Research on the method of multi-station integrated data center module location based on fuzzy analytic hierarchy process

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Abstract. Internet data center module (IDC) is an important part of the multi-station integrated substation, and its site selection will be an important basis for the site selection and construction of the multi-station integrated substation. In order to be useful to the practical engineering, the fuzzy analytic hierarchy method is proposed to analyze the location of IDC. There are six factors influenced in total which land price, policy environment, the annual average temperature, industrial electricity, network environment and peer development. FAHP has been adopted for calculating and sequencing priority membership value for every single factor thoroughly. According to the factor, different priority location has been chosen. Finally, based on the fuzzy analytic hierarchy process, the paper proves the effectiveness and convenience of the site selection method, through analysis of the three regions.

1. The introduction

The 14th Five-Year Plan further emphasizes the construction of Internet of Things application infrastructure and service platform. At the same time, 5G, edge computing, cloud service and other business development accelerates, and the demand for data center keeps increasing [1]. In 2019, the number of data centers in China was about 74,000, of which 36.1 percent were extremely large or large data centers that had been built or planned to be under construction. However, there is still a big gap between the data and that of the United States, which accounts for 40% of the global total, and China's large data centers still have a large space for development.

In this context, State Grid also proposed the multi-station integrated substation construction model, which includes data centers, energy storage, substations and so on. [2-4]. Under the new construction mode, how to determine the scale configuration and site selection of data center modules will become the key research direction of the future power grid [5].

Literature [6] proposed the distributed cloud computing architecture based on substation, and analyzed the site selection by constructing the connection formula of substation and integrated energy nodes. The assumed data center business is mainly oriented to the internal business of power grid. Literature [7] proposed to take cost as the core goal and optimize site selection strategy to reduce the investment cost of network operation and construction. Literature [8] puts forward a calculation method that takes construction cost, land cost and network connection cost as the core to determine the site selection of data center.
The above literatures provide reference for the location of data center module of multi-station fusion substation, but the location method is complex and not convenient for practical engineering. Considering the key factors of site selection and engineering convenience, this paper proposes the method of fuzzy analytic hierarchy process (FAHP) for site selection of multi-station integrated substation.

2. Data Center Location Method Based on Fuzzy Analytic Hierarchy Process

The basic idea of fuzzy analytic hierarchy process (FAHP) is to decompose the problem itself according to the nature and overall goal of multi-objective evaluation, and to form a bottom-up ladder hierarchy structure [9-11]. The overall steps of fuzzy analytic hierarchy process for multi-station integrated substation are shown in Fig. 1.

![Flow chart of fuzzy hierarchy analysis site selection method for data center module of multi-station integrated substation](image)

Figure 1. Flow chart of fuzzy hierarchy analysis site selection method for data center module of multi-station integrated substation.

Step (1): The influencing factors of site selection of multi-station integrated data center module were analyzed. Data center location when the general consideration of geological disasters, talents, traffic, meteorology, land, electricity, network resources, the policy environment, industry development, and so on and so forth, for with the substation & data center, due to the transformer substation construction has considered the geological disaster prevention and control and the transportation is convenient, and the grid operations staff may concurrently hold the position of data center operations staff after training, so the first three factors can be considered as substation siting together have considered, don't need special consideration as a data center location. Therefore, the station selection factors of multi-station integrated substation data center module mainly include...
weather, land price, electricity price, network resources, policy environment, and peer development situation.

Step (2) : in view of the influence factors were analyzed, and establish a hierarchical relationships between the impact factors, as shown in the figure below, from top to bottom is divided into four layers, and the comprehensive indexes including the costs and benefits, the cost is divided into construction costs and operating costs, construction costs and the main restricted to land and the policy environment, the data center city with a policy support for examination and approval of project prophase the time it takes the human cost of relative advantage; Operating costs are mainly limited by weather and electricity prices. Areas with low meteorological temperature are conducive to natural heat dissipation and reduce electricity consumption. Revenue is limited by network resources and peer development. Generally, regions with rich network resources and better peer development indicate strong demand in data center leasing market, high rental rate and relatively good revenue.

