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Dynamic Thermal Rating of Transmission Line Based on Environmental Parameter Estimation

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Abstract

The transmission capacity of transmission lines is affected by environmental parameters such as ambient temperature, wind speed, wind direction and so on. The environmental parameters can be measured by the installed measuring devices. However, it is impossible to install the environmental measuring devices throughout the line, especially considering economic cost of power grid. Taking into account the limited number of measuring devices and the distribution characteristics of environment parameters and transmission lines, this paper first studies the environmental parameter estimating method of inverse distance weighted interpolation and ordinary Kriging interpolation. Dynamic thermal rating of transmission lines based on IEEE standard and CIGRE standard thermal equivalent equation is researched and the key parameters that affect the load capacity of overhead lines is identified. Finally, the distributed thermal rating of transmission line is realized by using the data obtained from China meteorological data network. The cost of the environmental measurement device is reduced, and the accuracy of dynamic rating is improved.

Keywords

Dynamic Thermal Rating, Environmental Parameters, Ordinary Kriging Interpolation Method, Transmission Line

1. Introduction

At present, with the rapid economic development and social electricity consumption increasing, transmission lines are important part of the power system. Because of the constraints of the existing transmission line technical regulations, the transmission capacity of transmission lines is limited. Due to the high cost and long construction period of overhead transmission lines, whether make full use of the transmission capacity of existing overhead lines becomes a concern problem of the power sector [1].

The thermal load capacity of the transmission line is related to the real-time environmental parameters, such as ambient temperature, wind speed, wind direction, and so on. In order to obtain accurate environmental parameters throughout the transmission line, we can install dense environmental parameter measuring device. Due to the cost and the limited number of the installation location of parameter measuring devices, environmental parameters of many areas along the transmission line are

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difficult to obtain [2]. In order to obtain real-time data such as wind speed, wind direction and ambient temperature at the location without measuring device, the spatial interpolation method can be used to estimate the environmental parameters [3,4]. All spatial interpolation methods are based on the first law of geography. It means the closer the spatial position is, the more similar the environmental parameters are [5]. In recent years, the spatial interpolation method has been applied to various research fields. In [6], only five temperature monitoring points are used to interpolate by the inverse distance weighted interpolation method and the Kriging method. The conclusion is that the inverse distance weighted interpolation method has high accuracy. However, the known points are too few and the conclusions are not representative. Khairnar et al. [7] studies the application of common interpolation methods in the accuracy of digital elevation model. It is found that the difference between ordinary Kriging interpolation results and the actual value is the minimum, and the surfaces given in the visible edges are the smoothest. In [8], the optimal exponent of the inverse distance interpolation method are given by the enumeration and the cross validation. The exponent corresponding to the minimum root mean square error is the best value, but it does not take into account the computational efficiency when the amount of data is large. In [9], the ordinary Kriging method based on the spherical model variation function is applied to the construction process of the fingerprint database, which effectively reduces the workload and improves the working efficiency of the fingerprint positioning staff. In [10], the ordinary Kriging method is used to interpolate the seawater temperature profile, which proved that the ordinary Kriging method is effective in the interpolation of seawater temperature profile by comparing the fitting of points and faces with the sample profile.

In summary, commonly used interpolation algorithms are anti-distance weighted interpolation method and ordinary Kriging interpolation method. Taking into account the limited number of measuring devices and the distribution characteristics of overhead lines, this paper first studies the estimation method of environmental parameters throughout transmission lines. Based on the widely used inverse distance interpolation method and ordinary Kriging interpolation method, the estimation of the environmental parameters at the location without measuring device along the overhead transmission line is realized. Furthermore, based on the IEEE and CIGRE standard heat balance equations, the distribution dynamic thermal rating throughout overhead lines is achieved to excavate thermal transmission capacity of overhead transmission line. It not only reduces the investment cost, but also improves the accuracy of the line dynamic thermal rating, with a certain theoretical and practical value.

