TRAMWAY SYSTEM VULNERABILITIES CAUSED BY STORM. CASE STUDY: LIGHTNING IN ORADEA, 10-TH JUNE 2013

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ABSTRACT: Short history, theoretical presentation, risk analysis of damage probability of extreme weather effects, lightning and storm, technical and economic aspects, recommendation for public transport operators. Case study: example of a lightning damage effects in Oradea.

KEYWORDS: extreme weather, storm, lightning, reliability and disponibility of tramway system

1. INTRODUCTION

The effects of extreme weather (storm, rains, lightning, winds, ...), unfortunately are a risk factor in the operation of public transportation systems. The specific case of electric traction (metro, tramway, trolleybus, cable car), specifically a system that is subject to this phenomenon, extreme weather are especially dangerous to the power supply systems. To reduce the risk of operational safety is a high priority. The importance of public transport systems makes a through analysis of the designers, installers and operators, effects of adverse weather conditions in order to minimize the probability coefficients of damage appearance.

2.THE LIGHTNING PROTECTOR

The definition of a powerful lightning discharge between cloud and cloud, or between clouds and the ground (or other ground facilities) and one or more times repeated form, accompanied by a sound effect. This phenomenon has been observed continuously throughout our history, the cause and content of the phenomenon was analyzed also by the ancient thinkers. However, only the eighteenth century we get satisfactory answers and explanations to the effects of lightning, and then did the first lightning protection proposals. First documents we know from America by Benjamin FRANKLIN in 1749, independent from him, in Europe the Czech Prokop DIVIS priest, who has been described in detail for the first lightning rod his model in 1754. Also, it where not remember named masters in attempts which the buildings metal structure covering of eventually lightning rod firework organization achieved (example might be over a thousand years old Sri Lanka Anuradhapura temple, in which the silver and gold metal plates preserved the building oflightning destroy, compared to other nearby contemporary buildings but, which were destroyed by lightning strikes over the history). As a similar approach can be evaluated the church tower NEVIANSKY (architect Akinfy DEMIDOV, Russian, period 1725-1732), which has been equipped with metal protection structure. The first officially registered lightning rod was by FRANKLIN ("lightning attractor" or "Franklin rod"), applied in the city of Philadelphia - The Christ Church [2]. In the nineteenth century appears more similar systems, are bound to names of great inventors (William Snow HARRIS, Nikola TESLA). The basic theory contains common ways, practical implementation has differences. A calculation method has become universally accepted, by the Hungarian scientist dr.Tibor HORVÁTH, in the middle of the XX.-th century, "the rolling ball" theory [3]. The basic composition: the critical radius of protection is proportional by the current intensity generated by the discharge can be determined based on which a safety ring (which probability is the largest value near 46 m!).

Analysis of the statistical weather data resulted in map editing experience, in which lightning probabilities can be calculated from the last 30-40 years of data. Building on values between 1961-1990 the average number of storm days in Romania, results are in the following map [7]:

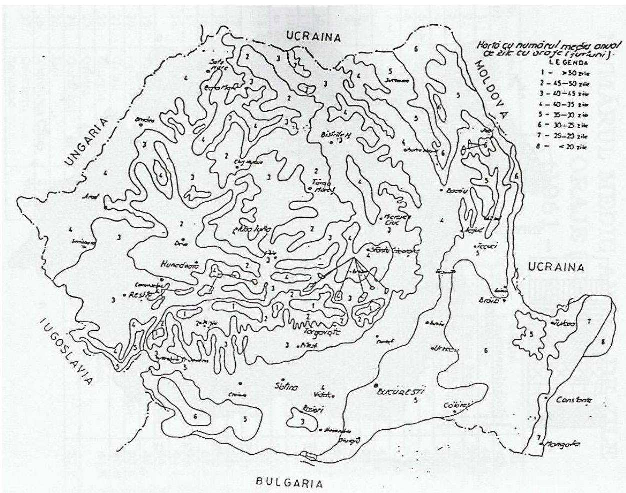

Fig.1 - The KERUANIC Map (included in the I20/2000- Romanian Lightning protection standard)

Coefficients used in the calculations and parameters: (E_d)-generated by lightning energy, (N_d)-the frequency of lightning strikes average Impaction, (N_c)-the lightning-year average accepted, (N_k)-KERUANIC coefficient. The I20/2000 Normative [7] contains the calculation formulas, tables, be determined on the basis of which the likely effects of weather extremes.

