ASSESMENT OF ENERGY EFFICIENCY FOR URBAN ELECTRIC TRANSPORT SYSTEMS

FELEA IOAN, CSUZI ISTVÁN, DALE EMIL, DAN FLORIN

Abstract:
The paper has a structure in four parts. In the first part is justified the concern of the authors regarding the electric energy audit (EEA). In the second part are specified the entities and the work style in elaboration of EEA. The third part contains the synthesis of the results, as in the last part are given the conclusions obtained from analyzes.

Key words: electrical energy audit, energy efficiency, urban transport, optimization.

1. INTRODUCTION

The sustainable development is one of the dominant topics of globalization. In domain of energy, the operation of this concept mainly is realized through reducing fossil fuels consume in two ways:

- Through increasing energy processes efficiency;
- Through increasing the grade of renewable energy utilization.

The scopes and action ways of European Union are very clear defined and regulated [1,2], in essence, aiming to reduce till 2020 the energy consumption obtained from fossil fuels with 20% and to increase the renewable sources weight.

In Romania, the power engineering efficiency is more under the value in relation with countries with high technology. In Romania, there are many technological processes and services in running with high energy intensity, under technology aspect, with [2-3] times greater as the modern similar processes of "pennant" countries.

In the last period, there are made legislative and financial efforts [3,4] as to Romania be aligned at European standards, under aspect of energy efficiency and of a more intense utilization of renewable energies.

The Electrical Energy Audit (EEA), is one from the modalities of regularization [5], to may identify the ways to grow of energy conversion processes. In this paper is synthesized the made EEA for two operators of urban transport – S.C. URBIS S.A. Baia Mare (URBIS) and Oradea Transport Local (OTL). After explanation of some defining elements of contour and of some specific aspects of mathematical modelling, there are integral presented the conclusions of the made study, with general interest, taking into account the weight of the consumption for Romanian electric traction and the possibilities of energy efficiency increasing.

2. DEFINING THE CONTOURS

In each case, to specify the contour of EEA, is constituted from urban electric transport system URBIS, respectively, OTL, compounded from subcontours (SB):

- Transformer + rectification stations (STR) and the supplying networks (SN);
- Means of transportation (MT).

STRs are of 2 x 100 % and are sized in relation with the scope of the transport network. The contour URBIS has two STRs as OTL has five. The main technical data are given in table 1.

Table 1 – The mean technical data of the equipments and installations of "OTL" and "URBIS"

Contour	Station	Trafo $2xS_n$[kVA]	Rectifier $2x[I_n[A]/U_n[V]$	Electric network	
				injection	contact
OTL	Salca(S1)	1300	1500/600	CYABY1x1400mm^2	Cu 80 mmp /6135m
	Cicero(S2)	950	1500/600	CYY3x70mmp	TTF100mmp /1200m Cu 80 mmp /2050m
	Duilu Zamfir+ Odobescu(S3)	950	1500/600	CHPBY1x400 mmp	TTF100mmp /5127m Cu 80 mmp /3440m
	Gară (S4)	1250	1300/600	CYABY3x120 mmp	TTF 10 mmp /3306m Cu 80 mmp /3709m
	Zona de Vest(S5)	950	1500/600	CHPBY1x300 mmp	Cu 80 mmp /8313m
URBIS	S1	1500	1600/600	ACYEY1x300 mmp	TTb 80
	S2	1600	1600/600	ACYEY1x300 mmp	9200m

In MT of URBIS contour is of three types of trolleybuses:

- **SAURER** GT 560/640-25 – (7 pieces), 148 places, driving with asynchronous motor by inverter;
- **ROCAR** EDM 212 E – (1 piece), 92 places, driven by a motor with d.c. (classical);
- **ROCAR** EDM 217 E – (1 piece), 156 places, driven by a motor with d.c. (classical).

IN MT of OTL contour is 79 trams of three types:

- **TATRA** of **kT4D** and **T4D,** 69 being in circulation;
- **SIEMENS ULF** 10 in circulation.

The scope of the realized service is given by the specific indexes: number of racing (Nr), the covered distance (D), transported passengers (N_p). For analyze period the values of the indexes are given in table 2.

Table 2 – Values of indices that characterizes the scope of services

Contour	Indicators		
	n_r [races / day]	d [km/day]	N_p[passenger / day]
URBIS	82	1234.84	16.195
OTL	624	11650	136.488

The unit of reference associated to BEE is a normal weekday (24 hours).

