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MODELLING AND ASSESSING ENERGY PERFORMANCE OF AN URBAN TRANSPORT SYSTEM WITH ELECTRIC DRIVES

ABSTRACT

Energy conservation is one of the key priorities of sustainable development strategy. Transport systems are responsible for about one third of energy consumption. As result, the identification of solutions to reduce energy consumption in these systems is essential for the implementation of the sustainable development strategies. The present work is dedicated to identifying the possibilities for a reduction in the consumption of electric energy in electric urban public transport systems, using the audit of their electricity system. After justifying the importance of these concerns, a mathematical model of the electrical energy balance of the electric urban public transport system and its components is presented. The analysis is applied to determine the losses in the system components and useful energy, based on the evaluation and energy consumption measurements. The measurements to reduce energy losses are identified and characterized under technical and economic aspect, optimal electrical energy balances being done on this basis.

KEY WORDS

electrical energy audit, energy efficiency, urban transport, optimization

1. INTRODUCTION

Sustainable development is one of the dominant topics of globalisation. Transport and energy are two key challenges in the sustainable development strategy of the European Union (EU) [1]. It is known that at the EU level, the power consumption in systems of transport accounts for about 30% of all consumption, greenhouse gas emissions caused by the means of transport being as in [2]. Therefore, it is clear that environmental concerns with regards to reduction of energy consumption in the transport systems are very important and included in the main concerns to increase the social, economic and environmental performance of these systems [3, 4].

The operating concept and the targets of sustainable development, for energy-intensive processes, including those of transport, result through the reduction of fossil fuel consumption in two paths:

a) by increasing the efficiency of energy processes;
b) by increasing the use of renewable energy sources.

Targets and pathways to the action of the European Union are very clearly defined and regulated [5, 6] aimed essentially at the reduction by 2020 of energy consumption of fossil fuels by 20% and increase in the share of renewable sources.

In Romania, energy efficiency is much lower than in the countries with top-of-the-line technology. Still, many processes and technology services do exist. In Romania, these take place with energy intensity of [2-3] times greater than similar processes modernised in the "flagship" countries under technological aspect. In the last period, legislative and financial efforts are made [7, 8] for the alignment of the Romanian status to the European standards, not only by the appearance of energy efficiency but also under the aspect of renewable resource usage.

From the perspective of sustainable development, it is essential that local authorities take care that:

– development takes priority over urban public transport (UPT), which will reduce auto traffic with all the implications;

– development of electrified UPT, transport system which is much cleaner, relatively quiet and of enhanced safety in circulation.

Specific problems of urban public transport systems are reflected in literature on the subject. A significant part of work deals with the performance of UPT systems, performance quantified by: efficiency, quality of service, impact on the environment. In [4, 9] the factors are identified which influence the application of UPT with a particular focus, especially, on the quality service, and in [10] the methodology applied in the preparation of studies of quality of the UPT system is proposed and exemplified. Detailed methodology for the assessment of quality of the service of transport is made in [11, 12], using the deciding factors of impact such as: availability, comfort, and convenience. Availability of the transport system is examined in terms of frequency of the service zone and service coverage. For the UPT system with buses the comfort and convenience are analyzed. The effectiveness of concrete UPT systems is analyzed for example in [12, 13, 14]. The authors' work [12] analyzed and compared UPT with buses and trolleybuses, assuming that the variance of UPT is a complex problem, dependent on many economical, technical and eco-friendly factors. The performed analysis shows that the containing values obtained for the two variants include specific consumption of energy and are very close. Thus, in [13] the effectiveness of UPT systems of 12 cities in Europe and 7 in Brazil is analyzed. On the basis of the obtained results the authors have come to the conclusion that in nine cities in Europe and in one in Brazil UPT is effective while inefficiency is due to social interferences. The energy efficiency of UPT with electric traction is presented in [14]. It aims at determining energy efficiency for locomotives and its impact on the optimization of the running lines parameters, the modernisation of the stations and optimal management of traffic.

Electrical energy audit (EEA) is one of the procedures used to identify ways to increase the efficiency of conversion of energy processes [14-19].

In the spirit of current concerns regarding the identification of the electricity consuming processes, with the aim of increasing the effectiveness of their energy, the work is devoted to the analysis of energy-performance of electrified urban transport system processes and identification of solutions to increase the energy efficiency of these processes.

The contributions made by the authors in the work consist of:

– adaptation model of a general electro-energy balance (EEB) for a contour, referring to the electric urban transport system (EUTS) contour;
– performing two extensive case studies that have covered all EEA stages ending with the determination of indicators to performance characterisation of energy;
– identification of solutions for increased efficiency of the two analyzed systems and preparation of the optimal EEB.

The work summarizes the EEA carried out for the urban transport operator: Oradea Local Transport (OTL), a company of urban transport which serves the public transport of a city (Oradea) with 183,123 inhabitants.

2. ELECTRICAL ENERGY BALANCE MODEL FOR *EUTS*

The structural and functional specificity of EUTS and the fact that in literature [19-22] one shall not find the mathematical formula of the EEB specific for these systems requires the presentation of the proposed EEB model, applied by designers in this work. The authors have prepared the electro energy elaboration model for EEB [23, 24], from which, in this paper a synthesis will be presented.

2.1 EEB diagram

Based on the EUTS structure and regarding the components of this system, where the energy losses take place, one can find the EEB diagram presented in *Figure 1*.

