Study on risk assessment of trans-regional transmission lines tripping disaster induced by wildfire

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Abstract. In recent years, there are more and more incidents of trans-regional transmission line tripping caused by wildfire. How to reduce the occurrence of such incidents has become a hot topic in domestic academic research. Hence, the associated risk factors of trans-regional transmission lines tripping disaster induced by wildfire is quantified based on system engineering theory of "human - machine - environment". A risk assessment index system is established by the application of analytic hierarchy process (AHP), and a certain transmission line in Hunan Province is taken as an example to conduct risk assessment analysis in this paper. The results indicate that the regional geographic location factors, the frequent meteorological disaster factors and the sacrifice festival burning situation exist relatively serious security risks. Increasing the coniferous trees planting area and enhancing the summer and the force of fall fire supervision are expected to be carried out for reducing security risks.

1. Introduction

In recent years, the demand for transmission lines grids of the country has also increased with the rapid development of the national economy [1]. Moreover, the National Development and Reform Commission issued the 'Notice on Comprehensively Promoting the Reform Work of Trans-provincial, Trans-regional and Regional Power Transmission Price' in December 2017, which indicated that the construction of power grid has become an indicator of coordinated development across multiple counties, cities and even provinces. However, long-distance transmission lines often cross the mountainous terrain [2], which is extremely vulnerable to various natural and climatic disasters and faces the challenges of severe disasters. Taking Jiangxi Province as an example [3], there were 333 transmission line trip accidents caused by wildfire from 2010 to 2014. These accidents may lead to a large-scale blackout, which will affect seriously the normal life of the residents, the normal operation of the factory and cause the serious economic loss.

How to reduce or even avoid such incidents has become a hot topic in academic research [4]. The data and laws of wildfire trip points by counting the number of wildfire and the severity of grid trips have been analyzed in a large number of studies at home and abroad [5]. The mechanism and characteristics of the transmission lines tripping disaster caused by wildfire have also attracted

extensive attention [6]. It is found that the disaster is owning to the coupling of surface temperature and internal conductivity change of the transmission line which is caused by wildfire. The exploitation of the early warning and monitoring system for wildfire is a hot topic for researchers as well [7]. Based on the original video surveillance and infrared imaging, the new wildfire warning and monitoring system consisting of the communication network and expert detection software is developed to realize real-time monitoring of fire information. In addition, most research about risk assessment of transmission lines tripping disaster are conducted from the multiple points of induced wildfire, and the corresponding disaster risk assessment model will be established by researching the main impact factors of the tripping disaster, then the severity of disaster is showed by predicting the probability of disaster [3, 8-10, 11].

In summary, such disasters have been analyzed in the predecessors' research from the perspectives of wildfire induced transmission line trip disaster mechanism, prediction and early warning, statistical identification, risk model and so on. However, the influence of wildfire on the whole transmission line is emphasized in most studies, and the impact of the transmission line structure and people on the transmission line tripping disaster is ignored. Therefore, the risk assessment model which is consisting of people, trans-regional transmission lines and the induced wildfires circumstances is established by the theory of "human-machine-environment" and the using of Analytic Hierarchy Process (AHP) in the paper. Finally, the potential risks are found and the safety suggestions are put forward.

2. Building the model of trans-regional transmission lines tripping disaster induced by wildfire

2.1. Introducing the evaluation methods

The Analytic Hierarchy Process (AHP) was developed in 1970s. AHP are widely used in the risk assessment due to the methodological systematization and succinctness, etc. The evaluation steps are as follows: first, the basic risk is classified, then the relative weight of each risk factor is calculated by constructing the risk factors judgment matrix and establishing the hierarchical structure of the system hierarchy, and the consistency of the indices are checked in the third step. If passed, the comprehensive weight of each indicator will be calculated. Otherwise, the risk factor judgment matrix will be reconstructed until the risk factors pass the consistency test. Finally, the comprehensive weight of each layer element will be obtained.