The loading level of the equipments and installations when the measurements were made was normal for he assured service.

The utilized measuring devices are:

- The network analyzer (NA) of type C.A. 8334 B (2 pieces), placed in the secondary transformer from each station;
- real and reactive power counters – ENERLUX TCDM – AEM Timisoara, placed in the primary of the transformer.

As example, in figures 1, 2 and 3 are given the load curve (P, Q, S) of station S1 (URBIS) respectively, for stations S1 and S4 (OTL).

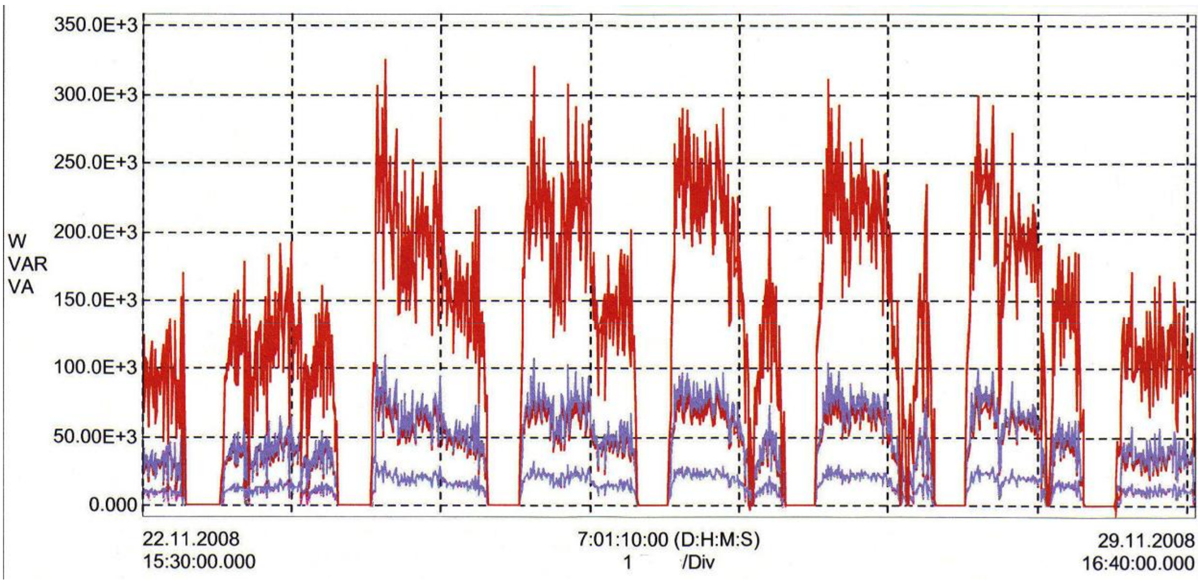


