Improved calculation method of dynamic current carrying capacity of transmission line

ZHANG Ruopeng¹², TIAN Mingxing¹²*, SUN Lijun²³ and Su Zhaoxu¹²

¹ School of Automation & Electrical Engineering, Lanzhou Jiaotong University, Lanzhou, 730070, China
² Rail Transit Electrical Automation Engineering Laboratory of Gansu Province, Lanzhou Jiaotong University, Lanzhou, 730070, China
³ Key Laboratory of Opto-Technology and Intelligent Control Ministry of Education, Lanzhou Jiaotong University, Lanzhou, 730070, China

*Corresponding author’s e-mail: tianmingxing@mail.lzjtu.cn

Abstract. The calculation of the dynamic current carrying capacity of transmission lines in a domestic traction network is based on IEEE 738 standard. However, because IEEE 738 standard is derived under specific climate and geographical conditions, only when the climate and geographical conditions are stable can the accurate ampacity be calculated. However, in practical application, due to the rapid change of climate factors and large meteorological monitoring error, the results calculated by IEEE 738 standard have large errors. Therefore, this paper puts forward the method of using convective heat dissipation coefficient and equivalent radiation heat dissipation coefficient to deal with the problems caused by unstable meteorological factors. By this method, the dynamic current carrying capacity of the transmission line can be calculated only by measuring the conductor temperature and ambient temperature, which simplifies the calculation process of the dynamic current carrying capacity of the transmission line and reduces the dependence on meteorological parameters.

1. Introduction

For the design and operation of the electrified railway line, the ampacity of the traction transmission line is a very important parameter [1-2]. The size of the current-carrying capacity directly determines whether the line can operate normally and transmit electric energy efficiently [3]. At present, there are many standards for calculating ampacity. After weighing the accuracy of several calculation standards [4], this paper decided to improve it based on the IEEE 738 standard. IEEE738 standard is derived under the condition of constant meteorological and geographical conditions, so the calculation results are more accurate when the meteorological and geographical conditions are relatively stable. However, due to the vast geography of China, the geographical and climatic conditions of OCs are very complex. At the same time, due to the rapid change of weather and the monitoring error of monitoring devices, the accumulated error will have a great impact on the calculation results [5]. Therefore, we need to find a method to deal with the meteorological environment and other factors that are difficult to monitor, which makes the calculation process of conductor ampacity simple and reduces the dependence on meteorological parameters.
2. Materials and Methods

2.1. Calculation method of ampacity based on IEEE738 standard

When the traction network transmission line works normally, it will produce heat (Joule heat), and the
resistance and current of the transmission line have a great influence on the Joule heat power. The heat
generated by the transmission line will be exchanged with the heat of the surrounding environment,
that is to say, the transmission line will increase its temperature by absorbing the solar radiation heat,
and also reduce its temperature by radiating heat through convection and radiation. According to the
IEEE738 standard, the overhead transmission line meets the heat balance equation shown in equation
(1):

\[ mC_p \frac{dT}{dt} = I^2R(T) + p_s - p_c - p_r \]  

In formula (1), \( m \) is the mass of the transmission line per unit length (kg·m\(^{-1}\)); \( C_p \) is the specific
heat capacity of the transmission line material (J·kg\(^{-1}\)·°C\(^{-1}\)); \( T \) is the temperature of the transmission
line (°C); \( R \) is the resistance of the transmission line per unit length (Ω·m\(^{-1}\)). \( p_c \) is the convective heat
dissipation power per unit length of transmission line (W·m\(^{-1}\)); \( p_r \) is the convective heat dissipation
power per unit length of transmission line (W·m\(^{-1}\)), and \( p_s \) is the solar radiation heat absorption power
per unit length of transmission line (W·m\(^{-1}\)).

When the heat generated by the current (Joule heat) and absorbed by the transmission line reach a
dynamic balance with the heat emitted by the line itself, the temperature of the line remains constant.
At this time, the temperature change on the left side of equation (1) is 0, which can be written as follows:

\[ I^2R(T) + p_s - p_c - p_r = 0 \]  

The allowable current carrying capacity of the transmission line refers to the current carrying
capacity of the transmission line when the transmission line works at the maximum allowable
temperature \( T_{max} \) for a long time. The allowable ampacity can be calculated by equation (3):

\[ I_{max} = \sqrt{\frac{p_c(T_{max}) + p_r(T_{max}) - p_s}{R(T_{max})}} \]  

The resistance \( R \) of the conductor can be obtained from formula (4):

\[ R(T) = R_{ref}[1 + \alpha_l(T - T_f)] \]  

In formula (4), \( R_{ref} \) is the resistance value of transmission line at reference temperature (Ω·m\(^{-1}\)); \( \alpha_l \) is the resistance temperature coefficient (°C\(^{-1}\)); \( T_f \) is the reference temperature (°C\(^{-1}\)).

