Over-temperature Risk Assessment of Overhead Conductor with Low Time Resolution of Meteorological Data

Xiong CHEN¹, Li-li GU²*, Wang WANG¹ and Xu-dong ZHANG²

¹NARI Technology Co., Ltd, Nanjing, China;
²Nanjing University of Science and Technology, Nanjing, China
*Corresponding author

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Abstract. IEEE-738 standard model is widely used to estimate overhead conductor temperature. However, the accuracy of this model is affected by the time resolution of environment meteorological data. Generally, the number of estimated results reduces and the discrete step-length of IEEE standard model increases with the decreasing of the time resolution. Therefore, the estimated accuracy is decreased and the highest conductor temperature is easy to be missed. As a result, the over-temperature risk of conductor is raised. For this reason, an approach, based on the IEEE standard model, the random characteristics of meteorological data and principle of Monte Carlo simulation, is proposed to assess the over-temperature risk of overhead conductor with the low time resolution of meteorological data. The validity of the proposed approach is verified by simulation results.

Introduction

In engineering, the ampacity of transmission lines is affected by the operating temperature of overhead conductor largely. The accurate conductor temperature estimation contributes to improve ampacity of transmission line and economic efficiency of power network. In addition, the conductor temperature estimation provides the necessary data for line design, conductor life evaluation and electric network analysis[1-4]. Therefore, it is important to improve the estimated accuracy of conductor temperature.

At present, the IEEE-738 standard model[5] is usually used to estimate the temperature of conductor. The advantages of this model is simple principle and low computational complexity. In this model, the real conductor temperature can be estimated, so long as the current and environmental data of conductor have been measured. Recently, the IEEE standard model is further developed to improve its feasibility and estimate conductor temperature more precisely. For example, in [6], the fuzzy algorithm is used to determine the meteorological data in the IEEE standard model and improve the reliability of conductor temperature estimation. In [7], a new conductor temperature model, based on the dynamic stochastic autoregressive integrated moving average model and the IEEE standard model, is proposed for over-temperature protection method of transmission line. A prediction method of conductor temperature is proposed in [8] based on echo stat network. In [9] the transient equivalent wind speed coefficient is used in IEEE standard model to reduce the dependence of conductor temperature estimation on the wind speed and wind direction. Moreover, some other algorithms are also combined with IEEE standard model to improve the reliability of wire temperature estimation, such as chaos model, numerical weather prediction and black-box corrective algorithm [10-12].

However, the above studies are performed without considering the time resolution of environment meteorological data. When the meteorological data is measured with the low time resolution. The highest temperature of conductor is possibly missed so that the over-temperature risk of conductor will be raised. At present, it is hard to measure the meteorological data in high-speed. That is due to the following two reasons. Firstly, the high-speed data acquisition increases the cost of monitoring systems and the difficulty of transmission line maintenance, especially when a large of number of monitoring systems is required. Secondly, the power condition...
of meteorological monitoring systems is poor since these systems usually to be mounted on the tower. Therefore, the meteorological monitoring systems have to be operated in sleep mode frequently to save the power and the meteorological data has to be obtained with the condition of low time resolution. In practical engineering, the sampling period of meteorological data can be up to more than 10 min\textsuperscript{[13]}.  

In this paper, an approach, based on the IEEE standard model, the random characteristics of meteorological data and principle of Monte Carlo simulation, is proposed to assess the over-temperature risk of overhead conductor with the low time resolution of meteorological data. In this approach the over-temperature risk of overhead conductor is determined in the form of probability. Several simulation results show the effectiveness of the proposed approach.

The Principle of Temperature Estimation Model of Overhead Conductor

Overhead conductor run in outdoor environment for a long time, the temperature are affected by heat generation of conductor, intensity of sunlight, convection of environment and radiation, etc. IEEE standard model is widely used to estimate the temperature of conductor. The temperature rising process as shown in Eq. 1:

$$\frac{dT_i(t)}{dt} = \frac{1}{mc_p} \left[ R(T_i)I^2 + q_s - q_c - q_r \right].$$  \hspace{1cm} (1)

where: \(t\) is the time; \(mc_p\) is heat ampacity of conductor per unit length; \(T_i(t)\) is the temperature at \(t\); \(I\) is electricity through conductor; \(q_s, q_c\) and \(q_r\) is the heat absorption of sunshine, convection, radiation of conductor per unit length; \(R(T_i)\) is the resistance of conductor at \(T_i\).