The content of this paper is organized as follows: in Section 2, we present the estimation of environmental parameters by inverse distance weighted interpolation and ordinary Kriging interpolation. The methodology of conductor ampacity calculation based on IEEE and CIGRE standards is described in Sections 3. In Section 4, we present the comparison of two kinds of interpolation methods. Using the data obtained from China meteorological data network, the distributed thermal rating of transmission line is realized. Section 5 gives the conclusion.

2. Estimation of Environmental Parameters

In this section, we estimate the environmental parameters by inverse distance weighted interpolation and ordinary Kriging interpolation.

2.1 Estimation of Environmental Parameters by Inverse Distance Weighted Interpolation

The first law of geography is considered to be the basis of the current interpolation theory, that is, the closer the distance is, and the higher the similarity of attributes is. The word "distance" is the Euclidean distance between the known environmental parameters point and the point to be estimated, and able to interpolate data from a two-dimensional or three-dimensional space.

Assuming W_j is the point to estimate environmental parameter in two-dimensional apace study areas, the coordinates are (X_j, Y_j). The corresponding attribute value is Z_j. $W_i(i=1,2,\cdots,n)$ is the measurement point with known environmental parameters. The corresponding coordinates are (X_i, Y_i). The attribute value is Z_i, then distance between the known environmental parameters point and the environment parameters point to be estimated is $d_{ij}=\sqrt{(X_i-X_j)^2+(Y_i-Y_j)^2}$. If the number of the known environmental parameters point is n, its corresponding weight coefficient is w_i, the expression of the formula is:

$$w_i=\frac{(1/d_{ij})^k}{\sum_{i=1}^{n}(1/d_{ij})^k} \tag{1}$$

From (1) we can see that the weighted coefficient sum of the measured points of all known environmental parameters is 1. That is $\sum_{i=1}^{n} w_i=1$. $k(k>0)$ is the variable parameter of distance exponent. When k is close to 0, the parameter to be estimated at the point W_j is close to the average of all known points. When k is greater than 10, the parameter to be estimated at the point W_j is approximately the same as the nearest known point. According to the weight coefficient w_i, the attribute value Z_j at the point to be estimated is

$$Z_j=\sum_{i=1}^{n}(Z_i\times w_i) \tag{2}$$

2.2 Estimation of Environmental Parameters by Ordinary Kriging Interpolation Method

The Kriging interpolation method is originated from geology, and its essence is similar to the inverse distance interpolation method. The weights of known environmental measurement points are given, and the values of the estimated points are weighted. The advantage of the Kriging interpolation method is that it takes into account the distance relationship between the estimated points and the known parameter measurement points, the whole spatial distribution characteristics and correlations of the known environmental measurement points [11]. In detail, the weights corresponding to the known measurement points make the minimum variance of the error between the estimated and the true values, so the weights corresponding to the known measuring points closest to the estimated points are not necessarily the greatest. The related concepts of the Kriging interpolation method are as follows.

$Z(x)$ is a variable that characterizes a natural phenomenon in the region and reflects the distribution characteristics of a particular attribute. The data at any spatial measurement point can be regarded as a random variable, and the set of random variables at each point in the space constitutes a random function.

$Z(x)$ has local and structural characteristics, there is some correlation between the two variables $Z(x)$ and $Z(x+h)$ where the distance is h between the point $x+h$ and the point x, but the correlation decreases as the distance increases. $Z(x)$ meets the second order stationary hypothesis:

$$E[Z(x)] = E[Z(x+h)] = m \quad (\forall x, \forall h) \tag{3}$$

$\gamma(x,h)$ is an important parameter in the Kriging interpolation method. It is the key to solve the corresponding weight of the estimated value by the Kriging interpolation method, which embodies the spatial relation and stochastic characteristic of $Z(x)$. The value $\gamma(x,h)$ is the half of the variance of $Z(x)$ at the point x and the point $x+h$, as shown in Eq. (4).

$$\begin{aligned} \gamma(x,h) &= \frac{1}{2} Var[Z(x) - Z(x+h)] \\ &= \frac{1}{2} E[Z(x) - Z(x+h)]^2 - \frac{1}{2} \{E[Z(x)] - E[Z(x+h)]\}^2 \\ &= \frac{1}{2} E[Z(x) - Z(x+h)]^2 \end{aligned} \tag{4}$$

