A FUZZY COMPREHENSIVE EVALUATION METHOD FOR CONNECTION MODES OF URBAN HV/MV DISTRIBUTION NETWORK

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ABSTRACT

A fuzzy comprehensive evaluation method is proposed to select distribution network connection modes, in which the complicated feeding mode selection is simplified by means of multiple attribute decision making, the membership functions conformed to the features of evaluation attributes are built, and a comprehensive evaluation system for distribution network planning is constructed. Taking the connection mode selection of a certain typical development area in Shanghai as example, different connection modes are evaluated, and a scheme to evaluate distribution network planning is obtained. The reasonableness and feasibility of the proposed method is verified.

INTRODUCTION

It is important for HV/MV distribution network planning to select the right connection modes. And the issue of which connection mode is most suitable for the selected distribution network is also highly concerned. However, at present, the methods of connection modes selection are just depended on planner's working experience and personal judgment, which are not the systemic evaluation methods. As a result, the economy and stability cannot be fully reflected in planning schemes.

In this paper, the process of multiple attribute decision making is simplified, using in urban HV/MV distribution network connection mode selection. The membership functions conformed to the features of evaluation attributes are established. And combined expert experience with ration calculation, a comprehensive evaluation system is established, which can solve the problem of decision making factors' uncertainty.

A COMPREHENSIVE EVALUATION SYSTEM FOR URBAN HV/MV DISTRIBUTION NETWORK

Evaluation index of distribution network

After classifying and analysing the elements of distribution network, such as reliability, economy, voltage quality, network loss and the like, an analysis model of distribution network connection modes selection can be established. The evaluation indexes are showed in figure 1.

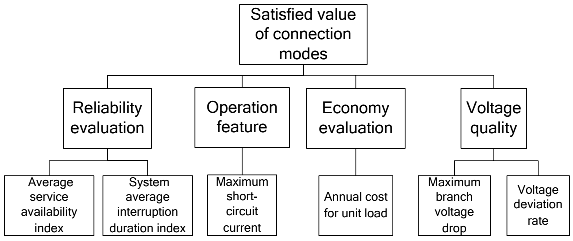

Fig. 1 The structure of distribution network connection mode evaluation system

First layer: object layer

Evaluating the satisfied value of connection modes

Second layer: evaluation layer

Including operation characteristic evaluation, reliability evaluation, economy evaluation and voltage quality evaluation.

Third layer: factors layer

Including six indexes: maximum short-circuit current, ASAI, SAIDI, annual cost for unit load, maximum voltage-drop, voltage deviation rate.

Membership functions selection

Membership functions include many types, such as rectangular distribution function, trapezoidal distribution function, normal distribution function, and so on. According to the demand of practical engineering project, such as the project of urban HV/MV distribution network connection mode selection in Shanghai, some membership functions can be selected as follows.

(1) Maximum short-circuit current index $I_{\max}$

$$\mu = \begin{cases} 1, & 0 \le I \le I_{\max} \\ 0, & I > I_{\max} \end{cases} \quad (1)$$

In formula 1, μ is the membership degree of evaluation attribute, I is the rated short-circuit current in corresponding voltage level, $I_{\max}$ is the maximum short-circuit current in corresponding voltage level. In this paper, $I_{\max}$ is appointed as 16kA in 10kV distribution network or 25kA in 110kV distribution network[10].

(2) Maximum branch voltage drop index ΔU_m

$$\mu = \begin{cases} \exp(-\lambda \Delta U_m), & 0 \le \Delta U_m \le \Delta U_{max} \\ 0 & \Delta U_m \ge \Delta U_{max} \end{cases} \quad (2)$$

In formula 2, ΔU_m is the maximum branch voltage drop value, $\Delta U_{\max}$ is the maximum acceptable voltage drop value, λ is the regulating parameter of curve. Researches show that the maximum branch voltage drop membership function curve can reflect the changing trend of $\Delta U_{\max}$ membership degree effectively, when λ equal to 0.25. And according to the actual situation of distribution network, $\Delta U_{\max}$ equals to 2%.

