Research on multi-source coordination evaluation model of regional energy Internet

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Abstract. Energy Internet is the direction of energy development and an important means to change energy structure and improve energy efficiency. In order to promote the application and development of energy Internet, starting with the study of the key factors affecting the level of energy efficiency in the regional energy system, a multi-source optimization energy efficiency evaluation index system of regional energy Internet is established. Through the subjective evaluation of the first level indicators, the objective evaluation of the second level indicators and the final comprehensive empowerment, the comprehensive evaluation model of regional energy Internet multi-source optimization energy efficiency is built. Finally, taking a multi-source coordinated optimization operation of a park in Zhejiang Province as an example, the scientific rationality of the evaluation indexes and methods is verified.

1. Regional Energy Internet multi-source coordination evaluation system

The energy Internet is based on the Internet technology and centered on the power system, closely coupling the power system with the natural gas network, the heating network, and the industrial, transportation, building systems, etc., to realize the "multi-source complementarity" of electricity, gas, heat, renewable energy, etc[1-2]. Therefore, the study of multi-source coordination is an important means to improve the energy efficiency of regional energy Internet[3].

1.1. Overview of multi-source optimization operation system of regional energy Internet

In order to achieve the goals of energy conservation, environmental protection and economic operation, improve the comprehensive utilization efficiency of multi energy, reduce environmental pollution and enhance energy security, it is necessary to study the multi-energy coordination and optimization system from the perspective of regional energy Internet[4-6]. Through the development of multi-source coordinated optimization system, we can effectively improve the efficiency of energy utilization, reduce environmental pollution, develop smart grid, strengthen energy security, optimize energy structure, and provide scientific and effective technical means for reducing energy consumption.

The overall framework of the regional energy Internet multi-source optimized operation system is shown in Figure 1. The overall architecture of the platform includes equipment layer, measurement layer, substation layer, network layer and master station layer[7].
1.2. Index System
The purpose of building energy Internet multi-source optimization energy efficiency index system is to comprehensively reflect the overall level of energy efficiency optimization of State Grid Corporation, intelligent power consumption area and residential users. Therefore, the selected indexes should be established on the principles of scientificity, standardization, practicability, guidance, comparability, dynamics and stability[8].

The multi-source optimization energy efficiency evaluation system achieves the subjective evaluation of the first level indicators from four aspects of energy physical efficiency, energy economic efficiency, energy ecological efficiency and energy supply reliability. Then through the comprehensive and systematic objective evaluation of the secondary indicators, including the comprehensive energy consumption, energy consumption per unit building area, per capita energy consumption, energy consumption per unit product, energy consumption per unit output value, changes in user energy consumption cost, changes in user energy use income, and exploitable potential benefits, the comprehensive evaluation system of regional energy Internet multi-source coordinated operation is shown in Table 1.
Table 1. Comprehensive evaluation system of coordinated operation of regional energy Internet

| Target layer | Criterion layer | Indicator Layer |
|--------------|----------------|-----------------|
| Energy physical efficiency | Comprehensive energy consumption | Energy consumption per unit output value |
| | Energy consumption per building area | User energy cost change |
| | Per capita energy consumption | Change of user’s energy use income |
| | Energy consumption per unit product | Potential benefits |
| Comprehensive evaluation of coordinated operation of regional energy Internet | Pollutant emission reduction per building area | Energy ecological efficiency |
| | Per capita pollutant emission reduction | Pollutant emission reduction per unit output value |
| | Save standard coal | Energy supply reliability |
| | Power supply reliability | System vulnerability |
| | System stop frequency | System energy supply adequacy |

2. Model evaluation

According to the above index system of multi-source energy efficiency evaluation, through the subjective evaluation of the first level index based on G1 group judgment and the objective evaluation of the second level index based on entropy weight method, the weight of the index in the whole energy efficiency evaluation model is determined, and based on this, the comprehensive evaluation model of multi-source optimization is designed and analyzed.

2.1. Subjective evaluation of primary index based on G1 group judgment

In order to avoid the influence of analytic hierarchy process (AHP) in subjective evaluation on the calculation results of each index weight and reduce the calculation amount when the judgment matrix is inconsistent, G1 group judgment will not need to test the consistency of the judgment matrix[9].

