ELECTRICITY QUALITY CHARACTERIZATION AT POWER CONSUMERS LEVEL FROM CITY OF ORADEA

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Abstract - The paper is about de level of electricity quality in the power network and at power consumers from an urban area. The analysis was done at the request of local electricity company. After highlighting the importance of preoccupations, electricity non-quality effects and regulatory framework, in the paper is presented the working methodology and results synthesis. The last part of the paper contains the conclusions of the study.

Keywords: electricity, quality, power consumers, effects.

1. INTRODUCTION

The importance of power supply service assurance is now well known and, as a result, very clearly regulated at European [1, 2, 3] and national [4,5] level. A well-known component of power supply service is the electricity quality and the other is the continuity of this service. The definition, characterization through indicators and the investigation of electricity non-quality effects are major concerns of researchers in electric power field, both fundamentally (theoretical) and operationally, of phenomenon reality in power networks [6 ÷ 14]. Effective analysis of phenomenon span and electricity non-quality effects in distribution power networks (DPN) is imposed on the one hand by the regulatory constraints [1 ÷ 5] and on the other hand by network operators interest to optiomize the electricity transport, distribution and usage processes.

The paper continues the preoccupation of authors based on electricity quality theme [15 ÷ 20] basically being a synthesis of results obtained from investigation of two essential aspects which characterize electricity quality, respectively harmonic regime(HR) and asymmetrical regime(ER) in DPN and at electricity consumers level, consumers from Oradea city. The analysis have a strictly applicative character and was performed at SDEE Oradea request, based on the service provider contract no. 34264/2014, entitled "Characterization of electricity quality at power consumers level from Oradea city".

In accordance with the objectives agreed with the beneficiary, analysis was conducted on power consumers suspected that generates harmonic and/or asymmetrical regime. It was decided together with the contract beneficiary that 2 industrial consumers, 7 residential and urban public consumers, one service-type consumer and one local public transportation-type consumer should be analyzed, as highlighted on third part of the paper.

An essential objective assumed in analysis was the establishment of degree in which the HR is transmitted through electric transformers from the HR source (the consumer), in DPN. For this if the power consumer point was equipped with measurement cell then the analysis was performed both on low voltage (LV) and medium-voltage (MV).

When performing the investigation (measurements, evaluations, and interpretations) we took into consideration the stipulations of internal regulations so:

- According to *Performance Standard for Power Distribution Service*, the most important factor to characterize HR is asymmetry or imbalance coefficient, determined by negative sequence component (K_n), defined as the ratio between the mean of effective values calculated for ten minutes of negative component and the mean of effective values calculates for ten minutes of positive component, expressed in percentages;
- According to the same Standard, the voltage distortion factor at LV and MV must be smaller or equal than 8%, and in normal operation conditions, harmonic voltages at separation points in DPN, at LV and MV, cannot exceed the limits indicated in table 1 for 95% during a week.

Table 1 –Effective values of voltage harmonics [5]

Odd harmonics (% from fundamental)				Even harmonics (% from fundamental)	
NOT multiple of 3		Multiple of 3			
Rank	Threshold	Rank	Threshold	Rank	Threshold
5	6%	3	5%	2	2%
7	5%	9	1,5%	4	1%
11	3,5%	15 şi 21	0,5%	6 la 24	0,5%
13	3%				
17	2%				
19,23,25	1,5%				
19,23,25	1,5%				

Without being normalized in field literature, in practice, is recommended that THD_I should not exceed 20%.

2. METHODOLOGY

For each consumer/power consumption point where the analysis was done, in the detailed report have been shown the following characterization elements:

- Short description: The activity that takes place there, connection scheme to power network, the features of electrical transformers, measurement points;
- The recordings;
- The values of characterization indicators of harmonic regime (HR) and asymmetrical regime (AR).

Of all indicators/coefficients defined and used in field literature [1÷8], considering internal regulations and the interest of beneficiary, for this case the following coefficients were used:

$$K_{ns0} = \frac{I_d}{I_0} \text{ (asymmetry coefficient for current);} \quad (1)$$

$$r_U = \frac{U_{min}}{U_{max}} \text{ (asymmetry ratio for voltage);} \quad (2)$$

$$r_I = \frac{I_{min}}{I_{max}} \text{ (asymmetry ratio for current);} \quad (3)$$

$THD_I = \sqrt{\sum_{v=2}^{50} I_v^2}/I_1$ (total harmonic distortion for current); (4)

$THD_U = \sqrt{\sum_{v=2}^{50} U_v^2}/U_1$ (total harmonic distortion for voltage); (5)

$N_I^2 = \frac{1}{3}\cdot\left\{\left(\frac{I_R}{I_{med}}\right)^2 + \left(\frac{I_S}{I_{med}}\right)^2 + \left(\frac{I_T}{I_{med}}\right)^2\right\}$ (imbalance coefficient for current); (6)

It is calculated the asymmetry coefficient of current k_{ns2}, called in *Performance Standard for Power Distribution Service* as asymmetry or imbalance coefficient (k_n).

