REAL –TIME MONITORING OF OVERHEAD TRANSMISSION LINE AND ITS RISK ASSESSMENT

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ABSTRACT

To avoid unnecessary accident and to insure that overhead transmission lines operate safely, on-line monitoring operation state and dynamic security evaluation are necessary. Dynamic Line Rating (DLR) system has been introduced in monitoring the real-time weather and line conditions. The conductor temperature in operation is affected by complex components. This paper analyzed the characteristics of operating line temperature, and found that the line load, tension and wind speed are the main contributors to conductor temperature. The conductor temperature model affected by multiple factors based on multiple regression analyses is set up right after parameter estimations. The experiments did on 110kV lines have been discussed and proved the accuracy of the temperature model. In addition, to maintain transmission line reliability under uncertainty, on-line risk assessment is provided to evaluate thermal overload risk of overhead transmission lines. The main results of experimental studies in field are also presented.

1. INTRODUCTION

Overhead transmission lines are normally required to run at a certain temperature to avoid strength loss and maintain adequate ground clearance. Conductor strength loss and permanent sag increase due to creep elongation of the conductor accumulate over time. So it is definitely necessary to monitor on-line conductor temperature and sags and to evaluate dynamic security, which avoid unnecessary contingency accident and insure overhead transmission lines operate safely.

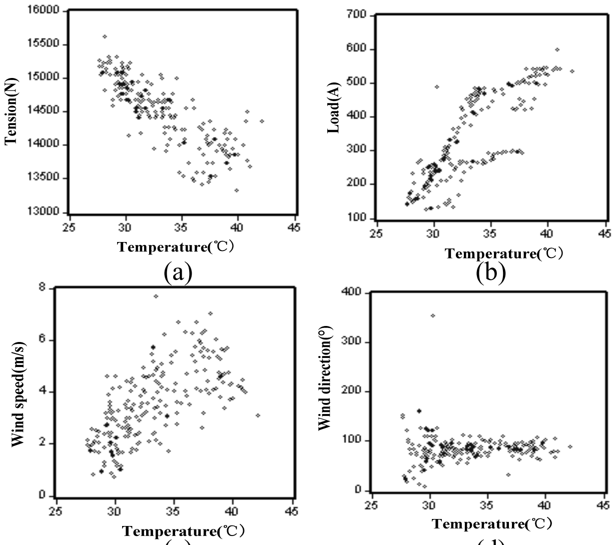
However it is difficult to calculate or measure the value of conductor temperature precisely using the traditional methods. The direct temperature measurement methods had some disadvantages including high cost, requiring much more hardware and communications [1-2]. The direct tension monitoring method achieved by CAT-1 system [3] established the tension-temperature relationship [4]. Because the behavior of the line is monitored during an outage over three months, the conductor temperature is inaccurate when the lines operate at high current [5].

The DLR system is designed to evaluate transmission capacity dynamically by monitoring the real-time weather conditions and transmission line parameters [6], which contributes to study the relationships between conductor temperature and tension, load, weather conditions etc. The DLR system is composed of sampling terminals installed on dead-end configuration of a line and one control instrument equipped in dispatch center. The data between the sampling terminals and the control instrument is transmitted through GPRS/GSM.

The purpose of this paper is to present a temperature model for overhead transmission line. The experiment revealed that the temperature of operating line is influenced by complex factors including line load, tension, and environment conditions. The paper analyses the components that exert the vital influence on conductor temperature, and presents a multiple regression model for conductor temperature. The accuracy and applicability of the model has been discussed and proved.

2.CONDUCTOR TEMPERATURE CHARACTERISTICS

Simultaneous weather and conductor data collected by terminal data acquisition of DLR system were analyzed with statistics method, and the scatter plots are shown in Figure 1.



(a) (b)

(c) (d)

Fig.1 Scatter plots for conductor temperature and influence factors

The above figures show that the conductor temperature is related to line load, tension and environment. Fig.1 (a) shows the conductor temperature increase with the decrease of line tension. Conductor temperature is linearly related to line tension. Fig.1 (b) shows the increase of conductor temperature with line load in accordance with a power function. The relation between conductor temperature and wind speed is approximately linear. Conductor temperature is rare related to wind direction shown in Fig.1 (d).

Correlation matrix of conductor temperature and influence factors is described in Tabe1. The correlation coefficients which significantly affect conductor temperature are 0.83196 and -0.82685 respectively. Therefore line tension and load are the main contributors to conductor temperature. Wind speed is also one of the influence factors, the correlation coefficient is 0.66372. Wind direction scarcely contribute to conductor temperature, the correlation coefficients is only 0.0507, which is in accordance with the conclusion drawn from fig.1 (d). So influence of wind direction is negligible in the conductor temperature model.

