International Journal of Smart Home
Vol. 9, No. 4 (2015), pp. 25-34
http://dx.doi.org/10.14257/ijsh.2015.9.4.03

Fisher Linear Discriminant Method for Forest Fire Risk Points on Transmission Line

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Abstract

With the continuous expansion of power grid, a large number of transmission lines through forests. Forest fire disasters seriously threaten the safe, economic and stable operation of power grid, so that the demand of discriminating fire risk points in transmission line corridors is getting more and more imperative. In this paper, a Fisher discriminant analysis method was put forward based on multivariate statistical analysis to assess the status of forest fire risk points. Firstly, impact factors on forest fire were defined. Secondly, the correlation between impact factors and the stability of fire risk point was analyzed with the historical material of forest fire. Next, multidimensional variables of the stability of fire risk point were turned into one-dimensional variables by projection method. Finally, the distances between one-dimensional variables were calculated and used to discriminate the status of stability of fire risk points. In a case in Shanxi province, this method has been verified.

Keywords*: forest fire risk point, Fisher discriminant analysis, stability assessment*

1. Introduction

With high-speed industrialization and rapid development of Hi-Tech industry in China, electric power grid plays a more and more important role in the safety system of power supply. Economy and society will be more and more dependent on the reliability and safety of electric power. The power grid system is not isolated but connected closely with and influenced by natural and social environment. Its operation safety and reliability are related to not only itself but the natural and social environment. China is a mountainous country so that transmission line project has to be built across dense forest regions in some cases. As the lifeblood of power grid operation, transmission lines will transmit power and are so vulnerable to their complex environment that any outer force would damage them and cause blackouts. In recent years, due to global warming, the extremely climate has caused a lot of forest fires. Once forest catches fire, those transmission lines nearby are prone to phase fault or ground fault so to trip out or even to cause power failure, which not only threaten the safety of the forest, peoples' lives and properties, but also seriously impact the safety and reliability of those transmission lines [1, 2] and the stability of power grid and people's daily life [3].

Transmission line forest fire risk point discrimination is a process to find out fire-prone points along transmission lines, and to discriminate their status of stability, according to a

Serial of factors such as historical forest fire data, landform type, vegetation type, climate type, human factor [4] and so on. Forest fires on those risk points could threaten

ISSN: 1975-4094 IJSH

the resources and the safety of power grid. Research on transmission line forest fire risk point discrimination is significant to avoid transmission line failures caused by forest fires, and to help for forest fire prevention and control.

In this paper, transmission lines across forests were picked out as research objects in Shanxi province. The possibility of forest fires and their impact on transmission lines have been analyzed. According to forest fire historical data, a Fisher discriminant function method based upon multivariate statistical analysis was proposed to evaluate the status of stability on forest fire risk points. This method has been verified in a practical case, and the result showed that this method is simple, low cost, easy to implement especially for a kind of public prediction and disaster prevention systems.

2. Analysis on Impact Factors for Forest Fire Disaster along Transmission Lines

According to historical data, the occurrence and development of forest fire are related to factors of landform, vegetation type, climate, human activities and so on. The geographic and natural environment is complex in Shanxi province. There are mainly maintains and hills which account for 80% of total areas of Shanxi province with rich forest plant resources. Forest lands of 2962374 ha are divided into 8 big regions with various plant types such as scrubland, needle broadleaf mixed forest, coniferous forest, deciduous broad-leaved forest, subalpine thickets or subalpine meadow (Figure 1). Besides, the climate of Temperate Continental Monsoon usually causes forest fires frequently (Figure 2). According to statistics, 700 forest fires have occurred in Shanxi province in nearly three years, some of which have caused trip-outs on a 220kv or above transmission lines, and seriously impacted the safe, economic and stable operation of power grid.

