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Influence of Selected Parameters of Overvoltages on Hazard of Insulating Systems in MV Power Lines

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Introduction

MV distribution power networks are composed of overhead power lines with bare or covered conductors and power cables placed in the ground or in the air (slung under support constructions). One of serious electric hazards influenced network elements, causing by direct or indirect atmospheric discharges, are diver overvoltages [2]. The level of overvoltage hazard in MV power network systems – considered below – is evaluated basing on selected results of computer simulations, laboratory tests on models, and measurements in real power networks. Computer simulations were made by means of Pspice program - Design Center Eval packet [1].

Hazard due to lightning discharges

Lightning hazard is connected with the so-called thunderstorm activity on a given area, evaluated either by means of thunderstorm maps or distant-reading registrations of electromagnetic effects coming from a lightning location system (LLS). Thunderstorm maps contain closed lines between points signified the same average number of thunderstorm days in the year (D). Since mean value of this number D = 20 days/year in Polish area then average lightning strike density can be estimated on the level of N_r = 1.9 strikes/km^2·year (Fig. 1). For the purpose of this publication only the most frequent negative lightning strikes (20-30 kA) are considered.
Lightning stroke number in one year (N_L), calculated for a line which length is l (in km) and average height is h (in m), can be estimated basing on empirical relationship: $N_L = 0.027\ N_r\ l\ h^{0.5}$ [2]. Hence, for h = 10 m and a segment line of 1 km, average lightning stroke number is N_{L1} = 0.162 strikes./km·year. Taken into account that [3]:

- typical expected lightning stroke currents comply with values specifics in references,
- wave impedance of the conductor is circa 480 Ω,
- surge resistance to earth of overhead line support is circa 10 Ω,
- the BIL of insulating system composed of the insulator and insulating covering on the conductor is 125 + 90 = 215 kV.

Then each direct lightning stroke to line conductors and almost each stroke to line supports may cause either flashover on insulators or breakdown of insulating covering. Such events can take place simultaneously in several points of the power line.

The analysis of induced overvoltages due to lightning strokes is facilitated by contemporary computing technique. In order to simulate such process various models of power lines with covered conductors during overvoltages can be used: Rusck's, Taylor's or Agrawal's models for example.

Maximum value of overvoltages (U_{max} in kV) induced within covered conductors (in respect of the ground) depends on several factors: lightning current (i_s in kA), distance between the lightning stroke channel and the line (d in m), height above ground of conductors (h in m), and time-parameters of the lightning wave, i.e. time-constants relevant to wave front (T in μs) and half-value of wave tail (τ in μs).

These factors can be allowed for calculating by means of relevant coefficients (k), introduced to the following relationship [3]:

$$U_{\max}(d) = k_u\ i_s\ \exp\left(k_0 + k_1 \ln d + k_5 \ln^5 d\right),$$

where $k_u = \dfrac{h}{10}\left[1 - 0.1975\ (T - 0.8) - 3.333 \cdot 10^{-4}\ \dfrac{4}{h^{0.6}}\ \tau\right]$;

$$k_0 = 2.25 + 3.25 \exp\left(-\frac{|T - 0.1|^{1.45}}{0.55}\right);\quad k_1 = -\frac{k_0 - \sqrt{k_0}}{3.45};$$

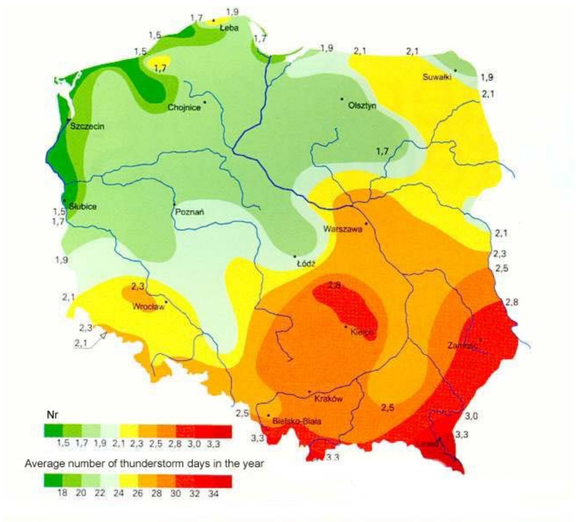


Fig. 1. Average lightning strike density in the years N_r in Polish area

$k_5 = \left[-0.9 + 7.5\left(T - 0.02\right)\right]\cdot 10^{-4}$ $\quad for\ 0 < T \le 0.1\,\mu s$ and

$$k_5 = \left[0.7\exp\left(-\frac{\left|T-0.19\right|^{1.4}}{0.19}\right) + 0.18\left(1-0.667^{\frac{\tau-28.85}{28.85}}\right) - 1.15\right]\cdot$$

$\cdot 10^{-4}$ $\ for\ T > 0.1\,\mu s.$

Computer simulation of transient states

Computer simulation of transient states resulting from atmospheric discharges can be realized by means of computer programs, which allow us to analyse transients occurring within electric systems. Such programs, applied also to design of overvoltage protective systems, can be of various types depending on their function, e.g. EMTP (Electro-Magnetic Transients Programs) and PSpice (Simulation Program with Integrated Circuits Emphasis) or specialized programs applied to analyse and calculate of selected electric phenomena. Results obtained from simulations should be verified by comparing with measurement results related to physical models or real technical objects.

