Dynamic Capacity Increase Scheme of Traction Network Considering Capacity Increase Risk

Zhaoxu Su\textsuperscript{1,2}, Mingxing Tian\textsuperscript{1,2,*}, and Lijun Sun\textsuperscript{1,2}

\textsuperscript{1}School of Automation & Electrical Engineering, Lanzhou Jiaotong University, Lanzhou, 730070, China
\textsuperscript{2}Rail Transit Electrical Automation Engineering Laboratory of Gansu Province, Lanzhou Jiaotong University, Lanzhou, 730070, China

*Corresponding author: tianmingxing@mail.lzjtu.cn

Abstract. To make better use of the transmission capacity of the traction power supply system, the static temperature increasing and dynamic capacity increasing schemes are introduced into the traction network to tap the transmission potential of transmission lines. Aiming at the reliability problem of line capacity increasing, the capacity increasing scheme of traction network considering the time-varying characteristics of wind speed is studied. In this paper, the risk assessment scheme of medium-term capacity increase based on the Monte Carlo test and the calculation method of safety time of static temperature rise and capacity increase is proposed. The influence of time-varying characteristics of wind speed on the reliability of the existing physical capacity increase system is effectively evaluated, and the temperature change process of the transmission line is analyzed. The "thermal inertia" is used to conduct emergency capacity increase of traction network to save scheduling optimization time. The example shows that the method proposed in this paper is a new and effective method, which is of great significance to tap the transportation potential of the existing traction network.

1. Introduction

The temperature and maximum allowable operating current carrying capacity of the transmission line in the traction network are the main factors in the process of traction network dispatching. The temperature and current carrying capacity of transmission line are closely related to the environmental temperature, wind speed, wind direction, altitude, sunshine intensity and physical characteristics of transmission lines\textsuperscript{[1]}. At present, in the process of traction network scheduling, the conductor temperature is mostly empirical, and the capacity margin is large in the process of conductor operation, which will cause a certain degree of waste. The maximum allowable sustained current is mostly under relatively severe weather conditions (wind speed 0.5m/s, wind direction angle 90°, ambient temperature 40°C and sunshine intensity 1000 Wm\textsuperscript{-2}) are calculated. The actual situation is that the probability of this severe weather condition is very small and the calculation results are not accurate. Reference [2] puts forward the theory of electro-thermal coupling, which describes the coupling relationship between electricity and heat of transmission line, and establishes the electro-thermal coupling model of transmission line about Joule heat and affected by environmental factors around the line. Most of the above studies [1-6] focus on the temperature and ampacity of transmission line in power system, while the traction power supply system also faces the problems of optimal dispatching, so it is necessary to systematically study the temperature and ampacity of transmission line in the traction network.
In this paper, the characteristics of transmission line operating temperature affected by geographical and climatic parameters are used to explore the thermal stability transmission capacity of the traction network. The risk assessment scheme of medium-term traction network considering the time-varying characteristics of wind speed and the static temperature and capacity increasing method of the traction network using the thermal inertia of the transmission line which based on the operating temperature of the transmission line and the comprehensive maximum allowable operating current carrying capacity of the traction network are proposed. The example shows that the proposed method can improve the transportation capacity of the traction network as much as possible on the premise of ensuring the safe operation of the traction network. It provides effective technical support for traction network dispatching center to increase capacity.

2. IEEE-738 Standard physical compatibilization model

The overhead transmission line meets the heat balance equation shown in equation (1)\(^{(1)}\).

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

Where: \(m\) 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; \(P_c\), \(P_r\), and \(P_s\) are the convective heat dissipation power, radiant heat dissipation power and solar radiant heat absorption power, W·m\(^{-1}\); \(R(T)\) is the temperature of the transmission line per unit length in \(T\), Ω·m\(^{-1}\).

\[
T = T_0 + \frac{1}{mC_p} \int_{t_0}^{t_f} \frac{\partial R(T)}{\partial T} dt
\]

Equation (2) is the integral form of formula (1) under the finite difference interval \((t_f - t_0)\).

Convective heat dissipation power \(P_c\) is related to wind speed, air density, ambient temperature, wind direction angle and outer diameter of transmission line; radiation heat dissipation power \(P_r\) is related to ambient temperature; solar radiation heat absorption power \(P_s\) is related to altitude and light intensity; transmission line resistance \(R\) is a function of conductor temperature \(T\), and the specific calculation formula is shown in reference [2].

