URBAN ELECTRIC RAIL TRANSPORT – 2. EVALUATION OF ENERGY LOSSES DUE TO DEFICIENCIES IN RECTIFYING STATIONS AND ASSOCIATED RAILS OF URBAN ELECTRIC TRANSPORT IN ORADEA CITY

LINGVAY Iosif*, CSUZI István**, SILAGHI Emeric**, LINGVAY Carmen*
*CS I. - INCDIE ICPE-CA, Bucureşti, www.icpe-ca.ro; E-mail: lingvay@icpe-ca.ro, coroziune@icpe-ca.ro
**Regia Autonomă de Transport Local, Oradea, www.otlra.ro; E-mail: dir.gen@otlra.ro, nigel_baily@yahoo.com

Abstract - In order to optimize the energy consumption, one has analyzed the tram supply network's 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 tracks, but also on the distribution elements and the measurement elements of the rectifying stations (power supply).

Key words: electrically powered urban transportation, energy, energy losses

1. INTRODUCTION

Urban transport contributes significantly to environment pollution (pollutants, dust, noise etc). From this perspective, urban transport systems with electric traction have some advantages, such as not polluting the urban air with pollutants and produce relatively small noise. Given these considerations, starting in the 19th century already were concerns for sustainable development of urban transport systems with electric traction. This was done in the City of Oradea too, and yet in 1906 the existing rail and urban transport by steam traction was "re-tech" by replacing every elements for electric traction [1].

In terms of technology, in 2008 started the acquisition of modern cars (Figure 1. - Ulf Siemens 151 - equipped with converters, induction motors and system for recovering braking energy), measurement contributing both to increased comfort and, especially, the energy efficiency of urban public transport rail; tram traction was done almost entirely driven by DC motors (speed control) with resistance.

Also in order to reduce specific energy consumption (kWh / passenger), recently, in 2009 started the first theoretical and experimental studies to increase energy efficiency in the operation of trams, by reducing energy losses on both supply elements and equipment on inland infrastructure (power cables, tread, contact lines).

Figure 1. Modern suburban wagons, the last generation - Ulf Siemens type, on the streets of Oradea.

Energy losses E_P on the supply system of trams, can be expressed as [2] amount of losses due to voltage drops on power system E_{PLA} and energy consumption due to insulation system of contact lines E_{PLC}, like (1):

$$E_P = E_{PLA} + E_{PLC} \tag{1}$$

where (2) and (3):

$$E_{PLA} = \left(\Delta U_- + \Delta U_+\right) \cdot \int_0^t I_{tr}(t) \cdot dt \tag{2}$$

$$E_{PLC} = \frac{U_A^2}{R_{I+} + R_{DSS}} \cdot t \tag{3}$$

From relations (1), (2) and (3) is found that a given load (charge), and consequently a traction current I_{tr} and given voltage (U_A), practically loss of power on the supply lines grows to:

- increasing resistance of the contact line R_C
- increasing resistance of supply power cable „+" (R_{C+}) and „–" (R_{CI-})
- growing resistance of tracks - R_S
- insulation's resistance decrease on the contact line (R_{I+})
- resistance decreasing (leakage) between the running rails and ground (R_{DSS}).

In this context the paper is to present results of investigations on the evaluation of energy losses by means of rolling elements and the distribution and extent of rectifying stations of infrastructure of electric urban rail transport in Oradea city.

2. EXPERIMENTAL

2.1. Evaluation of energy losses on items for distribution and extent of rectifying stations

Rectifier current distribution is achieved by cutting the current bar with corresponding sections currents passing through them. Measurement of currents in different parts of the plant is achieved by interconnection of suitable shunts (Figure 2).

