Multi-dimensional Index System Optimization of the Distribution Network Based on Sensitivity Analysis Method

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Abstract—The research about distribution network has reached a good level currently, but there is not exit a comprehensive and rational approach to evaluation indicators of the distribution grid in overall level. Therefore, this paper presents the method of sensitivity analysis. This method can be applied to engineering for multi-dimensional evaluation of the distribution network index. Through the establishment of the sensitivity analysis functions, the sensitivity degree of each index to the distribution network can be achieved and some relevant index can be classified optimization in order to the key point to improve the distribution network. This method can be also used to provide a direction to the further development and construction of distribution network. Meanwhile, the normal distribution method are used to the index interval optimization in order to provide a good theoretical basis to the optimize of indicator interval of the distribution grid.

Key words: Sensitivity analysis; normal distribution; evaluation system; deviation; power grid construction.

I Introduction

Distribution network construction is a complex and difficult engineering with the feature of large scale, uncertainty and involved a wide field[1]. After grasped the direction of the distribution network construction, improvement can be achieved by conducting construction. Retrofit planning of distribution network can be achieved on the basis of analysis of the distribution network. The distribution network analysis is based on the analysis of indicator system of the distribution network in order to make an accurate and scientific assessment for the distribution network.

For the evaluation of multi-index system, the widely adopted evaluation method is by solving out the weights of each indicator, but it is complex and difficult. The determination of weight method can be classified as the subjective method and objective method. The subjective weight method includes eigenvector method[2], Delphi method[3], analytic hierarchy process method[4], expert marking method[5-6], precedence chart method[7], fuzzy analytic hierarchy process method[8] and so on. The objective weight method includes entropy method[9], principle component analysis method[10], improved entropy method[11-12] and so on. But these methods are complex and difficult to calculation. The amount of calculation is very big when need to handle a lot of data. Furthermore, these methods are easily affected by the limitations of capabilities of decision maker. The method has a great randomness and strong subjectivity.

For the multi-dimensional index system, the

relativity can be defined as the measured of changes of two different class index. The multi-objective decision is the problem of choose the optimal alternative with multi-objective consideration. This method occupies a very important position in the research field of management, economics, operations research and systems engineering and so on.

Under the above background, this paper provides the sensitivity analysis method which is objective, fast and ordinary. This method is also suitable for engineering evaluation analysis.

II Optimization of multi-dimensional index system

A. Sensitivity Analysis Method

The meaning of sensitivity analysis is analysis the sensitivity degree displayed due to the change of surrounding condition of the system. After building the mathematical model and finding out an optimum solution, sensitivity analysis of linear program can be conducted according to the research data change. This analysis can be viewed from two perspectives. Firstly, we hope to know the impact degree of data change to the optimal result. Secondly, we would like to know the allowed variation degree of data in order to keep the optimal result unchanged. The specific steps of sensitivity analysis Method includes three steps. Firstly, collect the specific data. Secondly, establish specific power grid characteristic function. Thirdly, carry on the relativity analysis.

Power system can be seen as a movement system, the general movement system model can be expressed as the following formula:

$$dX(t) = F[X(t)] \tag{1}$$

We can Taylor expand this formula, and ignore the two times and above items of the objective function. Due to the system is operating in the original point, each variable does not change, so $F[X_0] = 0$, and assume that $A = dF(X)/dX|_{X_0}$, then we can be obtained:

$$d\Delta X / dt = dF(X)/dX|_{X_0}\ \Delta X = A\Delta X \tag{2}$$

$$A = \begin{bmatrix} \frac{\partial F_1}{\partial X_1} & \cdots & \frac{\partial F_1}{\partial X_N} \\ \vdots & & \\ \frac{\partial F_N}{\partial X_1} & \cdots & \frac{\partial F_N}{\partial X_N} \end{bmatrix} \tag{3}$$

After these steps, a non-linear function would approximately turn into a linear function.

On the other hand, the model of the distribution network can be simplified and implied quantitative analysis. The characteristic function equation about the system can be simplified.

$$y = \sum_{i=1}^{n} k_i x_i \tag{4}$$

$$k_i = \frac{\partial y}{\partial x_i} \approx \frac{\Delta y}{\Delta x_i} \tag{5}$$

After solving out the partial derivative and from sensitivity matrix, we can get the influence factors sensitivity which can influence the system characteristics, and conduct sensitivity analysis furthermore. The variable of y in (4) is the dependent variable. It represents some characteristics of system, such as safety quality, technical equipment and so on. The variable of xi is the independent variable. It represents indicators which are related to the system characteristics. The variable of ki is the sensitivity of xi to the variable of y. It means the relativity of some index to this characteristic. The variable of n is the total number of indicators. In order to overcome the problem of the inconsistent of data unit in the course of calculate, it need to transform the data into the form of non-dimensional firstly.

Non-dimensional is the method of eliminate the influence of the index dimension through simple mathematical changes. There are many kinds of non-dimensional method and can be summed up as linear dimensionless method[14-15], line type non dimensional method[16-17] and dimensionless curve

method[18-19]. In this paper, we choose the linear dimensionless method to deal with the data. The specific solution steps can be achieved in literature16 and 17.

