ANALYSIS ON THE ENERGY PERFORMANCES OF OTL TRAMS

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Abstract - This paper summarizes the results obtained from measurements carried out on trams operated with DC motors at the request of Oradea Transport Company (OTL). It aims on achieving a comparative analysis electrically driven trams (EDT) with d.c. motors (DCM), in terms of energy performance, based on a defined synthetic indicator and evaluated in the paper. The paper is structured in four parts. After presenting the importance of this analysis, through the significant use of electric energy (EE) in urban public transport and a brief description of the system under analysis, the second part of the paper presents the workings and results with respect to 21 pieces of EDT-DCM.

Comparative interpretation of the results and conclusions of the analysis are contained in Part three of the paper and in the last part is specified the need and how to further research this area.

Keywords: trams, energy performance, power auditing.

1. INTRODUCTION

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

Operating concept and targets on the sustainable development, for energy-intensive processes, including those of transport, results through the reduction of fossil fuel consumption in two ways:

a) increasing the efficiency of energy processes;

b) 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 to the reduction by 2020 of the energy consumption from fossil fuels by 20% and increase the share of renewable sources by 20%.

In Romania, energy efficiency is much lower than in other countries with top-of-the-line technology. Still, many processes and technology services 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 European standards, not only by the appearance of energy efficiency but also under the aspect of renewable resource usage.

From perspective of sustainable development, it is essential that local official have to pay attention to:

- 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, is relatively quiet and enhanced safety in circulation.

Specific problems of urban public transport systems are reflected in literature on the subject. A significant part of work aims the performance of UPT systems, performance quantified by: efficiency, quality of service, impact to the environment. In [4,9] one identified factor which influence the application of the UPT with a particular focus, specially, on the quality service, and in [10] one proposed and exemplified a methodology applied in the preparation of studies of quality of the UPT system. Detailed methodology for the assessment of quality of the service of transport shall be made in [11,12], out using the deciding factors of impact such as: availability, comfort, and convenience. Availability of the transmission system is examined in terms of frequency of the service zone and service coverage. For a system of UPT with buses shall be analysed comfort and convenience. Effectiveness of concrete UPT systems is analysed for example in [12,13,14]. The authors work [12] analysed, compared, UPT with buses and trolleybuses, assuming that the variance of the UPT is a complex problem, dependent on many economical, technical and eco-friendly factors. Performed analysis show that the containing values obtained for the two variants, include specific consumption of energy, and are very close. Thus, in [13] one shall assess the effectiveness of the UPT systems of 12 cities in Europe and 7 in Brazil. On the basis of results obtained, the authors get to the conclusion that, in nine cities in Europe, and in one of Brazil UPT is effective; the 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 to the optimization of the running lines parameters, the modernisation of the stations and optimal management of traffic.

The Power Audit (EEA) is one of the procedures used to identify ways to increase the efficiency of conversion of energy processes [15÷18].

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.

This paper concerns fall in line of identification based on Power Auditing of the energy performance of trams of OTL Oradea company, continuing and deepening the concerns earlier stated [19 ÷ 23] by comparative analysis of EDT – DCM (TATRA) in order of their ranking in terms of energy aspects and identifying concrete measures to increase the energy efficiency of those trams.

UPT using in Oradea started in 1906. OTL has the following features [21,24].

- Average number of passengers served daily: 22,761.
- Average distance travelled 2,405,000 km a year;
- Average daily consumption of EE: 8759.8 MWh;
- Average cost per passenger and km EE: 0.055 LEI / passenger x km;
- Double rail length divided into five zones : 39.86 km [24];
- The installed capacity in the five recovery substations: 5550 kVA;
- The total EDT: 73 of which, for maximum carrying capacity is required 44 pieces;
- Types of EDT used:
  →Produced by TATRA (Czech Republic), with DC motors without energy recovery, type KT4D (20 pieces) and T4D + B4D (43 pieces) in circulation, and two pieces of T4D processed for snow cleaning, as so in circulation a total of: 20 + 43 = 63 pieces
  →Produced by SIEMENS (Austria) 151 ULF (Ultra Low Floor): 10 pieces.

