Performance study of UEI based on the relatively matching of energy supply-demand information entropy

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Abstract. This paper studies the performance of UEI (Ubiquitous Energy Internet) by means of its energy supply-demand matching degree. First of all, the energy supply-demand matching degree of UEI is defined, and then the information entropy of energy supply-demand matching degree is defined either by use of Shannon’s information entropy theory. On the basis of these two definitions, the energy matching degree information entropy of the distributed Energy Internet is defined. By the study of information entropy characteristic and energy supply-demand matching degree, the evaluation model of energy supply-demand matching degree of UEI is provided, and the performance of UEI is evaluated. Finally, the effectiveness of this evaluation model in solving the supply-demand performance evaluation problem of UEI is proved by an example.

1. Situation of performance evaluation of energy internet
American scholar Jeremy Rifkin [1] put forward the concept of EI (Energy Internet). The EI based industrial revolution will become the key technical means to promote the transformation and development of China’s energy industry [2]. At present, researches study both supply-demand sides of EI systems [2-4], for example Li H. etc. and Zeng M. etc. Study both supply-demand sides of EI by synergistic optimization [3,4], meanwhile the research of performance evaluation of EI is rare. In fact, as the EI developed from concept phase to applied phase, EI development level evaluation comes to be an important direction of the energy research, which calls for building an evaluation index system of EI. Nowadays, an evaluation system of EI has not yet built in the domestic, and the related foreign criterions that united into standards for different practical application case are not built. At present, the performance evaluation of EI are studied in several aspects, which is shown as following.

The studies on energy efficiency of EI are processed in terms of match of energy supply-demand, supply and dispatch of energy. K. Wang considers that EI system includes a mass of consumers and equipment. So it is important to guarantee stability and safety of the whole system [5]. Sun evaluates switched stability of EI accurately, thinking that it is an important factor for EI performance to transmit EI steadily. Meanwhile he used theoretical analysis and simulation to prove the reliability of energy function which evaluates the stability of energy network [6]. Wang studied system-level stability of energy network and discussed how to maintain a stable and healthy energy network environment. He established an energy network system-level stability evaluation model based on
critical energy function [7]. Orgerie A. C. and other researchers analyzed evaluation and simulation methods of energy resources consumption from the perspective of energy-saving. They put forward some technologies to improve resource allocation, scheduling, pointing out that there are many research directions for energy-saving, but still faced with many unsolved problems, such as the best balanced way between energy and performance [8].

The concept of UEI is put forward in advance by Xinao Group in China. As a new type “Internet+” smart energy, UEI builds a loop body of energy production, storage, application, regeneration through coupling information technology and energy, and finally generates an integral ubiquitous energy network which connects to information net.

The performance evaluation of the UEI is inspired from the performance evaluation of the EI, and entropy is used in researches [9,10] to evaluate the overall performance of the systems. Information entropy is used in this research for UEI connects energy to information.

This article tries to evaluate UEI performance through match of energy supply-demand based on information entropy principle.

2. Definition of energy supply-demand match of UEI

For UEI composed of several distributed energy stations, its energy supplies and user’s demands do not always match completely. The randomness comes from user’s energy using, partial energy supplies such as solar and wind and fluctuation of gas and power energy supplies.

2.1. Definition of energy supply-demand match of UEI

The energy for UEI is divided into four forms: electricity, gas, heat and cold. If energy demands value of a distributed energy station “i” belongs to energy users at time “t”, the actual demand of energy is:

\[ E_c(i,t) = (E_{E_c}(i,t) \ E_{G_c}(i,t) \ E_{H_c}(i,t) \ E_{C_c}(i,t)) \]  

(1)

The actual energy supply value of the distributed energy station “i” belongs to energy users at time “t” is:

\[ E_s(i,t) = (E_{E_s}(i,t) \ E_{G_s}(i,t) \ E_{H_s}(i,t) \ E_{C_s}(i,t)) \]  

(2)

When the energy supply is insufficient, the actual value of energy supply can be measured, but the demand value of energy users cannot, so the only way is using the predicted value of energy demand to substitute the actual energy demand. When the energy supply is sufficient, the actual value of energy supply is the demand of energy users. Define \( E_{\text{max}}(i,t) \) as the maximum energy supply value of distributed energy station i at time t, \( E_s(i,t) \) as the predicted user’s energy demand value of the distributed energy station i at time t, and then the actual value of energy demand can be defined as:

\[ E_s(i,t) = \begin{cases} E_s(i,t) & \text{if } E_s(i,t) = E_{\text{max}}(i,t) \\ E_s(i,t) & \text{if } E_s(i,t) < E_{\text{max}}(i,t) \end{cases} \]  

(3)

The difference between the actual energy demand value \( E_s(i,t) \) (1) and the actual energy supply value \( E_s(i,t) \) (2) is defined as the matching value of energy supply, it is:

\[ T(i,t) = E_s(i,t) - E_s(i,t) = (E_{E_s}(i,t)-E_{E_s}(i,t) \ E_{G_s}(i,t)-E_{G_s}(i,t) \ E_{H_s}(i,t)-E_{H_s}(i,t) \ E_{C_s}(i,t)-E_{C_s}(i,t)) \]  