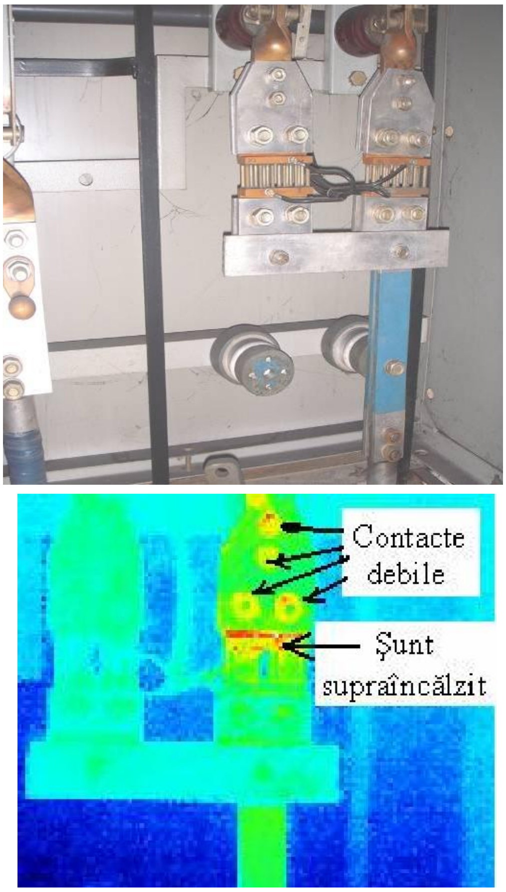

Fig. 2. CICERO power station: turning point "23th August" - two shunts mounted in parallel load unbalanced, the right joints are overheated, and heat is taken up by body part of the shunt also overheating it

The joints between current bars and between bars and shunts are achieved with usage of screws. Under these conditions the contact resistance of joints is determined by the processing quality (roughness and flatness) of the contact surfaces and the clamping force of connecting bolts. In terms of specific energy consumption, the ideal is that power bars are properly designed; currents are balanced as they merge and resistances of elements to be as small as it can be. Of course undersized or improperly combined elements, because currents passing through these heat them appreciably above room temperature, obviously lead to wasted energy. In Figure 2., is given a detailed picture of the distribution system via „–" line; rectifying station "Cicero"; and "weak" points; - overheated debilitated joints (record done with thermo-camera type Fluke TI 20). Similar situation, contact overheating and shunt heating was recorded at rectifying station "Pod CFR" (Figure 3).

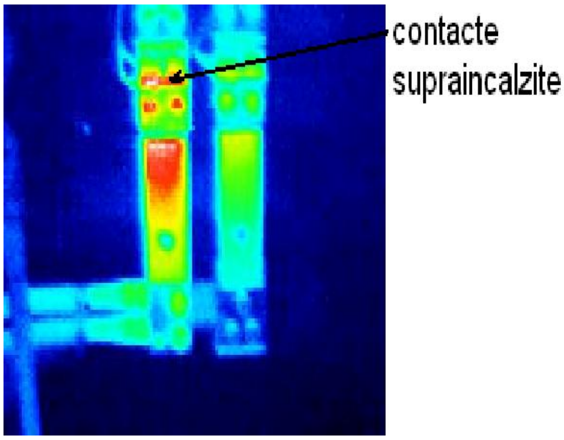

Fig. 3. Overheated elements on the shunt's connecting part, on the „turning" bar of supply section S1 at „Pod CFR" station

In Figure 4 is presented the heating of slipper and shunt given by the deficient contact on the slippers' connection and excessive contact resistance between the cable end and return the body slippers (improper crimping).

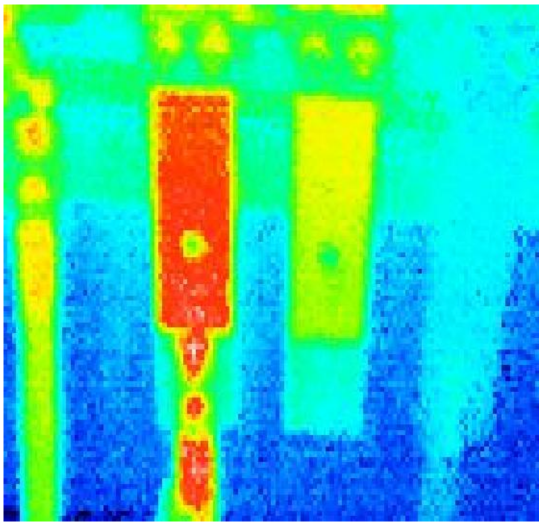

Fig. 4. Feeble connection on cables S2 – at rectifying station „Pod CFR".

Another common issue leading to wasted energy is the excessively high contact resistance R due to the weakening of constricting elastic elements or poorly maintained/manufactured surfaces of separators. Thus, Figure 5. presents the image (captured with thermo-camera) of the returning cable's separator "Iosia" at "Zamfirescu" rectifying station. It is remarkable that the contacts of the divider, a current of 200A was measured with a voltage of 2.8V, which corresponds to a contact resistance of 14mΩ and hence the unnecessary dissipation of a power of 560W.