2. PROCEDURE AND RESULTS

EEA refers to trams operated on EDT - DCM. In order to achieve the EEA measurements were performed on a total of 16 of the 44 EDT - DCM, type T4D - B4D and that a number of 5 of the 25 KT4D -type EDT - DCM. The measurement results for five of the EDT - DCM -type T4D B4D could not capitalize due to registration errors. Measurements were performed in normal operating conditions, which imply the existence of all specific operating conditions: start-up, acceleration, standard load, braking, no load. With electrical operation recordings, the number of passengers was noted in order to calculate the efficiency indicators (energy, economic) of each EDT - DCM audited and, on this basis, to create a hierarchy of the EDT - DCM for the beneficiary. The EEA contour is represented by each EDT - DCM for which measurements were made. Meter used was a network analyser (AR) type FLUKE 345 [25].

FLUKE 345 recordings were presented in the documentation for each TAE-MCC:

- Registration centralizer;
- The sequence of the spreadsheet;
- The curve of current and voltage;
- Statistics on voltage variation;
- The curve of the active power;
- The curve of active energy.

We give an example, particular case EDT - DCM no. 02-102. Measurements recorded are shown in Fig. 1÷5 and Table 1.

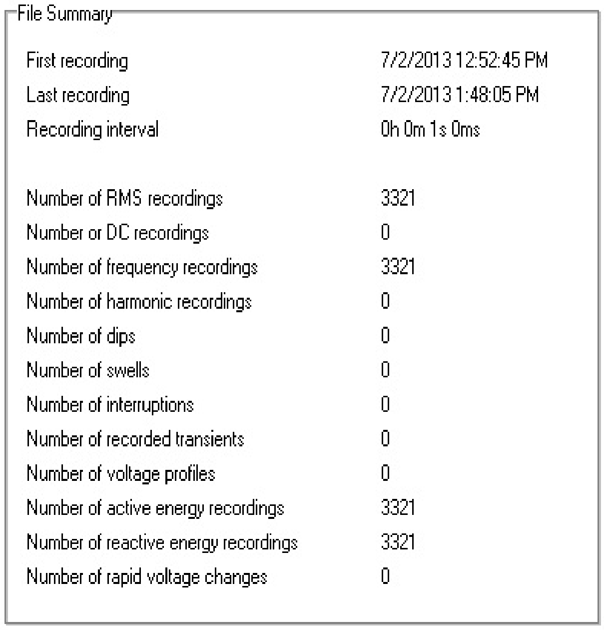

Fig. 1 – Registration centralizer

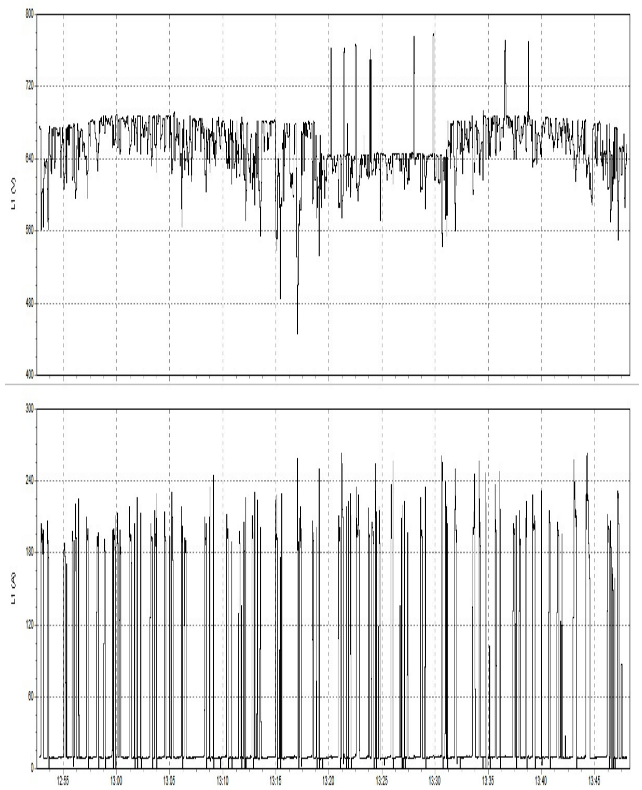

Fig. 2 – The curve of current and voltage

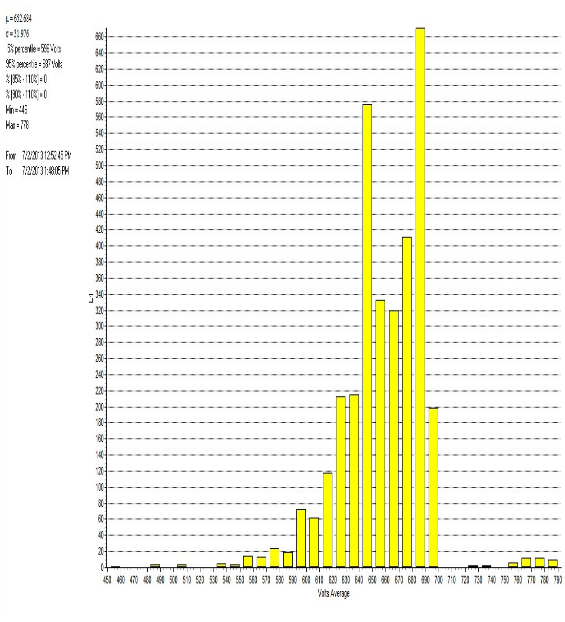

Fig. 3 – Statistics on voltage variation

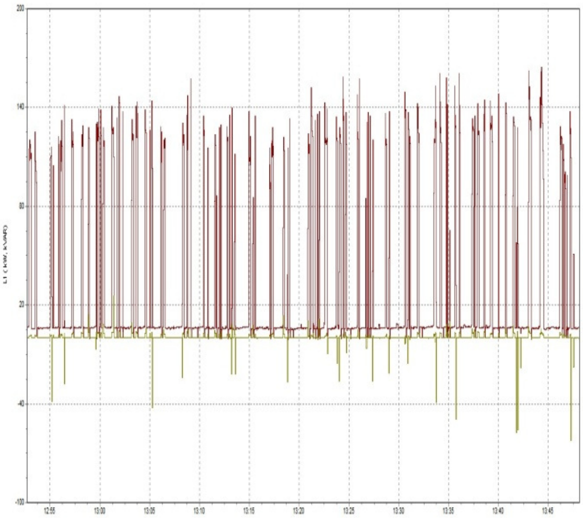

Fig. 4 – Active power curve

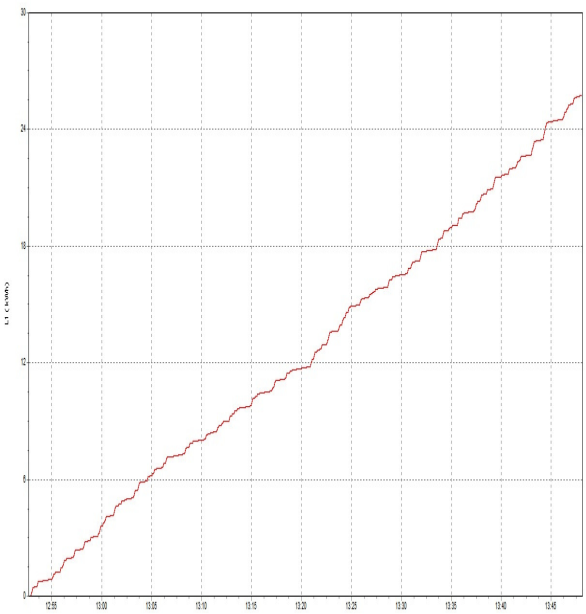

Fig. 5 – Active energy curve

Table 1 – Spreadsheet sequence:

Date	Function	Duration	L1 Min	L1 Avg	L1 Max
7/2/2013 12:52:45 PM 0ms	Voltage		674 V	674 V	674 V
7/2/2013 12:52:45 PM 0ms	Current		9.84 A	9.84 A	9.84 A
7/2/2013 12:52:45 PM 0ms	Active Power		6.63 kW	6.63 kW	6.63 kW
7/2/2013 12:52:45 PM 0ms	Reactive Power		0 kVAR	0 kVAR	0 kVAR
7/2/2013 12:52:45 PM 0ms	Apparent Power		6.63 kVA	6.63 kVA	6.63 kVA
7/2/2013 12:52:45 PM 0ms	Power Factor		0.999	0.999	0.999
7/2/2013 12:52:45 PM 0ms	Active Energy				0.00 Wh
7/2/2013 12:52:45 PM 0ms	Reactive Energy				0.00 VARh
7/2/2013 12:52:45 PM 0ms	Frequency		0 Hz	0 Hz	0 Hz
7/2/2013 12:52:46 PM 0ms	Voltage		674 V	674 V	674 V
7/2/2013 12:52:46 PM 0ms	Current		9.84 A	9.84 A	9.84 A
7/2/2013 12:52:46 PM 0ms	Active Power		6.63 kW	6.63 kW	6.63 kW
7/2/2013 12:52:46 PM 0ms	Reactive Power		0 kVAR	0 kVAR	0 kVAR
7/2/2013 12:52:46 PM 0ms	Apparent Power		6.63 kVA	6.63 kVA	6.63 kVA
7/2/2013 12:52:46 PM 0ms	Power Factor		0.999	0.999	0.999
7/2/2013 12:52:46 PM 0ms	Active Energy				3.00 Wh
7/2/2013 12:52:46 PM 0ms	Reactive Energy				0.00 VARh
7/2/2013 12:52:46 PM 0ms	Frequency		0 Hz	0 Hz	0 Hz
7/2/2013 12:52:47 PM 0ms	Voltage		676 V	676 V	676 V
7/2/2013 12:52:47 PM 0ms	Current		9.86 A	9.86 A	9.86 A
7/2/2013 12:52:47 PM 0ms	Active Power		6.67 kW	6.67 kW	6.67 kW
7/2/2013 12:52:47 PM 0ms	Reactive Power		0.07 kVAR	0.07 kVAR	0.07 kVAR
7/2/2013 12:52:47 PM 0ms	Apparent Power		6.67 kVA	6.67 kVA	6.67 kVA
7/2/2013 12:52:47 PM 0ms	Power Factor		0.999	0.999	0.999
7/2/2013 12:52:47 PM 0ms	Active Energy				5.00 Wh
7/2/2013 12:52:47 PM 0ms	Reactive Energy				0.00 VARh
7/2/2013 12:52:47 PM 0ms	Frequency		0 Hz	0 Hz	0 Hz
7/2/2013 12:52:48 PM 0ms	Voltage		676 V	676 V	676 V
7/2/2013 12:52:48 PM 0ms	Current		9.86 A	9.86 A	9.86 A
7/2/2013 12:52:48 PM 0ms	Active Power		6.67 kW	6.67 kW	6.67 kW
7/2/2013 12:52:48 PM 0ms	Reactive Power		0.07 kVAR	0.07 kVAR	0.07 kVAR
7/2/2013 12:52:48 PM 0ms	Apparent Power		6.67 kVA	6.67 kVA	6.67 kVA
7/2/2013 12:52:48 PM 0ms	Power Factor		0.999	0.999	0.999
7/2/2013 12:52:48 PM 0ms	Active Energy				6.00 Wh
7/2/2013 12:52:48 PM 0ms	Reactive Energy				0.00 VARh
7/2/2013 12:52:48 PM 0ms	Frequency		0 Hz	0 Hz	0 Hz

The evolution of the number of passengers transported by EDT - DCM; the analysis is presented in Figure 6 and 7.