When the Joule thermal power generated by the current is equal to the heat absorption power and heat dissipation power of the transmission line, the temperature of the transmission line reaches constant. At this time, when the operating temperature of the transmission line reaches its maximum allowable operating temperature \(T_{max}\), the maximum allowable continuous current carrying capacity can be expressed as:

\[
I_{T_{max}} = \sqrt{\frac{P_c + P_r - P_s}{R(T_{max})}}
\]

3. Risk assessment index of capacity expansion

The probability of over temperature refers to the probability that the operating temperature of the transmission line exceeds its thermal rating, and the thermal rating required by the line design code is taken as the critical range for the safe operation of the line\(^{(3)}\).

The risk assessment index of transmission line capacity increase is:

\[
P_w = P(T_s \geq T_{s_{max}}) = \frac{N_w}{N}
\]

Where: \(N_w\) is the number of times when the transmission line operating temperature \(T_s\) is greater than its thermal rating \(T_{s_{max}}\) in Monte Carlo simulation experiment; \(N\) is the total number of Monte Carlo experiments. It can be found that the size of the risk assessment index is relative, and the capacity increase risk assessment index has a great relationship with the number of MC experiments. Often, if the number of MC experiments is more, the temperature exceeding probability of the corresponding current level on the corresponding transmission line will be much smaller. On the contrary, if the
number of MC experiments is less, the temperature exceeding probability of the corresponding current level on the corresponding transmission line will be larger. Therefore, when selecting the risk assessment index size, the traction dispatching center should select the appropriate risk assessment index based on the number of MC tests.

4. Equivalent circuit model of traction network and current distribution of transmission line

For the equivalent circuit model of the traction network, please refer to reference [4]. On the basis of this model, the current distribution coefficient of each transmission line of the traction network $k_g$ can be obtained, so as to obtain the calculation formula of comprehensive carrying capacity $I_{max}$ of the traction network and the matching operation carrying capacity of each transmission line when the traction network reaches the comprehensive carrying capacity $I_{max}$, as shown in formula (5) and formula (6).

$$I_{max} = \min \left\{ \frac{I_{max}}{k_g} \right\}$$  \hspace{1cm} (5)

The maximum allowable operating current carrying capacity of each transmission line in the traction network $I_{pe}$ is as follows:

$$I_{pe} = I_{max} k_g$$  \hspace{1cm} (6)

Where: $g$ can take $j$, $c$ and $r$ to represent contact wire, messenger wire and reinforcing wire respectively in the power supply section with reinforcing wire. $g$ can take $j$ and $c$ to represent contact wire and messenger wire respectively in the section without reinforcing wire; $I_{g\text{max}}$ is the maximum allowable operating current carrying capacity when temperature of transmission line $g$ reaches its thermal rating; $k_g$ is the current distribution coefficient of transmission line of $g$.

![Figure 1. Calculation flow chart of medium-term capacity increase scheme.](image1)

![Figure 2. Calculation flow chart of static temperature and capacity increase.](image2)
5. Implementation process of traction network capacity increase

In this paper, two schemes of traction network capacity increase are proposed, one is the risk assessment scheme of medium-term capacity increase considering the time-varying characteristics of wind speed, and the other is the scheme of static temperature increase and capacity increase using "thermal inertia" of transmission line. The temperature rise time of transmission line is calculated, that is, the minimum time when the operating temperature of each transmission line rises to its maximum allowable temperature when the large current passes through the traction network. The specific calculation process of two schemes is shown in Fig. 1 and Fig. 2, respectively.

6. Cases analysis

Suppose that a single line direct supply transmission line is erected in Jiamusi of China power supply section, and the spatial distribution is shown in reference [4], in which (horizontal, height) unit is mm. Selection of transmission conductor: contact wire CTAH120, messenger wire JTMH95 and reinforcement wire LGT 185/30. See reference [4] for specific parameters of conductor. In this power supply section, the locomotive is a constant power model [7], and the traction network operates stably at a constant current of 1700A.

### Table 1. Meteorological parameters of Jiamusi.

| wind speed $V_w$(m/s) | Wind angle $F_y$(deg) | Ambient temperature $T_a$(℃) |
|-----------------------|-----------------------|-----------------------------|
| 1.8                   | 45                    | -15                         |
| Altitude $H_e$(m)     | Emissivity $\varepsilon$ (-) | Solar radiation heat absorption power (W/m) |
| 81.2                  | 0.5                   | 22.24                       |

6.1 Calculation of current distribution coefficient

In reference [4], the author uses the parameters of transmission line and the spatial relative position relationship of transmission line of the traction network to take the equivalent depth of current in the ground $D_g = 93000mm$ and calculate the current distribution coefficient in detail. See the Table 2. for the specific coefficient.