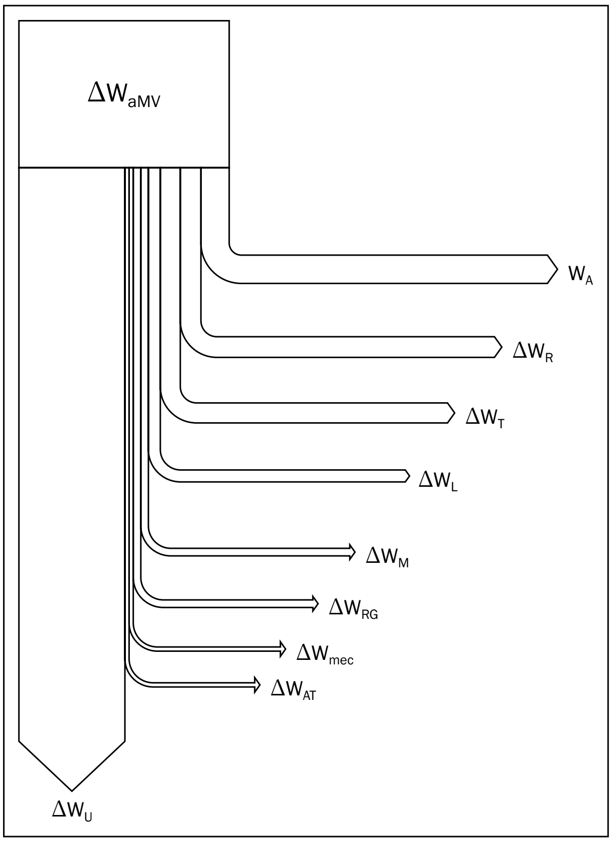


Figure 1 - EEB Diagram for EUTS [24]

The supply of EUTS from the National Energetic System (NES) is done via medium voltage / low voltage (MV/LV) electric transformers, the absorption of Electric Energy (EE) being made at MV. Therefore, the energy absorbed by the system is measured on the MV side. The magnitudes shown in *Figure 1* are:

- W_{aMV} – absorbed energy, [measured on the MV of the electrical transformer (ET)];
- W_A – auxiliary energy consumption in recovery station (RS);
- ΔW_R – energy losses on the rectifier (R) of RS structure;
- ΔW_T – energy losses on the ET from RS structure;
- ΔW_L – energy losses on power line (PL) including its three components:
  - $\rightarrow \Delta W_{LS}$ – energy losses of PL from RS structure;
  - $\rightarrow \Delta W_{LI}$ – energy losses of injection PL;
  - $\rightarrow \Delta W_{LC}$ – energy losses of contact PL (on contact wires);
- ΔW_M – energy losses on motors from means of transport (MT) structure;
- ΔW_{RG} – energy losses and consumption on the equipment used to adjust the working parameters of MT;
- ΔW_{mec} – mechanical energy losses in the transmission mechanism of MT;
- ΔW_{AT} – energy losses in other components of MT;
- W_U – useful energy that produces useful effect (MT operation).

For EUTS, EEB components are determined by adding up the subcomponents obtained at each RS and MT level. Useful Energy (W_U) is obtained by subtracting the energy losses from the absorbed energy (W_{aMV}).

EEB components are the same for real and optimal EEB only that in the present case of optimal EEB some of the components, with the exception of useful energy, could have reduced values than in the real EEB.

2.2 Specific EEB equations

EEB equation written at EUTS level reflects the EEB diagram presented in *Figure 1*.

$$W_{aMV} = W_U + \Delta W = W_U + W_A + \Delta W_T + \Delta W_R + \\ + \Delta W_L + \Delta W_M + \Delta W_{RG} + \Delta W_{mec} + \Delta W_{AT} \quad (1)$$

For auxiliary EE consumption (W_A) the following evaluation possibility is presented, that can be interpreted as a "verification key":

$$W_A = W_{aMV} - W_{aLV} - \Delta W_T \quad (2)$$

where: W_{aLV} - represents the absorbed EE (registered) on the LV side of the main ET.

EEB can be classified as follows:

- Specific equipment of EUTS;
- Vehicles used at EUTS.

In this case, for the two sub-contours, the following EEB equations can be written:

a) for RS sub-contour and PL with EE:

$$W_{aMV} = W_{U1} + W_A + \Delta W_T + \Delta W_R + \Delta W_L \quad (3)$$

where W_{U1} - useful energy at the level of the studied equipment

$$\Delta W_L = \Delta W_{LS} + \Delta W_{LI} + \Delta W_{LC} \quad (4)$$

b) for MT subcontour:

$$W_{a2} = W_U + \Delta W_M + \Delta W_{RG} + \Delta W_{mec} + \Delta W_{AT} \quad (5)$$

adding,

$$\Delta W_{U1} = \Delta W_{a2}$$

To evaluate the EEB components of the ET one can use the complete following expression [25]:

$$\Delta W_T = \left[\left(\frac{U}{U_n}\right)^2 \Delta P_{Fn} + \lambda \frac{U}{U_n}\frac{I_{on}}{100} S_n\right] T_0 + \\ + \beta^2 \left[\Delta P_{Wn} + \lambda \frac{U_{kn}}{100} S_n\right] \tau + \Delta W_{TD} \quad (6)$$

where:

- U – operational voltage, effective [V];
- U_n – nominal voltage [V];
- $\beta = S/S_n$ – apparent relative load;
- S – apparent power [kVA];
- S_n – nominal power [kVA];
- $\Delta P_{Fn}/\Delta P_{Wn}$ – nominal power losses in the windings and iron [kW];
- λ - 0.03kW / kVAr – active equivalent of reactive power;
- T_o – operating time (when connected) [hours];
- τ – load operation times [hours];
- I_{on}/U_{kn} – the nominal value of the current idling and short-circuit voltage [%];
- ΔW_{TD} – additional energy losses caused by deforming regime (DR) of the transformer [kWh];

Expression (6) is written under the assumption of nominal voltage frequency.

For the electric rectifiers RS the following expression can be used:

$$\Delta W_R = k_{PR} \cdot P_m \cdot \tau + \Delta W_{RS} \quad (7)$$

where:

- k_{PR} – loss coefficient on the rectifier;
- P_m – average power put through the rectifier;
- ΔW_{RS} – supplementary consumption or losses of the elements of the rectifiers structure, mainly on the resistors used for protection.

