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Contributing by Monitoring Energy Efficiency to the Development of Optimization Measures to Improve Energy Performance in an Industrial Platform

Laurentiu Constantin Lipan

Abstract

Greenhouse gas emissions and climate change are currently major international problems. This makes it important to increase energy efficiency. The implementation of energy efficiency improvement measures has reduced energy demand for industrial platforms, so that energy plans designed before these measures are no longer appropriate for current tasks (extensions are not considered at this time). I intended to give a clear image and a better understanding of the factories' power consumption (the industrial area in question is located near a city). A power plant-specific power system is quite disruptive, as can be seen from the monitored data at the power plant users and from the general power supply voltage bars (110 kV, 20 kV) as well as from the voltage bars of the adjacent users. Based on real-time measurements and monitoring devices, the following characteristic curves have been extracted for local energy systems. That is because data analysis is easy to be used for monitoring energy efficiency and elaborating optimization measures to improve power performance.

Keywords: greenhouse gas emissions, intelligent platforms, advanced metering infrastructure (AMI), intelligent networks, U-THD, I-THD

1. Introduction

The experimental study of the energy action/behavior of an industrial user allows to highlight its energetic performance, practical ways to improve its energy use, as well as validating the theoretical hypotheses formulated in order to assess this user. Assessing the power quality supplied in the public system and observing the quality indicators for compliance with accepted standard limits plays an important role in order to establish the optimal functioning parameters for this industrial power user. In this paper, the results of the experimental study achieved at a large-scale/industrial power user are exposed, along with the problems that emerged from

this research. Moreover, solutions for solving these kind of problems are indicated. The analysis of the power supply quality of the three-phase general power supply circuit of the analyzed user was performed on the 110 kV side in the measuring cells in the secondary measuring circuits of the T1 110/20 kV transformer, 16 MVA.

2. Analysis of the quality of the electrical power on the bars of 110 kV

“Analysis of the quality of the electrical power supply of the three-phase general power supply circuit of the user on 110kV” is based on “Study on the quality of power supply including load analysis, problems regarding voltage/current fluctuations, interruptions in the company’s power supply, flicker monitoring, asymmetries, harmonic levels on voltage and current, for the general supply on the 110kV side of the company in the Intelligent Electrical Connections Station, without personal workers, with Advanced Metering Infrastructure (AMI)”.

The electrical installations (Figure 1) of the analyzed industrial user consist of:

- two 110/20 kV 16 MVA substations (one being in reserve) – Figure 2 and Table 1;

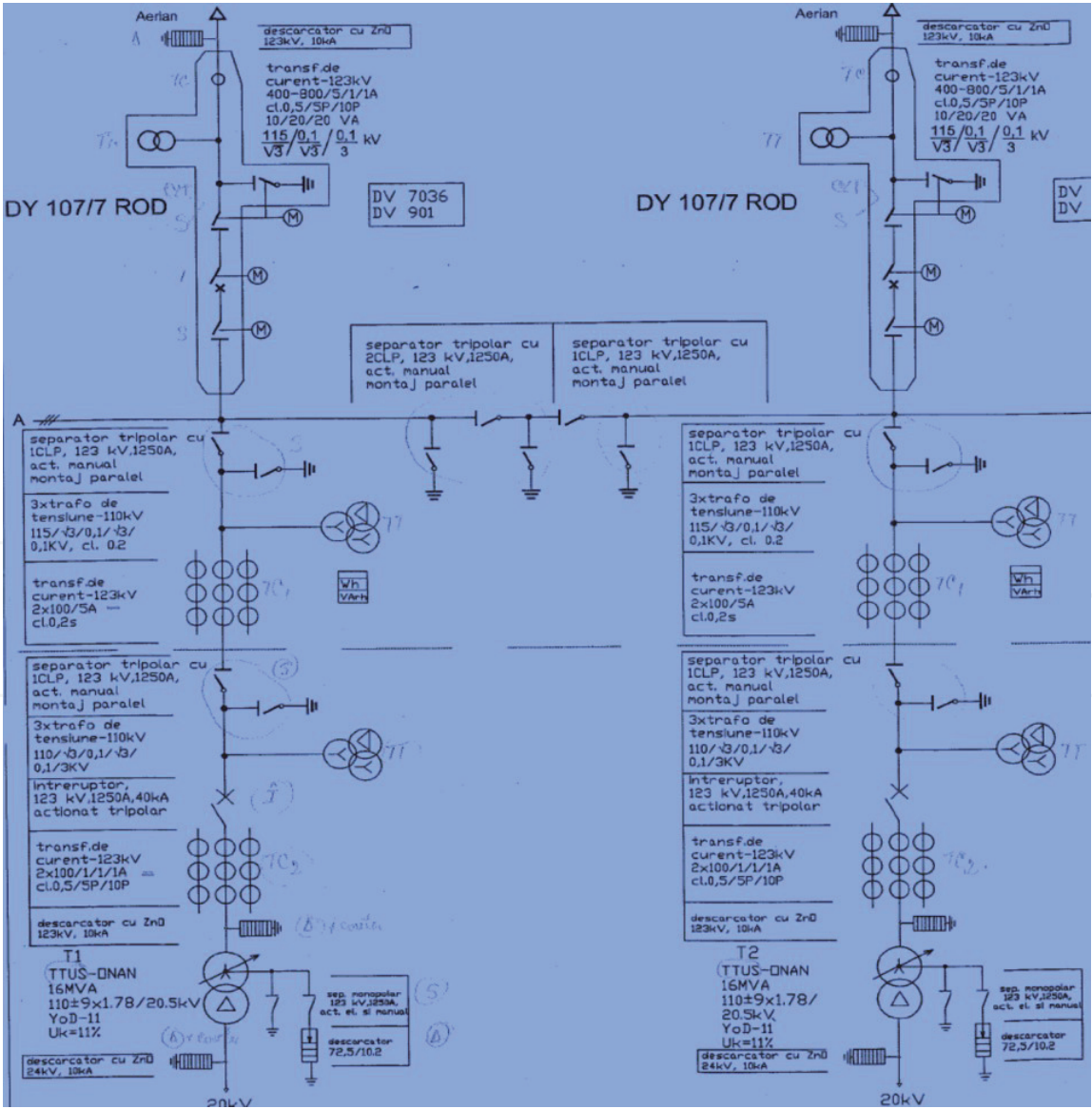


Figure 1. 110 kV single-wire power supply diagrams of the analyzed company with transformers 1 and 2, 110/20 kV of 16 MVA [copyright © 2020 PLT – Adapted working scheme] .

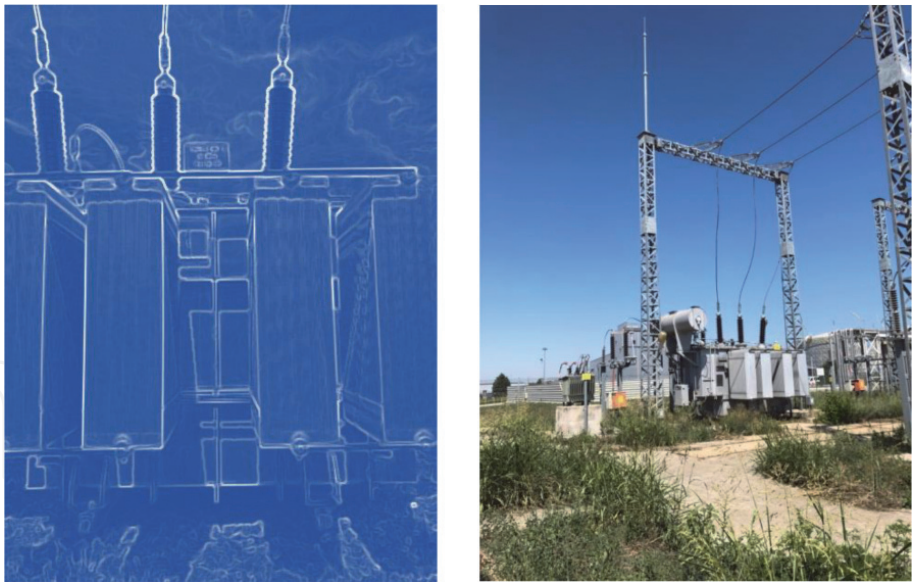


Figure 2.
Real photo - transformer 1 (T1), 110/20 kV of 16 MVA.

Transformer	S_n	ΔP_0	ΔP_{sc}	Tension		Fabrication year	
				U_{MT}	U_{MT}		
	MVA	kW	kW	kV	V		
TTUS-ONAN	16	38	300	110	20.5	2008	
TTUS-ONAN	16	38	300	110	20.5	2008	

Table 1.
Characteristics of the transformer in the transformer station.

- four 20/0.4 kV substations - PT1, PT2, PT3 and PT4;
- electrical distribution boards (intelligent electrical networks platforms);
- 0.4 kV power receivers (users).

The measuring point for the analyzed substation, in which the monitoring equipment was mounted, is represented by the entry point on the 110 kV (**Table 1**) side of the 110/20.5 kV, 16MVA transformer, or the exit point from the 110 kV electrical connection station of the conveyor (the common part with that of the distributor – the IT cells are actually located in the same premises). **Table 2** presents some samples of measurements performed for the analyzed transformer in the electrical connections station.

Thus, an ION7600 Class A type analyzer was installed (**Figure 3**), approved and verified up to date (for monitoring the various electrical quantities that will be presented below), in order to make an energy analysis of the monitored electrical measures for the technological process in the general connections power station, at the supply point inside the company.

The analysis of the data registered in the period 26/06/2021 at 16:20–20/08/2021 at 19:00, for the power supply of the receivers within the company allows for the highlighting of the electrical characteristics of the power supply system.

