Transmission Line Tower Model and Lightning Protection Performance Calculation Based on Wavelet Analysis

Su Ningjie

Department of Mechanical Engineering, North China Electric Power University (Baoding), Baoding 071000, China

Keywords: Wavelet transform, Transmission line tower, Lightning protection performance calculation

Abstract: Lightning overvoltage is the main cause of breakdown of insulators in high voltage transmission lines, and lightning protection measures are different for different types of lightning overvoltage. In order to prevent lightning accidents, it is very important to accurately evaluate the lightning wave performance on transmission lines, and the transmission line tower model and lightning protection performance calculation based on wavelet analysis are very important. The research shows that the results calculated by lumped inductance and single WI(wave impedance) model are too conservative, and if the insulation standard of power station is calculated by this model, the problem of excessive investment will inevitably occur. However, the multi-WI model accurately simulates the lightning current intrusion process in transmission line towers.

1. Introduction

Introduction

As far as lightning overvoltage is concerned, the characteristics of power grid structure and environment determine that there are regular differences in the region [1], and because this characteristic will be affected by various unstable factors such as climate, it is not easy to distinguish by practical experience [2-3], so the identification of transmission line overvoltage has important practical significance.

2. Transmission Line Tower Model

2.1 Establishment of Multi-Wi Model

According to the characteristics of WI(wave impedance), the WI of a vertical cylinder only decided by the radius and height of the cylinder [4], and an empirical formula can be developed to describe the WI of a single vertical conductor:

$$Z_T = 60\left(\ln\frac{2^{\frac{3}{2}h}}{r} - 2\right) \quad (1)$$

In practice, the longitudinal conductor in the transmission line tower is generally inclined, so it can be corrected based on the above formula, which comes from the empirical formula of measurement results, and its equivalent correction radius r, R formula:

$$r = r_T^{\frac{1}{3}} r_B^{\frac{2}{3}} \qquad R = R_T^{\frac{1}{3}} R_B^{\frac{2}{3}} \quad (2)$$

Transmission line tower can be separated into major bracket and bracket, every part is assumed to be evenly distributed, and WI can be calculated by their own size and geometric function. The WI Z_{TK} of each part of the main bracket is calculated as follows:

  DOI: 10.25236/iccem.2021.058

$$Z_{TK} = 600\left(\ln\frac{2^{\frac{3}{2}}h_k}{r_{ek}} - 2\right)(3)$$

$$r_{ek} = 2^{\frac{1}{8}}\left(r_{TK}^{\frac{1}{3}}r^{\frac{2}{3}}\right)^{\frac{1}{4}}\left(R_{TK}^{\frac{1}{3}}R^{\frac{2}{3}}\right)^{\frac{3}{4}}(4)$$

With or without a bracket, the actual measurement shows that the WI of the multi-conductor system is reduced by about 10% after the bracket is added [6], then the WI of each part of the bracket is:

$Z_{LK} = 9Z_{TK}$ (5)

At the same time, it can be seen from the measurement results that it takes more time for the wave to pass through the multi-conductor system with the bracket, so the length of the bracket part is 1.5 times that of the corresponding part of the main bracket.

2.2 Equivalent Circuit Modeling Method

CDEGS software is the abbreviation of Current distribution, electromagnetic fields, grounding and soil structure analysis. It is a powerful tool software to solve engineering problems such as grounding of power system, electromagnetic field and electromagnetic interference. It can calculate the grounding potential, conductor potential and electromagnetic field generated by the network structure composed of live conductors at any position on the ground or underground under normal, fault, lightning and transient conditions [7].

Let the impedance of the device calculated by CDEGS be $Z(s)$, the impedance calculated by traditional equivalent circuit be $Z_T(s)$, and the impedance of the model established by black box theory be $F(s)$, then the relationship among them can be expressed as follows:

$$F(s) = Z(s) - Z_T(s)(6)$$

$$F(s) = \sum_{k=1}^{N}\frac{res_k}{s - p_k} + se + d\,(7)$$

The impedance $F(s)$ of the black box model can be written in the form of pole-residue by rational function approximation. The pole p_k and its corresponding residue res_k are real numbers or conjugate complex pairs, the first-order term e and constant term d are real numbers, and N is the total number of poles.