Regarding the supply network of EUTS, three situations can be found:

- electric three-phase short links of RS, with the expression:

$$\Delta W_{L3} = 3 \cdot k_f \cdot I_m^2 \cdot R_L \cdot \tau \quad (8)$$

- lines (supply and contact lines) direct current (two-phase), with the expression:

$$\Delta W_{L2} = 2 \cdot k_f \cdot I_m^2 \cdot R_L \cdot \tau \quad (9)$$

- short sections travelled by the current, with the expression:

$$\Delta W_{L1} = k_f \cdot I_m^2 \cdot R_L \cdot \tau \quad (10)$$

where:

R_L – ohmic resistance of mono-phase line [Ω];

I_m – average value of measured current at the end of the supply line [A];

k_f – the form coefficient of the I = f(t) function;

For sections that operate deformingly, additional losses are calculated with the following expression:

$$\Delta W_{LD} = \Delta W_L k_{DI}^2 \quad (11)$$

To obtain the components of (ΔW_{LS}, ΔW_{LI}, ΔW_{LC}) of ΔW_L, the resultant partial values for all the sections of the same RS, LI, and LC type of EUTS will be summarized.

The power loss to the group of engines in the MT structure (ΔP_M) is determined on the basis of the EEB model of a group of engines fed from a common point [22].

The power loss of the equipment that adjusts the working parameters of MT will be evaluated from the hypothesis that the charge level of the adjusting equipment of any type (dimmer, dimmer of continuous voltage, converters) is in accordance with the charge level of the MT of the main engine structure [24, 26].

The power loss and the power consumption in other components of MT (lights, air conditioning installations, etc.) is determined from the hypothesis that they are not normally charged proportionate to the MT [24, 26].

The loss of power on drive mechanisms of MT structure (ΔP_{mec}) will be determined with the following expression:

$$\Delta P_{mec} = P_o - (\Delta P_M + \Delta P_{RG} + \Delta P_{AT}) \quad (12)$$

where:

P_o – power consumption at idling of MT determined from the recordings in real functioning conditions.

For a fleet of MT, judging will be done with reference to a sufficient number of MT mediated so that the results should be applicable to the level of MT of EUTS. After the calculation of power losses (ΔP_M, ΔP_{RG}, ΔP_{AT}, ΔP_{mec}) the energy losses are calculated:

$$\Delta W = \tau_j \cdot \Delta P_j;\ j = \{M, RG, AT, mec\} \quad (13)$$

2.3 Specific indicators of energy efficiency

Given the general recommendations [19, 20, 23] and the specific service provided by EUTS, EEA will assess the following indicators:

A) Specific EE consumption for unitary service:

- Specific EE consumption per roundtrip

$$C_c = W_{aMV}/N_c \quad (14)$$

- Specific EE consumption per length unit:

$$C_D = W_{aMV}/D \quad (15)$$

- Specific EE consumption per passenger:

$$C_{CL} = W_{aMV}/N_{CL} \quad (16)$$

where:

N_{CL} = number of passengers;

N_C = number of roundtrips;

D = travelling distance.

The three values (N_C, D, N_{CL}) are determined for the analysis time, the same as for W_{aMV}.

B) Specific consumption for “tons-kilometre”

$$C_{CD} = W_{aMV}/m \cdot D \quad (17)$$

m – average mass of MT including passengers.

C) EE cost to achieve the “t x km” unit:

$$C_{UW} = W_{aMV} \cdot k_w/m \cdot D \quad (18)$$

k_w – cost of specific EE.

D) Income for “kWh” consumed:

$$V_{UW} = P_{CL} \cdot N_{CL}/W_{aMV} \quad (19)$$

where:

P_{CL} – price of one MT roundtrip.

In the realized analysis of incomes, the MT load degree is determinant, taking into account the main significance of proper consumption.

3. DEFINING THE CONTOURS AND ELEMENTS OF ENERGY CONSUMPTION CHARACTERIZATION

The contour analyzed at OTL is divided into the following sub-contours:

- Recovery stations sub-contour (RS);
- Supply network sub-contour (injection and ignition);
- Means of transport sub-contour (MT).

RS has a configuration of 2x100% type. OTL has five RSs. Technical data on RS on the two contours analyzed are shown in *Table 1* (processing based on information from 26).

MT sub-contour of OTL is composed of 79 trams of three types:

- TATRA kT4D type and T4D+B4D - 69 pieces in circulation;
- SIEMENS ULF151 - 10 pieces in circulation.

The extent of service carried out is presented by specific economic indicators: number of round-trips (N_C), the travelled distance (D), carried passengers (N_{CL}). For the period of analysis the medium values of these indicators were: N_C = 624 round-trip/day, D = 11.650 km/day and N_{CL} = 136,488.

The reference unit associated with EEB is (24 hour) a normal average working day. The charge level of equipment during measurements has been normal for the services provided by the two analyzed systems.

The appliances of the extent used:

- the network analyzer (NR) type C. A. 8334 B (2 used), placed to measure in the two transformers secondarily;

Table 1 - Technical data of power equipment from "OTL" [26]

Station [RS]	Transformer 2xSn[kVA]	Rectifier 2x[In[A]/Un[V]	Electric network	
			Injection	Contact
Salca (RS1)	1,300	1,500/600	CYABY1x1400mm2	Cu 80 mm2 /6,135 m
Cicero (RS2)	950	1,500/600	CYY3x70mm2	TTF100 mm2 /1,200 m Cu 80 mm2 /2,050 m
Zamfirescu (RS3)	950	1,500/600	CHPBY1x400 mm2	TTF100 mm2 /5,127 m Cu 80 mm2 /3,440 m
Rail station CFR (RS4)	1,250	1,300/600	CYABY3x120 mm2	TTF 10 mm2 /3,306 m Cu 80 mm2 /3,709 m
Zone Vest (RS5)	950	1,500/600	CHPBY1x300 mm2	Cu 80 mm2 /8,313 m

