

The environmental evaluation of substation based on the fuzzy analytic hierarchy process

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Abstract. This paper studies on the different influences on the environment of the substations and puts forward an index system of environmental protection through the fuzzy analytic hierarchy process. A comprehensive environmental evaluation on a substation is carried out through investigation and measurement of the current environmental factors, and the statistical data has validated the effectiveness and feasibility of this evaluation index system. The results indicate that the proposed model has high efficiency.

1. Introduction

In view of the environment impact on the surrounding residents, environmental issues caused by the power substations, including waste[1], electromagnetic environment[1-2] and SF₆ leakage, get more and more serious along with the rapid development of the power grids. In order to eliminate people's fear on environmental pollutions and to promote the construction of green substations, it is important to assess the impact of substations on environment effectively and comprehensively. However, only few literatures have studied on this problem. There is a lack of complete substation environmental evaluate system[1] and a comprehensive evaluation model which are necessary to protect the environment from pollutions produced by substations.

There are many influence factors concerning substations, while the correlations between these factors are too weak to build a well-defined evaluate system. Meanwhile, many influencing factors are fuzzy and cannot be quantified. As a decision method focusing on fuzzy data, Analytic hierarchy process (AHP) can express a complex problem in an orderly hierarchical structure. It is easy to determine the weight of different indicators by comparison, judge and calculation. By applying the fuzzy comprehensive evaluation method[3-5], which is a comprehensive evaluation based on fuzzy mathematics, the qualitative evaluation can be transformed into quantitative evaluation according to the membership degree theory of fuzzy mathematics. Based on these two methods, comprehensive evaluation of substation can solve the multi-factor and multi-index weight problem. This paper presents a fuzzy hydrological level evaluation model based on fuzzy analytic hierarchy process. The evaluation model will help to control the pollutions emissions of the substation and optimize its layout design.



2. Environmental status of substation

There are many problems in substation environmental management such as waste water, audible noise, radio interference and so on. There are two kinds of waste water generated during the operation of the substation, one is domestic sewage and the other is oily waste water, both of them will pollute groundwater and soil. The leakage of SF₆ gas and its decomposition products will be accumulated to the indoor space, resulting in local hypoxia and poisoning. During the substation operation, the audible noise generated by the power transmission equipment will affect the surrounding environment. In addition, the power transmission equipment always causes the radio interference and it will affect the surrounding environment and interfere with the wireless communication equipment such as mobile phones, televisions and radios on nearby residents. What's more, the power frequency electromagnetic field has long-term ecological effects on the human, animal and even plants[6]. A large number of studies have shown that the incidence of cancer in high-intensity electromagnetic field (such as childhood leukemia, adult brain tumour and breast cancer) is much higher than the crowd in low exposure.

For the current analysis of the substation status, most factors are weakly correlated, and some of the concepts are too fuzzy to quantify the standard. Therefore, in order to get a reasonable evaluation of these factors, the fuzzy comprehensive evaluation method is applied in this paper.

3. Evaluation model of substation environmental protection

In this chapter, a fuzzy comprehensive evaluation model is established through five steps. Step 1: establish an index system. Step 2: determine the indexes weight set. Step 3: establish the fuzzy comment set and get the judgement matrix. Step 4: select the synthesis operator and get the fuzzy comprehensive evaluation result. Step 5: analyse the fuzzy comprehensive evaluation result and take targeted measures. The details are described in the following.

3.1. The establishment of index system

In this paper, the substation environmental protection index system covers substation waste, SF₆, audible noise, radio interference and electromagnetic environment, to ensure the integrity of the indicators. In addition, subjective factors should be considered, such as substation environmental management level. Substation environmental impact index system is established as shown in figure 1.

