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Disaster Risk Assessment of Transmission Lines Based on TOPSIS

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Disaster Risk Assessment of Transmission Lines Based on TOPSIS

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Abstract. It is of great significance to ensure the safe and reliable operation of the power grid by effectively evaluating the disaster risk of the power grid lines and arranging the sequence of line guard reasonably. A disaster risk assessment method of transmission lines based on TOPSIS is proposed in this paper where six typical natural disasters of the line are considered, the comprehensive risk values of different lines under different disasters combined with the hazards of line accidents is determined, the risk assessment of multiple transmission lines are realized, and its feasibility is verified by applying it to multiple transmission lines in a certain area of China Southern power grid.

1. Introduction

Extreme natural disasters are the most important external threats to the power grid, especially overhead transmission lines. According to relevant documents, the proportion of power grid accidents caused by natural disasters such as lightning strikes, typhoons, ice storms, bird pests, mountain fires, mudslides, and mountain collapses is increasing year by year in China. These disasters not only bring great damage to power facilities, but also bring great challenges to the meteorological disaster prevention and mitigation work of power system[1-2].

In order to cope with the damage caused by extreme natural disasters to overhead transmission lines and strengthen the construction and protection of power systems, many research institutions and provincial grid power companies at home and abroad have carried out research on the operational risks of transmission lines under natural disasters. To overcome the shortcomings of Lightning distribution map and quantitative calculation method of lightning stroke, a differential and multi-level lightning risk assessment model of "tower - tower section - line" is brought forward[3]. Song Xiaozhe et al. proposed a risk assessment method for power grid transient stability under typhoon weather conditions[4]. Tom B et al. build a power system icing risk assessment model by using the fault tree analysis method, which can evaluate the disconnection of the transmission line and the collapse of the tower effectively[5]. Liu Mingjun et al. established a risk assessment model for the fault trip of the transmission line by computing the probability of line failure under the condition of mountain fire and the occurrence probability of mountain fire on the line corridor[6]. Xiong Xiaofu et al. put forward a transmission line failure rate model that taking into account different meteorological grades and meteorological factors, and proposed a risk analysis method of transmission line based on grey fuzzy theory[7]. Aiming at the shortcomings of current study of mutual impact on varied meteorological disasters on the overhead transmission line, Deng Honglei et al. introduced a comprehensive risk assessment method of transmission line based on AHP and entropy weight method by considering the risk weights, risk probability and risk consequences of various meteorological disasters[8].

In view of the above assessment methods, some studies considered the effects of a natural disaster alone and while the simultaneous effects of various disasters is neglected. Some studies only focused on the failure probability of transmission lines and ignored the consequences of failure so that the assessment results are not comprehensive.

Therefore, in order to remedy the deficiency of the above methods, a disaster risk assessment method of transmission lines based on TOPSIS is proposed in this paper where not only the impact of six natural disasters on transmission lines over the years, but also the hazards of line accidents determined by the load reduction ratio of power grid are considered, a disaster risk assessment model for multiple transmission lines is established, the rationality and feasibility of the proposed method are verified by comparing different methods and analysing the actual situation.

2. Risk assessment framework based on TOPSIS

In this paper, six typical natural disasters are selected including lightning strikes, typhoons, ice storms, bird pests, mountain fires, and external force destruction. Risk assessment framework is shown in Figure 1. The combination of disaster trip-out rate and accident levels of transmission lines is used as assessment system. Combined with the degree of hazard under different disasters, multiple transmission lines are evaluated according to the TOPSIS method.