$$k_n = k_{ns2} = \frac{I_i}{I_d} \quad (7)$$

For this purpose, it is calculated phasor values and then effective values of the two components [21].

$$\begin{cases} \underline{I_i} = \frac{1}{3}\cdot\left(\underline{I_R} + a^2\cdot\underline{I_S} + a\cdot\underline{I_T}\right) \\ \underline{I_d} = \frac{1}{3}\cdot\left(\underline{I_R} + a\cdot\underline{I_S} + a^2\cdot\underline{I_T}\right) \\ a = -\frac{1}{2} + j\cdot\frac{\sqrt{3}}{2} \\ a^2 = -\frac{1}{2} - j\cdot\frac{\sqrt{3}}{2} \end{cases} \quad (8)$$

In relations (8) it will be replaced from measurements the following:

$$\begin{cases} \underline{I_R} = j\cdot I_{linie1} \\ \underline{I_S} = -\frac{\sqrt{3}}{2}\cdot I_{linie2} - j\frac{1}{2}\cdot I_{linie2} \\ \underline{I_T} = -\frac{\sqrt{3}}{2}\cdot I_{linie3} - j\frac{1}{2}\cdot I_{linie3} \end{cases} \quad (9)$$

From relations (8) and (9) is obtained [21]:

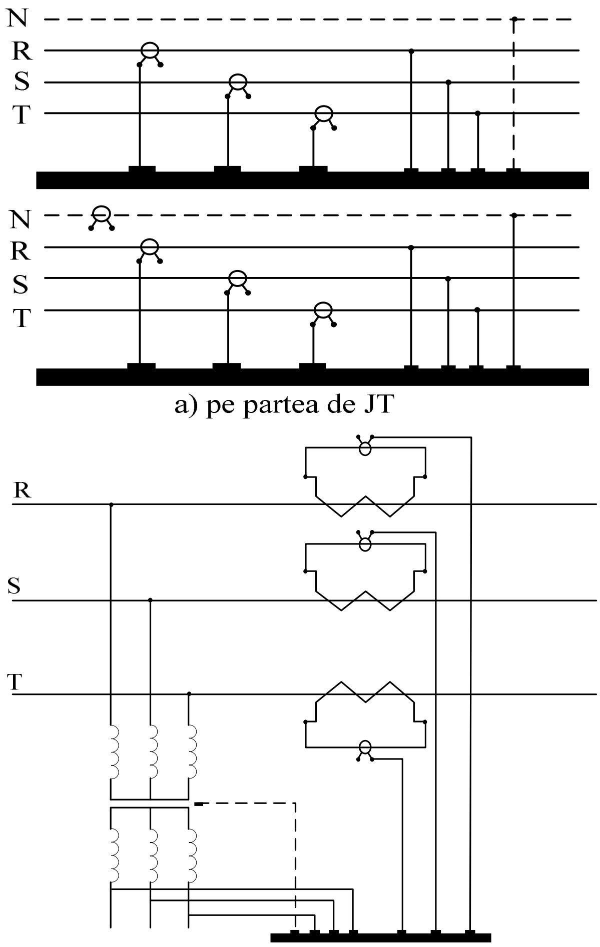
$$\begin{cases} \underline{I_d} = a_1 + j\cdot b_1 \Rightarrow I_d = \sqrt{a_1^2 + b_1^2} \\ \underline{I_i} = a_2 + j\cdot b_2 \Rightarrow I_i = \sqrt{a_2^2 + b_2^2} \end{cases} \quad (10)$$

where:

I_d – effective value of current direct sequence component;
I_0 – effective value of current homopolar sequence component;
U_{min} – minimum of voltage effective value;
U_{max} – maximum of voltage effective value;
I_{min} – minimum of current effective value;
I_{max} – maximum of current effective value;
I_v – current effective value at “v” rank harmonic;
I_1 – current effective value of fundamental harmonic;
U_v – voltage effective value at “v” rank harmonic;
U_1 – voltage effective value of fundamental harmonic;
(I_R, I_S, I_T) – current effective values on the three phases (R, S, T);
I_{med} – the mean of current effective values
I_i – effective value of current reverse sequence component;

Where recordings were made both at LV and MV indicators listed above are determined at both voltage levels. We mention that for the same ETS/measuring point, the recordings on LV and MV were made simultaneous.

To get the recordings we used two Chauvin Arnoux CA 8334B power analyzers(PA). Connection scheme of PA in DPN are shown in figure 1.