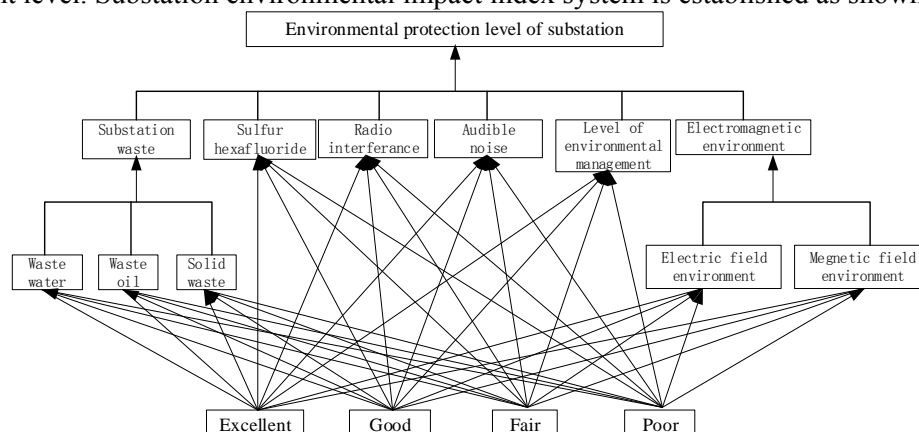


Figure 1. Evaluation index system for substation environment.

In the case of judging the corresponding factors, we need to determine the weight between the various factors. AHP is applied to determine the weight set of indexes in the following.

3.2. Determination of the indexes weight set

In this paper, the expert scoring method is used to judge the factors of each level, and then the quantitative representation of the relative importance is given. The mathematical model is established to calculate the weight of the relative importance of all the factors of each level, and sorted. Judgment

matrix[3] is obtained by comparison of two factors, the reference numbers 1 ~ 9 and their reciprocal are shown in table 1.

Table 1. Assignment standard of elements in the judgement matrix.

a_{ij}	Definition	a_{ij}	Definition
1	Ai and Aj are equally important	2	Between the same and slightly important
3	Ai is slightly more important than Aj	4	Between slightly and obviously important
5	Ai is more important than Aj	6	Between the obvious and the extremely important
7	Ai is extremely important than Aj	8	Between the very obvious and the absolute important
9	Ai is absolutely important than Aj		

Judgment matrix A to the largest eigenvalue of the eigenvalue of the λ_{\max} , after normalization is the same level, factors for a certain level of the relative importance of a certain sort of weight, this process is called hierarchical single order. If the result of the comparison is exactly the same before and after, the elements of matrix A should also satisfy:

$$a_{ij}a_{jk} = a_{ik}, \forall i, j, k = 1, 2, \dots, n \quad (1)$$

If the maximum eigenvalue λ_{\max} of the matrix A is equal to n and the consistency is satisfied, it is necessary to check whether the judgment matrix satisfies the consistency after passing the judgment matrix. The judgment steps are as follows:

- 1) Calculate the consistency index CI

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (2)$$

- 2) Find the corresponding average random consistency index RI, as shown in table 2.

Table 2. The different value of RI with different n.

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.52

The value of RI is obtained by constructing 500 sample matrices in random numbers, extracting the positive constructor matrix from 1 to 9 randomly and its reciprocals to obtain the mean of the largest eigenvalues and defining:

$$RI = \frac{\lambda'_{\max} - n}{n - 1} \quad (3)$$

- 3) Calculate the consistency ratio CR

$$CR = \frac{CI}{RI} \quad (4)$$

- 4) Level total ranking and consistency check

Finally, the weight between elements of the same order and the whole set of elements should be deduced. According to the index questionnaire designed in figure 2, the table will be handed over to the relevant experts for evaluation and scoring. According to the expert evaluation form of recycling, the hierarchical model is established to determine the judgment matrix and the weight of each index is obtained. As shown in table 3-5.

It is estimated that the index weight of each index is passed the consistency test. We can get the weight set as $A = \{\text{Waste water, Waste oil, Solid waste, Radio interference, Audible noise, Environmental management level, Electric field environment, Magnetic field environment}\} = \{0.0293, 0.1172, 0.0293, 0.0738, 0.1392, 0.2529, 0.2687, 0.0896\}$.

Table 3. Criteria for each index judgment matrix.

