Lightning Performance of Unshielded 220kV Transmission Lines Equipped with Metal-oxide Arresters

Pengkang Xie^{*}, Zhen Fang

State Key Laboratory of Disaster Prevention & Reduction for Power GridTransmission & Distribution Equipment, Changsha 410007 China.

Abstract. Overhead ground wires have been proved to be effective to protect conductors from direct lightning strikes, but breakouts of ground wires have been frequently reported. In order to prevent ground wire breakout incidents to happen, unshielded 220kV lines equipped with metal oxide arresters (MOAs) whole line have been proposed in this paper. After cancelling ground wire, lightning strike risk of transmission lines becomes much higher. In order to improve the anti-lightning abilities of unshielded transmission lines, it is necessary to obtain the lightning energy absorption ability of these MOAs. In this paper, simulation model of MOA equipped unshielded 220kV transmission line was built, the influences of lightning parameters, striking occurrence point and grounding resistance of transmission tower on the absorbed energy of MOAs were calculated, and the suggested energy absorption ability of MOA was given, which can give references for the improvement of power supply reliability of transmission lines.

1 Introduction

Overhead ground wires are used to reduce the tripping rate of transmission lines caused by lightning[1,,2]. However, breakouts of renewable energy transmision line ground wires have been frequently reported in recent years due to icing, bird damage, corrosion, wind and so on. To solve this problem, transmission lines without overhead ground wires were proposed [3,4], in order to maintain and enhance the lightning protection ability at the same time, metal-oxide arresters(MOAs) are installed on each phase of each tower. Thus, in order to improve the lightning performance of these unshielded transmission lines, lightning performance assessment and proper selection of line arresters are needed, and an accurate calculation of the energy absorption capability of MOAs is necessary[5-8].

Lightning performance assessments of transmission lines have been studied by scholars. In [7,8], the relationship between lightning failure rate and the design and environmental parameters of transmission lines were studied. The detailed modeling of storm characteristics were proposed, and subsequent strokes were considered in lightning failure rate calculation. In [9], equipments such as MOAs have been proposed to improve the lightning performance of transmission lines. However, till now, lightning performance assessment of unshielded transmission lines equipped with MOAs have not been studied, and the subsequent strokes of lightning were not usually considered in energy absorption calculation of MOAs.

For unshielded transmission lines, the probability of direct lightning strikes of conductors increases

significantly. Once the the lightning energy absorbed by MOA exceeds its energy absorption ability, MOA failure and lightning trip-out of transmission line will happen[10]. In view of the exiting studies, this paper focuses on the calculation of the relationship between the energy absorption capability of MOAs and the lightning failure rate of unshielded transmission lines. Statistical distribution of lightning parameters and subsequent strokes have been taken into account in the simulation, transient models of various components of 220kV unshielded transmission lines were built. The influence of grounding resistance, striking point on the absorbed energy of MOAs was analyzed, and the desired MOA energy absorption ability for expected lightning failure rate of the studied 220kV unshielded lines was obtained. The research of this paper provides a promising way for lightning protection in high mountainous areas.

2 Lightning parameters

2.1. Lightning current parameters

The equation of cumulative probability distribution of lightning current peak in the target area in recent 10 years is shown in Equation (1)[3], where I_p is the amplitude of lightning current. a=23.5 and b=2.67 are constants determined by lightning activity. The lightning current amplitude is shown in Figure 1a.

$$I_P = \frac{1}{1 + \left(\frac{I}{a}\right)^b} \tag{1}$$

Corresponding author: xiepengkang@126.com

[©] The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).



(a) Distribution of Lightning current amplitude (kA)



(b) Distribution of cloud-to-ground return-stroke times **Fig. 1.** statistic data of lightning in target areas

Subsequent strokes in a lightning flash are considered in this paper, statistical number of subsequent strokes in a lightning flash are shown in Fig. 1b, the average number of impulse currents in a lightning flash is 3, and the max subsequent stroke number is 9. The average amplitude of return strokes is 0.4 times the amplitude of first stroke[4]. According to the statistic data, in this paper, the waveform of each lightning stroke is set to $2.6/50\mu$ s, the stroke number in each lightning flash is set to 3, and the time interval between each subsequent strokes Δt is set to 60ms[6].

