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THE RISK OF DAMAGES ANALYSIS OF TROLLEY WIRES AND THE RAILWAY TRAFFIC CONTROLLING DEVICES DUE TO LIGHTNING DISCHARGES[1]

ANALIZA RYZYKA USZKODZEŃ SIECI TRAKCYJNYCH I URZĄDZEŃ STEROWANIA RUCHEM KOLEJOWYM SPOWODOWANYCH WYŁADOWANIAMI ATMOSFERYCZNYMI

A b s t r a c t

The research of natural statics and damages connected with them is difficult in consideration of their random occurrence. Making a decision about necessaries and effectivities of resources usage of the lightning surge protection and about the choice of a suitable protection method, should be preceded by an estimation of the risk due to damages lightning discharges. In the report, the risk analysis of damages of the railway traction and of the control command and signaling equipments due to lightning discharges for a real case of damage, is represented. In the risk analysis, a fragment of a rail track in which lightning discharges appeared, was taken into account. The results of these occurrences estimation, calculated by the LIOV software, taking into account real parameters of the system, have been also represented.

Keywords: lightning protection, damages, risk management, railway traction, control command and signaling equipments

S t r e s z c z e n i e

Badanie naturalnych wyładowań atmosferycznych i szkód z nimi związanych jest utrudnione ze względu na ich losowe występowanie. Podjęcie decyzji o konieczności i efektywności stosowania środków ochrony odgromowej i przepięciowej oraz o wyborze odpowiedniej metody ochrony powinno być poprzedzone oszacowaniem ryzyka szkód spowodowanych wyładowaniami atmosferycznymi. W artykule przedstawiono analizę ryzyka uszkodzeń sieci trakcyjnych i urządzeń sterowania ruchem kolejowym spowodowanych wyładowaniami atmosferycznymi dla jednego przypadku uszkodzenia. W analizie ryzyka uwzględniono fragment szlaku torowego, na którym wystąpiły wyładowania atmosferyczne. Przedstawiono również wyniki oceny tych zjawisk przy pomocy programu LIOV, uwzględniając parametry rzeczywiste układu.

Słowa kluczowe: ochrona odgromowa, uszkodzenia, zarządzanie ryzykiem, sieci trakcyjne, urządzenia sterowania ruchem kolejowym

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[1] The author of this paper bears full responsibility for the language and quotations.

1. Introduction

Trolley wires and railway traffic controlling devices (rtc) enclose in their own range considerable areas of the country and are subject to the influence of lightning flashes in a large rate. The fulminic threat can be a result of a stroke immediate hit into the trolley wires or the non–traction line (NTL) or a result of induced voltages by nearby discharges to earth. As a result of surges influences, damages of electric and electronic devices or of their components can appear causing losses eg. in the form of delays of trains and their results. The choice and the installation of suitable protection resources for rtc devices and of the electric traction against the results of lightning discharges to earth influence gives marked advantages which can be evaluated basing on the methodics of management the lightning damages risk, in detail described in the standard EN 62305–2: 2012 – Protection against lightning – Part 2: Risk management [1]. In accordance with this norm, the decision of necessaries and effectivities of the usage of lightning and surges protection and of the choice of a suitable protection method, should result from the estimation of damages risk due to atmospheric discharges.

2. The management of lightning damages risk

The qualification of the risk of damages caused by strokes according to the standard EN 62305–2: 2012 – Protection against lightning – Part 2: Risk management [1] demands taking into account many factors and parameters. To estimate the risk of damages for the given object, it is required taking into account tens of different data describing among others constructional features of the object, its location, the geometry and measurements and also the level of surges resistance of the electric and electronic equipment. It is also required the qualification of the accepted value of the risk by the protection resources designer or the user of the object, which after exeeding it, the qualification of the material consequential losses range resulted from the immediate hit of the stroke into the structure and of the losses related to the influence of the nearby discharges to earth, will be indispensable.

In the analysis, it was accepted that trolley wires, non–traction lines and the connected to them devices rtc are service – devices. One of the decisive of the threat factors is the average of one year's number of strokes hitting into trolley wires, non–traction lines (NTL) and connected to them rtc devices or nearby them. Knowing these parameters we can qualify the probability that the discharge will hit into mentioned devices.The losses resulted from this are in consequence of damages [2, 3]. A result of damages are also delays of trains and due them additional losses. Values of these factors depend considerably on the correctly definite equivalent of the assembling area.