3. SCHEMATICALLY ABOUT TRAMWAYS

An electric-drawn schematic representation of urban public transport system is as follows:

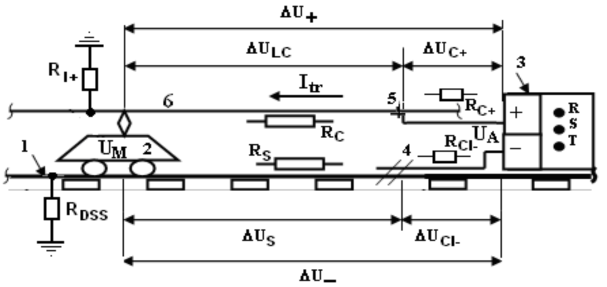

Fig. 2 - The electrical characteristics and power supply voltages and circuits

The indications contained in Fig.2 have details of [1]:
1 - tram rails;
2 - electric vehicles;
3 - transformers and power unit;
4 - the negative terminal (leakage current) "-" on the rails;
5 - Power cable "+" contact wire;
6 - General power wires twisted copper;
$\mathbf{I_{TR}}$ - the vehicle input current;
$\mathbf{R_{I+}}$ - input resistance relative to the ground;
$\mathbf{R_{DSS}}$ - rail/ground resistance ("stray current");
$\mathbf{R_S}$ - the track resistance between the vehicle and the Power station;
$\mathbf{\Delta U_{LC}}$ - potential differences in the relevant section of the contact line;
$\mathbf{\Delta U_-}$ - voltage drop across the "-" line (track);
$\mathbf{\Delta U_{CI-}}$ - the return cable voltage drop "-";
$\mathbf{\Delta U_{S-}}$ tension between the 4-point and the vehicle;
$\mathbf{U_A}$ - the rectifier power supply;
$\mathbf{U_M}$ - engine power.
$\mathbf{R_{C+}}$ - the resistance of the input power "+";
$\mathbf{R_{CI}}$ - the return current cable "-";
$\mathbf{R_C}$ - rail section as defined by the connection resistance of the vehicle position;

4. IMPORTANCE OF GROUNDING (EARTH)

The most important element of safety in the electrical power supply systems (transformers, rectifiers, electric cables, pipes, rails, vehicles, ...) the kind of grounding connections, which can provide protection even against lightning strikes. In order to protect human and material values of absolute priority normative values provided by the standards compliance. To the user (traveler, or staff) safety, determine the extent of the contact voltage, which is measured during a touching any metal surface and the surface of the land experiencing generate a voltage difference one step length. Just as in Fig.3.a and Fig.3.b shown [5], the ground-foot skin resistance $3\rho_s$ where ρ_s- the conductivity of the earth, R_1- for land vehicles people conductivity and R_u- the man conductivity.