Fig. 1 – Load curve for station S1 – transformer 1 - URBIS

ISSN 2067 – 5534 © 2010 JSE

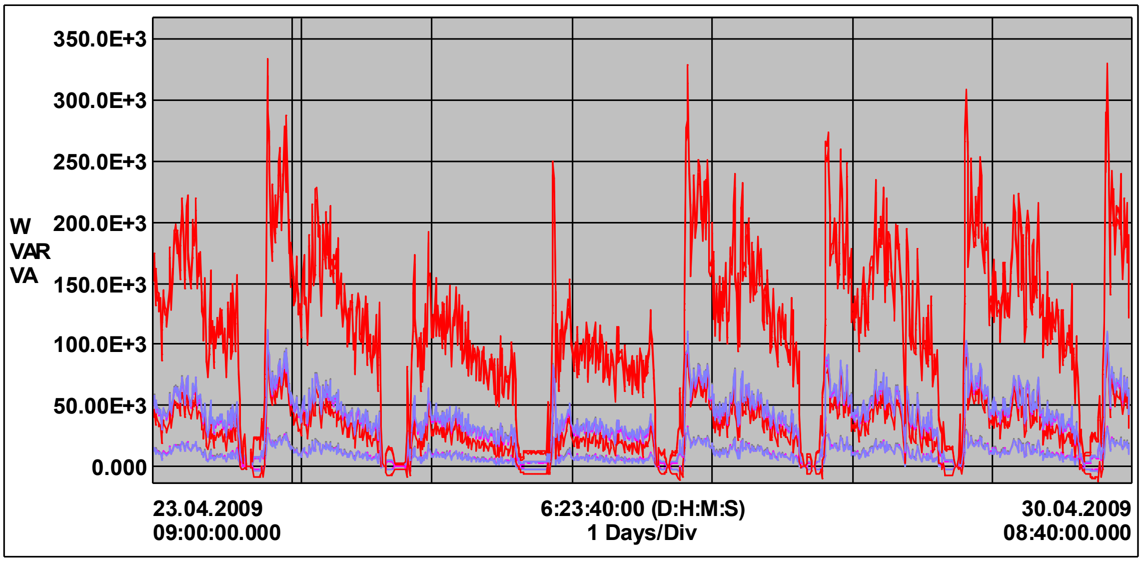


Fig. 2 - Load curve for station S1 – transformer 1 - OTL

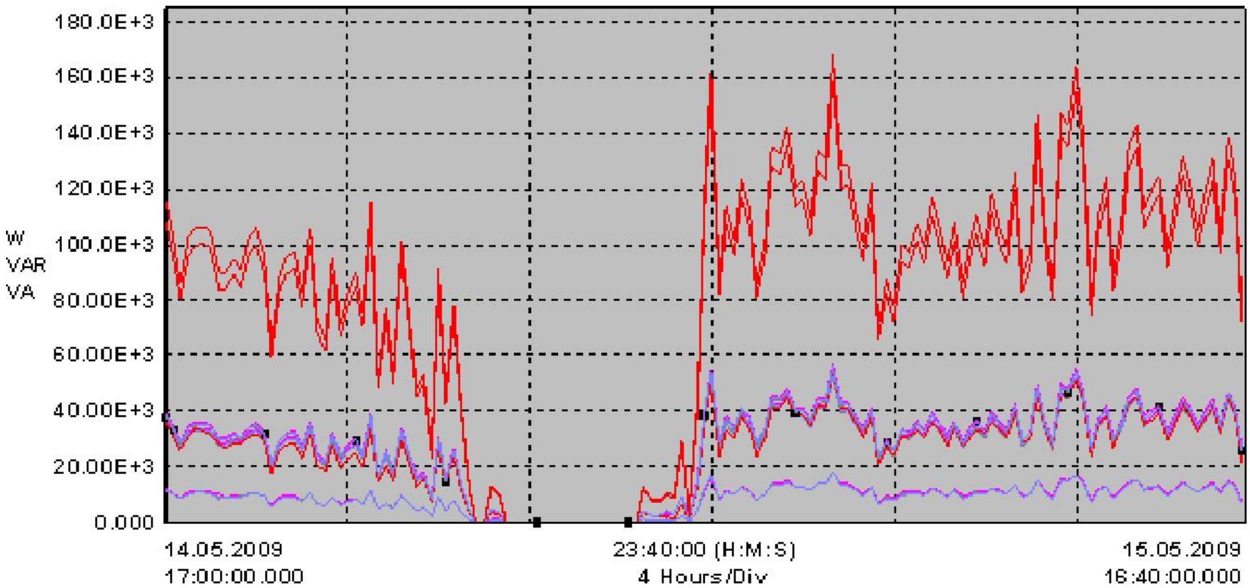


Fig. 3 - Load curve for station S4 – transformer 1– OTL

The NA has many registering facilities, including the ample of distorting and non symmetrical mode (DNSM).

In both cases the systems measures (U, I, P) are symmetrical, but there are significant distortional modes (DM). In figure 4 are plotted the curves of elements that characterizes the DM in station S3 – OTL.