2.2. Establishing the multistage structure of trans-regional transmission lines tripping disaster induced by wildfire

According to the characteristics of the transmission line tripping disaster induced by wildfire, referring to historical risk analysis and design data and comprehensively using the method of system engineering in this disaster risk, three primary risk indices are identified which could have serious consequences. Respectively, they are the wildfire induced factors, the basic factors of trans-regional transmission lines and human factors. The primary risk indices is divided into secondary risk indices and partial secondary risk indices are divided into tertiary risk indices. Finally, 16 first indices including Geographical factor[1], Vegetation factor[3,12], Climatic factors[13], Transmission line and tree clearance distance[2,4,5], Load situation[9,14], Equipment historical damage rate[8,9,10], Transmission line Voltage[15], Trans-regional distance (km)[15], Corner tower type(transmission line angle)[6], Line type[15], Sacrifice festival burning situation[1,2,5], Planting of fire-resistant species[4], Flame retardant spray times/year[4], Improvement of emergency plan[2,4], Equipment supervision[4], Deliberate arson causes consequences[4] and 14 secondary indices including Slope direction[1], Slope angle[3,5], Geographic location (four major geographic regions)[4], Average age of trees /year[1], Forest classification (use angle)[11], Woodland type (section)[4], Average combustible load /kg·hm^{-2}[2,4], Type of tree (flammability angle)[1,4], Woodland moisture content[4], Vegetation density[1], Season[1,10], Frequent meteorological disaster[2,10], relative humidity[1,2], Average precipitation[1] are divided. The multistage structure of trans-regional transmission lines tripping disaster induced by wildfire is established after quantitatively handling various indices. What needs to be note is that

Trans-regional transmission lines basic factors and People Factors just have first indices layer, as shown in table 1(a) and table 1(b).

Table 1. The multistage structure of trans-regional transmission lines tripping disaster (a).

Criterion layer	First indices layer	Secondary indices layer	Assessment factor and score				
Wildfire induced factors a	Geographical factor a_1	Slope direction a_{11}	Night side		Sun face		
			2		6		
		Slope angle a_{12}	Below 25 degrees		Above 70 degrees	More than 25 degrees, less than 70 degrees	
			2		4	6	
		Geographic location a_{13}	North-west region	Qinghai-Tibet Area	Northern region	Southern region	
			2	2	4	6	
	Vegetation factor a_2	Average age of trees /year a_{21}	Less than 20		More than 20, less than 50	Greater than 50	
			2		4	8	
		Forest classification (use angle) a_{22}	Protective forest	Special purpose forest	Economic forest	Timber forest	Firewood
			2	4	4	6	8
		Woodland type (section) a_{23}	Nursery	Immature forest land	Shrubbery	Sparse woodland	Woodland
			2	2	4	6	6
		Average combustible load/kg*hm^{-2} a_{24}	Less than 3		Greater than 3, less than 7	Greater than 7	
			2		4	6	
		Type of tree (flammability angle) a_{25}	Flame retardant trees		Flammable trees	Flammable trees	
			2		4	6	
		Woodland moisture content a_{26}	high	Higher	general	Lower	low
			2	4	6	8	10
		Vegetation density a_{27}	high	Higher	general	Lower	low
			2	4	6	8	10
	Climatic factors a_3	Season a_{31}	summer	winter	spring	autumn	
			2	6	8	8	
		Frequent meteorological disaster a_{32}	Mountain torrent	other	drought	Thunders torm	high temperature
			2	4	6	6	8
		relative humidity a_{33}	high	Higher	general	Lower	low
			2	4	6	8	10
		Average precipitation a_{34}	high	Higher	general	Lower	low
			2	4	6	8	10

Table 1. The multistage structure of trans-regional transmission lines tripping disaster (b).

Criterion layer	First indices layer	Assessment factor and score				
Trans-regional transmission lines basic factors b	Transmission line and tree clearance distance b_1	25m or more		10m or less		DC line 12-17m, AC line 8m-14m
		2		4		6
	Load situation b_2	Near rated load		Below rated load		Exceeding load
		2		4		6
	Equipment historical damage rate b_3	low		Medium		high
		2		4		6
	Transmission line Voltage b_4	High voltage transmission line		Ultra high voltage transmission line		UHV transmission line
		2		4		6
	Trans-regional distance(km) b_5	Less 50	50-100	100-200	200-300	More than 300
		2	4	6	8	10
	Corner tower type (transmission line angle) b_6	SJ1 Corner tower	SJ2 Corner tower	SDJ1 Corner tower	SJ3 Corner tower	SJ4 Corner tower
		2	4	5	6	7
	Line type b_7	DC line		AC line		
		2		6		
People Factors c	Sacrifice festival burning situation c_1	Good		General		Serious
		2		4		8
	Planting of fire-resistant species c_2	Good		General		Serious
		2		4		8
	Flame retardant spray times / year c_3	Greater than 2		Less than 2, greater than 1		Less than 1
		2		4		8
	Improvement of emergency plan c_4	Perfect		More perfect		Leaks
		2		4		8
	Equipment supervision c_5	good		general		difference
		2		4		8
	Deliberate arson causes consequences c_6	Nothing serious		Generally serious		Especially serious
		4		8		10