Suppose that the ratio \( p_{k-1}/p_k \) of the importance degree of the evaluation index \( x_{k-1} \) and \( x_k \) can be expressed by \( r_k \), that is, \( r_k = p_{k-1}/p_k \), where \( p_k \) represents the weight corresponding to the k-th evaluation index in the index set X. Meanwhile,

\[
p_m = (1 + \sum_{k=2}^{m} \prod_{i=k}^{m} r_i)^{-1} \quad (1)
\]

\[
p_{k-1} = r_k p_k (k = m, m-1, \ldots, 3, 2) \quad (2)
\]

\[
r_k = \frac{1}{L_k} \sum_{i=1}^{L_k} r_{ik} \quad (3)
\]

According to the above formula, the weight coefficient \( p_i(1) \) determined by L1 experts can be calculated. Finally, the weight coefficient of the index is:

\[
p = c_1 p_1(1) + c_2 p_2(2) + \cdots + c_c p_c(\varepsilon) \quad (4)
\]

Where, \( c_i = L_i/L \)—The proportion of the number of experts who determine a certain weight in the total number of experts.

2.2. Objective evaluation of secondary index based on entropy weight method

Entropy weight method is an objective evaluation method to judge the degree of variation of an index through its information entropy value, and then to judge its weight. Generally speaking, the smaller
the index information entropy is, the greater the degree of variation is, the more information is provided and the greater the corresponding weight is. The specific steps of entropy weight method to determine the weight are as follows:

1. Calculate the characteristic proportion of the i-th system of index j as

\[ t_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \]  

2. The entropy value of calculation index j is

\[ e_j = -k \sum_{i=1}^{n} t_{ij} \ln(t_{ij}) \]  

where, \( k = 1 / \ln n \)

3. The difference coefficient of index j is calculated as

\[ g_i = 1 - e_j \]  

\[ q_j = g_i / \sum_{i=1}^{n} g_i \]  

2.3. Analysis of comprehensive evaluation model for multi-source optimization

This project evaluates the operation effect of multi-source optimization by comprehensive fuzzy analytic hierarchy process. According to the evaluation system of multi-source optimization energy efficiency index, the first level evaluation factors set of the evaluation model is \( U = \{ U_1, U_2, U_3, U_4 \} = \{ \text{energy physical efficiency}, \text{energy economic efficiency}, \text{energy source ecological efficiency}, \text{energy supply reliability} \} \), then the secondary sub factor set of each evaluation factor in the comprehensive evaluation set is

\[ \begin{align*}
U_1 &= \{ u_{11}, u_{12}, u_{13}, u_{14} \} = \{ \text{Comprehensive energy consumption}, \text{Energy consumption per building area}, \text{Per capita energy consumption}, \text{Energy consumption per unit product} \} \\
U_2 &= \{ u_{21}, u_{22}, u_{23}, u_{24} \} = \{ \text{Energy consumption per unit output value}, \text{User energy cost change}, \text{Change of user's energy use income}, \text{Potential benefits} \} \\
U_3 &= \{ u_{31}, u_{32}, u_{33}, u_{34} \} = \{ \text{Pollutant emission reduction per unit building area}, \text{Per capita pollutant emission reduction}, \text{Pollutant emission reduction per unit output value}, \text{Save standard coal} \} \\
U_4 &= \{ u_{41}, u_{42}, u_{43}, u_{44} \} = \{ \text{Power supply reliability}, \text{System vulnerability}, \text{System stop frequency}, \text{System energy supply adequacy} \} 
\end{align*} \]

Where, \( u_{ij} \) represents the j-th sub factor of the i-th evaluation factor of the system. The weight of each evaluation factor is allocated, and the weight of each factor is selected by referring to the distribution of secondary sub factors in Figure 2 evaluation system, and the weight coefficient matrix is established.

\[
W = [w_1, w_2, w_3, w_4]
\]

According to the operation of multi-source coordination and optimization, five level evaluation level set is selected, namely \( V = \{ v_1, v_2, v_3, v_4, v_5 \} \), which respectively represent excellent, good, average, poor, very poor.