By viewing with thermo-camera, contacts have been identified not only debilitated the contact elements of the pathways of DC recovery stations, but the supply system so that, in Figure 6., it is noted that the terminal slipper S phase output of the transformer 6 / 0.7 kV of rectifying station "Gara"; has much higher contact resistance than the phases R and T.

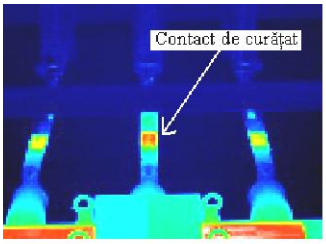

Figure 6. Station P-ța Bucureşti – ST 2 „Gară”-overheated contact Phase”S”

After identifying joints at feeble contact resistances, they started to re-mediate them. They were measured (with multi-meter HC81), registered (with GRAPHTEC midi LOGGER GL200) and averagely calculated for a common traffic for 1 hour, voltage drops ΔU_{mediu} between „–” bar of each rectifying station and the slippers of the returning cables, each on every section. Also, it had been registered (with a data acquisition and memory tool type GRAPHTEC midi LOGGER GL200) and averagely calculated (common traffic for 1 hour) current intensity I_{mediu} on each returning cable. From these data, the recovered saved energy amount was expressed E_{Ec} , on an average scale of 19hours/day. The results are presented in Table 1 as it follows.

Analyzing the Table 1. indicates that, by cleaning and restoring contacts related elements, distribution and extent of the bar „–”; the supply stations of trams in Oradea, achieved an energy saving of 89,965 kWh / day, which emphasizes the importance of maintenance / ongoing maintenance.

Table 1. Evaluation of energy losses. Experimental and calculated data sets

Location	Voltage drop – ΔU_{mediu} [V]			I_{mediu} [A]	E_{Ec} [kWh] (col.3 x col.4 x 19h)
	Before remedial	After remedial	Difference [V] (col.1 – col.2)		
0	1	2	3	4	5
Rectifying station „Gară”					*Total E_{Ec} = 15,821 kWh/day*
Turntable 1	2,21	1,31	0,90	154,2	2,637
Turntable 2	3,45	1,82	1,63	178,9	5,541
Turntable 3	3,92	2,01	1,91	210,6	7,643
Rectifying station „Salca” (garage)					*Total E_{Ec} = 10,260 kWh/day*
Turntable 1	1,81	0,89	0,92	125,7	2,197
Turntable 2	1,83	0,92	0,91	135,6	2,345
Turntable 3	2,49	1,21	1,28	235,1	5,718
Rectifying station „Cicero”					*Total E_{Ec} = 14,530 kWh/day*
Turntable 1	2,98	1,89	1,09	248,7	5,151
Turntable 2	4,01	2,11	1,90	259,8	9,379
Rectifying station „Pod CFR”					*Total E_{Ec} = 31,087 kWh/day*
Turntable 1	1,26	0,61	0,65	59,9	0,740
Turntable 2	2,36	1,32	1,04	211,3	4,175
Turntable 3	7,89	1,88	6,01	229,2	26,172
Rectifying station „Zamfirescu”					*Total E_{Ec} = 18,267 kWh/day*
Turntable 1	3,87	1,69	2,18	198,6	8,226
Turntable 2	3,21	1,81	1,40	210,2	5,591
Turntable 3	2,99	1,66	1,33	176,1	4,450
					Total amount of saved energy / working day = 89,965 *kWh/day*

2.2. Evaluation of energy losses on rails

Rails are made of all embankments, foundations, rails, switches, and not least the urban rail transport lines associated with electric traction on the rails. With few exceptions, in most cases, running paths are also used to provide return path "-" for traction currents (current bar "-"). In these situations, according to the schemes and considerations presented in [2], a current full tram traction and position data, loss of energy tread EPCR Ohmic resistance is determined by the running track on the section of SR momentary position engine wagon and return center position (where the cable connections that "-"), return (4) and (5).

$$E_{PCR} = \int_0^t \Delta U_S(t) \cdot I_{tr}(t) \cdot dt \tag{4}$$

where ΔU_S means the voltage drop of track resistance R_S and traction current, respectively (5);

$$\Delta U_S(t) = R_S \cdot I_{tr}(t) \tag{5}$$

from (4) and (5), results that (6):

$$E_{PCR} = R_S \int_0^t I_{tr}^2(t) \cdot dt \tag{6}$$

Analyzing the relations (4), (5) and (6), that evaluation of energy loss is proportional to tread the voltage drop on tracks, in which case you can define the energy efficiency of the running track that ηCR the ratio of energy losses on the tread and the energy consumed by motor coach. By clarification and simplification is reached (7):

$$\eta_{CR} = \frac{\Delta U_S}{U_A} \tag{7}$$

US the mean value of voltage drop on a load rail (service) time, and AU is the voltage (between rail lines and contacts).

