Substation Location Selection Using GIS and Improved Matter-Element Extension Method

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Abstract. In order to overcome the subjectivity and limitations of traditional substation site selection methods, and to achieve efficient and visualized substation site selection, this study conducted five candidate site locations to avoid the red line area in the geographic information system, then conducted a comprehensive evaluation of the site’s economics. Using the improved matter-element model, an evaluation index system for substation site selection was established covering four intermediate levels of poor geological treatment costs, vertical layout, policy compensation and special costs, and divided into five evaluation levels: excellent, good, average, and poor, Difference, and then determine each section domain and the object to be evaluated, use programming software to calculate the maximum correlation degree of the five areas to be selected for A, B, C, D, E are 0.9118, 0.8172, 0.9202, 0.9485, 0.8557. Respectively belong to the five levels of poor, general, general, poor, and general. Finally, in the GIS system, according to the economic efficiency of site selection from high to low, it corresponds to "cyan-blue, green, yellow, orange and red" in a gradual colour sequence for the five site selection areas Colouring. The results prove that this method has better early warning and auxiliary decision-making functions for substation site selection.

Keywords: Geographic Information System, Improved Matter-element Method, Substation Site Selection, Comprehensive Evaluation

1. Introduction
In the planning of the distribution network, the location of the substation is very important. The choice of a suitable site not only directly affects the construction investment and operating costs of the substation, but also relates to the planning of the distribution network, power quality and power supply reliability. With the continuous deepening of the application of computer technology and the further improvement of optimization theory, especially the large-scale application of geographic information system (GIS), the problem of substation location planning has changed from manual solution to the era of computerized solution. The widespread application of computers in substation site selection and
planning has greatly improved the speed and quality of planning, and has injected new vitality into traditional planning.

Huawei Luo proposed an optimized location method of distribution network substation based on geographic information system (GIS) and differential evolution improved particle swarm [1]. This method uses GIS to determine the number of substations, establishes a constrained objective function based on substation investment and operating costs, and uses particle swarm optimization to optimize the location of substations. Mingfan Chen proposed a method based on Agent technology to realize automatic location selection and grid planning of substations. Through the application of artificial intelligence, the automatic location selection of substations can be quickly and accurately realized, and it is proved by the application of actual cases of Hainan planning projects. The feasibility and practicality of the method are discussed [2]. In order to solve the problem of selecting two similar candidate sites for similar substations, Chunxu Qin chose a comprehensive evaluation method based on Delphi, Analytic Hierarchy Process, Grey Relational Analysis and Fuzzy Comprehensive Evaluation (DHGF) to select the location of the substation [3]. T.R. Ayodele proposed a wind farm location model based on geographic information system. Using interval type-2 fuzzy analytic hierarchy process, a suitable wind farm site selection in Nigeria was determined. The model focuses on the use of fuzzy sets to represent the expert's linguistic judgments, and the purpose is to solve the problems of uncertainty, ambiguity and inconsistency in wind farm site selection decisions [4]. Ling-Ling Li proposed a combination of optimization based on biogeography and population competition algorithm (BBOPC) to improve the economics of substation location planning [5]. Shunbin Rao proposed a new method of substation site selection based on geographic information system (GIS) and extension comprehensive optimization evaluation, and realized the computer solution of site selection model [6]. Siwen Zhao aimed at the shortcomings of the standard particle swarm algorithm that it is easy to fall into the local optimum and the slow convergence speed of the differential evolution algorithm in the later stage, and proposed the differential particle swarm algorithm to optimize the two. The Voronoi diagram is combined with the mathematical model of substation location to determine the power supply range and planned capacity of the substation, and then verify the actual load rate of the substation, which improves the search efficiency [7]. By analyzing the relevant literature, it can be found that the studies that have been carried out have considered relatively little analysis of the whole process of substation site selection, and lack of research on the visualization of substation site selection.