3. The method used to estimate the risk of lightning damages occurrence

To estimate the risk, it is assumed that the current of the stroke is the main source of the damage and can cause damage depending on the characterization of the subjected to protection structure. To most important concerning characterizations belong: the kind of the construction, contents and uses, the kind of the service device – and of provided protection resources.

In association with the occurrence of different cases of hits and lightning influences, different risk components elements are qualified, taking into account reasons of damages as well as types and kinds of losses. On regard of the place of the stroke, the following sources were specified :

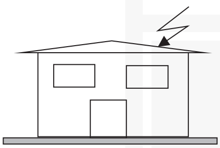
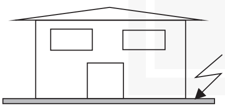
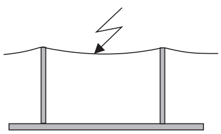
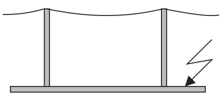
S1 – flashes to a structure,
S2 – flashes near a structure,
S3 – flashes to a line,
S4 – flashes near a line.

Considering the practical use of the risk estimations, three basic types of damages which can appear as a result of lightning strokes were favoured (Table 1) :

D1 – injury to living beings by electric shock,
D2 – physical damage,
D3 – failure of electrical and electronic systems.

Table 1

The classification taking into account the source of damages, types of damages and losses depending on the point of stroke [1]

Lightning flash		Structure	
Point of strike	Source of damage	Type of damage	Type of loss
	S1	D1 D2 D3	L1, L4[a] L1, L2, L3, L4 L1[b], L2, L4
	S2	D3	L1[*], L2, L4
	S3	D1 D2 D3	L1, L4[a] L1, L2, L3, L4 L1[b], L2, L4
	S4	D3	L1[b], L2, L4

a) Only for properties where animals may be lost
b) Only for structures with risk of explosion and for hospitals or other structures where failures of internal systems immediately endanger human life

The damage of a building object in consequence of a lightning stroke can be limited to a part of the structure or can include the whole object, or surrounding structures or the environment (eg. chemical or radioactive issues). Every type of the damage, alone or together with other damages, can produce different consequential losses in subjected to protection structure. The type of the loss, that can appear, depends on proprieties of the structure itself and its contents. In the case of the analysed service – devices the following types of losses were taken into account [1, 4]:

L1 – loss of human life (including permanent injury),
L2 – loss of service to the public,
L4 – loss of economic value (structure, content, and loss of activity).

In accordance with the standard EN 62305–2:2012 [1], in the risk assessment of *R* as probables of one year's average losses for every type of the loss, that can appear in the structur, it is ought to mark the suitable value of the risk:

– R_1: The risk of the human life loss in quoted standard [1] was qualified with the equalization containing of eight coefficients. The risk of the life loss can be understood as for eg. the result of a railway disaster due to the damage of rtc devices or the loss of the service workers life. Taking into account concerning coefficients of the analysed object we received:

$$R_1 = R_{B1} + R_{C1} + R_{U1} + R_{V1} + R_{W1} + R_{Z1} \tag{1}$$

– R_2: The risk of the public service loss:

$$R_2 = R_{B2} + R_{C2} + R_{V2} + R_{W2} + R_{Z2} \tag{2}$$

– R_4: The risk of the material value loss:

$$R_4 = R_{B4} + R_{C4} + R_{U4} + R_{V4} + R_{W4} + R_{Z4} \tag{3}$$

Each components of the risk marks:

– R_A, R_B, R_C – components of threats carried in by the immediate lightning discharge into the object (the source of the threat S1),
– R_M – the component of the threat carried in by the lightning discharge nearby the structure (the source of the threat S2),
– R_U, R_V, R_W – components of threats carried in by the discharge into attached to the structure service – devices (the source of the threat S3),
– R_Z – the component of the threat carried in by the immediate lightning discharge nearby the service – device attached to the structure (the source of the threat S2).

In Fig.1 the proseding algorithm of the resources choice of the lightning protection with the specification for: 1) the building structure and 2) for the service – device is illustrated. Components of the risk for the service – device can be appointed from the general equation as:

$$R_X = N_X \cdot P_X \cdot L_X \tag{4}$$

where:

N_X – number of dangerous events per annum,
P_X – probability of damage to a structure,
L_X – consequent loss.