Numerous measurements show great influence of the overvoltage front duration on the level of overvoltages induced in other elements of a system. In order to confirm the level of overvoltage hazard and influence of the overvoltage front duration on the increase of voltage gradient within insulating systems in power network sections, a computer simulation has been carried out, based on PSpice program. Additionally laboratory measurements on models of power multicore screened and non-screened cables were made [4].

Schematic diagram of the simulated system is presented in Fig. 2. Parameter values of overhead /cable lines, taken into computer simulations, are as follows: C_0=0.1/7.37 μF/km; L_0=0.49/1.71 mH/km; R_0= =0.0289/0.35 Ω/km; Z_0=70/482 Ω; v=142.86/281.69 m/μs. Input of investigated system has been stimulated by electric pulse (V4 source) represented approximately overvoltages caused by direct or nearby lightning strokes. The end of the line is loaded with the resistance of a great value which simulates the load of the line end by MV/LV switching or transformer station.

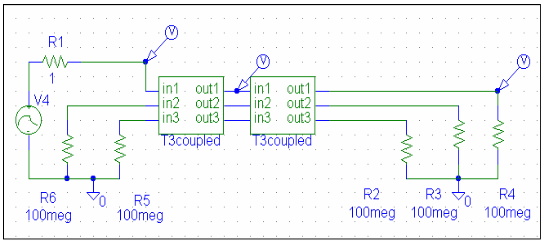
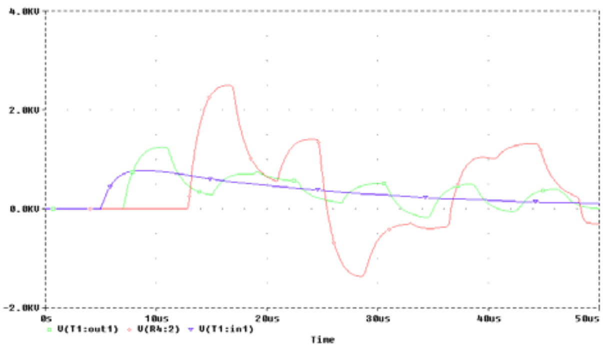


Fig. 2. Schematic diagram of the simulated system section composed of overhead and cable line segments: V4 – input pulse source; R1 – internal resistance of a source; T3, T3' – models of power overhead line (l=1670 m) and cable line (l=370 m); R2-R6 – loading resistances

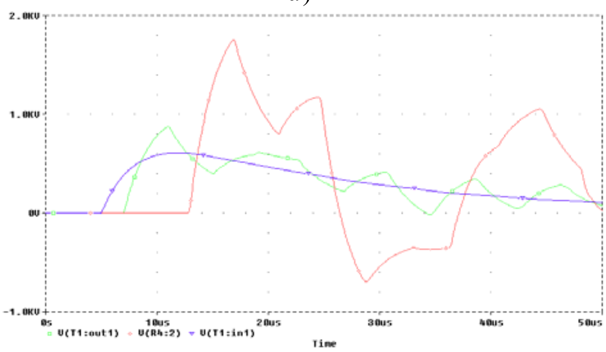
Example simulation results are presented in Fig. 3.

From transient time-dependent voltage at the beginning of the line results that each direct lightning stroke in power network elements and their vicinity causes overvoltage waves, which are capable to break down insulating systems. Moreover, such overvoltage hazard can occur many times at each point of a line.