	Waste	Radio interference	Audible noise	Environmental management level	Electromagnetic environment	Weights W_i	Consistency test	
							λ_{\max}	CR
Waste	1	2	1	1	1/2	0.1758	5.0882	0.0197 <0.1
Radio interference	1/2	1	1/2	1/3	1/6	0.0738		
Audible noise	1	2	1	1/2	1/3	0.1392		
Environmental management level	1	3	2	1	1	0.2529		
Electromagnetic environment	2	6	3	1	1	0.3583		

Table 4. Judgment matrix of electromagnetic environment.

	Electric field environment	Magnetic field environment	Weights W_i	Consistency test	
				λ_{\max}	CR
Electric field environment	1	3	0.75	2	0
Magnetic field environment	1/3	1	0.25		

Table 5. Judgment matrix of waste.

	Waste water	Waste oil	Solid waste	Weights W_i	Consistency test	
					λ_{\max}	CR
Waste water	1	1/4	1	0.1667	3	0
Waste oil	4	1	4	0.6667		
Solid waste	1	1/4	1	0.1667		

3.3. Judgment matrix

Through above analysis, each index should be determined. In this paper, we determine seven indexes through investigating and measuring waste water, waste oil, solid waste, audible noise, radio interference, electric field and magnetic field intensity. According to the ICNIRP Guidelines[7], the electric field intensity of public exposure value is 5kV/m, and the occupational exposure limit is derived for 10kV/m; the magnetic field intensity of public exposure value is 0.1mT, and the occupational exposure limit is derived for 0.5mT. According to the "GB15707-1995 high voltage AC overhead radio interference limit[8]", for the high voltage transmission line provisions in the distance from the margin of the line projection 20m, the test frequency of 0.5MHz, sunny conditions, not more than 55dB μ W/cm². According to the "GB12345-2008 industrial enterprises boundary environmental noise emission standards[9]", the noise limit is set at 60dB. Based on the above quantifiable indicators, the criteria for the division are shown in table 6.

Table 6. Indexing criteria.

	Excellent	Good	Fair	Poor
Waste oil	<2 kg	2~3 kg	3~4 kg	>4 kg
Solid Waste	<200kg and <500m ³ /year, <15 section / year	200~300kg and 500~750 m ³ /year, 15~20 section / year	300~400kg and 750~1000 m ³ /year, 20~30 section / year	>400kg and >1000m ³ /year, >30section/year
Audible noise	<60dB	60~65dB	65~70dB	>70dB
Radio interference	<48dB μ W/cm ²	48~50dB μ W/cm ²	50~53dB μ W/cm ²	>53dB μ W/cm ²
Electric field environment	<5kV/m	5~6kV/m	6~7kV/m	>7kV/m
Magnetic field environment	<100 μ T	100~120 μ T	120~150 μ T	>150 μ T

After investigation, waste water is mainly produced by the station staff. 100t/year/person is determined as a waste limit through questionnaire. In addition, the environmental evaluation of wastewater also includes waste water treatment facilities. Here, we take waste water as an example as shown in table 7.

Table 7. Fuzzy set of waste water.

Rank	Comments
Excellent	1. There is a complete sewage treatment facilities, including a grid wells, regulating pool, sedimentation tank, contact oxidation tank, outlet pool, sludge pool, rainwater wells and fans; 2. High efficiency of sewage treatment facilities; 3. <100t / year / person.
Good	1. There is a sewage treatment facilities, including a grid wells, regulating pool, sedimentation tank, outlet pool, rainwater wells and fans; 2. High efficiency of sewage treatment facilities; 3. 100 ~ 150t / year / person.
Fair	1. There is a sewage treatment facilities, including a grid wells, the pool; 2. The facilities of sewage treatment efficiency is poor; 3. 150 ~ 200t / year / person.
Poor	1. There is only a sewage treatment facilities, including a grid wells, the pool; 2. The facilities of sewage treatment efficiency in general.

Similarly, fuzzy evaluation is also used in the level of environmental management. Research found that many substations has no written rules, a little advanced substation has accumulated energy-saving experience, but for the establishment and development of environmental management system, but also basically a blank. A total of four levels is divided by environmental management regulations and the experience of staff.