(3) Voltage deviation rate index a%

$$\mu = \begin{cases} \exp(-\lambda a), & 0 \le a \le a_{\mathrm{m}} \\ 0, & a > a_{\mathrm{m}} \end{cases} \tag{3}$$

In formula 3, a_{m} is the maximum acceptable voltage deviation rate. Here we set λ equal to 0.25 in practice. And according to the actual situation of distribution network, the range of voltage deviation rate in 10kV distribution network is from -7%-+7%, and in 110kV the range is from -3%-+7%[10]. In this paper, the rate of 110kV distribution network is 3%.

(4) ASAI

$$\mu = \begin{cases} \sin[\pi/2(100 - x_0)](x - x_0), & x_0 \le x \le 100 \\ 0, & x \le x_0 \end{cases} \tag{4}$$

In formula 4, x_0 is the minimum value of average service availability. And according to the actual situation of distribution network in this paper, x_0 equals to 99.99.

(5) SAIDI

$$\mu = \begin{cases} \cos(\pi t / 2t_0), & 0 \le t \le t_0 \\ 0, & t > t_0 \end{cases} \tag{5}$$

In formula 5, t_0 is the maximum allowable value of SAID. According to the average interruption duration of distribution network, t_0 equals to 0.5h.

(6) Annual cost for unit load C

$$\mu = \begin{cases} 1, & C \le C_{\min} \\ \dfrac{C_{\max} - C}{C_{\max} - C_{\min}}, & C_{\min} < C \le C_{\max} \\ 0, & C > C_{\max} \end{cases} \tag{6}$$

In formula 6, $C_{\min}$ is the minimum value of annual cost and $C_{\max}$ is the maximum value of annual cost. According to the actual situation, in 110kV distribution network $C_{\min}$ =1000 RMB/MW and $C_{\max}$ =50,000 RMB /MW, and in 10kV distribution network $C_{\min}$ =0.5M RMB/MW and $C_{\max}$ =2M RMB/MW.

Index weight value setting

Standard index system[11] not only evaluating technical indexes, but also evaluating other human-factor indexes, such as human resource index, safety management index, and so on. In this paper, corresponding technical index and local weight factor are classified and normalized to obtain the final weight of evaluation scheme. The schematic of three layers evaluation attribute is showed in figure 2. In this figure, I_{Ω} is the set of the evaluation attribute system, $I_i^{(1)}$ (i= 1~3) is the first evaluation attribute layer of *i* type, and $\omega_{I_i^{(1)}}$ (*i*=1~3) is the local weight factor of the corresponding index $I_i^{(1)}$.

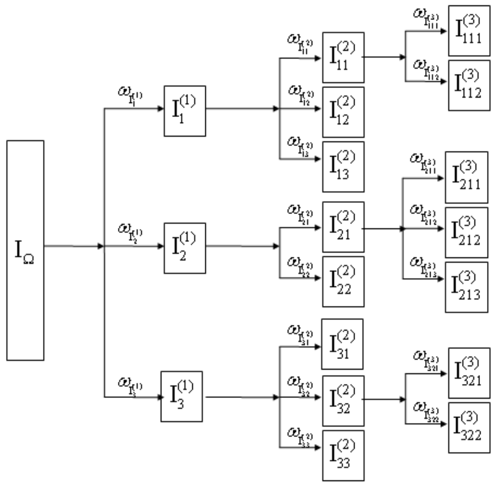

Fig2. The schematic of three layers evaluation attribute

For example, take { $I_{112}^{(3)}$, $I_{13}^{(2)}$, $I_{213}^{(3)}$, $I_{322}^{(3)}$ } as a evaluation attribute set, and its corresponding local weight factor is { $\omega_{I_{112}^{(3)}}$, $\omega_{I_{13}^{(2)}}$, $\omega_{I_{213}^{(3)}}$, $\omega_{I_{322}^{(3)}}$ } . After classifying and normalizing the chosen indexes, the final weight factor set can be obtained.