2.3. *Determining the weight of the evaluation indices*
Based on the established indicator system, the judgment matrix is constructed by comparing the factors of each criterion layer and judging the relative importance. Table 1 shows that the criterion factor layer includes the wildfire induced factors, the basic factors of trans-regional transmission lines and human factors, and formula 1 gives its judgment matrix.

$$A_1 = \begin{vmatrix} 1 & 5 & 1/2 \\ 1/5 & 1 & 1/5 \\ 2 & 5 & 1 \end{vmatrix} \tag{1}$$

The weight vector of criterion layer calculated is ω_1, ω_1= (0.5591 0.0887 0.3522).

Similarly, the first indices layer judgment matrix A_2, A_3, A_4 respectively corresponding to the weights are ω_2, ω_3, ω_4.

ω_2 = (0.0914 0.1660 0.3017); ω_3= (0.0289 0.0138 0.0188 0.0084 0.0052 0.0035 0.0102);

ω_4 = (0.1338 0.0123 0.0181 0.0517 0.0377 0.0987);

The secondary indices layer judgment matrix A_5, A_6, A_7 respectively corresponding to the weights are ω_5, ω_6, ω_7.

ω_5 = (0.0019 0.0084 0.0631); ω_6 = (0.0044 0.0281 0.0177 0.0393 0.0578 0.0107 0.0081);

ω_7= (0.1625 0.0769 0.0250 0.0373).

All the conditions that the random consistency ratio is less than 0.1 are met for the above judgment matrix, that is, the operation process passes the consistency test.

2.4. *Calculation and level judgment of disaster comprehensive risk*

Assuming that the c_i, c_j, c_k are respectively the criterion layer weight, the first indices layer weight, and the secondary indices layer weight. Formula 2 shows the calculation of the comprehensive weight c_{ijk} of the underlying factor. Then the underlying factor of the wildfire induced factors, the basic factors of trans-regional transmission lines and human factors are graded according to the reality. Various risk values will be obtained by multiplying the score by the composite weight coefficient of the underlying factor in next step. Finally, Comprehensive risk value of trans-regional transmission lines tripping disaster induced by wildfire will be obtained according to the sum of various risk values. What needs illustration is that, if $R3$, the current status is considered safe, if $3<R<7$, the current status is considered existing security threat, if $7<R$, the current status is considered dangerous.

$$c_{ijk} = c_i c_j c_k \tag{2}$$

3. Case application and risk assessment

3.1. *Case analysis*

A certain transmission line in Hunan Province is selected as the object of analysis in this paper. Through field research, four transmission lines related data and information of 220kV voltage is collected, including relevant environmental information, basic information of transmission lines and local cultural customs. In addition, the transmission line is analyzed by applying the model of trans-regional transmission lines tripping disaster induced by wildfire established in the previous chapter.

3.2. *Scoring the risk value of trans-regional transmission lines tripping disaster induced by wildfire*

In order to simplify the matrix operations and the operation process, the disaster risk assessment algorithm of trans-regional transmission lines tripping disaster induced by wildfire is written. Then, ten experts in related fields are invited to evaluate the elements of the criterion layer after field research and data statistics, and calculate the average of the 10 values obtained. Finally, comprehensive risk value of risk assessment is obtained by multiplying the score by the composite weight coefficient of the underlying factor. The average score of each factor is shown in table 2.
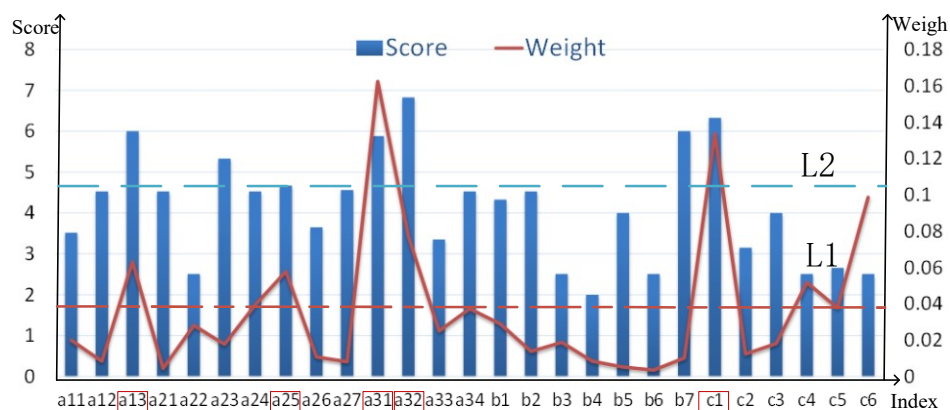
Table 2. The average score for the parameters of transmission lines tripping disaster