Figure 1. RS Imagine of Vegetation Distribution in Shanxi Province

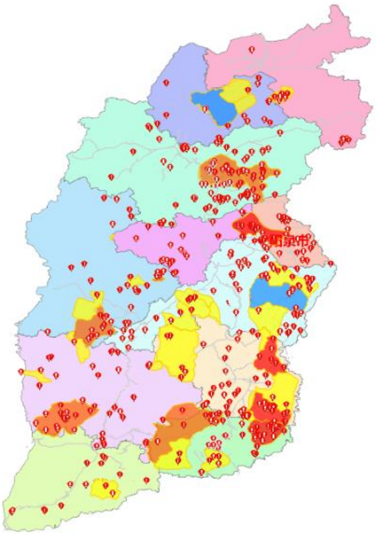

Figure 2. Historical Forest Fires Distribution in Shanxi Province

Based on historical forest fires relevant materials in Shanxi province, impact factors and indicators for forest fire disaster on transmission lines have been picked out and showed in Figure 3, and a spatial model has been built.

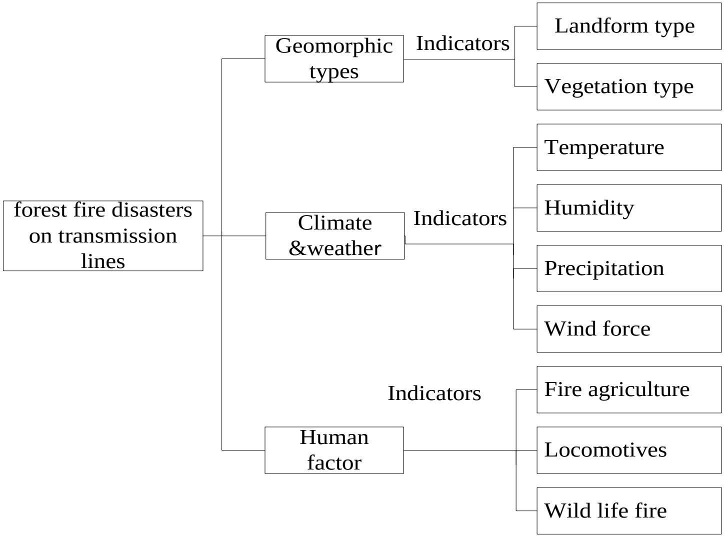

Figure 3. Impact Factors and Indicators for Forest Fire Disasters Of Transmission Lines

After analysis on the characteristics of forest fire risk points in 8 ranges and according to the occurrence probability of forest fire, the status of stability of forest fire risk points were divided into three types as the stable, the under-stable and the unstable. Then three factors of landform type, vegetation type, and human factor in 8 ranges have been quantified after statistics (Table 1).

Table 1. Impact Factors and Indicator Quantified Value

Impact factors	**Indicator value**			
	1	**2**	**3**	**4**
Landform type	North-slope	South-slope	Steep	Small slope
Vegetation type	High plant area	Dwarf plant area		
Human factor type	Fire agriculture	Locomotives spray fire	Wild life fire	

In terms of component analysis on those factors, the contribution rate of individual factor to the variation of stability at forest fire risk points has been worked out (Table 2), which implies the correlation between the stability and each factor [5].

Table 2. Contribution Rate of Factors to Variation on Stability

Impact factor	**Contribution rate %**	**Total contribution rate %**
Landform type	5.56	5.56
Vegetation type	6.32	10.78
Temperature	13.9	35.15
Humidity	14.21	37.14
Precipitation	14.98	40.03
Wind force	15.1	42.11

Human factor	29.93	67.98

The results in Table 2 showed that the most significant impact on variation of stability was from human factor, the more ones are from meteorological indicators, and the less ones are from vegetation factor and landform factor.

How those factors impacted on forest fire risk points' status of stability of transmission lines has been analyzed as below.

2.1 Impact by Landform Factor on the Stability of Fire Risk Points

Only the stable and unstable forest fire risk points impacted by landform factor were analyzed here below.