The one year's average number N of threatening events in consequence of lightning discharges, affecting the subjected to protection structure, is relative to the stormy activity of the region, where the structure stands and to physical proprieties of the structure. To calculate the number N, it is ought to multiply the density of strokes to the earth N_G by the equivalent area of assembling A_D of discharges for the given structure concedering the corrective components concerning physical proprieties of the structure. The density of lightning discharges to the earth N_G is the number of lightning discharges in 1 km^2 for a year.

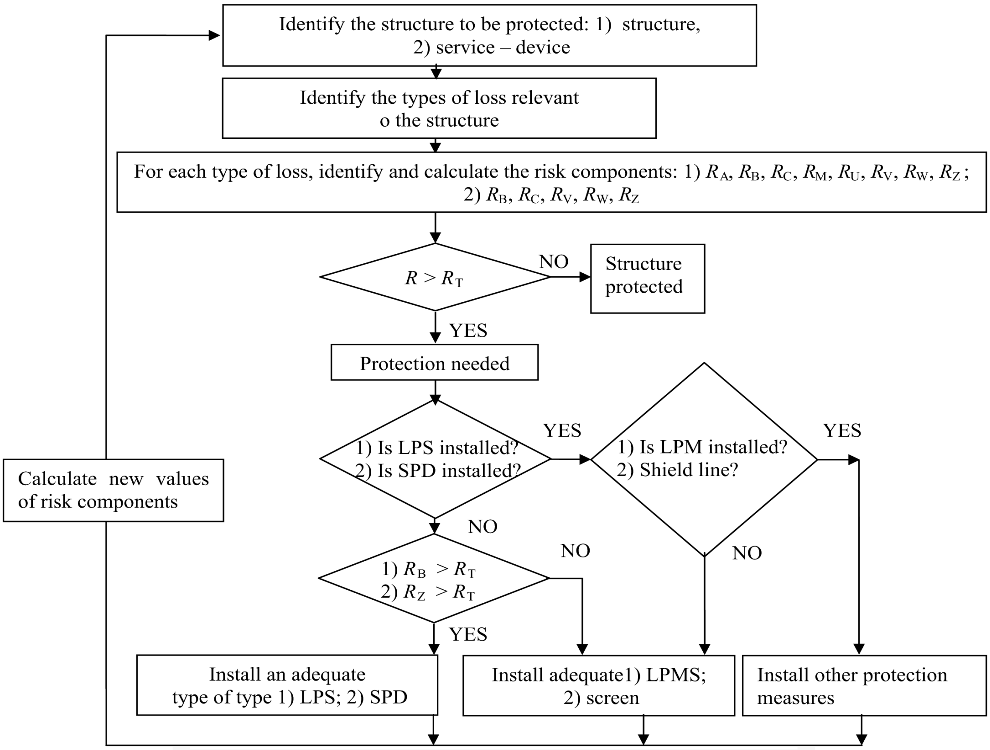


Fig. 1. The algorithm for deciding the need of protection and for selecting protection measures [1]

The prospective number of threatening events N_D for the analysed object can be marked from the dependence:

$$N_D = N_G \times A_D \times C_D \times 10^{-6} \tag{5}$$

for which:

- N_G – the one year's average density of lightning discharges to the earth,
- A_D – an equivalent area of assembling by the structure (m^2) described by the dependence:

$$A_D = L \times W + 2 \times (3 \times H) \times (L + W) + \pi \times (3 \times H)^2 \tag{6}$$

taking into account: the length L, the width W and the height H.

The relative position of the structure, compensating the influence of the surrounding structures or the endangered structure position, is qualified by the component C_D which accepts the values:

0.25 – for the surranded object with higher structures or trees,
0.5 – for the surranded object with structure or trees about the same height or lower,
1 – when there is a lack of other structures nearby,
2 – when the analysed structure is analysed isolated on a peak of a hill or of a knoll.

The estimation of the one year's average number of threatening events in consequence of discharges nearby the structure N_M can be marked from the dependence:

$$N_M = N_G \times A_M \times 10^{-6} \tag{7}$$

If $N_M < 0$, then for this estimation we should accept $N_M = 0$.

The risk R is the sum of component elements and its grand total can be introduced in the form of the dependence:

$$R = R_D + R_I \tag{8}$$

where:

R_D – the risk of the immediate hit into the structure,
R_I – marks the risk of the nearby lightning stroke.

In the used method, the probability of the introduced assumptions is certain, unless the protection is applied. The use of the protection reduces the probability according to the kind and effectivness of the given risk storage element. With reducents, the risk can be: lightning protection device, limiters of surges SPD, the transformer on the entry of the line to the object, shielding of the lines and wires or the use of limitting resources of the propagation of a fire.