Parameters	Values	Parameters	Values	Parameters	Values	Parameters	Values
a_{11}	3.52	a_{12}	4.53	a_{13}	6	a_{21}	4.53
a_{22}	2.51	a_{23}	5.33	a_{24}	4.53	a_{25}	4.67
a_{26}	3.65	a_{27}	4.56	a_{31}	5.88	a_{32}	6.83
a_{33}	3.35	a_{34}	4.53	b_1	4.33	b_2	4.53
b_3	2.51	b_4	2	b_5	4	b_6	2.51
b_7	6	c_1	6.33	c_2	3.15	c_3	4
c_4	2.51	c_5	2.66	c_6	2.51	-	-

The established evaluation model is used to assess the transmission line in Hunan Province, and the ultimately comprehensive risk value is 4.7064, which is meaning that there are potential risks.

3.3. Analyzing the risk of trans-regional transmission lines tripping disaster induced by wildfire
Figure 1 shows the coupling relation between score and weight of trans-regional transmission lines tripping disaster induced by wildfire.

Figure 1. The coupling relation between score and weight of trans-regional transmission lines tripping disaster induced by wildfire

The top-six score and weight of trans-regional transmission lines tripping disaster induced by wildfire are analysed, meaning that the weight index is higher than the dashed line of L_1 and the score index of the dashed line of L_2 is analysed. In particular, it is found that the factor of Geographic location (a_{13}), Type of tree (a_{25}), Season (a_{31}), Frequent meteorological disaster (a_{32}) and Sacrifice festival burning situation (c_1) have a higher score and weight according to figure 1. Therefore, the above five factors are emphatically analysed.

Located in the south of the Yangtze River, Hunan Province has a low dimension and is a subtropical monsoon humid climate with obvious continental characteristics. The climate of Hunan Province is characterized by the mild climate and distinct seasons. The high frequency of wildfire disasters is caused because of the abundant heat in Hunan Province and the drought in summer and autumn. In addition, the concentration of summer precipitation and the long duration of the drought period directly lead to the two most frequent natural disasters in Hunan Province – floods and droughts. Droughts will also intensify the outbreak of wildfire. This is the reason for the geographical factors, seasonal factors and the assessment scores and weights of frequent meteorological disasters as well. Therefore, it is necessary to strengthen the monitoring of wildfire in summer and autumn in Hunan Province.

The flammability of trees is directly related to the spread of wildfire. The climate characteristics of Hunan Province make wild evergreen conifers and deciduous conifers widely distributed, but

conifers have better combustion performance and are flammable. Once the pine forest fires, the disasters are endless, but the climate characteristics of Hunan Province make the evergreen broad-leaved tree species also have good growth, and most of the broad-leaved trees have higher water content, and the water evaporation needs to absorb a large amount of heat when exposed to heat. The self-burning temperature is lowered, making it difficult to be ignited and burned, thereby weakening the fire intensity and generating a fire-blocking ability. Therefore, it is possible to artificially reduce the number of coniferous species and increase the distribution area of broad-leaved trees.

The unsafe behaviour of people is an important reason for inducing the outbreak of wildfire, especially in the festivals of the ancestral festivals such as New Year's Eve, Qingming and Zhongyuan. Hunan Province is a multi-ethnic province, mainly including 11 ethnic minorities such as Tujia, Miao, Yi, Yao, Bai, and Hui, etc. The customs and habits of ancestor worship are not the same. Unreasonable burning sacrifices may directly cause wildfire. It is necessary to strengthen the behavioural norms of the ancestral festival activities, thereby reducing the possibility of wildfire.

4. Conclusion

In this paper, the analytic hierarchy process (AHP) is used to study the influencing factors of trans-regional transmission lines tripping disaster induced by wildfire, and the related risk assessment model is established. The model determines the value and weight of typical risk parameters, and the present situation of disaster risk in a region of Hunan. Finally, it is found that geographical factors, frequent meteorological disaster factors, tree species factors, seasonal factors, and burning conditions of the festival have a large threat on security. The effective means which can reduce such safety risks are put forward by planting area of coniferous forest trees, improving the intensity of wildfire regulation in summer and autumn, and standardizing the guidance of ancestral worship activities.

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