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Research paper

Shape of overvoltage waves arising at lightning strokes to overhead transmission lines

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Abstract

This article shows the cause of arising overvoltage thunderstorm waves on overhead transmission lines (OTL) with nanosecond leading fronts. The algorithm is given to estimate the duration of the leading front in the case of back-flashovers from the tower to the phase conductors.

Keywords: *lightning protection, thunderstorm overvoltage waves.*

1. Introduction

The damage of equipment at electric stations and substations occurs: a) at direct lightning strikes (DLS); b) when overvoltage thunderstorm wave pulses (OTW) come to the substation switchboards from the connected OTL. The protection of substation equipment from OTW is mainly carried out by overvoltage limiters. An effective equipment protection can be performed only from the waves in which the rate of voltage increase at the front edge of the pulse (steepness) does not exceed a critical value depending on the type of protected equipment, the characteristics of an overvoltage limiter and the distance between them. The waves, which have more critical steepness, can damage the insulation of substation equipment. If a wave has arisen from a lightning strike in OTL far from the substation, then its slope OTL, and it comes to the switchgear of the substation with less steepness than at the place of the lightning strike. Knowing the value of the critical slope, it is possible to determine the length of the OTL, in which even a wave with a vertical front becomes not dangerous for the substation equipment protected by overvoltage limiters. Lightning strikes in OTL beyond the boundaries of these areas lead to the emergence of waves that are not dangerous for the equipment. If a lightning hits OTL closer to the boundary, then they can lead to equipment damage, and the OTL zone up to these boundaries is called a dangerous zone. This is the established terminology [1-4], and the worst case is accepted for the calculation of lightning protection, when a wave with a vertical leading edge arises during a lightning strike into OTL. Indeed, the analysis of the leading fronts of waves during the strikes into OTL shows that the duration of the leading front of the wave makes about 30-100 ns. However, the reason for the steep front front the wave when a lightning strikes into OTL is completely incomprehensible. In this paper, we propose the mechanism for the generation of waves with such a duration.

2. Estimates of OTW leading front duration

At present, considerable material has been accumulated on the measurement of lightning characteristics during its strike into various objects and empirical formulas have been derived on its basis to estimate the probability of lightning steepness. An estimate of a lightning probability with a leading front duration of about 30 ns leads to a completely unrealistic probability of such an event occurrence [5-8]; i.e. such a wave front can occur 1 time in 10 billion years, which contradicts the statistics of observations. There must be an effective mechanism exacerbating the leading edge of the waves when a lightning strikes into OTL.

A lightning strike into OTL protected by a shield earth wire can occur in three ways:

1. A lightning strikes OTL tower or the earth wire near tower;
2. A lightning strikes a shield earth wire;
3. A lightning strikes the phase conductor, bypassing the shield wire (shielding failure shielding failure).

When a lightning strikes a phase wire, a wave with the steepness making the half of lightning steepness is formed at a strike in a poorly grounded object. The impedance of OTL phase conductor is about 400 Ohm, which is comparable to the wave impedance of the lightning channel. The decrease of the steepness is conditioned by the fact that the current flows from a lightning strike point along the phase conductor to both sides and its amplitude is reduced by half. For this case, the characteristic values of the leading edge duration of an emerging wave are the durations of 4-10 microseconds with the first lightning strike and about 1 microsecond with repeated lightning strikes into OTL [9].