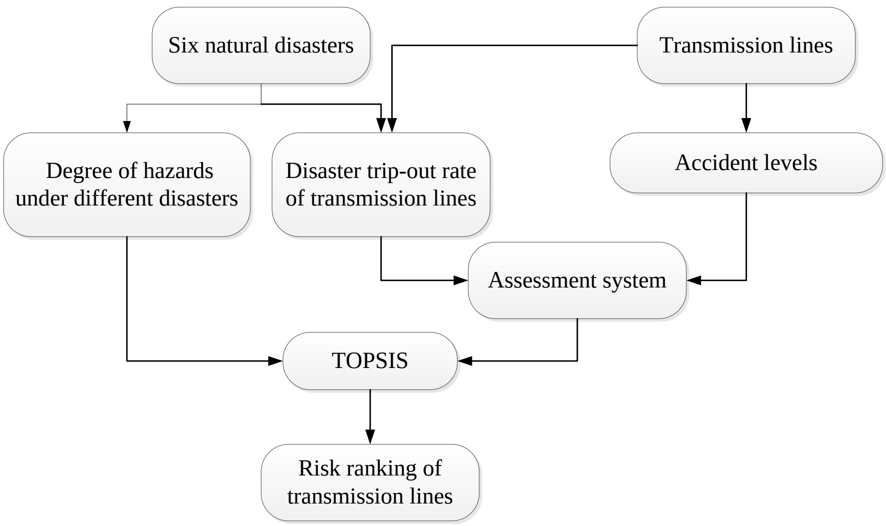

Figure 1. Risk assessment framework based on TOPSIS.

According to the regulations on emergency disposal, electric power safety accidents are classified into special major accidents, serious accidents, major accidents and general accidents based on the extent to which they affect the safe and stable operation of the power system or affect the normal supply of electric power (thermal power). Therefore, the accident of transmission lines is divided into the above four levels in this paper.

For the convenience of calculations, according to *the Regulations on Power Grid Operation Safety Risk Management of China Southern Power Grid Corporation*, the accident level is quantified and the quantified score table is shown in Table 1.

Table 1. Quantification of line accident levels.

S/N	Accident levels	Symbol	Quantized score
1	special major accidents	I	4000~8000
2	serious accidents	II	2000~2400
3	major accidents	III	400~600
4	general accidents	IV	200~250

2.1. Risk assessment method based on TOPSIS

The TOPSIS method which is presented by Hwang and Yoon is a MCDA (multi criteria decision analysis) method that is used to identity solutions from a finite set of alternatives. This method attempts to choose alternatives that simultaneously have the shortest distance from the positive ideal solution (the solution that maximizes benefit criteria and minimizes cost criteria) and the farthest distance from the negative ideal solution (the solution that maximizes the cost criteria and minimizes the benefit criteria). TOPSIS has been identified as a MCDA method which is suitable for problems with large number of criteria and alternatives which are provided with numerical or quantitative data. The method consists of the following steps:

1) Form decision matrix.

For multi-objective decision making system, m as the number of targets to be assessed, n as the number of assessment indicators, then the decision matrix is $R^* = (r_{ij}^*)_{m\times n}$.

2) Establish standardized decision matrix.

A standardized decision matrix $V = (v_{ij})_{m\times n}$ is obtained by dimensionless processing of decision matrix.

$$v_{ij} = (r_{ij}^* - r_{\min(j)}^*) / (r_{\max(j)}^* - r_{\min(j)}^*) \tag{1}$$

Where v_{ij} is the element of standardized matrix, and $r^*_{max(j)}$ and $r^*_{min(j)}$ are the maximum and minimum of the j th indicator respectively.

3) Establish weighted decision matrix.

The weighted decision matrix $X = (x_{ij})_{m\times n}$ is obtained by multiplying the weights of each indicator with the element of standardized decision matrix.

$$x_{ij} = w_j \cdot v_{ij} \tag{2}$$

4) Calculate the distances between the positive ideal solution and the negative ideal solution.

$$\begin{cases} S_j^+ = \max\limits_{1\le i\le m}\{x_{ij}\} \\ S_j^- = \min\limits_{1\le i\le m}\{x_{ij}\} \end{cases} \tag{3}$$

$$\begin{cases} S_{d_i}^+ = \sqrt{\sum_{j=1}^{n}(S_j^+ - x_{ij})^2} \\ S_{d_i}^- = \sqrt{\sum_{j=1}^{n}(S_j^- - x_{ij})^2} \end{cases} \tag{4}$$

5) Calculate close-degree.

$$\beta_i = S_{d_i}^- / (S_{d_i}^+ + S_{d_i}^-) \tag{5}$$

Where β_i is close-degree of the i th target. We can judge the order of the decision target according to close-degree, The larger the value of β_i, the closer to the positive ideal solution, that is, the better the target.