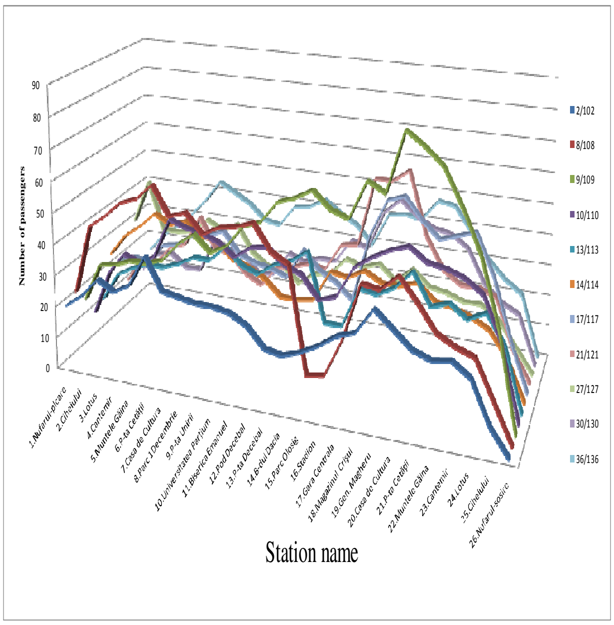

Fig. 6 Evolution of the number of passengers transported by T4D-B4D

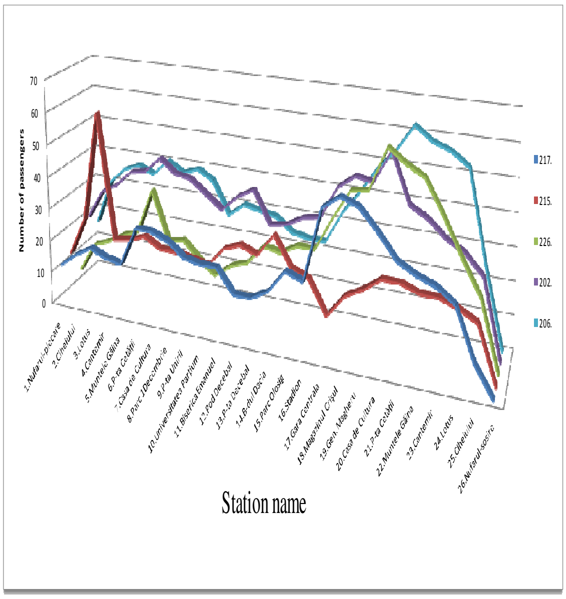

Fig. 7 Evolution of the number of passengers transported by KT4D

Based on measurements, absorbed power values are obtained correlated with the working regimes presented above with respect to the two types of trams (table 2)

Table 2 – Absorbed power by EDT - DCM:

Nr.	Identification (T4D-B4D)	P_0 [kW]	W_a [kWh]	t_c [h]	P_a [kW]
1.	02-102	6.63	25.5	0.92	27.7
2.	08-108	6.68	32	0.79	40.5
3.	9-109	7.77	38	0.91	41.8
4.	10-110	8	30	0.94	31.9
5.	13-113	5.35	27	0.85	31.8
6.	14-114	6.16	33.5	0.91	36.8
7.	17-117	7.2	40.7	0.91	44.7
8.	21-121	7.41	27.5	0.93	29.6
9.	27-127	6.91	28.5	0.83	34.3
10.	30-130	6.76	33.5	0.97	34.6
11.	36-136	9.46	39.5	0.92	42.9
Medium Values		**7.12**	**32.33**	**0.898**	**36.05**
Nr.	**Identification (KT4D)**	**P_0 [kW]**	**W_a [kWh]**	**t_c [h]**	**P_a [kW]**
1.	202	8.43	31	0.82	37.8
2.	206	6.96	28.5	0.88	32.4
3.	215	4.82	24	0.92	26.1
4.	217	6.51	23.5	0.96	24.5
5.	226	7.47	28.5	0.91	31.3
Medium Values		**6.84**	**27.1**	**0.898**	**30.42**