Measurements performed on the HV bars (High Voltage) in the above mentioned period have been achieved in order to carry out the electric power study

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1	timestamp	Vin c	VII ab	VII bc	VII ca	I a	I b	I c	KW a	KW b	KW c	KW tot	KVAR a	KVAR b	KVAR c	KVAR tot	KVA a	KVA b	KVA c	KVA tot	PF algi	PF algi	PF algi	PF algi	PF algi	PF algi	unbal
2717	07/22/2021@11:50	69364.77	120096	120732.2	119537.6	5.6	17.7	15.6	331.906	1226.982	1076.21	2635.098	-195.906	45.061	-55.463	814.4	1107.32	1691.92	1507.8	4352.8	-97.9	-97.2	-98.7	-98.23	0.231		
2718	07/22/2021@12:00	69318.06	120089.4	120564.5	119593.5	5.74	18	16.1	345.069	1248.145	1110.595	2703.809	-192.534	24.206	-73.869	877.462	1261.36	1775.58	1574.4	4596.4	-97.8	-97.1	-98.7	-98.16	0.359		
2719	07/22/2021@12:10	69199.33	119940.7	120568.5	119192.5	5.25	18.3	15.9	297.405	1262.232	1092.163	2651.8	-203.605	113.858	0	1149.39	1295.31	1829.22	1640.6	4751.4	-96.5	-96.5	-97.9	-97.03	0.257		
2720	07/22/2021@12:20	68886.89	11910.1	120045.7	119013.3	5.5	21.5	19.2	350.842	1459.584	1308.001	3119.427	-139.477	294.869	147.52	1134.79	1310.42	1848.38	1656.1	4801.9	-96.7	-96.2	-97.9	-97.17	0.258		
2721	07/22/2021@12:30	69134.2	119892.5	120023.3	119290.9	5.63	23.6	21.1	364.608	1597.301	1444.851	3408.761	-130.31	342.227	185.28	1208.11	1416.38	1871.39	1668.9	4942.1	-96.5	-96	-97.7	-96.97	0.337		
2722	07/22/2021@12:40	68960.91	119468.5	119900.1	118982.9	5.6	24.6	22.1	360.31	1661.39	1509.147	3530.846	-133.651	350.873	189.383	1195.94	1416.56	1860.61	1652.9	4917.9	-96.7	-96	-97.7	-97	0.33		
2723	07/22/2021@12:50	69121.02	119620.5	120215.4	119260.4	5.2	21.8	19.4	320.128	1477.828	1330.024	3127.98	-159.015	319.978	162.748	1282.07	1473.14	1943.41	1721	5124.9	-96.4	-95.7	-97.7	-96.82	0.404		
2724	07/22/2021@01:00	69069.45	119557.7	119892.4	119305.1	5.41	23.3	21.2	348.155	1565.875	1447.835	3361.605	-130.761	358.055	207.025	1191.33	1355.99	1809.31	1602.6	4756.7	-96.5	-95.7	-97.6	-96.81	0.392		
2725	07/22/2021@01:10	69084.29	119617.1	120164.5	119155.7	4.74	24	21.3	169.332	1618.173	1450.874	3238.379	-277.711	385.272	229.667	1207.5	1455.6	1887.24	1697.9	5208	-96.5	-96.2	-97.6	-97.07	0.264		
2726	07/22/2021@01:20	69178.7	119909.3	120452.8	119233.6	5.02	24.1	21.2	121.188	1624.545	1441.274	3187.007	-323.112	404.109	234.575	1194.32	1369.01	1842.2	1689.7	4891.7	-96.5	-96.4	-97.5	-96.97	0.288		
2727	07/22/2021@01:30	69343.09	120217	120649.8	119622.2	5.02	22.2	19.6	121.06	1493.904	1336.362	2951.326	-324.741	374.89	219.824	1277.81	1414.97	1947.38	1751.3	5102.8	-96.5	-96.1	-97.3	-96.81	0.365		
2728	07/22/2021@01:40	69452.26	120403.5	120749.8	119901.3	5.05	23.9	21.4	121.163	1609.7	1406.388	3197.25	-327.39	407.777	238.616	1143.81	1400.12	1821.75	1635.1	4905.8	-97	-96.3	-97.8	-97.24	0.282		
2729	07/22/2021@01:50	69501.78	120698	120810.3	119889.9	5.01	23.2	20.6	122.781	1556.137	1403.708	3082.623	-323.651	423.193	271.736	1384.9	1642.41	1966.59	1800.5	5398.1	-96.2	-95.9	-97.2	-96.65	0.257		
2730	07/22/2021@02:00	69710.47	120021.5	121282.9	120473.5	11.8	23.7	21.3	799.717	1596.425	1456.088	3852.231	-141.789	445.363	273.675	1348.42	1640.76	1888.42	1692.5	5210.2	-96.4	-95.4	-97.4	-96.59	0.312		
2731	07/22/2021@02:10	69606.97	120965.2	121202.1	120337.1	4.69	24.9	22.1	183.261	1670.374	1511.266	3364.9	-268.935	480.125	291.216	1250.62	1659.96	1907.14	1702	5255.5	-97	-96	-97.7	-97.13	0.314		
2732	07/22/2021@02:20	69848.27	120963.1	121257.9	120677.7	5.06	24	21.9	123.411	1618.511	1499.276	3241.198	-329.535	435.138	274.335	1194.06	1596.08	1864.98	1620.8	5068.3	-97.4	-96	-97.5	-97.19	0.506		
2733	07/22/2021@02:30	70229.56	121199.1	121886.6	121388.3	5.09	23.7	22	122.292	1606.833	1516.67	3245.795	-333.433	403.192	280.709	1237.04	1641.6	1875.89	1737.2	5242.9	-96.8	-96.5	-97.7	-97.18	0.171		
2734	07/22/2021@02:40	70517.95	122259	122561.1	121780	5.11	23.7	21.2	123.893	1624.19	1472.114	3219.998	-337.155	414.303	250.878	1226.24	1585.21	1701.8	5118.6	496.6	-96.4	-97.6	-97.06	0.18			
2735	07/22/2021@02:50	70385.34	122104.1	122597.1	121389.9	5.1	25.4	22.4	123.748	1731.188	1546.801	3401.738	-334.868	484.526	274.08	1252.33	1948.13	1731.7	5310.3	497.2	-96.3	-97.5	-97.16	0.432			
2736	07/22/2021@03:00	70888.16	122720.6	122986	122006.4	5.13	27.1	24.1	125.909	1641.614	1665.123	3632.646	-338.177	541.212	324.109	1162.11	1564.51	1812.3	4991.1	497.2	-96.3	-97.8	-97.25	0.286			
2737	07/22/2021@03:10	70820.06	122956.1	123237.5	122233.5	5.13	27.2	24.2	126.9	1854.677	1677.588	3659.165	-338.735	549.066	328.822	1268.48	1691.43	1942.17	1737.6	5358	-97.1	-96.1	-97.7	-97.16	0.323		
2738	07/22/2021@03:20	70910.19	123169.9	123438.4	122368.4	5.05	12.9	11.8	120.964	810.451	771.011	1702.426	-335.467	434.196	328.27	1240.71	1616.06	1805.46	1650.4	5119.5	-97	-95.8	-97.7	-97.02	0.382		
2739	07/22/2021@03:30	70887.12	122940.9	122988.5	122674.8	5.08	15.7	14.2	120.297	1083.945	980.943	2165.185	-336.056	262.726	140.214	1260.06	1668.78	1929.96	1702.9	5287.7	-97.1	-95.9	-97.7	-97.12	0.413		
2740	07/22/2021@03:40	70656.13	122773.8	122984.2	122049.8	5.09	23.4	21	123.105	1529.35	1413.842	3066.298	-336.805	640.807	447.667	1223.32	1608.27	1838.86	1650	5084.6	-97	-95.9	-97.7	-97.06	0.311		
2741	07/22/2021@03:50	71065.42	123464.3	123629.8	122713.4	5.11	20.8	18.3	122.199	1459.326	1293.412	2974.937	-341.149	269.851	127.601	1289.91	1681.86	1948.98	1734.1	5350.9	-97	-95.9	-97.6	-97.05	0.355		
2742	07/22/2021@04:00	71054.41	123416.6	123626.9	122690.4	5.12	23	20.3	122.483	1604.823	1427.361	3154.666	-340.958	335.379	178.569	1098.29	1552.99	1783.15	1580	4903.2	-97.5	-96	-97.6	-97.46	0.415		
2743	07/22/2021@04:10	70566.78	123300.3	123410.2	122578.5	5.11	24.5	21.8	122.428	1768.879	1533.07	3364.377	-340.633	359.836	190.926	1171.68	1634.59	1854.83	1676.6	5152.4	-97.2	-96.3	-96	-97.38	0.242		
2744	07/22/2021@04:20	71240.68	123759.1	123925.2	122992.3	5.13	24.3	21.4	123.487	1697.083	1589.09	3329.66	-342.943	374.624	201.202	1120.32	1621.31	1828.78	1662.6	5118.6	-97.1	-96.6	-98.2	-97.58	0.155		
2745	07/22/2021@04:30	71378.39	124053.4	124143.2	123314.6	5.14	23.1	20.6	123.733	1616.409	1457.481	3197.623	-344.169	353.384	174.347	1136.7	1626.2	1846.17	1648.7	5106.9	-97.5	-96.2	-98.1	-97.49	0.335		
2746	07/22/2021@04:40	71676.56	124465.3	124640.6	123799.4	5.16	24.1	21.5	124.869	1691.234	1520.701	3336.804	-346.858	377.634	208.768	1256.28	1694.38	1887.08	1677.7	5215.5	-97.1	-95.7	-97.7	-97.06	0.385		
2747	07/22/2021@04:50	71859.64	124869.3	124985	124123.3	5.15	21.6	19.2	123.646	1533.886	1369.552	3027.084	-347.428	270.171	113.717	1211.2	1630.31	1841.48	1637.1	5096.1	-97.1	-95.7	-97.9	-97.13	0.404		
2748	07/22/2021@05:00	71747.91	124547.7	124743.6	123909.9	5.12	22.4	19.9	123.673	1590.703	1421.462	3135.638	-344.68	263.722	119.339	1125.1	1599.31	1818.85	1640.1	5046	-97.4	-96.4	-98.1	-97.48	0.305		
2749	07/22/2021@05:10	71988.38	124584	125006.5	124095	4.99	20.6	18.5	142.182	1481.107	1389.92	2944.269	-327.374	240.113	104.584	1199.27	1683.53	1934.02	1712.9	5296.4	-97.4	-96.3	-97.9	-97.4	0.536		

Table 2. Measurement sheet for the transformation station on the first day of the monitoring period 13/03/2021 at 18:00–22/03/2021 at 16:10.