![Hierarchy diagram](image)

Step (3) : From bottom to top, for each single impact factor, fuzzy method was adopted to obtain the priority membership value of different schemes and order them. The specific steps are as follows:

1) Calculate the priority relation matrix of the impact factors

Including qualitative and quantitative schemes:

① For policy environment, network resources, peer development and other situations where specific quantitative indicators cannot be obtained, the priority relation matrix can be obtained by qualitative method:

\[
\begin{bmatrix}
X_{11} & X_{12} & \cdots & X_{1n} \\
X_{21} & X_{22} & \cdots & X_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
X_{n1} & X_{n2} & \cdots & X_{nn}
\end{bmatrix}
\]

(where n is the number of options to be selected)

The elements in the above matrix were obtained by using the expert scoring method of nine-scale from 0.1 to 0.9, as shown in Table 1 below:

| Scale values | Scale definitions |
|--------------|-------------------|
| X_{ij}=0.1   | Scheme j is big much better than scheme i |
| X_{ij}=0.2   | Scheme j is much better than scheme i |
| X_{ij}=0.3   | Scheme j is obviously better than scheme i |
| X_{ij}=0.4   | Scheme j is better than scheme i |
| X_{ij}=0.5   | Scheme j is the same as scheme i |
| X_{ij}=0.6   | Scheme i is better than scheme j |
| X_{ij}=0.7   | Scheme i is obviously better than scheme j |
| X_{ij}=0.8   | Scheme i is much better than scheme j |

Table 1. Expert scoring method table.
Scale values | Scale definitions
---|---
$X_{i} = 0.9$ | Scheme $i$ is big much better than scheme $j$

② For the impact factors of specific data targets of different schemes, such as land price, meteorology and electricity price, etc., the priority relation matrix can be obtained by using quantitative method, which is divided into two steps: normalization of index value and calculation of fuzzy priority membership value:

**Normalized formula:**

$$X_{i} = \frac{\max(X_{1},...,X_{n}) - X_{i}}{\max(X_{1},...,X_{n}) - \min(X_{1},...,X_{n})}$$  \hspace{1cm} (1)

$i = 1, 2,..., n$, where $n$ is the total number of schemes to be selected.

**Calculation formula of fuzzy priority membership value:**

$$X_{ij} = \frac{X_{i} - X_{j}}{2} + 0.5$$  \hspace{1cm} (2)

According to the above formula, the following priority relation matrix can be obtained:

$$\begin{bmatrix}
X_{11} & X_{12} & \cdots & X_{1n} \\
X_{21} & X_{22} & \cdots & X_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
X_{n1} & X_{n2} & \cdots & X_{nn}
\end{bmatrix}$$

(where $n$ is the number of options to be selected)

2）On the basis of obtaining the priority relation matrix, the fuzzy consistent matrix is obtained:

$$\begin{bmatrix}
X_{11} & X_{12} & \cdots & X_{1n} \\
X_{21} & X_{22} & \cdots & X_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
X_{n1} & X_{n2} & \cdots & X_{nn}
\end{bmatrix}$$

(where $n$ is the number of options to be selected)

In the above matrix

$$Y_{ij} = \frac{\sum_{k=1}^{n} X_{jk} - \sum_{k=1}^{n} X_{ik}}{2n} + 0.5$$  \hspace{1cm} (3)

$i, j = 1, 2,..., n$, where $n$ is the number of schemes to be selected.

