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Priority ordering of power grid emergency repair task based on algorithms of group AHP and TOPSIS

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ABSTRACT

An improved algorithm of Technique for Order Preference by Similarity to Ideal Solution (TOPSIS）is put forward to optimize power grid emergency scheduling. Based on TOPSIS algorithm, the expert decision-making weight coefficients are worked out by group analysis. Then the weights of target attributes of grid are set according to Group Analytic Hierarchy Process (AHP), which not only embodies experts' experience-based judgment but is more objective and reliable to improve the accuracy of the priority order of task. In the simulation analysis, the improved TOPSIS method is applied to get the priority order for urgent repair in power grid accident. The result is identical to the real situation so to have verified the feasibility of this method.

Key words: Power Grid, Priority, Analytic Hierarchy Process (AHP), Weight, TOPSIS

INTRODUCTION

Electric Power is a pillar industry for economic development. As a kind of important infrastructure of power grid, transmission lines frequently layout in remote areas, so they are vulnerable to natural disasters, such as wildfire, fierce wind, and icing etc., with serious failures consequently. In the emergency treatment process of transmission line, emergency management personnel should deal with failures as quickly as possible to avoid personnel injury and diminish economic losses. Therefore, it is always the focus to determinate the priority ordering of emergency repair tasks according to each task's significance promptly [1, 2].

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is an algorithm to make decision and assessment in the process of decision making based on multi-objective sand multi-attributes. By selecting the alternative solution which is the closest to the ideal one of TOPSIS, the priority Ordering is worked out. This method has been applied frequently in many fields, but fewer done in the electric power industry: In Literature [3] TOPSIS is applied to coal blending ratio of thermal power plant. In Literature [4], it is used to assess outer environment of transmission project. In Literature [5], it is used to analyze black-start of power grid. In Literature [6], it is applied to assessing unit load distribution. In Literature [7], it is used to evaluate intelligent reconstruction project for primary equipment in transformer substation.

According to the characteristics of power grid, a method based on algorithms of group AHP and TOPSIS is put forward to priority ordering of power grid emergency repair task, i.e. firstly, weights of multi-attribute indices are given to assess the priority of failure sites whereby group AHP so to ensure the objectivity and accuracy of those weights. Secondly, on the basis of original data matrix given by experts, data are processed, Euclidean closeness is calculated and then priority ordering is conducted. Finally, in a study case, this method is tested for its feasibility on priority ordering of power grid emergency repair tasks [8, 9].

ALGORITHMS OF GROUP AHP AND TOPSIS

Impact Factors in Power Grid Emergency System

Grid failures often occur in different sites simultaneously. In emergency repair decision-making process, sorts of attributes and grading criteria for each attribute should only be determined with fully understandings on the analyzed system. In this paper, factors are determined from the perspectives of failure-caused influences and the features of emergency repair, which affect the significance of each failure site and mainly comprise 4 target attributes as D1 (impact on electric equipment & personnel security), D2 (economic loss for production & people's life), D3 (transformation capacity increase effect of emergency repair), and D4 (consumed time for supplies transformation & emergency repair). The grading criterion of each target attribute is listed respectively in Table 1 for evaluation in practice. According to those grading criteria, decision-makers for priority ordering of urgent repair task could grade 4 target attributes of each failure site, and the normalized matrix could be established by normalization [10].

Table 1: Grading Criterion of Each Target Attribute

Target Attribute	Description	Score
Impact on Electric Equipment & Personnel Security (D1)	Serious	100
	High	70
	Moderate	40
	Low	10
Economic Loss for Production & People's Life (D2)	Serious	100
	High	70
	Moderate	40
	Low	10
Transformation Capacity Increase Effect of Emergency Repair (D3)	greater	100
	great	80
	general	50
	litter	30
	less	10
Consumed Time for Supplies Transformation & Emergency Repair (D4)	longer	100
	long	80
	general	50
	short	30
	shorter	10

Attributes' Weight by Group AHP

Weights could be set subjectively and objectively for algorithm of TOPSIS. Subjective weights are usually given by experts in certain field. Due to the interference of different knowledge background, experience, understandings on evaluated plan, preference and etc., experts always solve the same decision-making problem with an apparently inconsistent result. Based on the principle that the minority is subordinate to the majority, clustering analysis method is used to calculate relative weights by experts' quantified judgment on conformity of same attribute so that the subjectivity-caused bias is decreased[8, 11].