Parameters of Eq. 1 are shown as follows:

\[
q_s = \alpha_s Q_{sc} \sin(\theta) A.  \hspace{1cm} (2)
\]

\[
q_c = \pi D \varepsilon \sigma \left( \frac{T_i + 273}{100} \right)^4 - \left( \frac{T_0 + 273}{100} \right)^4.  \hspace{1cm} (3)
\]

\[
q_r = k_f K_{angle} \times (T_i - T_0).  \hspace{1cm} (4)
\]

where: \(\alpha_s\) is the absorption rate of conductor; \(Q_{sc}\) is the merged value of direct and scattering; \(\theta\) is incident angle of sun rays; \(A\) is the projected area of wire per unit length; \(A' = D/1000\), \(D\) is diameter of conductor. \(T_i\) is temperature of conductor; \(T_0\) is temperature of environment; \(\varepsilon\) is the radiation coefficient of conductor, 0.23~0.91, the value is usually 0.5 in practical application; \(\delta\) is Stephen-boltzmann constant; \(\rho_f\) is density of air; \(V_u\) is wind speed; \(\mu_f\) is aerodynamic viscosity; \(k_f\) is air heat transfer rate; \(K_{angle}\) is coefficient of the wind direction.

From Eq. 1 to Eq. 4, IEEE standard model is described as a first order nonlinear differential equation. The discrete model is used to estimate the temperature of conductor. Forward Euler dispersion method is recommended in standard model. Eq. 1 is discrete as:

\[
T_i^i = T_i^{i-1} + \frac{h}{mc_p} \left[ R(T_i^{i-1})I^2 + q_s^{i-1} - q_c^{i-1} - q_r^{i-1} \right].  \hspace{1cm} (5)
\]

where: \(h\) is discrete step-length.

Based on the numerical calculation method, the accuracy of the wire temperature estimation is affected by the discrete step-length. Generally, the larger value of \(h\), the fewer the number of temperature estimation results. The accuracy of temperature estimation is reduced, the highest operating temperature is easily missed for wire. 1min is recommended as discrete-step length in
IEEE standard model. However, due to the time resolution of meteorological data acquisition, the IEEE model may need to use larger value in practical engineering applications.

**The Random Model of Environmental Meteorological**

To improve the reliability of wire temperature estimation with low time resolution of meteorological data, some common models is given for random variation of wire environmental meteorology.

Generally, the wind direction of the environment is highly random and fluctuates greatly. Therefore, Von Mises (VM) distribution function is used to describe the random character of wind direction\(^{[14]}\). The range of the distribution angle of the model is \(0 \sim 2\pi\), the probability density function is expressed as:

\[
f(\varphi) = (2\pi I_0(k))^{-1} \exp(k \cos(\varphi - \mu_w)).
\]

(6)

\[
I_0(k) = \sum_{r=0}^{\infty} (r!)^{-2} (0.5k)^r.
\]

(7)

Where: \(I_0(k)\) is the normalized constant of the distribution, represented by the zero order Bessel function, \(k \in [0, \infty]\), \(\varphi \in [0, 2\pi]\); \(\mu_w\) is average value of wind direction.

The variation of wind speed in the environment is also highly random. Considering the large range of wind speed change, the random character of wind speed is described by Weibull distribution\(^{[15]}\). The probability density function is expressed as:

\[
f(v) = \begin{cases} 
\frac{k_w(v^2)^{-1}e^{-\frac{v^2}{2\lambda^2}}}{\lambda^3} & v > 0 \\
0 & v < 0
\end{cases}.
\]

(8)

Where: \(v\) is the random value of wing speed; \(k_w\) is the shape parameter; \(\lambda > 0\) is scaling parameters.

The ambient temperature changes periodically during the day and night. But in terms of minutes or tens of minutes, it is slow that ambient temperature changes, the range of change is also small. So in engineering, the random variation of ambient temperature can be described by normal distribution within a short time. The probability density function is:

\[
f(T_a) = \frac{1}{\sqrt{2\pi\delta^2}} \exp(-\frac{(T_a(t) - \mu_{amb})^2}{2\delta^2}).
\]

(9)

Where: \(T_a(t)\) is ambient temperature at t time; \(\mu_{amb}\) is ambient average temperature; \(\delta^2\) is variance.

Due to Changes of cloud thickness are difficult to quantify, there is no widely accepted random model of solar radiation at present. But in general, the short-term change of environmental sunshine is relatively slow, and the change range is small. This is similar to the change character of ambient temperature, normal distribution is applied to it. The probability density function is:

\[
f(W_s) = \frac{1}{\sqrt{2\pi\delta_s^2}} \exp(-\frac{(W_s(t) - \mu_s)^2}{2\delta_s^2}).
\]

(10)

Where: \(W_s(t)\) is solar radiation at t time; \(\mu_s\) is average solar radiation; \(\delta_s^2\) is variance of solar radiation.

**The Principle of Monte Carlo Simulation**

Monte Carlo method is referred to random sampling techniques, is used to simulate random process. The method is based on law of large numbers of probability. When the number of sample is large enough, the sampling frequency can be used as unbiased estimation of the system.
When the model and random distributions of parameters are confirmed, the steps of Monte Carlo simulation as shown in Table 1.