3）On the basis of obtaining the fuzzy consistent matrix, the priority membership value of different schemes under a certain impact factor is calculated according to the following formula:

$$S_{j} = \frac{(\prod_{j=1}^{n} Y_{ij})^\frac{1}{n}}{\sum_{k=1}^{n} (\prod_{j=1}^{n} Y_{kj})^\frac{1}{n}}$$  \hspace{1cm} (4)

$i = 1, 2,..., n$, where $Y_{ij}$ is the value of the i-th row and JTH column in the fuzzy uniform matrix.

Step (4) : According to Step (3), the priority membership value of different schemes corresponding to each impact factor at the bottom level (including land price, policy environment, meteorology, electricity price, network resources and peer development) was obtained.
Step (5) : using analytic hierarchy process (ahp) to calculate the bottom impact factor for a layer of the weight of impact factor of concrete including land price, the policy environment for the construction cost of the weight, weather, electricity price for the operating costs of the weight, construction costs, operating costs relative to the cost of the weight, network resources and industry development for the benefits of weight. The solution steps are as follows:

① The judgment matrix A is obtained by using the nine-scale method in Step (3) -①:

\[
\begin{bmatrix}
 a_{11} & a_{12} & \cdots & a_{1m} \\
 a_{21} & a_{22} & \cdots & a_{2m} \\
 \cdots & \cdots & a_{ij} & \cdots \\
 a_{n1} & a_{n2} & \cdots & a_{nm}
\end{bmatrix}
\]

Where, m is the number of impact factors in the lower layer, and aij is the importance of impact factor I relative to impact factor j, which is estimated by the 9-scale method.

② Take the maximum eigenvalue of matrix A (\(\lambda_{\text{max}}\))

③ The deviation consistency index of the judgment matrix was calculated as follows:

\[
CI = \frac{\lambda_{\text{max}} - m}{m - 1}
\]

④ Determine whether the consistency is satisfied according to the following formula:

\[
CR = \frac{CI}{RI} < 0.1 \quad \text{The value of RI is shown in Table 2:}
\]

| m  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| RI | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

⑤ If the consistency is satisfied, step ⑥ will be entered. If not, the judgment matrix will be adjusted until the consistency test is satisfied.

⑥ Weight values of different impact factors are calculated according to the following formula:

\[
W = [W_1, W_2, \ldots, W_m]
\]

\[
W_j = \frac{\left(\prod_{i=1}^{m} a_{ij}\right)^{\frac{1}{m}}}{\sum_{k=1}^{m} \left(\prod_{j=1}^{m} a_{kj}\right)^{\frac{1}{m}}}
\]

Step (6) : The weights of different impact factors at the lower level to the upper impact factors obtained according to Step (5) were multiplied by the different priority membership values of different schemes for the same impact factor in Step (4) to obtain the comprehensive priority membership values of different schemes for the upper impact factors.

\[
T_i = \sum_{k=1}^{m} (W_k \cdot S_i)
\]

i = 1, 2, ..., n, where n is the number of schemes to be selected;
K = 1, 2, ..., m, where m is the number of impact factors of the lower layer;
Ti is the comprehensive optimization membership value of the upper index of the ith scheme;
Si is the priority membership degree of the ith scheme for the KTH index in the lower layer;
Wk is the weight of the KTH index in the lower layer to the upper index.
Cycle step (6) until the priority membership value of different schemes under the top comprehensive index is obtained, and the scheme with the largest membership value is selected as the recommended site selection scheme.

3. Case analysis

3.1. Parameter Settings
This paper sets three locales, and the basic conditions are shown in Table 3.

| Land prices (yuan/m²) | Policy environment | Annual mean temperature (°C) | Industrial electricity (yuan/kwh) | Network resources | Industry development |
|-----------------------|--------------------|-------------------------------|-----------------------------------|-------------------|----------------------|
| Area A 34143          | Bad                | 13.6                          | 0.7                               | Very Good         | Very Good            |
| Area B 10589          | Good               | 20.9                          | 0.58                              | Good              | Good                 |
| Area C 5637           | Very Good          | 14.8                          | 0.4                               | Good              | Little Good          |