$\gamma(x,h)$ is related to the point x and the relative distance h. If only determined by the relative distance h, $\gamma(h)$ can be expressed as follows:

$$\gamma(h) = \frac{1}{2} E[Z(x) - Z(x+h)]^2 \tag{5}$$

What the variability of $Z(x)$ refers to is the value of the attribute related to its location. $\gamma(h)$ shows the variability of regional variable attribute values according to the spatial distribution characteristics of known measurement parameters. From Eq. (5) we can see that $\gamma(h)$ is a function of the relative distance between the two points in the study area. As shown in Fig. 1(a), the main parameters are: nugget, sill, partial sill and range.

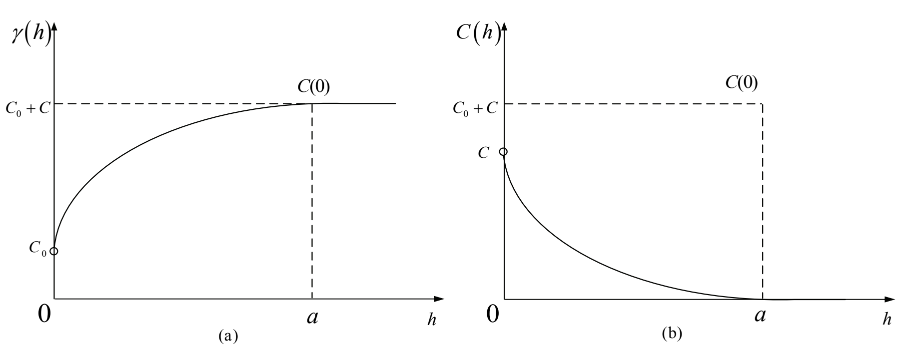


Fig. 1. Variation function graph: (a) variation function $\gamma(h)$ and (b) corresponding covariance function graph.

Nugget is the corresponding value of $\gamma(h)$ when the distance h between the two environmental measurement points tends to 0, which is shown in Fig. 1(a) as C_0 .

Sill is the corresponding constant of value $\gamma(h)$, When the distance h between two environmental measurement points increases to a certain extent, is shown in Fig. 1(a) as $C(0)$.

Partial sill is the difference between $C(0)$ and C_0 , $C = C(0) - C_0$, is shown in Fig. 1 (a) as C.

Range is the distance h between the two measured points, When $\gamma(h)$ increases from C_0 to $C(0)$, it is shown in Fig. 1(a) as a . Within the range $h < a$, the closer the two measurement points are, the larger the spatial correlation is. The two measurements have no spatial correlation in the range $h \geq a$.

Fig. 1(a) and (b) are typical variation function graphs and their corresponding covariance function graphs. The variation function and the covariance function are opposite to each other as the distance increases, as in Eq. (6)

$$\gamma(h) = C(0) - C(h) \tag{6}$$

Commonly used variation function models include circular model, spherical model, exponential model, and gaussian model.

The ordinary Kriging interpolation method is similar to the inverse distance interpolation method, that is, the estimated value $Z^*(x_0)$ at the point x_0 is the linear weighted sum of the values at the ambient known points $x_i (i = 1, 2, \cdots, n)$, as shown in (7):

$$Z^*(x_0) = \sum_{i=1}^{n} Z(x_i) \times \lambda_i \tag{7}$$

The sum of the weights of all known points satisfies Eq. (8) of Kriging interpolation method:

$$\sum_{i=1}^{n} \lambda_i = 1 \tag{8}$$

The optimality requires that the error variance between the actual value and the estimated value is minimum value, denoted by σ_{E} , as shown in (9).

$$\sigma_{\mathrm{E}} = \min\{Var[Z^*(x_0) - Z(x_0)]\} \tag{9}$$

The constructed function is given by the Lagrangian multiplication

$$\begin{aligned} F(\lambda, \mu) &= \sigma_{\mathrm{E}} + 2\mu(\sum_{i=1}^{n} \lambda_i - 1) \\ &= 2\sum_{i=1}^{n} \lambda_i \gamma_{i0} - \sum_{i=1}^{n}\sum_{j=1}^{n} \lambda_i \lambda_j \gamma_{ij} - \gamma_{00} + 2\mu(\sum_{i=1}^{n} \lambda_i - 1) \end{aligned} \tag{10}$$