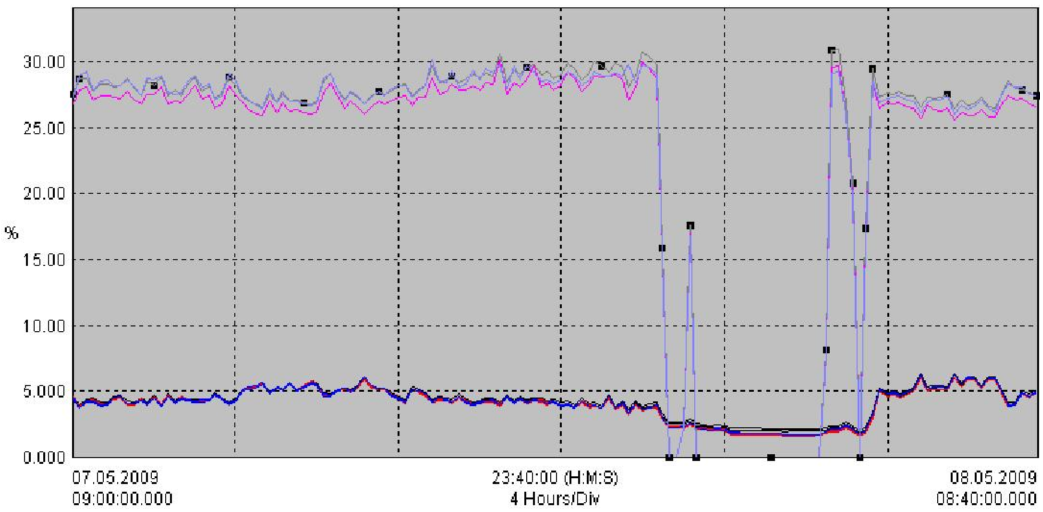


Fig. 4 – Characterizing elements of DM in station S3 transformer 1 – OTL

In each station is a service transformer (TSP). The NA was placed in the secondary of the PT making the same records as in the case of the main transformers. The working mode by the EEA elaboration is well known [5 ÷9].

The BEE equation is specified under the contour for which will be made the assessment, as: **SC1 ≡STR+RA**

For **SC1** ≡ **STR + RA** were used the following BEE equations:

$$W_{aMT} = W_U + \Delta W_T + \Delta W_L + W_A \qquad (1)$$

where,

W_{aMT}- is the absorbed energy in part of medium voltage, measured in connection point of NES (determined from the records of the beneficiary);

W_U - useful energy (outside of the contour), transferred to MT;

ΔW_T- energy losses in transformers;

To define the supplementary losses provoked by DM, it is used the model given in [10].

ΔW_R- energy losses in rectifiers;

ΔW_L- energy losses in supplying network (from station (ΔW_{LS}), of injection (ΔW_{LT}), and the contact (ΔW_{LC}));

W_A – auxiliary energy consumption in the station (proper services).

Means of transport (MT) implies:

SC2 ≡ the following equation of EEB:

$$W_a = W_U + \Delta W_M + \Delta W_{mec} + \Delta W_A \qquad (2)$$

where,

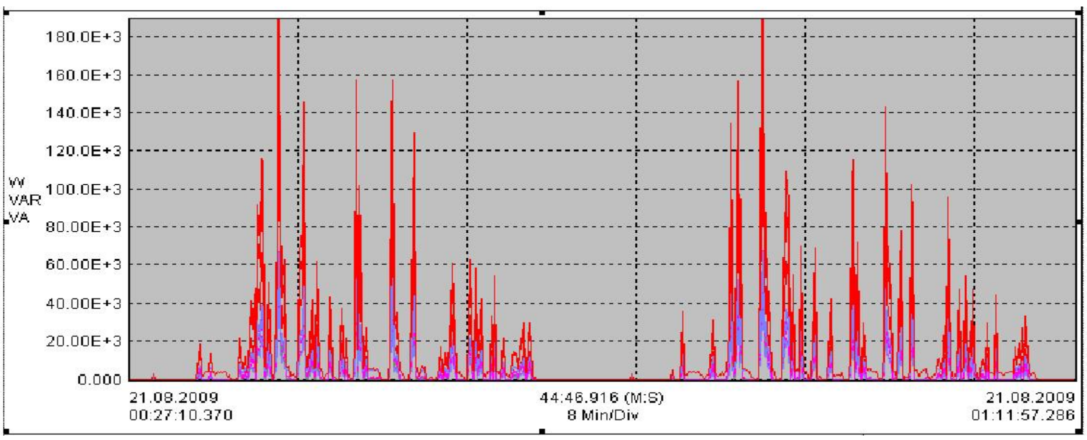
W_a – the absorbed energy is calculated basing on the results obtained from the precedent sub contour;

ΔW_M – energy losses in motors from the component of MT;

ΔW_{mec} – energy losses calculated basing on the records without load (at starting;