2.3 Establishment of Grounding Device Model of Transmission Line Tower

Grounding devices can be divided into manual grounding and natural grounding. Natural grounding devices include reinforced concrete poles, iron tower foundations, framework foundations of power plants and substations. Artificial grounding devices usually have three forms, including horizontal grounding, vertical grounding and the combination of horizontal and vertical grounding.

Horizontal grounding is generally used for lightning protection grounding of substations and transmission lines, vertical grounding is generally used for centralized grounding of lightning rods or wires, and the combination of horizontal grounding and vertical grounding is used for lightning protection of substations and transmission lines.

In this paper, the grounding resistance of graphite grounding device is calculated by MALZ of CDEGS software, and compared with common metal steel and copper grounding materials.

3. Calculation of Lightning Protection Performance Based on Wavelet Analysis

3.1 Data Decomposition of Wavelet Transform

As a time domain analysis tool, wavelet transform is applied to signal-noise separation, fault signal analysis and fault location, etc. Similarly, wavelet transform can also be applied to the analysis of lightning overvoltage data. Wavelet transform does not use time-frequency domain, but time-scale domain, which enables wavelet transform to extract high-frequency information and low-frequency information of lightning overvoltage data by changing the width of time window.

For many signals, images and other data, the high-frequency components usually correspond to the details of the signal and the small-scale analysis. The low-frequency components usually contain the characteristic information of the signal, which corresponds to the large-scale analysis [8]. The good localization of wavelet in both time domain and frequency domain makes wavelet transform perform well in signal classification.

Because the lightning overvoltage signal has the characteristics of high signal frequency and transient, it is just right to use the good time-domain and frequency-domain characteristics of wavelet transform to analyze the lightning overvoltage signal and make multi-scale analysis.

Any signal can be decomposed into infinite series of sub-wavelets by using wavelet transform, and the signal can be expressed as a set of signal waveforms formed by the linear combination of the translation b and expansion a of the generating function.

The wavelet transform of lightning overvoltage signal $u(t)$ can be expressed as:

$$F_u = (a, b) = \langle u(t), \psi_{a,b}(t) \rangle = \frac{1}{\sqrt{a}} \int_R u(t) \psi^* \left(\frac{t-b}{a} \right) dt \quad (8)$$

Where $u(t)$ is the time function of the input voltage waveform, and $\psi_{a,b}(t)$ represents a set of parameter-related functions, which are expressed as:

$$\psi_{a,b}(t) = \frac{1}{\left|\sqrt{a}\right|} \psi \left(\frac{t-b}{a} \right) \quad (9)$$

Among them, $\psi_{a,b}(t)$ is the wavelet basis function that depends on the parameter generating function a, b, which is the result of stretching and translating the wavelet generating function $\psi(t)$, and the wavelet generating function $\psi(t)$ is a square integrable function. b is the translation parameter, $b \in R$; a is the scale parameter, $a > 0$.

When $a = 1, b = 0$, $\psi_{a,b}(t) = \psi_{1,0}(t) = \psi(t)$; Decomposition of signals on this function system is called continuous wavelet decomposition.

3.2 Overvoltage Feature Extraction Based on Modulus Maxima of Wavelet Transform

The definition of wavelet analysis modulus maxima is that if $W_s f(x)$ is the wavelet transform of function $f(x)$, then under scale s, if in a certain neighborhood of x_0, for all $x \in (x - \delta, x + \delta)$, there are:

$$\left| W_s(x) \right| \leq W_s f(x_0) \quad (10)$$

Then x_0 is the modulus maximum point of wavelet transform and $W_s f(x_0)$ is the modulus maximum.

The modulus maximum of wavelet analysis is an important basis to characterize the abrupt change characteristics of signals. The modulus maximum of continuous wavelet transform is to convolve the wavelet basis function with the signal to be analyzed, and the maximum of the convolution results is the modulus maximum. At the same time, the magnitude of the modulus maximum reflects the steepness of the signal mutation, the positive and negative of the modulus maximum reflects the polarity of the signal mutation, and the time when the modulus maximum appears reflects the time when the original signal mutation occurs.

In this paper, the extraction of modulus maxima is realized by Matlab programming. The modulus maxima calculated at each point of the signal are compared with neighboring points. By setting the threshold, the modulus maxima of wavelet transform are obtained, and the graph of modulus maxima is generated step by step.