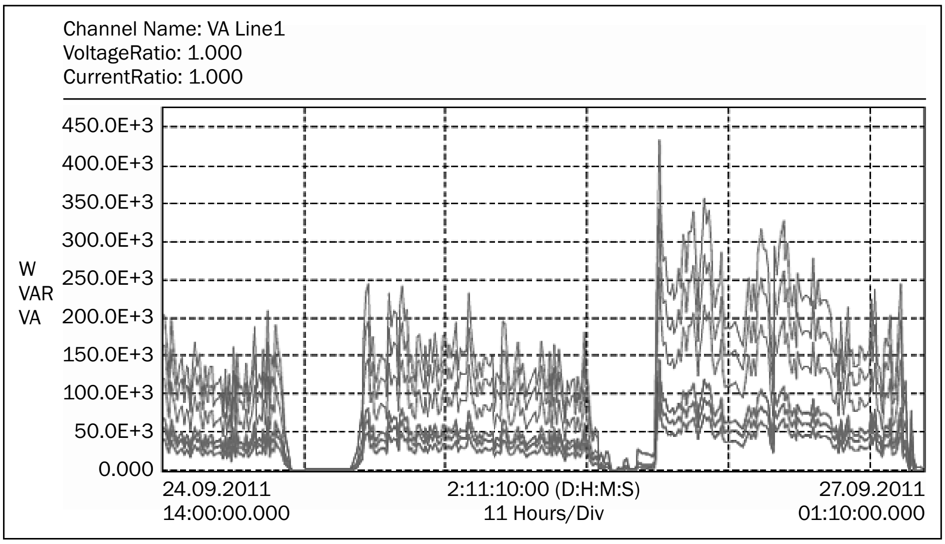


Figure 2 - Power curve of (RS_1) for the analyzed period [26]

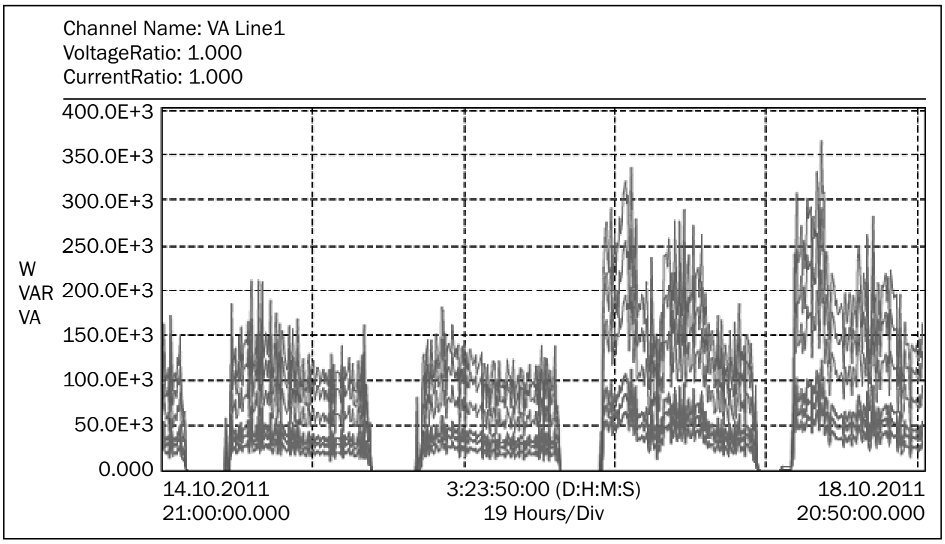


Figure 3 - Power curve of (RS_2) - OTL for the analyzed period [26]

– meters of active and reactive energy: - type ENERLUX TCDM-AEM Timisoara, accuracy class 0.5.

Figures 2-6 present the power curves (P, Q, S) of RS_1-RS_5.

The used network analyzers shall have the option of recording several measures of electricity, including characterization of the elements of EE quality. As an example, *Figure 7* shows changes in THD indicator (total harmonic distortion) for voltage and the current recorded in RS_4.

In each of the recovery stations there is an own service transformer (ST). Network analyzers have been

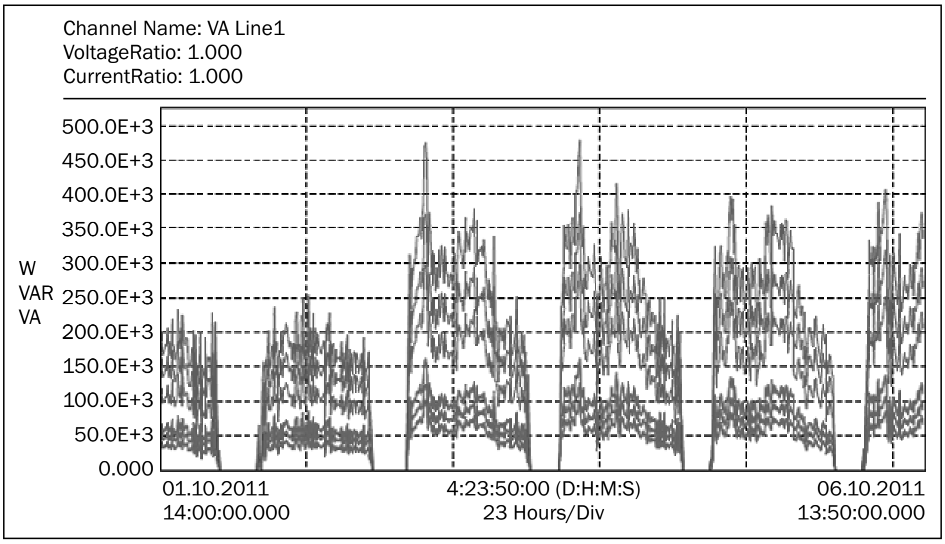


Figure 4 - Power curve of (RS_3) - OTL for the analyzed period [26]