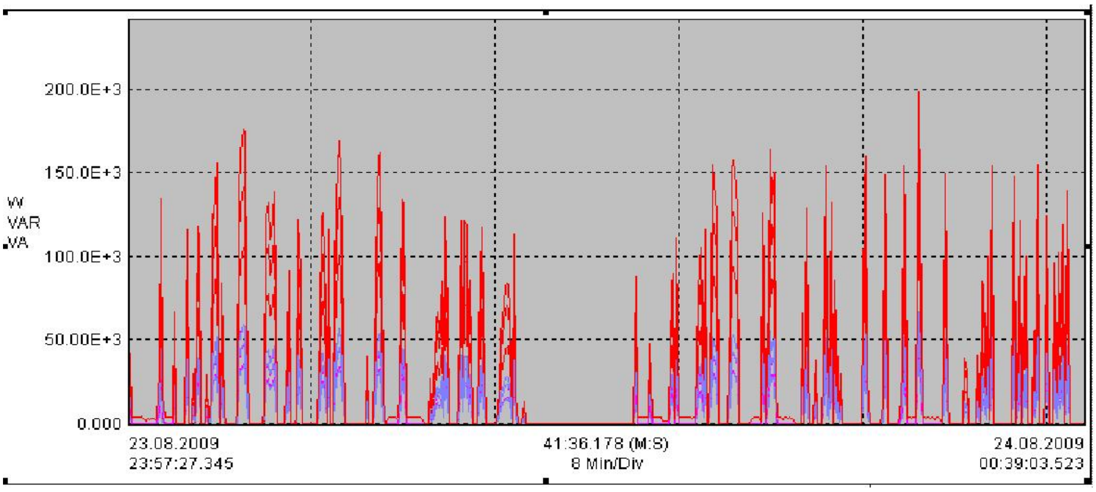
ΔW_A- estimated losses in other components of MT.

In figure 5 there is given as an example the recorded power without load for two types of trams (**kT4D** and **SIEMENS)**.



a.) tram Siemens ULF

ISSN 2067 – 5534 © 2010 JSE



b.)tram T4D

Fig. 5 – The load curve of tram in case of no-load

Basing on equation (2) it is calculated the useful energy (W_U) that represents the consumed energy in case of passenger's transportation. The obtained result will be compared with the values indicated in the technical book of MT. There will be made comparisons between the two types of MT.

3. THE OBTAINED RESULTS

Regarding the real EEB (diagrams, tables), for SC from the two contours may be seen in [11, 12].

Basing on the records (in unload and load) and assessments [11, 12], there were calculated the power compounds of EEB for MT, which are essential in the energy efficiency evaluation. The obtained results are synthesized in table 3.

Table 3- Power components of EEB for MT

Type MT	Trolleybuses (URBIS)			Trams (OTL)		
Component of power [kW]	SAURER GT 560/640-25	ROCAR 212 E	ROCAR 217 E	ULF	kT4D	T4D
Pa	64.94	42.6	49.85	92.11	106.84	108.18
Po	25.33	16.73	22.71	16.99	31.72	33.06
ΔP_M	5.84	7.67	10.97	6.44	13.89	14.06
ΔP_A	3.71	1.51	2.25	6.2	6.64	8.26
ΔP_{mec}	15.78	7.55	9.48	8.06	14.97	14.63
P_U	39.61	25.87	27.15	71.41	71.34	71.23
η[%]	61	60.7	54.5	77.5	66.8	65.8

The EEB of the ensemble MT (SC2) referring on a medium day in concordance with registering for many years are given in table 4.

Table 4 – EEB for MT(SC2)

	[11] Trolleybuses URBIS		[79] Trams OTL	
Characteristic	**[kWh]**	**[%]**	**[kWh]**	**[%]**
Input energy [W_a]	2556.105	100	18204,79	100
Output energy	2556.105	100	18204,79	100
1. Useful energy[W_U]	1545.305	60.46	12210,16	67,07
2. Losses	1010.8	39.54	5994,63	32,93
• Motors [ΔW_M]	302.43	11.83	2272,56	12,48
• Electric in other components ΔW_A]	132.31	5.18	1304,82	7,17
• Mechanics in transmission mechanics [ΔW_{mec}]	576.06	22.53	2417,24	13,28

For the stabilized contour, the real EEB is obtained by aggregation of the components and taking into account that the useful energy is that which is consumed for the movement of passengers. The results are given in figures 6 and 7.