### Table 2. Current distribution coefficient of transmission line.

| Coefficient name | $k_j$ | $k_c$ | $k_r$ |
|------------------|-------|-------|-------|
| Value            | 0.337 | 0.316 | 0.348 |

6.2 The maximum allowable operating current carrying capacity $I_{cmax}$ of messenger wire is affected by different meteorological conditions

![Figure 3. Wind speed effect.](image3)

![Figure 4. Wind direction angle effect.](image4)
The transmission capacity of the transmission line of the traction network depends on the operating temperature of the transmission line, and the operating temperature is closely related to the meteorological parameters along the corridor of the traction network. Using the control variable method, the influence of various geographical and climatic conditions on the maximum allowable operating ampacity of the contact line is obtained through MATLAB simulation, as shown in the Fig. 3., Fig. 4., and Fig. 5. The simulation parameters of CTAH120 contact wire are shown in the reference [4]. The simulation meteorological parameters are shown in the Table 1.

In the Fig. 3. to Fig. 5., the variation rate of the maximum allowable operating current carrying capacity of contact line with various geographical and meteorological parameters is also introduced. It can be seen from the comparison in the Fig. 3. that the wind speed condition has the most obvious influence on the variation of the maximum allowable operating ampacity of transmission line. With the increase of wind speed, the variation rate of the maximum allowable operating ampacity begins to decrease, which also shows that the influence of wind speed on the ampacity gradually decreases with the increase of wind speed, especially at low wind speed. From Fig. 2.. It can be seen that the effect of wind direction angle on the current carrying capacity of transmission line is second only to that of wind speed. With the increase of wind direction angle, the change rate of current carrying capacity with wind direction angle also decreases gradually. When the wind direction angle increases to about 70deg, the change rate of current carrying capacity with wind direction angle begins to increase again. That is to say, the current carrying capacity increases with the increase of wind direction angle, but when the wind direction angle is above 70deg, the degree of influence increases again. Fig. 3. shows the influence of the ambient temperature on the current carrying capacity and the change rate of the current carrying capacity with the ambient temperature. It can be found that the current carrying capacity decreases with the increase of the ambient temperature, and the influence of the increase of the ambient temperature on the current carrying capacity gradually decreases with the increase of the ambient temperature.

According to the above analysis, the geographical climate conditions have a great influence on the calculation results of the maximum allowable operating current carrying capacity. Compared with other geographical climate conditions, the wind speed has a significant impact on the maximum allowable operating current carrying capacity of transmission lines.

### 6.3 Calculation of safe operation time for static temperature and capacity increase of traction network

In order to ensure that the traction network uses the “thermal inertia” of transmission line to increase the transmission capacity of the traction network in a short time without overload risk, it is necessary to calculate the safe operation time of large current. The dispatch center can calculate the overload time corresponding to the allowable temperature $\Delta t$ according to equation (2). It is assumed that in the initial stage (before capacity increase), the traction network will operate stably according to the power mentioned above. Assuming that the number of locomotives is increased in the power supply section,
the comprehensive carrying capacity of the traction network will reach 3000A, and the temperature change curve of each transmission line is shown in the Fig.6.

It can be seen from the Fig.6 that the traction network bears the current carrying capacity of 3000A. Compared with the Table 3, the capacity increase is about 50%, and the capacity increase proportion is considerable, but the capacity increase time is only 95s.

Table 3. Maximum allowable operating current carrying capacity (A) / temperature (°C) of factory setting of transmission line of the traction network.

| Model          | $I_{\text{max}}$ | $I_{\text{max}}$ | $I_{\text{max}}$ | $I_{\text{max}}$ |
|----------------|------------------|------------------|------------------|------------------|
| Factory value  | 430/95           | 366/95           | 515/90           | 1143/-           |

6.4 Medium-term dynamic capacity increase scheme of traction network considering risk assessment

The wind speed data of Jiamusi meteorological center in 2020 was collected randomly at an interval of 10 minutes. In the risk assessment of dynamic capacity increase of the traction network, because when the messenger wire reaches its maximum allowable operating temperature, the transmission conductance of other traction network is far lower than its maximum allowable operating temperature, this paper focuses on the influence of wind speed on the messenger wire temperature, and the relaxation environment when other geographical and climatic parameters are conservative. 100 groups of Monte Carlo experiments are carried out on the messenger wire, and the temperature exceeding probability under different current levels is calculated, which is compared with the indexes required by the traction dispatching center to determine the appropriate medium-term capacity increase safety range.

