Load forecasting method for park integrated energy system considering process industrial production process

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Abstract. Aiming at the problem that the current integrated energy load forecasting method does not consider the actual production process and the coupling characteristics between multiple energy carriers, this paper proposes a load forecasting method for park integrated energy system considering process industrial production process. Firstly, taking the battery factory as an example, the production process of typical battery factories is detailed. Secondly, the composition of electricity, heat and cooling load in the battery factory is analyzed respectively, and the corresponding load forecasting model is established. Finally, the applicability and accuracy of the forecasting method proposed in this paper in different situations are analyzed by actual cases. The load forecasting method proposed in this paper fully considers the production process of typical process industry, which can provide an accurate load forecasting basis for energy management and planning of related industries.

Keywords: Battery factory, production process, park integrated energy system, model driven, load forecasting.

1. Introduction

Recently, with the continuous development of energy Internet related technologies and the deepening of demonstration construction, all walks of life are trying to change the traditional energy consumption system and further develop towards sustainable energy consumption with high quality, low carbon and high efficiency [1]. In many industries, industrial Internet has received more attention due to its potential scheduling space and its potential for energy conservation and emission reduction in coordination with production process. In terms of energy consumption, industrial electricity consumption in developing countries accounts for about 60% to 80% of the total national electricity consumption [2] based on the existing energy consumption statistics. In terms of regional management, many industrial users choose to establish industrial parks with autonomous scheduling capability to realize the current concept of "distributed autonomy, centralized coordination" of power grids with the continuous development of park economy. Therefore, it is of great significance to deeply analyze the production process in industrial parks and rationalize the energy production/consumption program of users for the realization of the goal of "energy conservation and emission reduction" and the friendly interaction between users and...
superior power grids. As an important basis for making reasonable operation and scheduling programs and planning and design programs for users, it is also an important problem to be solved urgently at present on how to improve the accuracy of load forecasting for process industrial users. It is of great significance for industrial users, power companies and society to accurately control energy consumption characteristics.

At present, there are mainly two solutions for the forecasting and analysis of typical user load characteristics. The first is the "data-driven method" based on historical statistical data combined with artificial intelligence and deep learning method to realize load forecasting and analysis. Reference [3] proposed a load forecasting method for regional integrated energy system considering dynamic and multi-energy coupling characteristics. By constructing a coding and decoding model based on long-short term memory network (LSTMED), the historical sequence characteristics and time dynamic characteristics of load were reflected. Reference [4] used long-short memory (LSTM) recurrent neural network to predict family load, and verified the advantages of LSTM method over traditional BP neural network method in forecasting accuracy. The second is the "model-driven method" that predicts the energy-using characteristics by fine modeling of energy-using equipment and links. Reference [5] proposed a depiction method of user load portrait by modeling typical energy consumption equipment in household users and combining the energy consumption behavior. Reference [6] fully considered the behavior factors of personnel, established the energy consumption model of lighting load, and proposed the forecasting method of household lighting load.

The above references have laid a good foundation for the research of this manuscript. However, there are still the following problems to be solved. First, most of the current forecasting and analysis of typical user loads only consider the electricity consumption characteristics. With the gradual deepening of multi-energy coupling degree, the coupling characteristics of different energy carriers on the terminal load side will affect the load forecasting. Second, although the existing studies have considered the personnel behavior factors in the process of load forecasting, they have not considered the productive factors such as process flow, and the production process flow does affect the important factors of industrial load characteristics.

Therefore, taking the battery factory in the process industry as the research object, this paper constructs the energy consumption model of different production process by detailed analysis of the production process in the park integrated energy system, which realizes the analysis of the typical energy consumption characteristics of the battery factory.