In order to assist power transmission and transformation projects in the preliminary site selection work, this paper proposes a substation site selection method based on geographic information system and matter element extension algorithm. First input the location avoidance area in the GIS, after avoiding the red line area, construct the substation location evaluation index system in the feasible area, and then use the improved matter-element extension algorithm to classify each candidate site on the GIS. Use GIS programming software to paint these candidate areas and ultimately guide the selection of substation sites. This method analyzes the whole process of substation site selection and visualizes the work of substation site selection. The calculation of examples in the article shows the scientificity and accuracy of the method.

2. Analysis of Key Influencing Factors in Substation Site Selection
Substation site selection is an important part of power grid planning and an important part of power system construction planning. Therefore, substation site selection must be carefully and comprehensively considered. There are many factors that affect the location of substations. Combining the characteristics of power transmission and transformation projects in Jiangsu area, and collecting feasibility study reports generated during the construction of power transmission and transformation projects in various regions, the location of substations considered before construction is targeted. The detailed study of the nature divides the site into two types of factors: strictly avoiding factors and considering economic factors.
Among them, the strict avoidance factor is the red line area of substation site selection, including the following aspects:

1. Natural environment

The selected site should have suitable geological conditions and flood control capabilities. It is necessary to clearly understand the hydrological and meteorological conditions such as the flood detention area, reservoir, spillway, and waterway requirements around the site. It’s also significant to determine whether to press the ore to prevent the mineral from causing damage to the substation after mining. Influencing, while avoiding bad geology, such as goaf areas, landslide areas, mud-rock flows, river ponds, subsidence areas, earthquake fracture zones, karst caves, shore erosion areas, and rock-prone road sections. If there is a mountain in the area, the stability of the mountain should be considered. The location of the substation should be located in hard soil areas as much as possible, on the one hand, it can reduce the input cost, on the other hand, it can reduce the loss and prevent the site from being damaged. The site should avoid key protected natural areas and cultural sites, avoid mineral deposits with important mining value, avoid ecological red lines, avoid or reduce damage to forests and environmental natural landforms, avoid cultivated land and farmland, and reduce agricultural losses.

2. Surrounding facilities

When determining the site of a station, the interaction with neighbouring facilities, such as airports, should be considered. If there are explosive depots, oil and gas pipelines and water pipes, they need to be avoided. The distance between the station site and the above-mentioned facilities shall meet the requirements of relevant regulations to ensure that the substation has no impact on the original facilities nearby.

3. Special area

The location of the substation must also be approved by the relevant military administration and aviation administration. For example, the construction of industrial facilities such as substations is prohibited within 2km of the military shooting range. The location of the substation should avoid the surrounding military, aviation, and communication facilities. The interference generated by these facilities will cause the loss of the internal facilities of the substation.

4. Architectural planning

The site selection of substations should consider regional construction planning. If you plan to build radio, television antennas, and navigation stations in the future, you should consider the proposed location and height of the relevant buildings before planning.

5. Line construction

When selecting the station site, it is necessary to consider whether it is convenient to enter and exit the voltage at all levels, ensure sufficient entry and exit corridors, and minimize line crossings, crossings and corners, so as to ensure the reliability and safety of power delivery and reduce line investment.

6. Distribution of existing substations

The location of the substation should consider the distribution of the original substation. Reasonable layout of regional power sources and substations can not only reduce the investment and loss of the secondary network, but also achieve the purpose of safe power supply. At the same time, the power supply flexibility of the power grid is greatly improved, and the instability of the load is effectively solved.

3. Construction of Substation Site Selection Evaluation Index System

Since the location of the substation must first consider evasive factors and avoid selecting the location of the substation in the red line area, the location of the substation mainly considers the technical and economic evaluation. The economic factors related to substation site selection include the following aspects: natural environmental factors, construction factors, policy factors, and special expenses.

Natural environmental factors mainly affect construction conditions. If there are many bad geological conditions in the area, the construction will be more difficult and the required investment
will increase. Poor natural environment will affect the operating life of substations and increase unit operating costs.