Assumed that there are m experts who will assess n plans, the set of decision-makers is $\mathrm{E}=\{E_1, E_2, \cdots, E_m\}$. $A^k=\left(a_{ij}^k\right)_{n\times n}$ is the judgment matrix by the expert No. k, where a_{ij}^k is the relative significance of attribute i to attribute j and shown in Table 5. Usually, conformity of expert judgment matrix should be tested following the next steps.

Step1: The conformity index ($C.I.$) is calculated as below.

$$C.I.=\frac{\lambda_{\max}-n}{n-1} \tag{1}$$

Where $\lambda_{\max}$ is the biggest eigenvalue of judgment matrix, and n is the order of this matrix.

Step2: The random conformity index ($R.I.$) would be worked out by several time computations of the random judgment matrix. In Table 2, the average random conformity index (ASCI) is listed after 1000 time computations to form a 1×6 matrix which is to be cited later in this paper.

Table 2: Average Random Conformity Index

Order	1	2	3	4	5	6
R.I.	0	0	0.52	0.89	1.12	1.26

Step3: The conformity ratio ($C.R.$) is calculated below.

$$C.R. = \frac{C.I.}{R.I.} \tag{2}$$

When there is $C.R. < 0.1$,the conformity of judgment matrix is acceptable. If the condition is not met, judgment matrix should be rebuilt or adjusted.

Table 3: Meanings for Significance Scale

Significance Scale	Meanings
1	Two elements are equally significant
3	The former element is significant
5	The former element is apparently significant
7	The former element is greatly significant
9	The former element is tremendously significant
2,4,6,8	Middle Values between above judgments
Reciprocal	If the ratio of element i to j is a_{ij} , then there is $a_{ji} = 1/a_{ij}$

Analysis would be conducted following the below procedures.

Step1: M experts would be divided into m classes, then there are $\mathrm{G} = \{G_1, G_2, \cdots, G_m\}$ and $q = m$.

Step2: Normalized matrix of $B^k = \left(b_i^k\right)_{n\times 1}$ is worked out by the normalization of judgment matrix. Where b_i^k is calculated as below.

$$b_i^k = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}^k}{\sum_{i=1}^{n} a_{ij}^k} \tag{3}$$

Step3: The conformity of experts' evaluation is represented with the cosine value of vector angle as below.

$$c_{ij} = \frac{B^i \cdot B^j}{\left|B^i\right| \times \left|B^j\right|} \tag{4}$$

If the value of c_{ij} is bigger, experts' evaluations for i and j are more similar.

Step4: The biggest c_{ij} would be picked up, and its related classes of expert G_s and G_t would be combined into a new class G_{q+1} . There are $c_{i,q+1} = \max\{c_{is}, c_{it}\}$ and $i \neq s, t$.

Step5: The classes G_s and G_t would be removed and the new one G_{q+1} would be put in. There is $q = q+1$.

Step6: If there is $q = 2(m-1)$, the cluster analysis ends. Otherwise, it goes to Step4.

Through the above analysis, experts are grouped into l classes. Experts' opinions in a same class are with a similar significance. Besides, the more experts are in a class, the greater weight coefficient would it be. Given that there are ξ_k experts in class k, the weight coefficient α_k of each expert class equals to the ratio of the number of experts in each class to the one of total experts, i.e. there are $\alpha_k = \xi_k / \sum_{i=1}^{l} \xi_i$ and $\sum_{i=1}^{l} \alpha_i = 1$. The weight coefficient of class k would be worked out now [9, 12].