The last component from the relation (4) that is to say the loss L_X depends on the considered of its type (L1, L2, L3 and L4) and on the type of damages calling it out (D1, D2 and D3). The comply with the following used symbols marking resulting losses in consequence of:

– L_T – shocks at touch and step voltages;
– L_F – the physical damage;
– L_0 – the damage of internal systems.

The decision about necessaries of the use of lightning protection demands the defining of the risk value R and comparing it with the value of the tolerable risk. For example, the value of the tolerated risk $R_T = 10^{-5}$ everywhere, the damages can cause a loss of a human life. In all other cases the qualification of the value R_T should be performed by suitable project–institutions and maintenances of the railway traffic.

4. The assessment of risk components

In Fig. 2 the registered along the railway rout strokes with chosen windows for which were assigned the location, time, value of currents and polarizations, were placed.

The system LINET for the analysed the case [3] noted lots and lots of discharges in the radius of 2 km from the railway line. The exactitude of the discharge location pronouncement given with an error 150–200 m, is based on the use of the TOA (Time–of–Arrival) technics was optimized thanks to the utilization of GPS system. The average error of the time resolution

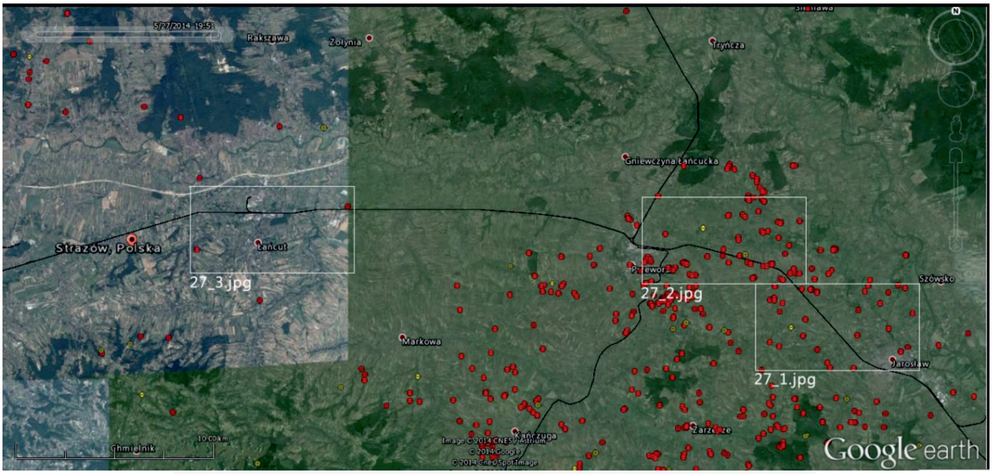


Fig. 2. The accepted to analysis fragment of the railway line (27_3.jpg) with registered lightning flashs [3]

for the whole system was qualified as equal 0.2 μs. According to data [3] on analysed section, the surge of the highest value 157.5 kA was registered in the distance 20 m from the axis of tracks and 40 m from the line NTL. This stroke caused the disconnection of rtc devices for 2760 minutes (46 hours). For the analysed devices, which are: the line NTL, trolley wires and the installed in the track rtc devices (with automatic lineal blockade) a simplified object (Fig. 3) of the length L, widths W and heights H, was accepted. In the case of analysis only the trolley wires and rtc devices installed in the track, an average value of parameters was accepted [5, 6]: H_1 = 6.7 m which is the average of the trolley wires suspension height, W_1 = 12.5 m being the average width of the object consisting of the following measurements: the width of two tracks (2 x 1.435 m), the average distance between tracks 4 m, the distance 2.5 m of the trolley wires columns from the axis of tracks and the average distance 1 m from the outside of the trolley wires columns for rtc devices installed along the tracks. To the analysis of the object containing additionally NTL line installed in the distance of 20 m from the track, the following values of parameters were accepted: the average value of the height for the line NTL H_2 = 10.7 m, the width W_2 = 29.7 m assigning the distance between the traffic passage where the rtc devices are installed behind columns of the trolley wires on one side and a non–traction line on the other side. In the analysis, two lengths of objects: L_1 = 9 km, assigning the chosen fragment of the track among neighbouring stations and L_2 = 45 km, being all distance between extreme stations of the analysed section in which atmospheric discharges appeared, were took into account. Extreme columns in Fig. 3 marked as S1 – columns of the trolley wires and S2 columns of the line NTL. Additionally, in table 2 and 3 calculated values of assembling equivalent areas for 100 kilometres of tracks were placed, marked as A_{M1} for the trolley wires and A_{M2} for the line NTL.

