ELECTRICAL BEHAVIOR ANALYSIS OF AN INDUSTRIAL CONSUMER

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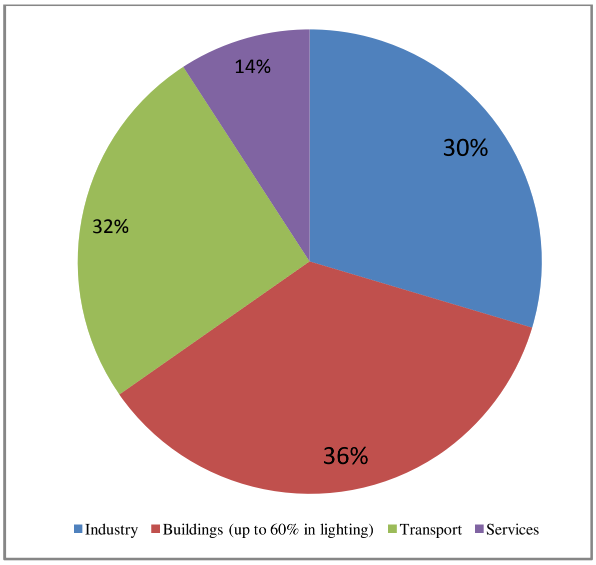
Abstract –In the paper is presented anelectrical behavioranalysis of an industrial consumer. The analysis has the purpose to identify the solutions to increase of energy efficiency, also pointing out the extend of the recommendations that has been applied in this regard, in the elaborated electricity audits. In the first part of the paper is made a justification of preoccupation and is presented the objective of analysis. The second part has the working methodology. Then follows the results obtained and on the last part the conclusions of analysis is given.

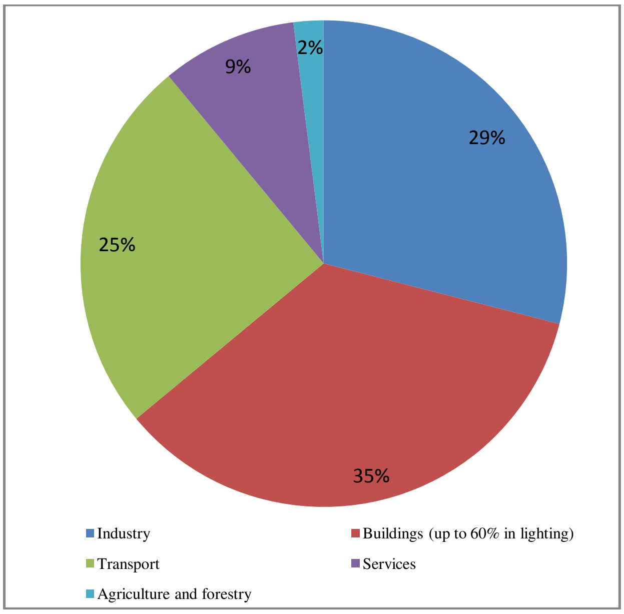
Keywords:energetic efficiency, industrial power consumer, energetic behavior.

1. INTRODUCTION

The industry is a major power energy consumer, with important commitments and targets regarding the reduction of energy consumption [1, 2, 3] – figure 1.



a) Power energy consumption weight in 2013



b) Power energy reduction target

Fig. 1 –Power energy consumption and reduction target regarding economic sectors in RO[1]

Power energetic consumption reduction for industry implies the growth of industrial processes energy efficiency. Identifying the solutions of energy efficiency it's done by electricity audits (EA) [4, 5, 6].
The consumer which makes the object of this analysis – S.C. Celestica Romania S.R.L. has understood the utility of EA and requested 5 EA starting from 2008 until 2015. In each case beside EA of some internal processes has been conducted EA at a general outline(GO) level, at transformer station(TS) level and at the level of electrical distribution network betweenTS and general electric panels. The general outline of EA is presented in figure 2.

As presented in [7], in general outline of EA, are included the equipment and installations indicated in Table 1.

