COMPREHENSIVE OPTIMAL SELECTION OF CONNECTION MODE FOR DISTRIBUTION NETWORK BASED ON FAHP

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ABSTRACT

By analysis of traditional connection mode and assessment system for distribution network, a new connection mode by use of the principle of elementary connection for distribution network is presented in this paper. A feasible connection mode of distribution network is constructed by use of various combinations of elementary connection variables and inherent constraint conditions in regions of electricity consumption. An optimal connection mode can be worked out by use of Fuzzy Analytic Hierarchy Process (FAHP) to comprehensively evaluate connection modes by security, reliability and economy performances. Results of calculation example IEEE-14 node system show that the proposed method is feasible.

KEYWORDS

Distribution Network, Elementary Connection, Fuzzy Analytic Hierarchy Process (FAHP), IEEE-14 node system

1. INTRODUCTION

With the rapid development of economy, the demand for electricity is growing, and requirements of reliability and economy performances in Electricity are more stringent. How to choose the optimal connection mode is an important piece of work in the planning and construction of MV power distribution network structure. The structure and connection of distribution network is complicated, and traditional mode only analyses the reliability and economy of it. The selection of connection is based on planners' personal experience and subjective judgment, which is unconvincing.

Some scholars have made studies in this field. For example reference [1] classifies connection modes of MV power distribution network according to Structured Element Theory, which provides new ideas to MV power distribution network planning. Reference [2] constructs a feasible connection mode of distribution network by various combination of elementary connections, proposes a dynamic evaluation model for elementary connection and achieves typical connection modes for distribution network under different boundary conditions. Reference [3] proposes an integrated decision making method of connection mode for High voltage distribution network by use of Interval AHP.

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This paper uses FAHP to evaluate different combinations of connection modes based on elementary connection mode. The judgment matrix constructed in this paper can make full use of the information in alternative program, and can combine the qualitative and quantitative analysis organically. This provides new method to select optimal elementary connection mode for distribution network.

2. ELEMENTARY CONNECTION M FOR DISTRIBUTION NETWORK

2.1. Elementary Connection Method

Element is defined as the basic unit of energy transportation in distribution network, which means the simplest power supply mode in connection mode. For the aspect of structure, element usually consists of power source, load, line or several elements. The structure of elementary is shown in Figure 1.

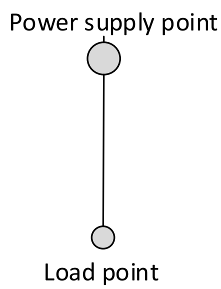


Figure 1. Structure of element

Elementary connection is the most basic and indivisible part of distribution network, which shows its characteristics as a whole to the outside. Several elements can be combined to form complex and diverse distribution network according to certain principles, as is shown in Figure 2.

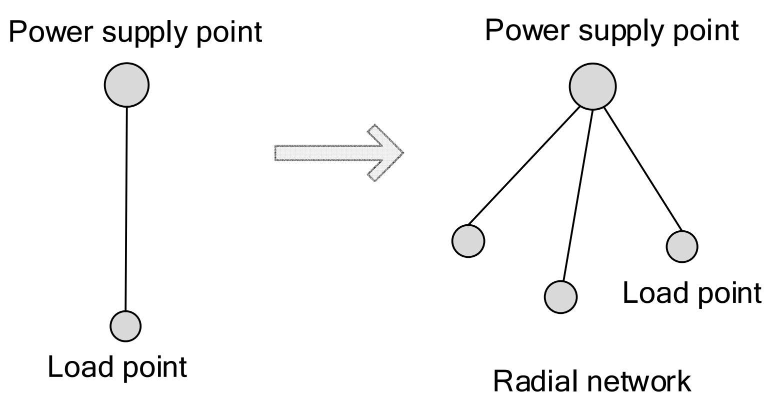


Figure 2 Diverse distribution network by combination of elements

2.2. Combination of Elements

Any complex network U in planned area has equivalent elementary connection mode correspondingly. Each kind of connection and its parameters constitutes an elementary collection (elementary variables), while each elementary variable contains all categories of parameters of this kind of connection.

