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The Research on Optimum Location of Transformer Substation Based on Fuzzy Analysis Hierarchy Process

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Abstract: Because of many factors and hard to make a decision, a fuzzy analysis hierarchy process is applied to select location of transformer substation to avoid the problem of disaccord of judgment matrix in analysis hierarchy process. Fuzzy analysis hierarchy process works as follows: firstly, to build the fuzzy consistent matrix by building hierarchy structure charts, then to synthesize all schemes to obtain the optimum location of transformer substation. The 220kV transformer substation location is evaluated to obtain the optimum location, finally identify this method's efficiency and correctness.

Keywords: Fuzzy Analysis Hierarchy Process, Selection of Location of Transformer Substation, Hierarchy Structure Chart, Fuzzy Consistent Matrix, Transmission and Change Electricity Engineering, Optimum Location

1. INTRODUCTION

The selection of location of transformer substation is an important part in electric power system plan. The network structure, the quality of power supply and the economy of running in which future electrical power systems are affected by the location of transformer substation directly. So it is crucial to select the location of transformer substation reasonably for the reasonable layout and running economically of electrical network.

It refers to many factors when you select the location of transformer substation, so you need to apply many methods to analysis the selection of location of transformer substation． Quotation [1]. [1]researched the application of computation model of multiple source continual selected location which based on different rules in selection of location of the transformer substation of city network，and put forward a new combination model in order to obtain the best location at the certain load level. Quotation [2]. considered the relation is ambiguous, which is between many related factors in the process of selecting location and the information of geography space, and also considered some decision indexes which were uncertain fuzzy variables. It researched on the function of information management and space analysis in the geography information system (GIS), then we could obtain the feasibility of sample set from some feasible location of substation. And it also researched on the order from qualitatively to quantitatively with the fuzzy pattern recognition theory. Finally we got a new method to confirm the superiority of different decision indexes and sampled data. This method can improve the quantity level of comprehensive policy-making and visualization degree when you select the location. Quotation [3]. researched the data fusion technology applied to the selection of location, it changed from the D-S evidence theory which combined with picture element level data to hierarchical analysis synthetic judgment method which combined with decision level. This method offered a new way to deal with multiple factors of selecting location. Quotation [4-12]. used other means to research selection of location of transformer substation. Quotation [4-6]. used the fuzzy comprehensive evaluation method to evaluate the chose locations and confirmed their precedence order, during the process of fuzzy comprehensive evaluation, weight distribution of factors is crucial to the result. It used analytic hierarchical process to assure the weight of all the factors related with location related to total target, it was more scientific to confirm the weight. But the hierarchical analysis process has its own flaws, that is, this method hard to get the consistent indexes of judgment matrix and there is difference between consistence of judgment matrix and consistence of decision thought. So fuzzy analytic hierarchy process is applied to selection of location for transformer substation in this paper, it makes the result more scientific and reasonable.

2. FUZZY ANALYTIC HIERARCHY PROCESS

Analytic hierarchy process (AHP) is a decision technique that can combine qualitative and quantitative factors developed by Tom Saaty in 1977. It divided complex problems into many factors, then these factors are formed to a hierarchical representation according to the dominant relationship, determine the relative prioritization by comparing every two of them and, finally take into consider of decision maker, determine the order of different factors' relative importance. Because it hard to get the consistence index of judgment matrix and there is difference between consistence of judgment matrix and consistence of the human-being thought, the fuzzy consistence matrix is introduced into AHP getting an effective and practical fuzzy analytic hierarchy process.

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The difference between FAHP and AHP is the fuzzy of judgment matrix. In order to avoid the things that the first is more important than second one, the second one is more important than the third one, but the third one is more important than the first one, it must have the consistence generally while constructing the judgment matrix. A chaotic without being deliberated judgment matrix may lead to wrong calculation. So it is necessary to change this matrix into fuzzy consistence matrix in the grade of importance, equal importance and unimportance to distinguish relative importance of all the factors in every level compared to some factor in the superior level. There is no need to judge the consistence of matrix if the matrix is transformed into fuzzy consistent matrix. And also maintain the consistence.