In view of the actual situation of a substation, 100 questionnaires are sent to the staff of the substation. We can obtain a judgment matrix through the statistical processing of data.

3.4. Judge the actual case

First of all, we need to determine the fuzzy synthesis operator. There are four kinds of fuzzy operators[10], including (\vee, \wedge) 、 (\vee, \bullet) 、 (\oplus, \bullet) and $(+, \bullet)$. The model $(+, \bullet)$ takes into account the influence of all factors, and retains the single factor evaluation information. For the substation environmental level evaluation factors characteristics, we choose the model $(+, \bullet)$ as the fuzzy synthesis operator of environmental level.

Taking a 220kV substation as an example, the noise forecasting model of the substation is established by measurement combined with CadnaA software. According to the actual geometric size modeling, we built a basic model of the building which the height of wall is 2.3m, the height of firewall is 7.5m. Two main transformers are the main sound source, the sound pressure level using the measured value is 77.2dB (A), calculate the elevation of 1.5m. The noise distribution results are shown in figure 2. The noise area of the statistical area is (0.833,0.111,0.037,0.019).

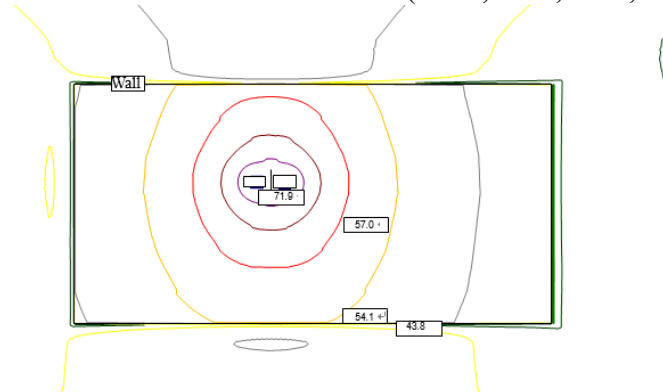


Figure 2. Noise distribution of substations.

In the evaluation of the electromagnetic environment of the substation, we can get the distribution of substation electromagnetic environment through the measurement and IES boundary element simulation software. This simulation is validated by comparing with certain sets of the measured data. To verify the accuracy of the calculation model, this paper takes the 220kV switch-yard as an example, choose a sampling line in the center of the work corridor, and the height of the measurement is 1.5m. Then, the simulation results on the sampling line are compared with the actual measurement results. The results are shown in figure 3 and figure 4.

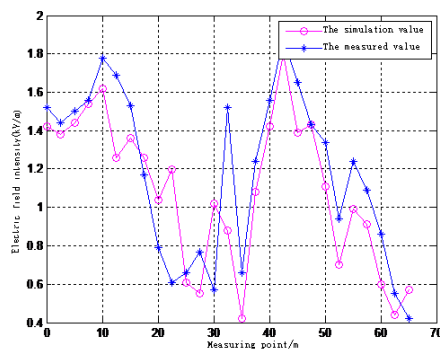


Figure 3. The electric field intensity distribution of the 220kV switch-yard.

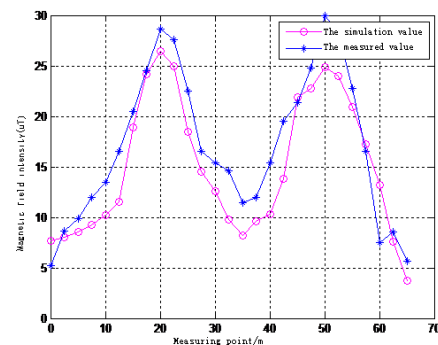


Figure 4. The magnetic field intensity distribution of the 220kV switch-yard.

The distribution results are shown in figure 5 and figure 6. According to the statistics, the electric field environment is judged as (0.667,0.167,0.083,0.083), and the magnetic field environment is judged as (0.995,0.005,0,0).