The distribution of landform types is shown in Table 3. The stable risk points are about 40% in north-slope landform, 10% in south-slope landform, 40% in small slope landform, and around 10% in steep landform. However, for those unstable risk points, the proportion in north-slope landform reduced to about 15%, in small slope landform reduced to about 10%, instead in south-slope landform and in steep landform increased to about 40% and 35% respectively.

The above analysis shows that stable risk points always appear in north-slope and small slope landform, and conversely unstable risk points usually appear in south-slope and steep landform.

Table 3. Distribution of Landform Types

Landform	**Proportion %**	
	Stable status	***Unstable status***
North-slope	40	15
South-slope	10	40
Small slope	40	10
Steep	10	35
Total	100	100

The distribution of Vegetation types is shown in Table 4. The stable risk points are about 70% in high plant area, and 30% in dwarf plant area. However, for the unstable risk points, the proportions are about 30% in high plant area and about 70% in dwarf plant area. These results show that high plant area is contributed to the stability on risk points, but dwarf plant area is not.

Table 4. Distribution of Vegetation Types

Vegetation types	**Proportion %**	
	Stable status	***Unstable status***
High plant area	70	30
Dwarf plant area	30	70
Total	100	100

2.2 Meteorological Indicators' Impact on the Stability of Fire Risk Points

Choosing temperature, humidity, precipitation and wind force as indicators [6-9], and taking Shanxi province as an example, the impact of meteorological factors on stability of fire risk points as shown in Table 5. The results show that temperature and wind force will weaken the stability of risk points, but higher humidity and more plentiful rainfall will enhance the stability of risk points.

Table 5. Meteorological Indicators for Stability of Forest Fire Risk Points

Average value of indicator	**Temperature/ ℃**	**Humidity /%**	**Precipitation/mm**	**Wind force**
				Level
Stable	<0	>75	>10	<2
Under-stable	0-10	55-75	5-10	3-4
Unstable	>30	<55	<5	>5

2.3 Human Factors' Impact on the Stability of Fire Risk Points

The statistics of the human factors which impact on the stable and unstable status of fire risk points have been done (see Table 6) [10], and the results show that locomotives spray fire brings much less troubles to fire risk points, compared with factors of fire agriculture and wild life fire.

Table 6. Distribution of Human Factors

Human factor	**Proportion %**	
	Stable status	***Unstable status***
Locomotives spray fire	80	5
Fire agriculture	10	50
Wild life fire	10	45
Total	100	100

3. Assessment Method for Transmission Lines' Forest Fire Risk Points

The above analysis shows that many factors will influence the status of the fire risk points on transmission lines. M stands for the status of stability at fire risk points, which is the function of impact factors set, [$X_1, X_2, ..., X_n$], and is expressed as below:

$$M = f(X_1, X_2, ..., X_n) \tag{1}$$

To make the formula (1) practical, a Fisher discriminant method based upon multivariate statistical analysis was used to assess the status of stability of forest fire risk points. According to the principle of 'Similar projects produce similar results', this approach will make use of the engineering analogy method [11] to compare and analyze amount of historical forest fire data thereafter.

3.1 Fisher Linear Discriminant Analysis Model

Discriminant analysis is a multivariate statistical analysis method to identify the category of the research objects according to their characteristic values. The basic principle is according to certain criterion, to establish discriminant function, to classify things.

According to fire risk points' status of stability, the general samples are classified into three sub-general samples of the stable, the under-stable, and the unstable respectively [12]. M_i is the status of stability of forest fire risk points, which is a seven-dimensional feature matrix as expressed in formula (2).

$$M_i = f(X_{i1}, X_{i2}, ..., X_{i7}), \tag{2}$$

In the above formula, $X_{i1}, X_{i2}, ..., X_{i7}$ are 7 indicators of landform, vegetation, temperature, humidity, precipitation, wind force and human factor. Then the stability status type of M_i would be discriminated and classified into the corresponding sub-general sample according to indicators of the impact factors.

