Research on Interaction Potential Evaluation Method of User-side Resources Accessing Energy Internet

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Abstract. With the deepening of the revolution in energy production and consumption, the process of large-scale development and utilization of renewable energy on the production side and the re-electrification of deep substitution of fossil energy by electric energy on the consumption side are accelerating. The increasingly important strategic position of user-side resources will play an important role in promoting re-electrification, building energy Internet, and meeting electricity demand in a clean and green way. This paper aims at the user-side resources participating in power grid interaction, analyzes the characteristics of different energy consumption demands and access to various resources of industrial, commercial, residential and public sector users, comprehensively considers the application of various resources such as distributed energy in different types of users, establishes interaction potential simulation models, quantifies the interaction potential of different resources, evaluates the utilization potential of user-side resources, and provides an effective tool for developing the utilization of user-side resources.

1. Introduction

The development environment of energy Internet has greatly promoted the development of user-side resources such as distributed generation, energy storage and electric vehicles. The user-side equipment for energy consumption, energy storage and energy supply are increasingly abundant, which proposes increasingly urgent demand for convenient and flexible access to the energy Internet, so as to connect the user-side resources to the power grid, give full play to the characteristics of various resources, and jointly promote the optimal operation of the system in a flexible and efficient way, and realize the bidirectional interaction between the source network and the load storage. Therefore, combining with user-side data, analyzing the ability of various resources to participate in optimizing user-side energy consumption behavior, peak load shifting, etc. to realize user load interaction and fine management has become a research hotspot under the background of the development of power user big data technology and the intervention of various resources on the user-side.

In Reference [1], the typical user load curve clustering algorithms for different production industries is established based on C-means clustering algorithm, and the interaction potential of typical users to participate in staggering peak power consumption is analyzed. In Reference [2], the electricity consumption behavior of residents is analyzed, the price elasticity coefficient is used to simulate the load change of residents under the incentive of electricity price, and an evaluation index system is established to evaluate the interaction potential of residents to participate in peak load shifting. In References [3] and [4], the models of distributed renewable energy and energy storage device are
established, and the dispatching simulation is carried out to analyze the ability of flexible load, distributed energy and energy storage to participate in the interaction of power grid. In References [5] and [6], the models of distributed renewable energy and the travel uncertainty of electric vehicle users are established, to analyze the effect of renewable energy and electric vehicle participating in distribution network interaction and providing auxiliary services.

However, in the above documents, different users and different access resources are studied separately only from the perspective of specific power users or specific access resource analysis methods, while ignoring the impact of different users' energy consumption requirements on access resources, resulting in deficient accuracy and comprehensiveness of the analysis results of interaction potential obtained by the analysis methods.

Based on the classification of national economic industries, this paper analyzes the different energy consumption needs of all kinds of users and the characteristics of all kinds of resources under the urban distribution network, comprehensively considers the applications of distributed energy, energy storage device, electric vehicles and other resources in different types of users, and establishes an interaction potential evaluation method system to quantify the interaction potential of different resources.

2. Research on Evaluation Method of Interaction Potential of Distributed Energy

2.1 Interaction potential analysis

2.1.1 Industrial type users
Considering the needs of reliable and stable energy supply for industrial type users, it is difficult to simply deploy large-scale distributed energy sources to industrial users and realize local consumption. Through economic policies, industrial type users can be encouraged to install distributed energy and distributed energy generation can be supported to access the power grid, so as to achieve the output and consumption of clean electricity, and also bring direct economic benefits for industrial type users to build and use distributed energy [7]. On the whole, a strong interaction potential can be provided for industrial type users by large-scale construction of distributed energy.

2.1.2 Business type users
In this example, we can see that only the load characteristics of business type users fluctuate obviously and are random, and there are obvious differences in different energy consumption seasons. Energy supply reliability is not much required for the load of business type users, which can be met by deploying distributed energy sources. In addition, the energy consumption behavior of business type users can be guided by economic policies. Therefore, there is a strong interaction potential in business type users deployed with distributed energy.