When a lightning strikes the tower, a lightning current flows through the grounding device of the tower into the ground. An increasing voltage appears on the tower and a breakdown of the air gap along the insulators set takes place at the voltage exceeding the impulse strength of insulators. OTW appears on the phase conductor. The breakdown time consists of: 1) the waiting time for the appearance of the primary electron, which leads to the formation of an avalanche; 2) the time movement of the avalanches (streamer, leader) through the discharge gap to the opposite electrode; 3) the switching time, which is defined as the time from the achievement of the opposite electrode electron by the avalanches to the current rise between the electrodes (between the tower and the phase conductor) to the maximum value. The breakdown time of the air gap can reach several microseconds. However, in order to evaluate the rise time of voltage on the phase conductor, the time of the first two stages of the discharge should not be taken into account. The potentials equalization of the phase conductor and the support traverse begins and ends during the switching stage only. The estimation of air gap switching time at atmospheric pressure can be carried out like the estimate of the front duration in respect of lightning discharge main stage [9]. Aleksandrov [1.9] established that the duration of the discharge front is determined by the time of an electromagnetic wave path along the leader channel and does not depend on its polarity. Switching time (t_k) can be estimated by the following formula:

$$t_k = \frac{H_{ins.str}}{v_p}, \quad (1)$$

where $H_{ins.str}$ – the construction height of insulator string, v_p - the speed of the main discharge electromagnetic wave movement along the leader, which can be taken equal to 0.1 to 0.3 m/ns.

With the garland construction height of 1.2 m, characteristic for the OTL of the voltage class 110 kV, the voltage rise time on the leading edge of the OTW will make 3 - 10 ns.

3. Estimation of dangerous wave occurrence probability

From previous estimates of OTW leading edge duration, it follows that at any overlap of insulation from the support to the wire, there are OTWs with a nanosecond leading edge, which are dangerous for substation equipment. The worst case considered in lightning protection literature is the most common case, which is repeated under any reverse overlap of insulators on OTL. The same can be said for the breakdown of the air gap (overlap) between the lightning shielding earth wire and the phase conductor. If such an overlap occurs, then OTW takes place with a leading edge duration of 15 - 50 ns for OTL 110 with a wire-conductor distance of 5 m, which is a dangerous OTW. This case is usually not considered in the calculation of OTL protection from lightning, since the probability of the spark overlap transition is less than 0.05 and there is no disconnection of the line. At the same time, the probability of spark overlapping wire - line is quite high (Figure 1), and OTW takes place with each such an overlap, which is dangerous for substation equipment.

The probability of OTW occurrence consists of 4 terms for the OTL with the shield earth wire:

$$N = N_1 + N_2 + N_3 + N_4 \quad (2)$$

where N_1 - the number of back-flashovers from the tower to the phase conductor when the lightning strikes the tower or the earth wire near tower;

N_2 - the number of flashovers from the phase conductor to the tower when shielding failure is occurred;

N_3 - the number of back-flashovers between the earth wire and the phase conductor when the lightning strikes the shielding earth wire;

N_4 - the number of back-flashovers from the tower to the phase conductor the lightning strikes the shielding earth wire t.

At the calculations of OTL lightning protection, the terms 3 and 4 are not taken into account because of the low probability of insulation impulse overlap transition into a power arc. At the same time, they are not equal to zero, depend on a span length, as shown on Fig. 1 and they should be taken into account at the calculation of OTW number.

The dependences of the Fig. 1 were calculated for: single-circuit OTL 220 kV with one shielding earth wire; cross-section phase conductors - 185 mm^2; the height of towers - 30 m. The impulse resistance of grounding devices was assumed equal to 10 ohms, the thunderstorm activity - 45 lightning hours per year.

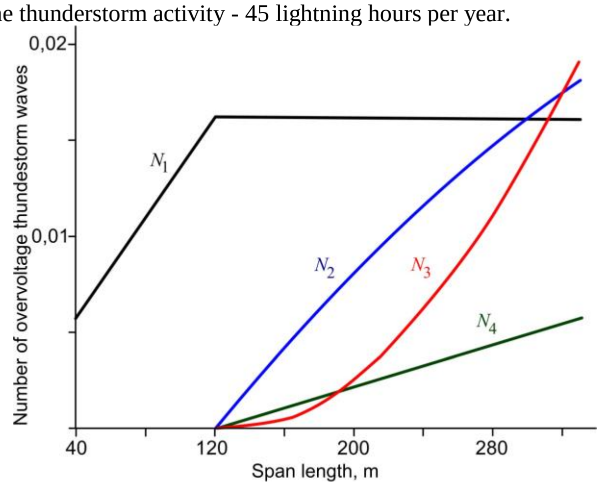

Fig. 1. Number of OTW arising in a span of overhead line with lightning shielding earth wire