In elementary connection combination, elementary combined variable T(x) is characterized by a 4-element array(x，U，G，M), as is shown in Figure 3. Among them, x_i (i=1, 2…n) means different category of elementary connection, U_i (i=1, 2…n) means the objective factors of the planned regions where elementary connections combine, G_i (i=1, 2…n) means different load property of one certain planned district, M_i (i=1, 2…n) means corresponding constraint conditions.

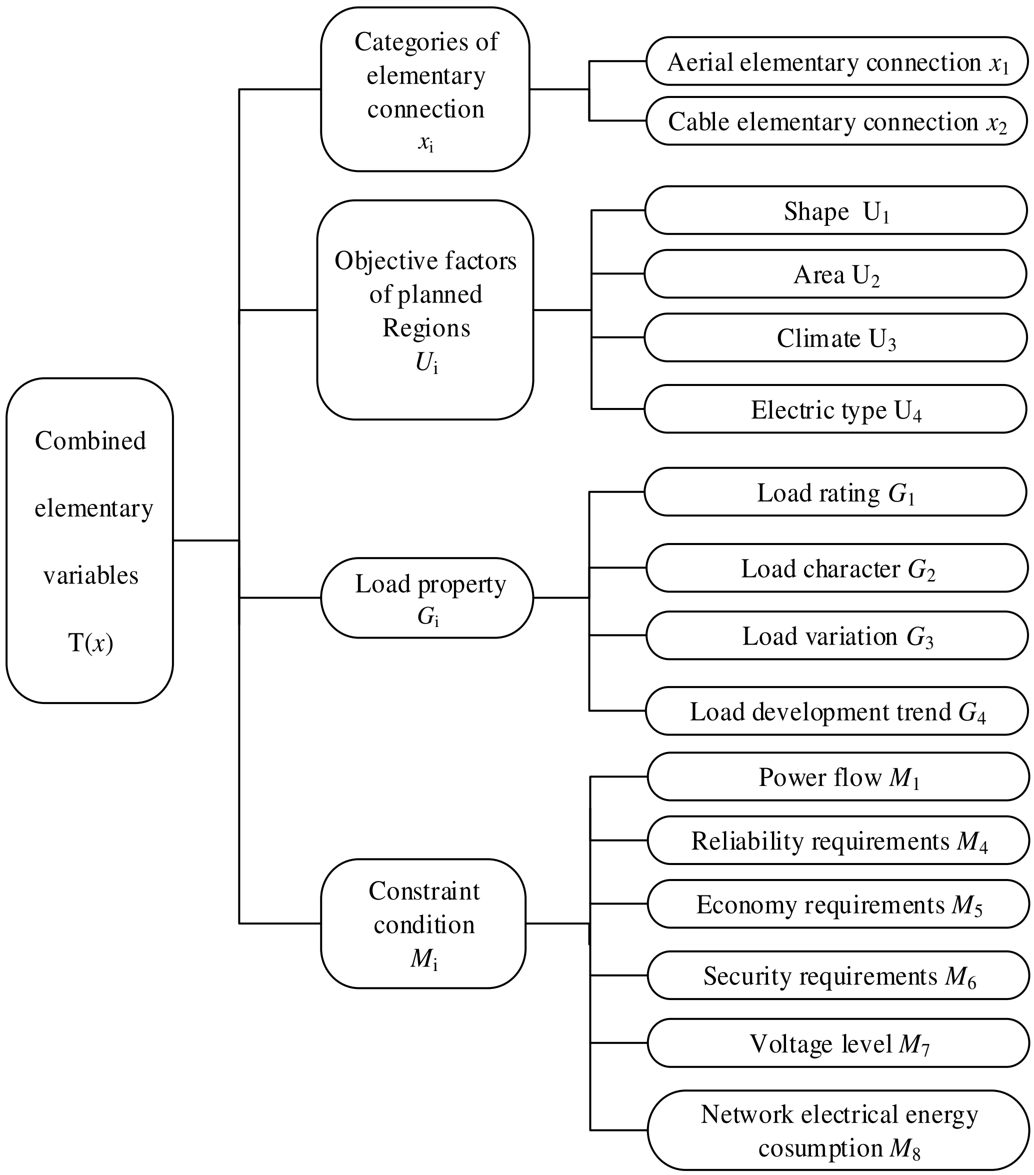


Figure 3 Combined variables of elementary connection

3. THE THEORY OF FAHP

In order to adapt to the ambiguity and uncertainty of the judgment matrix, this paper uses the triangular fuzzy number proposed by Dutch scholar Van Laarhoven to give the fuzzy judgment matrix. It is expressed with an interval, instead of a single judgment value [4].

4. COMPREHENSIVE EVALUATION SYSTEM FOR THE OPTIMAL CONNECTION MODE BASED ON FAHP

4.1. The Basic Evaluation Index

4.1.1 Safety

Safety indicators applying to all distribution network connection method are the fault severity index C_{SF} and wiring safety index S_S.

$$C_{SF} = (\sum_{i=1}^{N_B} C_F^i) / N_B \quad (1)$$

Where N_B is the number of branches, C_F^i is a single fault severity index of the I line.

$$S_S = k' / C_{SF} \quad (2)$$

Where k' is the strength index of the spatial grid structure system. A distribution network connection security is higher, the larger the k' is, the probability of failure after load rejection will be smaller, the smaller the negative impact of the failure is.

4.1.2. Reliability

System mean power frequency index F_{SAIFI}, system average outage duration index F_{SAIDI}, the average power supply reliability index η_{ASAI}.

$$F_{SAIFI} = \frac{\sum_i \lambda_{si} N_i}{\sum_i N_i} \quad (3)$$