That is

$$\{ \tilde{\omega}_{I_{112}^{(3)}}, \tilde{\omega}_{I_{13}^{(2)}}, \tilde{\omega}_{I_{213}^{(3)}}, \tilde{\omega}_{I_{322}^{(3)}} \} = \frac{1}{\sum \omega_i} \{ \omega_{I_1^{(1)}} \omega_{I_{11}^{(2)}} \omega_{I_{112}^{(3)}}, \omega_{I_1^{(1)}} \omega_{I_{13}^{(2)}}, \omega_{I_2^{(1)}} \omega_{I_{21}^{(2)}} \omega_{I_{213}^{(3)}}, \omega_{I_3^{(1)}} \omega_{I_{32}^{(2)}} \omega_{I_{322}^{(3)}} \} \tag{7}$$

In formula 7,

$$\sum \omega_i = \omega_{I_1^{(1)}} \omega_{I_{11}^{(2)}} \omega_{I_{112}^{(3)}} + \omega_{I_1^{(1)}} \omega_{I_{13}^{(2)}} + \omega_{I_2^{(1)}} \omega_{I_{21}^{(2)}} \omega_{I_{213}^{(3)}} + \omega_{I_3^{(1)}} \omega_{I_{32}^{(2)}} \omega_{I_{322}^{(3)}} \tag{8}$$

Then, the final comprehensive scores for different connection modes can be obtained from formula 9.

$$P = \sum_{i=1}^{n} \omega_i \mu_i \times 100 \tag{9}$$

In formula 9, P is the final score for each connection mode, ω_i is the normalized weight value for *i* type evaluation attribute, μ_i is the membership degree of *i* type evaluation attribute, and n is the number of the selected evaluation attributes.

APPLICATION EXAMPLE

Example description

A typical 10kV and 110kV distribution network in Shanghai development zone is discussed as an example in this paper. The evaluation attributes' value of different

connection mode can be calculated by power flow. And using the fuzzy comprehensive evaluation method to evaluate all the factors synthetically, such as economy, reliability and operation character of distribution network, the optimized connection modes for different voltage level can be obtained finally.
The specific situation of the development zone can be list as follows:

The area is 3000 hm^2

The range of load density is from 72 W/m^2 to 98 W/m^2

The annual economy increasing rate is about 18.5%

The capcity of 110kV substation is 3×40 MVA, and the average load rate of its main three transformers is 68.2%

The capcity of 10kV substation is 2×800 kVA, and the average load rate of its main three transformers is 67.8%

Then, considering other factors, such as geography and circumstance, the candidate connection modes can be list as follows.
For 110kV distribution network, the candidate connection modes are:

radial connection mode with medium point

whole radial connection mode

hand in hand connection mode with two sides power supply and one breaker

annular connection mode

single side power supply three-T-type connection mode

For 10kV distribution network, the candidate connection modes are:

overhead line connection mode with single source radial type

annular overhead line connection modes for different bus outlet-line

cable line connection mode with single side power supply double-T-connect type

cable line connection mode with"3-1"master-slave type

cable line connection mode which connecting bus outlet-line and switching station

cable line connection mode with single source radial type

annular cable line connection modes for different bus outlet-line

Weight calculation of evaluation attribution

Using the above-mentioned weight selection method, the weight set of the parameters, such as $I_{\max}$、$\Delta U_{\max}$、$a\%$、η_{ASAI}、t_{SAIDI} and C, can be calculated through literature [11].

That is,
{ ϖ_1 , ϖ_2 , ϖ_3 , ϖ_4 , ϖ_5 , ϖ_6 }={0.105,0.032, 0.032,0.128,0.128,0.180}.

After normalizing these weight factors, the final weight factor of each evaluation attribute can be achieved. Table 1 shows the specific data. In table 1, ω_i is the weight factor of each evaluation attribute, $\sum_{i=1}^{6}\omega_i$ =1.