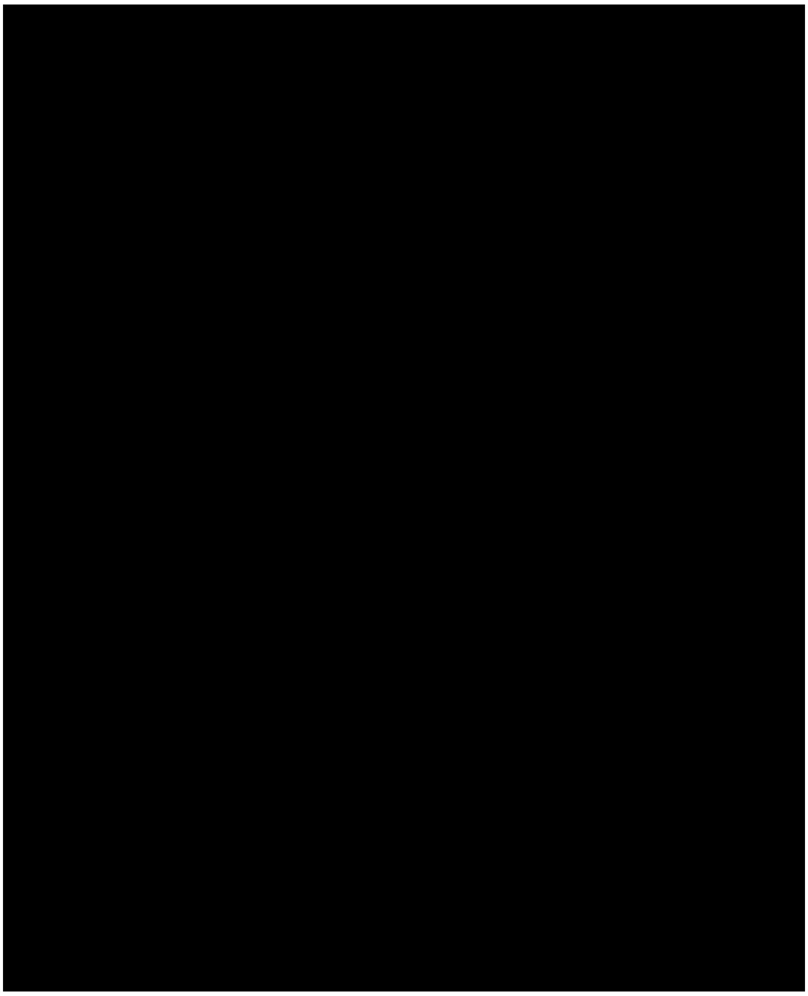


Figure 2 – The general outline of EA of CELESTICA

Table 1 - Main technical data for transformers and installations of the analyzed contour

No. Crt.	Name of equipment	Technical characteristics	
1.	Power transformers (T1, T3,T5)	S_n =1000kVA; U_{1n} / U_{2n} =20/0,4 kV; f_n = 50Hz; ΔP_{wn} =12 kW; ΔP_{Fn} =1,95 kW; u_{kn} =16%, i_{0n} =2%; Connection: Δ/y_0 - 5	
2.	Power transformers (T7, T7,T9)	S_n =2000kVA; U_{1n} / U_{2n} =20/0,4 kV; f_n = 50Hz; ΔP_{wn} =22 kW; ΔP_{Fn} = 3,2kW; u_{kn} =6,3%, i_{0n} =1,5 %; Connection: Δ/y_0 – 5	
3.	Distribution instalations EE	CA de la T1 la BA1	WT2 2x(C2XY4x300)+C2XY1x150; L=14m
		CA de la T3 la BA2	WT4 2x(C2XY4x300)+C2XY1x150; L=14m
		CA de la T5 la BA3	WT4 2x(C2XY4x300)+C2XY1x150; L=13m
		CA de la T7 la BA4	4xCXY 4x1x300+C2XY 1x300; L=15m
		CA de la T8 la BA5	4xCXY 4x1x300+C2XY 1x300; L=15
		CA de la T9 la BA6	4xCXY 4x1x300+C2XY 1x300; L=14m

The provided service by S.C. Celestica Romania S.R.L., is manufacturing of computers, receivers, TV-s, servers, phones, to customers such as IBM, PHILIPS, SAMSUNG, BskyB, RIM, EMC, SIEMENS, etc.

The technological flux of S.C. Celestica Romania S.R.L., is given in fig.3.

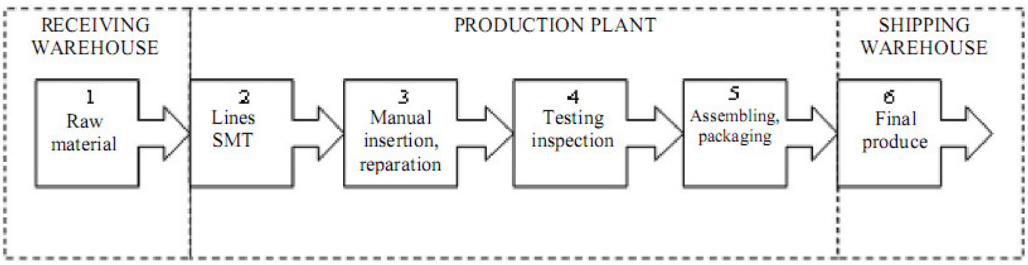


Fig. 3 - Diagram of technological flux

The unit of the reference: the EE consumed for an hour have been determined basing on the made registrations [7].

The loading level of the installations and equipment during the measurements is the normal one for the assured service by S.C. Celestica Romania S.R.L.. After making BEE for an average hour, will be make refer on annual BEE, based on the monthly registered EE consume.

The measuring devices used:

- Network analyzer (NA) type of C.A. 8334 B (2 pcs.), placed in the secondary of the two transformers in each station;
- Active and passive energy contours of ENEGLUX TCDM – AEM Timisoara, placed in the primary of the transformer.

2.WORKING METHODOLOGY

As against [7] in which is presented solutions to grow of energy efficiency as a result of EA done in 2011 at S.C. Celestica Romania S.R.L., in this paper we make the analysis of electrical behavior(EB) of this consumer. By EB we understand, in this paper, the highlighting and interpretation of time evolution, at GO of the following parameters:

- Annual consumption of energy (active, reactive);
- Power energy losses;
- Energy efficiency;
- Circulation of reactive power on GO;
- Quality of electrical energy;
- Load factor of TS and optimal coonfiguration of it;
- Energetic intensity.

Annual consumption of electrical energy it is recorded in delimitation points with electrical energy provider and at medium-voltage level of TS on GO has been aplied the ecuation of electricity balance [8, 9].

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

where,
W_{aMT} – absorbed electric energy, measured at connection point with with SEN (at MV level);
ΔW_T – energy losses on transfomer;
ΔW_L – energy losses on power lines of distribution network;
Considering the fact that transformers runs independently, to calculate the losses of power energy in each transformer it's used the relationship [10]:

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

where:
U-operational efective voltage;
$\beta=S/S_n$- relative apparent load;
S-appaent power;
λ-0,03kW/kVAr- active equivalent of reactive power;
T_A- duration use at load S;
ΔW_{TD}- additional energy losses due to harmonic regime(HR) of transformer.