$$F_{SAIDI} = \frac{\sum_i N_{si} N_i}{\sum_i N_i} \quad (4)$$

$$\eta_{ASAI} = \frac{8760 \sum_i N_i - \sum u_i N_i}{8760 \sum_i N_i} \quad (5)$$

Where λ_{si} is the average outage rate of load point I; U_i is the average annual outage time; N_i is number of user.

4.1.3. Economy

Economic evaluation mainly includes two aspects of financial performance evaluation and technical and economic benefit evaluation. Financial evaluation is mainly from future load demand forecasting whether the investment will get profit; Technical and economic benefit evaluation is from the Angle of power distribution network itself to judge the economic benefits of planning scheme.

Financial Net Present Value Rate N_{PVR} and Internal rate of return I_{RR} are higher showing the better economic benefit.

$$N_{PVR} = \frac{N_{PV}}{I_p} \tag{6}$$

Where N_{PV} is Net present value; I_P is the present value of the investment; I_{RR} is usually calculated by interpolation.

$$I_{RR} = i_1 + \frac{N_{PV}(i_1)}{N_{PV}(i_1) + |N_{PV}(i_2)|}(i_2 - i_1) \tag{7}$$

Where i_1, i_2 respectively taken by the trial with lower and higher discount rate; $N_{PV}(i_1)$、$N_{PV}(i_2)$ respectively corresponding to the net present value of i_1 and i_2. Economic benefit evaluation of technology, the use of units of total assets of the maximum expected return as evaluation indexes F_P:

$$F_P = \frac{F_{\max}}{C_E} \tag{8}$$

Where F_{max} is grid maximum expected earnings; C_E is total assets of grid. The index reflect the unit total assets of the maximum expected profit contribution of power grids, besides considering grid power supply capacity, also considering the power supply reliability, line loss, electricity price, the influence of such factors as the index. The higher the parameter values are, the better the power grid technology economy is.

