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PARAMETERS OF MEDIUM VOLTAGE DISTRIBUTION OVERHEAD LINES INFLUENCING THEIR LIGHTNING PERFORMANCE

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ABSTRACT

In the paper, the influence of earth wires at medium voltage overhead lines to their lightning performance will be described. In addition, the influence of earth wires at few spans in front of the substation to the transformer lightning overvoltage failure rate will be examined. There are some confusions concerning of the influence of tower footing impedance of medium voltage overhead lines without and with earth wires to the annual flashover rate, which will be explained.

1. INTRODUCTION

The medium voltage overhead line towers are built as reinforced concrete, lattice steel, or in our country rarely as wooden towers. Medium voltage overhead lines are generally not equipped with earth wires, except sometimes few spans in front of the substation.

According to technical regulations, the proposed overhead line tower grounding resistance should be less then 15 Ω, regardless of presence of earth wire or not.

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Significant savings can be obtained if the overhead lines are built with reduced or without additional grounding loops. The following effects caused by absence of the grounding loop should be analyzed:

- annual flashover rate due to the lightning discharges
- safety factors as step and touch voltage during faults
- withstand fault current through the tower footing without its damage.

In the paper only annual flashover rate due to the lightning discharges will be discussed. Safety conditions can be achieved in urban environment by surface coating with the insulation materials and if the tower is in uninhabited areas there is no need of special measures for reduction of touch and step voltage due to the extremely low coincidence of presence of person and simultaneous ground fault close to the tower.

In the paper the following cases of the medium voltage systems lightning performances influenced by the tower footing impedances will be examined:

- overhead line without earth wire annual number of flashovers per 100 km,
- overhead line with earth wire annual number of flashovers per 100 km,
- mean time between failures of medium voltage transformers when impinging lines are not equiped with earth wire,
- mean time between failures of medium voltage transformers when impinging lines are equiped with earth wire at few first spans.

2. MEDIUM VOLTAGE OVERHEAD LINES LIGHTNING PERFORMANCE DEPENDENCE ON TOWER FOOTING IMPEDANCE

The comparative analyses of the behavior of the medium voltage overhead lines without and with earth wire when exposed to lightning overvoltages will be presented. Only direct lightning strikes will be analyzed because induced overvoltages are completely independent on the tower footing impedance.

There is general opinion that overhead line tower footing impedance should be as small as possible. In the case of the overhead lines without earth wire the only overhead line parameters influencing annual flashover rate are:

- overhead line effective conductor height, which is calculated as:

$$h_e = h_{\max} - \frac{2}{3}s \tag{1}$$

where: $h_{\max}$ is the maximum conductor height at tower,
s is conductor maximum sag,

- basic insulation level (BIL).

The annual flashover rate of the line without and with earth wire can be computed according to the equivalent circuits presented in Fig. 1a and Fig. 1b, respectively. The lightning overvoltage appearing at the phase conductor when lightning current magnitude is I_l can be calculated from the relation:

$$U_f = \frac{Z_c I_l}{4} \tag{2}$$

where Z_c is surge impedance of the phase conductor.

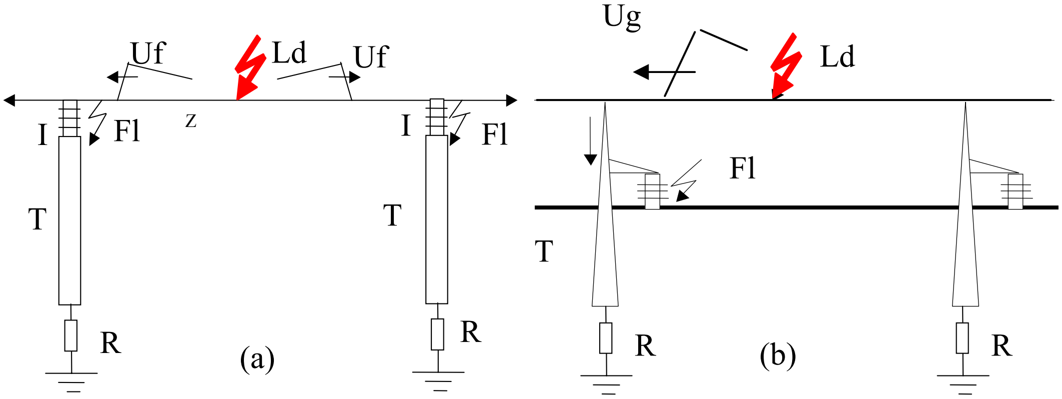

Fig. 1: Equivalent circuit for computation of flashover rate due to the lightning discharge to the overhead line without earth wire (a) and with earth wire (b)