FAHP can be used in many projective practices, for example, quotation[14]. comprehensively judge the decision of city electric network's plan based on FAHP; quotation[16]. researched the application in aspect of optimum seeking for scheme; quotation[17]. researched the application in the optimum seeking for basement process. But it is the first time to use FAHP in the selection of location of transformer substation. The steps of FAHP are as followings:

2.1. Develop a Hierarchical Representation

Divide factors into different levels according to the analysis of all the factors. The hierarchical can be divided into three levels, top level (target level), middle level (rule level) and bottom level (scheme level or measure level). Then mark the relationship between the top factor and bottom factor, and expressed by structure chart.

2.2. Form the Precedence Relation Matrix

The relative importance of the every level factors relative to the top ones can be expressed in matrix (e.g. $F = (f_{ij})m \times m$), the elements in the matrix can be determined by following ways: f_{ij} =1.0 if element I is more important than element j; then f_{ij} =0, if element j is more important than element I; and the third condition is f_{ij} =0.5 when they are equally important.

2.3. Transform to the Fuzzy Consistence Matrix.

First to summarize by line in the fuzzy judgment matrix, denote it by:

$$\boldsymbol{r_i = \sum_{k=1}^{m} f_{ik}, k = 1,2,\cdots,m} \tag{1}$$

Then do the mathematical manipulation like this:

$$r_{ij} = \frac{r_i - r_j}{2m} + 0.5 \tag{2}$$

Then the matrix $R = (r_{ij})_{m \times m}$ based on this manipulation is fuzzy consistent.

2.4. Calculate the Relative Importance of Every Level Factors Relative to the Top Ones

The purpose is to predict the important order of all factors in this level relative to some factors in the top level according to the fuzzy consistence of judgment matrix. This order can be expressed by relative data, the measure used usually is root method, that is, first get the geometric mean of column vector in the matrix A, then normalize it, the result is the weight vector, the calculation formula is as follow:

$$\boldsymbol{w_s = \left[\prod_{j=1}^{n} a_{ij}\right]^{1/n} / \sum_{h=1}^{n}\left[\prod_{j=1}^{n} a_{hj}\right]^{1/n}, i = 1,2,\cdots,n} \tag{3}$$

The steps of calculation are: *1)* get a new vector by multiplication in line for all the factors in the matrix A; *2)* extract n for every component in the new vector; *3)* normalize the new vector you get last step, finally you can get the weight vector.

2.5. Calculate the Relative Importance of Factors in Every Level Relative to Total Target.

It must carry on from top to bottom when you calculate the relative importance of factors in every level relative to total target. We assumed that the weight sequencing vector of n_{k-1} factors in the k-1 level relative to the total target:

$$w^{(k-1)} = \left[w_1^{(k-1)}, \quad w_2^{(k-1)}, \quad \cdots, \quad w_{n_{k-1}}^{(k-1)}\right]^T \tag{4}$$

Suppose the sequencing weight vector of n_k factors in k_{th} level relative to j_{th} factor in the $(k-1)_{th}$ level for the criterion:

$$P_j^{(k)} = \left[p_{1j}^{(k)},\quad p_{2j}^{(k)},\quad \cdots,\quad p_{n_k}^{(k)} \right]^T \tag{5}$$

Where，the weight of the factors which can not be dominated by j is 0. Let's pick:

$$P^{(k)} = \left[p_1^{(k)},\quad p_2^{(k)},\quad \cdots,\quad p_{n_{k-1}}^{(k)} \right] \tag{6}$$

That is $n_k \times n_{k-1}$matrix, it means the order of factors in k_{th} level relative to every factor in the $(k-1)_{th}$ level. So the composition sequence vector $w^k$of factors in k_{th} level relative to total target is:

$$w^{(k)} = \left[w_1^{(k)},\quad w_2^{(k)},\quad \cdots,\quad w_{nk}^{(k)} \right]^T = P^{(k)} w^{(k-1)} \tag{7}$$