2.2 . Indicator weights of multi-objective systems

2.2.1 Subjective weight of indicators. Subjective weight calculation is a method that reflects the experience or subjective preference of decision makers. The commonly used subjective weight calculation methods include analytic hierarchy process(AHP) , improved analytic hierarchy process (IAHP), G1 and Delphi method. In this paper, G1 and IAHP are used to determine the subjective weight.
G1 is a method to determine the weights of indicators by calculating the relative importance between indicators. its value is determined by experiences of experts[9]. The method consists of the following steps:
1) Determine the relative order of indicators.
The assessment system consist of n indicators, that is, $\{a_1, a_2, \cdots, a_n\}$. The order of importance of n indicators is determined according to the assessment rules , such as $\{ a_1{}^* \succ a_2{}^* \succ \cdots \succ a_n{}^* \}$.
2) Calculate the relative importance between adjacent indicators.

$$r_j = a_{j\text{-}1}{}^* / a_j{}^*, \quad j = 2, 3, \cdots , n \tag{6}$$

Where r_j is determined by the experts according to the parameter table of G1 method.
3) Calculate the subjective weight.

$$w_n^* = (1 + \sum_{k=2}^{n} \prod_{j=k}^{n} r_j)^{-1} \tag{7}$$

$$w_{j-1}^* = r_j w_j^* \tag{8}$$

The AHP method is a systemic analysis method proposed by *Saaty* in the mid-1970s. It is an approach to determine the relative importance of a set of activities in a multi-criteria decision problem and is possible to incorporate judgments on intangible qualitative criteria alongside tangible quantitative criteria. The improved analytic hierarchy process (IAHP) is established on the basis of analytic hierarchy process. This method makes full use of the subjective experience of the decision maker, divides the various factors into different levels to quantify and ranks the advantages and disadvantages of the decision scheme. At the same time, the consistency checking error caused by the unreasonable value of the judgment matrix element is avoided[10].

2.2.2. Objective weight of indicators. Objective weight calculation method is a quantitative analysis method, which calculates the indicator weight according to the sample data by a certain mathematical method. The commonly used objective weight calculation methods include entropy method, grey correlation analysis method and the coefficient of variation (CV). In this paper, entropy method and CV are used to determine the objective weight.
In order to facilitate the calculation of objective weights, a primitive data matrix $R = (r_{ij})_{m\times n}$ is first established, which assumes that there are m targets to be assessed and n indicators in the assessment system. $S = (s_{ij})_{m\times n}$ is a dimensionless matrix of the primitive data matrix and obtained by extreme value method.
Entropy method was first introduced by *Claude Elwood Shannon* into information theory. At present, it has been widely applied in engineering technology, social economy and other fields. The basic idea of entropy method is to determine objective weights according to the variability of indicators.

Generally speaking, the smaller the information entropy of an indicator, indicating that the greater the degree of variation of the indicator value, the more information it provides, the greater the role it plays in the comprehensive evaluation, the greater its weight [11].

The coefficient of variation (CV) is a widely used scaleless measure of variability in many disciplines. CV is estimated by the ratio of the sample standard deviation over the sample mean[12]. The method consists of the following steps:

1) Calculate the mean and standard deviation of each assessment indicator.

$$\mu_j = \sum_{i=1}^{m} s_{ij} / m \tag{9}$$

$$\sigma_j = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(s_{ij} - \mu_j)^2} \tag{10}$$

2) Calculate the coefficient of variation.

$$v_j = \sigma_j / \mu_j \tag{11}$$

3) Calculate objective weight.

$$w_j = v_j / \sum_{j=1}^{n} v_j \tag{12}$$

2.2.3. Comprehensive weight of indicators. In order to make the indicator weight not only reflect the subjective experience of the decision maker but also conform to the objective facts, this paper integrates the above subjective and objective weights and obtains a comprehensive optimization indicator weight[13]. The relative importance coefficients of subjective weight and objective weight are γ and $1\text{-}\gamma$. The optimization model is established as follows.

$$\min L = \sum_{j=1}^{n}\left[\gamma\sum_{a=1}^{2}(w_j - w_{aj})^2 + (1-\gamma)\sum_{b=3}^{4}(w_j - w_{bj})^2\right] \tag{13}$$

Where w_j , w_{aj} and w_{bj} is the j th weight coefficient of the optimization indicator weight vector W, subjective weight vector W_a and objective weight vector W_b respectively.

