URBAN ELECTRIC TRANSPORT ON RAILS – 3. ANALYSIS AND EVALUATION OF ENERGY LOSSES ON POWER LINES AND THEIR INSULATION SYSTEM

Iosif LINGVAY[1], Emeric SILAGHI[3], István CSUZI[2], Carmen LINGVAY[4]
[1]dr. ing., CS I, Secretar ştiinţific – INCDIE ICPE-CA, Bucureşti, E-mail: lingvay@icpe-ca.ro
[2]drd. ing. Director General al R.A. Transport Local Oradea, E-mail: dir.gen@otlra.ro
[3]ing. R.A. Transport Local Oradea, E-mail: nigel_baily@yahoo.com
[4]drd. ing. IDT I., INCDIE ICPE-CA, Bucureşti, E-mail: coroziune@icpe-ca.ro

Abstract: Order to optimize the energy consumption, one has analyzed the tram supply network's "+" contact wires energy losses from Oradea city. As a result of the studies and determinations carried out, in current conditions, we determined that there are considerable energy losses, not only on the contact cables, but also on their supporting insulators.

Key words: electrical powered urban transportation, energy losses, trams, contact wire.

1. INTRODUCTION

Industrialization, urbanization, large urban agglomerations imposed the development of the organized public urban transport system on rails. Urban transports significantly contribute to environmental pollution (nuisance, dust, sound, etc.). From this point of view, the electric urban transport systems present a series of advantages, like: don't pollute the urban atmosphere with noxious, relatively low noise pollution, etc. Regarding these considerations, in the 19th century one already was concerned about the sustainable development of urban transport systems with electric traction.

The energy supply system of the urban transport systems with electric traction is usually done by D.C. So, the engine wagons are provided with elements (pantograph) that provides network connection „+" contact wires and rails used as a return for „–" traction currents.

In the context of sustainable development, to reduce noxious emanation – especially CO_2, reducing specific energy consumption, including urban electric traction, are of particular importance.

Above were examined constructive factors of infrastructure related to urban electric transport, which contribute to system energy losses, to the increasing of specific energy consumption in urban electric transport. Also, one has analyzed the energetic aspects of rectifying stations and the running routes related to the electric urban transport from Oradea, and the main causes of energy losses on these elements.

The purpose of this work is to present the results of the investigations regarding the evaluation of energy losses on the contact lines related to the electric urban transport infrastructure on rails in Oradea city.

2. EXPERIMENTAL

For the evaluation of energy losses on related infrastructure elements of the contact line of electric urban rail transport in Oradea, also for identifying and localizing the constructive elements causing waste, one made specific investigations and determinations in the field both to evaluate the degree of isolation from ground contact line and to determine the ohmic voltage drops on contact lines and their power cables.

2.1 Evaluation of energy losses due to the supporting insulators of the contact line

The insulated contact lines ensure the „+" currents path from one end of the „+" power cable to the engine wagons pantograph. At a given U_A voltage, the E_{PLC} energy losses on contact lines insulators are determined by the quality of insulation of the contact lines and by their degree of insulation R_{I+} (1).

$$E_{PLC} = \frac{U_A^2}{R_{I+} + R_{DSS}} \cdot t \quad (1),$$

where R_{DSS} represents the insulation degree from the ground track., and t the time while the contact line is under charge.

Regarding these considerations, and that the damaged insulators of the contact lines can cause serious accidents – with the help of a FLUKE 1550 B type mega-Ohmmeter, we measured the insulation resistance of the contact lines across all the tram supply sections in Oradea. The determinations were done after decoupling the power cables at a given 1000V charge.

Fig. 1. Measuring the insulation resistance of the contact lines

Considering R_{DSS} negligible, and having the determined values of the resistances, through (1), daily energy losses were calculated, due to contact lines insulators(at a given U_A = 650 V charge). The results are presented in table 1.

The Analysis of Table 1, shows that , at the determinations time, on ST2 Salca / ST2 Cicero and ST2 Zamfirescu supply areas, the insulation resistances were exuberantly high, under 0.5 MΩ, meaning that , from a total of E_{PLC} = 209,269 kWh/day, 203,777 kWh/day (approximately 97,4%) regards these sectors.

It should be noted that the values R_{I+} measured , represent the global values on that certain supply sector, that is the result of resistance to all the insulator (in parallel) mounted on the supply sector. In these conditions, the exuberantly low values from ST2 Salca / ST2 Cicero and ST2 Zamfirescu sectors is due to damaged insulators that must be identified and replaced.