Or

$$w_i^{(k)} = \sum_{j=1}^{n_{k-1}} p_{ij}^{(k)} w_j^{(k)}, i = 1,2,\cdots,n \tag{8}$$

We can express it like this:

$$w^{(k)} = P^{(k)} P^{(k-1)} \cdots w^{(2)} \tag{9}$$

Where $w^{(2)}$ is the sequencing vector of the factors in 2_{nd} level relative to total target.

3. FACTORS OF SELECTION LOCATION OF TRANSFORMER SUBSTATION

There are many factors when we select the location of transformer substation, so it needs to consider them economically, here are the factors:

3.1. Close to the Center of Load

We must analysis the position and function of supply load, load distribution, supply demand and transformer substation in the system when we choose the scheme of location of substation. It can reduce the investment and loss of electric network if we take the location more close to the centre of load.

3.2. Make the Electrical Network Layout More Reasonably

We should consider the original power supply, newly built power supply and the power supply plan to construct in that district. If we do like that, it can make the layout of power supply and transformer substation more reasonable. It is also possible to reduce the investment and loss of secondary electric network and supply power safely.

3.3. Make the Outgoing (incoming) Line Convenient

We should consider the convenience of outgoing (incoming) line in every voltage when we select the location. It can reduce the crossing of line, spanning and corner as much as possible.

3.4. The Favor of Topography of Substation to the Layout of Transformer Substation

When selecting the location, we should not only implement the spirit that is to save the land, don't occupy or occupies little farmland, but also consider the topography which favor for the layout of transformer substation.

3.5. The Better Geological Conditions of the Substation

We must consider the geological conditions fully when select the location of the substation. We should avoid the places such as the faultage, landslide, collapse, limestone caves, also avoid the areas of mineral resources.

3.6. Environment is Suitable

The location of substation should be away from flammable or explosive things, the serious contaminated areas, and it must satisfy the distance with radio-communication facilities.

3.7. The Transportation Should be Convenient

We must consider both the transportation of large-scale equipments such as equipments, materials, transformers and the convenience of transportation while it works or overhauls. Usually the location of substation should close to the road, the distance to the substation can be shorter, the purpose is to reduce the investment.

3.8. We should consider the conditions of flood prevention, water and electricity used, and convenience of supply and drainage.

4. THE SELECTION OF LOCATION OF 220KV TRANSFORMER SUBSTATION

This paper uses the FAHP to analysis the location of substation according to its characters. Because there are no inspection conditions, the data of example in this paper takes from "the report of selection of some 220kV transformer substation” of one electric power institute. Take the a, b, c, d 4 alternative substation in that transformer substation for example to verify.

4.1 Build a Hierarchical Structure

After the data are processed, we should appraise synthetically the 5 related factors, that is net-work structure (U_1), out condition of substation (U_2), investment analysis(U_3), difficulty degree of expropriation(U_4) and special superiority(U_5), where P_1,P_2,P_3,P_4 represent separately the 4 alternative substations a, b, c, d. Fig.1 is the hierarchical structure of location E of this transformer substation.

4.2 Form the Precedence Relation Matrix.

The set of related factors is $u=\{U_1,U_2,\cdots,U_5\}$; the evaluation set is v=[0,1]. Table 1 is the assessment values of single factor given by expert based on all the related factors of 4 alternative substations.