In order to solve the corresponding weight coefficient $\lambda_i (i = 1, 2, \cdots, n)$, the partial derivative of λ and μ is solved from Eq. (10). If the partial derivative functions is zero, we get Eq. (11):

$$\begin{cases} \dfrac{\partial F}{\partial \lambda_i} = 2\gamma_{i0} - 2\sum_{j=1}^{n} \lambda_j \gamma_{ij} + 2\mu = 0 \\ \dfrac{\partial F}{\partial \mu} = 2(\sum_{i=1}^{n} \lambda_i - 1) = 0 \end{cases} \tag{11}$$

The matrix is used to represent the above equation:

$$\boldsymbol{K} = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \cdots & \gamma_{1n} & 1 \\ \gamma_{21} & \gamma_{22} & \cdots & \gamma_{2n} & 1 \\ \vdots & \vdots & \cdots & \vdots & \vdots \\ \gamma_{n1} & \gamma_{n2} & \cdots & \gamma_{nn} & 1 \\ 1 & 1 & \cdots & 1 & 0 \end{bmatrix}, \boldsymbol{\lambda} = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_n \\ -\mu \end{bmatrix}, \boldsymbol{Y} = \begin{bmatrix} \gamma_{10} \\ \gamma_{20} \\ \vdots \\ \gamma_{n0} \\ 1 \end{bmatrix} \tag{12}$$

$$\boldsymbol{\lambda} = \boldsymbol{K}^{-1}\boldsymbol{Y}$$

After determining the variance function model and obtaining the distance between the environmental measurement points, we can get the corresponding variation function value. The weight coefficient can be obtained from Eq. (12), and the weight coefficient is substituted into Eq. (7) to estimate the environmental parameters [12,13].

3. Dynamic Rating of Transmission Line

Transmission line is a bridge between using electricity and power generation, and thermal load capacity of transmission line is influenced by the surrounding environment temperature, such as wind speed, wind direction and ambient temperature. The grid dispatcher determines the actual transmission capacity of the line according to the static thermal rating, determines the maximum permissible carrying current value of the transmission line under the harsh environmental conditions. Compared to the static thermal rating technology, the dynamic thermal rating technology uses the measuring equipment to monitor the current meteorological parameters and it can effectively tap the existing transmission line current carrying capacity.

3.1 Thermal Equilibrium Equation

The thermal load capacity of the transmission line is gotten by thermal balance, when the heat generation and divergence in a balanced state, that is, the generated heat is equal to the divergent heat. The Joule heat by current flow and the sunshine absorption heat are belong to the generated heat. The convective heat by the surrounding environment factors such as ambient temperature and wind speed, and the radiation heat of the line itself are belong to the divergent heat. The thermal equilibrium equation in the steady state of the circuit is given by (13)

$$q_c + q_r = q_s + I^2 R(T_c) \tag{13}$$

where q_c is the convection heat, q_r is the radiation for the line itself, q_s is the heat absorbed for the sun, $I^2R(T_c)$ is the Joule heat. The dynamic heat ratings for the transmission lines are calculated by Eq. (13). The IEEE standard [14], as well as the CIGRE standard [15] developed by the International Council on Large Electric Systems, gives the detail expressions of Eq. (13). The two standards are different, but are all based on the thermal equilibrium.

3.2 Influence of Ambient Parameters on Dynamic Thermal Rating under Two Kinds of Standards

The ambient temperature, wind speed and wind direction of the line will affect the thermal load capacity of the transmission line. This section explores the influence of the above environmental parameters on the dynamic thermal rating based on IEEE standard and CIGRE standard. For the LGJ-400/50 transmission line, using the IEEE standard and CIGRE standard, assuming that the wind direction and the direction of the line perpendicular to each other, the dynamic thermal rating is calculated according to the changes of the wind speed. In this paper, when calculating the dynamic thermal rating, the maximum allowable temperature is set as 70°C. The static thermal rating of the transmission line is 592 A, as shown in Fig. 2.