The subjective weight of target attribute are set, where there are ω=（$\omega_1, \omega_2, \cdots, \omega_n$）, and $\sum_{i=1}^{n} \omega_i = 1$. According to the above calculated weight of each expert, the solution would be conducted by the method of weighted logarithm least squares as below.

$$\min f(\omega) = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{m}\xi_k[\ln(a_{ij}^{k}) - \ln(\omega_j / \omega_i)]^2 \tag{5}$$

Making $\partial f(\theta)/\partial\theta_j = 0$, then Eq.5 will be shifted into Eq.6 and the weight of each attribute would be calculated to form the weight matrix W [9].

$$W = (\omega_j)_{n\times 1} = \left(\frac{[\prod_{t=1}^{n}\prod_{k=1}^{m} a_{jt,l}^{\xi_k}]^{\frac{1}{n}}}{\sum_{i=1}^{n}[\prod_{t=1}^{n}\prod_{k=1}^{m} a_{jt,l}^{\xi_k}]^{\frac{1}{n}}}\right)_{n\times 1} \tag{6}$$

Improved Algorithm of TOPSIS

TOPSIS assumes that the effectiveness decreases monotonously for each attribute, therefore the ideal solution vector comprises the best attribute values, but the negative ideal solution vector comprises the worst attribute values. Then evaluation on the significance of above mentioned elements would be conducted, i.e., comprehensive analysis on significance of p factors and q attributes would be implemented. Here, q attributes could be the solutions of those factors, and priority ordering of significance of each factor should be determined according to its attribute value and Euclidean distance of its ideal solution. For further improvement, Euclidean distance of its negative ideal solution would be considered at the same time [13].

As for p systems, q indices are picked up to comprehensively evaluate and the original data matrix is as below.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1q} \\ x_{21} & x_{22} & \cdots & x_{2q} \\ \cdots & \cdots & \cdots & \cdots \\ x_{p1} & x_{p2} & \cdots & x_{pq} \end{bmatrix}_{p\times q} \tag{7}$$

Original data are normalized to get normalized matrix B as below.

$$B = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1q} \\ b_{21} & b_{22} & \cdots & b_{2q} \\ \cdots & \cdots & \cdots & \cdots \\ b_{p1} & b_{p2} & \cdots & b_{pq} \end{bmatrix}_{p\times q} \tag{8}$$

Where there are $b_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{m} x_{kj}^2}}$ $i = 1, 2, \cdots, p$ and $\mathrm{j} = 1, 2, \cdots, \mathrm{n}$.

Standardized matrix Z is calculated by $Z = BW$, i.e., Z is got by weighting the normalized matrix B as below.

$$Z = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1q} \\ z_{21} & z_{22} & \cdots & z_{2q} \\ \cdots & \cdots & \cdots & \cdots \\ z_{p1} & z_{p2} & \cdots & z_{pq} \end{bmatrix}_{p\times q} = \begin{bmatrix} b_{11}w_1 & b_{12}w_2 & \cdots & b_{1q}w_q \\ b_{21}w_1 & b_{22}w_2 & \cdots & b_{2q}w_q \\ \cdots & \cdots & \cdots & \cdots \\ b_{p1}w_1 & b_{p2}w_2 & \cdots & b_{pq}w_q \end{bmatrix}_{p\times q} \tag{9}$$

Ideal solution vector Z^+ is composed of the best attribute values and negative ideal solution vector Z^- is composed of the worst attribute values as shown below.