Construction related factors need to consider the local transportation costs, the amount of earthwork and the difficulty of foundation treatment, etc. The more complex the working conditions and the greater the amount of work, the higher the construction cost;

In terms of policies, it is necessary to consider local costs related to demolition compensation, water supply and drainage, electricity, land use, etc. The related costs are also different in different regions due to different policies. The compensation for land acquisition required for different regions and different types of land is also different. If the land is close to in urban areas or planting high-value cash crops, the compensation is higher; in Jiangsu Province, different areas have different requirements for the treatment of facades, and the costs are also different.

Combining the economic factors of substation site selection and taking into account the actual engineering experience, it is concluded that the technical and economic indicators affecting substation site selection mainly cover the four levels of poor geological treatment costs, vertical layout costs, policy compensation costs and special costs, as shown in Table 1 shown. These factors mainly affect the construction and operation and maintenance costs of substations. The location of substations should be selected in the case of meeting other conditions to choose a more economical solution.

### Table 1. Evaluation System

| Target layer | Factor level               | Indicator level (Processing costs) |
|--------------|----------------------------|-----------------------------------|
| Evaluation index system of substation site selection | Cost of bad geological treatment | Deep soft soil, Digging filling, Sand liquefaction, Karst cave (partially treatable), Land subsidence |
|              | Vertical planning          | Natural elevation                  |
|              | Compensation policy        | Compensation for demolition        |
|              | Special expenses           | Cost of facade                     |

### 4. Evaluation of Substation Site Selection Based on GIS and Improved Matter-Element Extension

#### 4.1. The Concept of Matter-Element Extension Method

The matter-element extension theory is one of a series of theoretical methods proposed by Chinese scholar Wen Cai to solve the contradictory problems in the fields of economy, management control and artificial intelligence [8].

The matter-element extension theory has a wide range of applications in the production process of industrial products. As a product design idea, it has many advantages such as strong comprehensiveness and good adaptability. For industrial products, the conceptual idea is simple but the actual structure is complex and the consideration factors are diverse. Features can be better targeted. However, the methods and ideas of matter element extension in the site selection problem have not been studied and applied much.

#### 4.2. Introduction to Geographic Information Systems

The definition of geographic information system consists of two parts. On the one hand, geographic information system is a subject, an emerging interdisciplinary of description, storage, storage, analysis output, and spatial information theory and methods, on the other hand, geographic information system is a technical system based on geospatial database and geographic information system use geographic analysis to provide researchers with various spatial and dynamic geographic information in a timely manner, or provide computer information technology systems for geographic research and geographic

research services [9]. The core issues of geographic information systems can be summarized into five aspects: location, geographic conditions, changing trends, changing patterns and geographic models.

Geographic Information System technology is a computer technology that integrates spatial data collection, storage, analysis, processing, and application. It can solve various geospatial information problems with brand-new methods. Due to the continuous improvement of computer hardware and software, geographic information system has also been developed rapidly, and has been widely used in flood control, land management, and geological disaster evaluation, and has achieved good results [10, 11].

In the research of this article, based on the collected data and survey data, the appropriate grading standards are selected to classify the evaluation indicators, and the evaluation model is embedded in Omap software. According to the judgment matrix determined by experts in the field of substation engineering, the weight of each impact index is obtained through the analytic hierarchy process, and the evaluation result of the substation site selection is obtained using the improved matter-element extension model.

4.3. Improved Matter-Element Extension Model Based On GIS

4.3.1. Improved matter-element extension model. The matter-element extension model is a modeling method formed by the organic fusion of matter-element theory and extension theory, which realizes qualitative and quantitative analysis of things. The model establishes an n-dimensional basic matter element with \( R=(N,c,v) \), establishes the classical domain, value range and evaluation level of each index, calculates the correlation degree and correlation function of each index, and finally determines the level of the evaluation object. The classic matter-element model is prone to defects such as meaningless correlation function and greater influence of the distance function by the relative position of the index, which affects the accuracy of the evaluation result. This paper establishes an improved matter-element extension model by quantifying the classical domain and the matter element to be evaluated, and calculating the new distance function and correlation degree, so as to realize the accurate evaluation of the substation location.