(4)

According to the definition of actual energy demand value in the formula (3), the match value of energy supply-demand of the jth energy belonging to a distributed energy station “i” at time “t” is defined as:
\[
E_{\mu}(i,t) - E_{\mu}(i,t) = \begin{cases} 
E_{jc}(i,t) - E_{\mu}(i,t) & \text{if } E_{jc}(i,t) > E_{\mu}(i,t) \\
0 & \text{if } E_{jc}(i,t) = E_{\mu}(i,t) 
\end{cases} 
\]

\( j \in \{E,G,H,C\} \) (5)

2.2. Matching degree of energy supply-demand of UEI

According to the definition of the matching value of energy supply-demand of UEI, the matching degree of the jth energy supply-demand belonging to a distributed energy station “i” at time “t” of UEI is defined as:

\[
R_{j}(i,t) = \frac{E_{jc}(i,t) - E_{\mu}(i,t)}{E_{jc}(i,t)} \quad j \in \{E,G,H,C\} 
\]

By this definition, the matching degree of energy supply-demand belonging to a distributed energy station “i” at time “t” of UEI is defined as:

\[
I(i,t) = (R_{E}(i,t) \quad R_{G}(i,t) \quad R_{H}(i,t) \quad R_{C}(i,t)) 
\]

2.3. The probability distribution of the matching degree of energy supply-demand of UEI

Anytime, for UEI, there is match information of the energy supply-demand side, and the information is recorded in UEI. By the analysis of energy demand historical data of energy users, the predicted energy demand value is obtained. According to the actual users demand value of each distributing energy station in historical record, and the actual energy supply value of distributed station and the maximum energy supply value of distributed station, the matching degree of energy supply-demand can be calculated by the form of electricity, gas, heat and cold. And the matching degree of energy supply-demand \( T(i,t) \) of different energies in each period is calculated, and then the matching degree of supply-demand of UEI energy \( I(i,t) \) is calculated.

Computing energy matching degree \( I(i,t) \) of a distributed energy station “i” at time “t” through the matching degree of energy supply-demand in each period, and then analyze data, obtain the distribution probability \( p_{j} \quad j \in \{E,G,H,C\} \), which is a relative matching degree of energy supply-demand of a distributed energy station “i”. Based on the distribution data of the energy supply-demand matching degree, we can obtain the parameters of data distribution of matching degree of energy supply-demand by data fit.

3. Performance evaluation model of UEI based on the matching degree of energy supply-demand information entropy

As a complex energy information system coupling information and energy, the information of UEI is an orderly measurement of energy. The production, transmission, storage and consumption of different kinds of energy can be reflected through the change of corresponding energy information, at the same time influence the order degree of the system. It will have an important influence on the order degree of the whole energy information system and in turn on the feedback and adjustment energy information towards energy system.

3.1. Definition of Shannon’s information entropy

Shannon proposed that information is used to eliminate uncertainty and solved the problem of measurement of probability information in his famous “mathematical theory of communication”. On this basis, Shannon put forward the measure formula of information entropy:
\[ H = -\sum_{i} p_{i} \ln p_{i} \] \hspace{1cm} (8)

3.2. Definition of matching degree information entropy of energy-supply-demand of UEI

According to the definition of UEI, it is composed of several regional distributed energy stations, and each regional distributed energy station is composed of several distributed stations. The classic definition of information entropy (8), combined with the structure definition of UEI and the definition of energy-supply-demand matching degree (6,7), the energy supply-demand matching degree information entropy of UEI in the period of time “\(m\)" is defined as:

\[
T_{m} = -\sum_{i}(\sum_{j}(p_{ij} \ln p_{ij}) + \sum_{j}(p_{ij} \ln p_{ij}) + \sum_{j}(p_{ij} \ln p_{ij}) + \sum_{j}(p_{ij} \ln p_{ij}))
\]

\[
= -\sum_{i} \sum_{j}(p_{ij} \ln p_{ij}) \quad j \in \{E,G,H,C\}
\] \hspace{1cm} (9)

Here, \(p_{ij}\) \(j \in \{E,G,H,C\}\) is distribution probability of matching degree of certain energy supply-demand in the period of “\(m\)" of four types of energy supply of the distributed energy station “\(i\)" which constitute the UEI.

3.3. Performance evaluation model and calculation procedure of UEI energy match information entropy of energy-supply-demand

The information match entropy of energy supply-demand of UEI can generally evaluate the supply-demand match performance of UEI in a period. The independent variable of formula (9) is defined as the information entropy which is correspondingly distributed of energy supply-demand matching degree of UEI. So the bigger the information entropy of energy supply-demand matching degree is, the worse the energy supply-demand match performance of the whole UEI will be. However, the smaller the information entropy of energy supply-demand matching degree, the more optimized the energy supply-demand match performance of the whole UEI.