The constraints of eq. (13) are as follows.

$$\sum_{j=1}^{n} w_j = 1,\ 0 \le w_j \le 1 \tag{14}$$

The subjective and objective expectations of each indicator weight are calculated based on the moment estimation theory.

$$\begin{cases} E(w_j) = (w_{1j} + w_{2j}) / 2 \\ E(w_j') = (w_{3j} + w_{4j}) / 2 \end{cases} \tag{15}$$

Calculate the subjective weight coefficient of each indicator.

$$\gamma_j = E(w_j) / (E(w_j) + E(w_j')) \tag{16}$$

Calculate the relative importance coefficient of subjective weight.

$$\gamma = \sum_{j=1}^{n} \gamma_j / n \tag{17}$$

Calculate the comprehensive weight of indicators according to eq. (13) ~ (17).

3. An application of proposed model

The model is applied to the disaster risk assessment of 8 transmission lines in a certain area of China Southern Power Grid. The voltage level of the transmission line to be evaluated is 220kV. In this paper, lightning strikes, typhoons, ice storms, bird pests, mountain fires, and external force destruction are used as indicators to be evaluated, set up C={C_1, C_2, C_3, C_4, C_5, C_6} as indicators set to be evaluated. Taking 8 overhead transmission lines as targets to be evaluated, set up M = {M_1, M_2, M_3, M_4, M_5, M_6, M_7, M_8} as target set to be evaluated.

3.1. Calculation of comprehensive indicator weights

3.1.1. Calculation of subjective weights. According to the degree of risk and harm caused by six kinds of disasters to transmission lines, the relative order of indicators is established, where lightning strikes > ice storms > mountain fires > external force destruction > typhoons > bird pests. The relative importance of indicators is determined through expert experience, where r_2 = 1.6, r_3 = 1.4, r_4 = 1.2, r_5= 1.2, r_6= 1.4. Reference eq.(6) ~ (8) calculates the weights of indicators in relative order, where w_1^* = 0.3361, w_2^* = 0.2101, w_3^* = 0.1501, w_4^* = 0.1251, w_5^* =0.1042, w_6^* = 0.0744. Therefore, the subjective weight vector W_1 determined by G1 method is as follows, W_1= (0.3361, 0.1042, 0.2101, 0.0744, 0.1501, 0.1251).
According to the relative order of indicators mentioned above, we can calculate the subjective weight based on IAHP, and its weight vector W_2 is as follows. W_2 = (0.4679, 0.0384, 0.2613, 0.0214, 0.1385, 0.0724).

3.1.2 Calculation of objective weights. The trip distributions of all 220kV transmission lines in a certain area of the South China Power Grid in recent 8 years is shown in Table 2.

Table 2. A regional trip distributions of transmission lines in recent eight years.

	C_1	C_2	C_3	C_4	C_5	C_6
2009	33	3	12	1	2	6
2010	27	6	22	1	4	3
2011	36	1	8	2	1	1
2012	18	4	5	1	1	2
2013	29	3	15	3	7	2
2014	22	2	28	1	3	11
2015	13	2	23	2	3	1
2016	34	7	7	2	1	9

We can establish the primitive data matrix according to table 2. In order to facilitate calculation of objective weights, the maximum value method is applied to dimensionless processing of the primitive data matrix, and the matrix S is obtained.

$$S = \begin{bmatrix} 0.9167 & 0.4286 & 0.4286 & 0.3333 & 0.2857 & 0.5455 \\ 0.7500 & 0.8571 & 0.7857 & 0.3333 & 0.5714 & 0.2727 \\ 1.0000 & 0.1429 & 0.2857 & 0.6667 & 0.1429 & 0.0909 \\ 0.5000 & 0.5714 & 0.1786 & 0.3333 & 0.1429 & 0.1818 \\ 0.8056 & 0.4286 & 0.5357 & 1.0000 & 1.0000 & 0.1818 \\ 0.6111 & 0.2857 & 1.0000 & 0.3333 & 0.4286 & 1.0000 \\ 0.3611 & 0.2857 & 0.8214 & 0.6667 & 0.4286 & 0.0909 \\ 0.9444 & 1.0000 & 0.2500 & 0.6667 & 0.1429 & 0.8182 \end{bmatrix}$$

We can calculate the objective weight vector based on entropy weight method, and its weight vector W_3 is as follows, W_3 = (0.0463, 0.1545, 0.1475, 0.0905, 0.2287, 0.3326).
According to eq.(9) ~(12), the objective weight vector W_4 based on CV is calculated, where W_4 = (0.0871, 0.1666, 0.1593, 0.1289, 0.2102, 0.2479).