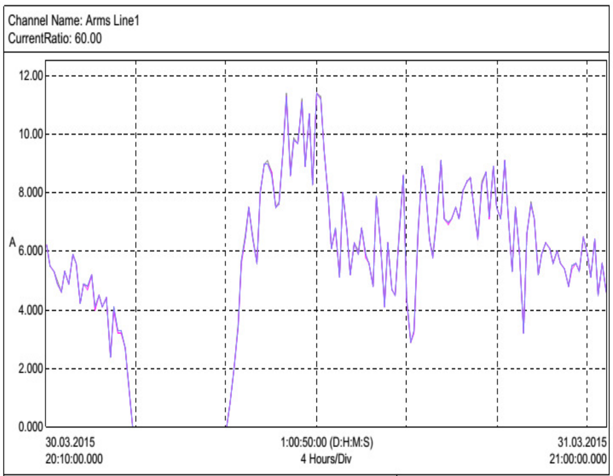
a) pe partea de JT

b) pe partea de MT

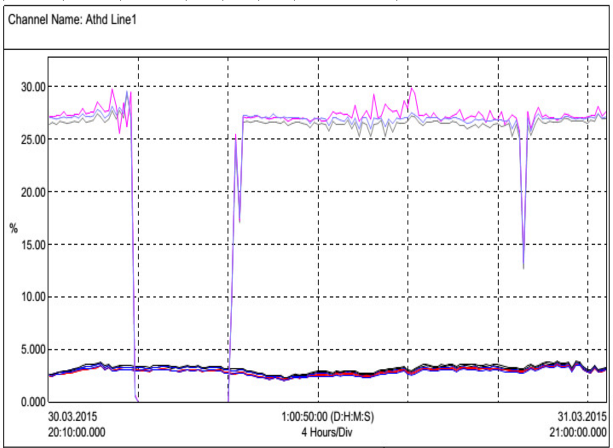
Fig. 1 – Connection scheme of PA

3. RESULTS

Research report[22] contains a number of 6 electrical scheme where are presented the place of each ETS within the power network of Oradea city, a number of 113 figures showing the results obtained with PA and a number of 50 tables containing the evaluated coefficients concerning electrical power quality. We are presenting below some of these PA recordings (figure 2 ÷ 7)

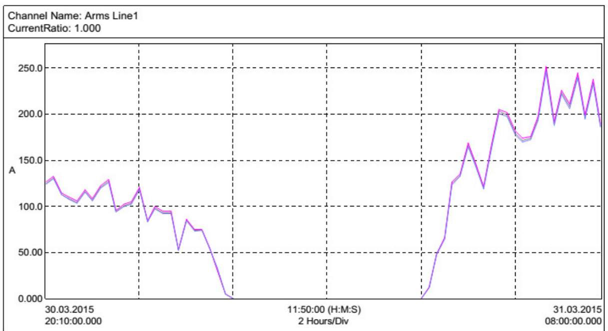


Name	Date	Time	Avg	Min	Max	Units
Arms Line1	30.03.2015	20:10:00.000	5.2793	0.0000	11.400	A
Arms Line2	30.03.2015	20:10:00.000	5.2580	0.0000	11.400	A
Arms Line3	30.03.2015	20:10:00.000	5.2667	0.0000	11.400	A

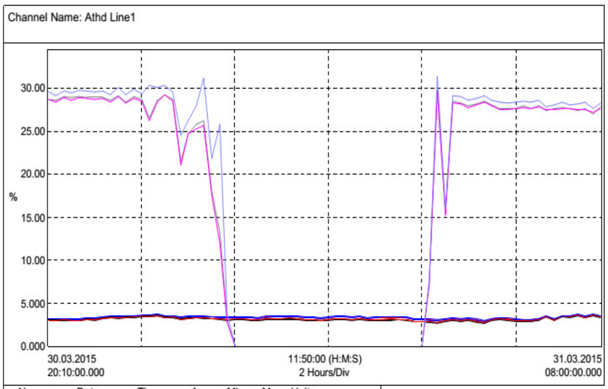


Name	Date	Time	Avg	Min	Max	Units
Athd Line1	30.03.2015	20:10:00.000	21.677	0.0000	29.400	%
Athd Line2	30.03.2015	20:10:00.000	22.340	0.0000	29.900	%
Athd Line3	30.03.2015	20:10:00.000	22.051	0.0000	29.600	%
Uthd Line1	30.03.2015	20:10:00.000	3.1453	2.3000	3.8000	%
Uthd Line2	30.03.2015	20:10:00.000	2.9113	2.1000	3.6000	%
Uthd Line3	30.03.2015	20:10:00.000	3.1013	2.3000	3.7000	%
Vthd Line1	30.03.2015	20:10:00.000	3.2607	2.4000	3.9000	%
Vthd Line2	30.03.2015	20:10:00.000	2.9647	2.2000	3.6000	%
Vthd Line3	30.03.2015	20:10:00.000	2.8813	2.1000	3.5000	%