To calculate the additional power losses in transformers it has been used the relations given in [11, 12 and 13]. In each EA done at concerned consumer we aimed to identify and recommend the optimal configuration of transformer group 3×1000 kVA and 3×2000 kVA, applying the methodology indicated in [14, 15 and 16].

To evaluate power losses in power lines from GO we used the relations [14, 15 and 16]:

$$\Delta W_L = 3 \cdot k_f^{\,2} \cdot I^2 \cdot R_L\,(1+k_{DI}^{\,2})\cdot\tau\cdot 10^{-3} \quad [\text{kWh}] \quad (3)$$

where:
k_f-isshape coefficient of function $I = f\ (t)$which represents the variation in time of line current I;
I – current value measured at the powered end of line;
RL – equivalent resistance, on phase, of considered line[Ω]
K_{DI} – distortion coefficient of current curve [17]
From relation (1), after calculation of energy losses, knowing the energy entered in GO of EA, it was calculated the useful energy and then the energy eficiency.

The reactive power circulation in GO of EA it's established by summing the records taken from the 6 transformers.

Electrical energy quality it is appreciated considering the following characterization elements, obtained from recordings made at each transformer level:

- Maximum relative value of voltage deviation from the nominal value;
- Imbalance degree of current system, established at each transformer level with the relation [18]:

$$N_I^2=\frac{1}{3}\left[\left(\frac{I_R}{I_{med}}\right)^2+\left(\frac{I_S}{I_{med}}\right)^2+\left(\frac{I_T}{I_{med}}\right)^2\right] \quad (4)$$

- Harmonic content of current and voltage appreciated through values (THD_I, THD_U), at each transformer level, values registered by AR. It has been calculated a global value of THD_Iat GO of EA, using the relation;

$$THD_I^{CG}=\frac{\sum_{i=1}^{6}THD_{Ii}\,x\,I_{medi}}{I_{med}^{CG}} \quad (5)$$

$i=\overline{1,6}$ - 6 transformers (marked with $T_1\div T_3$and $T_7\div T_9$)

Regarding the voltage (unique parameter at GO of EA) we tracked and graphically represented only THD_U^{max} of those 6 transformers.

Loading degree it's calculated by dividing absorbed power by installed power, regarding each transformer and for Go of EA. Optimal configuration of two groups of transformers ($T_1\div T_3$şi $T_7\div T_9$) was established considering "minimal power losses" criterion.

Energetic intensity was determined accordingly to definition as being the division of electrical energy consumption at Go level of EA(W_{aMT}) and the value of achieved production.

The evaluations have been done, on every year, based on mean values of recorded parameters. To highlight the evolution in time of parameters above mentioned which characterize the EB of the consumer we are using graphical representations.

3. THE RESULTS

To have an image of evolution in time of measured parameters as entries of Go of EA, in figures 4 ÷ 13 are given some of the conducted measurements.

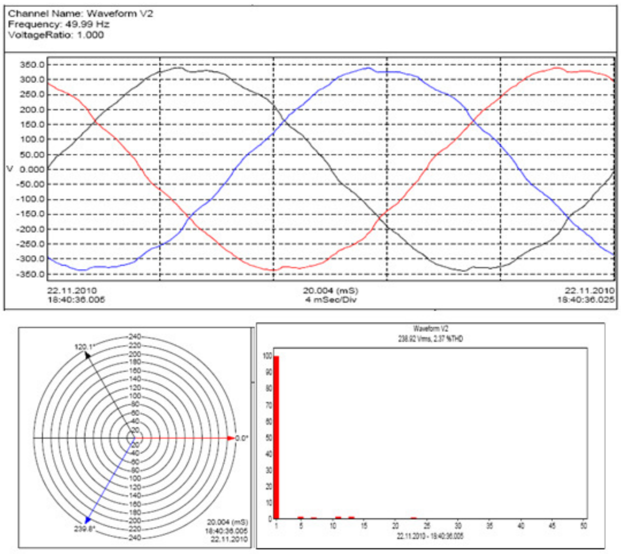


Fig. 4 – Characterization elements of voltage quality on secondary of transformer T1 (2010)

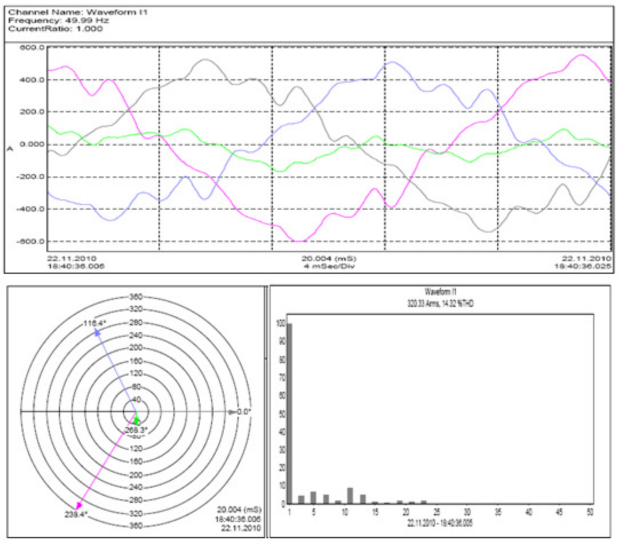
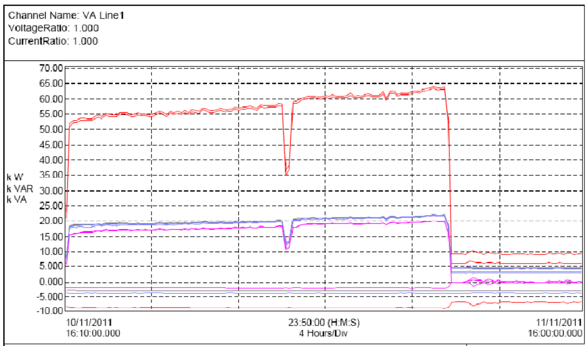
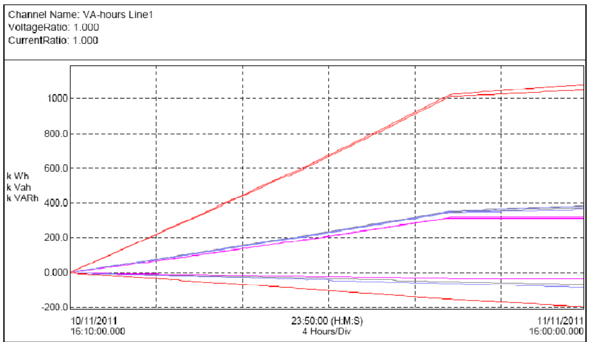