2.2. Impact area



Fig. 2. EGM of the unshielded transmission line

The lightning strike points are randomly distributed on the transmission line corridor. This paper uses Electro

geometric model (EGM) to calculate the width of the impact area $Y_{\text{max}}[8]$. As shown in Figure 2, R_g is the striking distances to the ground and R_c is the striking distance to the conductors. The impact area is equal to $Y_{\text{max}}*L$ where L is the length of line span.

2.3 Modeling of moa and its failure estimation



Fig. 3. EGM of the unshielded transmission line

A wide band electric model of MOA is introduced in this paper, shown in Figure 3[7]. The stray parameters are obtained as follow:

$$L = \frac{h}{n} (\mu H) \tag{2}$$

$$R_L = 8 \times 10^8 L(\Omega) \tag{3}$$

$$C = 12.31 \frac{n}{h} (pF) \tag{4}$$

$$R_{C} = \frac{0.15 \times 10^{-8}}{C} \,(\Omega) \tag{5}$$

In the equations above, n means the number of ZnO varistors connected in parallel, and h(m) is the height of the arresters.

The voltage-current curve of variable resistance R(i) is shown in Figure 4.



Fig. 4. Voltage-current curve of the variable resistance in the MOA model.

The energy absorbed by MOA during a lightning flash process can be obtained by Equation (6).

$$W = \int_{t_0}^t u_A(t) \dot{i}_A(t) dt \tag{6}$$

Where *W* means the energy absorbed by arrester, $i_A(t)$ means the instantaneous current flowing through the arrester, u(t) is the residual voltage of the arrester, which

can be obtained by Figure (3) and Equation (1) to (4). t_0 and t mean the start and ending time of a lightning flash process. It is assumed that if the absorbed energy exceeds the energy absorption capability of MOA, MOA failure will happen, leading to fault tripping of transmission lines[7].



Fig. 5. Electric model of transmission tower and insulator

The simulationmodelof 220kV transmission towerand insulator are shown in Figure 5. In which $Z_{t1}(200\Omega)$ is the surge impedance between the tower top and the phase arm, $Z_{t2}(150\Omega)$ is the surge impedance between the insulator suspension point and phase arm, $Z_L(=71.12\Omega)$ is the impedance of the tower body, and Z_g represents the grounding resistance. In this paper, lumpconstantequivalent circuit is used to model the grounding electrodes, which is approximated to grounding resistance, ranging from 5 to $50\Omega[7]$.

The insulators on the transmission line are installed in parallel with the MOAs on the transmission tower, which can be modeled as a switch *S* and a 200pF capacitor C_i , shown in Figure 5. If the lightning overvoltage exceeds the critical breakdown value 960kV, the switch is closed and flashover happen, which can also lead to fault tripping of transmission lines[6].

3. Simulation results and analysis

3.1 Simulated waveforms



Fig. 6. Simulation condition

Assuming the tower span length to be 400m, the grounding resistance of each tower to be 15Ω . The lightning current is a 30kA, 2.6/50µs single strike, the lightning flash strikes phase C conductor between tower 2 and tower 3 (100m and 200m from tower 2 respectively). The waveforms of the negative lightning current, the residual voltage of the MOA, and the simulated transient currents flowing through the nearest arrester are shown in Figure 7. Under lightning currents, the voltage between the insulators equals to the residual voltage of the MOA. From Figure 7(b) and Figure 4, it can be indicated that, because of the nonlinear voltagecurrent characteristics, the residual voltage of MOA are restrained to a low value and will not cause the external insulation flashover of insulators. Due to the refraction and reflection effects of lightning current waves, the flash occurrence point influences little on the current amplitude flowing through the nearest arrester.



(c) Current flowing through tower 2 arrester **Fig. 7.** Current waveform of lightning and current



Fig. 9. Influence of strike point on the MOA absorbed energy

Figure 8 shows the energy absorbed by each arrester and Figure 9 shows the influence of strike point on the energy absorbed by nearest MOA. When strike point is 200m from tower 2, the energy absorbed by the arresters are 248kJ and 187kJ. When strike point is 100m from tower 2, the energy absorbed by the arresters are 221kJ and 175kJ and 140kJ. It is confirmed that, because of the diversion effect, the lightning current flows through arresters on several adjacent towers, and the striking point can influence the energy absorbed by MOA.