Influence of steepness of the pulse front on the level of overvoltages generated in screened and belted cables was also investigated basing on simulation results. They show that duration of the wave front does not affect the increase of voltage gradient within insulating systems of screened cables. However, such a regularity has not been observed in case of belted cables. It means that maximum value of voltage influenced insulating systems during lightning discharges is strongly dependent on duration of their wave fronts.



a)



b)

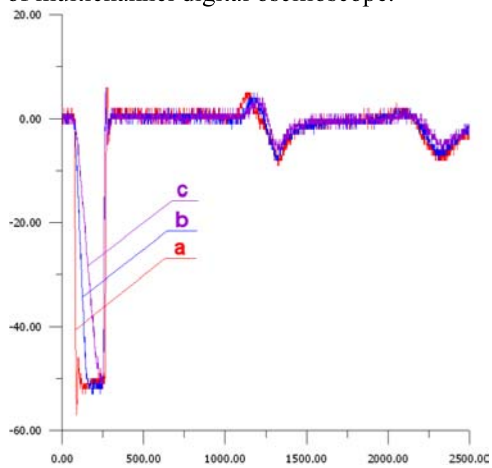
Fig. 3. Transient time-dependent overvoltages occurring at determined points "V" of a system (Fig. 2) for different slopes of the stimulated pulse fronts

Transient time-dependent voltages obtained as a result of simulation process performed by means of models available in the program show that these models ignore an important phenomenon occurring in a line due to wave effects – increase of resistance of conductors caused by skin effect and increase of dielectric losses.

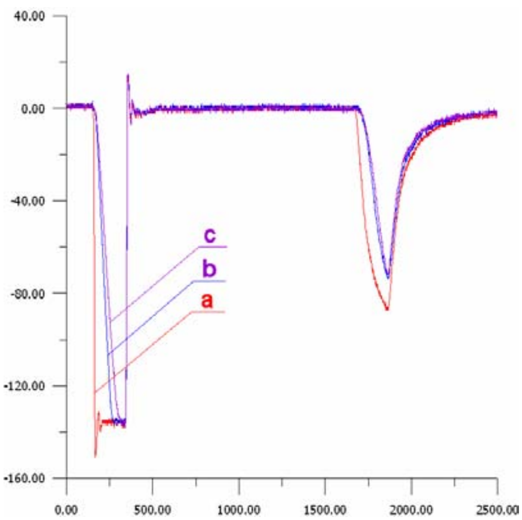
A consequence of such an imperfection of models is the amplitude of signals returning from a line is considerably greater than the amplitude measured.

Measurements in model systems

Results obtained from simulation process were verified basing on the measuring system made both for three-core belted and single-core screened cables. They were equipped with the special pulse generator which allows us to regulate the slope and wave front duration. In the case of three-core line only one from all the conductors was energized by the generator of rectangular pulses. Transient time-dependent voltages caused by the pulse in energized conductor (in the three-core line and in non-energized neighbouring conductors) were registered by means of multichannel digital oscilloscope.



a)



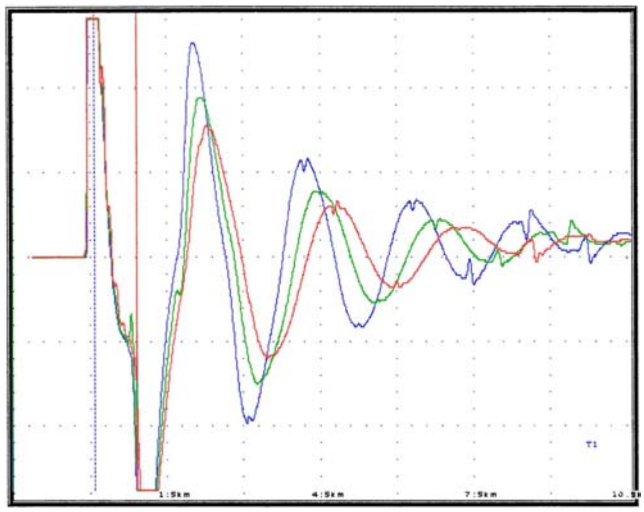
b)

Fig. 4. Time-dependent overvoltages occurring in line models: traditional three-core a) and single-core b). Input signal: amplitude 4.1 V, breadth $\Delta t = 250$ ns; a, b, c – input impulses V_a, V_b, V_c for different pulse rise times

Measurements were made for different values of wave front overvoltages. Example results of these measurements are presented in Fig. 5.

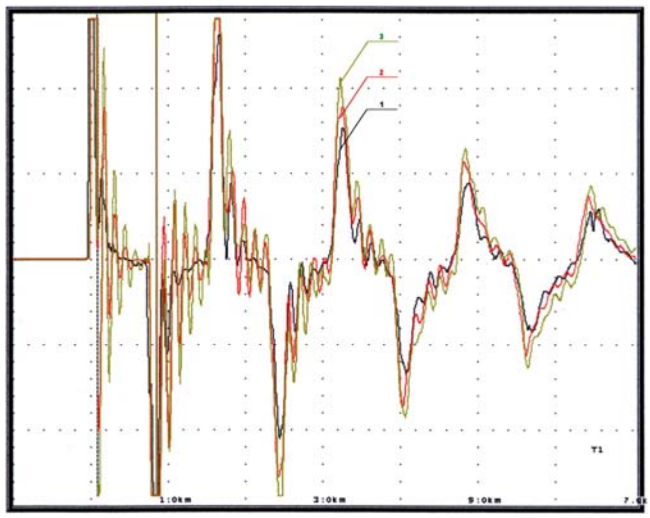
Influence of the load value at cable ends, on the size of overvoltage waves induced in neighbouring and powered cables has been measured. It was observed that the highest amplitudes of overvoltages occur in lines with unpowered ends. Combination of a greater number of measurement results, performed with different configurations of cable connections and different shapes of forcing pulse are available in publications [5] and [6].