4.2. Steps of Comprehensive Evaluation System for the Optimal Connection Mode

4.2.1 Steps of Build Connection Method of Distribution Network by Elementary Connection

1) Forecast a kind of electricity area for load, based on annual electricity consumption electricity area, by investigating each load types and each type the number of users to calculate the predictive load value.
2) According to the load forecasting, determine the level of substation capacity, the number of new substation, the substation location and planning, making its meet the requirements of the load level and already some technical constraints, and making the optimal economic indicators.
3) According to the source of capacity, load rate, line number from substation site selection constant volume and the load capacity of transformer substation from load forecasting. Using the elementary connection method determine how many primitive wirings from power to the load for

power supply can meet the requirements. Through the formula 11, we can calculate the number of elementary connection.

$$N = \frac{P_2}{P_1 \theta / n} \tag{9}$$

Where Source capacity noted P_1, load factor noted θ and the number of wires on substation noted P_2.

4) According to the number of primitive connection, determining its primitive connection type and planning the needs of geographical conditions, analysing the distribution network wiring inherent in the various constraint conditions, screening to get the typical connection mode satisfied conditions.

5) According to the above steps for distribution network connection method, we use FAHP to evaluate and get the optional connection method from safety, reliability and economy aspect.

4.2.1 Steps of FAHP Algorithm

1) Build fuzzy triangle judgment matrix

Pairwise comparing the indicators of each level, build the fuzzy triangle judgment matrix $A=(a_{ij})_{n\times n}$. It has the following characteristic:

$$a_{ii} = 0.5, \quad i = 1,2,...,n; \tag{1}$$

$$a_{ij} + a_{ji} = 1, \quad i, j = 1,2,\ldots,n; \tag{2}$$

In order to make any two solutions about the relative importance of certain standards for quantitative description, we usually use the 0.1~0.9 scaling, comparing a_1, a_2, … , a_n, we can get the following fuzzy triangle judgment matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

2) Calculate the weight of fuzzy triangle judgment matrix

Reference [5] inferred a formula calculating the weight of fuzzy triangle judgment matrix. The formula of fully contains the excellent characteristics of fuzzy triangle judgment matrix and its judgement information, small amount of calculation and convenient for computer programming implementation, has brought great convenience for practical applications.

$$W_i = \frac{\sum_{j=1}^{n} a_{ij} + \frac{n}{2} - 1}{n(n-1)}, \quad i = 1,2,...,n \tag{10}$$

3) Inspect the consistency of fuzzy triangle judgment matrix

In order to judge if the result of weight is reasonable, reference [6] inferred a method of inspect the fuzzy triangle judgment matrix by using the compatibility of matrix:

Definition 1:

$$I(A,B)=\frac{1}{n^3}\sum_{i=1}^{n}\sum_{j=1}^{n}|a_{ij}+b_{ij}-1| \tag{11}$$

Where A, B are the index of compatibility, $(a_{ij})_{n\times n}$, $(b_{ij})_{n\times n}$ are fuzzy triangle judgment matrix
Definition 2:

$W=(W_1, W_2, \dots, W_n)^T$ is the weight vector o f A, and $W_{ij}=\frac{W_i}{W_i+W_j}(\forall i, j=1,2,...,n)$ so $W^*=(W_{ij})_{n\times n}$ is the characteristic matrix of A. About Policymakers' attitude α, when compatibility indicators I(A,W*)≤α, we could regard the judgement matrix as consistency. The smaller theαis, which indicates policy makers on the consistency of fuzzy judgment matrix is higher, usually α=0.1.

For the actual problem, experts give judgment matrix on the same factors X.

$$A_k=(a_{ij}^{(k)})_{n\times n}, k=1,2,\cdots m$$

They are all fuzzy triangle judgment matrix, so we can get their set of weights.

$$W^{(k)}=(W_1^{(k)},W_2^{(k)},\cdots,W_n^{(k)}), k=1,2,\cdots,m$$

Inspect satisfactory compatibility between the judgment matrixes.

$$I(A_k,A_l)\le\alpha,\quad k\ne l; k,l=1,2,\cdots,m$$

Then we take m set of weighted average as the weight of factors set X vector distribution.

$$W_i=\frac{1}{n}\sum_{k=1}^{m}W_i^{(k)}, i=1,2,\cdots n$$

4) Calculate comprehensive weight

After getting each layer of judgment matrix for local weight, using the following formula to calculate connection method of a layer of attribute weights.