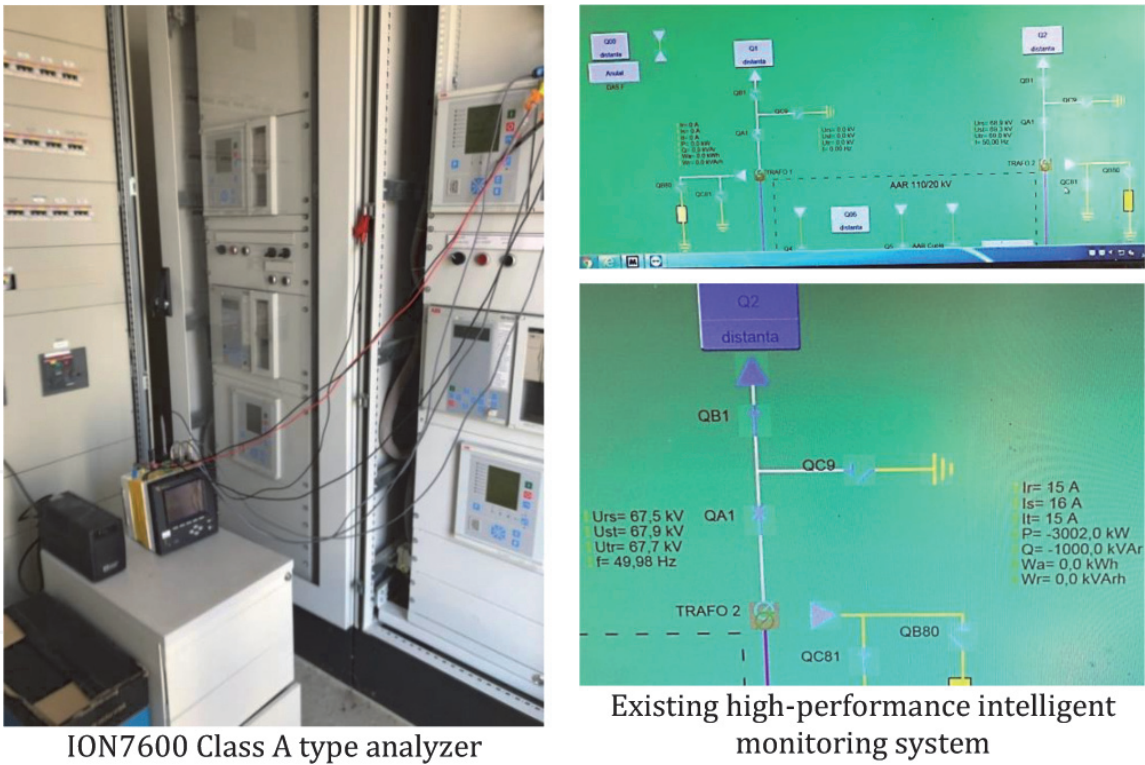


Figure 3. Real photo – Measure cell for transformer 1 (T1), 110/20 kV of 16 MVA in Consumer’s Power Station [copyright © 2020 PLT – Working scheme & photo].

within the company. The measurements that were recorded are calculated as the average values of the electrical quantities, at an interval of 10 minutes, according to current quality standards IEC 61000–3–4 [1].

The voltage at the supply bars of the receivers shows variations (60.136 ... 72.53) kV voltage per phase/(104.254 ÷ 126.17) kV voltage between phases, for TGD (Figure 4a and b), which must fit within the limits of $60 \pm 10\%$ / $110 \pm 10\%$ kV



Figure 4.
Voltage curve at the supply bar for TGD: a - voltages between phases, b - voltages per phase.

(54 ... 66/100 ... 120 kV). Rapid variations in voltage values caused by specific processes within the company (factory) lead to the recording of voltage fluctuations, accompanied by the flicker effect. The 3-phases are relatively symmetrically charged. It has been observed that the values of the supply voltage during the measurements did not exceed the normal (normed) limit values.

The voltages at the supply bars have a shape close to a sinusoid, being characterized by a relatively low total THD distortion factor (**Figure 5**), which fits within the values allowed at the low voltage supply bars (THD admitted = 8%). The total voltage distortion factor - THD U (**Figure 5**) is relatively low (it fits between the values (1 ÷ 2.1%).

Figure 6 shows the variation of the unbalance factor during recording. It is observed that the values of the negative unbalance factor ($k_s = V_{unb}$):

$$k_s = \frac{U^-}{U^+} \tag{1}$$

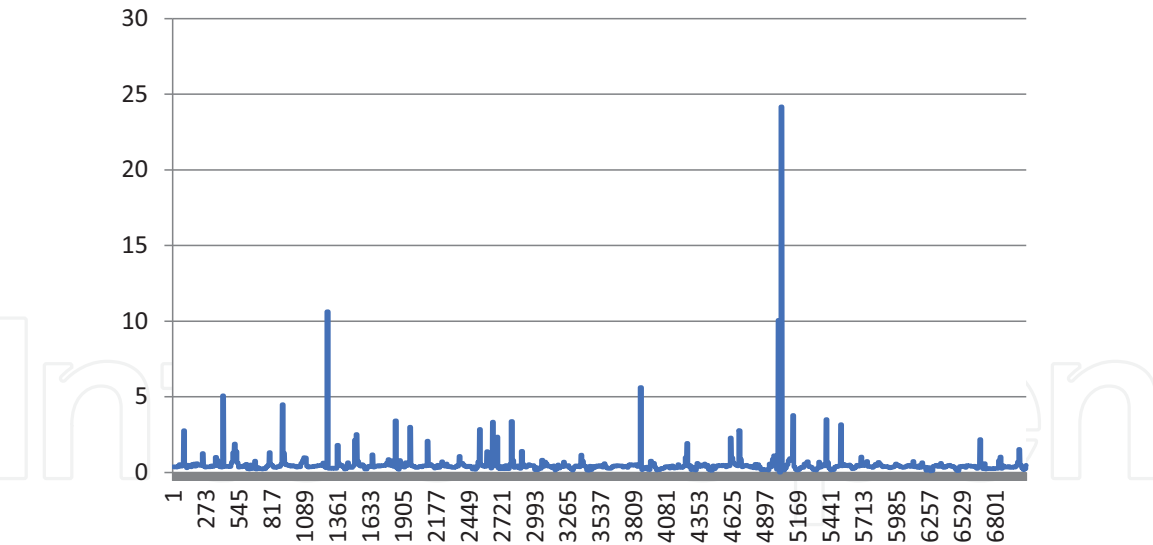


Figure 5.
Voltage distortion factor on supply phases a, b, c (THD U) - monitored values.

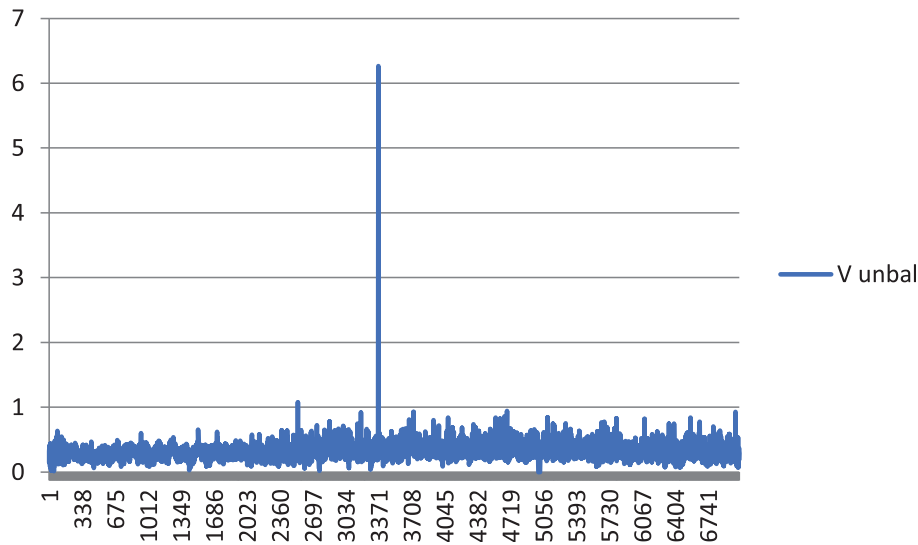


Figure 6.
Negative voltage unbalance factor at TGD supply bars (ks).

where U is the negative sequence voltage (inverse) and U_+ is the positive sequence voltage (direct), does not exceed the permissible values of the negative unbalance factor ($<2\%$) at TGD (power supply point) in the monitored enclosure.

The analysis of the data in **Figure 6** highlights an unbalance factor of about 5%, which indicates the existence of unbalanced and non-linear three-phase users connected in the low voltage network, unevenly, fact which causes different voltage drops on the three phases. It is important that the unbalance factor of the voltages between the phases has values within the accepted limits so that the three-phase motors connected in a triangle in the low voltage network are not affected by the unbalance of the supply voltages. Connecting star motors could lead to a reduction in their operating performance [2].