If there is “\(m\)" period to evaluate performance model for certain distributed station “\(i\)" of UEI, the information entropy evaluation model of energy supply-demand matching degree of UEI is defined as:

\[
\min T_{m} \quad m \in [1,2,...,m]
\] \hspace{1cm} (10)

The specific calculation steps of the information entropy evaluation model of energy supply-demand matching degree are:

- Collect the match value of energy supply-demand according to formula (4), and calculate the matching degree value of energy supply-demand.
- Complete the histogram analysis of matching degree data distribution of energy supply-demand.
- Fit the probability distribution for the obtained histogram, and obtain the statistics value of the data fitting (if it is a normal distribution, the sample mean and variance can be obtained).
- Put the statistics of probability distribution of each energy supply-demand matching degree as raw data to substitute the definition of information entropy of energy supply-demand matching degree (9), and calculate the evaluation value of distributed energy station “\(i\)" corresponding to the information entropy of energy supply-demand matching degree in a certain period “\(m\)".
- If different schemes are adopted at different time for UEI, the evaluation principle of performance of energy supply-demand match of different scheme is that minimal evaluation value.

4. Example of the performance evaluation of UEI based on the information entropy of energy supply-demand match

This example refers to the energy accumulation load of block 1 of UEI in Sino-German Ecopark of
Qingdao China. Combining with the technical improvements of Sino-German Ecopark from 2015 to 2016, four kinds of energy distribution (fitting data conforms to normal distribution) of electricity, gas, heat and cold was estimated in November 2015 and November 2016 (The construction area is \(64.39 \times 104\) m\(^2\) in the first block, and the main living body is resident, the accumulative electricity load designed as 36598 MWH every year, and the accumulative heat load designed as 23421 MWH every year, the accumulative cold load designed as 3677 MWH every year, the residents gas is \(413 \times 104\) m\(^3\) per year as the calculating base, because the calculation is executed in November of Qingdao, so only the electricity, gas and heat load is calculated and the cold load is not).

The estimation values (These data came from data accumulation and analysis in Sino-German Ecopark of Qingdao from 2015 to 2016.) of the matching degree distribution parameter of the energy supply-demand of UEI are shown in tables 1 and 2.

### Table 1. Data of block 1 in November 2015 (Unit: \(\times 10^4\)MWH).

| Energy category | electricity | gas | heat | cold |
|-----------------|-------------|-----|------|------|
| Distribution average | 1.311 | 1.453 | 109.988 | 0 |
| Standard deviation | 1.639 | 0.872 | 56.273 | 0 |

### Table 2. Data of block 1 in November 2016 (Unit: \(\times 10^4\)MWH).

| Energy category | electricity | gas | heat | cold |
|-----------------|-------------|-----|------|------|
| Distribution average | 0.984 | 1.046 | 79.294 | 0 |
| Standard deviation | 0.656 | 0.581 | 46.042 | 0 |

### Table 3. Information entropy of energy supply-demand matching degree of block 1 in November 2015 and 2016.

| Energy entropy | November 2015 | November 2016 |
|----------------|---------------|---------------|
| Electricity    | 5.000         | 1.320         |
| Gas            | 5.504         | 5.185         |
| Heat           | 7.480         | 7.119         |
| Cold           | 0             | 0             |
| Sum            | 17.985        | 13.664        |

Based on the data of tables 1 and 2, referring to the information entropy evaluation model of energy supply-demand matching degree of UEI in formula (9) and (10), the information entropy data of energy supply-demand matching degree of UEI is calculated, it is shown in table 3.

A clear conclusion can conduct from table 3: the information entropy values of energy supply-demand matching degree in November 2015 are higher than information entropy value of energy supply-demand matching degree in November 2016, according to the evaluation model of information entropy of energy supply-demand match in formula (10), it is obviously that block 1 of UEI has a greater degree of energy match in November 2016.

To prolong the conclusion, the present information entropy value of energy supply-demand matching degree is smaller than the value of November 2016. That is to say, the energy supply-demand matching degree is higher than the value of November 2016. It is clear that the energy supply-demand matching degree will be higher and higher if Sino-German Ecopark operates well.

### 5. Conclusion

This paper establishes an evaluation model of UEI based on information entropy of energy supply-demand matching degree. This evaluation model of UEI of information entropy of energy supply-demand matching degree combines the energy match values with the matching degree of UEI, which can have a comprehensive performance evaluation of energy supply-demand match of UEI that
combined the demand for electricity, gas, heat and cold energy. And this evaluating result can pick out the best scheme of UEI. At the end of this paper, an example is given to illustrate the effectiveness of the information entropy of the energy supply-demand matching degree of UEI built in this paper.

The evaluation model is useful in EI’s operation evaluation. But the selection of the initial data is hard in today’s EI (such as UEI). In the operation of EI, data is the core secret between some departments, so this kind of EI is not real EI which combines information with energy clearly. To select data easily, a detailed information system must be set up, and the information analysis must be a common used function in this system. And the data that is need in the information entropy calculation of the energy supply-demand matching degree of EI must be designed and collected clearly in this system. With this database, the information entropy of energy supply-demand matching degree will indicate the current energy supply-demand matching degree in the EI, and which will tell us the status of the EI and alarm us to modify the system in time.

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