Fig. 5 – Characterization elements of voltage quality on secondary of transformer T2 (2010)



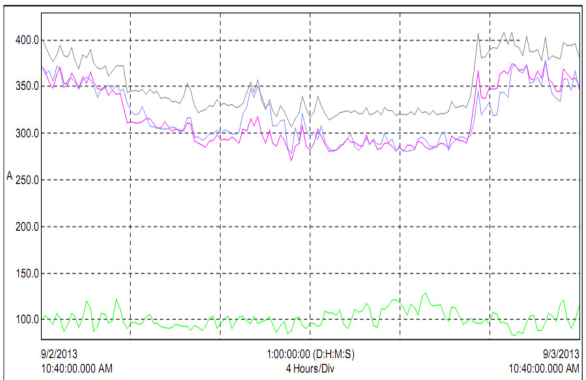
Name	Date	Time	Avg	Min	Max	Units
VA Line1	10/11/2011	16:10:00.000	15.924	4.3008	22.050	k VA
VA Line2	10/11/2011	16:10:00.000	13.321k	0.0000	20.173k	VA
VA Line3	10/11/2011	16:10:00.000	15.856	4.4618	22.086	k VA
VA Sum of Phases	10/11/2011	16:10:00.000	45.101	8.9076	64.309	k VA
VAR Line1	10/11/2011	16:10:00.000	-2.9356	-3.0508	-2.7585	k VAR
VAR Line2	10/11/2011	16:10:00.000	-1.5399k	-2.1343k	0.0000	VAR
VAR Line3	10/11/2011	16:10:00.000	-3.6232	-3.8309	-3.4730	k VAR
VAR Sum of Phases	10/11/2011	16:10:00.000	-8.0987	-8.7835	-6.5144	k VAR
W Line1	10/11/2011	16:10:00.000	15.465	3.2109	21.853	k W
W Line2	10/11/2011	16:10:00.000	13.195k	0.0000	20.069k	W
W Line3	10/11/2011	16:10:00.000	15.141	2.7469	21.791	k W
W Sum of Phases	10/11/2011	16:10:00.000	43.800	6.0172	63.713	k W

Fig. 6 – Load curves of power for air treatment instalation (2011)



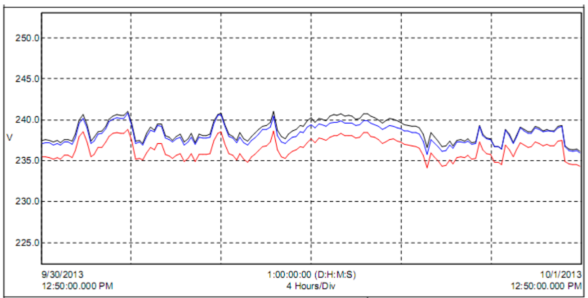
Name	Date	Time	Max	Units
VA-hours Line1	10/11/2011	16:10:00.000	382.18	k Vah
VA-hours Line2	10/11/2011	16:10:00.000	319.69	k Vah
VA-hours Line3	10/11/2011	16:10:00.000	380.54	k Vah
VA-hours Sum of Phases	10/11/2011	16:10:00.000	1.0824M	Vah
VAR-hours Line1	10/11/2011	16:10:00.000	-470.43	VARh
VAR-hours Line2	10/11/2011	16:10:00.000	-308.27	VARh
VAR-hours Line3	10/11/2011	16:10:00.000	-578.83	VARh
VAR-hours Sum of Phases	10/11/2011	16:10:00.000	-1.3575	k VARh
W-hours Line1	10/11/2011	16:10:00.000	371.16	k Wh
W-hours Line2	10/11/2011	16:10:00.000	316.67k	Wh
W-hours Line3	10/11/2011	16:10:00.000	363.38	k Wh
W-hours Sum of Phases	10/11/2011	16:10:00.000	1.0512M	Wh

Fig. 7 – Load curves of energies for Curbele de sarcină ale energiilor air treatment instalation(2011)