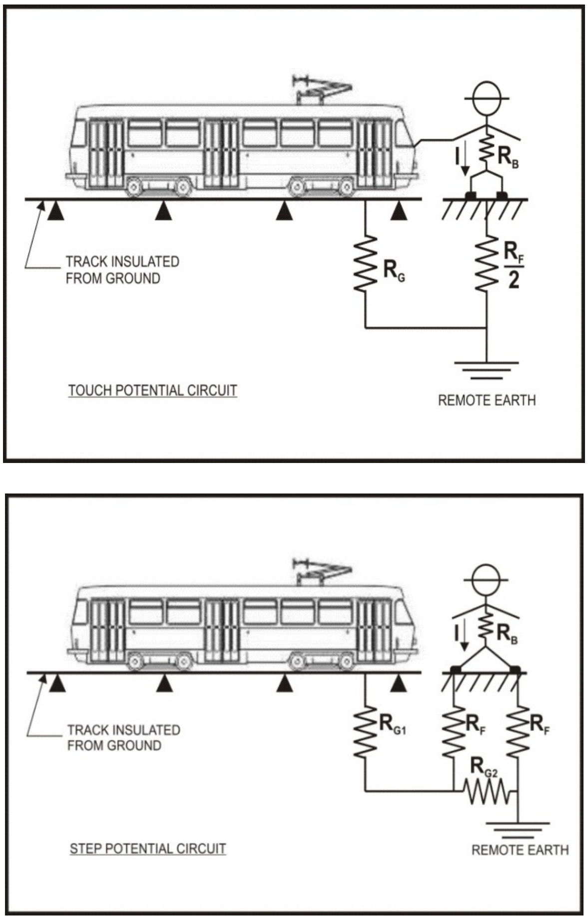

Fig. 3.a and 3.b - Equivalent models for contacts between human bodies and vehicles

The contact potential difference (U_C) [5]:

$$U_C = I \times (R_U + 1.5\rho_s) \qquad (1)$$

The stride potential difference between the two barefoot soles U_P [5]:

$$U_P = I \times (R_U + 6\,\rho_s) \qquad (2)$$

The ρ_s is an approximate calculation (wet concrete), 100 Ohm/meter, so R_1=1.5x100=150Ω. The IEEE80's [10] standard as R_U =1.000Ω. If we accept the standard felt-age power levels as I_{min}=2mA, the limith as I_p=60mA, the maximum value of a life support I_{adm}=80mA, the voltage differences are:

U_{Cmin} = 2,3 V

U_{CP} = 69 V

U_{Cadm} = 92 V

Based on these calculations, determined as the maximum accepted value is 70 volts. The existence of the earth connection is the most important part of the lightsafety protection, lightning protection is based on the existence of the grounding. Acceptance of the values of grounding resistance R_{Pmax}:

a.) 5Ω - on natural earth
b.) 10Ω - on artificial earth connections

The touch-grounding and lightning protection system than definable the value $R_{Pmax}=1\ \Omega$, if this is not done, it is essential to place additional electrodes to achieve lower resistance value [6], [8], [9].

5. EXTREME WEATHER EVENTS: STORM AND LIGHTNING

A lightning rod three main subunits are: grounding, "capturing lightning" and the grounding terminals (drain wire). The type of lightning can be a "classic" vertical (Franklin) and horizontal (surface) model. Determined volume of a security that security precautions probability of lightning protection under the regulations in place appropriate standards, be calculated by the following relations [3], [6]:

a.) lightning rod height≤ 30m:

$$\frac{r_x}{h_a} = \frac{1{,}6}{1+\frac{h_x}{h}} \qquad (3)$$

b.) the lightning rod height of 30m ≤h ≤100 m:

$$\frac{r_a}{h_a} = \frac{1{,}6}{1+\frac{h_x}{h}} \cdot \frac{5{,}5}{\sqrt{h}} \qquad (4)$$

where the r_x, h_a, h_x are in meters, noted in Fig. 4:

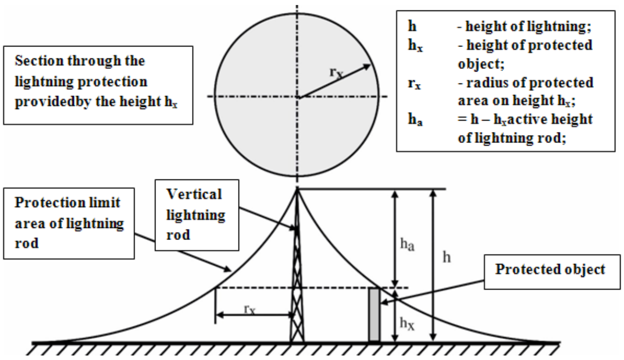

Fig. 4 - A simplified representation of Franklin rod lightning protector and the protected area

6. CASE STUDY: LIGHTNING CAUSED VULNERABILITY IN ORADEA

Oradea case is rather unfortunate weather conditions, the annual number of storm days can not exceed 40 (see Fig.1), the statistical processing of the contingency relationship can be inferred measurable effects [4].