3.1.3. Calculation of comprehensive weights. The subjective weight vectors W_1, W_2 and objective weight vectors W_3, W_4 obtained above are brought into eq.(13) ~ (17) to calculate the comprehensive weight vector W. That is, W = (0.2190, 0.1200, 0.1908, 0.0816, 0.1853, 0.2033).

3.2. Disaster risk assessment of transmission lines based on TOPSIS
The multi-year trip distribution of 8 transmission lines to be evaluated is shown in Table 3. Length of transmission line to be evaluated and accident levels determined according to the load reduction ratio of the power grid are shown in Table 4.

Table 3. Trip distributions of overhead transmission lines to be evaluated in recent years.

	C_1	C_2	C_3	C_4	C_5	C_6
M_1	8	0	2	0	0	1
M_2	7	1	6	0	1	0
M_3	10	0	4	1	0	1
M_4	6	1	0	0	0	1
M_5	5	0	3	1	2	0
M_6	5	0	6	0	1	2
M_7	3	1	4	0	0	0
M_8	9	1	1	0	0	1

Table 4. Length and accident levels of transmission lines.

	Length（km）	Accident levels	Symbol
M_1	30.815	general accidents	IV
M_2	13.511	serious accidents	II
M_3	47.685	general accidents	IV
M_4	16.255	major accidents	III
M_5	24.146	serious accidents	II
M_6	44.860	general accidents	IV
M_7	25.788	general accidents	IV
M_8	36.482	major accidents	III

We can calculate the disaster trip-out rate of 8 transmission lines by using the data of Tables 3 and 4, and the decision matrix of the assessment system R^* is established by multiplying the quantized score in Table 1.

$$R^* = \begin{bmatrix} 0.0519 & 0.0000 & 0.0130 & 0.0000 & 0.0000 & 0.0065 \\ 1.0362 & 0.1480 & 0.8882 & 0.0000 & 0.1480 & 0.0000 \\ 0.0419 & 0.0000 & 0.0168 & 0.0042 & 0.0000 & 0.0042 \\ 0.1476 & 0.0246 & 0.0000 & 0.0000 & 0.0000 & 0.0246 \\ 0.4141 & 0.0000 & 0.2485 & 0.0828 & 0.1657 & 0.0000 \\ 0.0223 & 0.0000 & 0.0267 & 0.0000 & 0.0045 & 0.0089 \\ 0.0233 & 0.0078 & 0.0310 & 0.0000 & 0.0000 & 0.0000 \\ 0.0987 & 0.0110 & 0.0110 & 0.0000 & 0.0000 & 0.0110 \end{bmatrix}$$

A standardized decision matrix V is established according to eq. (1).

$$V = \begin{bmatrix} 0.0292 & 0.0000 & 0.0146 & 0.0000 & 0.0000 & 0.2642 \\ 1.0000 & 1.0000 & 1.0000 & 0.0000 & 0.8932 & 0.0000 \\ 0.0193 & 0.0000 & 0.0189 & 0.0507 & 0.0000 & 0.1707 \\ 0.1236 & 0.1662 & 0.0000 & 0.0000 & 0.0000 & 1.0000 \\ 0.3864 & 0.0000 & 0.2798 & 1.0000 & 1.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0301 & 0.0000 & 0.0272 & 0.3618 \\ 0.0010 & 0.0527 & 0.0349 & 0.0000 & 0.0000 & 0.0000 \\ 0.0754 & 0.0743 & 0.0124 & 0.0000 & 0.0000 & 0.4472 \end{bmatrix}$$

To combine with the degree of hazard under different disasters, we need consider the comprehensive weight of indicators mentioned above. A weighted decision matrix X is established based on eq. (2).

$$X = \begin{bmatrix} 0.0064 & 0.0000 & 0.0028 & 0.0000 & 0.0000 & 0.0537 \\ 0.2190 & 0.1200 & 0.1908 & 0.0000 & 0.1655 & 0.0000 \\ 0.0042 & 0.0000 & 0.0036 & 0.0041 & 0.0000 & 0.0347 \\ 0.0271 & 0.0199 & 0.0000 & 0.0000 & 0.0000 & 0.2033 \\ 0.0846 & 0.0000 & 0.0534 & 0.0816 & 0.1853 & 0.0000 \\ 0.0000 & 0.0000 & 0.0057 & 0.0000 & 0.0050 & 0.0736 \\ 0.0002 & 0.0063 & 0.0067 & 0.0000 & 0.0000 & 0.0000 \\ 0.0165 & 0.0089 & 0.0024 & 0.0000 & 0.0000 & 0.0909 \end{bmatrix}$$

According to eq. (3) ~ (4), we calculate the distance between the evaluated target and the positive ideal solution and the negative ideal solution, and get S_d^+ = (0.3979, 0.2200, 0.4054, 0.3525, 0.3044, 0.3906, 0.4207, 0.3775), S_d^- = (0.0542, 0.3552, 0.0354, 0.2061, 0.2258, 0.0739, 0.0092, 0.0929).