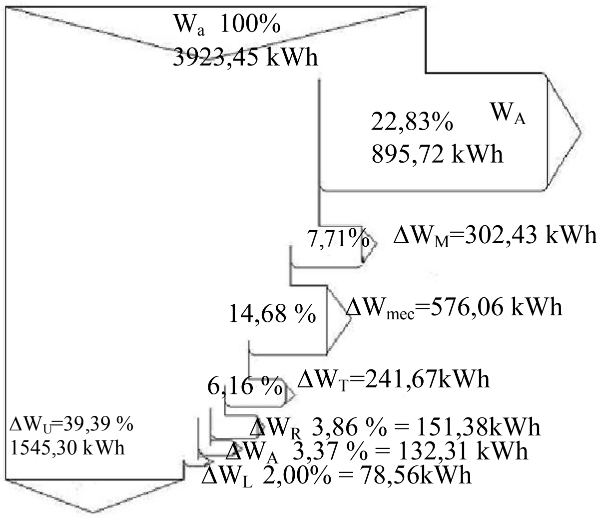


Fig 6 – Diagramm Sankey of real EEB *for URBIS*

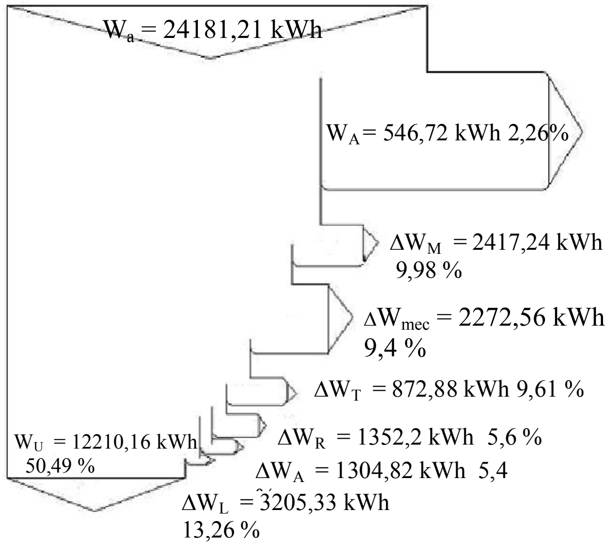


Fig 7- Diagramm Sankey of real EEB *real for OTL*

From the energy and economic efficiency indicators recommended in [5], there were calculates that will be calculated in this case (table 5).

Table 5 –Indicator of efficiency

Indicator		URBIS	OTL
Specific consume of EE	For a route [kWh / route]	49.8	39
	For the unit of route length [kWh/km]	3.7	2.09
	For transported passengers [kWh/passenger]	0.25	0.18
	kW·h [t·km]	0.1328	0.062
Incomes / [kWh]	[lei/kWh]	5.14	8.4

4. CONCLUSIONS. THE OPTIMAL BALANCE

The measurements and the made assessments in EEA of the two urban electric transport entities, allows the following conclusions:

1. The energy efficiency level is between the normal limits in such systems. The evaluation given in table 5 was made with hypothesis that the average weight of a passenger is 75 kg, as the price of one route is 1.3 lei. In OTL, the energy efficiency is superior toward URBIS, explained as: the trams have a superior efficiency toward the trolleybus, a more intense use of the transport system ensemble by OTL toward the URBIS, normal weight of auxiliary consumes at OTL toward URBIS, where the weight of auxiliary consumes is exaggerate.

2. The power transformers and rectifiers from STR operate more under the nominal power (table 6).

ISSN 2067 – 5534 © 2010 JSE

Table 6- The level of load of the transformer from STR

Contour	Station	S_n [kVA]	S_{max} [kVA]	β_m	β_o
URBIS	S1	1500	326	0.081	0.64
	S2	1600	221	0.041	0.54
OTL	S1	1300	227	0.11	0.54
	S2	950	257	0.11	0.56
	S3	950	293	0.16	0.56
	S4	1250	164	0.07	0.54
	S5	950	199	0.1	0.54

- (β_m, β_o) – are the medium (β_m) and optimal (β_o) load factors

For rectifiers this mode of load is beneficial under energy aspect and reliability aspect too. For transformers, the under loaded mode implies a insufficient operation under energy aspect, that is reflected in the diagram of balance (fig. 8, 9).

3. STR has a pronounced disadvantage under aspect of the load, meanly by URBIS. The level of the circulated load through the stations in relation with the total load is:
URBIS (63% - S1; 37% - S2); OTL (23% - S1; 19%-S2; 30% - S3; 17% - S4; 11% - S5);

4. The network supplying (injection and contact), as well as the sections from the structure has high degree of load unbalance. All sections of injection are under loaded that is useful for its reliability and energy efficiency.

5. The loading electric values (currents, powers), are high variable, specific to electric action system by means of transport. This fact inevitable and is reflected through increasing of the power losses in power transformers and supplying network, toward when the load should be constant.

