Day-ahead sharing model of multi-integrated energy service providers based on source-load matching degree

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Abstract. The limited regulation capacity in the integrated energy community is a key factor restricting the development of the community-based integrated (distributed) energy system. Based on this, a model for optimal sharing of day-ahead energy in multi-communities considering the matching degree of source-load curves between communities is proposed. Firstly, the relationship between energy supply and multi-energy flow is analysed concretely in a single community. A mathematical model that includes electric vehicles and multiple energy conversion equipment is built, then, an objective function minimizing the cost of energy purchase, equipment operation and maintenance, and EV battery loss is established. Secondly, the comprehensive Spearman constant and Euclidean distance matching index based on photovoltaic and load data among the communities are considered to optimize the multi-community operation efficiency with the goal of minimizing the energy interaction cost. Finally, in a 3-community simulation system simulation, results show that the multi-energy sharing mode can effectively improve the overall economy of the system and the photovoltaic consumption capacity. The introduction of matching index also improves the energy transmission efficiency, verifying the rationality of the proposed model.

1. Introduction

The construction of energy Internet is an important approach to seek sustainable resource saving and environmental-friendly development, which makes the parallel growth of thermal and cold electricity and the collaborative optimization between production and supply in the region possible [1]. The park-level integrated energy service provider is one of its typical applications.

At present, the penetration rate of distributed energy resources (DERs) in modern energy system continues to increase due to its flexibility and efficiency, environmental protection as well as multiple interactions. The model of power production and consumption on demand side has also been changed. Information interaction and energy interconnection are used to complete intelligent power consumption and two-way interaction between energy and information [2]. On the other hand, the reform of distribution and sale separation has brought more emerging entities into the market. Integrated energy service providers are changing from suppliers to service providers [3]-[5]. As community energy managers, they can maintain the balance of supply and demand according to the information released by the market, but the maximum energy utilization rate cannot be achieved only by internal coordination of the community. Therefore, how to carry out multi-user and multi-regional energy interconnection, realize reasonable sharing of internal resources, and improve economic benefits has become a hot topic.

This paper proposes an energy interaction form considering the matching degree of source and load among different communities. The integrated energy service provider is responsible for day-ahead energy scheduling, and describes the energy structure of the community. The community with
photovoltaic, EVs and micro gas turbine unit is modeled and analyzed. On the basis of meeting the matching index, the minimum daily cost can be obtained by energy scheduling, and the optimal utilization of resources can also be realized. Finally, an example is given to compare the cost of each community in different scenarios, results verify that the communities with successful matching can effectively absorb clean energy and reduce their own electricity purchase costs.

2. Multi-energy Community Structure

Fig.1 shows the structure of community energy network. The integrated energy service provider (IES) collects and forecasts the regional load, power output and weather information according to the energy management system (EMS), and plans unit output in advance, so as to realize the coordination between energy production and supply. The communities are connected by physical and information structure, service providers make use of the complementary and interactive of consumption behavior of each community to further utilize the energy and the keep balance between supply and demand.

If there is no energy interaction between communities, when a power supply shortage occurs, the service providers directly purchase electricity from the grid. In inter community interaction mode, service providers make energy interaction plans with multiple communities according to the matching information, achieve mutual assistance through energy dispatching, and obtain economic benefits. When the interactive energy still cannot meet the load demand, the service provider purchase electricity again.

![Figure 1. Community energy network structure](image)

3. Optimization Model of Multi Integrated Energy Community Scheduling Based on Matching Index

3.1. Matching Index

Considering the trend of photovoltaic and daily load curve, the greater the difference of community curves, the more efficient energy complementary and consumption. To measure the matching degree and realize the effective utilization of energy, a matching degree measurement index between communities based on Spearman correlation coefficient and Euclidean distance is proposed.

Spearman correlation coefficient is an index to evaluate the correlation between two statistical variables using monotone equation, which represents the correlation direction of two independent variables. Its intuitive definition is as follow:

\[
\rho=1- \left[ 6 \sum_{j=1}^{24} d_j^2 / J(J^2 - 1) \right] 
\]  

(1)

Where: 6 is the coefficient of Spearman correlation coefficient standard formula; \( \rho \) is the correlation coefficient between any two vectors; \( J \) is the vector dimension. In this paper, a day is divided into 24 periods, which represents 24 pairs of independent and identically distributed data; \( d \) is the difference of the rank of the elements in the two vectors in the ascending sequence.

The successful energy sharing matching communities feature in surplus of some communities and shortage of others. When an overall shortage occurs, the community will purchase electricity from the grid.
3.2. Objective Function

Comprehensive energy service providers carry out energy sharing among communities according to matching information. When the overall power shortage occurs, the transaction with the power grid can achieve the lowest day-ahead cost. The operation and maintenance cost of micro gas turbine and battery loss of EV are also considered in the objective function, is as follow:

$$
\min \sum_{m=1}^{M} \sum_{t=1}^{T} \left( v_{gas,m} + c_{gas} + c_{from-g, t} L_{t} \eta_{g} \right) + \sum_{m=1}^{M} \sum_{t=1}^{T} c_{gas} \left( p_{gas, t} + p_{gas} \right)$$  \hspace{1cm} (2)