B. Deviation

In this paper, the index relativity period can be classified as earlier stage, middle stage and later stage with consideration of credible of project construction. The earlier stage is the early indicator improvement and at a very low level, but the relativity is very high. The middle stage is the indicators to improve the fast period and at a middle level. The relativity is relatively high. The later stage is the end of index improvement and has reached the first-class level. In this stage, the amount of improvement is very low and difficult[20-21]. The figure of change trend of the specific relativity is shown in Fig.1.

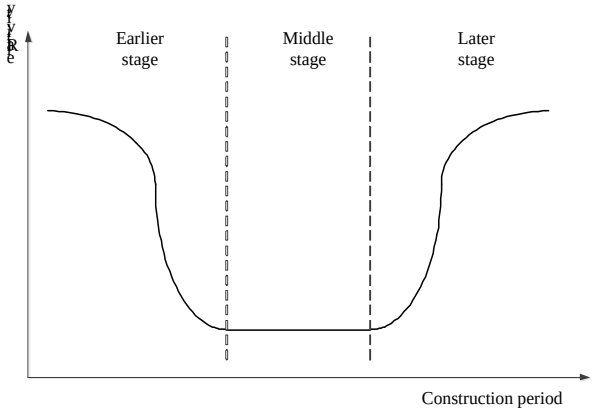

Fig.1.The relationship of index relativity and construction period

Typically, if we take some index as an object, the development and change tendency of a certain indicator can be divided into two cases. Firstly, the value of the index is close to the first-class value from big to small. Secondly, the value of the index is close to the first-class value from the small to big. Whatever this index object is in which development period, it always exit a certain gap d compared with the first-class values (if the index value is in the first-class interval, then d=0). The figure of indicators development trend is as show below.

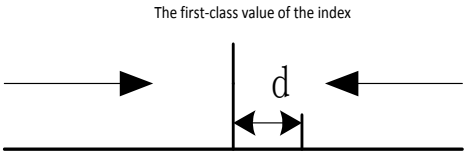

Fig.2. Indicators development trend

Therefore, the variable of deviation which represented by the letter of D can be calculated as follows:

$$D = \frac{|x - x_N|}{x_N} \quad (6)$$

The variable of x in (6) is the actual value of the indicator, x_N is index base value which can be selected when the index reached in the first-class index interval. The deviation of D is the deviation. It represents the deviation level between index value and first-class index base value. The larger the deviation, the greater the deviation level between index value and first-class index base value. On the contrary, the smaller the deviation, the greater the deviation level between index value and first-class index base value. From the perspective of priority degree of improve of the grid index, when the development stage of the index is in the later stage, the smaller the deviation, the smaller the priority degree of improve of the grid index. That means the lower the sensitivity. But because of the limitations of the method of sensitivity analysis, it is necessary to conduct priority optimization of index system by using the deviation on the basis of sensitivity. The limitations of the sensitivity analysis method can be eliminated by introducing the concept of deviation.

C. Normal Distribution

Normal distribution is a very important probability distribution in the fields of mathematics, physics and engineering and has a great influence on many aspects of statistics. If a random variable X obeys the probability distribution with an unknown parameter μ and a scale parameter σ , the probability density function can be shown as follows:

$$f(x)=\frac{1}{\sqrt{2\pi}\sigma}\exp(-\frac{(x-\mu^2)}{2\sigma^2}) \quad (7)$$

The random variable obeys normal distribution. The normal distribution can be recorded as: $X \sim N(\mu,\sigma^2)$. It means X obeys $N(\mu,\sigma^2)$, or X obeys Normal distribution.

when $\mu=0$, $\sigma=1$, then the normal distribution becomes the standard normal distribution, as follows:

$$f(x)=\frac{1}{\sqrt{2\pi}}\exp(-\frac{x^2}{2}) \quad (8)$$

For a sample value，we can average the data to get $\overline{x}$ and calculate the standard deviation σ. According to the principle of the optimal solution of normal distribution method, the optimal interval values of normal distribution can be achieved and got the data interval from A to E. Finally, according to the actual situation, the section can be selected.

III Case analysis

In this paper, we chose the index evaluation system of distribution network as the research object. The most important part is the index system related to the distribution network including the N-1 standard of 10（20）KV network, the proportion of single line/single transformer in 110KV substation, average load ratio of 10KV transmission line, average repair time of low voltage distribution network, the N-1 standard of 35 KV network, ratio of 10（20）KV switches without oil. We select data samples of X, Y and Z as three groups, X and Y are the actual value of the sample data, Z is the optimal value of sample data, the specific data are shown in the following table.

Table I BASIC DATA OF EVALUATION INDEX

Index	Unit	*X*	*Y*	*Z*
N-1 standard of 10(20)KV network	%	27.87	30.45	100
The ratio of single L/Single T in 110KV substation	%	21.82	25	5
Average load ratio of 10KV transmission line	%	23	28	50
Average repair time of low voltage distribution network	min	170	140	40
Qualified rate of N-1 standard of 35 KV network	%	96.32	91.67	100
Ratio of 10（20）KV switches without oil	%	91.24	100	100

A. Index Classify Optimization

After transforming the data above into the data without dimension, the specific results are shown in the following table.