1. Determine the classic domain matter element of the index

Among them, \( N_j \) is the jth level of the matter element, \( c_1,\ldots,c_n \) are the corresponding characteristic values of the index to be evaluated, \( v_{j1},\ldots,v_{jn} \) are the value ranges of \( c_i \) when in the jth level, \( v_{ji}=(a_{ji},b_{ji}) \)

\[
R_j = (N_j,c_j,v_j) = \begin{pmatrix} 
N_j & c_1 & v_{j1} \\
& c_2 & v_{j2} \\
& & \ldots \\
& & \ldots \\
& c_n & v_{jn} 
\end{pmatrix} = \begin{pmatrix} 
N_j & c_1 & \{a_{j1},b_{j1}\} \\
& c_2 & \{a_{j2},b_{j2}\} \\
& & \ldots \\
& & \ldots \\
& c_n & \{a_{jn},b_{jn}\} 
\end{pmatrix}
\]

bji) That is, the classic domain of evaluation indicators.

2. Determine the node area matter element Rp of the index

Among them, \( P \) is the overall level of the index to be evaluated, \( v_p=(a_p,b_p) \), that is, the section domain, and \( v_{ji} \in v_p \).

\[
R_p = (p,C_p,v_p) = \begin{pmatrix} 
p & c_1 & v_{p1} \\
& c_2 & v_{p2} \\
& & \ldots \\
& & \ldots \\
& c_n & v_{pn} 
\end{pmatrix} = \begin{pmatrix} 
p & c_1 & \{a_{p1},b_{p1}\} \\
& c_2 & \{a_{p2},b_{p2}\} \\
& & \ldots \\
& & \ldots \\
& c_n & \{a_{pn},b_{pn}\} 
\end{pmatrix}
\]
3. Determine the index domain \( R_p \) to be evaluated
Among them, \( P_0 \) is the object to be evaluated. \( q_1, \ldots, q_n \) are the actual data corresponding to \( c_1, \ldots, c_n \).

4. Standardize each classic domain

\[
R_p = (p, C_i, q_{ji}) = \begin{pmatrix} P_0 & c_1 & q_1 \\ c_2 & q_2 \\ \vdots & \vdots \\ c_n & q_n \end{pmatrix} \tag{3}
\]

5. Standardize the value of the object to be evaluated

6. Calculate the distance \( D \) of the new classical domain value range. According to the calculated standardization results, the distance \( D \) of the classical domain value range of the object to be evaluated is recalculated. The calculation results are as follows:

\[
\hat{R}_j = (N_j, c_i, V_{ji}) = \begin{pmatrix} N_j & c_1 & \{a_{ji} / b_{pi}, b_{ji} / b_{pi}\} \\ \vdots & \vdots \\ c_n & \{a_{nj} / b_{pn}, b_{nj} / b_{pn}\} \end{pmatrix} \tag{4}
\]

\[
\hat{R}_j = (p, C_i, q_{ji}) = \begin{pmatrix} P_0 & c_1 & q_{1ji} / b_{p1i} \\ \vdots & \vdots \\ c_n & q_{nji} / b_{pi} \end{pmatrix} \tag{5}
\]

\[
D(q_{ji}, V_{ji}) = \left| q_{ji} - \frac{a_{ji} + b_{ij}}{2b_{pi}} \right| - \frac{b_{ij} - a_{ji}}{2b_{pi}} \quad i \in (1, 2, \ldots, n) \tag{6}
\]

\[
K_j(p_0) = 1 - \sum_{i=1}^{n} \omega_i D_{ij} \tag{7}
\]

\[
\hat{K}_j(p_0) = \frac{K_j(p_0) - \min K(p_0)}{\max K(p_0) - \min K(p_0)} \tag{8}
\]

7. Calculate the degree of relevance \( K_j(p_0) \)
Among them, \( \omega_i \) is the weight of each evaluation index. \( D_{ij} \) is the improved correlation function of the index to be evaluated.

8. Determine the evaluation level
Assume $K'_j(R_0) = \max\{ K'_j(R_o) \}$, Then the object $R_0$ to be evaluated belongs to $j'$ level.