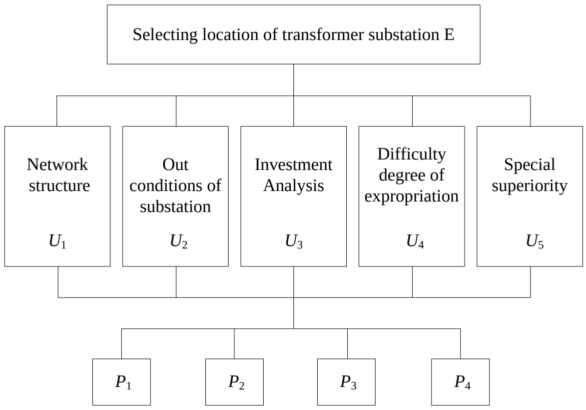

Figure 1 Hierarchy structure of selecting location of transformer substation

According to the evaluation opinion given by expert, we can construct 6 precedence relation matrixes. They are E-U,U_1-P,U_2-P,U_3-P,U_4-P,U_5-P, and the values derived from (1) are showed in table 2~7.

4.3 Transform to the Fuzzy Consistence Matrix

The fuzzy matrix derived from (2) is showed in table 8~13.

Table1.Single Factor Assessment Values of All Sites

Appraisal project	a	b	c	d
Network structure U_1	0.78	0.8	0.75	0.75
Out condition of substation U_2	0.6	0.6	0.75	0.75
Investment analysis U_3	0.75	0.6	0.7	0.6
difficulty degree of draft U_4	0.75	0.7	0.6	0.6
Special superiority U_5	0.6	0.6	0.6	0.6

Table2. Value of E-U

E	U_1	U_2	U_3	U_4	U_5	r
U_1	0.5	1	1	1	1	4.5
U_2	0	0.5	0	0	0.5	1
U_3	0	1	0.5	0.5	1	3
U_4	0	1	0.5	0.5	1	3

Table3. Value of U_1-P

U_1	P_1	P_2	P_3	P_4	r
P_1	0.5	0	1	1	2.5
P_2	1	0.5	1	1	3.5
P_3	0	0	0.5	0.5	1
P_4	0	0	0.5	0.5	1

Table4. Value of U_2-P

U_2	P_1	P_2	P_3	P_4	r
P_1	0.5	0	0	0	1

P_2	0.5	0.5	0	0	1
P_3	1	1	0.5	0.5	3
P_4	1	1	0.5	0.5	3

Table5. Value of U_3-P

U_3	P_1	P_2	P_3	P_4	r
P_1	0.5	1	1	1	3.5
P_2	0	0.5	0	0.5	1
P_3	0	1	0.5	1	2.5
P_4	0	0.5	0	0.5	1

Table6. Value of U_4-P

U_4	P_1	P_2	P_3	P_4	r
P_1	0.5	1	1	1	3.5
P_2	0	0.5	1	1	2.5
P_3	0	0	0.5	0.5	1
P_4	0	0	0.5	0.5	1

Table7. Value of U_5-P

U_5	P_1	P_2	P_3	P_4	r
P_1	0.5	0.5	0.5	0	1.5
P_2	0.5	0.5	0.5	0	1.5
P_3	0.5	0.5	0.5	0	1.5
P_4	1	1	1	0.5	3.5

Table8. Value of E-U

E	U_1	U_2	U_3	U_4	U_5
U_1	0.5	0.85	0.65	0.65	0.85
U_2	0.15	0.5	0.3	0.3	0.5
U_3	0.35	0.7	0.5	0.5	0.7
U_4	0.35	0.7	0.5	0.5	0.7
U_5	0.15	0.5	0.3	0.3	0.5

Table9.Fuzzy Value of U_1-P

U_1	P_1	P_2	P_3	P_4
P_1	0.5	0.375	0.6875	0.6875
P_2	0.625	0.5	0.8125	0.8125
P_3	0.3125	0.1875	0.5	0.5
P_4	0.3125	0.1875	0.5	0.5

Table10.Fuzzy Value of U_2-P

U_2	P_1	P_2	P_3	P_4
P_1	0.5	0.5	0.25	0.25
P_2	0.5	0.5	0.25	0.25
P_3	0.75	0.75	0.5	0.5
P_4	0.75	0.75	0.5	0.5

Table11.Fuzzy Value of U_3-P

U_3	P_1	P_2	P_3	P_4
P_1	0.5	0.8125	0.625	0.8125
P_2	0.1875	0.5	0.3125	0.5
P_3	0.375	0.6875	0.5	0.6875
P_4	0.1875	0.5	0.3125	0.5