Fig. 2 – Recordings on MV cell – ETS Gară – OTL

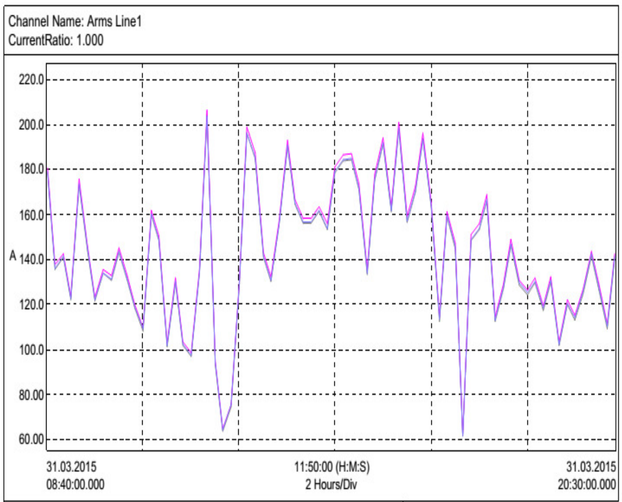


Name	Date	Time	Avg	Min	Max	Units
Arms Line1	30.03.2015	20:10:00.000	83.969	0.0000	248.60	A
Arms Line2	30.03.2015	20:10:00.000	85.011	0.0000	251.30	A
Arms Line3	30.03.2015	20:10:00.000	83.196	0.0000	245.40	A

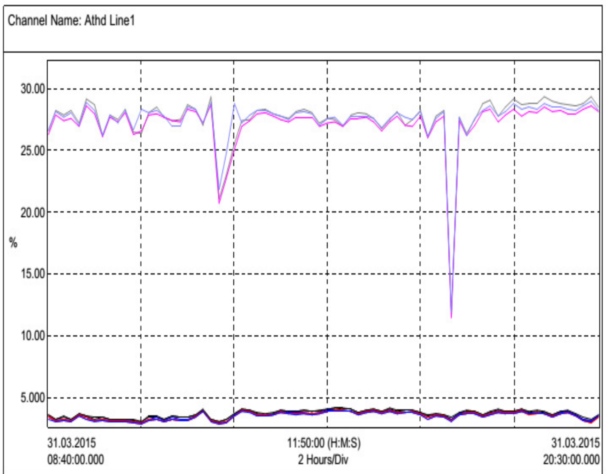


Name	Date	Time	Avg	Min	Max	Units
Athd Line1	30.03.2015	20:10:00.000	17.081	0.0000	29.800	%
Athd Line2	30.03.2015	20:10:00.000	16.968	0.0000	29.600	%
Athd Line3	30.03.2015	20:10:00.000	17.928	0.0000	31.400	%
Uthd Line1	30.03.2015	20:10:00.000	3.0958	2.7000	3.6000	%
Uthd Line2	30.03.2015	20:10:00.000	3.3111	2.9000	3.7000	%
Uthd Line3	30.03.2015	20:10:00.000	3.2958	2.9000	3.8000	%
Vthd Line1	30.03.2015	20:10:00.000	3.1681	2.7000	3.7000	%
Vthd Line2	30.03.2015	20:10:00.000	3.1681	2.8000	3.7000	%
Vthd Line3	30.03.2015	20:10:00.000	3.3903	3.0000	3.8000	%

Fig. 3 - Recordings on LV cell –ETS (transformer 1) Gară - OTL

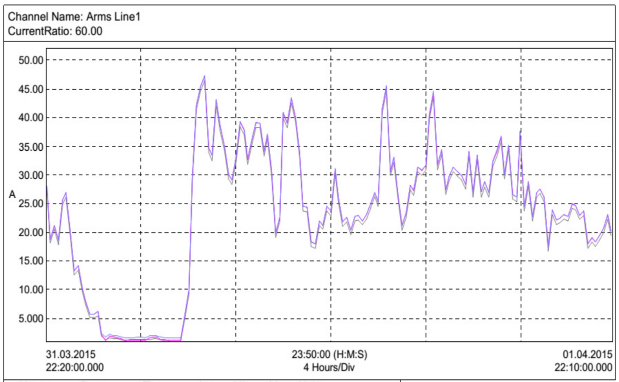


Name	Date	Time	Avg	Min	Max	Units
Arms Line1	31.03.2015	08:40:00.000	141.96	61.600	204.30	A
Arms Line2	31.03.2015	08:40:00.000	144.14	62.500	206.70	A
Arms Line3	31.03.2015	08:40:00.000	142.54	61.900	204.00	A

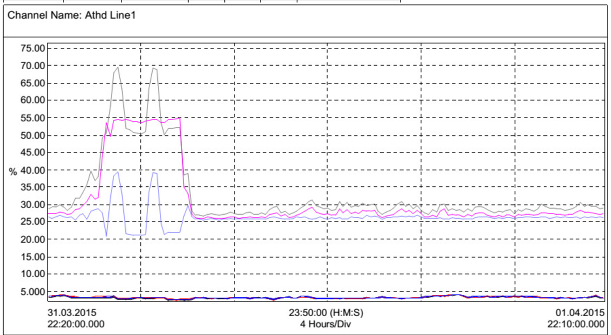


Name	Date	Time	Avg	Min	Max	Units
Athd Line1	31.03.2015	08:40:00.000	27.558	11.800	29.400	%
Athd Line2	31.03.2015	08:40:00.000	27.176	11.500	28.700	%
Athd Line3	31.03.2015	08:40:00.000	27.542	12.000	29.000	%
Uthd Line1	31.03.2015	08:40:00.000	3.6847	3.1000	4.2000	%
Uthd Line2	31.03.2015	08:40:00.000	3.4972	2.9000	3.9000	%
Uthd Line3	31.03.2015	08:40:00.000	3.5875	3.0000	4.0000	%
Vthd Line1	31.03.2015	08:40:00.000	3.7222	3.1000	4.2000	%
Vthd Line2	31.03.2015	08:40:00.000	3.5639	3.0000	4.0000	%
Vthd Line3	31.03.2015	08:40:00.000	3.4944	2.9000	3.9000	%