Using the expert scoring method, the index evaluation matrix is given, and the comprehensive objective evaluation decision matrix is established.
\[ R_i = \begin{bmatrix} r_{i1} & r_{i2} & \ldots & r_{i15} \\ r_{i21} & r_{i22} & \ldots & r_{i25} \\ \vdots & \vdots & \ddots & \vdots \\ r_{i41} & r_{i42} & \ldots & r_{i45} \end{bmatrix}, \quad R = \begin{bmatrix} b_{11} & b_{12} & \ldots & b_{15} \\ b_{21} & b_{22} & \ldots & b_{25} \\ \vdots & \vdots & \ddots & \vdots \\ b_{41} & b_{42} & \ldots & b_{45} \end{bmatrix} \]

The formula of Bi single level evaluation model is as follows:

\[ B_i = W_i \times R_i \]  \hspace{1cm} (9)

Find out the comprehensive evaluation results:

\[ C = W \times R \]  \hspace{1cm} (10)

The specific ability score table is shown in Table 2.

| S level | description | score |
|---------|-------------|-------|
| 5       | v_1         | excellent | 90+  |
| 4       | v_2         | good     | 80~90 |
| 3       | v_3         | average  | 70~80 |
| 2       | v_4         | poor     | 60~70 |
| 1       | v_5         | very poor| <60  |

### 3. Case analysis

Now, taking the multi-source coordinated and optimized operation of a park in Zhejiang Province as an example, after the multi-source coordinated and optimized operation for a period of time, the expert experience scoring table of each sub factor is given, as shown in Table 3.

| Sub factor name                                      | Score | Sub factor name                                      | Score |
|------------------------------------------------------|-------|------------------------------------------------------|-------|
| Comprehensive energy consumption                     | 89    | Pollutant emission reduction per unit building area  | 83    |
| Energy consumption per building area                 | 85    | Per capita pollutant emission reduction               | 93    |
| Per capita energy consumption                        | 95    | Pollutant emission reduction per unit output value   | 83    |
| Energy consumption per unit product                  | 92    | Save standard coal                                   | 95    |
| Energy consumption per unit output value             | 98    | Power supply reliability                             | 83    |
| User energy cost change                              | 78    | System vulnerability                                 | 92    |
| Change of user's energy use income                   | 84    | System stop frequency                                | 89    |
| Potential benefits                                   | 85    | System energy supply adequacy                        | 98    |

According to the evaluation scores of each factor in the expert scoring table in Table 3 and the above formula, the weight matrix and comprehensive objective evaluation decision matrix are developed and established, as shown in Table 4.
Table 4. Fuzzy scoring table for coordinated and optimized operation of energy Internet

| Evaluation factors | Evaluation level | wi | wij | Wij |
|--------------------|------------------|----|-----|-----|
|                    | v1   | v2   | v3   | v4   | v5  |
| U1                 | u11  | 0.3  | 0.6  | 0.1  | 0   | 0   | 0.356 | 0.206 |
|                    | u12  | 0.1  | 0.6  | 0.2  | 0.1 | 0   | 0.215 |
|                    | u13  | 0.6  | 0.2  | 0.1  | 0.1 | 0   | 0.224 |
|                    | u14  | 0.5  | 0.3  | 0.1  | 0.1 | 0   | 0.205 |
| U2                 | u21  | 0.8  | 0.2  | 0    | 0   | 0   | 0.273 |
|                    | u22  | 0.1  | 0.5  | 0.2  | 0.1 | 0   | 0.126 |
|                    | u23  | 0.6  | 0.2  | 0.1  | 0.1 | 0   | 0.387 |
| U3                 | u31  | 0.1  | 0.5  | 0.2  | 0.1 | 0.1 | 0.125 |
|                    | u32  | 0.5  | 0.3  | 0.2  | 0   | 0   | 0.255 |
|                    | u33  | 0.1  | 0.5  | 0.2  | 0.1 | 0.1 | 0.261 |
|                    | u34  | 0.6  | 0.2  | 0.1  | 0   | 0   | 0.359 |
| U4                 | u41  | 0.1  | 0.5  | 0.2  | 0.1 | 0.1 | 0.481 |
|                    | u42  | 0.5  | 0.3  | 0.1  | 0.1 | 0   | 0.167 |
|                    | u43  | 0.7  | 0.2  | 0.1  | 0   | 0   | 0.236 |
|                    | u44  | 0.8  | 0.1  | 0.1  | 0   | 0   | 0.116 |