$$W_i^{k+1}=\sum_{j=1}^{n}W_{ij}^{(k)}W_j^{(k)},\ i=1,2,...,m \tag{12}$$

Where m represents the number of connection method; W_i^{k+1} is I connection method toward a certain attribute $A^{(k+1)}$ in k+1 layer; n is the number of child attributes of $A^{(k+1)}$; is the weight of $W_j^{(k)}$ $A^{(k+1)}$

toward child attributes j in k layer; $W_{ij}^{(k)}$ is the weight of I connection method toward child attributes j.
Finally, we select the highest weight connection mode, as a typical connection mode of distribution network planning.

5. Example Analysis

A specific example is given to further introduce the application of this method. We use IEEE Graver 14 system, which has 14 independent node, 20 transmission lines, and 5 generators. The system structure is as shown in the following picture. The specific parameters can be inquired in reference [7].

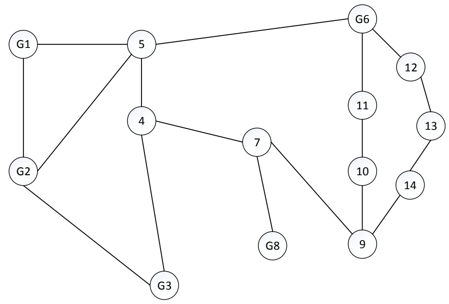
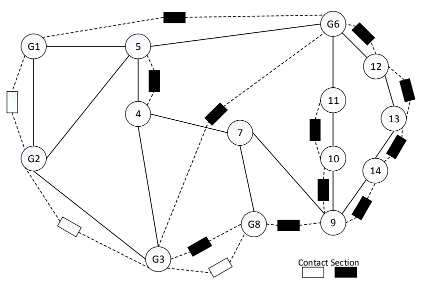
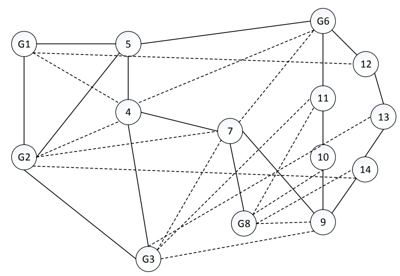


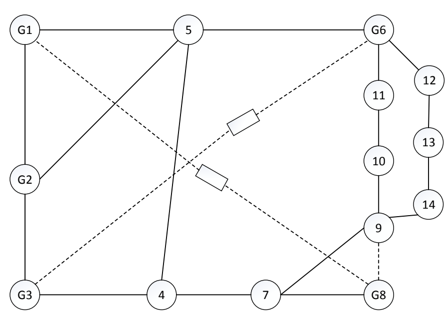
Figure 4. IEEE Graver 14 system initial structure



(a)
(b) Two section two contact connection



(b) "4-1"connection



(c) 4-6 connection

Figure5. Structure of distribution network based on elementary connection

According to the above 3 connection method, using FAHP Algorithm.