2. Production Process Flow of Battery Factory
Taking the battery factory that mainly produces battery cells as an example, the production process of power cells and 3C cells is shown in Figure 1. The cell production process mainly includes three steps: cell production, packing line, formation and capacity grading. In the production and manufacturing process, power failure is not allowed in the coating, drying, liquid injection, capacity grading and other processes, and its load characteristics are relatively clear [7], while power failure is allowed for a short period of time (within 30 minutes) in the stirring process, and the whole production cycle of the battery cell is about 25 days.

Fig. 1 Cell production process
3. Load Modeling Analysis

3.1. Electrical Load Modeling Analysis
The electrical load in the battery factory is mainly related to the production process, which can be divided into two types. The first type is continuous production electrical load, which specifically refers to the power consumption required by the part of the production process that does not allow power failure. Its status only depends on the start and end of the order. This type of load can be specifically expressed as:

\[ P^E_c(t) = \sum_{i=1}^{N_c} u_{c,i}(t) M_{c,i} P_{c,i}(t) \]  

Where \( P^E_c(t) \) is the total power consumption of continuous production load in period-\( t \); \( N_c \) is the total number of production workshops; \( M_{c,i} \) is the output quantity of production workshop \( i \). \( M_{c,i} \) is a fixed value for continuous production electrical load. \( P_{c,i}(t) \) is the power consumption for unit quantity of products produced by production workshop \( i \) in period-\( t \); \( u_{c,i}(t) \) is a Boolean variable and represents the working state of production workshop \( i \) in period-\( t \). The following constraints need to be met:

\[ \begin{align*}
  O^{c^\text{on}}_{c,i}(t) - O^{c^\text{off}}_{c,i}(t) &= u_{c,i}(t) - u_{c,i}(t-1) \\
  O^{c^\text{on}}_{c,i}(t) + O^{c^\text{off}}_{c,i}(t) &\leq 1
\end{align*} \]  

Where, \( O^{c^\text{on}}_{c,i}(t) \) and \( O^{c^\text{off}}_{c,i}(t) \) respectively represent the start and end states of the production workshop \( i \).

The second type is discrete production power load, which specifically refers to the power consumption required by sudden production tasks. Its status is directly related to orders and production tasks. This type of load can be specifically expressed as:

\[ P^E_d(t) = \sum_{j=1}^{N_d} u_{d,j}(t) M_{d,j} P_{d,j}(t) \]  

Where, \( P^E_d(t) \) is the total power consumption of discrete production load in period-\( t \); \( N_d \) is the total number of production workshops; \( M_{d,j} \) is output quantity of the production workshop \( j \). Different from the continuous production electrical load, \( M_{d,j} \) is not a fixed value, but is related to the quantity of orders and the completion time. \( P_{d,j}(t) \) is the power consumption for unit quantity of products produced by production workshop \( i \) in period-\( t \); \( u_{d,j}(t) \) is also a Boolean variable.

In conclusion, during the statistical period, the calculation equation of battery factory power consumption is as follows:

\[ P^E = \sum_{i=1}^{N_c} P^E_c(t) + P^E_d(t) \]  

Where \( NT \) is the load statistics period.

3.2. Heat Load Modeling Analysis
The heat load in the battery factory is mainly related to the "drying" process in the production process, which is similar to the calculation method of continuous production electrical load. The calculation of heat load can be specifically expressed as follows:

\[ P^H(t) = \sum_{k=1}^{N_h} u_{h,k}(t) M_{h,k} P_{h,k}(t) \]  

Where, \( P^H(t) \) is the total heat consumption of drying production load in period-\( t \); \( N_h \) is the number of drying workshops; \( M_{h,k} \) is the output quantity of the drying workshop \( k \), which is usually set to a
fixed value; $P_{h,k}(t)$ is the heat consumption of unit quantity of products produced by drying workshop k in period-t.

