storage planning method of the park energy system designed this time is used to optimize the energy storage scheme of the park, and the installed capacity of renewable energy before and after optimization is obtained, as shown in Table 2:

| Scene                                  | Before optimization | After optimization |
|----------------------------------------|---------------------|--------------------|
| Energy storage configuration is not considered | 1268                | 1836               |
| Only consider adding electric energy storage configuration | 654                | 1022               |
| Gees is considered                      | 2648                | 3684               |
| Only cooling load is considered         | 1680                | 2300               |
| Only heat load is considered            | 2365                | 2906               |

It can be seen from table 2 that under different scenario conditions, the average installed capacity of renewable energy after optimization is 2349.6 kW and the value before optimization is 1723kW, indicating that the designed energy storage planning method has higher performance.

4. Conclusions
The result of electric / thermal energy storage planning is not only more economical, but also can ensure the safety and reliability of system operation. The electric / thermal energy storage planning
model is established to consider the balance of energy supply and demand, cold / thermal / electrical coupling and energy complementarity to meet the load demand. At the same time, the electric energy storage capacity is reduced and the waste of renewable energy is reduced, which brings both environmental and economic benefits. Due to the limited research conditions, this paper does not conduct in-depth research on electromagnetic energy storage, and will focus on relevant topics in the future.

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