Fig. 4 - Recordings on LV cell –ETS (transformer 2) Gară - OTL

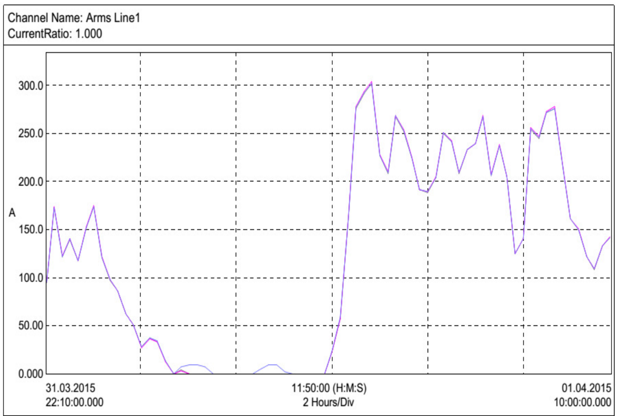


Name	Date	Time	Avg	Min	Max	Units
Arms Line1	31.03.2015	22:20:00.000	22.976	1.2000	46.500	A
Arms Line2	31.03.2015	22:20:00.000	23.656	1.1000	47.300	A
Arms Line3	31.03.2015	22:20:00.000	23.738	1.7000	47.400	A

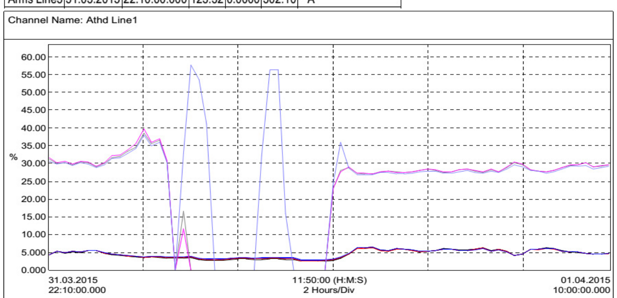


Name	Date	Time	Avg	Min	Max	Units
Athd Line1	31.03.2015	22:20:00.000	33.162	26.700	69.600	%
Athd Line2	31.03.2015	22:20:00.000	31.314	26.000	54.900	%
Athd Line3	31.03.2015	22:20:00.000	26.376	20.900	39.400	%
Uthd Line1	31.03.2015	22:20:00.000	3.2632	2.4000	4.0000	%
Uthd Line2	31.03.2015	22:20:00.000	3.3660	2.7000	4.1000	%
Uthd Line3	31.03.2015	22:20:00.000	3.2590	2.5000	4.0000	%
Vthd Line1	31.03.2015	22:20:00.000	3.1250	2.4000	3.9000	%
Vthd Line2	31.03.2015	22:20:00.000	3.1938	2.5000	4.0000	%
Vthd Line3	31.03.2015	22:20:00.000	3.2389	2.6000	4.0000	%

Fig. 5 – Recordings on MV cell – ETS Salca - OTL

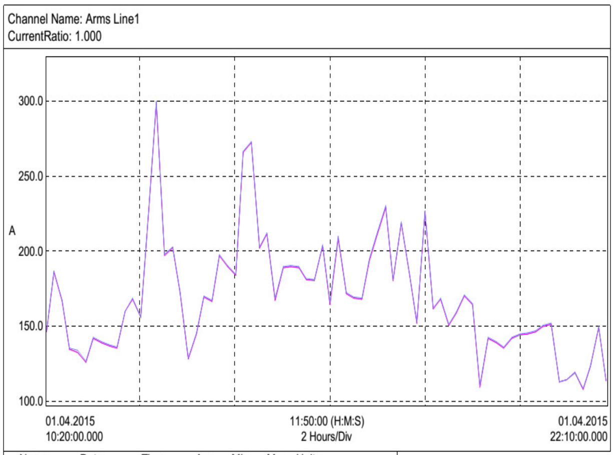


Name	Date	Time	Avg	Min	Max	Units
Arms Line1	31.03.2015	22:10:00.000	122.25	0.0000	301.30	A
Arms Line2	31.03.2015	22:10:00.000	122.81	0.0000	303.50	A
Arms Line3	31.03.2015	22:10:00.000	123.32	0.0000	302.10	A