The variation of the measured values of the negative unbalance factor ks , determined as the ratio between the negative sequence component of the voltage curve U_- and the positive sequence component of the voltage curve U_+ , is indicated in **Figure 6** [3].

The analysis of the data in **Figure 7** highlights the fact that, at the low voltage bars of the receiver supply system, the admitted levels of voltage fluctuations are exceeded in many cases, in the public network ($Pst_{admitted} = 0.9$, and

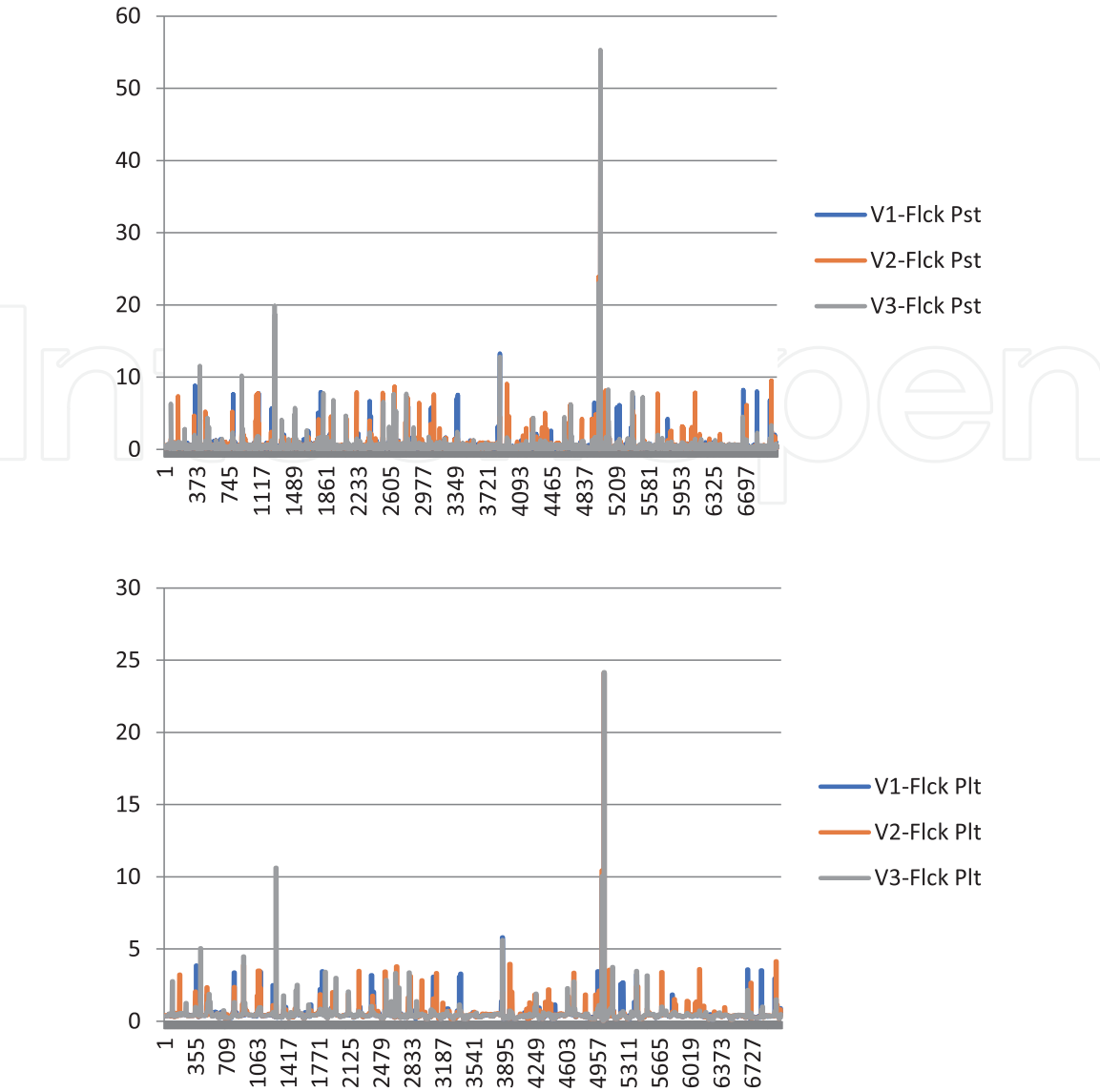


Figure 7.
Variation in the level of voltage fluctuations at the supply bars of the TGD.

Plt_admitted = 1.0) [3–6]. The number of events that lead to values higher than those admitted in the public network is small and is due to specific processes. In addition, in the energy system of other users, the admitted values are different from those in the public network, established according to the effects of the process carried out. The data in **Figure 7** indicate that higher voltage variations occur in phase c, accompanied by a higher level of flicker indicators. It is noted that the curves Pst and Plt in the general connections table (TGD) inside the studied company (factory), have almost the same shape (allure).

Moreover, based on the measurements, it is observed that at the feed bars of the TGD, the flicker level (Pst, Plt) is within the normalized parameters (limit). The disturbances determined at the supply bar are due, first of all, to the variation, in wide limits, of the reactive power necessary for the operation of the furnace. In the case of AC voltage supply, the efficient operation of the oven requires the existence of a low power factor, which requires the adoption of measures to improve it.

The variability specific to the technological process may require adequate compensation of the reactive power. The wide variation of the reactive power absorbed from the mains supply causes rapid voltage variations (voltage fluctuations) at the supply bars (usually within the accepted limits of slow voltage variations, +10%, in mains networks high voltage) accompanied by the phenomenon of flicker in users connected in the same area of use. The complexity of the phenomenon, as well as its

propagation in the power supply network, requires experimental determinations to be based on the analysis of the level of disturbances in users in the area and, if necessary, to evaluate measures to reduce the level of disturbances.

The technical study carried out comprises a wide area of use in which it has been identified and analyzed, in particular, the electromagnetic disturbance in the form of voltage fluctuation which causes flicker phenomenon. The determinations in the area followed a large number of parameters and quality indicators, but the detailed analysis focused on the short-term and long-term flicker indicators Pst, measured according to the recommendations of IEC 61000.

Also, the electrical quantities determined in the representative points of the scheme in the area were analyzed, namely at the high voltage supply bar of the analyzed user, at the high voltage supply bar of other users in the area and at the low voltage bar, at which are powered by the affected receptors.

The determined values enable the comparison with the admitted values recommended or imposed by the international CEI standards and the RET&RED performance standard (RET = Electrical transmission networks; RED = Electrical distribution networks).

In order to ensure the quality of electricity, limit values are indicated in the standards and norms in force, technical energy norms for limiting voltage fluctuations, including the flicker effect, in electricity transmission and distribution networks - NTE 012/14/00 and standards international IEC 61000-4-30 ver. III, IEC 61000-3-7: 2008 and IEC 61000-2-2. The national standards NTE 012/14/00, Ord_12_2016_RET and international performance standard IEC 61000-4-30 ver.3, IEC 61000-3-7: 2008 and IEC 61000-2-2 indicate, for the low voltage level, the limits of compatibility in **Table 3**. For the range of medium, high and very high voltages, the planning values of the flicker indicators on short-time (Pst) and long-time (Plt) are indicated in **Table 4**.

For the low voltage level, in any time interval of one week, the long-term flicker indicator must meet the $Plt < 1$ condition for 95% of the time. The same condition is imposed for the average voltage level [3-6].

Due to the fact that low voltage users are affected by voltage fluctuations (flicker phenomenon) during the operation of the electric arc furnace, experimental determinations have been proposed, in particular, to verify the compliance of the level of disturbances within the accepted limits by international standards. Also, the curves

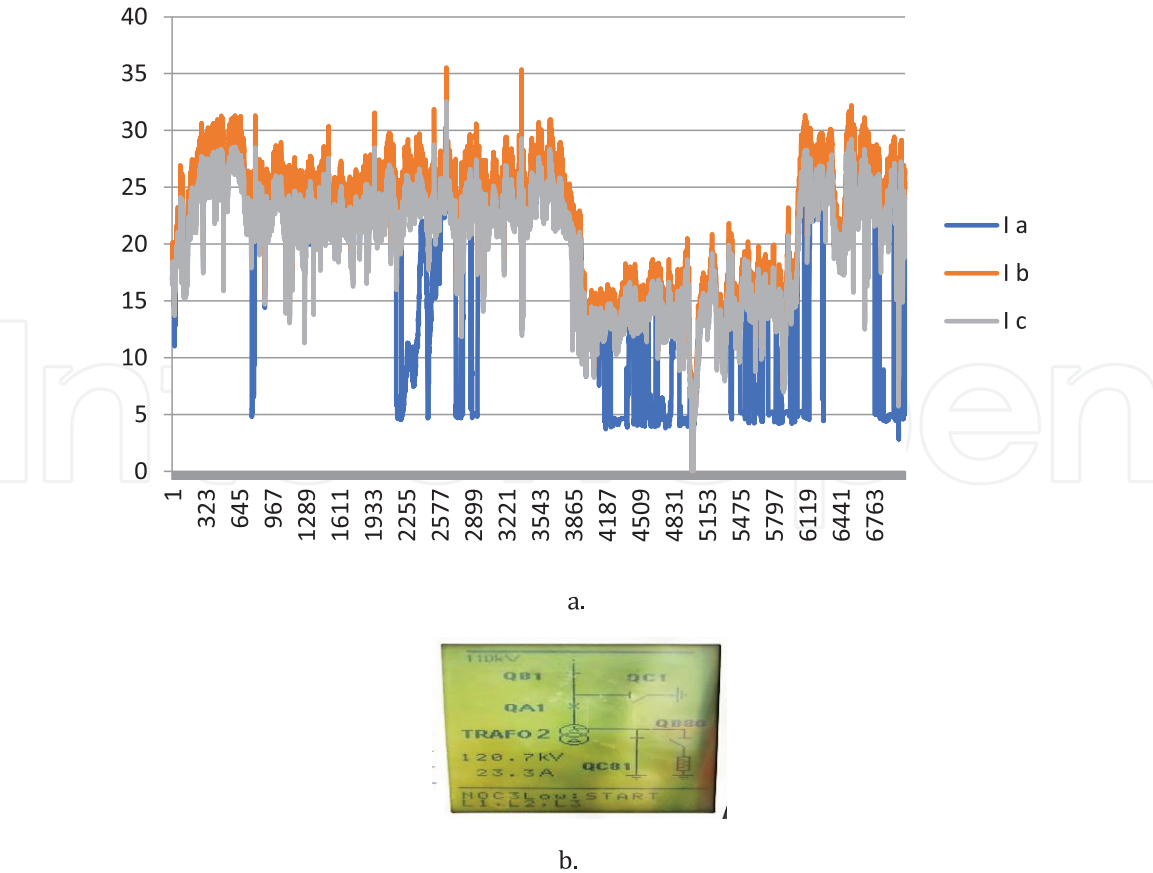
Flicker indicator	Compatibility level
Pst	1.0
Plt	0.8

Table 3.
Compatibility limits for flicker indicators in low voltage networks.