4. Estimation of OTW trailing edge duration

As was noted above, the shielding failure (the second term) in (3) does not lead to steep leading front of OTWs. The reason why the probability of such an event is taken into account in (2) is the occurrence of a vertical slice (the trailing front of OTW). The appearance of OTW with such a front is also dangerous for the insulation of power transformers, like steep front. Since almost any lightning strike into the phase conductor leads to the flashovers of the insulators on the nearest supports, and to the vertical trailing front (slice), then any lightning strike into the phase line is dangerous and the probability of such an event should be reduced. The statement about the arising vertical voltage drop at flashovers from the phase conductor to the tower follows from the calculations in which it is assumed that the resistance of tower earthing device and its inductance are zero. It is not correct to transfer this calculation results to real OTL, for which the ground resistance is 10 ohms or more, and the tower inductance is more than 15 μH. Even in the case of a discharge a concentrated (undistributed) capacitance (OTL) to the ground, the estimate leads to a discharge time constant of 1.5 μs with such parameters. In the case of flashovers from the phase conductor to the tower, an additional lightning current channel to the ground through the tower arises when a lightning strikes. The discharge of a lightning does not stop and its time characteristics can be estimated like a blow to the support. Often the literature provides photographs of the broken power transformer wiring insulation as the proof of vertical drop voltage (). It is not clear at all how the authors of the works can distinguish the effect of the nanosecond OTW leading front arising at each inverse overlap from the cut off trailing edge by these data. At that the origin of such an edge is completely incomprehensible. The issue of the appearance or the absence of cut waves is extremely important. The tests of many types of high-voltage equipment are carried out by cut-off pulses of lightning overvoltage. Each such test can damage equipment with large economic losses. If the cut waves are not a correct transfer of the correct theoretical solution to real conditions and they do not exist in practice, then is it worth to bring an expensive equipment to the risk of failure?

In order to calculate the lightning resistance index β2 of PS, the following formula can be proposed [11-14]:

$$\beta_2 = \sum_{i=1}^{n} \frac{L_{dz}}{100} \frac{N_T}{100} \left(\Delta_T \cdot P_1 + \Delta_w \cdot (P_3 + P_4) \right) \quad (3)$$

where *i*, L_{dz} - the number and the length of OTL protected approaches, connected to the substation; N_T – the number of lightning strokes in the i-th OTL, reduced to the length of 100 km with the activity of the atmosphere in 100 thunderstorm hours per year (N_T); Δ_T – the part of lightning strikes into tower; Δ_w – the part of lightning strikes into wire (into the middle of the span); P_1, P_3 , P_4 - the corresponding probabilities (2).

5. Measures to improve the reliability of substation equipment operation

In the zone of the protected approach to substation, the lightning shield earth wire has a dual nature - it increases the lightning protection of the overhead line in some cases and always worsens the lightning protection of the substation. It is proposed to revise the requirements for the equipment of the protected way to the substation. The main criterion in the development of such measures should be the principle of spark overlap reduction on the phase conductor overhead lines in the protected approach zone to the substation. To increase the lightning protection of substation from the incoming OTW, it is possible to propose the following measures in addition with those exist:

1. The supports of OTL are equipped with an additional ground loop in the zone of the protected approach to the substation to reduce the impulse resistance of tower grounding.
2. To reduce the specific inductance of the towers for example, by the installation of stretches.
3. To use dielectric crossheads on OTL towers in the zone of the protected approach to the substation to reduce the probability of overlapping on the support;
4. To reduce the height of towers, and to use portal supports with a horizontal arrangement of phase conductors for single-circuit OTL.