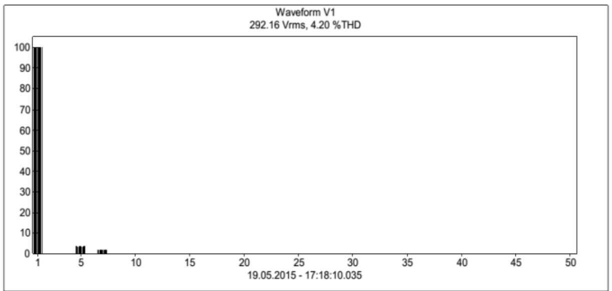


Name	Date	Time	Avg	Min	Max	Units
Athd Line1	31.03.2015	22:10:00.000	21.439	0.0000	38.600	%
Athd Line2	31.03.2015	22:10:00.000	21.500	0.0000	39.700	%
Athd Line3	31.03.2015	22:10:00.000	25.903	0.0000	57.700	%
Uthd Line1	31.03.2015	22:10:00.000	4.4736	2.5000	6.4000	%
Uthd Line2	31.03.2015	22:10:00.000	4.5931	2.8000	6.4000	%
Uthd Line3	31.03.2015	22:10:00.000	4.6264	2.8000	6.5000	%
Vthd Line1	31.03.2015	22:10:00.000	4.5681	2.6000	6.5000	%
Vthd Line2	31.03.2015	22:10:00.000	4.5583	2.6000	6.5000	%
Vthd Line3	31.03.2015	22:10:00.000	4.6611	2.9000	6.5000	%

Fig. 6 – Recordings on LV cell - ETS (transformer 1) Salca - OTL



Name	Date	Time	Avg	Min	Max	Units
Arms Line1	01.04.2015	10:20:00.000	168.93	107.60	299.60	A
Arms Line2	01.04.2015	10:20:00.000	168.84	107.80	299.10	A
Arms Line3	01.04.2015	10:20:00.000	169.64	108.30	300.10	A



Waveform V1

	(%)		(%)		(%)
H01	100.0	H19	0.3	H37	0.2
H02	0.0	H20	0.0	H38	0.0
H03	0.4	H21	0.1	H39	0.1
H04	0.1	H22	0.0	H40	0.0
H05	3.5	H23	0.3	H41	0.4
H06	0.4	H24	0.1	H42	0.1
H07	1.9	H25	0.3	H43	0.2
H08	0.0	H26	0.0	H44	0.0
H09	0.2	H27	0.1	H45	0.1
H10	0.0	H28	0.0	H46	0.0
H11	0.4	H29	0.4	H47	0.4
H12	0.2	H30	0.1	H48	0.1
H13	0.2	H31	0.2	H49	0.2
H14	0.0	H32	0.0	H50	0.0
H15	0.2	H33	0.1		
H16	0.0	H34	0.0		
H17	0.4	H35	0.4		
H18	0.1	H36	0.1		

Fig. 7- Recordings on LV cell - ETS (transformer 2) Salca - OTL

In figures 8 and 9 are presented the indicators used to characterize HR(THD_U, THD_I) at LV and MV of ETS under OTL company management and in figures 10 and 11 are shown the values of THD_I from the others ETS/consumer points analyzed.