Figure 10 shows the simulated waveforms when a 300kA, 2.6/50µs single pulse lightning current strikes the top of tower 3. As the tower is connected to the ground by a grounding resistor, most of the lightning current

flows into the ground and the transient current flowing to the conductors is 20kA, which will not cause damage to the MOA. As most lightning current is less than 300kA, for transmission lines equipped with arresters, the failure rate of MOA caused by the lightning back flashover is so small that can be neglected.



Fig. 10. Influence of strike point on the energy absorbed by MOA

3.2 Influence of soil resistivity

In order to represent the multi-stroke process, three continuous impulse currents were used to present lightning flash for simulation. These impulse currents have a waveform of $2.6/50\mu$ s, the time interval between these impulses are 60ms, and the amplitude of first impulse is 30kA, the second and third impulse is 1/4 of the first one[9]. Assuming that the lightning occurrence point locates at the middle of the span length (200m from tower 2), the variation of MOA absorbed energy with tower grounding resistance is shown in Figure.11.



Fig.11. Variation of MOA energy absorption with grounding resistance

As shown in the figure, when the grounding resistance is 5Ω , the max energy absorbed by MOA is 542kJ. With the increasing of grounding resistance, the diversion effect become more obvious. The lightning current flows through more MOAs into the ground and the max MOA absorbed energy decreases. It can be confirmed that, for unshielded transmission lines equipped with MOAs whole line, failure rate of MOA caused by back flashover can be neglected, the increasing of grounding resistance can alleviate the energy stress of single MOA. Compared with traditional shielded lines, a larger grounding resistance can improve the lightning protection ability of MOA quipped

unshielded lines, which are more applicable in cold mountainous regions where grounding resistance is hard to be reduced.

4. Conclusion

This paper proposes a promising way for lightning and icing protection in high mountainous areas. The simulation model of unshielded transmission line equipped with MOAs was built, the distribution of lightning current flowing through MOAs was obtained, and the variation of MOA absorbed energy with grounding resistance and lightning parameters were analyzed, according to which the following conclusions can be made:

1. When lightning strikes the tower, as the towers are connected to the ground by a grounding resistor, most of the lightning current flows into the ground and the transient current flowing to the conductors are much smaller. The damage rate of MOA caused by back flashover can be neglected.

2. When lightning strikes the conductors, because of the diversion effect, the lightning current flows through several adjacent MOAs to the ground. With the increasing of grounding resistance, the max energy absorbed by single MOA decreases and the lightning current flows through more MOAs. Due to the refraction and reflection effects of lightning current waves, the flash occurrence point influences little on the amplitude of the current flowing through the nearest arrester. This work is supported by Changsha Science and Technology project in Hunan Province (kq 1804051), and Science and Technology project of State Grid Corporation of China (5216A01600W3,5216A01800JG)

References

- 1 F. Napolitano, IEEE Trans. Electromagn. Compat., **53**, 108, (2011).
- 2 Y. Zhang, Q. Yang, S. Xie and C. Zhang, IEEE T. Electromagn. C., **43**,1, (2019).
- 3 X. Jiang, S. Fan, Z. Zhang, C. Sun and L. Shu, IEEE T. Dielect. El. In., 25, 919, (2010).
- 4 S. Visacro, C.R. de Mesquita, R.N. Dias, F.H. Silveira and A. De Conti, IEEE T. Electromagn. C., **54**, 1028, (2012).
- 5 W. Sima, D. Luo, T. Yuan, S. Liu, P. Sun and T. Li, IEEE T. Power Deliver., **33**, 2125, (2018).
- 6 F.H. SilveiraS. Visacro and A. De Conti, IEEE T. Electromagn. C., **55**, 1195, (2013).
- 7 W. Sima, D. Luo, T. Yuan, S. Liu, P. Sun and T. Li, IEEE T. Power Deliver., **33**, 2125, (2018).
- 8 P. N. Mikropoulos and T. E. Tsovilis, IEEE Trans. Dielectr. Electr. Insul., **20**, 202, (2013).
- 9 A. Borghetti, C. A. Nucci, and M. Paolone, IEEE Trans. PowerDeliv., 22, 684, (2007).
- 10 P. N. Mikropoulos and T. E. Tsovilis, IEEE Trans. Dielectr. Electr. Insul., **20**, 202, (2013).