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Backflashover rate of quadruple-circuit transmission lines due to first and subsequent return strokes

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ABSTRACT

The backflashover rate (BFR) of typical 220/110 kV quadruple-circuit transmission lines due to direct negative first and subsequent return strokes and the effects of common lightning protection measures are quantified. The method based on ATP-EMTP and IEEE electro-geometric model (EGM) is adopted. The results show that the peak current distribution of the first and subsequent stroke has great influence on the BFR. The subsequent strokes propagate along the first stroke channel may lead more multi-circuit trip-out than the first stroke. The influence of tower foot resistance on single and double circuit BFR due to the first stroke is more serious than that due to subsequent strokes. The protection measures of unbalanced insulation, insulation strengthen and coupling ground wire are effective for BFR due to first and subsequent strokes.

1. Introduction

Multi-circuit transmission lines have been adopted increasingly in Guangdong power grid due to the lack of land supply for power transmission line construction. The incidents of multi-circuit simultaneous outages of multi-circuit transmission lines may significantly influence the secure operation of power grid. For example, the statistical data of Guangdong power grid during 2007–2009 shows that the lightning outage of 110 kV transmission lines is 84 times per year, and 74% of them are multi-circuit outages [1]. The statistical data and theoretical analysis show that the backflashover is the primary cause for multi-circuit trip-out. Therefore, it is crucial to improve the lightning performance of multi-circuit transmission lines to fulfill the increasing demand of stable power supply.

Lightning observation data show that more than 70% of the lightning ground flashes have multiple strokes [2]. Only the parameters of the first negative strokes are used in current lightning protection design standards and recommended practices of transmission lines [3–7]. However, in areas with more lightning activities, there are dozens of circuit breaker faults in outdoor substations caused by multiple stroke lightning incoming waves recorded in China [8]. The subsequent strokes on the ground wire of 500 kV transmission line were observed in Japan [9]. The impact of subsequent strokes on multi-circuit transmission lines is considered in Russian lightning protection design standards but without recommendation provided [10]. The effects of subsequent stroke on transmission and distribution lines have been analyzed by Silveira et al. [2,11,12], Datsios et al. [13] and Michishita [14] recently. The results show that the backflashover rate associated with negative subsequent strokes is sometimes more serious than that with first strokes, especially to the tall towers with height above 30 m [11,12]. The towers of multi-circuit transmission line are much higher than traditional ones and attract more lightning strokes. The investigations of subsequent stroke and effects of many protection measures are therefore necessary.

In this paper, the lightning backflashover rate (BFR) of typical quadruple circuit transmission line with dual voltage 220/110 kV on the same tower located in Guangdong power grid associated with direct negative first and subsequent strokes is analyzed based on Electromagnetic Transient Program-Alternate Transients Program (EMTP-ATP) and electro-geometric model (EGM) recommended by IEEE Std. 1243. The effects of lightning current parameters and common lightning protection measures are also investigated.

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2. Parameters of analysis model

2.1. Parameters of lightning strokes

The double-ramp waveform [7] is adopted to represent the return-stroke current waveform. The parameters of return-stroke current waveform recommended by IEEE Std. 1410 [15] are adopted. For negative first and subsequent stroke, the median values of lightning current front time and tail time are considered. The waveform is selected as 3.83/77.5 μs and 0.67/30.2 μs, respectively. The cumulative probability distribution of first and subsequent stroke is given by the IEEE Std. 1243 type [3],

$$P_{F/S}(I) = \frac{1}{1 + \left(I/\alpha\right)^{\beta}} \tag{1}$$

and the probability density of first and subsequent stroke is given by:

$$f_{F/S}(I) = \frac{\alpha I^{\beta-1}}{\beta^{\alpha}\left[1 + \left(I/\alpha\right)^{\beta}\right]^{2}} \tag{2}$$

where I is the prospective first or subsequent return stroke peak current (kA), α is the median peak current of first or subsequent stroke (kA), β is the coefficient of distribution. For the first stroke, the lightning location system (LLS) data of Guangdong province in 1999–2008 [16] is adopted, α is 22.78 kA and β is 2.58. For the subsequent stroke, α is 12 kA and β is 2.7 recommended by IEEE Std 1243 [3]. The impedance of return-stroke channel is assumed as 400 Ω.

2.2. Parameters of the quadruple circuit transmission line

The dimension of 220/110 kV quadruple circuit transmission line tower subject to analysis is shown in Fig. 1. The multistorey surge impedance tower model proposed by Hara et al. [17] is adopted for analysis. The power frequency resistance of each tower footing is assumed to be 10 Ω, and the current dependent grounding resistance model recommended by CIGRE [4] is adopted for impulse grounding resistance. The ground resistivity is set as 500 Ω·m.