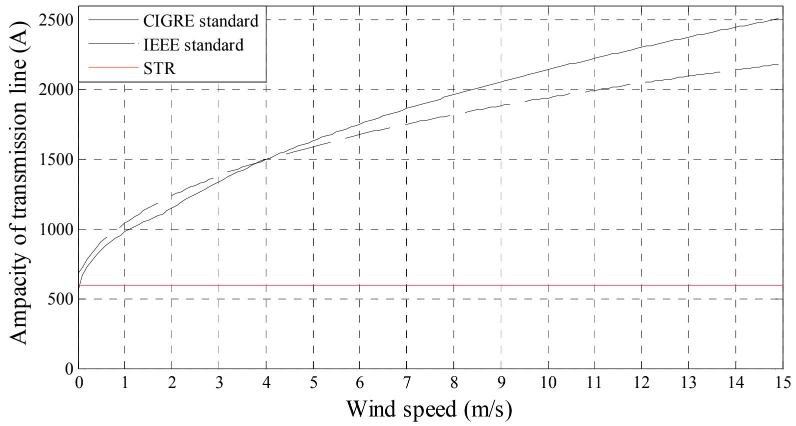


Fig. 2. Influence of wind speed on DTR under two kinds of standards.

As can be seen from Fig. 2, the line ampacity increases rapidly with the increase in wind speed. When the wind speed is less than 4 m/s, the maximum allowable carrying capacity of the IEEE standard is higher than that calculated by the CIGRE standard. When the wind speed is more than 4 m/s, the dynamic thermal rating of the CIGRE standard is relatively large. When the wind speed is 15 m/s, line ampacity calculated by the IEEE standard and the CIGRE standard is 2176.0 A and 2503.5 A, respectively, which is increased by about 267.6% and 322.8% compared to the static heat setting.

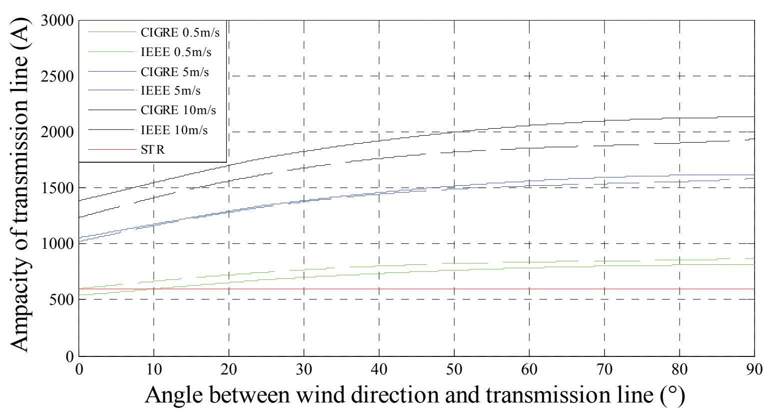


Fig. 3. The influence of wind direction and line orientation angle on DTR under two criteria.

Fig. 3 shows the variation of the current carrying capacity of the transmission line under the two standards when the wind direction increases from 0° to 90°, and with the wind speed of 0.5 m/s, 5 m/s, and 10 m/s, respectively.

It can be seen from Fig. 3, under the same ambient temperature, the corresponding convection cooling effect is the worst when the wind direction angle is 0°, so the line dynamic thermal rating is minimum, and when wind direction angle is 90°, the corresponding convection cooling is the best, the line dynamic thermal rating is maximum. Therefore, in addition to wind speed, the effect of wind direction on the line thermal load capacity cannot be ignored. However, in practice, due to the presence of line disturbances, the effect of the wind direction on the line thermal load capacity is smaller than theoretical calculation.