Table 1. The isnulation resistance ofthe contact cables and the daily related energy losses

Location	R_{I+} [MΩ]	E_{PLC} [kWh] /day
0	1	2
Rectifying station „Gară”		
Turntable 1	155	0,065
Turntable 2	75	0,135
Turntable 3	56	0,181
Rectifying station „Salca”		
Turntable 1	19	0,553
Turntable 2	0,18	56,333
Turntable 3	39	0,260
Rectifying station „Ciceron”		
Turntable 1	0,49	20,694
Turntable 2	44	0,230
Rectifying station „Pod CFR”		
Turntable 1	3,52	2,881
Turntable 2	32	0,317
Turntable 3	45	0,225
Rectifying station „Zamfirescu”		
Turntable 1	33	0,307
Turntable 2	0,08	126,750
Turntable 3	30	0,338
		Total E_{PLC} = 209,269 kWh/day

On a single supply sector, usually, there are over 500 insulators – some of which can be hardly approached. In this situation, the identification of damaged insulators is a real problem. A relatively simple way of finding the damaged insulators is with a visual check from the ground, with thermo-vision, seeing the high temperature insulators, caused by dissipated P_D power:

$$P_D = \frac{U_A^2}{R_{I+}} \qquad (2)$$

From (2) shows that the dissipated power, implicitly the insulators overheating, increases with decreasing of the insulating resistance.

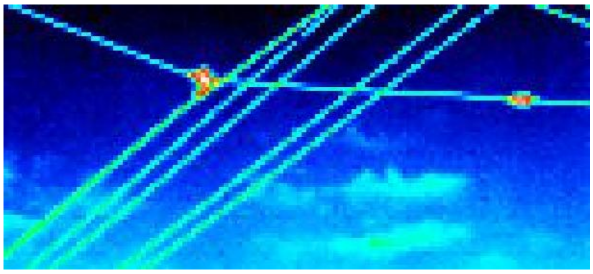

Fig. 2. Overheated insulators – images captured with FLUKE TI20 type.

It should be noted that by thermo-vision can not only detect damaged insulators, but also other sources of localized energy waste on contact lines. So, Figure 3, presents an image of the identified insulators with weak resistance joint with low resistance and an undersized connection cable.

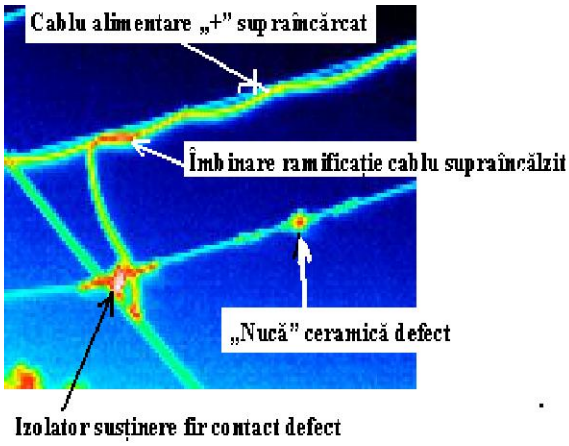

Fig. 3. P-ța București sector from „GARA” station – supply at Berzei section.

Given the above, and also the usless energy consumption on damaged insulators by the time the contact lines are under U_A, charge, nomatter is trams travel or not on the given sector, results the apparent importance of the maintenance works that damaged insulators will be detected and replaced.

2.2. Evaluation of energy losses due to ohmic voltage drops on the contact lines

Contact wires are made of oxygen-free copper conductor as in EN 1977 – 1998 [3]. They meet technical requirements in [4] and recently [5]. According to [3], the metals conductivity is 59,0 m/Ω mm² - which equals with a 0,016949 Ωmm^2/m resistivity. The contact lines section – by economic considerents – is usually 100mm^2, which

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means that for a 1km contact line corresponds as 169 mΩ resistance.
Unlike running routes, at contact lines the risk of discontinuity is practically zero. The ohmic discontinuity of the contact wire practically equals to it s physical discontinuity.
In these conditions, E_{PLC} energy losses on contact lines strictly result from the ohmic voltage drops on them, due to traction currents:

$$E_{PLC} = \Delta U_{LC} \cdot \int_0^t I_{tr}(t) \cdot dt \qquad (3)$$

where ΔU_{LC} represents voltage drops on contact lines, and it is determined by the contact lines resistance R_C between the wagons position and the „+” supply cable and the traction currents intensity I_{tr}. (4):

$$\Delta U_{LC} = R_C \cdot I_{tr} \qquad (4)$$

It is noted that in relation (4), I_{tr} is not a constant, varies in time, depending on traffic and load the engine wagon, and R_C is determined by the momentary position of the engine wagon situation when $\Delta U_{LC} = F(t)$.
Regarding the above, results that the energy losses on contact lines, at a given charge, depend on the constructive parameters of the contact lines, respectively the contact lines section and the length of the supply sector. It is noted that on the double tracked sections, one can substantially reduce energy losses bypassing them with a 100mm^2 sectioned conductor, extent that practically line resistance of the contact line decreases to half. Of course, the number of bypasses is technically and economically limited. In practice it is recommended that they should be run at a 200÷ 250 m distance between them.