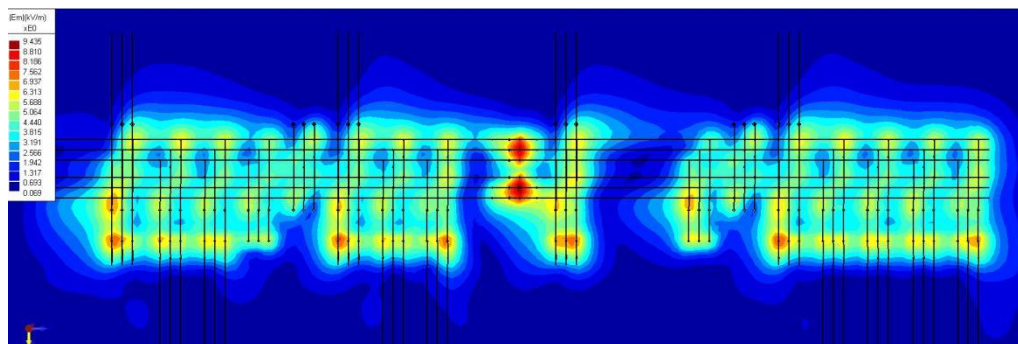


Figure 5. Electric field distribution.

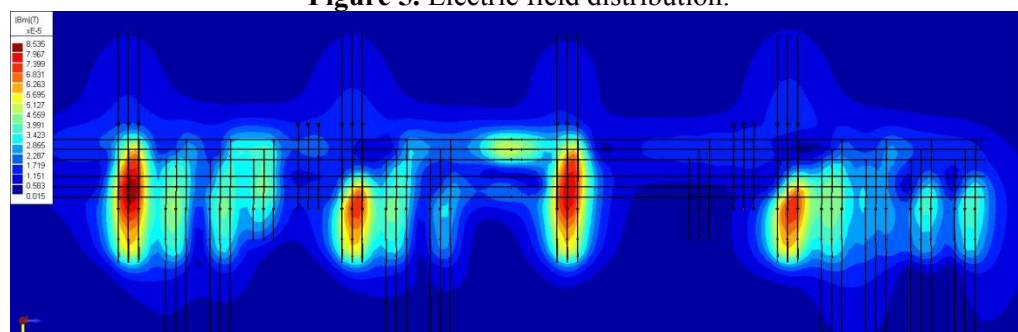


Figure 6. Magnetic field distribution.

We can get the appropriate evaluation of waste oil, solid waste and radio interference by direct judgments, and obtain fuzzy evaluation of waste water and environmental management level through the questionnaire. In summary, the comprehensive judgment matrix is shown below.

$$R = \begin{bmatrix} 0.38 & 0.53 & 0.09 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0.82 & 0.11 & 0.07 & 0 \\ 0.833 & 0.111 & 0.037 & 0.019 \\ 0.21 & 0.65 & 0.14 & 0 \\ 0.667 & 0.167 & 0.083 & 0.083 \\ 0.995 & 0.005 & 0 & 0 \end{bmatrix}$$

Get a comprehensive evaluation of the results

$$B = A \times R = (0.5091, 0.3953, 0.0707, 0.0249)$$

According to the principle of maximum membership, the environmental protection level of substation is excellent. However, the proportion of excellent environmental protection is only 0.5091. In view of the judgment matrix, we should focus on the improvement of waste water, solid waste and environmental management. For the waste water, waste water treatment facilities should be built, such as grille, regulating pool, contact oxidation tank and so on. For the solid waste, waste materials should be promptly clean up; returned lead-acid batteries should be recycled timely in accordance with the provisions. For the level of environmental management, staff should be gathered to summarize the experience of the formation and get a reasonable rules and regulations.

4. Conclusions

In this paper, a comprehensive investigation on the environmental status of the substation is carried and a new substation environmental evaluation system is established. In this model, the AHP and the fuzzy evaluation method are used to evaluate the environmental status of substations. Based on the above methods, results show that the level of waste management and environmental management should also be taken into highly consideration. Moreover, it is necessary to establish an environmental protection management system of substations and to improve the environmental awareness of substation staff. To sum up, the evaluation method has certain industrial practicality.

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