In Fig. 1, denotations have the following meaning:
Ld – lightning discharge,
Uf – lightning overvoltage wave propagating along the phase conductor,
Ug - lightning overvoltage wave propagating along the earth wire
I – insulation at the tower,
Fl – flashover across insulation,
T – overhead line lattice or reinforced concrete tower,
R - tower footing impedance

In Table 1 the minimum lightning current of the direct strike to the phase conductor causing insulation flashover at the line without earth wire is presented in dependence on the line insulation level.

Table 1: Minimum lightning current of the direct strike to the phase conductor of the line without earth wire which can cause insulation flashover in dependence of nominal voltage

Un (kV)	10	20	35
BILL (kV)	75,00	125,00	170,00
I_g (kA)	0,76	1,13	1,44

The denotations in Table 1 have the following meaning:
Un (kV) – nominal overhead line voltage,
BIL(kV) – basic insulation level,
I_g (kA) – peak value of the lightning current into the discharge point.

In Table 1 the surge impedance variation with the top conductor height is taken into account.

Lightning discharge currents which are less then 2 kA can hardly appear in nature. From this reason, it can be concluded that the every lightning strike to the medium voltage overhead line without earth wire will cause insulation flashover at the closest towers.

Annual flashover rate per 100 km of the overhead line without earth wire is computed in dependence of effective top conductor height and nominal overhead line voltage. The lightning incidence to the overhead line is estimated according to [1]:

$$N_i = 2.8 N_g H_e^{0.6} \qquad (3)$$

where: N_g is the annual ground flash density (1/years,km^2), assumed 2,8 for flat area in our country,
H_e is the effective top conductor height-

The results for 10, 20 and 35 kV systems are presented in Table 2.

Table 2: Annual flashover rate per 100 km of overhead line without earth wire in dependence of conductor height and nominal voltage

Un (kV)	10	20	35
BIL (kV)	75	125	170
He (m)	Annual flashover rate per 100 km		
10	32.2	32.2	32.2
12	36.5	36.5	36.5
14	39.4	39.4	39.4
16	42.6	42.6	42.6

The line flashover rates of the lines without earth wires due to the lightning overvoltages are independent on the insulation level and is strongly dependent on the average conductor height due to the attractive effect of the overhead line.

In Fig 2, the annual number of flashovers caused by lightning discharges per 100 km of the overhead lines are presented for various tower footing impedances and voltage levels. The results are presented for overhead lines with and without earth wires. The results of the case of lines with earth wires are denoted by EW.
In Figure 2. the top conductor height of the overhead lines without earth wires of 10 and 20 kV were 10 m and for 35 kV 16 m.

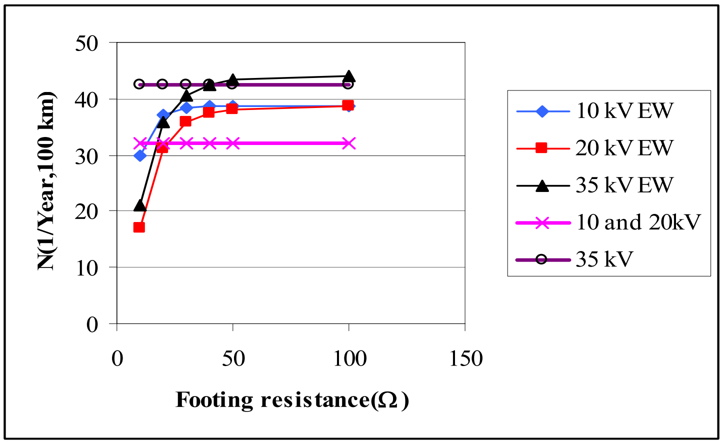

Fig. 2: Annual number of flashovers per 100 km overhead line with (EW) and without earth wire due to the lightning discharges in 10, 20 and 35 kV systems

The earth wire reduces the flashover rate of the 10 and 20 kV line only when tower footing resistances are smaller than 20 Ω and in the case of 35 kV system when tower footing resistances are smaller than 40Ω. The overhead line with earth wire flashover rate is independent on the tower footing resistance if it is greater than 40 Ω.

