Comprehensive Energy Efficiency Assessment of Energy Internet Based on Entropy Weight Method

Lei Guo1, Linyu Wang1, Yongli Wang2*, Yuanyuan Zhang2, Huanran Dong2, Danyang Zhang2

1 State Grid (Suzhou) Urban Energy Research Institute, State Grid Energy Research Institute, Suzhou, Jiangsu, 215000, China
2 North China Electric Power University, Beijing, 102200, China

*Corresponding author’s e-mail: wyl_2001_ren@126.com

Abstract. In recent years, with the depletion of fossil energy and the aggravation of environmental crisis, the contradiction between the development of human society and traditional energy institutions has become increasingly prominent. The worldwide demand for energy supply and structural transformation has increased, and the energy industry has spawned many development directions. This paper analyses the boundaries of comprehensive energy efficiency evaluation oriented to energy internet, constructs the index system of comprehensive energy efficiency evaluation, expounds the calculation methods of each index, gives the evaluation benchmarks, and establishes a comprehensive energy efficiency evaluation method with energy analysis as the core. Finally, an example is given to analyze the evaluation method based on the actual data to realize the effective evaluation of comprehensive energy efficiency, and to verify the integrity of the index system and the effectiveness of the evaluation method.

1. Comprehensive Energy Efficiency Evaluation Index System

1.1. Assessment of borders

Integrated energy system is the physical carrier of energy Internet [1]. Document [2] proposes that integrated energy system includes all kinds of energy, such as electricity and heat. It covers all levels of energy system of region, community and family. Literature [3] points out that the research boundary of integrated energy system is medium voltage network, medium pressure natural gas network and thermal distribution network, and as an important carrier of energy conversion technology, hermoelectric unit and heat pumps are indispensable. As shown in Figure 1, the boundary diagram of integrated energy efficiency assessment for energy Internet should cover distributed power generation, distribution network, thermal network, energy storage system and load.
1.2. Index System
In order to ensure the rationality and applicability of comprehensive energy efficiency assessment, the principles and directions of evaluation indicators are determined. The comprehensive energy efficiency evaluation index system should be able to fully and truly reflect the energy efficiency level of the integrated energy system. The current national and industrial standards and relevant design manuals should be taken as evaluation criteria, and comprehensive consideration should be taken to ensure the balance and integrity of the index system. The following principles should be followed in constructing the index system [4]:

1) Indicators should be few, not many, simple and not complex.
2) Indicators should be independent.
3) Indicators should be representative.

Distributed renewable energy is the main primary energy of energy Internet [4]. In order to embody the role of distributed energy, the scheme layer of comprehensive energy efficiency evaluation index system should include the proportion of distributed power generation and the capacity of distributed power generation. Because of the unbalanced distribution of cold and heat media flow in air conditioning system, excessive flow in some loops and insufficient flow in some loops, the index of hydraulic balance in the scheme layer of thermal network includes the index of hydraulic balance in the pipeline network. The water supply rate and heat loss rate of the system directly reflect the degree of heat and cold loss, and the power consumption and heat transfer ratio of the system reflects the reasonable allocation level of the heat network transmission and distribution system. There are two main types of energy storage system: electric energy storage system and heat storage system. The energy efficiency of electric energy storage system and heat storage system are the indicators of the scheme layer. Load mainly refers to all kinds of end loads that can realize electrothermal conversion. The corresponding scheme layer indexes are CCHP - secondary energy comprehensive utilization efficiency, CCHP annual average energy comprehensive utilization efficiency, average boiler thermal efficiency and chilled water (heat pump) unit efficiency. In addition to the above indicators related to various cold and heat sources, the end energy efficiency ratio of air conditioning system can reflect the energy efficiency level of the end air supply system, and the PPD index represents the comfort level of the room, which can indirectly reflect the energy efficiency of the system.

2. Model evaluation

2.1. Index System Construction
According to the principle of entropy weight method, the evaluation index layer is divided into three layers: target layer, criterion layer and scheme layer. The specific index system is shown in the following Figure:
2.2. Entropy Weight Method Model Construction

Entropy method is a method that uses the information to determine the weight of the index and make a comprehensive evaluation. In comprehensive evaluation, the value of entropy can reflect the degree of variation of an index and the size of its information quantity, the larger the amount of information, the smaller the value of entropy; and vice versa. The implementation steps of the entropy method are as follows:

The same trend treatment of one index.

The two indicators are dimensionless and normalized.

It is assumed that \( x_{ij} > 0 \) if this assumption is not satisfied, appropriate methods (such as efficacy coefficient method) can be used for data transformation.

Third, calculate the entropy of each index:
\[ e_j = -k \sum_{i=1}^{n} p_{ij} \ln(p_{ij}) \]

In the model, \( k = \frac{1}{\ln n} \), \( 0 \leq e_j \leq 1 \).