6. On each contour ensemble the reactive power (energy) consumption is under the corresponding level of neutral power factor, implying the inexistence of reactive energy factor.

7. The level of voltage harmonics is in compliance with the rules, as the current harmonics are more above the normal limits (table 7).

Table 7 – Level of THD indicators (Total Harmonically Distortion)

Contour	Station	THD_U[%]	THD_I[%]
URBIS	S1	2,4	23
	S2	1,55	21,7
OTL	S1	4,34	29,02
	S2	5,24	27,11
	S3	5,12	27,15
	S4	3,77	29,97
	S5	3,51	28,81

The values above, of the current harmonics, reflects appropriate undimensioning or unoperating of the filters in the frame of power rectifiers of the two stations. The power effects of the current harmonics (supplementary energy losses) are small because the load of the transformer is reduced.

8. The made measurements and evaluations that refers on the three type of trolleybuses from URBIS, reflects:
a) inexistence of some appropriate value of the indicator of "the output capacity" (η), for two types, such:

- 61% - trolleybus SAURER GT 560;
- 60.7 % - trolleybus ROCAR 212 E.

A value significant smaller (54.5%), was obtained for the trolleybus ROCAR 217 E.

b) for the ensemble of the 11 trolleybuses, was obtained a good output capacity (60.45%), so, it is clear that the energy losses takes place mainly in mechanism of transmission (22.53%) and in motors (11.83 %).

c) basing on the records made in 2008 October, results that the average value of passengers is 196, that exceeds the recommended value of transport capacity of each trolleybus. Therefore, the 11 trolley buses are loaded to maximum.

d) the calculated value for specific energy consumption "t km" defined basing on EEA is 132.8 Wh / t km. This value is under the inscribed value in technical book of the trolleybus type ROCAR 212 E (160 Wh/ t·km – at nominal load). This finding reflects a normal operation of the trolleybuses.

9. The measurements and evaluations that refers on the three types of trams from OTL, reflects mainly the followings:
a) net superiority under energy aspects of ULF trams, toward of the other two types (table 3):
b) testing without load of the three type of trams ((2- Ulf, 4- kT4D and 4-T4D) reflects some dispersion of absorbed energy values without load, namely:

- [28,61; 32,84] kW – for kT4D;
- [29,92; 35,53] kW – for T4D;

The dispersion signifies the fact that the trams have differentiated rate of wear and exists the possibility to reduce the energy consumption through a deeper maintenance.

a) the testing the trams under load and plotting the load curves [(N_{CL} = f(t), N_T = f(t), P = f(t), P=f(N_{CL}) şi P=f(N)], reflects a good correlation between the absorbed energy and number of passengers, respectively, absorbed energy and number of trams.

b) for the ensemble of the 79 trams (10- ULF, 25- kT4D, 44 -T4D), from the measurements and made evaluations is obtained a good output capacity (67.45%). The greatest weight has the energy losses in transmission mechanisms (13.28%) and in motors (12.48%).

10. For the ensemble energy efficiency contour is better by OTL, so:

a) approximate 39.4%, the most part of the energy losses are in STR sub contour + RA (34.85%) and not in MT (25.76%). This unusual situation is determined by the exaggerate weight of STR auxiliary consumption (22.83%).

b) for the ensemble of OTL contour, the energy efficiency is 50.49%, the most part of the losses are in MT (24,78%) and not in NA (13,26%).

11. Reduction of energy consumption in the analysed contour may be done by applying of the following technical administrative measures:

a) replacing of under loaded transformers with adapted power transformers at level of the consumption;

b) balancing of STR and RA;

c) compensating DM;

d) replacing MT with small performance with a better performance one, such:

- ROCAR EDM 217 E trolleybuses with SAURER GT 560 at URBIS;
- Trams of kT4D and T4D with ULF at OTL.

e) replacing the classical adjusting system (by resistor) with electronic adjusting of kT4D and T4D trams velocity, respectively at ROCAR trolleybuses;

f) deeper maintenance of MT;

g) reduction of auxiliary consumption from STR of URBIS;

12. The application mode of this measures and analyzes of feasibility, may be consulted in [11, 12]. Applying the above measures, if the evoked effects are recorded [11, 12] there are obtained optimal EEB synthesized graphical (fig. 8, 9).

