Dynamic Thermal Rating of Overhead Lines under Fog-Haze Environment

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Abstract. Dynamic thermal rating (DTR) is more accurate and can better utilize the transmission/distribution capacity of an electric power system compared to static thermal rating. It is beneficial to integrate DTR into power system planning problems where modeling the DTR is vital. In this paper, under the background of the increasingly severe fog-haze weather, the influence of which on the thermal rating of overhead transmission lines is analyzed. Based on this, the idea of using the time series forecasting model, which is autoregressive integrated moving average (ARIMA), to predict the short-term thermal value of overhead lines under fog-haze conditions is proposed. The forecast results showed that this study has practical significance for improving the safety and economic operation level of power systems as well as efficient utilization of transmission line load capacity under fog-haze environment.

1. Introduction

In recent years, the fog-haze weather in China has become increasingly serious and has had a profound impact on people’s lives and production. The fog-haze mainly occurs in winter and spring, and its duration continues to increase, as well the distribution range is also expanding. The “Green Paper on Climate Change” issued jointly by the Chinese Academy of Social Sciences and the China Meteorological Administration points out that in the past 50 years, the number of haze days in most parts of eastern China has ranged from 25 days to 100 days, and local areas have exceeded 100 days. It can be seen that fog-haze has generally increased [1-2]. The fog-haze environment will also exist in a large area in a short time. Therefore, the operation, maintenance and dispatch control of the power system will also be affected by fog-haze, especially for the thermal rating of overhead lines.

In addition, in the late 1970s, the concept of dynamic thermal rating (DTR) [3-5] has been proposed for the purpose of improving the transmission line load ability, quickly get widespread attention and get the practice application [6-8]. DTR is a technology used to dynamically increase the ampacity of an overhead line. Research shows that, compared with the traditional static thermal rating (STR), DTR can significantly improve the ampacity of transmission lines [8]. It's no doubt that it provides an effective way to fully tap potential of the transmission ability in today's strained resources.
Therefore, under fog-haze environment, it is of great significance to predict the dynamic thermal rating of overhead lines.

As dynamic line-rating forecasts constitute an important input to network management solutions, as described in [9], [10], over the last 40 years, research on overhead dynamic line ratings, a relatively narrow field in electrical engineering, has seen an exponential growth. [11] Applies an expert system to predict DLR in what is one of the first applications of knowledge engineering techniques to this problem. In [12], a statistical risk analysis of the ratings of Polish overhead lines is performed and compared successfully against static line rating. Other than, a new study has been mentioned, as for [13], taking advantage of the future weather forecast data, especially micro-area wind speed, as well as computer simulation technology to simulate the future wind speed of the overhead line, then achieving the future evaluation of DTR.

The difference from the above study is that because of the fog-haze conditions, the fluctuation of the wind speed and direction is small and the regularity is strong, so it is easy to grasp the future accurate fluctuation range of the thermal rating. Therefore, based on historical meteorological data obtained from on-line monitoring equipment (in fog and haze environment), this paper uses the technique of autoregressive integrated moving average (ARIMA) to learn and predict the weather along the future overhead line, and finally obtains the future short-term fluctuations of the overhead line's heat setting value. Trend. This, to a certain extent, provides the basis for the operational personnel to reasonably set up the overhead temperature of overhead lines and improve the conservatism of the STR.

2. METHODOLOGY

2.1. Heat Balance Model for DTR

The DTR can be calculated using the heat balance model, which has been investigated in both the IEEE standard [14]. And the DTR of the overhead line is mainly affected by four factors: ambient temperature, wind speed, wind direction and solar radiation. Thus, the thermal rating can be calculated by (1),

\[ q_i(T(t)) + q_s(t) = q_r(T(t)) + q_c(T(t)) \] (1)

Where, \( t \) is the time (s) and \( T \) is the temperature of the wire (°C), \( q_i \) is the resistance heat of conductor per unit length considering the temperature effect of conductor resistance (w/m). \( q_s \) is heat gain rate from sun (w/m), \( q_c \) is the convected heat loss rate per unit length (w/m), \( q_r \) is radiated heat loss rate per unit length (w/m).