The component C_D compensating the influence of surrounding structures or the endangered position was accepted as equal 0.5 that is so, as for the surrounded structure by other structures or trees about the same height or lower and of the surrounded structure by higher structure or trees the value C_D is lower by half than previously accepted and equal C_D = 0.25.

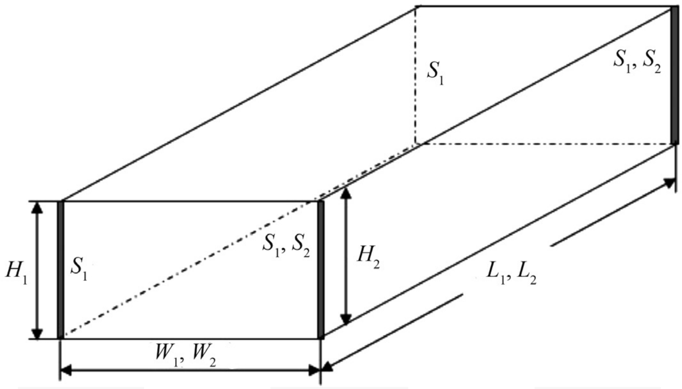


Fig. 3. The accepted to analysis the general scheme of the structure

Table 2

The evaluating of the risk chosen storage components [1] for discharges into the service – device

A_D [m²]		Number of threatening events N_D			
		N_G=2/km²/year C_D = 0.5	N_G=2/km²/year C_D = 0.25	N_G =3/km²/year C_D = 0.5	N_G =3/km²/year C_D = 0.25
A_{D11}	476071	0.48	0.24	0.36	0.18
A_{D12}	850242	0.85	0.43	1.28	0.64
A_{D21}	2313271	2.31	1.16	3.47	1.73
A_{D22}	4230642	4.23	2.12	6.35	3.17
A_{D1}	5271771	5.27	2.64	7.91	3.95
A_{D2}	9395142	9.40	4.70	14.4	7.50

For the analysed area the average of one year's density of lightning discharges to–earth carries out N_G =2.7 km² a year [7]. For the calculations N_G in the range 2÷3 km² a year was accepted. The assembling area from the dependence (6) was marked as:

1) A_{D11} – for the catenary wire (of the trolley wires) of the length L_1 = 9000 m, widths W_1 = 12.5 m and heights H_1 = 6.7 m.
   A_{D12} – for the line NTL of the length L_1 = 9000 m running in the distance W_2 = 29.7 m from the track on the height H_1 = 10.7 m.

The appointed values of the assembling area carried out properly:

2) A_{D21} – for the catenary wire (of the trolley wires) of the length L_2 = 45000 m W_1 = 12.5 m, H_2 = 6.7 m were accepted.
   A_{D22} – for the line NTL of the length L_2 = 45000 m, running in the distance W_2 = 29.7 m from the track on the height H_1 = 10.7 m.

To estimate the one year's average number of threatening events in consequence of discharges nearby the structure N_M from the dependence (7), the registered nearby discharges were found at the farthest 500 m from the track were taken into account.

Below, were marked the assembling areas of threatening events in consequence of discharges nearby the structure $A_{M11} \div A_{M22}$ and A_{M1} and A_{M22} for different (accepted similarly, as above) lengths L, widths W, $N_G = 2 \div 3$ / km^2 a year and of the accepted point in the distance 500 m [1] using Formula 9 (A.7 from the standard [1]):

$$A_M = 2 \times 500 \times (L + W) + \pi \times 500^2 \tag{9}$$

Values of losses L'_F and L'_O can be fixed in categories of a relative size of possible losses on the base of the following approximate dependence (E1 from the standard [1]):

$$L'x = n_p / n_t \times t / 8\,760 \tag{10}$$

where:

n_p – the average number of not served users;
n_t – the entire number of persons (served users);
t – ithe one year's period of the service loss (in hours).

For one case of rtc devices damages of the values n_p and n_t were skipped because of the lack of data. The value $t = 46$ hours from here the loss carries out $L = 5 \cdot 10^{-3}$. For example according to the Table E.1 of the standard [1], for the electric power supply, the typical average values of losses carry out $L'_F = 10^{-2}$ and $L'_0 = 10^{-3}$.