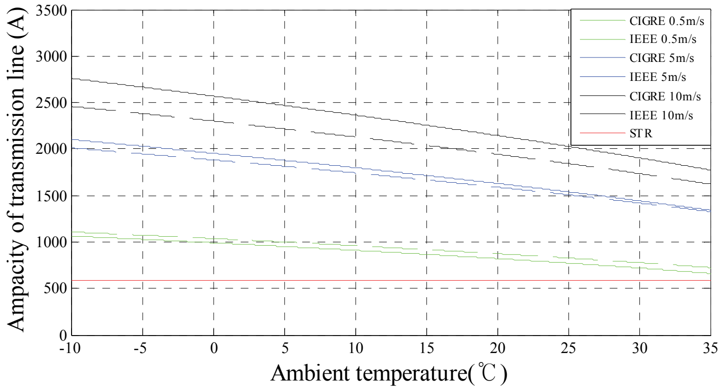
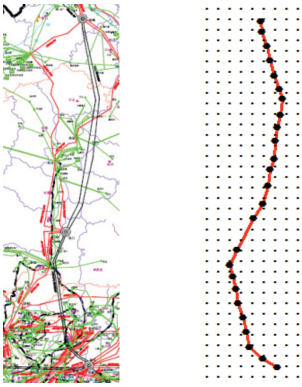


Fig. 4. The influence of temperature on DTR under two criteria.

Fig. 4 shows the variation of the current carrying capacity of the transmission line under the two standards when the ambient temperature increases from -10°C to 35°C, and with the wind speed of 0.5 m/s, 5 m/s, and 10 m/s, respectively. It can be seen from Fig. 4 that the ambient temperature also has an important effect on the thermal load capacity of the line. When the other environmental parameters remain unchanged, the lower ambient temperature is, the higher thermal load capacity is. On the contrary, the higher the ambient temperature corresponds to the lower line thermal load capacity. In the two standards, the ambient temperature has an impact on the convection heat and radiation heat.

4. Case Study

In order to combine with the actual line, this paper chooses a 750-kV transmission line from Yujiang, Luochuan to Xinyi according to the geographical wiring diagram of Shanxi power grid. The transmission line length is 386.7 km. In this paper, we select the region with the latitude range of 109.2° ~ 110.0°E and the latitude range of 34.6°–38.1°N at 8:00 on September 17, 2016. The range of longitude span is 80 km and the latitude span is 350 km, as we can see in Fig. 5(a).



(a) (b)

Fig. 5. The geographical location of the studied line: (a) geographic wiring diagram and (b) meteorological data network.

The environmental parameter data is from the China meteorological data network "GRAPES_MESO China and the surrounding area numerical forecast products", We can get the area of a total of 9×36=324 measure points and the corresponding environmental parameters (ambient temperature, wind speed, wind direction), as shown in Fig. 5(b). In this section, the cross validation method is used to evaluate the effect of the two interpolation methods on the environmental parameters estimation.

4.1 Comparison of Two Kinds of Interpolation Methods

The cross validation method is used to verify the estimation accuracy of interpolation algorithms. That is, each of the known environment data points is assumed to be an unknown quantity. Other known data is used to estimate the assumed unknowns, and the interpolation error between the estimated values and the known values is calculated. The mean absolute error (MAE) and the root mean squared interpolation error (RMSIE) are usually used as evaluation criteria of the interpolation accuracy. The smaller the calculated error value is, the closer the interpolation result is to the true value. MAE is used to estimate the impossible error range, and its expression is shown in Eq. (14).

$$\mathrm{MAE} = \sum_{i=1}^{n} (Z_{\mathrm{c},i} - Z_{\mathrm{o},i}) / n \tag{14}$$

where $Z_{\mathrm{o},i}$ is the known value of point i; $Z_{\mathrm{c},i}$ is the estimating result of point i; and n is the total number of environment data points.