The convective heat dissipation power \( p_c \), radiation heat dissipation power \( p_r \) and solar radiation
heat absorption power \( p_s \) satisfy equations (5) to (7).

\[ p_c = K_{angle}[1.01 + 1.35(D_0 \rho f V_w \mu_f)0.52]k_f (T - T_a) \]  

\[ p_r = 17.8D_0 \epsilon[(\frac{T + 273}{100})^4 - (\frac{T_f + 273}{100})^4] \]  

\[ p_s = \alpha Q_{so} \sin(\theta)A \]  

Where \( K_{angle} \) is the wind direction coefficient (pu); \( D_0 \) is the outer diameter of the conductor (m); \( \rho f \)
is the air density (kg·m\(^{-3}\)); \( V_w \) is the wind speed (m·s\(^{-1}\)); \( \mu_f \) is the dynamic viscosity of the air (kg·m\(^{-1}\)·s\(^{-1}\)); \( k_f \) is the thermal conductivity of the air (W·m\(^{-1}\)·°C\(^{-1}\)); \( T_a \) is the air temperature around the conductor.
(°C); $\varepsilon$ is the emissivity (pu); $\alpha$ is the heat absorption coefficient of the conductor (pu); $Q_{se}$ is the solar radiation intensity (W·m$^{-2}$); $\theta$ is the effective incidence angle (deg) of the sun; $A$ is the effective projected area per unit length of transmission line (m$^2$·m$^{-1}$).

2.2. Derivation method of convective heat transfer coefficient and radiative heat transfer coefficient

There are many geographical and climatic parameters (the speed of the wind, wind direction angle, ambient temperature, altitude, sunshine, etc.) required by IEEE738 standard to calculate ampacity, and the monitoring of these parameters is difficult and the error is large. Therefore, in this paper, all the coefficients except temperature in equation (5) and equation (6) are combined into one coefficient, which is called convective heat transfer coefficient $A_c$ and radiative heat transfer coefficient $A_r$. Then, formula (2) can be expressed as formula (8):

$$I^2R(T)+ p_a - Ac(T - T_a) - Ar[(\frac{T + 273}{100})^4 - (\frac{T_a + 273}{100})^4] = 0$$ (8)

At this time, if the coefficients $A_c$ and $A_r$ can be obtained, the current carrying capacity of the conductor corresponding to the maximum allowable temperature $T_{max}$ can be obtained by equation (3), and the obtained current is the large allowable current carrying capacity that the transmission conductor can bear.

Calculation steps:

(1) A certain length of a transmission line is selected as the experimental object, and a constant current $I_1$ is applied to the line. When the temperature of the line rises to a stable value, the temperature $T_1$ of the line is measured and recorded.

(2) Increase the current to another fixed value $I_2$. When the conductor temperature rises to a stable value, measure and records the conductor temperature $T_2$ again.

(3) By listing binary linear equations, such as equation (9). The heat dissipation coefficients $A_c$ and $A_r$ are obtained.

$$\begin{align*}
I_1^2R(T_1) + p_a - Ac(T_1 - T_a) - Ar[(\frac{T_1 + 273}{100})^4 - (\frac{T_a + 273}{100})^4] &= 0 \\
I_2^2R(T_2) + p_a - Ac(T_2 - T_a) - Ar[(\frac{T_2 + 273}{100})^4 - (\frac{T_a + 273}{100})^4] &= 0
\end{align*}$$ (9)

Where $T_1$, $T_2$ and $T_a$ are known, $I$ is the current passing through the transmission wire, and $R(T)$ can be obtained by formula (4).

(4) When the temperature is $T_{max}$, the conductor current carrying capacity can be obtained from the calculation formula (3).

2.3. Experimental device and system

This method is verified by experiments. The experimental device is mainly composed of a power console, experimental line (model is 10m long contact wire CTAH120 / catenary JTMH95), and automatic weather station. Monitoring points for conductor temperature, ambient temperature, and local meteorological conditions are installed outdoors. The experimental site in Lanzhou is shown in Figure 1.
3. Results & Discussion
In this paper, two groups of experiments are designed to verify. The selected transmission line model, parameters, and meteorological parameters of Lanzhou area are shown in Table 1 to Table 3.