Fig. 7. and Fig. 8. show the temperature curve of messenger wire under different current levels in Jiamusi area. The wind speed conditions in Fig. 7. and Fig. 8. are not exactly the same. They are two groups of wind speed series data randomly collected.

Figure 7. Temperature curve of messenger wire.

Figure 8. Temperature curve of messenger wire.

It can be found from the Fig. 7. and Fig. 8. that the conductor temperature is different when the messenger wire passes through different current levels, and the higher the current, the higher the temperature of the messenger wire. By comparing the Fig. 7. with the Fig. 8., it is obvious that the temperature of the messenger wire shows obvious random characteristics when the messenger wire passes through the same current due to the irregular fluctuation of wind speed, rather than the fixed value calculated under the steady-state condition. Although the overall change trend of the operating temperature of the messenger wire under different wind speed series is consistent under the same current, due to the influence of the time-varying characteristics of wind speed, the operating temperature of the messenger wire will exceed its thermal limit value at a certain moment or some moments, which will have an adverse impact on the safe capacity increase of the traction network.

100 groups of wind speed series collected in Jiamusi area were simulated by 100 Monte Carlo experiments with different current levels, and the temperature change curve of 100 groups of the messenger wire was obtained. According to the risk assessment index determined by the dispatching...
center, determine the current level allowed to pass through the messenger wire, and calculate the comprehensive current carrying capacity of the traction network by combining formula (5).

![Figure 9](image_url)

**Figure 9.** Probability of temperature exceeding standard of catenary under different current levels.

Fig. 9. shows the probability that the temperature of messenger wire of the traction network exceeds the maximum allowable operating temperature under different current levels in Jiamusi area. It can be found that when the messenger wire of Jiamusi traction network passes through 325A current, the operating temperature of the messenger wire may exceed its maximum allowable operating temperature, which is far lower than the maximum allowable operating ampicity set by the messenger wire factory. That is to say, if the traction network is operated according to the maximum carrying capacity designed by the messenger wire factory, the overload risk of the traction network will occur. Thus, it is necessary to consider the risk assessment when the traction network adopts the dynamic capacity increasing technology. It can be found from the Fig. 9. that the risk of capacity increase of messenger wire in Jiamusi area is significantly increased when the messenger wire passes through 525A or above. When the messenger wire passes through 600A or above, the probability of temperature exceeding standard of messenger wire of the traction network reaches 98%, which indicates that when the messenger wire current is increased to 600A to 700A in Jiamusi area, it is still possible to increase the capacity safely under some meteorological conditions, and it will not exceed the thermal limit value of the messenger wire, so as to make full use of the transmission capacity of the transmission line. Combined with the physical capacity increasing model, the medium-term temperature curve of messenger wire under different current levels is simulated to determine whether emergency dispatch or high-intensity capacity increasing can be carried out. After determining the risk assessment index, the dispatching center compares it with the Fig. 9. and selects the current level that meets the risk assessment index, so as to determine the optimal capacity increase limit of the traction network and maximize the transmission potential of the traction network.

### 7. Conclusion

In this paper, a medium-term capacity increase scheme considering the risk of capacity increase is proposed, and the safe operation time of the traction network under large current is calculated.

1. The current carrying capacity of the traction network depends on temperature limit value of transmission wires. The wind speed, wind direction angle, environmental temperature and other
meteorological parameters can have different degrees of influence on the operating temperature of messenger wire, and the wind speed has the greatest influence on the operating temperature of transmission line.

(2) The setting of the factory value of each transmission line of the traction network can not meet the geographical characteristics of China's vast territory and myriad meteorology. The maximum allowable operating current carrying capacity of the transmission line set in the factory will exceed the operating temperature limit of the transmission line of the traction network in some geographical and meteorological conditions in some areas, resulting in the overload risk of the traction network.

(3) By calculating the safe operation time of the traction network under large current and making full use of the “thermal inertia” of the transmission line of the traction network, the ultra short-term emergency capacity of the traction network can be increased. At present, the running speed of high-speed railway train has reached 350 km/h. If the front train can quickly pass through the power supply section under large current safe operation time, the traction network can meet the requirements of emergency dispatching operation.

(4) Under some meteorological conditions, the capacity increase limit of the traction network can be greatly improved. The traction dispatching centre can use this feature to make a short-term prediction of meteorological parameters along the corridor of the traction network, and simulate the short-term temperature change curve of each transmission line of traction network under different current levels in combination with IEEE-738 standard. Furthermore, the relationship between the peak operating temperature of transmission line and the through current is obtained, which can effectively evaluate the short-term capacity increase limit, provide sufficient response time for the traction dispatching centre to carry out capacity increase dispatching.

8. References

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