Where: M is the total number of communities after successful matching; T is the total time periods in a day, the dispatching time is 1h; $v_{gas,m}$ is the natural gas purchased by community n in t period, the unit is m$^3$; $c_{gas}$ is the gas price, which is 3.5 RMB/m$^3$; $p_{from-g, t}$ is the electricity purchased from the grid in community n in t period; $c_{buy, t}$ is the electricity purchase price, the time-of-the-time price is adopted; $c_{gas}$ is the unit operation and maintenance cost of gas turbine, the unit is RMB/kW·h; $L_{n}$ is the low calorific value of natural gas, taking 9.7 kW·h/m$^3$; $\eta_{g}$ is the power generation efficiency of gas turbine; $N_{ev}$ is all EVs in M communities; $c_{ev}$ is the unit cost of battery loss; $p_{ev, i}^{c,t}$, $p_{ev, i}^{d,t}$ are the charging and discharging power of the i-th EV; $\eta_{c}$, $\eta_{d}$ is the charging and discharging efficiency of EVs respectively.

3.3. Constrains

Constrains includes operation constraints of micro gas turbine and waste heat boiler, EV operation constraints, power balance in communities, balance of power purchase as well as sale between communities and matching constraints.

4. Example Analysis

4.1. Simulation Parameters

The system in this paper are: (1) three communities in the same area, including 5, 4 and 6 buildings respectively. The roof of each building is equipped with photovoltaic panels, and its installed capacity ranges from 60kWp to 120kWp; (2) the number and make of EVs in each community is set as 20, BYD song Pro; (3) each community is equipped with one micro gas turbine (500kW), one waste heat boiler and one refrigerator. The actual load data of a typical summer day are selected for example analysis, as shown in Fig.2-4.

![Figure 2. Daily load power curve of community 1.](image-url)
Figure 3. Daily load power curve of community 2.

Figure 4. Daily load power curve of community 3.

Tab.1 and 2 are specific parameters of micro gas turbine and EV and electricity price.

Table 1. Micro-combustion unit and electric vehicle parameter settings.

| Objective | Parameters | Value |
|-----------|------------|-------|
| Micro gas turbine | Rated power | 500KW |
| | $\eta_t$ | 0.2 |
| | $\eta_H$ | 0.8 |
| | $\eta_{cold}$ | 1.2 |
| | $\theta$ | 0.3 |
| | $\eta_{max}$ | 0.05 |
| | $\eta_e$ | 0.88 |
| | $\eta_d$ | 0.9 |
| | $E$ | 61.9 kw/h |
| | $p_r^{max}$ | 12 kw/h |
| | $p_d^{max}$ | 12 kw/h |

Table 2. Electricity parameter

| Time | Purchase price (RMB/kW·h) | Sale price (RMB/kW·h) | Type |
|------|---------------------------|-----------------------|------|
| 10:00~14:00 | 0.83 | 0.75 | Peak |
| 17:00~23:00 | 0.17 | 0.13 | Valley |
| 23:00~0:00 | 0.49 | 0.45 | Level |

4.2. Results Analysis

For scenario one, when a shortage of power occurs, community service providers purchase electricity from the grid, but the energy utilization rate is low, and the waste of solar power cannot be solved. Energy interaction in scenario 2 is shown in Fig.5, each community needs to receive real time energy information of others. Larger scale information interaction is easy to cause information channel blocking. The interaction power of community 2 and 3 is small, and the effect of implementation is not significant.

According to the matching value, the energy transmission between community 1 and 2, 1 and 3 can be obtained. As shown in Fig.6, scenario 3 uses matching indicators to provide guidance for
community energy interaction. The energy interaction between communities 2 and 3 is implemented in 1 and 2, 1 and 3, reducing information complexity, simplifying information processing, and improving energy transmission efficiency, effectively utilizing photovoltaic.

![Figure 5. Community power interaction in scene 2.](image1)

![Figure 6. Community power interaction in scene 3](image2)

Fig. 7, 8 and 9 are balance diagrams of the three communities after matching. The analysis shows that: during the period of 0:00-6:00, the output of micro gas turbine in community 3 has surplus, which can provide part of cold and thermal energy to community 2 and 3. In 12:00-20:00, there is a shortage of power supply in community 1. Firstly, the information is released to other community service providers to purchase photovoltaic. If photovoltaic cannot meet the supply, then purchase electricity from the grid. EV can realize intelligent charging and discharging according to the optimization target, discharge in peak load period and charge at night. The fluctuation amplitude is slowed down due to transferable load, photovoltaic and micro gas turbine are reasonably scheduled.

Fig. 9 is the commercial and residential dual-use community. Considering community features, community 3 has more photovoltaic output, but the energy consumption is also relatively higher. In order to ensure the temperature of the commercial area, the cold load will also exist throughout the day and account for a high proportion. During the period from 0:00 to 6:00, due to the large cold and thermal load, the output of micro gas turbine is more, and part of the thermal and cold energy can be sold, EV starts charging under the guidance of electricity price.

![Figure 7. Daily load power curve of community 1.](image3)
5. Conclusion
This paper takes the comprehensive energy community as the object, focuses on the economy of community operation and energy consumption, carries out the form of energy sharing from the perspective of load matching, and formulates the community day ahead cost minimization strategy. The results are as follows:

1) The energy consumption cost of each community can be reduced under the guidance of matching index, and good interaction mode can realize energy coordination and mutual assistance to a certain extent.

2) Compared with the two-way flow mode, the multi-directional sharing mode is more flexible. Through energy sharing, it fully taps the community energy response potential and improve energy utilization.

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