2.1.3 Resident type users
For resident type users, the access of distributed energy only alleviates the load demand during the day to a certain extent, and the interaction potential with power enterprises is low. To promote the use of distributed energy in residential type users, time will be required for technology upgrade to improve the cost performance of distributed energy.

2.1.4 Public sector type users
Public sector type users follow a fixed energy consumption rule and have strong controllability. The use of distributed energy can better meet the energy consumption needs of some users. Owing to the controllability and large-scale deployment of distributed energy, public sector type users under distributed energy access have strong interaction potential [8].
2.2 Interaction potential evaluation method

In the preceding part of the paper, the interaction potential of various types of users is qualitatively analyzed based on the random output of distributed energy. In this section, a quantitative method for the distributed energy interaction potential of a certain user will be proposed, where the optimal adjustment margin brought by the distributed energy output to the power grid is regarded as the interaction potential of distributed energy. The adjustment margin is the difference between the grid-side load value generated by the user relying only on the grid power supply and the grid-side load value generated after the user deploys distributed energy to participate in the interaction. The quantitative diagram of interaction potential is shown in Figure 1.

![Figure 1](image1.png)

Figure 1. Quantitative diagram of user interaction potential for distributed energy applications.

The whole idea of interaction potential measurement method is divided into four parts: prediction, calculation, optimization and dispatching results. The algorithm structure is shown in Figure 2.

![Figure 2](image2.png)

Figure 2. Structure Diagram of Distributed Energy Interaction Potential Evaluation Method for Specific Users

According to the above methods, this study evaluates and calculates the interaction potential of distributed energy based on the user community in a production park where distributed photovoltaic,
wind turbines and gas turbines are deployed. The simulation starts from the perspective of optimal energy consumption economy of users, and the objective function is as follows:

\[
\begin{aligned}
\min & C_{\text{fuel}} + C_{\text{om}} + C_{\text{grid}} \\
C_{\text{fuel}} &= \sum_{t=1}^{T}(\omega_{g} p_{g}(t) \Delta t) \\
C_{\text{om}} &= \sum_{j=1}^{P} \sum_{t=1}^{T}(\omega_{j,\text{om}} p_{j}(t)) \\
C_{\text{grid}} &= \sum_{t=1}^{T}(\omega_{eb}(t) p_{eb}(t) \Delta t)
\end{aligned}
\]  

(1)

Where, the first item is the fuel cost (the purchase cost of natural gas), wherein, \(\omega_{g}\) is the unit price of natural gas, \(p_{g}(t)\) is the input power of natural gas, and \(\Delta t\) is the unit time interval; the second item is equipment operation and maintenance cost, wherein, \(p_{j}(t)\) is the output power of equipment \(j\) at time \(t\), \(\omega_{j,\text{om}}\) is the unit operation and maintenance costs of equipment \(J\); the third item is the power grid transaction cost, wherein, \(\omega_{eb}(t)\) is the time-of-use electricity purchase price, and \(p_{eb}(t)\) is the electricity purchase power.

The electric power output of the gas turbine is modeled as:

\[
\begin{aligned}
p_{g,\text{chp}}(t) &= a_{g,\text{chp}} P_{g,\text{chp}}(t) \\
P_{g,\text{chp}} &\leq p_{g,\text{chp}}(t) \leq P_{g,\text{chp}}
\end{aligned}
\]  

(2)

Where, \(P_{g,\text{chp}}(t)\) is the electric energy output of gas turbine, \(P_{g,\text{chp}}\) and \(P_{g,\text{chp}}\) are the upper and lower limits of power output respectively, \(a_{g,\text{chp}}\) is the constant coefficient, taking 1.2.

The distributed photovoltaic output is modeled as:

\[
P_{e,\text{pv}}(t) = \eta_{e,\text{pv}} S_{\text{pv}} G_{\text{pv}}(t)[1 + k(w_{e}(t) - w_{\text{stc}})]
\]  

(3)

Where \(\eta_{e,\text{pv}}\) is the photovoltaic conversion efficiency, \(S_{\text{pv}}\) is the photovoltaic panel area, and \(G_{\text{pv}}(t)\) is the solar radiation intensity per unit area of photovoltaic panel. \(w_{\text{stc}}\) is the standard temperature, \(w_{e}(t)\) is the actual temperature, and \(k\) is the power temperature coefficient.