RMSIE is used to reflect the estimated sensitivity and extreme value effects on the measured point data [13]. The expression of which is expressed by Eq. (15):

$$\mathrm{RMSIE} = \sqrt{\sum_{i=1}^{n} (Z_{\mathrm{c},i} - Z_{\mathrm{o},i})^2 / n} \tag{15}$$

According to the cross validation module in geographic statistical analysis of ArcGIS software, MAE and RMSIE values of ambient temperature, wind speed and wind direction are estimated by different Kriging interpolation method and inverse distance interpolation method. In this case, it is assumed that each of the 324 points in Fig. 5 is the point to be estimated in order. The values of the point to be estimated is interpolated according to the other 323 known points. The final MAE and RMSIE are shown in Table 1.

Table 1. Cross validation results for different estimation methods

Cross validation	Circular	Spherical	Index	Gaussian	IDW
Temperature MAE (°C)	0.4162	0.5008	0.4473	0.3120	1.264
Temperature RMSIE (°C)	1.5328	2.4277	1.5911	0.9948	6.514
Wind speed MAE (m/s)	0.3896	0.3416	0.4332	0.4123	0.873
Wind speed RMSIE (m/s)	1.5906	1.4604	1.7572	1.6240	3.645
Wind direction MAE (°)	4.0951	4.3567	6.5569	6.1321	11.62
Wind direction RMSIE (°)	12.343	13.558	15.449	14.986	25.09

According to the results of Table 1, it can be seen that MAE and RMSIE of the various variation function model (circular, spherical, exponential, and Gaussian) of the ordinary Kriging interpolation method are smaller than those of the inverse distance weighted interpolation method. Therefore, the general Kriging interpolation method is effective. It can be seen by comparison that the Gaussian variation function model should be chosen when estimating the ambient temperature. The spherical model should be selected when estimating the wind speed, and the circular model should be selected when estimating the wind direction.

Table 2. Estimation of environmental parameters at 25 points of transmission line

Point	Longitude (E)	Latitude (N)	Temperature (°C)	Wind speed (m/s)	Wind direction (°)
1	109.676	37.989	22.31258	1.71582	156.3338
2	109.686	37.884	22.67912	2.14189	149.2344
3	109.729	37.744	23.01952	2.33556	143.2542
4	109.758	37.609	23.21038	2.26855	138.0481
5	109.792	37.470	23.42952	2.04048	131.4788
6	109.835	37.340	23.60655	1.84029	127.6865
7	109.864	37.244	23.64497	1.68302	125.5642
8	109.844	37.095	23.60006	1.58664	125.6270
9	109.820	36.970	23.35387	1.59052	124.9162
10	109.801	36.845	22.94237	1.58255	126.9266
11	109.792	36.671	22.68975	1.67703	136.2848
12	109.758	36.570	22.96728	1.94498	143.1490
13	109.739	36.416	23.63994	2.66577	155.6990
14	109.695	36.243	23.97541	3.58796	166.6059
15	109.614	36.113	23.72943	3.75889	174.8989
16	109.469	35.806	22.48813	1.522706	190.5641
17	109.404	35.666	21.78378	0.61640	193.0289
18	109.424	35.551	22.06700	0.53014	229.0574
19	109.457	35.435	22.58040	0.86832	257.9343
20	109.472	35.300	23.21345	1.47723	269.2503
21	109.515	35.166	23.27094	1.95238	284.4721
22	109.544	35.021	22.47640	2.07477	298.0574
23	109.577	34.882	20.53267	1.54755	299.1291
24	109.688	34.771	18.89304	1.05216	268.7144
25	109.823	34.685	19.47246	1.30290	239.6672

4.2 Distributed Dynamic Thermal Rating of Transmission Line

The overhead transmission line and surrounding environment parameters have spatial distribution characteristics. In order to obtain accurate environmental parameters, based on the geo-statistical analysis module of ARCGIS software, the environmental parameters of 25 points along the transmission line is estimated by ordinary Kriging interpolation method, which using the known data of a total of 324 measure points in Fig. 5. The results are shown in Table 2.

4.3 Dynamic Thermal Rating of Transmission Line Based on Environmental Parameter Estimation

Based on the estimated environmental parameters at 25 points, this section uses the IEEE and CIGRE criteria to calculate the dynamic thermal ratings at 25 points throughout the transmission line. The results are shown in Table 7. And the minimum dynamic thermal rating value is determined as the dynamic thermal rating value of the whole line. The calculated results and the distance to Hengyu point are shown in Table 3 and Fig. 6.