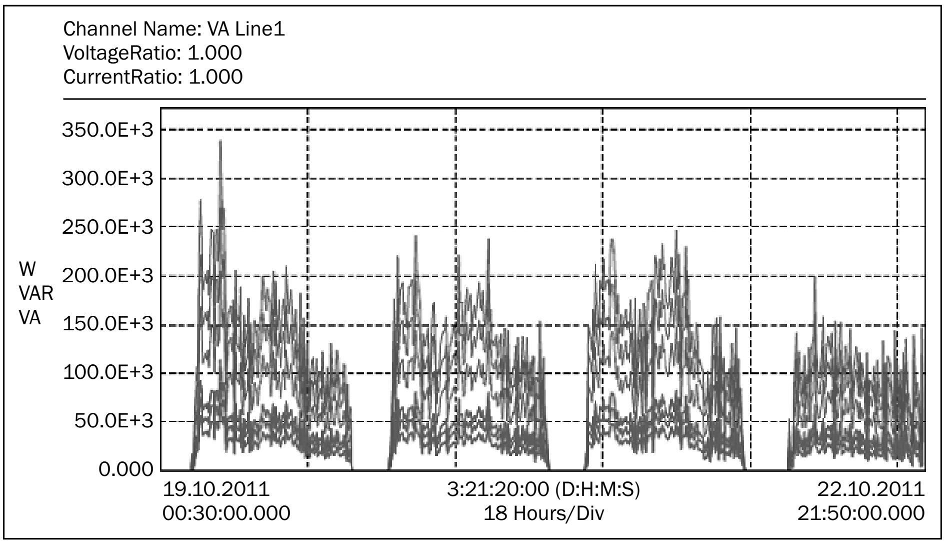


Figure 5 - Power curve of (RS_4) - OTL for the analyzed period [26]

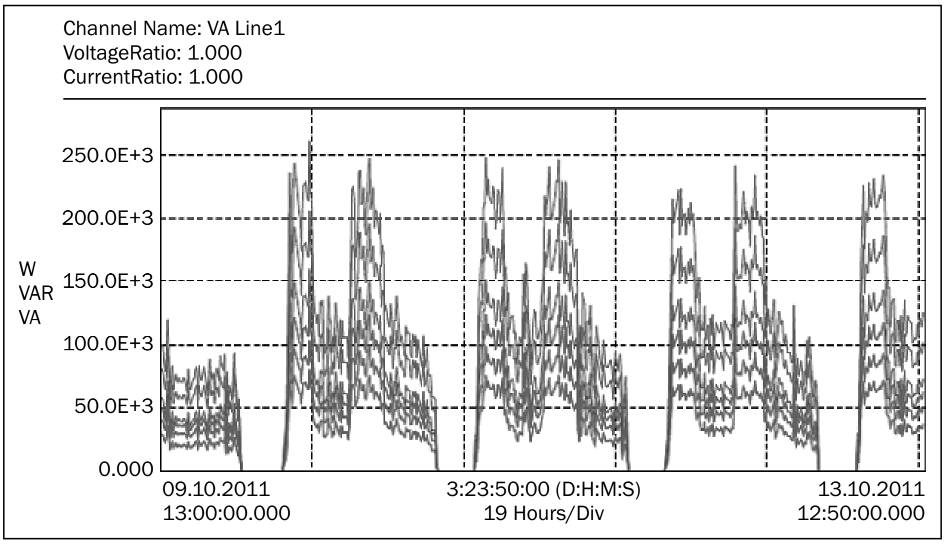
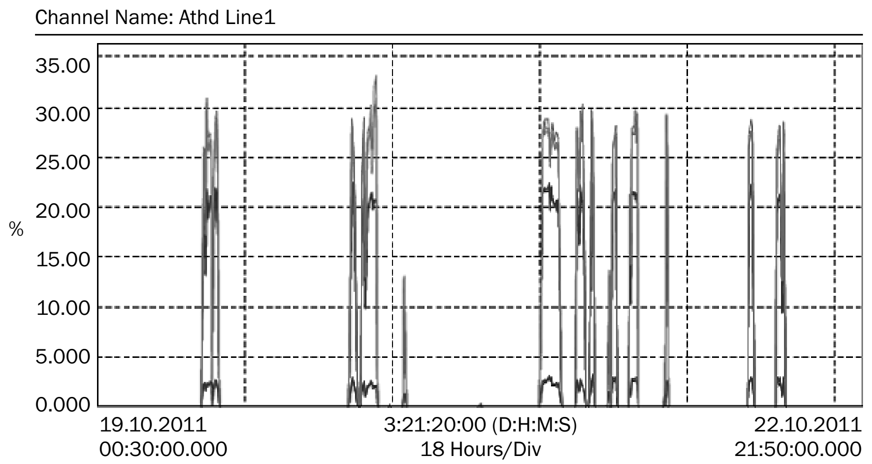


Figure 6 - Power curve of (RS_5) - OTL for the analyzed period [26]



Name	Date	Time	Avg	Min	Max	Units
Athd Line1	19.10.2011	00:30:00.000	3.4497	0.0000	33.100	%
Athd Line2	19.10.2011	00:30:00.000	3.3196	0.0000	30.400	%
Athd Line3	19.10.2011	00:30:00.000	3.3335	0.0000	30.800	%
Uthd Line1	19.10.2011	00:30:00.000	0.285	0.0000	3.1000	%
Uthd Line2	19.10.2011	00:30:00.000	0.301	0.0000	3.2000	%
Uthd Line3	19.10.2011	00:30:00.000	0.311	0.0000	3.2000	%
Vthd Line1	19.10.2011	00:30:00.000	2.5406	0.0000	22.200	%
Vthd Line2	19.10.2011	00:30:00.000	2.5561	0.0000	22.300	%
Vthd Line3	19.10.2011	00:30:00.000	2.5715	0.0000	22.500	%

Figure 7 - "THD" Indicator in RS_4 [26]

placed in the secondary side of these transformers to record electrical values which have also been monitored in the case of the main transformers [23, 24, 26].