The distributed wind power output is modeled as:

\[
P_{e,\text{wt}}(t) = \begin{cases} 0, & 0 \leq v_{c} \leq v_{c} \\ E_{\text{WT}}(v_{c} - v_{c})/(v_{c} - v_{c}), & v_{c} < v_{c} \leq v_{c} \\ E_{\text{WT}}, & v_{c} < v_{c} \leq v_{c} \\ 0, & v_{c} \geq v_{c} \end{cases}
\]  

(4)

Where: \(v_{c}\) is the cut-in wind speed; \(V_{r}\) is the rated wind speed; \(V_{co}\) is the cut-out wind speed; \(V_{r}\) is the wind speed when the fan actually works; \(E_{\text{WT}}\) is the rated power of the fan.

Meanwhile, the upper and lower limits can also be set for the purchased power. The balance between supply and demand of electric energy is constrained as follows:

\[
P_{e,\text{load}}(t) = P_{e,\text{chp}}(t) + P_{e,\text{pv}}(t)
\]  

(5)
\( P_{e, \text{load}}(t) \) is the power load of users, and the equipment configuration of the park is shown in Table 1.

| Type                | Parameters and units     | Numerical value |
|---------------------|--------------------------|-----------------|
| Steam turbine engine| Maximum power output     | 1500            |
|                     | Maintenance costs (yuan/kw.h) | 0.064       |
| Distributed photovoltaic | Power generation range (kw) | 800/0        |
|                     | Maintenance costs (yuan/kw.h) | 0.006       |
| Distributed wind power | Rated power (kw)        | 1500            |
|                     | Maintenance costs (yuan/kw.h) | 0.009       |
| Electricity price   | Peak hour electricity price (8:00 ~ 12:00, 17:00 ~ 21:00) | 1.3          |
|                     | Peacetime electricity price (12:00 ~ 17:00, 21:00 ~ 24:00) | 0.85         |
|                     | Valley hour electricity price (0:00 ~ 8:00) | 0.36         |

First, based on historical climate data, the prediction of summer climatic conditions in this area is shown in Figure 3.

![Figure 3. Meteorological simulation data diagram](image)

With the goal of optimizing the economy of user energy consumption, the distributed renewable energy output, gas turbine output and power purchase from power grid are optimized to meet the electric energy needs of users, and the source-grid interactive optimization operation simulation of distributed energy users is carried out, whose results are shown in Figure 4.
Further, the curves of users’ power purchase from the power grid before and after the application and interaction of energy sources are shown in Figure 5.

The operating costs of the production park are compared as shown in Table 2.

| Category                        | Fuel costs (ten thousand yuan) | Electricity purchase expenses (ten thousand yuan) | Operation and maintenance expenses (ten thousand yuan) | Total (ten thousand yuan) |
|--------------------------------|--------------------------------|--------------------------------------------------|--------------------------------------------------------|--------------------------|
| Distributed energy not deployed| 0.00                           | 4.80                                             | 0.02                                                   | 4.82                     |
| Distributed energy deployed    | 0.95                           | 1.29                                             | 0.20                                                   | 2.44                     |

It can be seen that after the application of distributed energy and participation in interaction, it can not only reduce the order of magnitude of purchasing power from the power grid to a certain extent
and cooperate with the power grid to meet the energy needs of users, but also play a better role in smoothing the load curve.

According to this method, the interaction potential of distributed energy users can be evaluated by evaluating the effect of grid energy supply for users deployed with different distributed energy sources.

3. Conclusion
In this paper, the interaction potential of distributed energy is quantified, and a variety of resource modeling is performed according to the resource access characteristics of different users, such as industry, commerce, residents, public sector and so on, thus forming an interaction potential evaluation method with wide applicability. The evaluation method, in combination with the user load characteristics and the actual situation of resource allocation, can evaluate the interaction potential of different access resources at different times of the day, providing reliable reference for carrying out friendly interaction with source network load.

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