3.3. Cooling load Modeling Analysis

The cooling load in the battery factory is mainly related to indoor ventilation and indoor temperature adjustment. In actual cooling or scenes, the interior of the factory workshop is usually simulated as a single isothermal air conditioning area [1]. Considering the relationship between heat generation and heat dissipation sources in the factory workshop, the indoor heat balance equation constructed in this paper is [8]:

$$H_k = \left[ H_1 + H_4 + H_5^{(2)} \right] - \left[ H_1 + H_5^{(1)} + H_5^{(2)} \right]$$  \hspace{1cm} (6)

Where, $H_1$--$H_6$ are different heat generating/dissipating sources. $H_1$ is convective heat transfer between the inner surface of the wall and air. $H_2$ is the heat generation/heat dissipation amount of the window. $H_2^{(1)}$ is the permeation heat consumption of the window, and $H_2^{(2)}$ is the illumination radiation heat outside the window. $H_3$ is the heat consumption of cold air invasion/ventilation. $H_4$ is the increment of sensible heat of building air per unit time. $H_5$ is the heat exchange power between indoor heat source and indoor air. $H_6$ is the heat exchange power between heating equipment and indoor air.

Based on the above indoor heat balance equation in the factory workshop, the calculation equation of cooling load in the factory workshop is as follows:

$$P_{c,t} = \frac{m_H \cdot C_p \cdot (T_{in}(t) - T_{in}(t))}{1 + C_{COP}}$$  \hspace{1cm} (7)

Where, $P_{c,t}$ is the demand for cooling load in the workshop in period-t. $m_H$ is the air flow rate of the central air conditioner. $C_p$ is that specific heat capacity of air. $C_{COP}$ is the energy efficiency ratio of the central air conditioner. $T_{in}(t)$ is the indoor temperature in period-t; $T_{H}(t)$ is the air supply temperature of the central air conditioner in period-t.

4. Research on Load Forecasting Method

The composition of electricity, heat and cooling loads in different periods of time in the battery factory is analyzed in combination with the specific production process above. Based on the composition of electricity, heat and cooling loads in different periods of time, the overall energy consumption load curve of the battery factory can be predicted in combination with external factors such as order quantity and ambient temperature. The specific expression is as follows:

$$\{ \Omega^E, \Omega^H, \Omega^C \} = \{ P_{c,t}^{(1)}(t), P_{c,t}^{(2)}(t), T_{in}(t), T_{H}(t) \}$$  \hspace{1cm} (8)

Where, the sets $\Omega^E$, $\Omega^H$, and $\Omega^C$ respectively represent the electric, heat and cooling load curves, and the composition and influencing factors of the load curves are given in the specific expression of the sets.

In conclusion, based on the production process, load composition and external influencing factors, the forecasting of electricity, heat and cooling loads in battery factories can be realized.

5. Case Analysis and Comparison

5.1. Case Overview

In this paper, a battery factory in southern China is taken as an example. The 1#-3# factory buildings in the integrated energy system of the factory park are used to produce power cells. Each factory building has 4 production lines. The specific production process distribution is shown in Figure 2. In order to
ensure the working comfort of the factory workshop, the temperature in the factory workshop is set to 23°C.

5.2. Load Forecasting Analysis

(1) Load forecasting and analysis of typical situations

Based on the load composition and forecasting analysis method, the typical daily power load curve of the battery factory studied in this paper is shown in Figure 3. On weekdays, due to the 24-hour shift system of cell production, the load decreases only at 7:00, 11:00, 15:00, 20:00 and 24:00 every day or during rest and dining. The load curve fluctuates regularly during the rest of the period according to the production line and process conditions. On holidays, the power load of the factory building drops to around 1000 kW except for the power support required by the production process, and the power consumption during the day is higher than that at night with the power consumption concentrated between 7:00 and 21:00. In addition, under different conditions of the number of production lines in operation, the power load curve analysis of the battery factory is shown in Figure 4. It can be seen that the operation of the production line has a direct impact on the power load, which also further illustrates the importance of considering the production process flow in load forecasting.