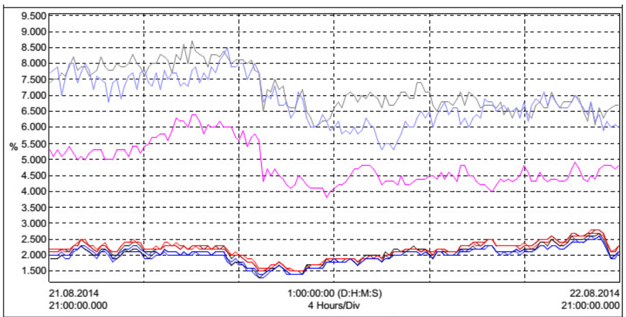
Name	Date	Time	Avg	Min	Max	Units
Arms Line2	9/2/2013	10:40:00.000 AM	316.61	271.30	378.00	A
Arms Line3	9/2/2013	10:40:00.000 AM	319.02	278.30	377.30	A
Arms Neutral	9/2/2013	10:40:00.000 AM	101.05	82.800	129.30	A
Arms Line1	9/2/2013	10:40:00.000 AM	349.46	307.30	408.60	A

Fig. 8 – Current curve for techenological line 1 (2013)



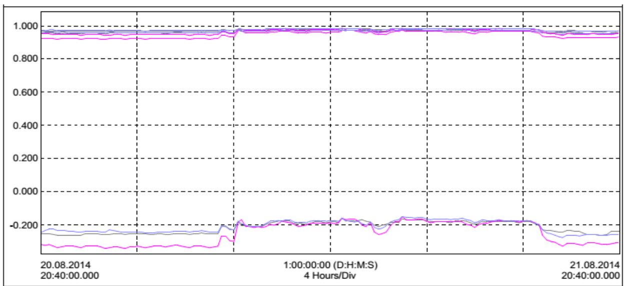
Name	Date	Time	Avg	Min	Max	Units
Vrms Line2	9/30/2013	12:50:00.000 PM	236.44	234.10	238.80	V
Vrms Line3	9/30/2013	12:50:00.000 PM	238.23	235.80	240.80	V
Vrms Line1	9/30/2013	12:50:00.000 PM	238.66	236.10	241.00	V

Fig. 9 – Phase voltage variations for vacuum instalation (2013)



Name	Date	Time	Avg	Min	Max	Units
Athd Line1	21.08.2014	21:00:00.000	7.2152	6.0000	8.7000	%
Athd Line2	21.08.2014	21:00:00.000	4.8545	3.8000	6.4000	%
Athd Line3	21.08.2014	21:00:00.000	6.8372	5.3000	8.5000	%
Uthd Line1	21.08.2014	21:00:00.000	2.1572	1.4000	2.8000	%
Uthd Line2	21.08.2014	21:00:00.000	2.1421	1.5000	2.7000	%
Uthd Line3	21.08.2014	21:00:00.000	1.9710	1.3000	2.6000	%
Vthd Line1	21.08.2014	21:00:00.000	2.0303	1.3000	2.7000	%
Vthd Line2	21.08.2014	21:00:00.000	2.1821	1.5000	2.8000	%
Vthd Line3	21.08.2014	21:00:00.000	2.0166	1.4000	2.6000	%

Fig. 10 – THD variations for main distribution electric panel 1 (2014)



Name	Date	Time	Avg	Min	Max	Units
DPF Line1	20.08.2014	20:40:00.000	0.973	0.962	0.983	
DPF Line2	20.08.2014	20:40:00.000	0.963	0.944	0.984	
DPF Line3	20.08.2014	20:40:00.000	0.975	0.961	0.985	
PF Line1	20.08.2014	20:40:00.000	0.963	0.951	0.977	
PF Line2	20.08.2014	20:40:00.000	0.945	0.920	0.974	
PF Line3	20.08.2014	20:40:00.000	0.964	0.948	0.978	
Tan Line1	20.08.2014	20:40:00.000	-0.216	-0.264	-0.161	
Tan Line2	20.08.2014	20:40:00.000	-0.253	-0.341	-0.150	
Tan Line3	20.08.2014	20:40:00.000	-0.210	-0.278	-0.149	

Fig. 11 – Power factor variation for main distribution electric panel 2(2014)

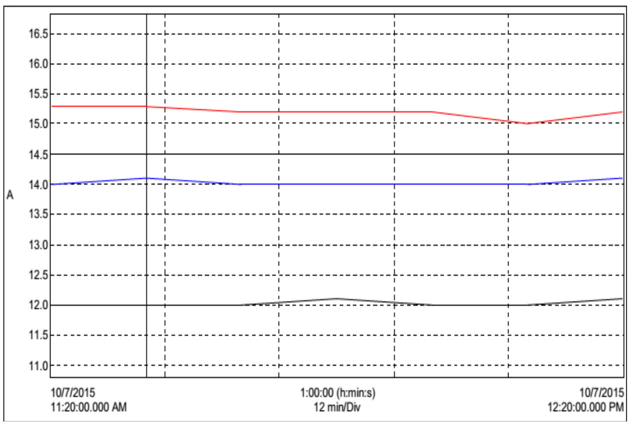
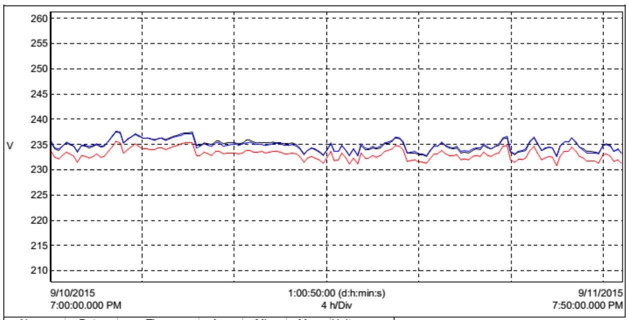


Fig. 12 – Current curve for main distribution electric panel 2 (2015)



Name	Date	Time	Avg	Min	Max	Units
Vrms Line1	9/10/2015	7:00:00.000 PM	234.847	232.700	237.500	V
Vrms Line2	9/10/2015	7:00:00.000 PM	233.076	230.900	235.600	V
Vrms Line3	9/10/2015	7:00:00.000 PM	234.848	232.700	237.600	V

Fig. 13 – Phase voltage variations for main distribution electric panel 1 (2015)

Other measurements can be viewed on [8].