Obtained transients reveal that pulse time parameters at the input of the examined system have great influence on the shape of reflected and induced wave in neighbouring cable wires. However, in case of unscreened cables, lowering of the input pulse inclination causes additional shifting of reflection amplitude to longer timing.



time (ns)

a)



time (ns)

b)

Fig. 5. Transient time-dependent overvoltages occurring in 20 kV cable lines [6]: HAKnFtA 3x120 mm^2 (a) and YHAKX 1x120 mm^2 (b) for different slopes of the stimulated pulse fronts

Tests of selected authentic 20 kV line sections including power cables HAKnFtA 3x120 mm^2 and YHAKX 1x120 mm^2 (see Fig.5) confirmed regularity observed in case of computer simulations (graphs in Fig. 3) and laboratory tests (graphs in Fig. 4).

Conclusions

The measurements and simulations, concerned influence of pulse overvoltages caused by direct or indirect atmospheric discharges, can be concluded as follows:

1. The analysis of computer simulation and laboratory test results prove that the duration of the overvoltage front does not affect the increase of the hazard for screened cable insulating systems.

2. The increase rate of the edge of overvoltage wave tail and its duration are parameters which have significant influence on cable insulating systems.

3. Electric field intensities occuring within cable insulating systems, due to atmospheric discharges increase along with the line length but further tests are required to determine nfluence of such a parameter on surge voltages.

4. Tests and many years of observations of atmospheric discharges show that peak value and steepness of wave front are random values of negligible correlation. It means that these parameters can be analysed independently.

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Z. Gacek, W. Skomudek. Influence of Selected Parameters of Overvoltages on Hazard of Insulating Systems in MV Power Lines // Electronics and Electrical Engineering. – Kaunas: Technologija, 2006. – No. 2(66). – P. 88–91.

Chosen problems relevant to overvoltage hazard of MV overhead power lines and power cables with polymeric insulation are discussed. Computer simulation results regarding the hazard due to lightning discharges occurring within MV power network systems are presented. These prove that 20 kV power network systems can be threatened by overvoltages during thunderstorms. Maximum values of total overvoltages induced within such conductors in dependence on distance between lightning stroke channel and a line have been estimated. Ill. 5, bibl. 6 (in English; summaries in English, Russian and Lithuanian).

З. Гацек, W. Скомудек. Влияние конкретных параметров перенапряжения на факторы ризики изоляционных систем в МВ линиях энергоснабжения // Электроника и электротехника. – Каунас: Технология, 2006. – № 2(66). – С. 88–91.

Обсуждаются конкретные проблемы, связанные с ризикой перенапряжений в надземных линиях энергоснабжения и кабелях с полимерной изоляцией. Представлены результаты компютерного моделирования, получены при моделировании вредных факторов разрядов молний, происходящих в МВ системах энергетической сети. Результаты доказывают, что перенапряжения могут быть опасны для 20кВ систем сети энергоснабжения при разряде молнии. Оценены максимальные значения сумарных перенапряжений индуктированых в таких проводниках в зависимости от расстояния между каналом разряда и линией. Ил. 5, библ. 6 (на английском языке; рефераты на английском, русском и литовском яз.).

Z. Gacek, W. Skomudek. Pasirinktų viršįtampių parametrų įtaka izoliacinių sistemų rizikos veiksniams MV energijos tiekimo linijose // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2006. – Nr. 2(66). – P. 88–91.

Aptariamos konkrečios problemos, susijusios su viršįtampių pavojumi antžeminėse energijos tiekimo linijose ir kabeliuose su polimerine izoliacija. Pateikti kompiuterinio modeliavimo rezultatai, gauti modeliuojant kenksmingus poveikius dėl žaibo iškrovų, vykstančių MV energetinio tinklo sistemose. Rezultatai įrodo, kad viršįtampiai gali kelti pavojų 20kV energijos tiekimo tinklo sistemoms žaibavimo metu. Įvertintos suminių viršįtampių, indukuotų tokiuose laidininkuose, maksimalios vertės priklausomai nuo atstumo tarp žaibo išlydžio kanalo ir linijos. Il. 5, bibl. 6 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).