Flicker indicator	Level of planning*	
	(Medium Tension) MT	(High Tension) IT
Pst	0.9	0.8
Plt	0.8	0.6

**The values of the flicker indicators were established considering that the transfer factor to the low voltage network is unitary. In real cases, this factor may vary and must be determined for different operating conditions. In this way, the values at the MT and IT levels may be appropriately higher. The values mentioned are for guidance only.*

Table 4.
Indicative values of the planning level for flicker indicators, in medium, high and very high voltage networks.



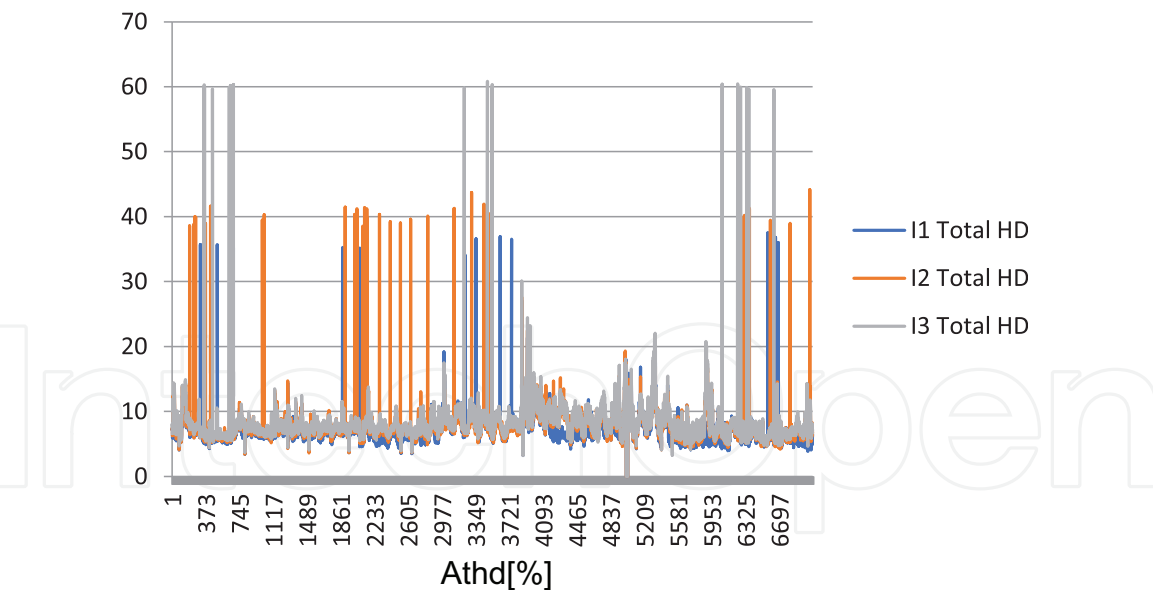


Figure 9.
Electric current distortion factor on supply phases a, b, c (THD-I or Athd) - monitored values.

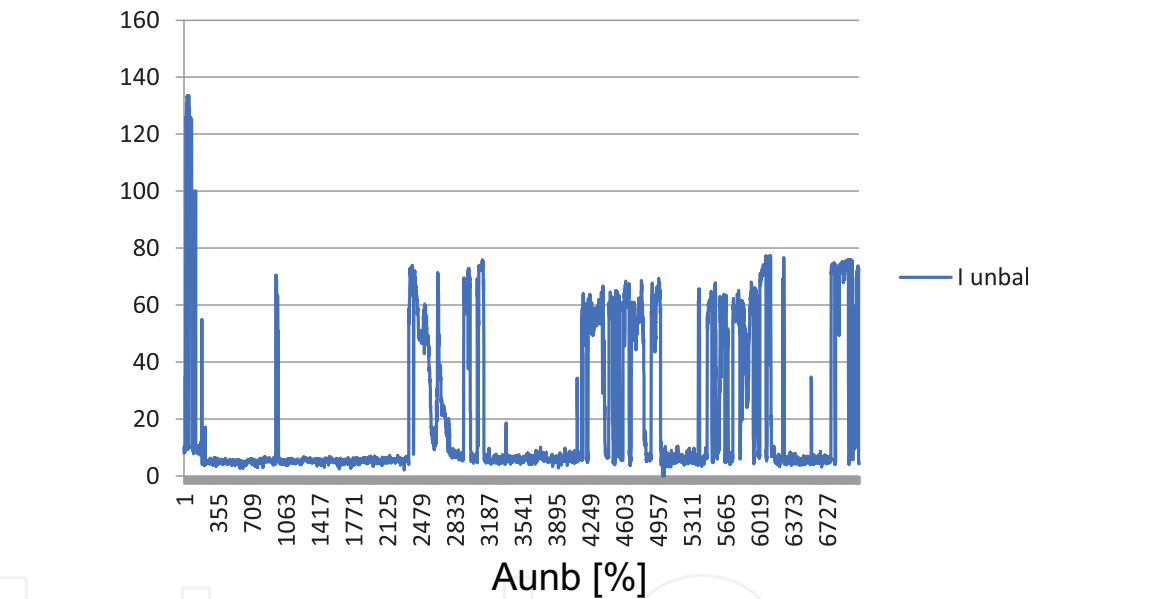


Figure 10.
Variation of the negative current unbalance factor of TGD ($k_s = A_{unb}$).

where I is the negative (reverse) sequence component of the electric currents, and I_+ is the positive (direct) sequence component.

The data in **Figure 10** shows that, during the recording, the unbalance factor of the electric current did not exceed the normal values in operation, these being determined especially by the voltage unbalance at the supply bars.

Special attention was paid to monitoring the values of electric currents in the supply circuits to determine both their loads and the level of losses in the user's electrical circuits.

Figures 11 and **12** show the variation P (active powers) and, respectively, Q (reactive powers) on the IT/MT (at 110 kV) bars, and **Figure 13** shows the variation of the apparent powers transited on the circuit (S), respectively, in **Figure 14** the variation of the three-phase powers comparative. The phase shift between the voltages and the electric currents monitored at the supply bar of the analyzed electrical equipment, in instantaneous values, is presented in **Figure 15**.

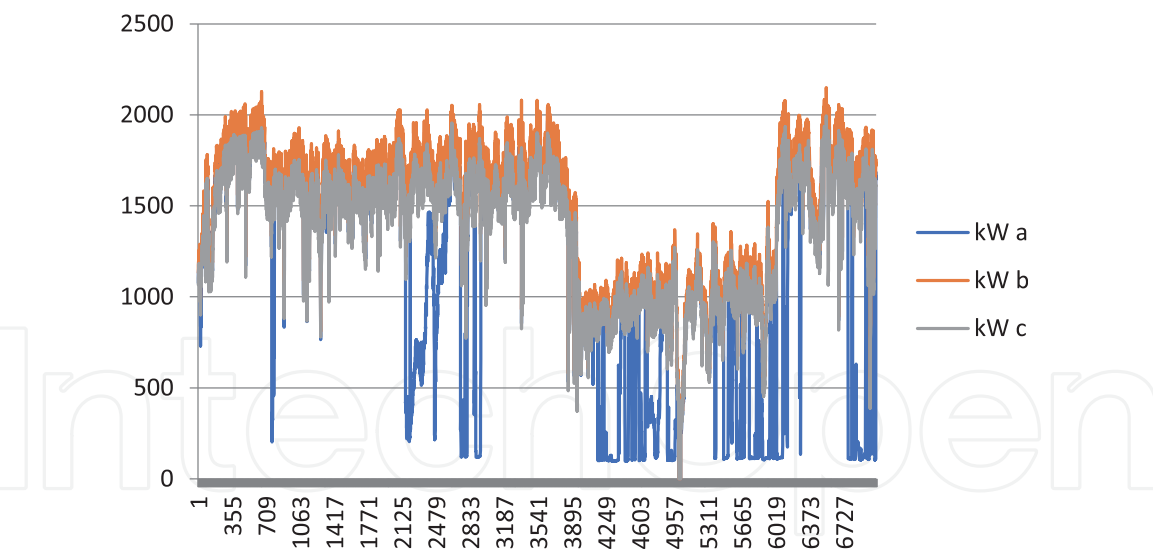


Figure 11.
 P [kW] variation on the IT bars at 110 kV.