Higher flashover rates in the case of overhead lines with earth wires when tower footing impedance are greater then 40 Ω are caused by greater overhead line attractive area due to the greater top conductor height. Medium voltage overhead lines equipped with earth wire can be more sensitive to the lightning overvoltages because top earth wire increases line attractive area. Backflash probability of medium voltage lines can be reduced in the case of very small tower footing resistances.

3. TRANSFORMER MEAN TIME BETWEEN FAILURES DUE TO THE LIGHTNING OVERVOLTAGES

If the overhead line without earth wire is impinging substation, direct strikes to the line can strongly endanger power transformer, especially if it is protected with surge arrester located a few meters far away from transformer terminals. The surge arrester location should be as close to the transformer bushing as possible, not more than 0.6m [2,3]. The best place for the surge arrester is at the transformer housing close to the bushing. Today they are manufacturers of the surge arresters who can claim that the surge arrester is safe to be placed close to the transformer bushings. In Fig, 3 the equivalent circuit of the overhead line impinging to the pole-mounted transformer is displayed. Lightning strike location is varied along the 4 spans in front of the transformer to investigate number of spans influencing the lightning performance of the transformer. The surge arrester is located in the classical way 3 m from transformer terminal and with 4 m long grounding connection.

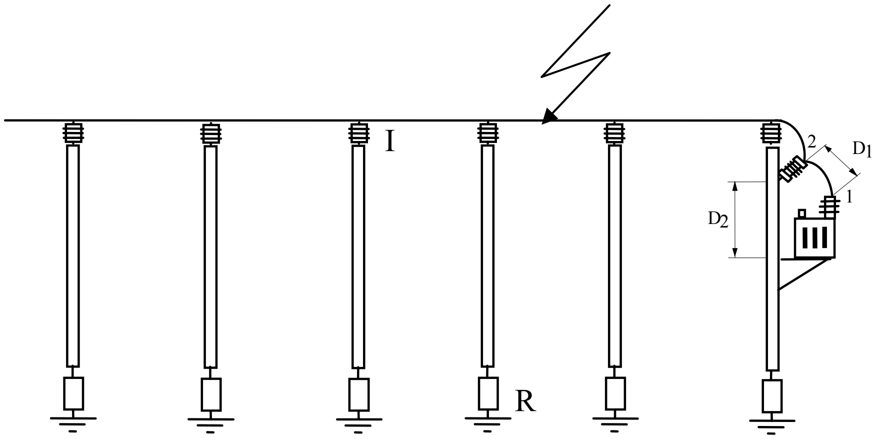

Fig. 3: Schematic presentation of the overhead line impinging pole-mounted transformer when lightning discharge occurs

The denotations in Fig. 3 have the following meaning:
D1- the length of conductor between surge arrester and transformer bushing,
D2-the length of grounding conductor between surge arrester and transformer housing.

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R –tower footing resistance
I-line insulation modeled as spark gap with voltage time characteristic.

The computed failure rates are presented in Fig. 4 for the lines without and with earth wire.