Table 1. Relevant parameters of contact wire CTAH120.

| Equivalent radius (mm) | Temperature coefficient of resistance (°C⁻¹) | Reference temperature (20°C) resistance value (Ω·km⁻¹) | Maximum allowable temperature (°C) | Limiting temperature (°C) | Current carrying capacity (A) |
|------------------------|---------------------------------------------|----------------------------------------------------|-----------------------------------|---------------------------|-----------------------------|
| 6.18                   | 0.0038                                      | 0.147                                              | 95                                | 200                       | 430                         |

Table 2. Relevant parameters of contact wire JTMH95.

| Equivalent radius (mm) | Temperature coefficient of resistance (°C⁻¹) | Reference temperature (20°C) resistance value (Ω·km⁻¹) | Maximum allowable temperature (°C) | Limiting temperature (°C) | Current carrying capacity (A) |
|------------------------|---------------------------------------------|----------------------------------------------------|-----------------------------------|---------------------------|-----------------------------|
| 5.50                   | 0.0027                                      | 0.231                                              | 95                                | 200                       | 366                         |

Table 3. Meteorological parameters of Lanzhou.

| Parameter name          | Unit     | Parameter value |
|-------------------------|----------|-----------------|
| Wind speed ($V_w$)      | m·s⁻¹    | 1.3             |
| Wind direction angle ($F_y$) | deg     | 45              |
| Ambient temperature ($T_a$) | °C      | 30              |
| Reference temperature ($T_d$) | °C      | 20              |
| Altitude ($H_e$)        | m        | 1600            |
| Emissivity ($\varepsilon$) | No unit | 0.5             |
| Radiant endothermic power ($p_s$) | W·m⁻¹ | 10.3            |
Experiment 1: firstly, the contact wire CTAH120 of the experimental wire was given a steady current of 139A for one hour. When the temperature of the wire rose to a stable value, the temperature of the wire was measured and recorded. Then increase the current to 233A, and measure and record the wire temperature again after 1 hour. The measured parameters are shown in Table 4. Finally, the convective heat transfer coefficient and heat transfer coefficient can be obtained by taking the measured parameters into equation (9), as shown in Table 5.

| Applied current (A) | 139 | 233 |
|---------------------|-----|-----|
| Measured wire temperature (°C) | 48.2 | 56.2 |
| Conductor resistance (Ω·km⁻³) | 0.163 | 0.167 |

Table 4. Parameters measured by contact wire CTAH120.

Table 5. The heat dissipation coefficient of contact line CTAH120.

| Convective heat dissipation coefficient $A_c$ | 0.672 |
| Radiation coefficient $A_r$ | 0.055 |

Experiment 2: for the catenary JTMH95, first add a stable current of 122A to the experimental wire for one hour, and then measure and record the wire temperature when the wire temperature rises to a stable value. Secondly, increase the current to 233A, and measure and record the conductor temperature again after 1 hour. The measured parameters are shown in Table 6. Finally, the measured parameters are brought into equation (9), and the heat dissipation coefficient and heat dissipation coefficient can also be obtained, as shown in Table 7.

| Applied current (A) | 122 | 203 |
|---------------------|-----|-----|
| Measured wire temperature (°C) | 49.8 | 58.8 |
| Conductor resistance (Ω·km⁻³) | 0.230 | 0.235 |

Table 6. Parameters measured by contact wire JTMH95.

Table 7. The heat dissipation coefficient of contact line JTMH95.

| Convective heat dissipation coefficient $A_c$ | 0.633 |
| Radiation coefficient $A_r$ | 0.049 |

After the equivalent heat dissipation coefficient $A_c$ and the equivalent radiation coefficient $A_r$ of the experimental conductor are obtained respectively, the ampacity of the contact wire CTAH120 and the messenger wire JTMH95 at the maximum allowable temperature (95 °C) can be calculated by equation (3), as shown in Table 8.

Table 8. Type of transmission conductor and its ampacity (A) / temperature(°C).

| position | Factory recommendations | Calculation results of maximum allowable ampacity |
|----------|-------------------------|-------------------------------------------------|
| Contact line CTAH120 | 430/95 | 449.8/95 |
| Load-bearing cable JTMH95 | 366/95 | 370.5/95 |
Compared with the current carrying capacity calculation method of IEEE738 standard, the improved method can calculate the current carrying capacity only by measuring the conductor temperature and ambient temperature, which not only simplifies the calculation process of the current carrying capacity of the transmission line but also reduces the dependence on meteorological parameters. It can be seen from Table 8 that the maximum allowable current-carrying capacity calculated by this method is higher than the allowable current-carrying capacity recommended by the factory, so it is also of great significance to improve the transmission efficiency of the transmission line.

4. Conclusions
(1) The improved method allows fewer meteorological parameters for carrying capacity calculation. Therefore, the calculation process is no longer as complicated as before. At the same time, because not too many meteorological monitoring devices (sensors) are needed, the monitoring cost can be reduced.

(2) Because the recommended allowable current carrying capacity of the outgoing conductor is obtained under certain climatic and geographical conditions, the reference basis of design is too conservative, which will reduce the transmission efficiency of the selected transmission conductor in practical application, and the current-carrying capacity obtained by the improved method is higher than that proposed by the outgoing conductor, so the allowable current-carrying capacity is adopted. As the basis of transmission line selection, it can improve the transmission efficiency of transmission line, and reduce the diameter and cost of the transmission line.

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