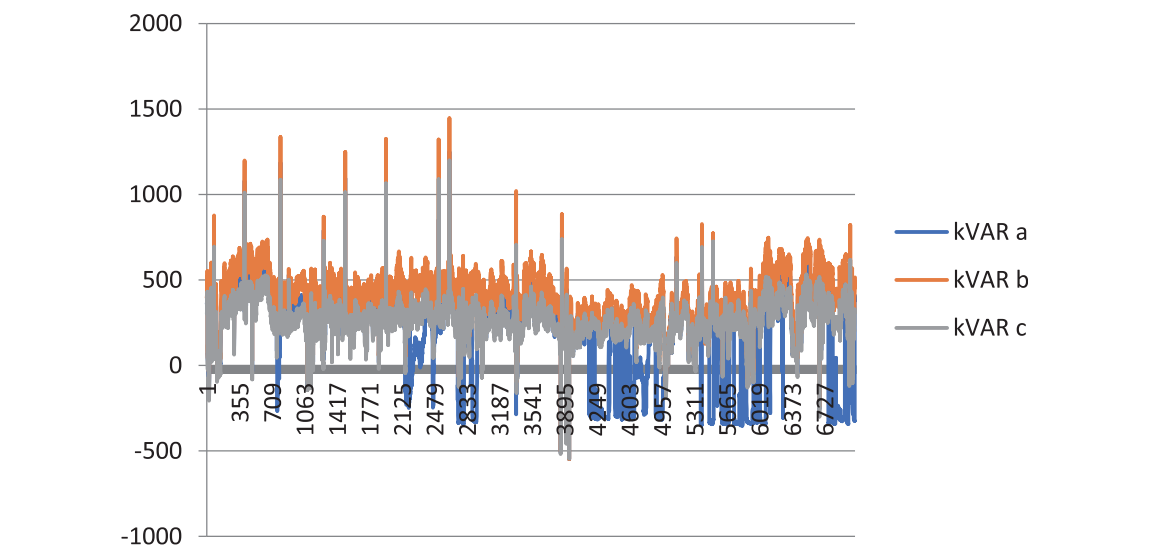


Figure 12.
 Q [kVAR] variation on the IT bars at 110 kV.

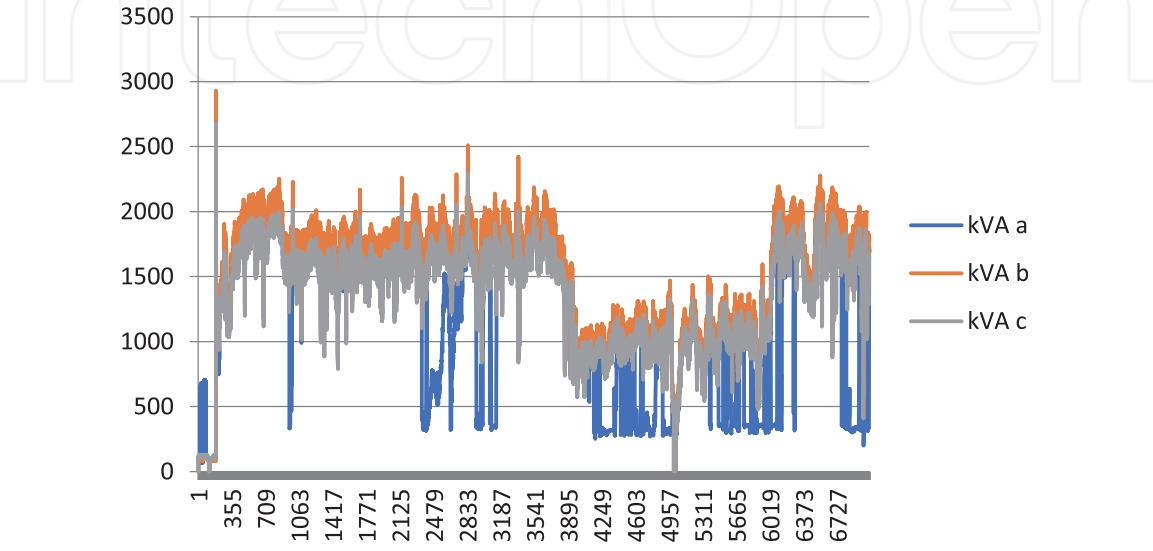


Figure 13.
Apparent single-phase powers transited through at 110 kV - S [kVA].

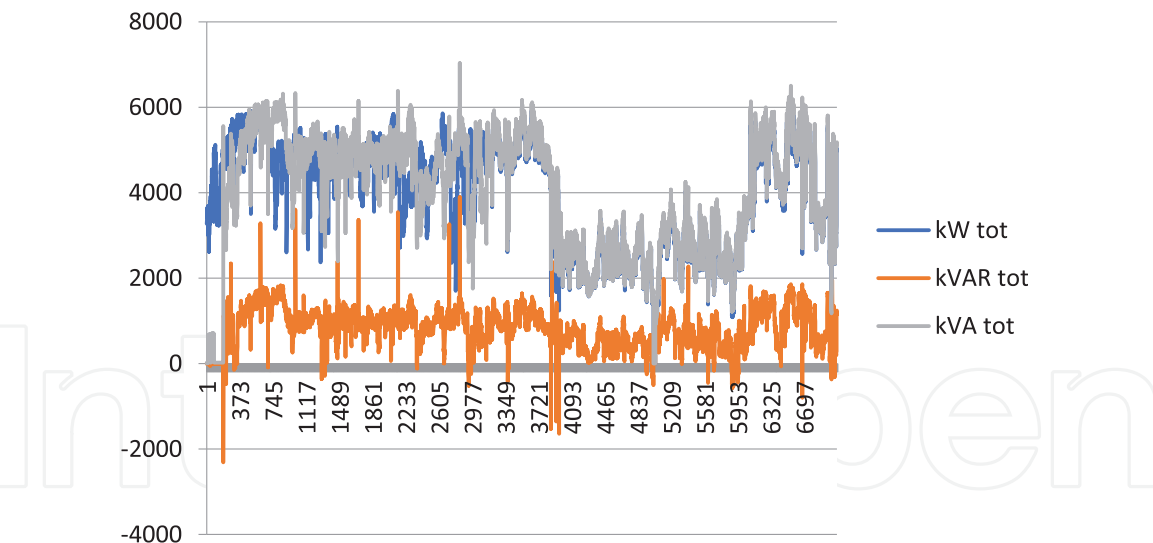


Figure 14.
Three-phase powers transited at 110 kV. SumP [kW], SumQ [kVAr], SumS [kVA].

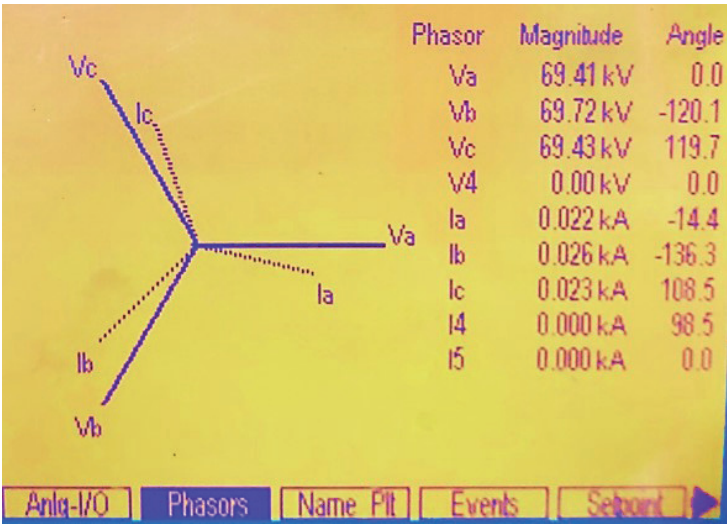


Figure 15.
The phase shift between voltages and electric currents at the supply bar at 110 kV.

The curves in **Figure 12** indicate that the user absorbs capacitive reactive power over a significant period of time. In comparison with the data in **Figure 14**, it is highlighted that the values of the capacitive power factor are within the limits accepted by the regulations in force. In order to ensure the control of the reactive power in the capacitive zone, and the limitation of some undesired increases of voltage in this interval, concrete solutions for the limitation of the capacitive regime were analyzed.

The PF power factor was determined based on the recorded energy values over a specified time interval:

$$PF = \frac{W_{trifazat}^P}{W_{trifazat}^S} \quad (3)$$

The PF value, although widely used in practical applications, provides correct information on the energy behavior of the consumer only in the case of a constant consumption during the time interval in which the power factor is evaluated.

The variation of the power factor during the recording, and in the time intervals in which the equipment was in operation, is indicated in **Figure 16** for each phase.

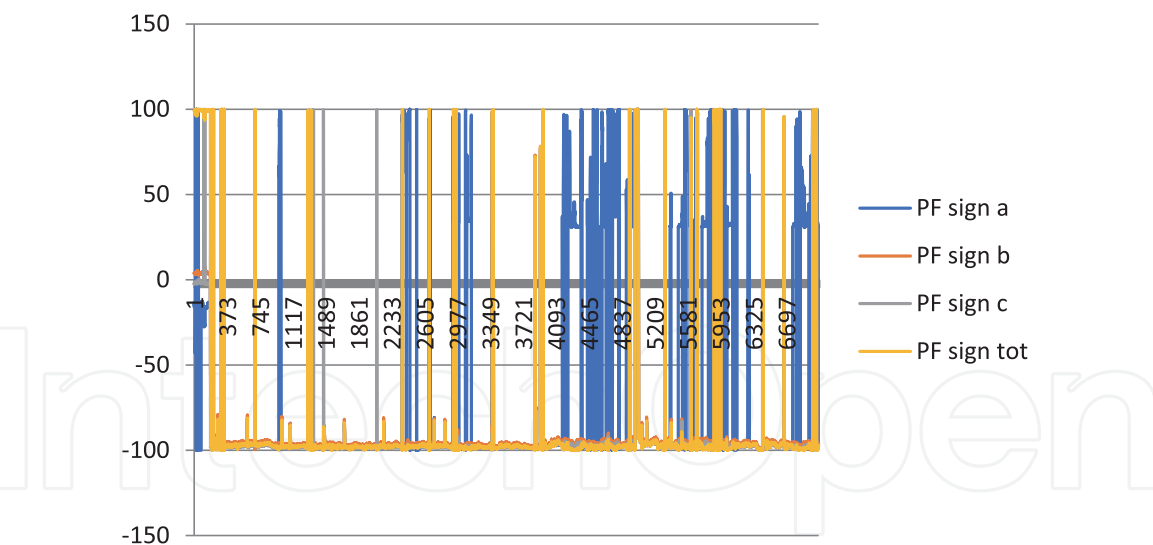


Figure 16.
PF variation (power factor) at 110 kV.