Table 7. Dynamic thermometric values at 25 points under two criteria

Point	Longitude (E)	Latitude (N)	IEEE standard (A)	CIGRE standard (A)	Distance (km)
1	109.676	37.989	913.9226	861.2586	0
2	109.686	37.884	1020.3153	974.0300	11.0
3	109.729	37.744	1089.3991	1052.5297	23.8
4	109.758	37.609	1133.9634	1096.0657	39.5
5	109.792	37.470	1155.5546	1107.8177	57.9
6	109.835	37.340	1155.2596	1104.5880	73.9
7	109.864	37.244	1134.9570	1089.4841	83.1
8	109.844	37.095	1229.1122	1189.4378	102.1
9	109.820	36.970	1233.2833	1193.5300	116.2
10	109.801	36.845	1234.7775	1195.4071	128.3
11	109.792	36.671	1243.8198	1200.6133	148.4
12	109.758	36.570	1276.3290	1225.2189	160.7
13	109.739	36.416	1340.3857	1326.8978	177.5
14	109.695	36.243	1386.1931	1412.5868	197.1
15	109.614	36.113	1470.9752	1509.8247	213.5
16	109.469	35.806	1110.9621	1070.9824	250.3
17	109.404	35.666	920.0518	889.3851	266.7
18	109.424	35.551	988.1336	964.6638	279.6
19	109.457	35.435	1092.5745	1067.4283	293.6
20	109.472	35.300	1202.5186	1167.0630	307.4
21	109.515	35.166	1264.6938	1213.7556	323.0
22	109.544	35.021	1248.0381	1203.9332	337.3
23	109.577	34.882	1179.6452	1140.5503	355.6
24	109.688	34.771	1132.0272	1104.8851	369.4
25	109.823	34.685	1224.0910	1196.1841	386.7

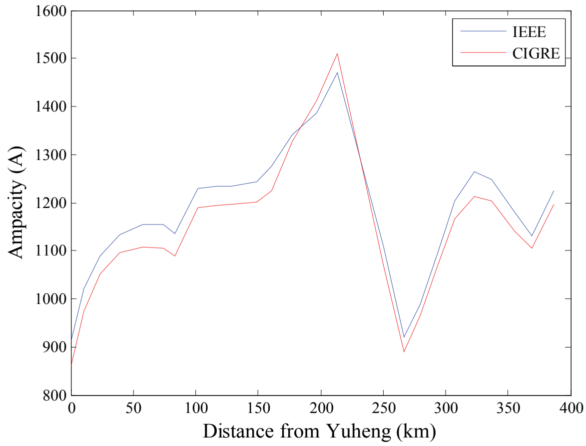


Fig. 6. Dynamic thermal rating corresponding to 25 points.

Table 3 and Fig. 6 shows that the dynamic thermal ratings at point 1 is 861.2586 A, which is calculated by the CIGRE standard. The wind speed at point 1 is 1.71582 m/s, the ambient temperature is 22.31258, and the angle between the wind direction and the line is about 2°, which can be seen in Table 2. Considering the ambient parameters, the dynamic thermal rating calculated by the CIGRE standard at point 1 is the smallest, so the dynamic thermal rating 861.2586 A at point 1 is taken as the dynamic thermal rating of the whole line.

5. Conclusion

In this paper, the estimating methods of the surrounding environment parameters of the transmission line is studied, the two calculation criteria of the dynamic thermal rating and the influence of the environment parameters on the line thermal load capacity are analyzed and quantified. The calculation and analysis are carried out according to the actual line based on IEEE and CIGRE standard. The key factors affecting the current carrying capacity of overhead lines are wind speed, ambient temperature and wind direction. Through the method of cross validation, it is proved that Kriging is an effective method to estimate the environmental parameters. According to the China meteorological data network, the dynamic thermal rating value considering the spatial distribution of environmental parameters and transmission line is realized. The study reduces the cost of the environmental measurement device, and improve the accuracy of dynamic rating throughout transmission lines.

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