2.3. Determination of total energy losses on current paths related to the power supply systems of trams

Total energy losses caused by current paths represents the total losses on all bars of distribution in rectifying stations, „-” rail connection cables, „+” contact connection cables, on running routes and contact lines. In these conditions, the energy losses on supply cables in time t are:

$$E_{PLA} = (\Delta U_- + \Delta U_+) \cdot \int_0^t I_{tr}(t) \cdot dt \qquad (5)$$

where ΔU_- is the sum of voltage drops on „-” currents paths and ΔU_+ is the sum of voltage drops on „+” current paths due to I_{tr} traction current.
In these conditions, the total series resistance of the current paths can be defined as :

$$R_{stot'} = (\Delta U_- + \Delta U_+) / I_{tr}(t) \qquad (6)$$

Based on these considerations, to evaluate the energy efficiency related to trams infrastructure in Oradea, with the help of a recording and data acquisition system GRAPHTEC midi LOGGER GL200, one registered the evolution in time of both the traction current and supply voltage of TATRA T4D tram. By processing the recorded data, one calculated the supply elements resistances of the passing tram. So, Figure 4 presents the evolution of the traction currents intensity registered on “Nufarul” sector heading from the return station towards the other end of the line. Figure 5 presents the evolution of the supply elements resistances calculated from the registered values as being $R_{stot'}(t) = dU_A(t) / dI_{tr}(t)$.

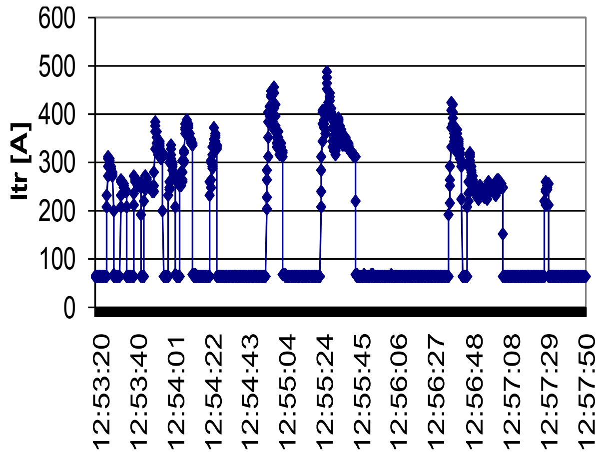

Fig. 4. The evolution of I_{tr} on „Nufarul” supply sector.

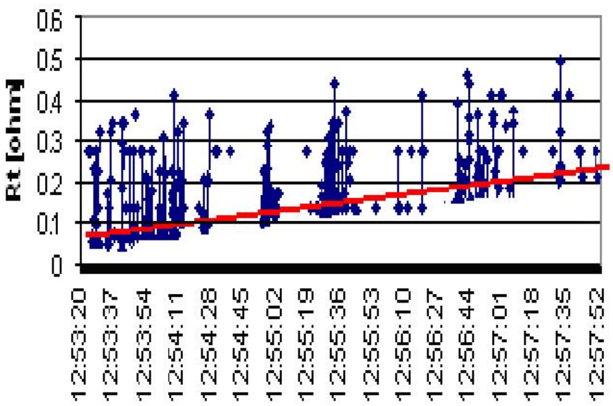

Fig. 5. The evolution of $R_{stot'}(t)$ on „Nufarul” supply sector.

Form the analysis of Figure 5 results that the evolution of the returning current paths resistance presents an increasing linear trend on away from the return center caused probably by both the Ohmic discontinuities of the running routes and the contact resistance between the pantograph and the contact line. Regarding the recorded values the lineal component registered values between 60mΩ (near the return station – given by the cables and cable joints resistances) and 220mΩ at the opposite end of the supply sector, in other meaning, for the 1200 m the running routes and the contact lines resistance is 220-60 = 160 mΩ.

Comparing the values of the running routes and the contact lines resistance, results that the lineal resistances (on the analyzed sectors) are approximately 52mΩ times higher, than those calculated on the basis of constructive parameters. This difference can be explained partially by high valued resistances of the rail ends joints and the few by passing of the contact lines and running routes. Note that, under current conditions, for this 52mΩ difference, for a 130A average traction current in a 19 hour traffic/ day we have a 16700kWh energy waste.

3. CONCLUSIONS

One analyzed and determined energy losses due to the ohmic voltage falls on the tram supply systems, and losses due to damaged insulations in the anchoring system of contact lines. From the analysis of the determinations in field results that the energy losses on the tram supply systems are appreciable , but can be diminished by the professional conduct of repair and maintenance, which first diminishes the lineal resistance related to power cables and secondly to increase the insulation resistance of the contact lines from the ground.

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