Table 3

The evaluation of the risk chosen storage components [1] for discharges nearby the service – device

A_M [m^2]		The number of threatening events N_M nearby the service – device	
		$N_G = 2$/km^2/year	$N_G = 3$/km^2 /year
A_{M11}	9797500	19.60	29.40
A_{M12}	9814700	19.63	29.44
A_{M21}	45797500	91.60	137.40
A_{M22}	45814700	91.63	137.44
A_{M1}	100797500	201.60	302.40
A_{M2}	100814700	201.63	302.44

The probability P'_V that the discharge into the line will cause physical damages and the probability P'_W that the discharge into the line will cause the damage of the service – equipment is related to the damage current I_a which is relative to proprieties of the line and of the used protection resources. For the non–shielded line, we ought to accept $I_a = 0$. For example for shielded lines, we ought to mark the damage current I_a from the dependence (D.7) (standards [1]):

$$I_a = 25\ U_w / (R_s \times K_d \times K_p) \tag{11}$$

where:

- K_d – the coefficient depending on the propriety of the line (Table D.1 [1]);
- K_p – the coefficient taking into account practical protection resources (Table D.2 [1]);
- U_w – the surge voltage held out [kV] (Table D.3 for cables and Table D.4 for devices of the standard [1]);
- R_s – the resistance of the cable screen [Ω/km].

In the case of telecommunication lines, to the evaluation of P'_V we accept that the maximum damage current I_a, has the values:
I_a = 40 kA for cables with a lead screen,
I_a = 20 kA for cables with an aluminium – screen.

For a known value of the surge current for eg. 150 kA given in the Table D5 of the standard [1], values of the probability P'_V and P'_W carry out 0.02.

The values of the probability P_Z, marking that the lightning discharge occurrents nearby the service – device will cause a damage of internal systems, depends on the proprieties of the service – device screen, surge voltage held out connected to the service – device internal system and of practical protection resources. If the coordinated system SPD is not used, suiting the EN 62305–4 [8], the value P_Z is equal to value P_{LI} which marks the probability of the internal systems damages in consequence of the discharge into the connected service – device. Proposed protection resources should be well–chosen in accordance with the standards EN 62305–3 [9] and EN 62305–4 [8].

5. Calculation of induced overvoltages using LIOV software

In accordance with the standard [10] with accessible data from the lightning current research, we can distinguish three kinds of discharges: the positive discharge, the first component of the negative discharge and the following component [11]. Maximum values of positive discharges currents can reach 200 kA. Positive discharges are rare occurrences being characterized that the discharge has its own beginning in the upper part of the thundercloud. This kind of discharging is characterized with a large energy mattering in the analysis and modelling [12].

The LIOV software (Lightning–Induced Over Voltage) [13] makes possible the marking of voltages for the overhead transmission line situated in a definite distance from the channel of the lightning descharges. In the modelling of the static electromagnetic field connection with the transmission line we mark the component of the electric and magnetical field nearby the line. The LIOV software consists of subroutines: MTLF (Modified–Transmission Line Fields) and MTLV (Modified–Transmission Line Voltages). The subroutine MTLF.exe serves marking the resultant magnetic field as a result of the current flow in the channel of the discharge taking into account the current speed in the channel of the static. The subroutine MTLV.exe has for an assignment marking the voltages induced along the line.

In the LIOV software it was assumed that the current at the static channel base is described by the dependence proposed by Heidler [14] and used also in the standard [10]:

$$i(0,t) = \sum_{k=1}^{2} \frac{I_{mk}}{\eta_k} \frac{\left(\frac{t}{\tau_k}\right)^2}{1+\left(\frac{t}{\tau_{1k}}\right)^2} \exp\left(-\frac{t}{\tau_{2k}}\right) \tag{12}$$

where:

I_{mk} – the maximum value of the current,

τ_{1k} – the time base of the first element of the function,

τ_{2k} – the time base of the second element of the function.

The factor is marked from the formula:

$$\eta_k = \exp\left(-\frac{\tau_{1k}}{\tau_{2k}}\left(\frac{\eta_k \tau_{2k}}{\tau_{1k}}\right)^{1/n_k}\right) \tag{13}$$

In the software it was accepted that the current at the static channel base has the form:

$$i(0,t) = i_{H1}(0,t) + i_{H2}(0,t) + i_{DE}(0,t) \tag{14}$$

and is the sum of two Heidler functions $i_{H1}(0, t)$ and $i_{H2}(0, t)$ described by the dependence (12) and parameters placed in the Table 4 as well as of the third – two–exponential function described by the dependence (15).