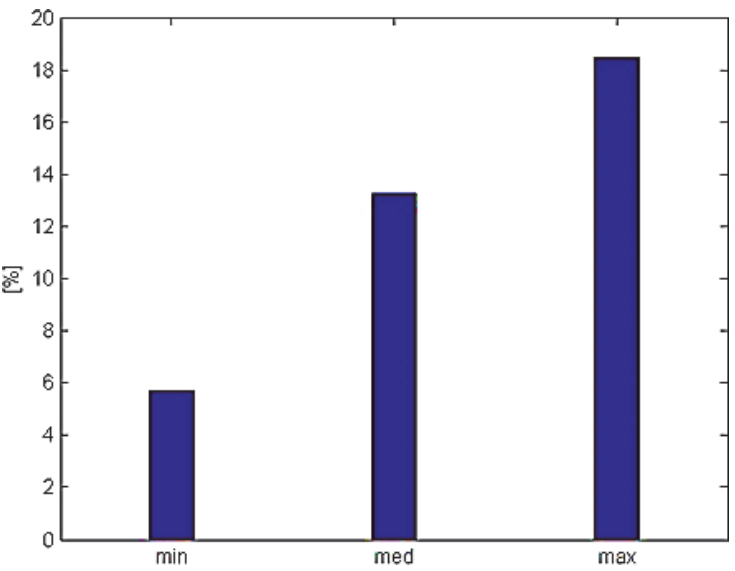


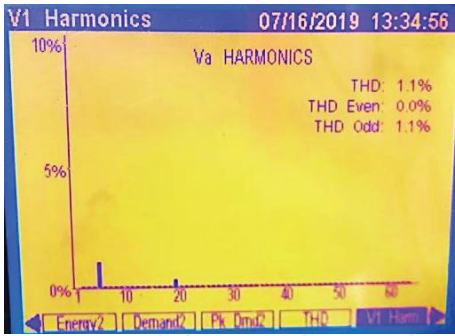
Figure 17.
Transformation station loading (load T1).

As it can be seen from the graph of the variation of the power factor (**Figure 16**), it is highlighted the fact that an important circulation of the reactive power appears in the supply circuit. The recorded values of the harmonic spectrum are affected by the specific operating mode, with frequent starts and stops of motors, as well as other electrical equipment (lighting, etc.). The real values of the harmonic spectrum can only be taken into account for stationary time intervals.

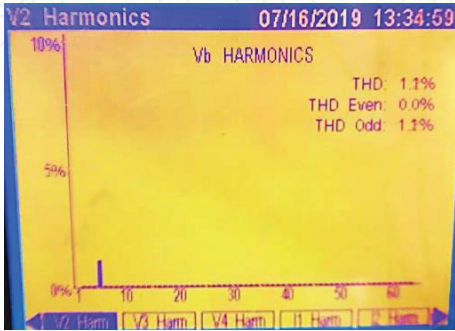
Figure 17 shows the minimum, average and maximum loads of the transformer during the monitoring period. The average load of the transformer station is about 13%, and the maximum load is 18%. Due to the low level of consumption in most operating cases, the transformer station operates poorly charged, which is an important source of energy loss. There are also times when the load is 6%.

Obs. In the power balance made for the transformer station of consumer, it is found that the transformer load does not exceed 18% of the nominal value (during 13/03/2021 at 18:00–22/03/2021 at 16:10).

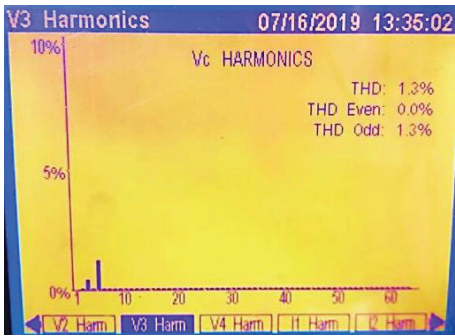
Figure 18 shows the values of the voltage harmonics on the three phases (a, b and c) at 110 kV. **Figure 19** shows the values of the current harmonics on the three phases (a, b and c) at 110 kV (in Cell Measure with Ion7600 Class A).



a



b.



c.

Figure 18. Voltage harmonics level on phases a, b and c at the supply bars - monitored values at 110 kV. a. Harmonic level [%] phase 1 (voltages). b. Harmonic level [%] phase 2 (voltages). c. Harmonic level [%] phase 3 (voltages).

The main observations that emerge from the analysis of the electrical measurements performed are:

- there is an imbalance of the charge of the three phases of the analyzed electrical circuit;
- the power level factor varies slightly, from negative calories to positive values;
- the flicker level varies strongly, but is maintained between optimal values;
- the level of electric harmonics is relatively high (note that electric harmonics 5 and 7 have very high values).

Under these conditions, the optimization of the power balance aims at the balanced charging of the three phases, the improvement of the power factor compensation, the improvement of the flicker level and the operation with an improved harmonic regime (harmonics of electric current).

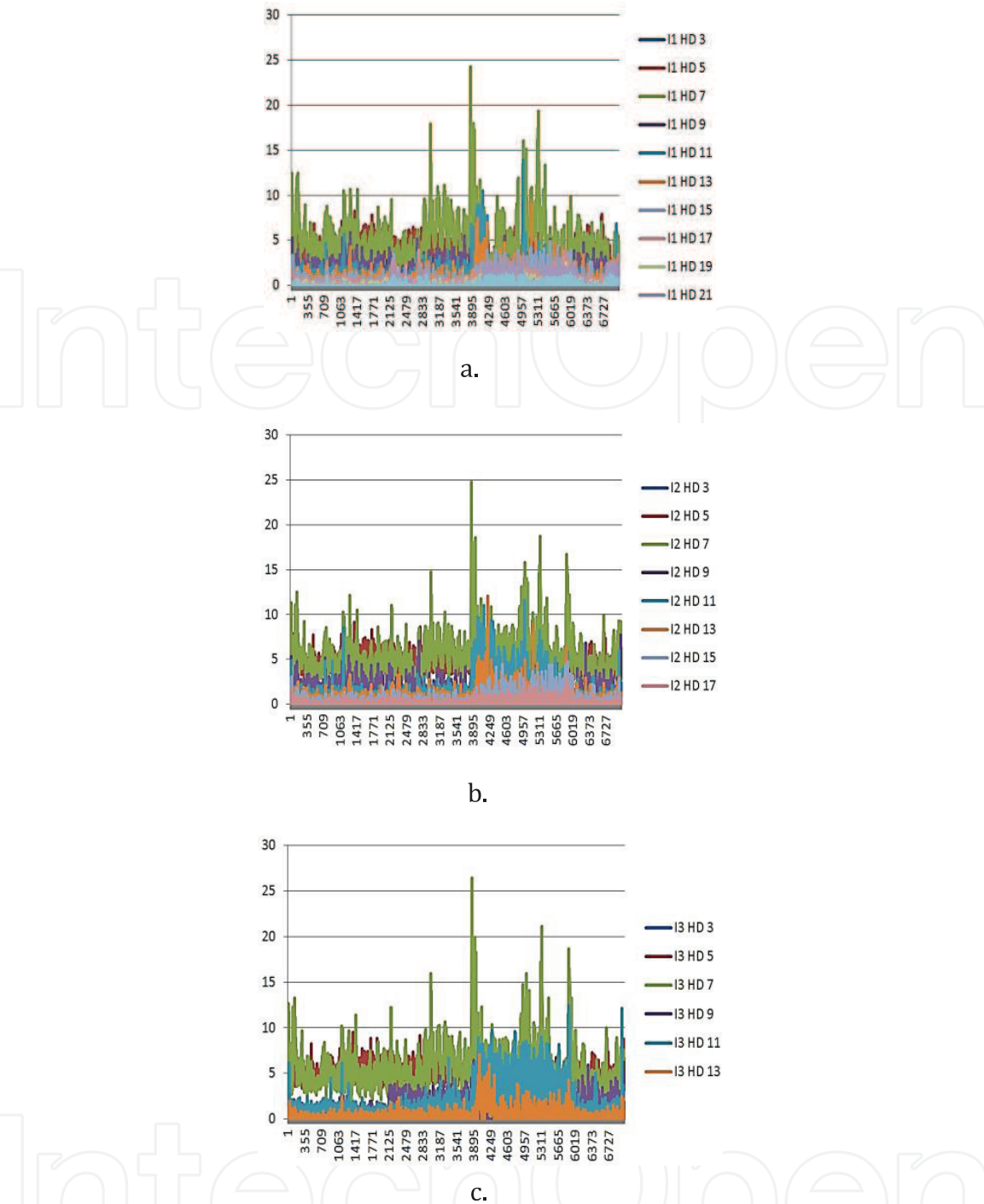


Figure 19.
The level of electric harmonics on phases a, b and c at the supply bars - monitored values at 110 kV.
a. Harmonic electric currents phase1 [%]. b. Harmonic electric currents phase 2 [%]. c. Harmonic electric currents phase3 [%].

There is a good classification of the voltage level on phases and between phases in the normed parameters (framing in the normed limits).

3. Events recorded during the monitored period

This chapter presents a series of events recorded during the monitoring period (Dips&Swells) [5, 6]. These events led to production interruptions that caused significant damage to the user through recalibration, cleaning, disposal of inferior products of poor quality, the realization of additional waste and implicitly additional specific costs.