The 6 km long transmission line with span length of 400 m is represented by a frequency-dependent J. Marti model. The phase conductor is composed of twelve-phase LGJ-400/35 type steel reinforced aluminum conductors with a radius of 13.41 mm and dc resistance of 0.0739 Ω/km. The conductors of 220 kV transmission line are two-bundle conductor with a bundle space of 400 mm. Two overhead ground wires (OHGW) are JLB4-150 type standard conductor with a radius of 7.875 mm and dc resistance of 0.2952 Ω/km. The sag length of conductor and OHGW are 9 m and 7 m, respectively. Two resistor circuits are connected at the ends of the line model in order to eliminate the reflection of travelling waves. The influence of operating voltage of phase conductor is analyzed by statistical method, with twelve results under different phase angle calculated.

The insulation of 220 kV and 110 kV transmission line are consisted of 16 and 8 pieces of glass insulators, respectively. Because of the nonstandard wave forms subject to consideration, the leader progression model proposed by Shindo and Suzuki [18] is adopted for backflashover current analysis. For BFR analysis, the positive polarity leader velocity factor is employed [18].

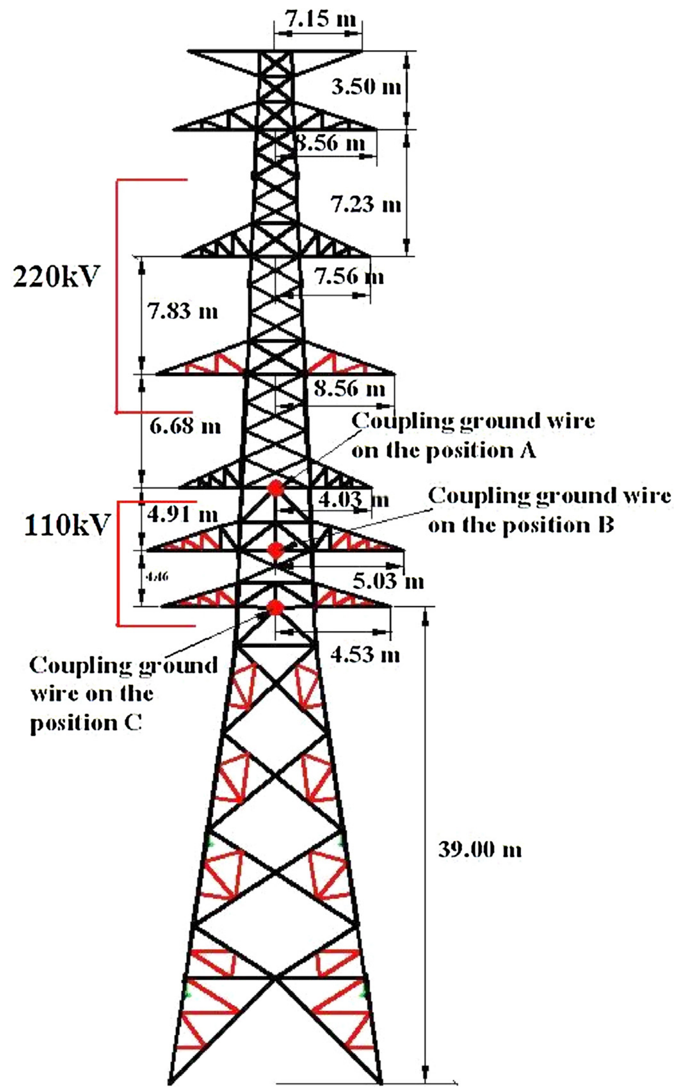

Fig. 1. Sketch map of the quadruple circuit 220/110 kV transmission line tower.

3. Calculation method

The first and subsequent strokes are assumed to terminate on the tower top. The simplified expression of transmission line collection rate suggested by IEEE Std. 1243 [3] is adopted,

$$N_{L-\text{former}} = 28h_g^{0.6} + b \tag{3}$$

where h_g is the average height of the ground wire, b is the cross arm width of the ground wire. The collection rate is related to the probability density of lightning current [7,19]. The expression (3) can not indicate the difference between first and subsequent stroke. In order to consider the effect of the first and subsequent stroke, the EGM is adopted. According to the EGM recommended by IEEE Std. 1243 [3], the strike distance r_s and r_c of first and subsequent stroke to the OHGW and phase conductor is described as

$$r_s = r_c = 10I^{0.65} \tag{4}$$

where I is the amplitude of the first or subsequent stroke current. The strike distance r_g of first and subsequent stroke to the ground is given by

$$r_g = \begin{cases} 0.36 + 0.17\ln(43 - h_c)r_s & (h_c < 40\,\text{m}) \\ 0.55r_s & (h_c \geq 40\,\text{m}) \end{cases} \tag{5}$$