The fundamental question is: how should we defend the lightning overhead power supply system for a vast area of the constituent subunits (power stations, rectifiers, vehicles, safety and signaling information systems, ...)? Exist two possibilities of damage cause: can be a direct impact of lightning energy discharge or an electromagnetic induction high tension peak wave form in the catenary wire system. In fact, the entire network can not provide full protection and security, only a reduced risk of accidents or a minimum probability of unexpected events. The economical estimation of the relative lower cost of service interruptions compared with a relative high cost of a full protection will be argued by the economic efficiency of the total cost of operation. A meteorological phenomenon took place in 2013, the June 10-th, in the early afternoon thunderstorms truck by lightning more Oradea, whose impact was the loss of Tramway services. The lightning touched sector was energy powered by the "Zamfirescu" street rectifier, the impact was at the pilar number 770 (Decebal-Aradului street crossing section), the effects of lightning was recorded by a datalogger. In a very short time, the maintenance team quickly solved the incident (poweroff, cable repair, reboot and restart).

Table 1 - The effects of extreme weather events on Tramway system in Oradea (between 2011-2013)

Year	Date	Location	Pilar nr.	Elements of contact system	Out of service time
2011	09.06	Str. Primăriei	920-927	Anchor	55 min.
		Parc 1 Decembrie	954-967	Anchor	
		Str. Primăriei	wire net	Anchor	
	14.06	Str. Aviatorilor	841	Reinforcement	25 min.
	16.07	P-ța Unirii	930-955	Anchor	30 min.
2012	11.06	Str. Eroul Necunoscut	652-655	Anchor	30 min.
		P-ța Cetății (Bloc Turn)	218-229	Anchor	
	06.07	Str.Cantemir, Pod Peța	wire net	Anchor	35 min.
2013	10.06.	Poliția de Frontieră – Decebal	770	Chaplet	55 min.
	10.07	Parc 1 Decembrie	962-973	Anchor	30 min.

For data collection were used a GRAPHTEC200 datalogger in monitoring connection shown in next table:

Table 2 - The"Zamfirescu" street recording channels of distribution beginning in June 2013

Channel	Value of...
Ch1	I_{+tot}
Ch2	I_{+ST2}
Ch3	I_{+ST5}
Ch4	U_{cc}
Ch5	I_{+ST6}
Ch6	Off
Ch7	I_{-ST2}
Ch8	I_{-ST4}
Ch9	I_{-ST5}
Ch10	I_{-ST6}

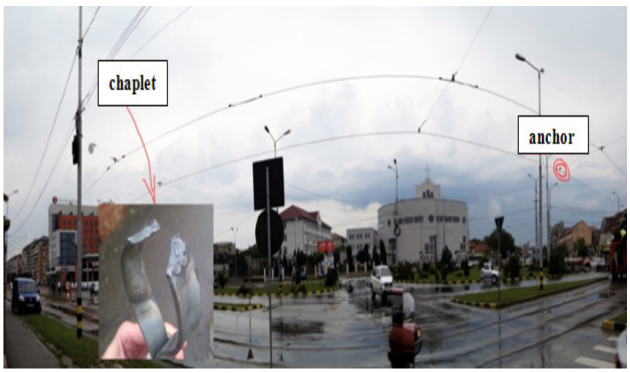

Fig. 5 - The location of the reported incident on June 10-th, 2013 and its impact

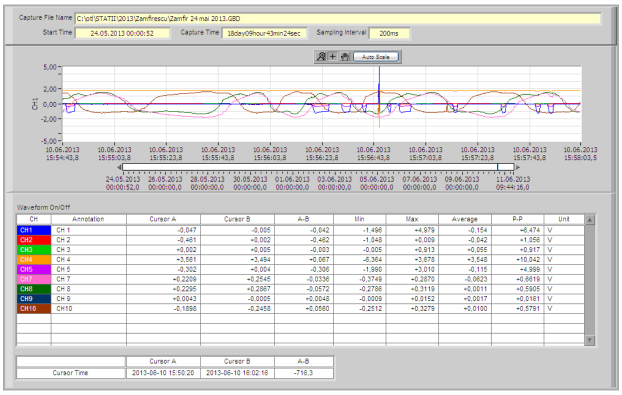

Fig. 6 - Data collection from "Zamfirescu" Power Station (between 15.50 to 16.00 on June 10-th, 2013)