1) Hierarchy

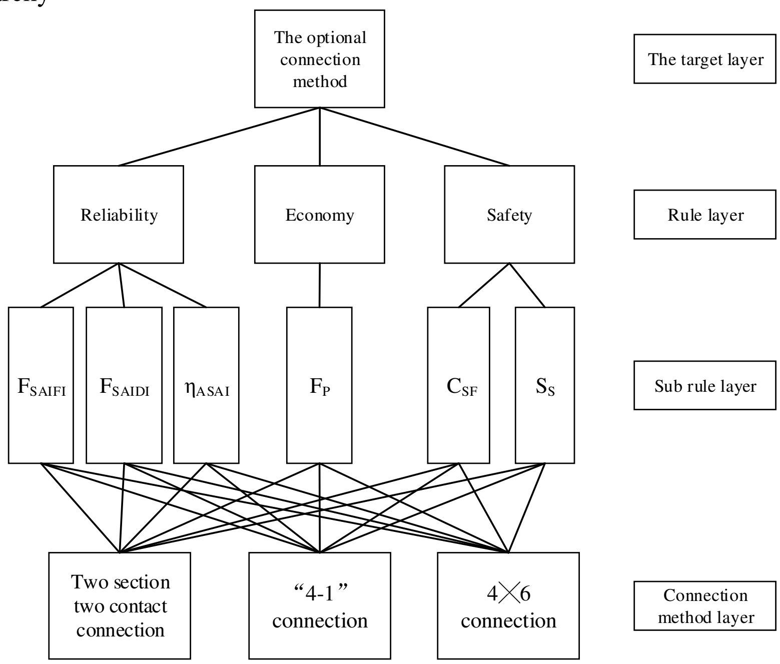


Figure6. Hierarchy

2) Judgement matrix and calculate weight

Expert 1 calculated the judgement matrix toward SAIFI is

$$A_1 = \begin{bmatrix} 0.5 & 0.2 & 0.2 \\ 0.8 & 0.5 & 0.5 \\ 0.8 & 0.5 & 0.5 \end{bmatrix}$$

Where a_1, a_2, a_3 respectively represent two section two contact connection, "4-1"connection and 4╳6 connection.
According to formula 10, weighting vector is

$$W_1 = [0.23\ 0.38\ 0.38]$$

The characteristic matrix of A_1 is

$$W_1^* = \begin{bmatrix} 0.5 & 0.378 & 0.378 \\ 0.622 & 0.5 & 0.5 \\ 0.622 & 0.5 & 0.5 \end{bmatrix}$$

According to formula 11, the compatibility indicators between A_1 and W_1*:$I(A_1 W_1^*)=0.063<$ 0.1.
Expert 2 calculated the judgement matrix toward SAIFI is

$$A_1' = \begin{bmatrix} 0.5 & 0.3 & 0.2 \\ 0.7 & 0.5 & 0.4 \\ 0.8 & 0.6 & 0.5 \end{bmatrix}$$

According to formula 10, weighting vector is

$$W_1' = [0.25\ 0.35\ 0.4]$$

The characteristic matrix of A_1' is

$$W_1'^{*} = \begin{bmatrix} 0.5 & 0.412 & 0.385 \\ 0.583 & 0.5 & 0.467 \\ 0.615 & 0.533 & 0.5 \end{bmatrix}$$

According to formula 13, the compatibility indicators between A_1 'and W_1'*：I(A_1'W_1^*)=0.062< 0.1.

Then two judgement matrix of experts, their compatibility indicators: I(A_1'，A_1)=0.089< 0.1. Integrate two experts' advises, weighting vector is

$$W = [0.24\ 0.37\ 0.39]$$

As for other factors, following the above steps to calculate.

3) Finally the complex weights of three connection method are shown in the following Table 1

Table1. Comprehensive weighted score.

	Reliability	Economy	Safety
two section two contact connection	0253	0.433	0.348
"4-1"connection	0.364	0.135	0.240
4╳6 connection	0.383	0.434	0.412
two section two contact connection	0.345		
"4-1"connection	0.246		
4╳6 connection	0.410		

Overall connection reliability, economy and safety of target are equally important. Thus we can see that 4╳6 connection shows good superiority in high reliability, high safety and high efficiency. But due to the selection of some degree in judgement matrix are related with planning of economic development, user requirement for power supply reliability, when change the emphasis of the planners, the results may change accordingly.

6. CONCLUSIONS

This paper proposes a connection mode of distribution network based on elementary connection method. By use of Fuzzy Analytic Hierarchy Process (FAHP) this paper comprehensively evaluates the inferred elementary connection mode from these three aspects, reliability, economy and safety in qualitative and quantitative ways. Then the optimal connection mode for distribution network is achieved in this way, which avoids the inherent shortcomings of traditional connection modes, breaks the traditional analytical methods of distribution network, and makes the analysis or application of connection modes for distribution network easier. Finally, the example analysis of IEEE-14 node system proves the feasibility of this proposed method.

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