P_0 - average power absorbed at no load working;
W_a - energy consumed (absorbed);
t_c - the duration;
P_a - medium power absorbed.

Since EDT - DCM analysed were tested for a single round on the same route (the same distance travelled) only indicator that is relevant to their ranking in terms of energy is "specific consumption per passenger transported EE" or "specific power consumption" [kW / passenger], which can be determined by the relationship:

$$SPC = \frac{W_a\,[kWh]}{\sum_{i=1}^{n} N_{ci} \cdot t_i [pass.\cdot h]} \tag{1}$$

The values obtained for the "SPC" indicator are shown in Table 3.

Table 3 – „SPC" indicator

No..	Identification *EDT - DCM T4D - B4D.*	SPC [kW/pass.]	No..	Identification *EDT - DCM – T4D*	SPC [kW/pass.]
1.	02-102	1.4016	1.	202	1.0214
2.	08-108	1.0696	2.	206	0.9233
3.	9-109	0.7765	3.	215	1.2276
4.	10-110	1.165	4.	217	0.9552
5.	13-113	1.1376	5.	226	1.0975
6.	14-114	1.3241	**Medium values**		**1.045**
7.	17-117	1.4280			
8.	21-121	0,9471			
9.	27-127	0.8427			
10.	30-130	1.5425			
11.	36-136	1.3359			
Medium values		**1.1791**			

3. CONCLUSIONS

Testing the actual operation of the two types of EDT - DCM (11-T4D-B4D and 5-KT4D), reflect a relatively high dispersion of the absorbed power values during no-load and full load, as follows:

- Power in no load regime (P_0):
  [5.35; 9.46] [kW]– for T4D-B4D;
  [4.82; 8.43] [kW]– for KT4D.
- Power for the medium load regime (P_a):
  [27.71; 44.72] [kW]– for T4D-B4D
  [24.48; 37.80] [kW]– for KT4D

Measurements and assessments made with reference to the two types of EDT - DCM reflects the superiority, in terms of energy consumption of KT4D to T4D-B4D as PCS indicator has smaller values for KT4D then T4D-B4D, although its energy efficiency is better than of KT4D. The mean values of significant values in terms of energy are:

Characteristic value	Type EDT - DCM	T4D-B4D	KT4D
No load absorbed power [kW]		36.0525	30.4152
Medium yield [%]		0.7395	0.7164
Medium SPC [kW/pass.]		1.1791	1.045

Synthetic indicator "specific power consumption" [kW / passenger] is located in a relatively large values interval, as follows:

- For T4D-B4D: [0.7765; 1.5425] [kW/pass.]
- For KT4D: [0.9233; 1.2276] [kW/pass.]

The dispersion is much higher for T4D-B4D than for KT4D.

Test in real conditions of operation of EDT - DCM reflects good correlation between output power and number of passengers

Significant dispersion of energetic performances of EDT - DCM tested reflects the need for a deeper/complex Power Audit, following the procedure and the detailed model presented, in order to identify components which through a deep maintenance would increase energy and economic performance of EDT - DCM.

4. THE METHOD OF FURTHER RESEARCH

The results obtained and shown in this paper do not allow complete and definitive answers due to the following causes:

• Only some EDT - DCM were analysed;

• There is no detailed EEA for components of the structure of EDT - DCM.