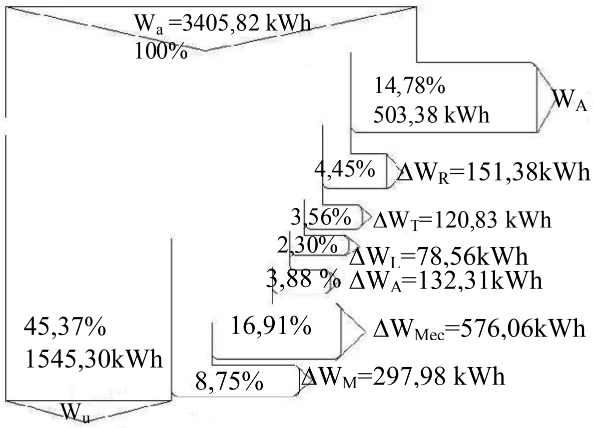


Fig 8 - Diagramm Sankey of optimal EEB at URBI

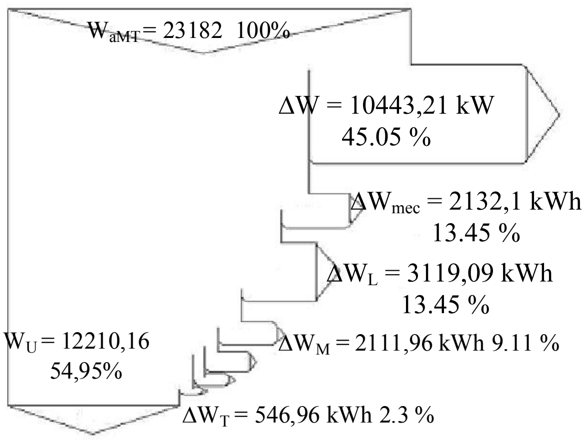


Fig 9 - Diagramm Sankey of optimal EEB at OTL

By applying the specifically measures of optimal EEB, it is obtained the impact reducing on the environment, and results in diminishing quantities of noxious discharged into the atmosphere [11,12].

REFERENCES

[1] ***Green Paper of Energy Efficiency or doing more with less, Commission of the European Communities, COM (2005) 256 final.

[2] ***Directive 2006/32/EC of the European Parliament and of the council on Energy and Use Efficiency and Energy Services, Commission of the European Communities.

[3] ***Law nr 199/2000 Privind ultilizarea eficientă a energiei / Regarding the efficient utilize of energy, published in Monitorul Oficial al României, Partea I nr. 734/2002.

[4] ***H.G. nr.339/2002 pentru abordarea normelor metodologice de aplicare a Legii nr. 199/2000 privind utilizarea eficientă e energiei / addressing rules for the application of Law no. 199/2000 regarding the efficient use of energy is published in Monitorul Oficial al României, Partea I, nr. 229/2002

[5] Al-Mansour F, et.all. Comparison of energy efficiency strategies in the industrial sector of Slovenia. Energy 2003;28:421–40.

[6] Sterling CA. Prevalence of components necessary for electrical demand side management savings persistence in the Albertan Industrial market sector, MS thesis, University of Alberta, Canada; 1996

[7] Thollander P, et. all. Reducing industrial energy costs through energy-efficiency measures in a liberalized European electricity market: case study of a Swedish iron foundry. Applied Energy 2005;81:115–26.

ISSN 2067 – 5534 © 2010 JSE

[8] Chirstina G., et. all. Energy Efficiency Improvement and Cost Savings Opportunities for the Vehicle Assembly Industry, 2008, LBNL-50939-Revision.
[9] Cleveland C., Encyclopedia of Energy, Elsevier Academic Press, San Diego, 2004
[10] 10.***„Ghidul de elaborare şi analiză a bilanţurilor energetice" / Guide of elaboration and analyze of power balances" in concordance with direction of ARCE NR. 245.
[11] Berinde T. ş.a. „ Întocmirea şi analiza bilanţurilor energetice" / Preparation and analysis of energy balance Vol I şi II, Editura Tehnică Bucureşti, 1976
[12] Carabogdan Gh. ş.a., „Bilanţuri energetice. Probleme şi aplicaţii pentru ingineri / Energy balances. Problems and applications for engineers" Editura Tehnică Bucureşti, 1986.
[13] Felea I., „Documentaţie privind auditul electroenergetic la / Documents viewing the electro-energy audit at S.C. URBIS S.A. Baia- Mare", Oradea, 2009
[14] Felea I., Documentaţie privind auditul electroenergetic la S1 OTL / Documentation viewing the electro-energy audit at S1 OTL, Oradea, 2009.