$$Z^{+}=\left\{\left(\max z_{ij} \mid j\in J\right),\left(\min z_{ij} \mid j\in J'\right) \middle| i\in P\right\}=\left\{z_1^{+},z_2^{+},\cdots,z_j^{+},\cdots,z_q^{+}\right\} \tag{10}$$

$$Z^{-}=\left\{\left(\min z_{ij} \mid j\in J\right),\left(\max z_{ij} \mid j\in J'\right) \middle| i\in P\right\}=\left\{z_1^{-},z_2^{-},\cdots,z_j^{-},\cdots,z_q^{-}\right\} \tag{11}$$

Where, J is a set of benefit-type attribute that is the higher its value, the greater its significance. J' is a set of cost-type attribute that is the lower its value, the less its significance. In this paper, there are $J=\{D1,D2,D3\}$ and $J'=\{D4\}$. Then the distance from ideal solution is calculated as below.

$$S_{i+}=\sqrt{\sum_{j=1}^{q}(z_{ij}-z_j^{+})^2} \tag{12}$$

And the distance from negative ideal solution is calculated as below.

$$S_{i-}=\sqrt{\sum_{j=1}^{q}(z_{ij}-z_j^{-})^2} \tag{13}$$

The relative closeness to ideal solution is worked out as below.

$$C_{i+}=\frac{S_{i-}}{S_{i+}+S_{i-}} \tag{14}$$

Where, when the value of C_{i+} is more close to 1, the subsystem is more important. Finally, the significance of subsystem is determined according to the value of C_{i+} [14]。

SIMULATION

There are 7 failure sites caused by nature disasters in certain power grid, and 3 experts evaluate 4 attributes of this power grid using the method mentioned above, and the judgment matrix is shown below.

$$A^1=\begin{bmatrix}1 & 1.5 & 1.25 & 2\\ 0.67 & 1 & 0.85 & 1.25\\ 0.8 & 1.18 & 1 & 1.5\\ 0.5 & 0.8 & 0.67 & 1\end{bmatrix}$$

$$A^2=\begin{bmatrix}1 & 2 & 2 & 4\\ 0.5 & 1 & 0.5 & 2\\ 0.5 & 2 & 1 & 1.5\\ 0.25 & 0.5 & 0.67 & 1\end{bmatrix}$$

$$A^3=\begin{bmatrix}1 & 4 & 2 & 2\\ 0.25 & 1 & 0.7 & 0.6\\ 0.5 & 1.43 & 1 & 1.1\\ 0.5 & 1.67 & 0.91 & 1\end{bmatrix}$$

According Literature [15, 16], the results of conformity test are 0.001498,0.036891 and 0.005468 respectively which are all less than 0.1 and meet the requirement for conformity, therefore the judgment matrix needs not to rebuild or adjust. According to Eq.3, the normalized matrix is worked out as below.

$$B^1=(0.337962, 0.222791, 0.264708, 0.174539)$$

$$B^2=(0.439571, 0.18981, 0.250534, 0.120085)$$

$B^3 = (0.449505, 0.128543, 0.212424, 0.209527)$

According to Eq.4, the conformities are worked out as $c_{12} = 0.977116$, $c_{13} = 0.95854$, and $c_{23} = 0.978335$. Therefore, expert 1 and expert 3 are grouped into a new class with 2 persons while expert 2 is the other class by himself. The weight of each expert is calculated below.

$\alpha_1 = \alpha_3 = 2/(2+2+1) = 0.4$, $\alpha_2 = 0.2$

According to Eq.6, the weight of each attribute is calculated below.

$W = (0.404697, 0.188403, 0.249148, 0.157752)$

According to Table1, experts graded for 4 attributes of 7 failure sites in Table 4.

Table 4: Decision on Significance of Power Grid Failure sites

Failure site	D1	D2	D3	D4
site1	50	50	50	50
Site2	80	50	50	50
Site3	50	70	50	50
Site4	50	50	80	50
Site5	50	50	50	70
Site6	80	90	70	30
Site7	20	40	30	70

D4, which is a reversal index, would be positively treated as $D4 = 100 - D4$. To take the site1as benchmark, the values of site 2, 3, 4, 5 would minus the ones of benchmark respectively and the results are listed in Table 5 where differentials for site 2, 3, 4, 5 from site1 on some attributes could been seen (positive value means more harmful and negative value means less harmful). Since the target function is the minimum value function, combining the positive treatment for attribute $D4$, the priority ordering for site1, 2, 3, 4, 5 is 2>4>3>1>5.

