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Improving the lightning protection effect of multi-circuit tower by installing coupling ground wire

Xi Wang*, Zhen Li, Jinliang He

State Key Lab of Power Systems, Department of Electrical Engineering, Tsinghua University, Beijing 100084, China

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ABSTRACT

Erecting coupling ground wire is a type of effective lightning protection measure to reduce trip-out rate of back flashovers. Nowadays coupling ground wires has been applied on some multi-circuits transmission lines in China. However, various setting positions of coupling ground wire have different impacts on the lightning protection effects, especially the multi-circuit lines. Taking the typical 500/220 kV and 220 kV quadruple circuit transmission lines for example, the paper presents and analyzes the effects of setting coupling ground wire on the center of cross-arm at different heights. The shunt coefficients of tower, ground wires and coupling ground wire, and the coupling coefficients are also compared and discussed in situations that the coupling ground wire is mounted in different positions.

1. Introduction

In the power system, some effective lightning protection measures are implemented to increase the maximum critical current amplitudes and reduce the trip-out rate of flashovers of transmission lines, such as reducing grounding resistance, improving insulation, insulation differentiation, installing parallel gaps and arresters. Despite the measures mentioned above, erecting the coupling grounding wire is also a widely used method for lightning protection of transmission lines. In comparison to other methods, its superiority is more obvious, especially in the areas where the soil resistivity is high or transmission lines have large grounding resistances.

The mechanism of the coupling grounding wire in improving the lightning protection effect of transmission lines includes two aspects. Firstly, it increases the coupling effect between phase conductors and grounding wire to make the induced voltage on conductor higher when a lightning strikes the tower top. Secondly, it reduces the shunt coefficient of tower, especially making lightning current easier to flow through the grounding devices of adjacent towers to decrease the potential on the top of the struck tower.

Nowadays coupling ground wire has been applied on some transmission lines to improve the characteristics of lightning protection of old lines in China [1–8]. During the process of implementation, much attention must be paid to checking the distance of coupling grounding wire and phase conductor [1], especially when considering the influence of wind.

The coupling ground wires have highly improved the lightning protection effect of transmission lines. For example, in 1963, a coupling grounding wire was mounted on the 220 kV Xinhang transmission line with one single grounding wire. The long-period monitoring indicated that the average grounding resistance is 16.8 Ω, and the current shunt percentages of the single grounding wire and coupling wire are respectively 19.2% and 15.2% [2]. Another example is 220 kV Wangxia line, which has erected the coupling wire as long as 21 km in 1996. Thereafter no trip out flashover has occurred until now, while the annual number of trip out is 2 times per year before 1996. The application of coupling ground wires have reduced the patrol for accident by 20 times, and the operating cost by 0.15 million RMB [7].

The various mounting positions of coupling ground wire have different impact on the lightning protection characteristics of transmission lines, especially for the multi-circuit lines. In general, there are two widely applied positions to mount the coupling wire, one is the middle of the uppermost layer cross-arm and the other is the middle of lowest layer cross-arm. The paper presents and analyzes the effects and protecting scope of mounting coupling ground wire on the center of different cross-arm for 500/220 kV and 220 kV quadruple-circuit transmission lines. The coupling coefficient and shunt coefficients of tower, ground wires and coupling ground wire when the coupling ground wires are installed in various mounting positions are also compared and discussed.

* Corresponding author. Tel.: +86 10 62788811; fax: +86 10 62784709.
E-mail address: wangxi525@gmail.com (W. Xi).

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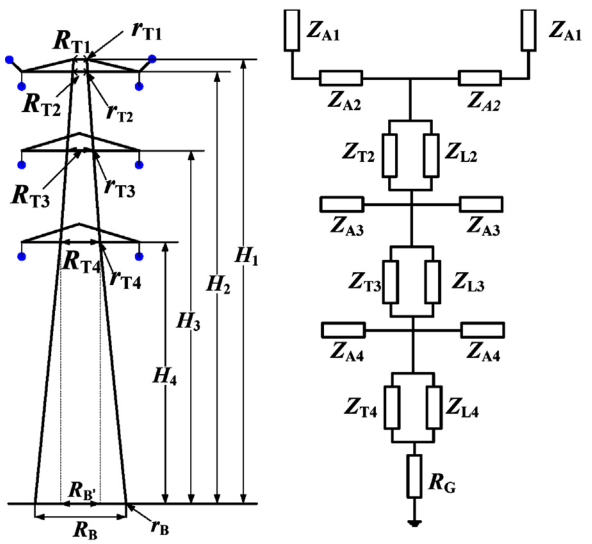

Fig. 1. Multi-wave impedance model of tower.

2. Calculation method

The software PSCAD/EMTDC is applied to calculate the critical lightning critical current amplitude, conductor coupling coefficient, and shunt coefficients of grounding wire, coupling wire and tower when a lightning strikes the tower top. The induced voltage of the lightning channel and the power-frequency voltages on phase conductors are taken into account as well.