Finally, according to eq.(5), we calculate close-degree of each target to get β = (0.1198, 0.6176, 0.0803, 0.3689, 0.4259, 0.1592, 0.0214, 0.1974)

The value of β indicates that the order of importance of the 8 assessment targets is $M_2 > M_5 > M_4 > M_8 > M_6 > M_1 > M_3 > M_7$. Therefore, the relative magnitude of disaster risk is ranked as follows, line 2 > line 5 > line 4 > line 8 > line 6 > line 1 > line 3 > line 7.

According to the evaluation results above, the power grid operation management departments need to focus on strengthening the risk prevention of line 2, line 5 and line 4. For the convenience of analysis and explanation, the disaster risk ranking results and comparison charts of transmission line under two assessment standards are shown in Table 5 and Figure 2 respectively.

Table 5. Ranking results of disaster risk for transmission lines under two assessment standards.

Line	**Close-degree**	**Total trip-out rate**	**Risk ranking**	
			TOPSIS	Traditional model
Line 1	0.119 8	0.000 357	6	4
line 2	0.617 6	0.001 110	1	1
line 3	0.080 3	0.000 336	7	5

line 4	0.368 9	0.000 492	3	2
line 5	0.425 9	0.000 456	2	3
line 6	0.159 2	0.000 312	5	7
line 7	0.021 4	0.000 310	8	8
line 8	0.197 4	0.000 329	4	6

As can be seen from Table 5 and Figure 2, the results of risk assessment based on total trip-out rate and the model proposed in this paper are inconsistent, and the risk ranking of transmission lines with the highest total trip-out rate may be improved or reduced after considering accident levels and the degree of hazard under different disasters. Considering the distribution of different disasters, the total trip-out rate of line 1 is higher than that of line 6, but line 6 suffers more times from ice storms and external force destruction. Compared with other disasters, the damage degree of ice storms and external force destruction is higher, so the risk of line 6 is higher. This is more in line with the actual situation. Considering accident levels of transmission lines, the total trip-out rate of line 4 is higher than line 5, but the load reduction caused by line 5 accident is larger, resulting in a wider range of blackouts, so the result of line 5 with higher risk is more reasonable. Based on the above analysis, compared with the traditional model, the model proposed in this paper are more realistic and feasible.

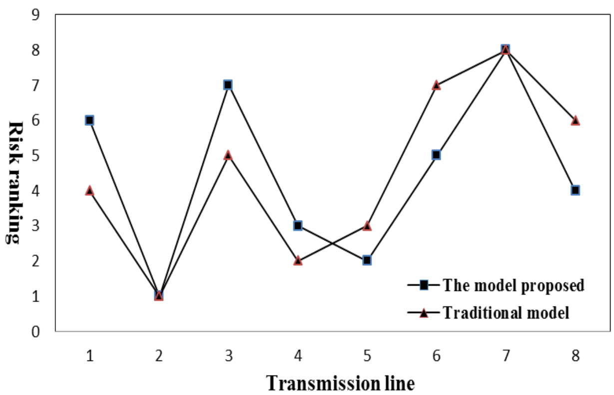

Figure 2. Comparison of disaster risk for transmission lines under two assessment standards

4. Conclusions

Developing comprehensive risk assessment of transmission lines is an important work to ensure the safe and reliable operation of power systems. In view of the influence of various natural disasters on transmission lines, a disaster risk assessment method based on TOPSIS for transmission lines is proposed in this paper. This method considers six typical natural disasters, accident levels of transmission lines and the degree of hazard under different disasters. Compared with the traditional method, the method proposed in this paper is more reasonable and scientific, more consistent with the actual comprehensive risk ranking of transmission lines. Application of this model provide an effective reference for the early prediction of line accidents and the formulation of safety plans.

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