In this paper, based on the feature extraction of wavelet transform modulus maxima, three subsequent useful feature quantities can be extracted, which can be used as the basis for identifying overvoltage types of transmission lines, namely:

The absolute value F_1 of the modulus maximum determined as the first modulus maximum point;

The product F_2 of the first modulus maximum point k_1 and the voltage U_{max} with the largest absolute value;

It is judged as the time interval T between the second modulus maximum point and the third modulus maximum point.

Among them, the magnitude of F_1 reflects the steepness of wave head of overvoltage signal; The polarity of F_2 reflects the initial change trend of voltage traveling wave; The value of T reflects the continuous discharge time of arrester. Through the feature extraction of overvoltage signal based on wavelet analysis modulus maxima, these three features can distinguish the wave head features of overvoltage signal well.

4. Calculation Result Analysis

In order to verify the correctness of the model and algorithm established in this paper, the results of simulation experiments reported in reference [9] are compared here. The current source is applied to the top of the transmission line tower, and then the voltage is measured at the top of the transmission line tower. Compared with the simulation results, the following figure 1 is obtained:

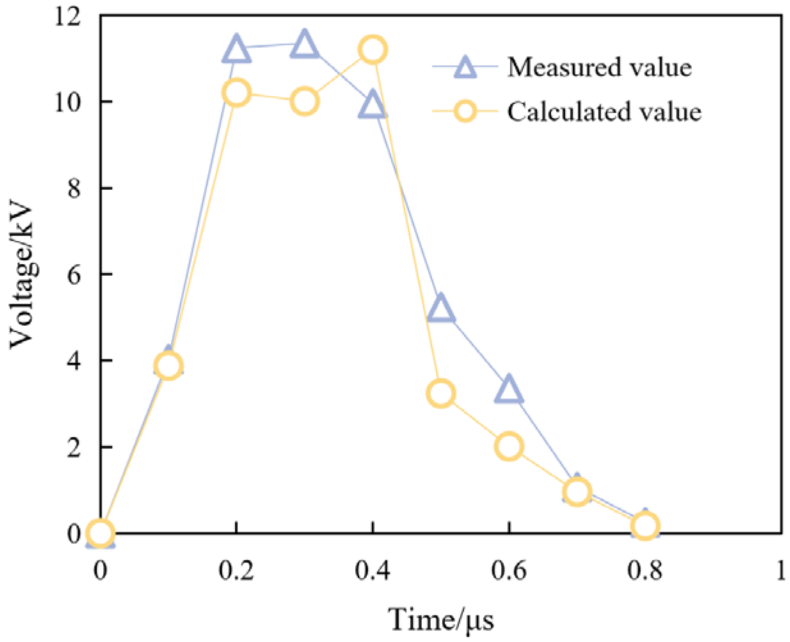

Fig.1 Comparison of Voltage Waveform between Top Calculation and Experiment

The simulation results show that the tower top potential of the traditional concentrated inductance model of transmission line tower is higher than the other two WI models. The multi-WI model introduced in this paper is used for simulation, and the tower top potential is lower. When the WI model is adopted, the influence of the grounding resistance of transmission line tower on the tower top potential is weakening, and the multi-WI model is weaker than the single WI model.

The calculation method of inductance model of transmission line tower has strong operability, wide application range and no influence of human factors on calculation error in practical engineering application. Although the WI model calculation method has high simulation accuracy and accords with the actual situation of wave propagation, it has great limitations in engineering application. It is not only affected by the calculation conditions, but also requires the calculators to reasonably choose the calculation time according to the actual situation in order to obtain reliable results.

Under the condition of no artificial grounding body, the overvoltage distribution of the lowest phase cross arm of 220kV transmission line tower is calculated under the conditions of 12.6m, 21.5 m and 25.5 m root opening. As shown in Figure 2.