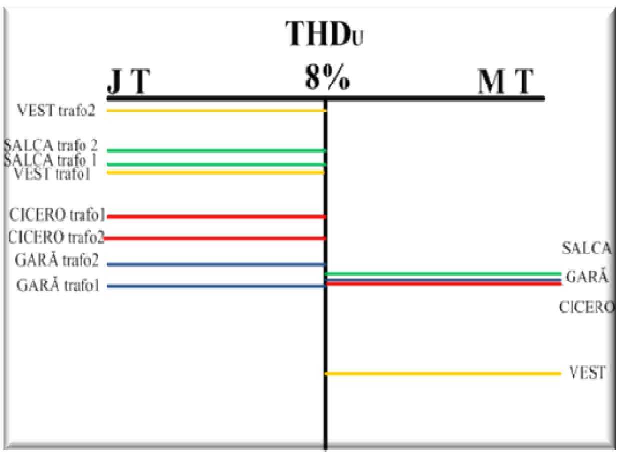


Fig. 8 – Values of coefficient THD_U – ETS OTL

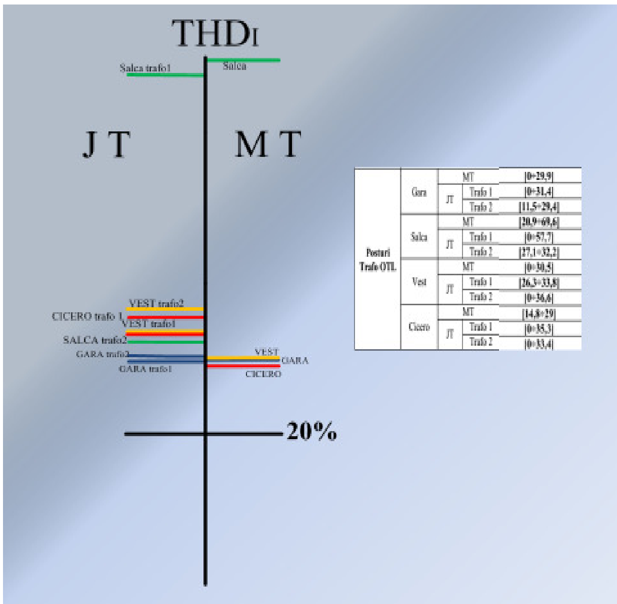


Fig. 9 – Values of coefficient THD_I – ETS OTL

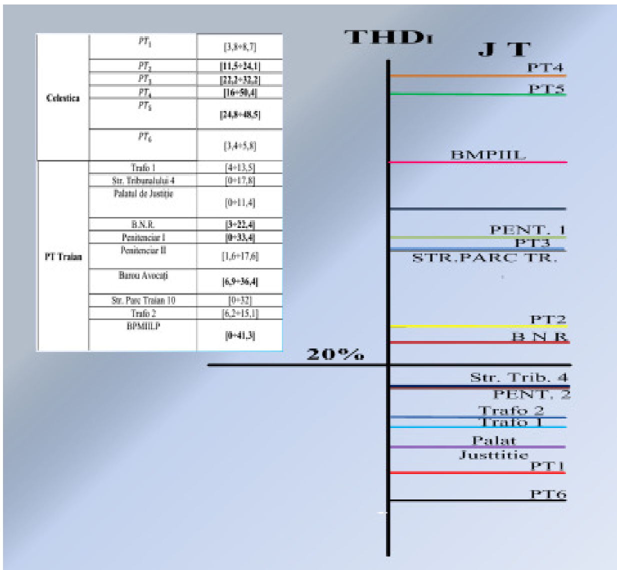


Fig. 10 – Values of coefficient THD_I at ETS "Celestica" and ETS "Traian"

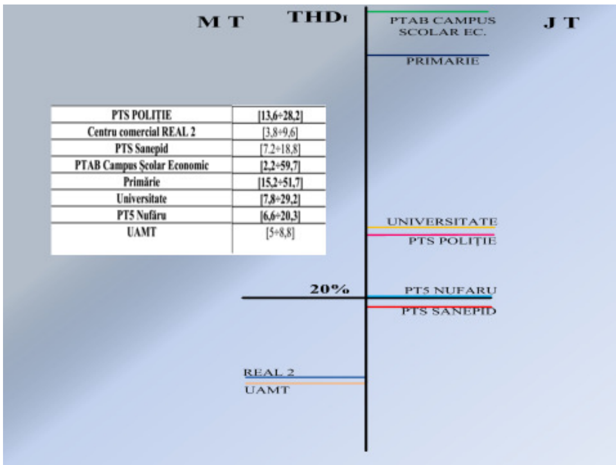


Fig. 11 – Operational levels of coefficient THD_I on specified consumer points

In analyzes we paid great attention to ETS belonging to OTL company – this being an urban power consumer with major impact on electricity quality from city of Oradea. I figure 12 are shown the levels of coefficient K_n for measurement points where this coefficient exceed the allowable values and in table 2 are given the values for others indicators which characterize HR.

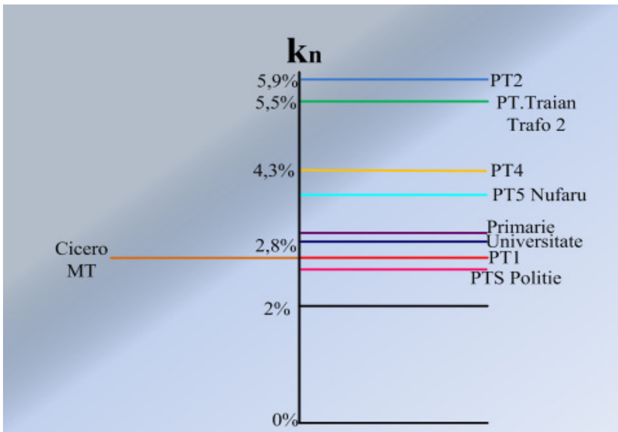


Fig. 12 – Values of „K_n" on consumer points where this coefficient exceeds the recommended limits

Table 2 – Synthesis of AR in DPN analyzed

Consumer / Consumer point		Indicators				
		Referring to voltage	Referring to current			
		r_U	r_I	k_{ns0}	N_I^2	$k_{ns2}[\%]$
ETS Celestica	PT_1	0,9774	0,687	[3,799÷4,345]	[1,0015÷1,003]	**2,8***
	PT_2	0,9780	0,612	[2,010÷2,524]	[1,0039÷1,0106]	**5,9***
	PT_3	0,9799	0,745	[1,898÷1,927]	[1,0004÷1,0007]	1,8
	PT_4	0,9789	0,354	[3,313÷7,091]	[1,0025÷1,0046]	**4,3***
	PT_5	0,9744	0,801	[21,824÷22,7]	[1,0004÷1,0007]	1,6
	PT_6	0,9787	0,493	[12,241÷23,074]	[1,0002÷1,0007]	1,3