The detailed calculation of which is conducted according to [24], where

\[ q_i(T) = I^2 R(T) \] (2)

\[ R(T) = \left( \frac{R(T_{high}) - R(T_{low})}{T_{high} - T_{low}} \right) \times (T - T_{low}) + R(T_{low}) \] (3)

\[ q_s = \alpha Q_{\alpha} \sin(\theta) A' \] (4)
\[
q_{1i} = [1.01 + 0.0372 \left( \frac{Dp_V}{u_f} \right)^{0.02}]k_jk_{\text{angle}}(T-T_c) \\
q_{2i} = 0.0119 \left( \frac{Dp_V}{u_f} \right)^{0.04}k_jk_{\text{angle}}(T-T_c) \\
q_{3i} = 0.0205 \rho_f^{0.5}T^{0.75}(T-T_a)^{1.25}
\]

(5)

\[
q_i(T) = 0.0178D_i \left( \frac{T + 273}{100} \right)^{j} - \left( \frac{T_c + 273}{100} \right)^{j}
\]

(6)

Where, I is conductor current (A), R(T) is AC resistance of conductor at temperature Tc (Ω), Thigh is maximum conductor temperature for which ac resistance is specified, Tlow is minimum conductor temperature for which ac resistance is specified, D is conductor diameter (mm), ε is emissivity (0.23 to 0.91), α is solar absorptivity (0.23 to 0.91), k_f is thermal conductivity of air (W/(m·°C)), A’ is projected area of conductor per unit length (mm/m2), qc1,qc2,qc3 is convected heat loss rate per unit length (w/m). At any wind speed, the larger of the two that calculated convection heat loss rates is used between qc1 and qc2 while qc3 is applied to zero wind speed. Qse is total solar and sky radiated heat flux rate elevation corrected (W/m²), ρ_f is density of air (kg/m³), μ_f is dynamic viscosity of air (Pa·s), θ is effective angle of incidence of the sun’s rays(°), T_a is ambient air temperature(°C), V_w is speed of air stream at conductor (m/s), kangle is wind direction factor.

2.2. ARIMA Model

An ARIMA model [15] can be expressed as

\[
\phi_p(B)\nabla^d x_t = \theta_q(B)\varepsilon_t
\]

(7)

Where

\[
\phi_p(B) = 1 - \phi_1B - \phi_2B^2 - \ldots - \phi_pB^p,
\]

(8)

\[
\theta_q(B) = 1 - \theta_1B - \theta_2B^2 - \ldots - \theta_qB^q,
\]

(9)

In which \( x_t \) represents the random variable to be modelled, \( \varepsilon_t \) is the white noise, and \( \phi_i \) \((i = 1,2,L\ p)\) and \( \theta_j \) \((j = 1,2,L\ q)\) represent the autoregressive (AR) and moving average (MA) parameters, respectively. \( B \) represents a backward shift operator. \( \nabla \) represents a backward difference operator. \( \nabla^d \) Represents a \( d \)-order difference. Model (7) can be denoted as ARIMA \((p, d, q)\).

3. SIMULATION

Based on the weather along the overhead line collected under the fog and haze weather conditions in Jinan, this paper takes a 220KV transmission line as an example to learn and forecast the haze weather patterns along the line. The ARIMA technology was used to train each meteorological element, and the short-term meteorological trend under haze and meteorological conditions was obtained. Then, the future overhead line thermal value was calculated according to equation (1). The examples in this paper predict the dynamic thermal rating changes in the short-term in the winter fog-haze environment. The forward-looking time interval is 15 minutes. Among them, the comparison of the forecast results of the four meteorological elements with the actual values are shown below.
Figure 1. Wind speed prediction result.

Figure 2. Ambient temperature prediction result.

Figure 3. Solar radiation prediction result.
From the above, it can be seen that under fog-haze weather, the wind speed fluctuated significantly and remained at a relatively low value for a long time, as for the wind speed is generally less than 1 m/s and the wind direction remains basically unchanged. In addition, the light intensity is weak under this condition, and the temperature variation range is small. Therefore, the regularity of the four meteorological elements is easier to grasp. The forecast results show that this method can learn the meteorological trends accurately along the route and characterize the effect of independent variables on the distribution characteristics fully of the DTR, in addition, giving more accurate forecasting values. The comparison between the prediction results and the actual values is as follows:

![Ampacity prediction result](image)

**Figure 4.** Ampacity prediction result.

Therefore, this method can provide more load capacity information of overhead lines for dispatchers, and there's important significance in the areas of network planning, low carbon operation and reliability analysis.

### 4. Conclusion

This paper proposes a prediction method for the dynamic thermal rating of overhead lines under fog and haze weather, and ARIMA technology is used to predict the future meteorology of the line by analyzing the meteorological changes along the line under fog-haze environment, and then the thermal rating of the overhead line is obtained, which improves the load capacity of the line. At the same time, the results of the study show that this method has good practicality for the prediction of the DTR under this meteorological condition and provides the important information on the operation of the line for the dispatcher.

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