Table II NON-DIMENSIONAL TREATMENT

Index	*X*	*Y*
N-1 standard of 10(20)KV network	0	0.035768751
The ratio of single L/Single T in 110KV substation	0.841	1
Load ratio of 10KV transmission line	0	0.185185185
Average repair time of low voltage distribution network	1	0.769230769
Qualified rate of N-1 standard of 35 KV network	0.558223289	0
Ratio without oil of 10（20）KV switches	0	1

According to the calculation results, the deviation and sensitivity of each index can be calculated and classified. The specific results are shown in the following table.

Table III THE FINAL RESULTS OF INDEX

Index	Sensitivity	Ratio of deviation	Index level
N-1 standard of 10(20)KV network	27.95	0.69	1
The ratio of single L/Single T in 110KV substation	6.29	4	1
Load ratio of 10KV transmission line	5.4	0.44	2
Average repair time of low voltage distribution network	4.33	2.5	2
Qualified rate of N-1 standard of 35 KV network	1.79	0.08	3
Ratio without oil of 10	1	0	3

（20）KV switches			

According to the calculation results of deviation and sensitivity, the grade of each index is shown in table III. Level l means the index is far from the first class value and need to optimize firstly. Level 2 means the index is still a little far from the first class value and need to optimize too. Level 3 means the index is close to the first class value and just need to maintain. Therefore，we need to deal with the N-1 standard of 10(20)KV network and the ratio of single L/Single T in 110KV substation first. Then, we need to optimize the load ratio of 10KV transmission line and Average repair time of low voltage distribution network. As for the index of N-1 standard of 35 KV network and ratio of 10（20）KV switches without oil, we just need to maintain them.

By analyzing the sensitivity of each index，we can compare the influence of each index to the distribution network and find out the weak point in the distribution network. At the same time, we can determine the improve priority of each index by the calculation result of sensitivity. In addition, the limitation of sensitivity analysis method can be overcome comparing with the analysis of deviation rate[22]. The result of sensitivity analysis can be furthermore optimized. It plays a Guiding role in the course of construction and improvement of power grid. It also helps to the exit power grid transformation with pertinence.

B. Optimization of Index Interval

Firstly, it should choose one interval as research subject. For example, rate of distribution network loss can be selected as research subject. Basic data should be collected before optimization of interval. The advanced data collected are shown in the following table:

Table IV THE RATE OF DISTRIBUTION NETWORK LOSS AMONG ADVANCED CITIES IN 2014

City	Repair time in middle voltage distribution network
Shenzhen	1.6
Foshan	2.05
Guangzhou	2.3
Xiamen	2.1
Shanghai	1.2
Tongren	1.15
Beijing	2.2
Hangzhou	1.89

1) Get the sample mean and variance.

$$\overline{x} = 1.81,\ \ \sigma = 0.417$$

2) According to the optimization principle of normal distribution, the optimization interval subjected to normal distribution can be obtained. The calculation result is shown in the following table.

Table V OPTIMIZATION INTERVAL SUBJECT TO NORMAL DISTRIBUTION

Interval	Value
$\overline{x}+1\sigma$	2.2284
$\overline{x}+0.33\sigma$	1.9489
$\overline{x}-0.33\sigma$	1.6736
$\overline{x}-1\sigma$	1.3941

3) Get value in each section.

Table VI VALUE IN EACH SECTION SUBJECT TO NORMAL DISTRIBUTION

Optimal value of index：14		Mean value of index：42.18	
section	Interval of data	number	city
Section A	x＜1.3941	2	Shanghai, Tongren
Section B	1.3941≤x＜1.6736	1	Shenzhen
Section C	1.6736≤x＜1.9489	1	Hangzhou
Section D	1.9489≤x＜2.2284	3	Xiamen, Foshan, Beijing
Section E	x≥2.2284	1	Guangzhou

The optimization interval of distribution network loss rate can be identified as 1.2% ～ 1.6736% according to the data in the table above. It should take some measures to improve the interval with the consideration of difference of data statistic caliber, so choosing 1%~2% as the optimization interval of distribution network loss rate. Other index of distribution network can be optimized according to this case.

IV Conclusion

The method of sensitivity analysis and normal distribution applied to the field of index system evaluation of distribution network are presented

firstly in this paper. This research method in the aspect of partition interval is not according to the previous subjective weight and not based on the preference of decision maker, as well as the calculation complexity of objective weight. This method classifies the huge index system Orderly and effectively through the calculation of sensitivity and variability, and find out the index which influent to the system significantly and need to improve at present in a high speed. In addition , the theory evidence is adequate. The method of normal distribution in statistics is used in the optimization of index interval flexibly, and provide good method and theory evidence for the optimization of index. At last, as the research depth of distribution network index system, it can be seen that evaluation mechanisms based on this method will help to the application of project practice.

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