Table 2 – continuation

Consumer / Consumer point				Indicators: Referring to voltage r_U	Referring to current: r_I	k_{ns0}	N_I^2	k_{ns2}[%]
ETS Traian	Trafo 1			0,971	0,295	[2,769÷3,399]	[1,3336÷1,3354]	1,3
	Str. Tribunalului 4			0,973	0,173	[0÷0,770]	[1,3507÷2,0395]	
	Palatul de Justiție			0,972	0,626	[0,235÷0,243]	[1,8898÷2]	
	B.N.R.			0,973	0,168	[0,981÷1,624]	[1,3553÷1,4216]	
	Penitenciar I			0,975	0,340	[0,645÷1,153]	[1,5÷1,5057]	
	Penitenciar II			0,975	0,343	[0,561÷0,576]	[1,4132÷1,4571]	
	Barou Avocați			0,972	0,250	[0,381÷0,518]	[1,3385÷1,3892]	
	Str. Parc Traian 10			0,972	0,001	[0,111÷0,719]	[1,3723÷2]	
	Trafo 2			0,971	0,359	[2,608÷3,013]	[1,3334÷1.3388]	**5,5***
	BPMIILP			0,972	0,449	[0,342÷0,342]	[3÷3]	
ETS OTL	Gara	MV		0,975	0,462		[1÷1,000003]	0,117
		LV	Trafo 1	0,974	0,338	[9.002÷19.453]	[1,0001÷1,0001]	0,65
			Trafo 2	0,976	0,302	[14.298÷27.025]	[1,00003÷1,00004]	0,45
	Salca	MT		0,971	0,0283		[1,0001÷1,0388]	1
		LV	Trafo 1	0,966	0,406	[13,881÷31,198]	[1,000009÷1,000013]	0,25
			Trafo 2	0,976	0,360	[0,222÷19,483]	[1,000002÷1,000007]	0,2
	Vest	MT		0,973	0,327		[1,5002÷1,5046]	
		LV	Trafo 1	0,974	0,162	[16,114÷28,383]	[1,000001÷1,000577]	0,075
			Trafo 2	0,956	0,3511	[11,658÷21,803]	[1,00014÷1,00016]	0,84
	Cicero	MT		0,976	0,093		[1÷1,015]	**2,8***
		LV	Trafo 1	0,976	0,402	[13,104÷26,137]	[1,000001÷1,000015]	0,07
			Trafo 2	0,976	0,462	[9,208÷21,754]	[1,000004÷1,000006]	0,17
ETS "Poliție"				0,978	0,366	[1,8948÷2,1505]	[1,3339÷1,3347]	**2,6***
Mall REAL 2				0,973	0,507	[÷]	[1,3334÷1,3336]	0,73
ETS "Sanepid"				0,979	0,472	[2,3166÷3,5558]	[1,33397÷1,33481]	1,9
ETS "Campus Școlar Economic"				0,974	0,034	[0,0843÷1,1729]	[1,4014÷2,1582]	**33,4***
ETS "Primărie"				0,974	0,176	[1,0630÷1,8154]	[1,3334÷1,3371]	**3,35***
ETS "Universitate"				0,965	0,219	[2,4134÷2,6644]	[1,3341÷1,3383]	**3,2***
ETS "Nufărul"				0,955	0,446	[2,6159÷2,9284]	[1,335÷1,3362]	**3,9***
UAMT				0,974	0,608	[÷]	[1,3334÷1,3337]	1,2

***Values above admissible limits, according to Performance Standard for Power Distribution Service.**

4. CONCLUSION

- The values of THD_U are below admissible limit (8%) for all consumers/consumers points analyzed. These values are lower on MV as against to LV on ETS of OTL company, which shows an attenuation by the transformer of voltage HR.
- Recommended values of THD_I (20%) is exceeded at the following consumers/consumer points:
  - S.C. CELESTICA (ROMÂNIA) S.R.L.: ETS_2÷ETS_5
  - ETS "Traian" with feeder lines: B.N.R., Penitenciar I, Barou Avocați, BPMIILP.
  - ETS OTL: maximum allowable values of THD_I are exceeded on all measument points, respectively Gara, Salca, Vest și Cicero. On ETS Salca, we recorded values of THD_I higher on MV than LV;
  - ETS "Campus Școlar Economic"
  - ETS "Primărie"
  - ETS "Universitate"
  - ETS "Nufărul"
- The recording from OT company reflects that harmonic residue generated on LV is transmitted to MV also;
- Referring to AR we find that allowable value of current asymmetry coefficient k_n (2%) is exceeded at the following consumers/consumer points:
  - S.C. CELESTICA (ROMÂNIA) S.R.L.: ETS_1, ETS_2, ETS_4
  - ETS "Traian" – Transformer 2
  - ETS OTL – Cicero at MV
  - ETS "Poliție"
  - ETS "Campus Școlar Economic"
  - ETS "Primărie"
  - ETS "Universitate"
  - ETS "Nufărul" – ETS 5

We are concluding that these types of analyzes are needed and useful, so is imperative their continuation by evaluating of HR effects and highlighting the counteracting solutions.

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