An important part of EEA has been dedicated to monitoring of MT. *Figure 8* presents as examples the load curves of two trams running empty (kT4D and SIEMENS) of the OTL, according to the tests made in 2009.

4. OBTAINED RESULTS

The real EEB (diagrams, charts) of the sub-contours can be found in the paper [23, 26]. From the records carried out (under load and empty) the EEA power components of MT (trams) are calculated, which are essential in increasing energy efficiency. The results are presented in *Table 2* (processing based on information from 26).

Table 2 - EEA Power components for MT [26]

Power components [kW]	ULF	kT4D	T4D	Power components [kW]	ULF	kT4D	T4D
Pa	92.11	106.84	108.18	ΔP_{AT}	2.32	2.04	2.54
Po	16.99	31.72	33.06	ΔP_{mec}	8.06	14.97	14.63
ΔP_M	6.44	13.89	14.06	P_U	71.41	71.34	71.23
ΔP_{RG}	3.88	4.6	5.72	η[%]	77.5	66.8	65.8

Table 3 - EEB of MT (SC2) [26]

Characteristics	Trams (OTL)	
	[kWh]	[%]
Absorbed energy [W_a]	17,969.65	100
Exiting energy [W_i]	17,969.65	100
1. Useful energy[W_U]	12,057.64	67.1
2. Energy Losses	5,912.01	32.
Motors [ΔW_M]	2,246.2	12.5
Electrical on adjusting equipment [ΔW_{RG}]	889.5	4.95
Electrical on other components [ΔW_{AT}]	404.31	2.25
Mechanical on mechanic components [ΔW_{mec}]	2,372	13.2

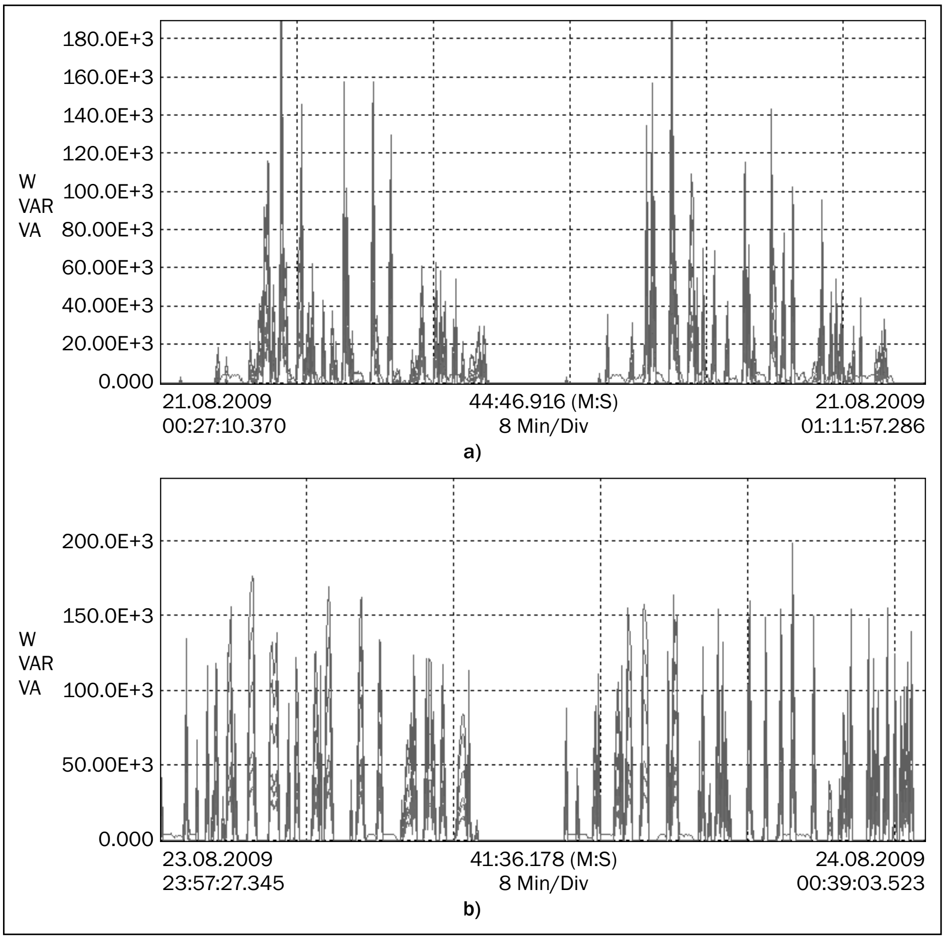


Figure 8 - Load curves on empty running for a) Siemens ULF tram b) T4D tram [26]

EEB of MT (SC2) regarding the average working day is presented in *Table 3* (processing based on information from 26).

For the established contour, the real EEB is obtained by the sum of components and taking into account the fact that the useful energy is actually the energy consumed for passenger transport. Results are given in *Figure 9*.

Based on expressions in Chapter 2, the calculated efficiency indicators are presented in *Table 4* (processing based on information from 27), where for the comparison sake, the obtained indicators for an entity with trolleybuses [27] and the previous analysis for OTL [23, 24, 26] are also given.