Table 5: Significance Differentials for Site 2, 3, 4, 5 from Site 1

Failure Site	D1	D2	D3	D4
Site1	0	0	0	0
Site2	30	0	0	0
Site3	0	20	0	0
Site4	0	0	30	0
Site5	0	0	0	-20

Fig.1 is drawn with the positive treatment attributes values of site 1, 6, and 7. According to the criterion that the bigger value means more harmful with a higher priority, the priority ordering is 6>1>7.

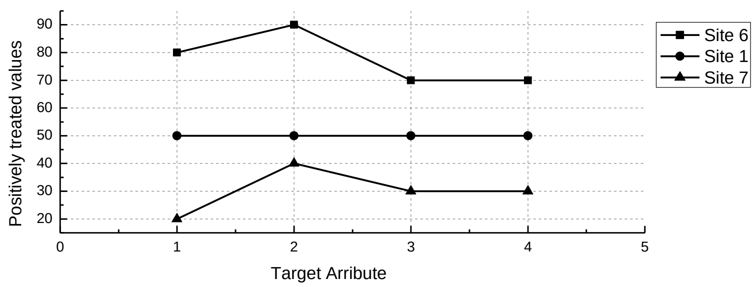

Fig.1: Attribute Value Comparison for Failure Site 1,6,7

According to Eq.7, Eq.8 and Eq.9, the data in Table 4 are transferred into standardized matrix below.

$$Z=\begin{bmatrix}0.132848 & 0.060061 & 0.083609 & 0.054823\\ 0.212557 & 0.060061 & 0.083609 & 0.054823\\ 0.132848 & 0.084085 & 0.083609 & 0.054823\\ 0.132848 & 0.060061 & 0.133774 & 0.054823\\ 0.132848 & 0.060061 & 0.083609 & 0.076752\\ 0.212557 & 0.108109 & 0.117052 & 0.032894\\ 0.053139 & 0.048049 & 0.050165 & 0.076752\end{bmatrix}$$

According to Eq.10 and 11, the ideal solutions and the negative ideal solution are worked out below.

$$Z^{+}=\{0.212557, 0.108109, 0.133774, 0.032894\}$$

$$Z^{-}=\{0.053139, 0.048049, 0.050165, 0.076752\}$$

According to Eq.12, Eq.13 and Eq.14, the significances for site1 to site 7 are worked out as $[0.454548,\ 0.693473,\ 0.491178,\ 0.552784,\ 0.432601,\ 0.918399,\ 0]$.

According to the above results, the priority ordering is 6>2>4>3>1>5>7. According to Table 5, When one attribute changes, the value of attribute is lower, the priority of emergency repair is higher, which is identical to the calculated results of 2>4>3>1>5 for priority ordering.

When changes happen at least to one target attribute, the priority ordering should be adjusted according to the real situation, and the final calculated priority ordering would be identical to the one in Fig.1. In the process of power grid emergency repair, the first important thing is to ensure personnel security, and the second one is to decrease the economic loss etc., which are supported by the reasonable result of simulation.

CONCLUSION

In this paper, a method based on algorithms of group AHP and TOPSIS is proposed for priority ordering of power grid emergency repair task. Firstly, the expert weight coefficient is calculated quantitatively through cluster analysis. Secondly, specific target attribute weight in power grid is worked out according to algorithm of group AHP to make the weights more reasonable and the priority ordering more accurate. The method that algorithms of group AHP and TOPSIS are combined to apply in evaluation on priority ordering of multi-failure site emergency repair task in power grid, would have a broad application prospect in electric power system in future.

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