Given these considerations, were determined voltage drops running through several supply sectors in Oradea, by recording voltage evolution rail / ramp at the opposite end from the center of the return sector (cable connection "-" to track) related.

Data was registered with the tool GRAPHTEC midi LOGGER GL200 (Figure 7.).

Figure 8. presents voltage evolution track/ground, determined by tram traffic (traction currents) registered at the Western part of sector „Zona industrială" (rectifier „Pod CFR") Oradea, on 16.09.2009. – during 12:54 and 13:25.

The processing of recorded values was calculated for each supply sector, the average values of both voltage drops on rails and for energy efficiency (the ratio between the average voltage rail / line contact 600 V).

Fig7. Data acquisition and memory tool type GRAPHTEC midi LOGGER GL200

Also, by simultaneously recording the intensities of current and mediation by sector were calculated the energy losses due rails EPCR (average circulation for 19 hours / day). Results are presented below in Table 2 as it follows.

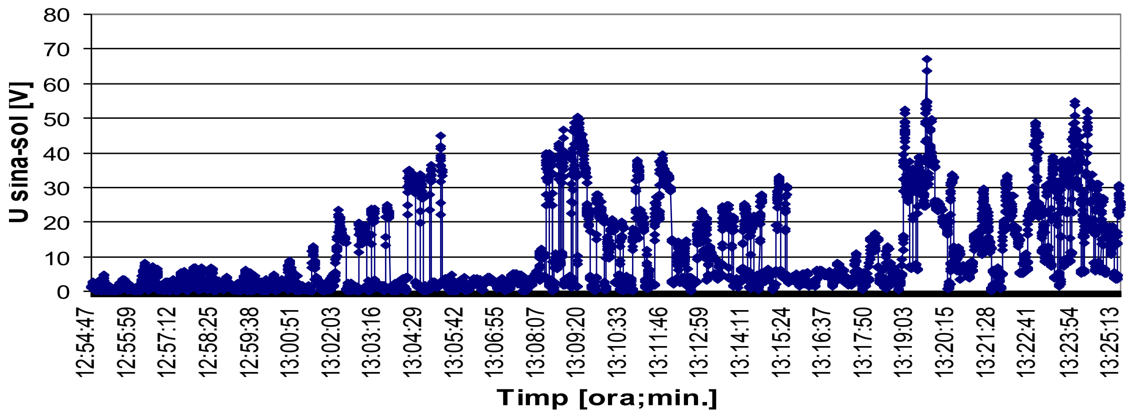

Figure 8. Evolution of voltage drop on the rails of the Western sector ("Sinteza") of urban electric rails of Oradea (sector „Zona industrială").

Table 2. Evaluation of energy losses on rails

Location	**Voltage drop ΔU_{mediu} [V]**			**I_{mediu} [A]**	**E_{PCR} [kWh]** (col.2 x col.4 x 19h)
	Maximum	**Average**	η_{CR} [% mediu]		
0	**1**	**2**	**3**	**4**	**5**
Rectifying station „Gară"					***Total E_{PCR} = 32,524 kWh/day***
Turntable 1	15,4	2,99	0,50	149.9	8,516
Turntable 2	19,8	3,22	0,54	168,2	10,290
Turntable 3	19,3	4,21	0,70	171,5	13,718
Rectifying station „Salca" (Garage)					***Total E_{PCR} = 28,993 kWh/day***
Turntable 1	25,3	2,99	0,50	130,8	7,431
Turntable 2	17,5	3,52	0,60	130,9	8,755
Turntable 3	32,7	3,77	0,63	178,8	12,807
Rectifying station „Cicero"					***Total E_{PCR} = 21,721 kWh/day***
Turntable 1	16,5	2,87	0,48	232,2	12,662
Turntable 2	9,6	1,99	0,33	239,6	9,059
Rectifying station „Pod CFR"					***Total E_{PCR} = 59,368 kWh/day***
Turntable 1	69,2	13,79	2,30	64,3	16,847
Turntable 2	27,67	6,18	1,03	201,4	24,031
Turntable 3	29,65	5,13	0,86	189,7	18,490
Rectifying station „Zamfirescu"					***Total E_{PCR} = 43,380 kWh/day***
Turntable 1	34,2	3,22	0,54	188,3	11,520
Turntable 2	29,7	3,03	0,51	207,2	11,929
Turntable 3	46,34	6,69	1,20	156,8	19,931
				Total amount E_{PCR} [kWh / **day]**	**185,986** ***kWh/day***