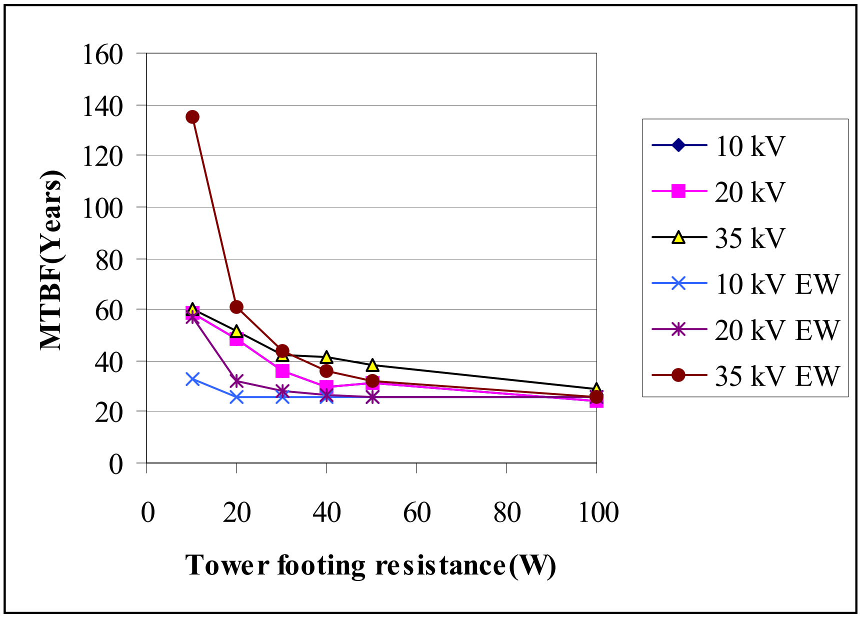

Fig. 4: Lightning performance of the power transformer protected with surge arrester with 3 m long connections for various footing resistances of impinging lines with earth wire (EW) and without earth wires

From Fig. 4 it can be seen that MTBF of the pole-mounted transformer significantly decreases when the tower footing resistance increases. The acceptable MTBF of pole mounted transformers is over 200 years. From Fig. 4 it can be concluded that even for tower footing resistances less than 10 Ω the transformer failure rate is not acceptable. Only in the case of the system of 35 kV transformer failure rate is close to the value which can be tolerated.

Computations are also performed for the surge arrester placed at the transformer housing. The case of the overhead lines with and without earth wire impinging transformer were analyses. In both cases, for analyzed tower footing impedances in the range of 10 to 100 Ω the risk of the transformer insulation failure was zero. It means that transformer is completely protected if the surge arresters are mounted on the transformer housing, independently on the tower footing impedance or presence of the earth wires.

From the analyzed case study of the pole mounted transformers lightning protection it can be concluded that only in the case of the surge arresters mounted at the transformer housing the transformer is completely protected independently on the tower footing resistances and presence of the earth wires.

CONCLUSION

The following conclusions concerning medium voltage tower footing resistance influence to the line and transformer lightning performance:

1. Overhead line without earth wire insulation failure rate is completely independent on the tower footing impedance
2. The earth wire application at medium voltage overhead lines can reduce line failure rate in the case of small tower footing resistances, but in the case of greater tower footing resistances failure rate can be even increased due to the increased line attractive area due to the higher top conductor height.
3. Pole mounted transformers protected with surge arresters located in a usual way few meters from transformer terminals are strongly endangered by lightning overvoltages independent on the earth wire application
4. Tower footing resistance can strongly influence surge arrester’s absorbed energy, but this topic is not in the focus of this paper.

References:

[1] A. Eriksson: The Incidence of Lightning Strikes to Power Lines, IEEE Transaction on Power Delivery, Vol. PWRD-2, No. 3. July 1987, pp. 859-870.

[2] M. Darveniza, D.R. Mercer, “Lightning protection of pole mounted transformers”, IEEE Transaction on Power Delivery, Vol.4, No.2, April 1989, pp.1087-1095.

[3] M. Savić, Z. Stojković:

[4] M. S. Savic: Engineering Method for High-Voltage Substations Lightning Performance Estimation, *Proc. IEE*, **Vol.136**, pt. C, No. 4, July 1989, pp. 222-229.

[4] Chisholm, W. A.; Janischewskyj, W.: Lightning Surge Response of Ground Electrodes, IEEE Trans. on Power Delivery, Vol.4, No.2, Apr. 1989., pp.1329-1337.

[5] Working group IEEE: A Simplified Method for Estimating Lightning Performance of Transmission Lines; IEEE Transaction on Power App. and Systems,**Vol.PAS--104**, No.4, April 1985.

[6].G. Brown: Joint Frequency Distribution of Stroke Current Rate of Rise and Crest Magnitude; Transaction on Power App. and Systems, Vol**. PAS--97**, No.1, January 1978, pp. 53-58.

[7] Berger, R. Anderson, H. Krninger: Parameters of Lightning Flashes; Electra, No 41, Paris, July 1975, pp. 23-33.