Table 1 Correlation matrix of conductor temperature and influence factors

	conductor temperature	Load	Wind speed	Wind direction	Line tension
conductor temperature	1.00000	0.83196	0.66372	0.05070	-0.82685
Load	0.83196	1.00000	0.66854	0.10122	-0.67229
Wind speed	0.66372	0.66854	1.00000	-0.09644	-0.58612
Wind direction	0.05070	0.10122	-0.09644	1.00000	-0.10289
Line tension	-0.82685	-0.67229	-0.58612	-0.10289	1.00000

3. MODELING OF OVERHEAD TRANSMISSION LINE TEMPERATURE

3.1 Multiple regression method (MRM)

Sometimes we wish to predict a random variable Y not just from one variable X but from a set of variables X_1, X_2, … X_c. The procedure is called the regression of Y on X_1, X_2, … X_c [7-8].

We give an algorithm multiple regression which estimates the intercept a and the regression coefficients b_1, b_2, … b_c in the regression equation

$$Y = a + b_1 X_1 + b_2 X_2 + \cdots + b_c X_c \qquad (1)$$

using least-squares estimation. The algorithm also calculates the standard errors of the estimates, the sums of squares of an analysis of variance, and the fitted values and residuals. If we have sets of measurements which are related by a nonlinear relationship, it may be possible to set up a linear regression between them by use of a transformation.

The mutual connection between independent and dependent variables is either linear or nonlinear. In accordance with that, we use MRM to determine the regression coefficients in the circumstances of either linearity or nonlinearity. The criterion that leads to selection of either a linear or nonlinear model is the coefficient of multiple determination (R^2). This coefficient demonstrates whether the model is an adequate representation of the presented situation. The R^2 is a quotient of the regression sum of squares (SSR) and of the total sum of squares (SST) [9]. If R^2 is closer to 1 the model formed is better.

Two statistical quantities have been determined to assess the use of the hypothesized models and to indicate the usefulness of the models to predict the required conductor temperature [10-11]. They are the coefficient of determination R^2 and F_{test}. F_{test} is computed by equation (2):

$$F = \frac{\frac{R^2}{K}}{\frac{(1-R^2)}{n-(k-1)}} \qquad (2)$$

The values of F are computed and compared with the critical values of F distribution $f_\alpha(v_1,v_2)$. Where v_1 and v_2 are the degree of freedom in the numerator (k) and the denominator ($n-k-1$) respectively, and α is the level of significance. When the value of F is greater than $f_\alpha(v_1,v_2)$, it indicate that the regression model is useful to predict the conductor temperature. The evaluation of R^2 and F test have been carried out for the different models and modeling techniques.

3.2 Modelling of conductor temperature characteristics

As proved previously, conductor temperature is related to transmission line load, tension, and wind speed. The mathematical model to evaluate the transmission line load, tension and wind speed as function of conductor temperature is given by MRM as depicted by the following equation:

$$\begin{aligned} T_c &= a_1 I_1' + a_2 I_2' + bF + cv + C \\ I_1' &= I \\ I_2' &= I^2 \end{aligned} \qquad (3)$$

Where I, F, v is the proportion of transmission line load, tension and wind speed, respectively. a_1、a_2、b、c、d are their regression coefficients respectively. C is intercept.

Following the previous statistic analysis, equation (3) could be derived to calculate the proportion of temperature. The multiple regression model of conductor temperature is

$$T_c = 3.57\times10^{-5} I^2 - 0.011727I - 0.003705F + 0.136156v + 85.74814 \qquad (4)$$

The coefficient of determination, R^2 for the model is 0.842, and the modified R^2 is 0.839, which was more than 0.8. The F_{test} is 285.03, and the probability of F-statistic is 0. This means that the model is applicable to predict conductor temperature, and that the model's considered variables contribute to conductor temperature.

4. RESULTS AND ANALYSIS

The DLR system was installed on 110kV transmission lines of Southern Power Grid. To analyze the relevant data collected by the DLR system with the established temperature model, the analysis result is shown in Table 2.

Table 2 Analysis sheet for conductor temperature

	Load (A)	Line tension (N)	Actual temperature (℃)	Computed value(℃)	Error %
1	259.17	14680	31.58	31.20	1.21
2	196.4	14814	30.32	30.17	0.49
3	196.4	15085	29.52	29.21	1.03
4	225.41	14905	29.73	29.93	0.66
5	220.13	14997	29.62	29.66	0.16
6	213.1	14905	29.58	29.96	1.28
7	544.88	13867	39.59	39.23	0.93
8	543.12	14183	39.31	38.13	3.01
9	519.21	13733	38.87	39.12	0.65
10	500.22	14004	38.26	37.69	1.49
11	434.46	13550	37.61	37.85	0.64
12	519.91	13958	38.59	38.41	0.46
13	539.6	13958	39.48	38.88	1.53
14	541.54	13912	38.69	39.06	0.94
15	541.19	14092	39.05	38.42	1.62
16	597.23	13775	40.84	41.00	0.39
17	497.23	13821	39.10	38.14	2.46
18	501.1	13733	39.01	38.58	1.10
19	502.51	14046	37.59	37.70	0.27
20	503.91	14004	37.37	37.87	1.34
21	500.92	14046	37.22	37.60	1.00
22	494.77	14275	36.58	36.53	0.14
23	493.89	14229	36.81	36.65	0.43
24	474.9	14546	35.34	35.25	0.26
25	468.57	14680	33.94	34.33	1.16

The experiments show that the conductor temperature value computed from the proposed model is close to the actual value, and the temperature difference is less than 2 ℃. The result shows an average error of 0.99% and a maximum of 3.01%. Figure 2 shows the different temperature curves.