Table 4

Parameters of the function described by the formula (12) [13]

The lightning current – the following component of the negative discharge					
k	I_{mk}, kA	τ_{1k}, μs	τ_{2k}, μs	η_k	η_k
1	10.7	0.25	2.5	2	0.639
2	6.5	2.1	230	2	0.874

$$i_{DE}(0,t) = I_m\left(\left(1-e^{-\alpha t}\right)-\left(1-e^{-\beta t}\right)\right) \tag{15}$$

For example, the given in standard [10] for the first level of the amplitude and shapes of the current courses protection, carry out for:

– the long stroke component: 400 A; 0.5 s,
– the first stroke component: 200 kA; 10/350 μs,
– following stroke components: 50 kA; 0.25/100 μs.

In standard [10] the temporary form of the impulse current for the first (10/350 ms) and the following (0.25/100 ms) stroke components is described by the equalization (of parameters given in Table 5):

$$i(t) = \frac{I}{k} \frac{(t/\tau_1)^{10}}{1+(t/\tau_1)^{10}} \exp(-t/\tau_2) \tag{16}$$

where:

- I – is the peak current,
- k – correction factor for the peak current,
- k – the corrective coefficient of the maximum value,
- t – time,
- τ_1 – is the front time constant,
- τ_2 – is the tail time constant.

Table 5

Parameters of impulse current for different levels of the lightning protection [10]

Parameters	First positive impulse			Subsequent negative impulse		
	Level of the lightning protection			Level of the lightning protection		
	I	II	III–IV	I	II	III–IV
I (kA)	200	150	100	50	7.5	25
K	0.93	0.93	0.93	0.933	0.933	0.933
τ_1 (μs)	19	19	19	0.454	0.454	0.454
τ_2 (μs)	485	485	485	143	143	143

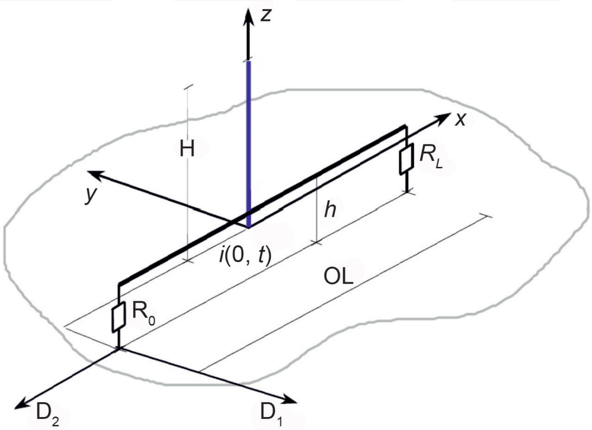


Fig. 4. The system of the discharge channel – transmission line [13]

In the modelling for the estimated value of the stroke [3], the stroke source model was modified limiting it to the maximum value of the first discharge. In standard [10] parameters for the stroke of the maximum value 150 kV are given and such data were accepted for calculations. The input datas in LIOVF software contain the entrance signal of the lightning current, brought into the given distance (Fig. 4) from the overhead transmission line of electric and geometrical given parameters [15]. Additionally the programme contains such data, as: the observation time, number of accepted samples for the analysis. The data is inscribed into the following programme windows. For calculations of the lines NTL of symmetrical triangular lines system the diameter d = 0.7 cm, and for the trolley wires d = 0.6 cm was accepted [5, 6]. The remaining parameters were qualified, as in the accepted model (Fig. 3). As a load of the line, impedances of equal values to the wave– impedance of the lines (of a catenary wire for the trolley wires and the line NTL) were given. The accepted for calculations section of the line had the length 1000 m (Fig. 4). The channel of the stroke was placed (in the half–way of the line) on the perpendicular of the line symmetry axis in distances y such, as for the analysed situation ie, for the stroke of a value about 157 kA (for the line NTL – 40 m, and for the trolley wires – 20 m).