Fourthly, the coefficient of difference of each index is calculated.

\[ g_j = 1 - e_j \]

Fifth, calculate the weight of each index:

\[ w_j = \frac{g_j}{\sum_{j=1}^{m} g_j} \]

Sixth, calculate the comprehensive evaluation value:

\[ v_j = \sum_{j=1}^{m} w_j p_{ij} \]

2.3 Evaluation Model

The comprehensive evaluation value is obtained from the evaluation value and weight coefficient of each evaluation index, and the evaluation model is established.

\[ Y = WX \]

In the formula, \( Y \) is the comprehensive evaluation value, \( W \) is the weight vector of the evaluation index, and \( X \) is the evaluation value vector of the evaluation index.

Assessment indicators are divided into three categories: positive indicators, inverse indicators, moderate indicators, the higher the level of energy efficiency. The above different types of indicators need to be dimensionless when evaluating.

3. Case study

Selecting some evaluation indexes for comprehensive energy efficiency evaluation. The actual value of the relevant indicators and the evaluation benchmark value are shown in Table 1.

| Index                                      | Actual Value of Area A(%) | Actual Value of Area B(%) | Actual Value of Area C(%) | Evaluation benchmarks(%) |
|--------------------------------------------|---------------------------|---------------------------|---------------------------|--------------------------|
| Distributed Power Generation Proportion     | 28.5                      | 26.3                      | 27.8                      | 30                       |
| Comprehensive Lossless Line Loss Rate in Low Voltage Station Area | 3.56                      | 3.58                      | 3.55                      | 10                       |
| Heat Loss Rate of Pipeline Network         | 4.88                      | 5.22                      | 5.03                      | 10                       |
| Efficiency of heat storage system          | 84.7                      | 85.2                      | 84.9                      | 90                       |
| CCHP Annual Average Energy Comprehensive Utilization Efficiency | 54.6                      | 83.2                      | 70.9                      | 70                       |

The following table can be calculated by using the method of entropy value, and the entropy values of each index can be obtained.
Table 2. Entropy Value of Indicators

| Index                                                        | Entropy |
|--------------------------------------------------------------|---------|
| Distributed Power Generation Proportion                      | 0.0804  |
| Comprehensive Lossless Line Loss Rate in Low Voltage Station Area | 0.0104  |
| Heat Loss Rate of Pipeline Network                           | 0.0146  |
| Efficiency of heat storage system                            | 0.2471  |
| CCHP Annual Average Energy Comprehensive Utilization Efficiency | 0.1971  |

The index transformation method is used to transform the index values of Table 4 into dimensionless ones. The number of transformed values is multiplied by 100 as the evaluation result. The evaluation result is shown in Table 3.

Table 3. Comprehensive Energy Efficiency Assessment Results

| Index                                                        | Area A evaluation score results | Area B evaluation score results | Area C evaluation score results |
|--------------------------------------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Distributed Power Generation Proportion                      | 95.0                            | 87.6                            | 89.6                            |
| Comprehensive Lossless Line Loss Rate in Low Voltage Station Area | 64.4                            | 64.2                            | 64.3                            |
| Heat Loss Rate of Pipeline Network                           | 51.2                            | 47.8                            | 49.6                            |
| Efficiency of heat storage system                            | 94.1                            | 94.6                            | 94.4                            |
| CCHP Annual Average Energy Comprehensive Utilization Efficiency | 78                              | 89                              | 81                              |
| Comprehensive Energy Efficiency Score                        | 66.6                            | 72.4                            | 68.2                            |

According to the evaluation results, the comprehensive energy efficiency score of energy system operation in each science and technology park is obtained. The comprehensive energy efficiency of B zone is slightly higher than that of A zone. The heat loss rate of pipeline network in B zone is slightly larger than that in A zone, while the proportion of distributed power generation in B zone is small, but the annual average comprehensive energy utilization efficiency of CCHP in B zone is larger than that in A zone. It can be seen that the reason why the comprehensive energy efficiency of Area B is higher than that of Area A is that the annual average energy utilization efficiency of CCHP is higher. To improve the energy efficiency of the whole system, for the energy system of Park A, further data analysis and operation optimization of CCHP energy system can be carried out firstly; for the energy system of Park B, analysis and adjustment should be carried out for the thermal pipe network of the system to reduce the heat loss rate of the pipe network, so as to further improve the comprehensive energy efficiency of the energy system.

4. Conclusion

Based on the characteristics of energy production, transmission and consumption of energy internet, this paper establishes a comprehensive energy efficiency evaluation system covering key elements of energy internet, such as distribution network, thermal network and load. A comprehensive energy system energy efficiency evaluation method based on entropy method is designed, which can quantitatively evaluate the comprehensive energy efficiency of energy system. It can be used to analyze and calculate the comprehensive energy efficiency of energy Internet projects, and the results of comprehensive energy efficiency evaluation have certain engineering reference value.

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