2.1. Tower model

The multi-wave impedance model, which was put forward by Yamada and Ishii [9,10], is used to simulate the tower. In this model, the tower composes the main bracket and brackets. Then assuming every part is distributed homogeneously, the wave impedance of different tower part can be calculated by its dimension and geometric function. Take a double-circuit tower for instance, it is simulated by the multi-wave impedance model shown in Fig. 1, where the tower body is divided into 4 segments (k) numbered as $k = 1$–4, the height of the segment is signed as H_k, the radius of the main bracket and the bracket for every segment is denoted by R_{Tk} and r_{Tk}, the wave impedances of the main bracket and the bracket are denoted by Z_{Tk} and Z_{Lk}, and the equivalent radius and the wave impedance of the cross-arm are denoted by r_{Ak} and Z_{Ak}. The formula for Z_{Tk} [10] is shown as Eq. (1).

$$Z_{Tk} = 60\left(\ln\frac{2\sqrt{2}H_k}{r_{ek}} - 2\right), \quad (k = 1\text{–}4) \tag{1}$$

where,

$$r_{ek} = \begin{cases} 2^{1/8}\left({r_{Tk}}^{1/3}{r_B}^{2/3}\right)^{1/4}\left({R_{Tk}}^{1/3}{R'_B}^{2/3}\right)^{3/4}, & (k = 1\text{–}3) \\ 2^{1/8}\left({r_{Tk}}^{1/3}{r_B}^{2/3}\right)^{1/4}\left({R_{Tk}}^{1/3}{R_B}^{2/3}\right)^{3/4}, & (k = 4) \end{cases} \tag{2}$$

The formula above ignores the influence of bracket part, and experiments indicates the impedance of vertical conductor system reduces by 10% after adding bracket into the tower, so the Z_{Lk} can be calculated by [10]:

$$Z_{Lk} = 9Z_{Tk} \tag{3}$$

The formula for wave impedance of cross-arm is

$$Z_{Ak} = 60\ln\frac{2h_k}{r_{Ak}} \tag{4}$$

where h_k represents the vertical distance of the kth cross-arm part and ground, and r_{Ak} can be selected as 1/4 of the height of cross-arm at the location jointing with the tower body.

2.2. Criterion of flashover

The leader progression model [15–19] is adopted as the criterion of flashover to judge whether the breakdown of insulation occurs under the circumstance of lightning surge with different wave shapes. Experiments show that the discharge process of a long air gap contains several continuous periods such as corona, streamer development, leader progression and main discharge [11]. The gap breakdown time T_B can be assumed as the sum of streamer development time T_S and leader development time T_L, which was written as Eq. (5) [12]. The streamer development time can be calculated by Eq. (6) [12], where E_{50} is the gap average electric field (MV/m) in the condition of 50% discharge voltage, the maximum average electric field (MV/m) before the breakdown is denoted as E, and the parameters k_1 and k_2 are obtained from the experiments on air gaps. Besides, formula (7) [12] shows how to calculate the velocity of leader development, where E_0 is the constant determined by polarity of gaps and selected as 500 kV/m generally. In addition, d refers to original length of gap (m), U is the transient voltage (kV), x means the left length of gap or the value obtained by subtracting leader length from the original gap length d, and k_3 and k_4 are selected as empirical values deduced from experiments on air gaps.

$$T_B = T_S + T_L \tag{5}$$

$$T_s = \frac{1}{k_1(E/E_{50}) - k_2} \tag{6}$$

$$V_l = k_3 d e^{k_4(U/d)} \cdot \left(\frac{U(t)}{x} - E_0\right) \tag{7}$$

3. Parameters used in calculation

Fig. 2 gives the sketch of 500/220 kV and 220 kV quadruple-circuit tower used in this paper. The upper and bottom two circuits of the 500/220 kV tower are 500 kV and 220 kV lines.

There are five cross-arms in 500/220 kV tower, and six layers of cross-arms in 220 kV tower. Single coupling ground wire was set on the center position of one cross-arm so that different positions to set coupling wire on would correspond to different ways to erect coupling wire.

The height of 500/220 kV quadruple-circuit tower is 92.1 m, and the grounding resistance is selected in the range from 5 to 30 Ω. The conductor types of 220 kV and 500 kV lines are 2×LGJ-300/25 and 4×LGJ-630/45, the bundle spans are respectively 0.4 m and 0.45 m. The lengths of insulator for 220 kV and 500 kV lines are respectively 2.937 m and 5.46 m. The grounding resistance for towers is fixed to 10 Ω.

The height of 220 kV quadruple-circuit tower is 63.5 m, the conductor type is 2×LGJ-300/25, and the bundle span is 0.4 m. The length of insulator is 2.32 m.

The 2.6/50 μs double-exponent wave was used as the lightning current in calculation, in which the wave impedance of lightning channel is selected as 300 Ω.

4. Impact of coupling wire on characteristics of lightning protection for 500/220 kV line

4.1. Impact of coupling wire on insulator voltage

The uppermost cross-arm of the tower is denoted as the first cross-arm, and the lowest cross-arm as the fifth cross-arm in Fig. 2(a); the first to third cross-arms correspond with the upper