Table12.Fuzzy Value of U_4-P

U_4	P_1	P_2	P_3	P_4
P_1	0.5	0.625	0.8125	0.8125
P_2	0.375	0.5	0.6875	0.6875
P_3	0.1875	0.3125	0.5	0.5
P_4	0.1875	0.3125	0.5	0.5

Table13.Fuzzy Value of U_5-P

U_5	P_1	P_2	P_3	P_4

P_1	0.5	0.5	0.5	0.25
P_2	0.5	0.5	0.5	0.25
P_3	0.5	0.5	0.5	0.25
P_4	0.75	0.75	0.75	0.5

4.4 Single Hierarchical Sequencing

According to the preceding fuzzy matrix, we can calculate the single hierarchical sequencing by (5):

E-U (U level related to E level):

$$w^{(2)} = (0.287 \quad 0.135 \quad 0.221 \quad 0.221 \quad 0.135)^T$$

$U_1 - P$ (P level related to U1 in the U level):

$$P_1^{(3)} = (0.284 \quad 0.352 \quad 0.182 \quad 0.182)^T$$

$U_2 - P$ (P level related to U2 in the U level):

$$P_2^{(3)} = (0.1385 \quad 0.1385 \quad 0.317 \quad 0.317)^T$$

$U_3 - P$ (P level related to U3 in the U level):

$$P_3^{(3)} = (0.356 \quad 0.182 \quad 0.284 \quad 0.182)^T$$

$U_4 - P$ (P level related to U4 in the U level):

$$p_4^{(3)} = (0.352 \quad 0.284 \quad 0.182 \quad 0.182)^T$$

$U_5 - P$ (P level related to U5 in the U level):

$$P_5^{(3)} = (0.2165 \quad 0.2165 \quad 0.2165 \quad 0.35)^T$$

4.5 Total Hierarchical Sequencing

According to the preceding single hierarchical sequencing, we can get the total hierarchical sequencing from (7):

$$\boldsymbol{w^{(3)} = p^{(3)}}$$

$$\mathbf{w^{(2)}} = \begin{bmatrix} \mathbf{0.284} & \mathbf{0.352} & \mathbf{0.182} & \mathbf{0.182} \\ \mathbf{0.1835} & \mathbf{0.1835} & \mathbf{0.317} & \mathbf{0.317} \\ \mathbf{0.356} & \mathbf{0.182} & \mathbf{0.284} & \mathbf{0.182} \\ \mathbf{0.352} & \mathbf{0.284} & \mathbf{0.182} & \mathbf{0.182} \\ \mathbf{0.2165} & \mathbf{0.2165} & \mathbf{0.2165} & \mathbf{0.35} \end{bmatrix}^T [0.287 \quad 0.135 \quad 0.221 \quad 0.221 \quad 0.135]^T$$

That is,

$$w^{(3)} = (0.293 \quad 0.258 \quad 0.227 \quad 0.222)^T$$

We can see that the evaluation sequencing of 4 alternative sites is a, b, c, d. So the priority is a, it is consistent with quotation [4]. It can be seen that FAHP is a worthy method for selection of location of transformer substation.

5. CONCLUSION

The selection of location of transformer substation is an important part of constructing transmission and transformer engineering project, the result affects the investment benefit of engineering directly. Fuzzy analytic hierarchy process (FAHP) is used for selection of location in this paper, and then built a model of selection of location of transformer substation based on FAHP. Using FAHP, it makes the result of evaluation is more reasonable and scientific, and also avoids the flaws of analytic hierarchy process. The target of this method is selection of location of transformer substation, and this method is simple and effective, it can increase the science and normalization of policy.

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