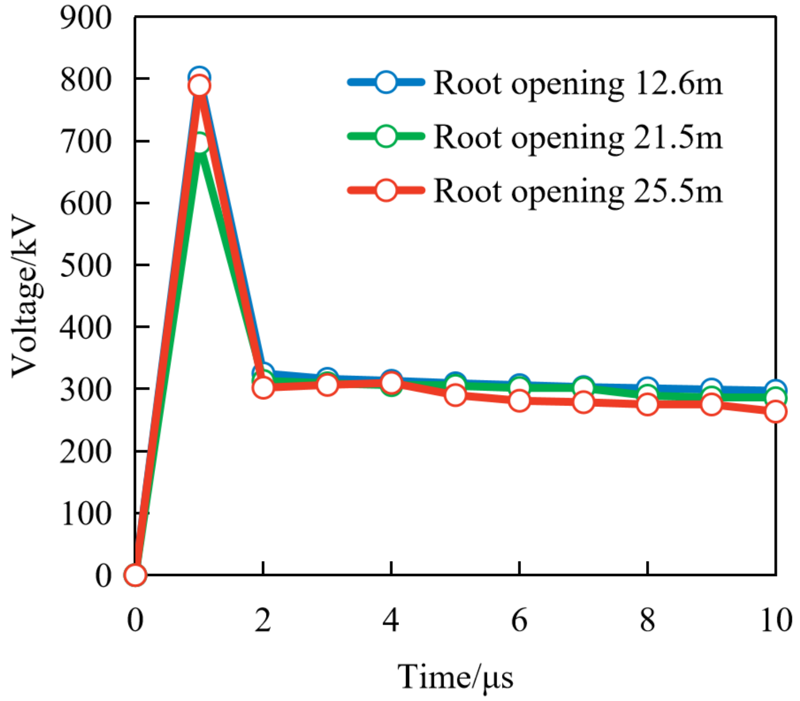

Fig.2 Overvoltage At the Lowest Phase Cross Arm of Transmission Line Tower

For areas with low lightning intensity and few thunderstorm days, it is impossible to reduce the soil resistivity. Under the condition that artificial grounding devices are not economical enough, the root opening of transmission line tower foundation can be appropriately increased to reduce the distribution of lightning overvoltage.

5. Conclusion

The calculation results show that the tower top potential of traditional concentrated inductance model of transmission line tower is higher than that of two kinds of WI models, and the tower top potential is low when the multi-WI transmission line tower model introduced in this paper is used for calculation. When the grounding resistance of the same transmission line tower is the same, there is little difference among them, which shows that the grounding resistance of transmission line tower has a great influence on tower bottom potential. On this basis, according to the difference of feature quantity, a comprehensive identification criterion system is proposed. At the same time, according to the long-term accumulated practical operation experience, an adaptive threshold correction strategy is proposed. Finally, the criterion system is applied to identify and analyze the overvoltage signals recorded in actual operation, and the results show that the method is reliable and effective.

References

[1] Gu S, Wang J, Wu M, et al. Study on Lightning Risk Assessment and Early Warning for UHV

DC Transmission Channel. High Voltage, vol. 4, no. 2, pp. 144-150, 2019.

[2] Tatematsu A, Terakuchi S, Yanagi T, et al. Lightning Current Simulation of 66-kV Substation With Power Cables Using the Three-Dimensional FDTD Method. IEEE Transactions on Electromagnetic Compatibility, no. 99, pp. 1-11, 2020.

[3] Jiang Z, Wu W, Wang B, et al. Development and Test of 500kV Lightning Protection Insulator. IEEE Access, no. 99, pp. 1-1, 2019.

[4] Liang Zhen, Zeng Lingli, Dai Heli, et al. Differential lightning protection transformation of a 500 kV mountain transmission line based on improved electrical geometric model. Electric porcelain arrester, no. 1, pp. 8, 2019.

[5] Wu Lihui, Chen Daopin, Chen Sixiang, et al. Lightning transient response modeling analysis of transmission line towers and grounding devices. Electric porcelain arrester, no. 1, pp. 7, 2020.

[6] Yin Hanxin. Research on the influence of pole tower grounding resistance model on lightning protection performance of counterattack. Modern Industrial Economy and Information Technology, vol. 10, no. 2, pp. 3, 2020.

[7] Zhang Sheng, Ou Min, Liang Panwang, Tang Guangzheng. Theoretical calculation and analysis of lightning protection performance of compact lines. Electromechanical Information, no. 33, pp. 2, 2020.

[8] Zhang Zihao, Yao Xiaodong. Research on fault location method of T-connection transmission line based on wavelet transform and branch location. New Generation Information Technology, vol. 2, no. 18, pp. 6, 2019.

[9] Deng Honglei, Xia Qiao, Zhou Chen, et al. Real-time risk assessment of lightning strikes on transmission lines based on monitoring lightning currents. Electric porcelain arresters, no. 3, pp. 6, 2019.