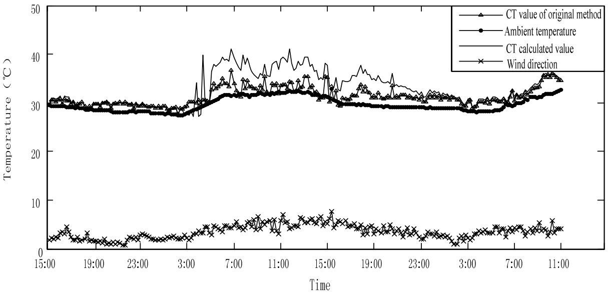


Fig.2 Curves of ambient temperature and conductor temperature (CT)

Fig. 2 shows that the conductor temperature varies with variances depend on line load, ambient conditions and time. The conductor temperature is higher than the ambient temperature during the hours of daylight due to high line load, and drops at sunset when the line load is low, which generally coincide with power system peak times. In addition, because conductor temperature decreases with the increase of wind speed, conductor temperature is not much higher than ambient temperature except for overload and unfavourable weather conditions.

The method constructing conductor sag model is the same as the conductor temperature one.

5. THERMAL OVERLOAD RISK

A better assessment of overhead line loading could be provided with the real-time line temperature and the monitoring data offered by DLR system. The risk assessment can prevent line overload, provide operators advance warning of impending clearance violations, and insure the potentially minimum clearances to ground for safety reasons even under worst case conditions.

We select a critical sag (S_{lim}) within which the operation of the line is safe, in that the line will not violate its minimum clearance [12]. The probability $P(S>S_{\lim})$ is an indicator of the risk associated with the condition of a line.

$$P(S > S_{\lim}) = \frac{N_s}{N} \qquad (5)$$

Where N_s is the number of $S > S_{lim}$ in an unit, and N is the total number of simulations.

The critical temperature corresponding the critical sag is required within the maximum steady-state design temperature of the conductor, which ensure the line will not overload.

The singular value decomposition Volterra chaos theory is applied to the risk prediction. A line risk assessment was carried out. And the prediction is showed in Fig.3 and Fig.4. The prediction values approach the actual ones. The prediction errors are less than 7%. From 18:40 on 1st June to 11:20 AM on 2nd June, there was no thermal overload risk.

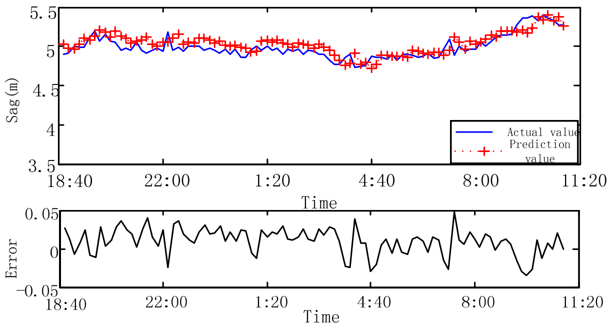


Fig.3 Prediction of conductor sag and error of prediction

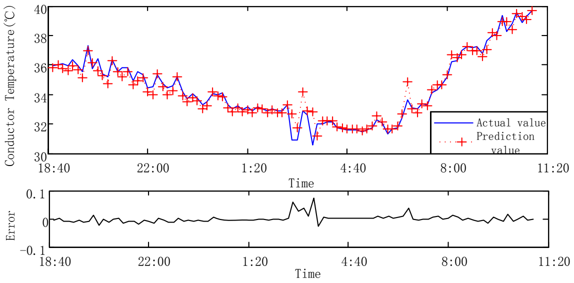


Fig.4 Prediction of conductor temperature and error of prediction

6. CONCLUSION

The variation of conductor temperature is affected by complex factors. This paper proved that line load, tension and wind speed are the main factors which contribute to the temperature of operating lines. Then a multiple regression model was designed to present the strong correlation among the operation line temperature and these multiple influence factors. The justification of applicability of the mathematical model has been verified by the experiment results.

The volterra chaos method is employed to predict the thermal overload risk. The prediction risk of thermal overload is tested to be effective and feasible, which is useful for on-line decision making in the line operation.

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