Based on evaluations from [8] supplemented with those defined in this paper we are giving in figures 14÷26, evolution in time of parameters which characterize EB of S.C. Celestica Romania S.R.L.

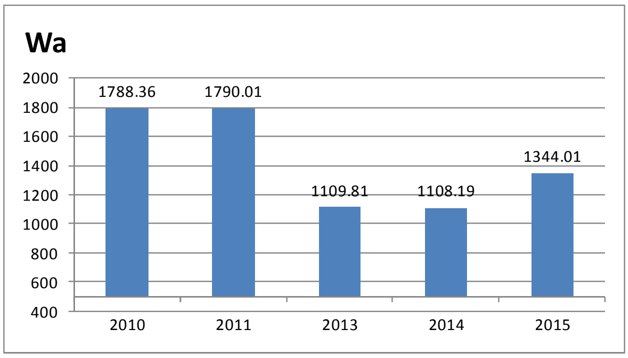


Fig. 13 – Absorbed electric energy time variation [kWh](real balance)

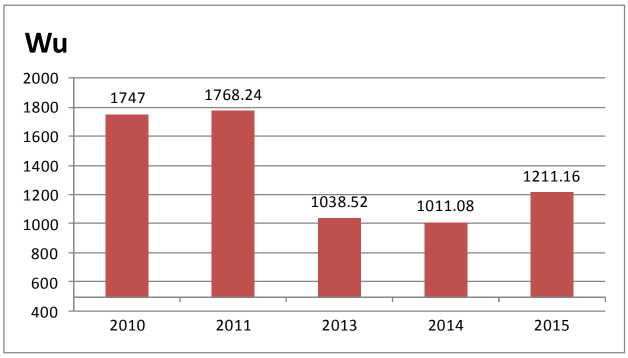


Fig. 14 – Useful energy time variation [kWh] (real balance)

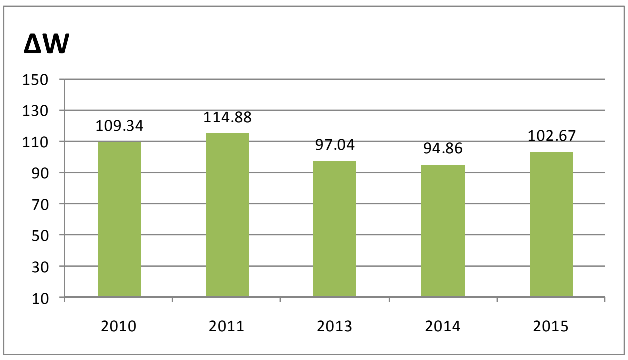


Fig. 15 – Total energy losses time variation[kWh](real balance)

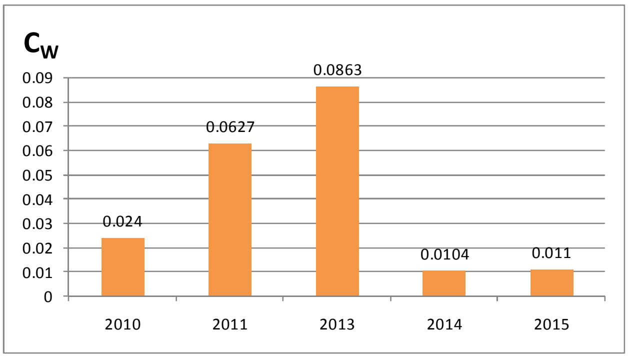


Fig. 16 –Time variation of electricity consumption per monetary unit obtained from provided service [kWh/leu](real balance)

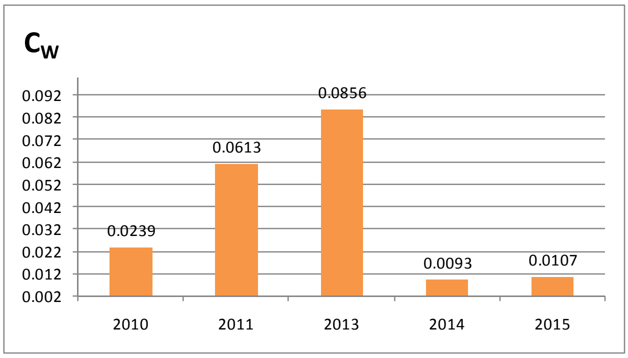


Fig. 20 – Time variation of electricity consumption per monetary unit obtained from provided service [kWh/leu](optimum balance)

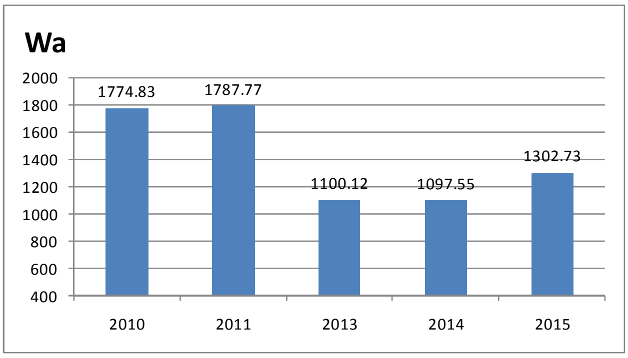


Fig. 17 – Time variation of absorbed energy [kWh](optimum balance)