Fisher linear discriminant analysis is to turn multidimensional variables into one-dimensional variables using projection method, and then to discriminate the status of stability in terms of distances between forest fire risk points.

Given that y_i is a point on the line y which is the linear projection of M_i, a Fisher discriminant function is built as in the formula below,

$$y_i = \sum_{j}^{n=7} w_{ij} X_{ij} + d, \tag{3}$$

Where X_{ij} are 7 impact factors which correspond to M_i, w_{ij} are weight coefficients of X_{ij}, and d is a constant which could be given according to empirical data.

When comes to several general samples, their discriminant functions would be calculated respectively by the above method, and then compared with each other to make conclusion.

Until now, a discriminant model for the stability of forest fire risk points on transmission lines in Shanxi province has been established.

3.2 Fisher Discriminant's Procedures

According to the analysis above, the steps to assess the stability of forest fire risk points is here below.

1) To build the discriminant function: According to historical data of forest fire disaster on transmission lines, the sample mean and covariance could be calculated, and then the discriminant function of y is established as below:

$$y = (\overline{x}_1 - \overline{x}_2)^T s^{-1} x, \tag{4}$$

Where $\overline{x}_1$ and $\overline{x}_2$ are the sample means, and s is a variance - covariance matrix.

2) To discriminate the status of stability of fire risk points: Combined with Fisher discriminant field diagrams, the corresponding discriminant function values could be worked out, and then the status of stability of fire risk points could be recognized and classified into different status of the stables, the under-stables and the unstable respectively.

4. Study on Cases

Based on data of fire disasters on transmission lines in Shanxi province for recent years, the application procedures of the above mentioned assessment model to discriminate the status of forest fire risk points has been illustrated as below.

Firstly, historical data from 90 fire risk points composed a general sample. Based on this sample and combined with all factors, variables were set as in Table 7. Then discriminant function would be built and status of fire risk points would be classified. Among the 90 fire risk points, given that there are 30 stable ones, 30 under-stable ones and 30 unstable ones.

Table 7. Impact Factor Variables

Impact factor indicators	Variables
Landform type	X_1
Vegetation type	X_2
Temperature	X_3
Humidity	X_4
Precipitation	X_5
Wind force	X_6
Human factor	X_7

According to the above procedures, the calculating process is as followed.

1) According to historical data of transmission lines, the sample mean and variance - covariance matrix could be worked out, and the coefficients of discriminant function were listed in Table 8.

Table 8. Fisher Discriminant Function Coefficients

Impact factor indicators	**Fisher discriminant function**	
	1	***2***
Landform type X_1	1.018	-0.33
Vegetation type X_2	0.561	0.309
Temperature X_3	-0.011	0.039
Humidity X_4	-0.049	0.081
Precipitation X_5	0.012	0.009
Wind force X_6	0.141	0.038
Human factor X_7	-0.065	-0.378
Constant d	-6.517	-0.931

The coefficients in Table 8 were plugged in the formula (3) and then 2 Fisher discriminant functions came out here below.

$$y_1 = 1.018X_1 + 0.561X_2 - 0.011X_3 - 0.049X_4 + 0.012X_5 + 0.141X_6 - 0.065X_7 - 6.517$$

$$y_2 = -0.330X_1 + 0.309X_2 + 0.039X_3 + 0.081X_4 + 0.009X_5 + 0.038X_6 - 0.378X_7 - 0.931$$

The discriminant function values of the 90 samples could be calculated and then total projections for each type general sample and their gravity position could be figured out.

2) Based on the previous two discriminant functions and projection, the Fisher discriminant field diagram was drawn and shown in Figure 4. Then the corresponding positions of two functions' values in two-dimensional space would indicate the status of each risk point obviously.

For example, indicators of impact factors for a fire risk point are as following:

North-slope landform (X1 = 1), short plant area (X2 = 2), the temperature (X3 = 2 ℃), humidity (X4 = 0.8), rainfall (X5 = 5 mm), wind force(X6 = 3), locomotive spray fire (X7 = 2). By calculating, the result is y1 = -4.085, y2 = -1.0972, which is plotted as the point at (-4.0 85, -1.0972) in the Figure 4, which indicates the risk point status is stable.