3.2. Location analysis
Based on steps (1) ~ (6) above, the data in Table 3 are used to determine the site priority by using the fuzzy analytic hierarchy process (AHP). The specific analysis steps are as follows:
1. The influence factor model was established, as shown in Figure 2.
2. According to Step (3) and (2), the priority relation matrix of land price influencing factors is obtained:
$$
\begin{bmatrix}
0.5 & 0.087 & 0 \\
0.913 & 0.5 & 0.413 \\
1 & 0.587 & 0.5
\end{bmatrix}
$$
3. The fuzzy consistent matrix of land price impact factor was calculated according to steps (3) and (2):
$$
\begin{bmatrix}
0.5 & 0.2935 & 0.25 \\
0.7065 & 0.5 & 0.4565 \\
0.75 & 0.5435 & 0.5
\end{bmatrix}
$$
4. According to steps (3) and (3), the priority membership value of the impact factors of land price in the three schemes:
Price: $[0.2268 \ 0.3715 \ 0.4017]$
5. Similarly, the priority membership values corresponding to policy environment, annual average temperature, industrial electricity price, network environment and peer development under the three schemes can be obtained respectively:
Policy environment: $[0.2650 \ 0.3448 \ 0.3902]$
Annual average temperature: $[0.3963 \ 0.2235 \ 0.3682]$
Industrial electricity price: $[0.2485 \ 0.3182 \ 0.4213]$
Network environment: $[0.3808 \ 0.3130 \ 0.3130]$
Peer development: $[0.3911 \ 0.2891 \ 0.3231]$
6. According to step (5), the weight of land price and policy environment on construction cost is obtained.
1. First, get the judgment matrix:
\[
\begin{bmatrix}
0.5 & 0.9 \\
0.1 & 0.5
\end{bmatrix}
\]

2. And then we get the eigenvalues: \( \lambda_{\text{max}} = 0.8 \);

3. The deviation consistency index of the judgment matrix was calculated as follows: \( CI = -1.2 \);

4. Judgment consistency: \( CR = \frac{CI}{RI} < 0.1 \);

5. Then the weight ratio of land price and policy environment to construction cost is \([0.75, 0.25]\).

7. According to Step (6), the priority membership degree value of different schemes for the construction cost of impact factors is \([0.2364, 0.3648, 0.3988]\).

8. And so on, it can be calculated that:

1. The weight of meteorological and electricity price for operating costs is \([0.396, 0.604]\). The priority membership value of different schemes for operating cost of impact factors is \([0.3107, 0.2841, 0.4052]\).

2. The weight of construction cost and operation cost to the total cost is \([0.667, 0.333]\). The value of priority membership for cost of different schemes is \([0.2611, 0.3379, 0.4009]\).

3. The weight of network resources and peer development for revenue is \([0.667, 0.333]\). The priority membership value of different schemes for benefits is \([0.3821, 0.3033, 0.3146]\).

4. The weight of cost and benefit for the comprehensive index is \([0.333, 0.667]\). The priority membership value of different schemes for the comprehensive index is \([0.3418, 0.3149, 0.3434]\).

According to the priority membership value of the final comprehensive index, site C is the optimal scheme, site A is the suboptimal scheme, and site B is relatively unrecommended.

4. Conclusion
In this paper, for the construction of multi-station fusion substation, fuzzy analytic hierarchy process is proposed to determine the site selection of multi-station integration substation. In this paper, land price, policy environment, annual average temperature, industrial electricity price, network environment and peer development are taken into the calculation as influence factors. The case analysis proves that this method can adapt to the current multi-station integrated substation site selection design. In this paper, three regions are taken into the calculation, which can be expanded according to the number of alternative regions in the actual project. It only needs to increase and modify the input matrix parameters, and there is no need to carry out complex model building and data calculation. Therefore, it has strong expansibility and adaptability in engineering application.

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