From table 4 and the formula, the decision matrix of comprehensive objective evaluation and comprehensive evaluation results are calculated, and the results are as follows:

\[
R = \begin{bmatrix}
B_1 \\
B_2 \\
B_3 \\
B_4
\end{bmatrix} = \begin{bmatrix}
0.365 & 0.449 & 0.122 & 0.064 & 0 \\
0.269 & 0.414 & 0.209 & 0.086 & 0.022 \\
0.381 & 0.342 & 0.164 & 0.075 & 0.038 \\
0.389 & 0.349 & 0.148 & 0.065 & 0.049
\end{bmatrix}
\]

\[
C = W \times R = \begin{bmatrix} 
0.356 & 0.382 & 0.16 & 0.072 & 0.03
\end{bmatrix}
\]

According to the comprehensive evaluation results and table 2 ability scoring table, the proportion of excellent (v1) and good (v2) in the evaluation results is 0.738, while the proportion of poor (v4) and very poor (v5) is only 0.102. The evaluation results are obviously biased to the left data. Therefore, the service ability of the multi-source optimized operation system of the energy Internet has reached above a good level.

4. Conclusion
This paper focuses on the comprehensive evaluation technology of multi-source coordinated and optimized operation of energy Internet. Firstly, the multi-source optimization operation system of energy Internet is summarized, and then the evaluation index system of multi-source optimization energy efficiency of regional energy Internet is established by studying the key factors affecting the energy efficiency level in the regional energy system. Then, a case study is carried out based on the G1 group judgment and entropy weight method, which proves the rationality of the evaluation indexes and methods and has a strong practical value.

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References

[1] Zeng Ming, Yang Yongqi, Liu Dunnan, Zeng Bo, Ou Yang Shaojie, Lin Haiying, Han Xu. Coordinated and optimized operation mode and key technology of "source network storage" of energy Internet [J]. Grid technology, 2016,40 (01): 114-124.

[2] Liu Zhenya. Smart grid supports the third industrial revolution[J]. State Grid, 2014(1): 30-35.

[3] Pu Tianjiao, Li Ye, Chen Naishi, Wang Xiaohui, Liu Guangyi. MAS based multi-source coordinated optimal dispatching of active distribution network [J]. Journal of electrical technology, 2015,30 (23): 67-75.

[4] Hong Xiao. Study on multi energy coordination evaluation model of regional energy Internet [D]. North China Electric Power University (Beijing), 2018.

[5] Song Jie, Luan Kaining, Zhang Weiguo, Meng Xianhai, Cui Gaoying, Duan Haowei. Software design of energy Internet multi-source optimization energy efficiency comprehensive evaluation [J]. Electrical appliances and energy efficiency management technology, 2019 (19): 54-60.

[6] Dai Liyuan, Xu Taishan, Wang Maxiang, Wang Haohao, Duanhui. Overview of coordinated real-time control technology for multi-source power grid [J]. Power science and engineering, 2017,33 (05): 16-23.

[7] Dai Xianzhong, Han Xinyang, Dong Yihua, Luo Haihua, Li Yu. Research on multi-source and multi-level coordinated optimization method of energy Internet [J]. Power engineering technology, 2019,38 (02): 1-9.

[8] Ma Junhua, Lu Yiming, Yuan Wenguang, Wang Lei, Huang Wenrui, Yan Xing. Research on energy internet evaluation system [J]. China power, 2018,51 (08): 38-42.

[9] Luo Yaoming, Mao Lifan, Yao Jianguang, et al. Comprehensive energy efficiency evaluation model for power users [J]. Journal of power system and automation, 2011, 23 (5): 104-109.