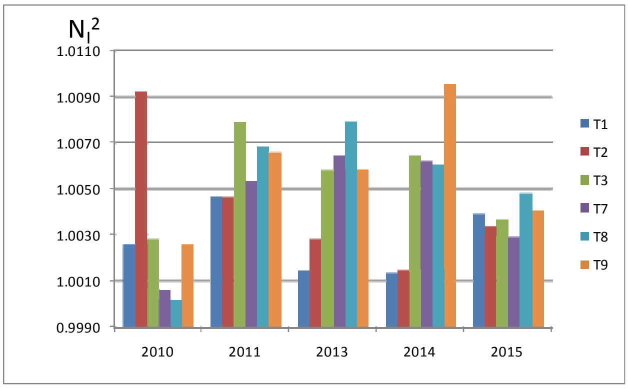


Fig. 21 – Imbalance degree of current system

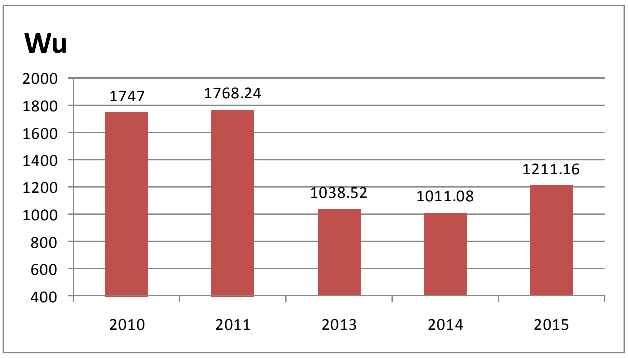


Fig. 18 – Useful energy time variation [kWh] (optimum balance)

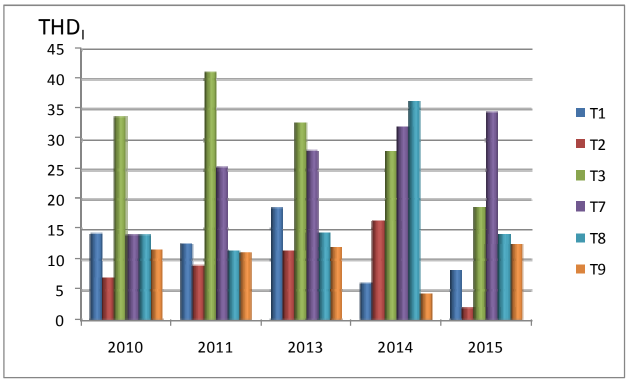


Fig. 22 – Current harmonics content [%]

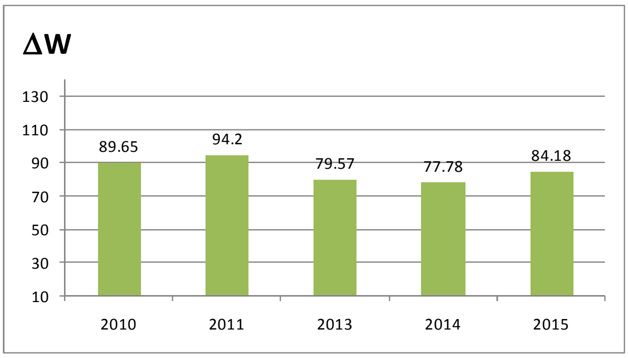


Fig. 19 – Total energy losses time variation[kWh](optimum balance)

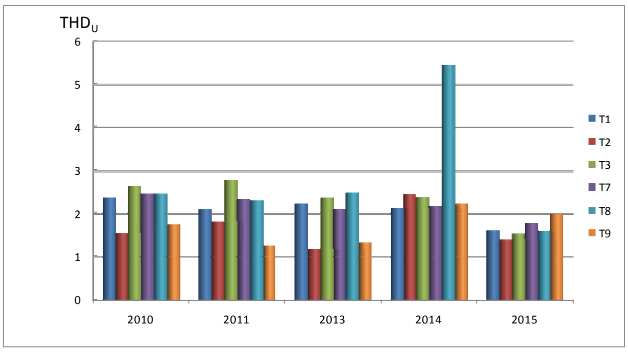


Fig. 23 – Voltage harmonics content [%]

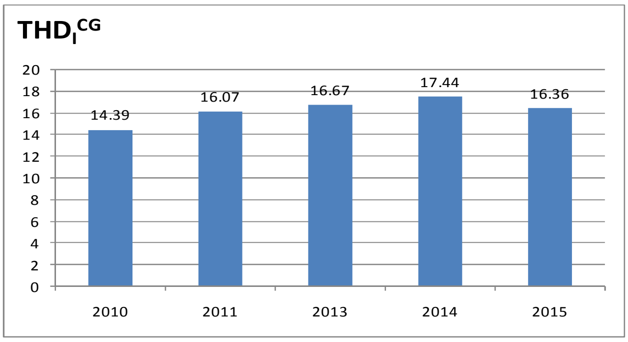


Fig. 24 – Global value of THD$_I$at CGlevel [%]