Tab. 1 Final evaluation attribute weight factor

Evaluation attribute	$I_{\max}$	$\Delta U_{\max}$	$a\%$	η_{ASAI}	t_{SAIDI}	C
ω_i	ω_1 =0.173	ω_2 =0.053	ω_3 =0.053	ω_4 =0.212	ω_5 =0.212	ω_6 =0.297

Example analysis

Table 2 shows the calculation indexes for 10kV distribution network in the typical development zone. And Table 3 shows the calculation indexes for 110kV distribution network in the typical development zone. Because the maximum short-circuit current of 10kV distribution network is irrelevant to its own connection mode selection, the short-circuit current and short-circuit capacity of 10kV distribution network are not listed in table 2. And in fuzzy comprehensive evaluation system, the satisfaction degree of the 10kV distribution network short-circuit current is 1. From table 2 and table 3, the final selected connection mode, which is obtained from considering all the evaluation factors synthetically, is different from the connection mode, which is obtained from just considering one evaluation attribute factor. The best connection modes for 110kV and 10 kV distribution network in this typical development area are listed in table 4 separately.

Tab.4 Best connection modes for development zone

Voltage	Best connection modes
10 kV	Annular overhead line connection modes for different bus outlet-line
110 kV	Whole radial connection mode

CONCLUSION

A comprehensive evaluation system for connection modes of urban HV/MV distribution network has been established in this paper, the method of using classified and normalized evaluation attribute to obtain the final weight factor has been presented, and the membership degree function of each evaluation index has also been proposed. Finally, the reasonableness and feasibility of the proposed fuzzy comprehensive evaluation method has been verified by a practical application example in Shanghai, China.

Tab. 2 Calculation indexes of 10kV distribution network

Connection mode	Reliability		Economy	Operation index	Voltage quality		Comprehensive score
	η_{ASAI} /%	t_{SAIDI}/(h/a)	C/ RMB	Power loss/MW	U_m/%	a/%	
Overhead line connection mode with single source radial type	99.995 6	0.384 6	126170	0.262 8	0.304 5	1.027 8	58.47
Annular overhead line connection modes for different bus outlet-line	99.996 6	0.300 3	110591	0.091 2	0.080 8	0.259 31	67.27
Cable line connection mode with single side power supply double-T-connect type	99.994 4	0.488 4	127545	0.296 9	0.139 1	0.735 8	49.33
Cable line connection mode with"3-1"master-slave type	99.997 2	0.242 2	119097	0.074 8	0.099 0	0.271 0	70.95
Cable line connection mode which connecting bus outlet-line and switching station	99.998 3	0.152 6	146131	0.044 8	0.104 3	0.127 2	76.03
Cable line connection mode with single source radial type	99.997 4	0.229 4	118699	0.084 5	0.106 1	0.253 0	71.73
Annular cable line connection modes for different bus outlet-line	99.997 6	0.207 6	119529	0.057 6	0.076 9	0.219 3	73.09

Tab. 3 Calculation indexes of 110kV distribution network

Connection mode	Reliability		Economy	Operation index					Voltage quality		Comprehensive score
	η_{ASAI} /%	t_{SAIDI} / (h/a)	C/RMB	10kV short - circuit capacity/MVA	10kV short - circuit current/kA	110kV short - circuit capacity /MVA	110kV short -circuit current /kA	Power loss/MW	U_m/%	a/%	
Radial connection mode with medium point	99.998 1	0.166 8	28003	186.395 5	10.761 9	1166.475 5	6.122 6	2.906 4	1.357 0	1.403 6	59.67
Whole radial connection mode	99.998 6	0.121 4	14312	186.395 5	10.761 9	1166.475 5	6.122 6	0.616 5	0.257 2	0.242 5	85.64
Hand in hand connection mode with two sides power supply and one breaker	99.998 0	0.179 4	25390	186.395 5	10.761 9	1166.475 5	6.122 6	3.286 8	1.252 3	1.522 6	58.43
Annular connection mode	99.998 0	0.177 6	24205	186.395 5	10.761 9	1166.475 5	6.122 6	3.147 5	0.871 8	1.211 9	60.73
Single side power supply three-T-type connection mode	99.997 7	0.201 8	40342	186.121 1	10.746 0	1166.475 5	6.122 6	4.820 1	1.585 8	2.178 8	38.37

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