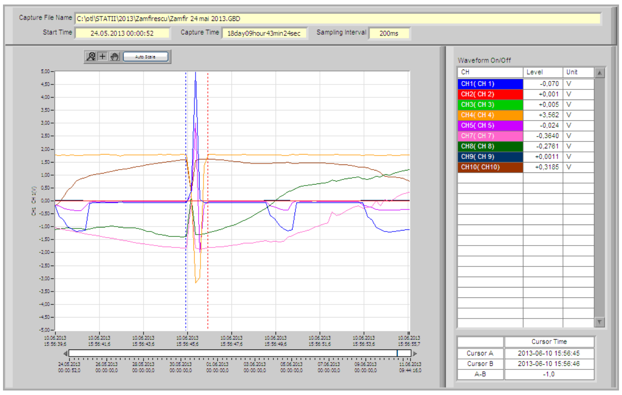

Fig. 7 - The "Big Moment": June10-th, 2013 at 15h 56m 45s, lightning discharge voltage and current diagrams

The Fig.6 show at 15h 56m 45 seconds at a peak observed phenomenon, which clarifies the translation impact of the lightning current flowin Fig.7. The electrical discharge is about half a second period recorded by the device, which looks like the diodes dissipate the discharge current. In the Ch4-U_{CC}, the power supply (orange) and Ch1-I_{tot}, the supply current (blue), both forms give the most. During the event, the discharge may be damaged the electrical insulation, so it is essential that these items to be immediately after the event (or in short time!) verified and cleaned/repaired/changed.

Table 3 – Insulation values for power cables

ST. ZAMFIRESCU - 18.06.2013 -			
ST	**Cable**	**Value at 1kv/10s**	**Value at 1kv/20s**
ST2	**1**	60,91 MΩ	70,26 MΩ
	2	65,83 MΩ	75,81 MΩ
	1+2	67,58 MΩ	85,21 MΩ
ST5	**1**	17,90 MΩ	19,71 MΩ
	2	18,44 MΩ	22,08 MΩ
	1+2	20,35 MΩ	18,50 MΩ
ST6	**1**	9,85 MΩ	10,18 MΩ
	2	10,66 MΩ	11,20 MΩ
	3	11,22 MΩ	11,57 MΩ
	1+2+3	8,30 MΩ	8,68 MΩ
ST VEST - 20.06.2013 -			
ST1	**1**	678 MΩ	887 MΩ
ST2	**1**	510 MΩ	706 MΩ
ST3	**1**	128,3 MΩ	149 ,6 MΩ

Table 4 - Insulation resistance of power supply contact wire sectors

ST. – ZAMFIRESCU			**ST. – VEST**	
ST/ DATE	**18.06.2013**	**31.07.2013**	**20.06.2013**	
ST2	**10 KΩ !**	199,2 MΩ	**ST1**	21,7 MΩ
ST5	4,15MΩ	4,85 MΩ	**ST2**	8,5 MΩ
ST6	**194 KΩ !**	253MΩ	**ST3**	11,06 MΩ

As we can see, the insulation values of cables show the value of damage. In lucky case remains a few tens of Mega-Ohm, not the same can be said with a very damaged insulation values, which have declined under value of Kilo-Ohm, the contact wires system requiring immediate maintenance. The line wire insulation may be damaged by "drag & drop" effects of discharges, the insulation value maybe re-store with a serious wash of insulators with acetone or other isopropyl alcohol, if need it is essential the elimination of the losses spare parts. During the repair, after related events we find to "Zamfirescu" ST2 sector 3 pcs of anchors must be replaced. The power station "Zamfirescu"-ST2 values are repaired from 10kΩ to 199,2MΩ after intervention, it's a best practice of a proper maintenance after unexpected events.

Fig. 8 - Samples of exchanged anchors and insulators

7. CONCLUSION

An electric-drawn public transportation system can have a relative immunity from the effects of extreme weather events, if should we manage to keep the proper design and maintenance of compliance with the security provided by the normative values. The reliability coefficients, and the standby features and results of the quality of maintenance cerified by ISO9001:2012 and ISO50001:2013- the use of quality as well as energy management systems guarantee to provide the insulation values, effectively maintaining the safety factors.

Obviously the financial relationship between the probability of failure and maintenance funds and investment, by all means should be adopted in appropriate ratio between the values and consistency.

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