While conducting rails using different types of tracks - in particular Type rail 40 or 49, or special tram rails (laid out in road routes). Theoretically, resistance running track line is given by the resistivity of steel Ω/m/mm2 ρ steel = 0.13 and Section rail (on rails type T40 = 5.095 mm2). Taking account of 5100 mm2 (2 rails 10.200 mm2 respectively), that resistance to a rail track running RS 1 km should be about. 13 mΩ. Comparing this value with the data presented in Table 2. (Columns 2 and 4) that, in practice rails resistance is much higher than those calculated theoretically. Thus, in one way approx. 400 m ("Salca" - Turntable 1) the average voltage drop of 2.99 V rails is an average current of 130.8 A, which equals the real strength of about RS. 22.8 mΩ to 5.2 mΩ theoretical value - meaning the real value is about 4.4 times higher than the theoretical. Similarly, the sector "Industrial Zone" - a way of running about 3 km (rail type 40 - the theoretical value RS = 39 mΩ) at an average current of 64.3 A falls recorded average voltage rails were 13.79 V, the equivalent resistance of 214 mΩ - is approx. more than 5.5 times the theoretical value.

The analysis on the ground rails, it appears that the real values unreasonably high can be explained by the design, implementation and maintenance sometimes running poor routes, particularly the joints between the ends of rails/expansion joints, switches, etc. Thus, in Figure 9. typical images of broken joints are presented; degraded and non-repairable, which leads to excessive increase rolling resistance path.

Fig. 9. Broken joints - sector / loop „Pod CFR”

Another cause of high values of RS is poor achievement of joints (track ends welded directly to a steel bar with Φ 10÷ 12mm. They have an excessively high resistance to that resulting from the rail section as a result are some "bottlenecks" of current path, and thus is overheating. Figure 10. presents a picture taken with Fluke TI20 thermo-cam, during and after the passage of a tram on a track whose joints were made by steel bar of Φ 12 mm.

Given the above, both in terms of reducing specific energy consumption for urban electric rail transport and to minimize damage of steel structures adjacent to the rails by leakage currents "stray" [2, 3], resulting in the importance of design, implementation and maintenance of rails.

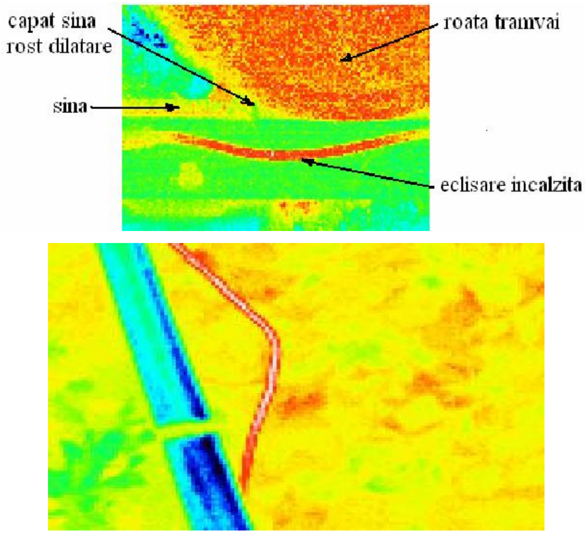

Fig. 10. Image presenting the heating of joint at the passage of a tram wagon

CONCLUSIONS

Energy issues were analyzed on the usage of rectifying stations and rails related to urban electric transport in Oradea city. Also by specific experimental measurements (measuring voltage drops, records through thermo vision etc.) the system's elements have been identified which, by their deficiencies, lead to wasted electricity. By identifying / locating joints with excessively high resistance passage in the rectifying stations. By identifying / locating joints excessively high resistance crossing the recovery stations, after their correction, we achieved an energy saving of approx. 90 kWh / day. Following the simultaneous monitoring of traction currents and voltage drops on rails was found that track resistances are higher than those resulting from rail section and length, fact explained by inadequate implementation and maintenance in the positioning and usage of tracks , which in the current operating conditions, leads to a waste of approx. 150 kWh / day.

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