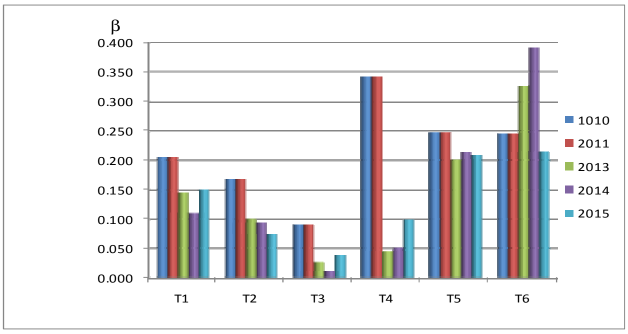


Fig. 25 – Loading degree

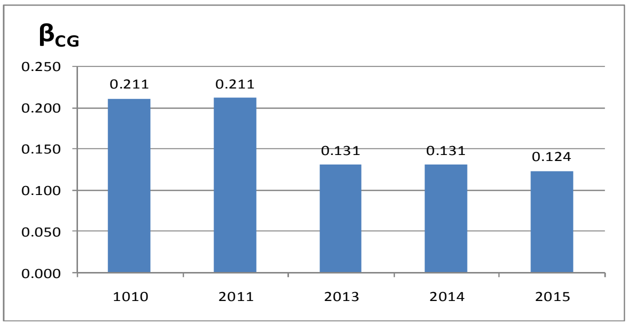


Fig. 26 – Loading degree at CG level

4. CONCLUSION

Considering the evaluation regarding the energetic behavior of analyzed consumer- S.C. Celestica Romania S.R.L., during 5 years[2010 ÷ 2015] we found out that:

- Substantial reduction of electric energy, starting with year 2013.
- Significant increase of energy losses at the level of analyzed contour, starting with year 2013. It is expected that by applying of some optimizing measures at contour level, mostly optimal configuration of the number of operating tranformers, energy losses can be reduced by 30%.
- Energetic intensity (C_W) have an increasing evolution for the first part of considered time interval[2010 ÷ 2013], followed by a substantial reduction, in the second part. It is estimatedthat there are reduction reservesof this indicator with 2,7% by applying optimization measures of electric energy consumption.
- Refering to electric energy quality we found the following:
  - ➢ At a global level a positive evolution of unbalance degree of currents system;
  - ➢ Maintaing at a relative high level of current harmonic contentmainly at transformers T_3, T_7 şi T_8, with a significant reduction in 2015;
  - ➢ Voltage harmonic content is under 3%, with a single exception (T8/2014 – over 5%);
  - ➢ The load level of global contour (transfromers and power lines) is way below under the nominal one, which reflects the substantial reserves for ptimization and growth of production.

Overall, we found an improvement of electrical energetic behaviour of consumer analyzed durind the evaluation period.

REFERENCES

[1]. *** Directiva UE nr. 27/2012 Privind eficienţa energetică http://www.europa.eu

[2]. *** „Eficienţă Energetică – prioritate pentru România”, ANRE, Bucuresti, 2016http://www.anre.ro

[3]. ***HG nr. 122/2015 pentru aprobarea Planului naţional de acţiune în domeniul eficienţei energetice http://www.anre.ro

[4]. *** Legea nr.121/2014 Privind eficienţa energetică

[5]. *** Dec. 2123/2014 - Privind aprobarea GHIDULUI de elaborare auditurilor energetice http://www.anre.ro

[6]. Carabulea A., Carabogdan I. Gh, „Modele şi bilanţuri energetice reali şi optime” Editura Academiei R.S.R., Bucureşti 1986

[7]. I. Felea, D. Albuţ-Dana, E. Barla, *Solution to increase the energy efficiency of industrial consumers. Case study CELESTICA Romania,* Journal of Sustainable Energy, ISSN 2067 – 5534, Vol. II, No. 2, pg. 16 – 20, 2011

[8]. Felea I., s.a. – Documentaţii privind AEE la S.C. CELESTICA ROMÂNIA S.R.L în perioada 2009 – 2015

[9]. Berinde T. şi Berinde M., „Bilanţuri energetice în procese industriale” Editura Tehnică Bucureşti,1985

[10]. Felea I., Dale E., „Efecte ale RDN”, Editura Universităţii Oradea, 2002

[11]. I. Felea ş.a. *Efecte ale regimului deformant*, Editura Universităţii din Oradea, 2009, 423 pg., ISBN 978-973-759-864-6

[12]. I. Felea, E. Dale, N. Coroiu, E. Barla - *Evaluarea gradului de afectare a eficienţei reţelelor electrice de distribuţie în regim deformant şi nesimetric*, Revista Energetica nr.10/ 2011, pag 352 – 357

[13]. I. Felea, G. Bendea, O. Chereches, C. Bendea, I. Almasan, *Considerations Regarding The Recovering Of Power Transformers Power Losses From HV / MV Electric Stations*, Journal of Sustainable Energy, Vol.II, Nr.3, December, 2011, ISSN 2067-5534

[14]. I. Felea, *Ingineria fiabilităţii în electroenergetică*, E.D.P. Bucureşti, 1996, 465 pg., ISBN 973-30-5685-5

[15]. I. Felea, I. Csuzi, F. Dan, *The Power Electric Audit Of Oradea Urban Transport Operator*, 8th World Energy System Conference, 1st -3rd July, 2010, Valahia University of Targoviste, Romania, indexata BDI

[16]. Felea I., s.a, Electricity Quality Characterization at Power Consumers Level From City of Oradea,Journal of Sustainable Energy, Vol.VI, Nr.4, pag. 138 – 144, December, 2015, ISSN 2067-5534

[17]. I. Felea, Fl. Dan, *Methodological Issues And Results Obtained From An Energy Auditing Of A Foundry*, Journal of Sustainable Energy, ISSN 2067 – 5534, CNCSI B+, Vol. I, No. 3, 2010, http://www.energy-cie.ro

[18]. *** - Standardul de performanţă pentru serviciile de furnizare a energiei electrice, ANRE, Bucureşti, 2008