![Fig. 2 Power cell production process distribution](image)

![Fig. 3 Typical electric load analysis](image)
Figure 5 and 6 are load curves of typical days of four seasons of cold load and heat load of battery factory buildings. Specific analysis shows that the fluctuation of the cooling load curve of the factory building is relatively gentle, the daytime cooling load is slightly greater than the night cooling load, the summer cooling load is obviously greater than that of other seasons, and the winter cooling load is obviously smaller than that of other seasons. However, the heat load curve of the factory building has obvious fluctuation trend, which is caused by the production process. The heat load curve of spring, summer, autumn and winter changes within 2MW.
(2) Forecasting accuracy analysis

In this paper, the mean absolute percentage error (MAPE) and the maximal relative percentage error (MRPE) are further selected to analyze the progress of the load forecasting method proposed in this paper, taking the electrical load as an example. The forecasting accuracy of the forecasting method proposed in this paper under different situations is shown in Table 1.

| Typical days | MAPE/% | MRPE/% |
|--------------|--------|--------|
| Working day  | 3.31   | 4.28   |
| Rest Day     | 2.73   | 3.86   |
| Spring       | 3.18   | 4.13   |
| Summer       | 3.15   | 4.11   |
| Autumn       | 3.24   | 4.21   |
| Winter       | 3.26   | 4.25   |

The specific analysis of the results in Table 1 shows that compared with rest days with relatively fixed energy consumption behavior, working days would affect the accuracy of load forecasting due to the uncertainty of production process and order arrangement. However, the difference in energy consumption in different seasons would also have a corresponding impact on the accuracy of load forecasting.

6. Conclusions

Taking the battery factory in the process industry as the research object, this paper fully considers the interactive influence of production process and building heat balance and other factors in the load forecasting, and proposes a load forecasting method for park integrated energy system considering the production process of process industry. Through theoretical and practical simulation analysis, the method proposed in this paper can realize load forecasting analysis of battery factories in different situations with high forecasting accuracy.

Future research will be based on the results of load forecasting and further combine with the production process to propose energy management and operation scheduling strategies for process industry.

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References

[1] Jin X, Mu Y, Jia H, et al. Dynamic economic dispatch of a hybrid energy microgrid considering building based virtual energy storage system [J]. Applied Energy, 2017, 194:386-398.
[2] Science and Technology Development Promotion Center of the Ministry of Housing and Urban-Rural Development. China building energy efficiency development report (2016): Building energy efficiency operation management [M]. Beijing: China Building Industry Press, 2016.
[3] Shaomin Wang, Shouxiang Wang, Haiwen Chen, et al. Multi-energy load forecasting for regional integrated energy systems considering temporal dynamic and coupling characteristics [J]. Energy, 2020, 195:116964.
[4] W. Kong, Z. Y. Dong, Y. Jia, et al. Short-Term Residential Load Forecasting Based on LSTM Recurrent Neural Network [J]. IEEE Transactions on Smart Grid, 2019, 10(1):841-851.
[5] GE Shaoyun, LI Jifeng, LIU Hong, et al. Domestic Energy Consumption Modeling per Physical Characteristics and Behavioral Factors [J]. Energy Procedia, 2019, 158:2512-2517.
[6] Widén J, Nilsson A M, Wäckelgård E. A combined Markov-chain and bottom-up approach to modelling of domestic lighting demand [J]. Energy & Buildings, 2009, 41(10):1001-1012.
[7] Yizhi Zhang, Xiaojun Wang, Jinghan He, et al. Optimization of Distributed Integrated Multi-energy System Considering Industrial Process Based on Energy Hub [J]. Journal of Modern Power Systems and Clean Energy, 2020, 8(5):863-873.

[8] Dan Wang, Qing'e Hu, Hongjie Jia, et al. Integrated demand response in district electricity-heating network considering double auction retail energy market based on demand-side energy stations [J]. Applied Energy, 2019, 248:656-678.