5. DISCUSSION

From the results outlined in *Table 4* one can find that energy efficiency at OTL had very small increase in 2011 in comparison to 2009 and it is greater than that of URBIS. This can be explained by: superior energy efficiency of tramways over that of trolleybuses, an increased use of services offered by OTL to those offered by URBIS, lower auxiliary consumption to OTL

Table 4 - Values of energetic and economic efficiency indicators [27] (processing based on information from 23, 24, 26, 27)

Indicators		URBIS [23]	OTL [23, 24, 26]	
			2009	2011
Specific EE consumption	Per one roundtrip [kWh / roundtrip]	49.8	39	38.69
	Per length unit [kWh/km]	3.7	2.09	2.07
	Per transported passenger [kWh/ passenger]	0.25	0.18	0.178
	kWh / [t x km]	0.1328	0.062	0.0615
Income/ [kWh]	[lei/kWh]	5.14	8.4	8.47

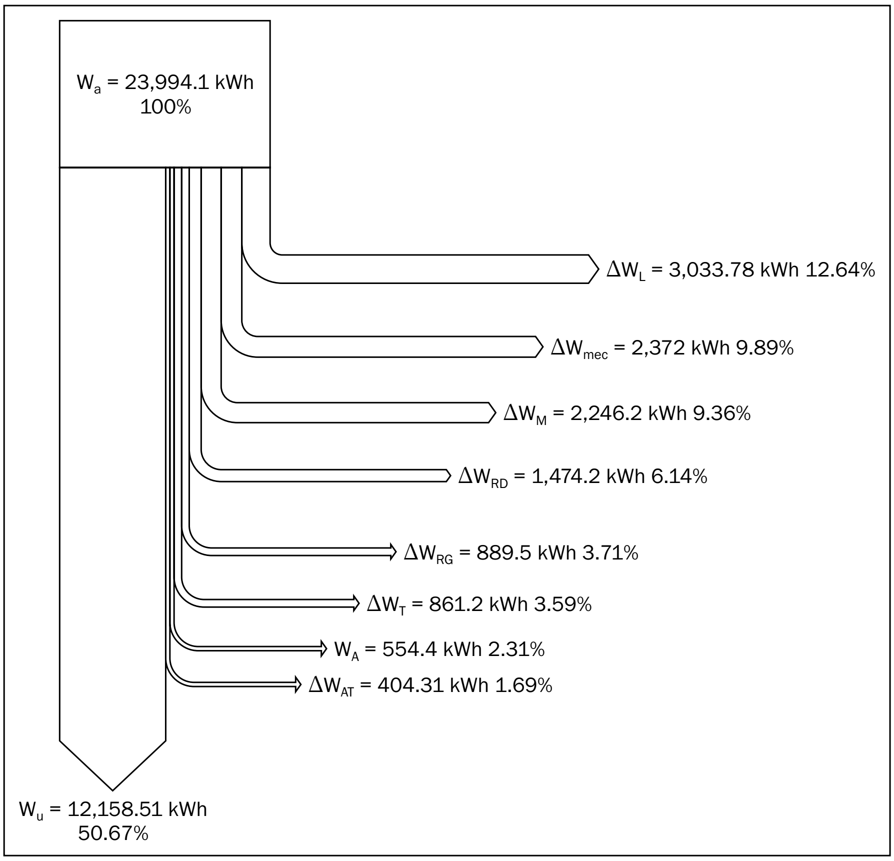


Figure 9 - Sankey diagram for real EEB of analyzed OTL contour [26]

than the exaggerated auxiliary consumption registered to URBIS. RS operating well below nominal power (*Table 5*).

RS has a pronounced imbalance regarding the load. The charge level of RS depending on the load is the following: 21.7% - RS_1; 15.9% - RS_2; 28.4% to RS_3; 15.5% - RS_4; 18.5% - RS_5. Power Network (injection and contact) as well as sections of its structure have a high degree of load imbalance. All injection sections are under-loaded, which is beneficial for their reliability and energy efficiency. Load electrical values (currents, powers) are variable specific to the electric transport systems. This fact is unavoidable and reflected by an increase of power loss in power transformers and power network, compared with the case when the load would be constant. Reactive power consumption (energy) is below the appropriate neutral power factor, which implies non-existence of reactive energy bills. The levels of voltage harmonics are in accordance with the rules, but the levels of current harmonics are not

Table 5 - Load level of recovery stations [26] (processing based on information from 26)

Station	S_n [kVA]	Transformer	S_{max} [kVA]	β	β_0	S_0 [kVA]
0	1	2	3	4	5	6
Salca	1300	T1	432.9	0.1	0.54	700
	1300	T2	395	0.1	0.54	700
Vest	950	T1	260.6	0.11	0.56	528
	950	T2	366.3	0.16	0.56	528
Duiliu Zamfirescu	950	T1	476.9	0.2	0.56	528
	950	T2	527.8	0.21	0.56	528
Railway station	1250	T1	338.1	0.085	0.54	675
	1250	T2	371.2	0.095	0.54	675
Cicero	950	T1	465.4	0.12	0.56	528
	950	T2	372.8	0.115	0.56	528

always between limits indicated by the normative. The principal harmonics are of 5, 7, 11, 13, 17, 19 orders. These values of degradations reflect an inappropriate dimensioning or malfunctioning of filters of the power rectifiers within the RSs. The energetic effects of current harmonics (additional losses of energy) are negligible due to reduced load on the transformers.

Table 6 - THD Indicator levels (Total Harmonic Distortion) [26] processing based on information from 26).

Station	Trafo	THD_U[%]	THD_I[%]
Salca	T1	2	3.5
	T2	1.4	1.9
Cicero	T1	10.2	12.5
	T2	24.5	28.9
Duiliu Zamfirescu	T1	25.1	28.2
	T2	25.3	27.8
Railway station	T1	22.5	30.6
	T2	22.5	33.1
Vest	T1	0.9	0.3
	T2	0.9	1.3

Power and energy losses in supplying network are significant (12.64% from the entered energy in the contour) with meaningful dispersion (5.7% in St. Vest; 20.31% in St. D. Zamfirescu). Most of the losses in the supplying network (ΔW_L) are on the contact network. Within the stations the short connections (ΔW_{LS}) are more under the losses in connection and injection networks. The measurements carried out on the three types of trams in OTL allow the formulation of the following statements:

a) Testing the free running of the three tram types (2-ULF, 4-kT4D and 4-T4D) reflects a certain dispersion of the power absorbed at free running as follows:
[28.61; 32.84] kW - for kT4D type;
[29.94; 35.53] kW - for T4D type.
b) The ULF tram types net superiority of energy was found, compared to other two types KT4D and B4D, but this aspect is not relevant enough if it is considered that the kT4D tram has 98 seats (25 seats), and tram T4D has 150 seats (44 seats).
c) Test of trams under load and drawing the load characteristics [(N_{CL} = f (t), N_T = f (t), P = f (t), P = f (N_{CL}) and P = f (N_T)], reflects good correlation between the power absorbed and the number of passengers concerned, between the power absorbed and the number of trams.
d) For those 79 trams (10-ULF, 25-44 and kT4D-T4D) measurements and assessments were carried out to obtain good efficiency (61.1%). Most have energy losses on transmission mechanisms (13.2%) and engines (12.5%).