To finalize the analysis it is necessary to perform measurements on all EDT - DCM, besides highlighting the overall energy performance indicator (SPC) of each of the following aspects:

• Influence of the mode of operation by tram drivers to EDT - DCM on the value of SPC;

• Energy losses and own consumption technologic for each component in the structure of EDT - DCM. In this regard Power Audit diagrams will be used in static (Fig. 8) and dynamic regime (Fig. 9).

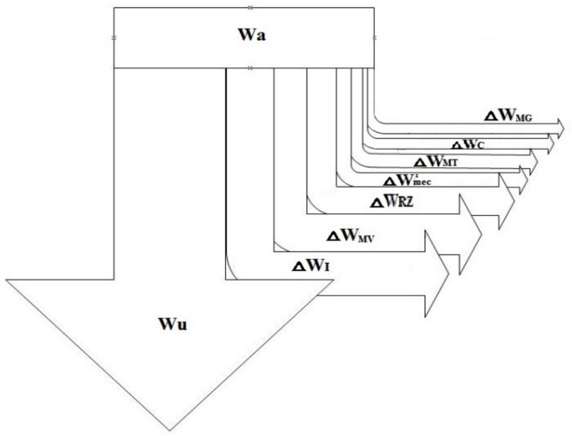

Fig. 8. –EEA diagram for EDT - DCM in static regime

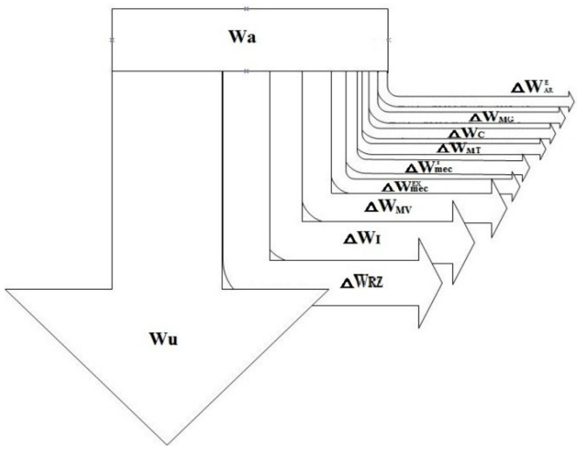

Fig. 9. –EEA diagram for EDT - DCM in dynamic regime

where:

W_a - energy absorbed;

ΔW_{RZ} - energy dissipated on starting, speed control and braking resistors (RZ) – it is interpreted as being a technological consumption required for EDT - DCM operation with this construction type .

ΔW_c - energy losses on the main electrical circuits EDT - DCM (except RZ and TM) respectively, conductors and contactors;

ΔW_{TM} - energy losses on traction motors (TM);

ΔW^{I}_{mec} - energy losses EDT - DCM mechanisms;

ΔW_{MG} - energy losses on the M - G group;

ΔW_{MV} - energy losses on the engine used for ventilation (only for KT4D)

ΔW_I - energy losses on illumination devices;

W_u - useful energy.

$\Delta\ W^{E}_{RL}$ - electrical energy losses on the feeding and running lines;

$\Delta\ W^{RL}_{mec}$ - mechanical losses through friction between EDT elements and RL elements;

Determination of EEA components shown in Fig. 8 and 9, involves the analysis on EDT - DCM of the following modes of operation, with the measuring specific quantities:

M01→ no load regime for the engine group. Group disconnected from the engine driven mechanism is powered at the rated voltage by means of the control;

M02→ static/no-load test of EDT - DCM. The engine group is coupled to the drive mechanism is powered at the rated voltage by means of the control, there is no contact with the road surface;

M03→ dynamic goal attempt. EDT - DCM without passengers, powered at the rated voltage, is moving on the path.

MS→ test in normal load EDT - DCM is moving with passengers throughout the usual route. Records on the number of passengers are made.

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