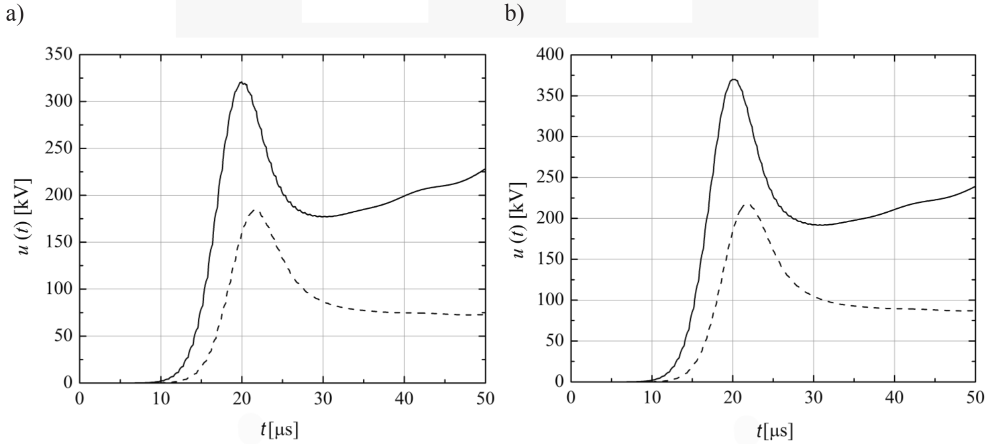


Fig. 5. Courses of surges for: a) trolley wires situated in the distance – 20 m from the channel of the stroke, b) the line NTL (for the distance – 40 m); the dashed lines – surges on both ends of the line, the solid lines – the nearest voltage to the stroke

For both distances 20 m and 40 m (Fig. 5) the surges reached values considerably above 300 kV. From the analysis of the temporary documentation concerning damages it results that this stroke was destructive for damaged rtc devices. The estimated values of surges confirm this assumption.

6. Conclusions

In consideration of that trolley wireses and NTL lines are not protected lightning wires. Occurrent surges at the immediate direct lightning strikes can be an order of megavolts. This is a very large threat for rtc devices and the traction. The induced overvoltages are also a large threat in the case of a lightning stroke nearby the traction and the non–traction line. Their values are lower, but the area of their influence and the number of lightning discharges in a year are considerably greater. The appointed as an example courses can be a tool helping in the protection design of the lightning protection or the isolation coordination.

References

[1] EN 62305-2:2012 Protection against lighting – Part 2: Risk management.

[2] Łoboda M., Lenarczyk K., *Correlation between recorded CG lightning discharges and shut-downs of selected HV overhead power transmission lines in Poland*, paper 48, International Conference on Lightning Protection (ICLP), Shanghai, China 2014.

[3] Materials thrown open by PKP Polish Railway Lines JSC, Railway Lines Establishment in Rzeszów.

[4] Markowska R., Sowa A., *Ochrona odgromowa obiektów radiokomunikacyjnych*, Oficyna Wydawnicza Politechniki Białostockiej, Białystok 2013.

[5] Głowacki K, Onderka E., *Sieci trakcyjne*, EMTRAK s.c., 2002.

[6] Szeląg A., *Zagadnienia analizy i projektowania systemu trakcji elektrycznej prądu stałego z zastosowaniem technik modelowania i symulacji*, Prace Naukowe, Elektryka z. 123, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2002.

[7] Łoboda M., *Aktualizacja danych częstości doziemnych wyładowań atmosferycznych w Polsce do oceny ryzyka zagrożenie piorunowego obiektów budowlanych*, Zeszyty naukowe Politechniki Rzeszowskiej, Elektrotechnika, Zeszyt nr 33, 2013, 156–169.

[8] EN 62305-4: 2011 Protection against lightning – Part 4: Electrical and electronic systems within structures.

[9] EN 62305-3:2011 Protection against lightning – Part 3: Physical damage to structures and life hazard.

[10] EN-62305-1:2012 Protection against lightning – Part 1: General principles.

[11] Rakov V.A., Uman M.A., *Lightning Physics and Effects*, Cambridge University, 2003.

[12] Wróbel Z., Ziemba R., Gamracki M., *Szacowanie zagrożenia piorunowego sieci trakcyjnych*, Technika Transportu Szynowego, nr 11/2008, 31–34.

[13] LIOV: Lightning-Induced Over Voltage Code: http://www.ing.unibo.it/die/liov/ [online: 19.08.16].

[14] Heidler F., *Traveling Current source model for LEMP calculation*, Proceedings of VI Symposium EMC, Zurich 1985, 157–162.

[15] Napolitano F., Borghetti A., Nucci C.A., Rachidi F., Paolone M., *Use of the full-wave Finite Element Method for the numerical electromagnetic analysis of LEMP and its coupling to overhead lines*, Electric Power Systems Research, 94, 2013, 24–29.