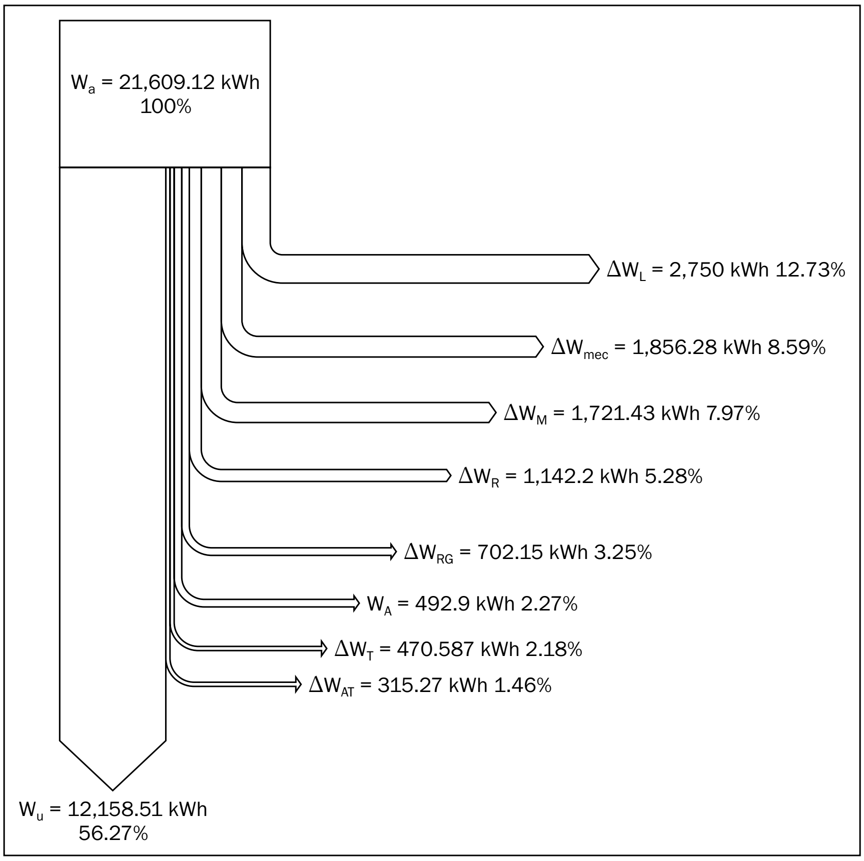


Figure 10 - Sankey diagram of optimal EEB for EUTS of OTL [26]

Reducing energy consumption in the two analysed contours can be done by applying the following technical and administrative measures:

a) Replacement of under-loaded transformers with power transformers adapted to the level of consumption;
b) Balancing the electric power supply networks (injection and contact);
c) Replacement of kT4D and T4D tram types by ULF-for OTL.
d) Replacing the classic tuning system (via resistor) by electronic speed adjustment, for kT4D and T4D tram types;
e) Better maintenance of means of transport.

Through the implementation of the measures listed above, and by recording the effects evoked, one can obtain the optimal EEB presented by specific charts from *Figure 10*.

6. CONCLUSION

The level of energy efficiency is within normal limits, specific to such systems. In both entities (OTL, URBIS) the transformers, rectifiers and power lines operate at a load factor more under sub-nominal that is beneficial in terms of reliability, but inefficient in terms of energy. OTL energy efficiency (traction with trams) is better than by URBIS (traction with trolleybuses).

Energy efficiency is about 50.67%, losses being mostly in the means of transport (24.65%) and not in the supply network (12.64%).

This dispersion means that trams have a different degree of wear and that there is the possibility of reducing energy consumption through a more intensive preventive maintenance. From the tests carried out it does not result that the classic trams (kT4D, T4D) with static source (for auxiliary consumption) perform below the aspect of energy than the trams with DC generator.

Specific measures are implemented to achieve optimal EEB and to reduce the environmental impact by reducing the quantity of pollutants discharged into the atmosphere. It is to be appreciated that the mathematical model structured in accordance with the structural and functional conditions of the system, results and conclusions formulated may be useful for other similar studies.

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REZUMAT

MODELAREA ŞI EVALUAREA PERFORMANȚELOR ENERGETICE ALE UNUI SISTEM DE TANSPORT URBAN ACȚIONAT ELECTRIC

Conservarea energiei este o preocupare cheie a strategiilor de dezvoltare durabilă. Sistemele de transport sunt responsabile de circa o treime din consumul actual de energie. Prin urmare, identificarea unor soluții de reducere a consumului de energie în aceste sisteme este esențială pentru dezvoltarea durabilă. Prezenta lucrare este dedicată identificării nivelului de eficiență energetică şi a posibilităților de reducere a consumului de energie în sistemele de transport public, pe bază de audit electroenergetic. După justificarea importanței preocupării, se prezintă modelul matematic al bilanțului electroenergetic al sistemului de transport public urban şi componentelor sale. Pe baza înregistrărilor şi a evaluărilor efectuate se determină pierderile de energie în componentele sistemului şi energie utilă. Analizând rezultatele se identifică soluțiile de optimizare a bilanțului electroenergetic al acestor sisteme.

CUVINTE CHEIE

audit electroenergetic, eficiență energetică, transport urban, optimizare

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