6. Conclusions

They put forward the hypothesis that the OTL without cable protection may have dangerous waves only when a lightning strikes the support with subsequent reverse overlapping on the phase wire. Fig. 1 shows the terms of OTL lightning resistance depending on span length. Usually N_2 and N_3 terms are neglected and only the probability of the cable protection break and the subsequent lightning strike into the phase wire are taken into account during the calculation of high voltage line lightning resistance, when a lightning strikes a cable. At the same time, the probability N_2 and N_3 of the terms differs from zero and increases with the span length increase. It turns out that a lightning shield earth wire, improving the lightning resistance of OTL both in general and in the zone of the protected approach to SS, starting from a certain length of the span, increases the probability of OTW occurrence with a steep front, dangerous for substation. Besides, the installation of a lightning shield earth wire increases the area of lightning collection and the number of strokes in OTL (in the wire). The requirements for the equipment of the protected approach to the substation must be revised since the lightning shield earth wire has a dual nature in the zone of the protected approach to substation - in some cases it increases the lightning resistance of OTL and almost always worsens the lightning protection of substation.

References

[1] Bazelyan E.M., Gorin B.N., Levitov V.I. Physical and engineering basis of lightning protection. L.: Gidrometeoizdat. 1978, 223 p.
[2] Bazelyan E.M., Raizer Yu.P. The physics of lightning and lightning protection. M.: Fizmatlit. 2001, 320 p.
[3] Alexandrov G.N. Lightning and lightning protection. M.: Science. 2008, 174 p.
[4] Rizk. F.A.M., Trinh G.N. High voltage engineering. Taylor & Francis Group, LLC, 2014, 804 p.
[5] Rizk. F.A.M. Modeling of Lightning Exposure of Sharp and Blunt Rods. // IEEE Transactions on power delivery. 2010, V. 25. No. 4, P. 3122-3132.
[6] Anderson R.B., Eriksson A.J. A summary of lightning parameters for engineering applications. // Proc. CIGRE, 1980, P. 33-46.
[7] Chisholm, W.A., Anderson J.G. Parameters of lightning strokes: a review. // IEEE Transactions on Power Delivery. 2005, V. 20, N. 1. P. 346-358.
[8] Dellera, L. and E. Garbagnati. Lightning stroke simulation by means of the leader progression model. Part II: Exposure and shielding failure evaluation of overhead lines with assessment of application graphs. // IEEE Transactions of Power Delivery. 1990, V. 5. N. 4. P. 2009–2022.
[9] Alexandrov G.N. The main stage of the lightning discharge: the mechanism and output characteristics. // ZhTF.2006. V.76. I.12. pp. 101-105.
[10] Gumerova N.I., Khalilov F.Kh., Khokhlov G.G. Assumptions during lightning discharge simulation into overhead transmission lines and the estimation of their influence degree on the result. // Electro. Electrical engineering. Power engineering. Electrotechnical industry. 2012, N 1. pp. 23-26.
[11] Usachev A.E., Yuditsky D.M. Lightning resistance of overhead transmission lines calculation method by the parameters of supports and spans taking into account the wind load. // Bulletin of Higher Educational Establishments: Problems of Power Engineering. 2014. No. 7-8. pp. 70-76.
[12] Usachev A.E., Yuditsky D.M. The new concept of substation protection from lightning overvoltage waves. // Bulletin of Higher Educational Establishments: Problems of Power Engineering. 2014. No. 11-12. pp. 94-100.
[13] Usachev A.E., Yuditsky D.M. Relative probability of lightning strikes in the supports of overhead transmission lines: calculation by electrogeometric method. // Proceedings of the higher educational institutions. ENERGY SECTOR PROBLEMS. 2014. № 9-10. pp. 47-54.
[14] Yuditsky D.M., Usachev A.E. Comparative evaluation of lightning strike amount into the supports and the upper phase line in the span of PL without a lightning shield earth wire // Proceedings of the higher educational institutions. ENERGY SECTOR PROBLEMS. 2018. № 3-4. pp. 3-11.