The degree to which the matter element to be evaluated is biased towards the adjacent level:

4.3.2. Embed model in GIS. Based on the evaluation index system for substation site selection screened in the previous section, the analytic hierarchy process is used to determine the weight of each index, and an improved matter-element extension method is used to establish an early warning model to realize the economic evaluation of substation site selection in the feasibility study stage. The basic steps of the model are as follows:

1. Grid site selection area

Combining with the landform and topography of the planned area, determine the overall city plan, detailed regulatory planning of each district, administrative division and power supply jurisdiction division, determine the main basis and principles of division, and divide the plan. The grid is divided into three levels: large area, medium area and small area. Large areas are divided according to administrative divisions, power supply jurisdictions and natural barriers. In order to avoid double calculation of regional load and avoid cross-regional power supply, the entire power supply planning area needs to be divided into a large area. The middle area is usually composed of several adjacent cells. According to the load situation in the middle area, the small area load is further divided to facilitate the calculation and distribution of the load in the power supply range of the middle area. Divide areas of different natures into small blocks. For land of different natures, different load indexes are provided in the calculation.

2. Input parameters

Input the geographic information parameters and artificial setting parameters stored in the GIS into the system, and perform parameter assignment for each area to be selected.

3. Scan and avoid the red line area

Use Omap software to compile the site-selected red line area into the GIS map, and process the information into constraints and introduce it into the model:

Among them, $(x, y)$ is the geographic information coordinates, and $N$ is the matter element scheme with $Y(c, v(x, y))$ as the feature element. Scan each area to be selected, if it is in the red line area, return to the previous step, if it is in the non-red line area, go to the next step.

4. Output evaluation results

Using GIS programming software to input parameters, the site selection area is evaluated based on the improved matter-element extension method, and the colouring is based on different degrees of membership as a reference for substation site selection.

5. Analysis of Examples

$$j^* = \frac{\sum_{j=1}^{m} jK'_j(p_0)}{\sum_{j=1}^{m} K'_j(p_0)}$$ (10)
This paper takes a region in Jiangsu Province as an example to verify the effectiveness of the early warning model for substation location selection based on GIS and improved matter element extension. The proposed substation is a 220KV step-down substation with a scale of 3*120MVA and a site area of 9,000 square meters. In the early site selection work, considering the avoidance factors analyzed in the first part, GIS was used to scan and avoid the distribution areas of these factors, and the feasible areas were divided according to terrain and roads, and five areas to be selected were obtained as shown in Figure 1, and then perform technical and economic evaluation.

![Figure 1. Area to be selected](image)

After investigation and evaluation by relevant experts in the field of substation engineering, the original data matrix of evaluation indicators is obtained. The results after standardized processing are shown in Table 2.

**Table 2. Data matrix**

| Index number | A     | B     | C     | D     | E     |
|--------------|-------|-------|-------|-------|-------|
| D11          | 1.9511| 1.8109| 0.8930| 1.4357| 1.0866|
| D12          | 0.1987|-1.1549| 0.1672| 0.1416|-1.3657|
| D13          | 0.4250| 0.9714| 1.2056| 0.9748| 0.5864|
| D14          | -1.2308| 0.9095|-0.4916|-0.5764|-0.3057|
| D15          | -0.6789|-0.9829|-1.0276|-1.2412|-0.6341|
| D21          | -0.7755|-0.4152|-0.9466|-1.1459|-1.0036|
| D31          | 0.9990|-0.2053| 1.5629| 1.1875| 1.7398|
| D32          | -0.4857|-0.4668|-0.4023|-0.1997| 0.1423|
| D41          | -0.4029|-0.4668|-0.9606|-0.5764|-0.2459|

This paper invites experts in the relevant fields of Jiangsu Power Grid Substation Engineering to score the importance of each factor of the evaluation index according to the importance of each evaluation index, and consider the actual engineering experience to obtain the judgment matrix, and use the analytic hierarchy process to obtain the evaluation index system indicators. The weights are shown in the following table:

**Table 3. Weight matrix**

| Index number | D11 | D12 | D13 | D14 | D15 | D21 | D32 | D41 | D42 |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|

8
Weights | 0.2877 | 0.0903 | 0.1395 | 0.0736 | 0.0445 | 0.0538 | 0.1242 | 0.1129 | 0.0736
---|---|---|---|---|---|---|---|---|---

After referring to the technical regulations of the power transmission and transformation engineering selection station of Jiangsu Power Grid Corporation and the power engineering design manual, the indicators proposed in Chapter 3 are divided into five evaluation levels, which are excellent, good, general, poor and difference.

| Table 4. Evaluation matrix |
|---|---|---|---|---|---|
| Index number | Excellent | Good | General | Poor | Difference |
| D11 | (0,400] | (400,600] | (600,800] | (800,1000] | (1000,1200] |
| D12 | (0,350] | (350,400] | (400,450] | (450,500] | (500,550] |
| D13 | (0,450] | (450,500] | (500,550] | (550,600] | (600,650] |
| D14 | (0,200] | (200,300] | (300,400] | (400,500] | (500,600] |
| D15 | (0,40] | (40,80] | (80,120] | (120,160] | (160,200] |
| D21 | (0,32.5] | (0,75] | (0,117.5] | (117.5,160] | (160,202.5] |
| D32 | (0,250] | (0,400] | (0,550] | (0,700] | (0,850] |
| D41 | (0,188] | (188,242] | (242,296] | (296,350] | (350,404] |
| D42 | (0,200] | (200,225] | (225,250] | (250,275] | (275,300] |

According to the model given in Section 4, use programming software to calculate in the computer to obtain the closeness and evaluation level of the five objects to be evaluated, $R_A$, $R_B$, $R_C$, $R_D$, and $R_E$.

| Table 5. Closeness matrix |
|---|---|---|---|---|
| Object to be evaluated | $D_1$ | $D_2$ | $D_3$ | $D_4$ |
| $R_A$ | 0.5592 | 0.7057 | 0.7851 | 0.8988 |
| $R_B$ | 0.7488 | 0.8132 | 0.8172 | 0.8165 |
| $R_C$ | 0.7564 | 0.8762 | 0.9202 | 0.8973 |
| $R_D$ | 0.6342 | 0.7640 | 0.9093 | 0.9485 |
| $R_E$ | 0.6893 | 0.7494 | 0.8557 | 0.8148 |

| Table 6. Evaluation grade matrix of matter to be evaluated |
|---|---|---|---|
| Location area | Maximum relevance | Degree of bias towards adjacent levels | Comprehensive evaluation grade |
| A | 0.9118 | 3.8060 | Difference |
| B | 0.8172 | 2.9738 | General |
| C | 0.9202 | 3.3365 | General |
| D | 0.9485 | 3.7262 | Poor |
| E | 0.8557 | 3.6836 | General |

According to the above table, the evaluation level of A site selection area is difference, the evaluation level of D site selection area is poor, and the evaluation levels of other site selection areas are general, but obviously compared to E area, the two areas B and C tend to be more general.
According to the calculation results of the improved matter-element extension model, in the GIS system, the color sequence of “cyan-blue, green, yellow, orange and red” is formed from high to low according to the economic efficiency of site selection. The site area B, site area C and site area E are painted with gradient color blocks between yellow and green and red. Site area D is painted orange, and site area A is painted red. Based on this, an early warning is provided for the site economy of the substation to assist the work in the site selection phase of the substation.

6. Conclusion
This article takes a certain area of Jiangsu Province as the research object, and through extensive collection of information and investigations, the key influencing factors that affect the location of substations are analyzed, and evasive factors and economic factors are screened out, and then substations are summarized from the economic factors. The site selection evaluation index system is comprehensively evaluated using an improved GIS-based matter-element model for five candidate locations in the area. After model calculation and coloring and marking in the GIS, you can visually see the economic distribution of these five proposed sites.

This method visualizes the work in the feasibility study stage of substation engineering, and has better early warning and auxiliary decision-making functions for substation site selection.

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