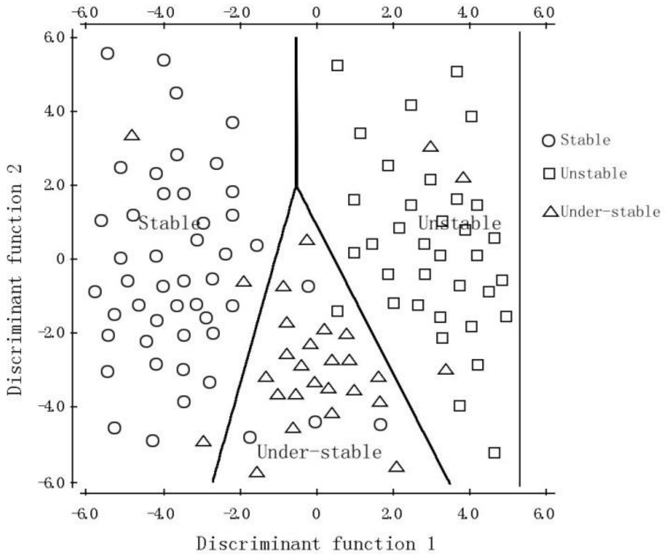

Figure 4. Fisher Discriminant Field Diagram

5. Analysis on Result

1) Test based on original training sample: the original training sample of 90 fire risk points was taken as the test sample, and test results are shown in Table 9. The result shows that, for the 30 original stable risk points, 28 discriminants are right and 2 ones are wrong, and for the 30 original unstable risk points and 30 original under-stable ones, 24 discriminants are right and 6 ones are wrong. The average accuracy is 84% for the general original sample.

Table 9. Test Result for the Original Training Sample

	Status	Stable	Under-stable	Unstable	Total
Number of risk points	Stable	28	2	0	30
	Under-stable	2	24	4	30
	Unstable	0	6	24	30
Accuracy %	Stable	93	7	0	100
	Under-stable	7	80	13	100
	Unstable	0	20	80	100

Note：The average accuracy is 84%.

2) Test based on extra sample: an extra test sample of 45 risk points was built, where 15 points are given for each type status of stability respectively. Test results are listed in Table 10.

Table 10. Test Result for Extra Sample

	Status	Stable	Under-stable	Unstable	Total
Number of risk points	Stable	14	1	0	15
	Under-stable	1	12	2	15
	Unstable	0	4	11	15
Accuracy %	Stable	93	7	0	100
	Under-stable	7	80	13	100
	Unstable	0	27	73	100

Note：The average accuracy is 82%.

After comparison and analysis on data in Table 9 and in Table 10, test results all show that the Fisher discriminant function method can accurately assess the stability status of forest fire risk points; there were wrong misjudgments between the stables and the under-stables or between the unstable and the under-stables, but not between the stables and the unstables. Therefore, this method would cause only a slight error which could be negligible in application to assess the status of stability of forest fire risk points in Shanxi province.

It is worth to mention that the multivariate statistical analysis method is based on historical data; therefore, the typicality of training sample has a significant influence on its applicability and accuracy. So choosing typical data as the training sample is necessary when this method is applied.

6. Conclusion

In this paper, after analysis on historical data of forest fire disasters and their impact factors in Shanxi province, a multivariate statistical analysis based discriminant method was proposed to assess the status of stabilty of forest fire risk points on transmission lines. It is simple, practical and ease to promote in public prediction and prevention systems. The test results show that the method is generally practical with the average accuracy of 82% in the test region.

ACKNOWLEDGEMENTS

This paper is supported by Beijing Higher Education Young Elite Teacher Project (Grant No. YETP0704), and the Science & Technology key Project of Shanxi Province Electric Power Company (No. KJ2013-130).

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