<table>
<thead>
<tr>
<th>Steps</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td>Based on random character of parameters, generating the number of parameter random data required for the simulation process. Generally, random parameters of uniformly distributed are obtained firstly, combined with random character of parameters, and generates random data.</td>
</tr>
<tr>
<td>Step 2</td>
<td>Based on random character of parameters, the appropriate random sampling method is designed and selected.</td>
</tr>
<tr>
<td>Step 3</td>
<td>The values of random sampling selected are used to simulate the object model.</td>
</tr>
<tr>
<td>Step 4</td>
<td>Based on simulation results, the target object is counted and analyzed.</td>
</tr>
</tbody>
</table>

**The Principle of Risk Assessment Method Proposed of Conductor Temperature**

An approach, based on the IEEE standard model, the random characteristics of meteorological data and principle of Monte Carlo simulation, is proposed to assess the over-temperature risk of overhead conductor with the low time resolution of meteorological data. Basic idea of the method is: firstly, based on the random character of meteorological and Monte Carlo method, random samples of meteorological data are obtained by simulating randomly the meteorological data between adjacent sampling points. Then, meteorological random sequences are gained by direct sampling technique for sample of meteorological data. Based on the random sequences, the wire temperatures are simulated randomly between adjacent sampling points. Finally, the temperature results of the random simulation are counted and analyzed, the risk probability of over-temperature operation is evaluated of the wire between adjacent sampling points. The problems are solved that the calculated values of wire temperature is too little and the maximum temperature is easy to miss with low temporal resolution. The implementation process of the proposed method as shown in Figure 1.

![Figure 1. Schematic diagram of risk assessment.](image)

In figure 1, \( \{X_i\} \) is the random sample set of the \( i \) th simulated meteorological data; \( N \) is the total simulation number; \( \{y_j\} \) is the meteorological random sequence set at the \( j \) time, \( \{T_j\} \) is the temperature set at the \( j \) time, \( m \) is the length of adjacent sampling points.

**Verification of Calculation Example**

An over-head wire of LGJ-240/30 conductor is studied as the object, the effectiveness of the proposed algorithm is verified by calculation example. The specification parameters of LGJ-240/30 can be referred in [17].

In the example, the variation process of electricity is shown in Figure 2. Where, the electricity has a crest between 60min~120min, is used to simulate short-term heavy load of simulation wire, the risk of wire over-temperature is increased.

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The parameters of the environmental meteorological random model are shown in Table 2. In engineering, the parameters of random model can be determined by the two methods as follows: the one, the data is obtained by the numerical weather forecast statistical data from weather station. Another one, through the Bayes analysis and markov chains simulation of historical monitoring data.[16]

<table>
<thead>
<tr>
<th>parameters</th>
<th>Wind direction</th>
<th>Wind speed</th>
<th>Sunlight intensity</th>
<th>Ambient temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>value</td>
<td>$k$</td>
<td>$\mu_{wd}$</td>
<td>$\lambda$</td>
<td>$\mu_{abmT}$</td>
</tr>
<tr>
<td></td>
<td>$\pi/6$</td>
<td>$k_w$</td>
<td>$2$</td>
<td>$20$</td>
</tr>
<tr>
<td></td>
<td>$\nu$</td>
<td>$\lambda_{abmT}$</td>
<td>$4$</td>
<td>$950$</td>
</tr>
<tr>
<td></td>
<td>$\sigma_w^2$</td>
<td>$\sigma_{abmT}^2$</td>
<td>$4$</td>
<td></td>
</tr>
</tbody>
</table>

Based on the random parameters, the random change process of environmental meteorological is given as Figure 3 and Figure 4.

To compare the influence of time resolution of meteorological data for estimating conductor temperature, the sampling cycle of 1min and 10min is used as the discrete step-length. Estimated temperature results of conductor as shown in Figure 5. At the discrete step-length of 1min, the number of estimated conductor temperature is big enough, the temperature change process is described well. From the result, the conductor temperature increases radically, even beyond 70°C. In practical engineering, the temperature limit of conductor is 70°C, so the conductor has run over temperature during this period. However, at the discrete step-length of 10min, the results of wire temperature estimation are sparse, and the accuracy of estimation is decreased dramatically. Therefore, over-temperature operation of the conductor may not be judged correctly. This indicates that the risk of over-temperature operation of the wire cannot be evaluated correctly with the low time resolution of meteorological data.

Based on the meteorological simulation data and discrete step-length of 10min, The wire temperature between different sampling points are simulated 1000 times. The temperature results of simulation are counted and analyzed, and the risk probability of wire over-temperature operation is obtained, as shown in Fig. 6. This shows that the probability of over-temperature operation of conductor is increased sharply at 60min~120min, and the highest probability of over-temperature up to 95%. The change trend of wire temperature is consistent with calculated result at the discrete
step-length of 1min. Therefore, the risk of over-temperature operation can be determined accurately by the proposed method, even if at the low time resolution of meteorological data. The transmission safety can be improved to some extent.

![Figure 6. Estimated results of conductor overheat probability.](image)

**Summary**

An approach is proposed to assess the over-temperature risk of overhead conductor with the low time resolution of meteorological data in this paper. The simulation results of calculation example show that the proposed approach can simulate conductor temperature randomly in one sampling step-length. Then, the over-temperature risk of overhead conductor can be determined accurately in the form of probability, even if the meteorological data is measured with the low time resolution.

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**References**