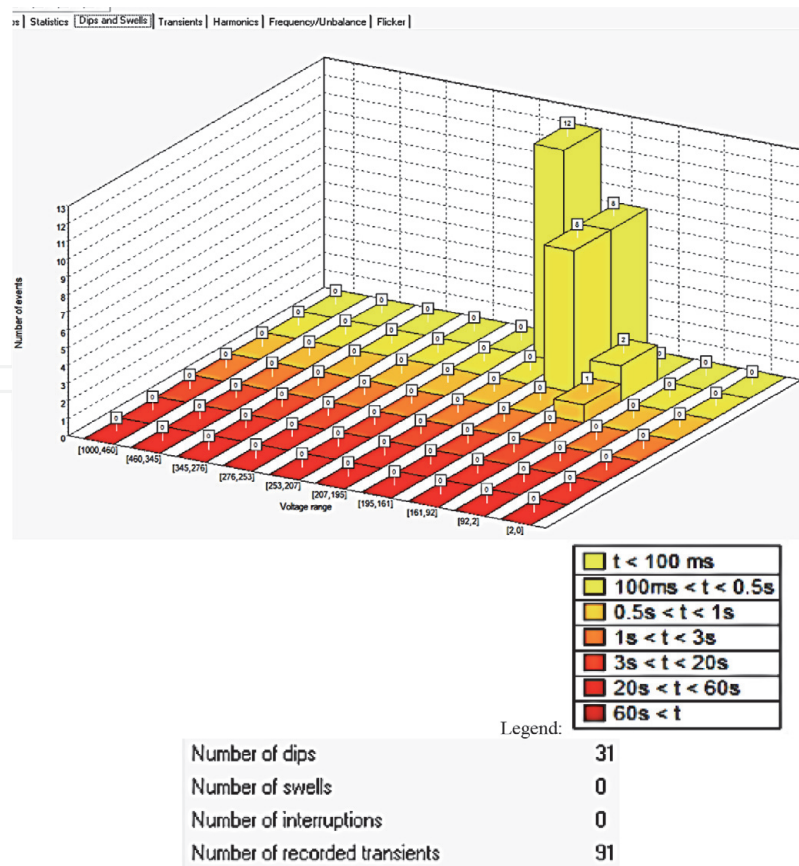


Figure 20.
Events noted in the first half of the 110 kV monitoring period in Electrical Station.

- Events noted in the first half of the 110 kV monitoring period in the Electrical Station at the consumer – **Figure 20.**
- Events noted in the last half of the 110 kV monitoring period in the Electrical Station at the consumer – **Figure 21.**

4. Technical analysis

According to the technical activity report, by downloading the monitored data by other industrial devices (such as SEPAMs), leads to the following technical statements assumed by the user [7]: “Event parity: approx. 5% of the total monitored events belong to the USER, and in approx. 95% of cases of origin of the Zonal Electricity Distributor and assumed by the Electricity Transporter.

That is, for month 1 there were 31 memorized events due to Zonal Electricity Distributor, at 2 ... 3 events of own influence - percentage, and for the 2nd month, there were 28 memorized events due to Zonal Electricity Distributor, at 2...3 events of own influence [7].

Obs. A series of additional information was analyzed that is not presented in detail in this chapter, but which competes or influences the proper functioning of the analyzed user, such as:

1. Cables, switches (with related power bars)
2. Specific operation of electrical equipment
3. Field findings

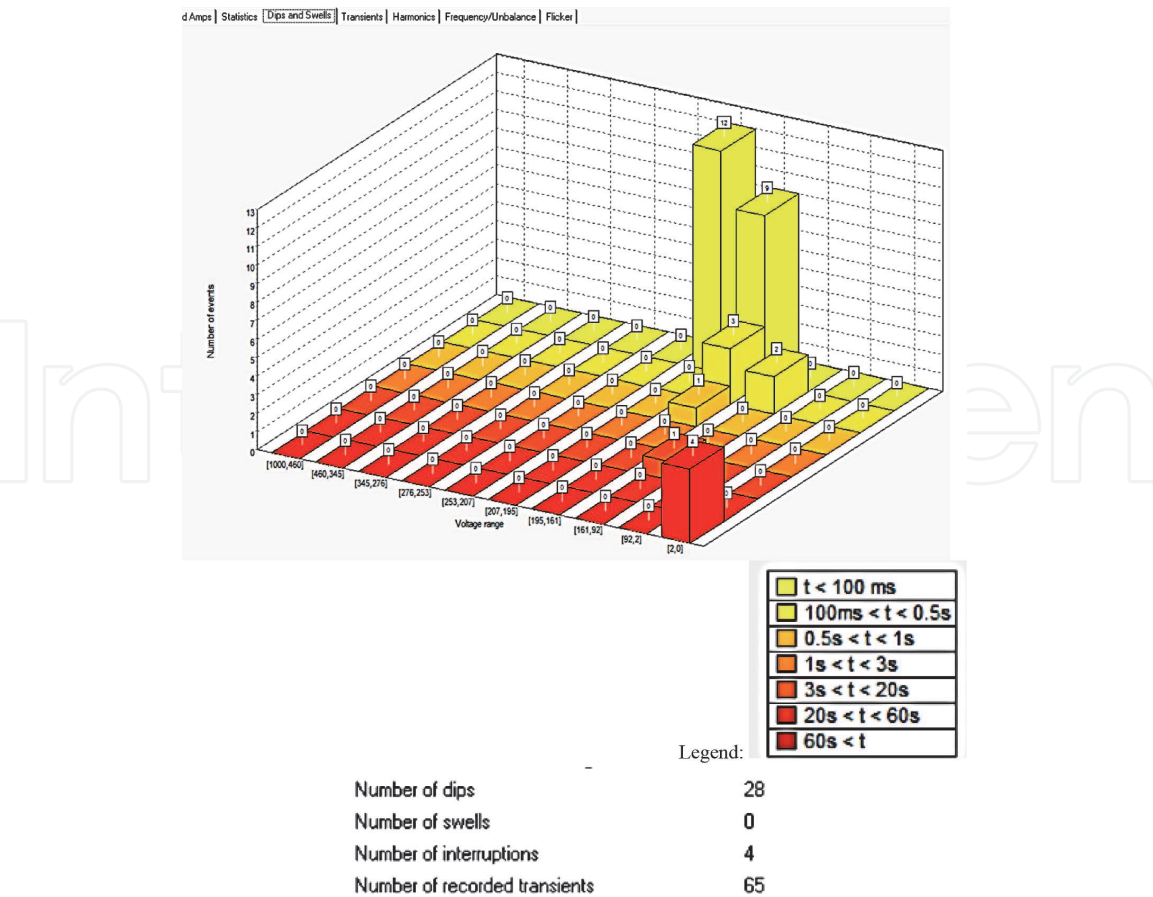


Figure 21.
Events noted in the last half of the 110 kV monitoring period in Electrical Station.

4. Protection information - provided by company representatives
5. Information specific to electrical networks
6. overall water demand, energy consumption and emission of conventional desalination processes - information such as size, emission [8] etc.
7. etc.

Thus, for the various events and power quality, the following recommendations were taken into account, presented in the **Table 5**:

The principle of operation/assembly/effects/etc. is similar to the one previously presented on specialized technical literature in the field.

The difference is given by:

1. The materials from which the insulation of various equipment will be made (cables, windings, etc.), which are much more expensive and specialized (unusual);
2. The electrical equipment/devices which is more expensive, being connected at 110 kV, compared to those connected at 20 kV, (also because of other reasons, related not only to insulation, see electromagnetic fields, etc.).
3. In the case of connection of these SVC type devices to the 20 kV bar, it is known that the reduction of the flicker level by a maximum of 2 times, is corroborated with an additional reduction by a few percent of the flicker level,

No.	Proposed operations	Equipment	Implementation Mod	Obs.
1	Internal - mandatory	PTs and transformers+users	After performing a STUDY REGARDING THE DISTRIBUTION OF USERS BY STANDARD, PRIORITY CATEGORIES, CRITICISM IN SOCIETY (distribution by PTs and transformers)	
2	Checking	Cables	With mobile technical cable testing laboratory	
		Breakers	With mobile technical testing laboratory - thorough verification inside	
		Contact resistors between IT&MT bars and related cables	Internal - with the company's electricians	
		Thorough grounding check	Check the sockets by removing the connection plates, cleaning, thoroughly checking for improvement and if necessary.	
		Transformers	With mobile technical testing laboratory - thorough verification of sensors, with cleaning of dust terminals, insulating cleaning, moisture, oxidation or oil.	
3	Purchase of equipment	Compensation of capacitive/ inductive operating modes	With specialized equipment made by established manufacturers	
			Proposal of a Rotary Compensator	
			Proposal of a PSS (Power System Stabilizer)	
			Proposal of an SVC (Static Var Compensator)	
			Proposal for a STATCOM (advanced FACTS device such as Back-to-back)	
4	Extensive inspections of the distributor's installation - Zonal Electricity Distributor	Checks for switching times and tripping and tripping times - various switching and protection equipment	With specialists or with the knowledge of the Zonal Electricity Distributor	external
		Protection settings	With specialists or with the knowledge of the Zonal Electricity Distributor	external
		Checking the operation of various switching equipment (switches, their automation etc.)	With specialists or with the knowledge of the Zonal Electricity Distributor	external
		Study and implementation of the increase of the short circuit power of the ZONAL ELECTRICITY DISTRIBUTOR power station from which the enterprise is supplied	With specialists or with the knowledge of the Zonal Electricity Distributor	external

No.	Proposed operations	Equipment	Implementation Mod	Obs.
		Checks of intervention modes in the 110 kV mains network of ZONAL ELECTRICITY DISTRIBUTOR (on the part of Medium Voltage and High Voltage) to the large users in the vicinity of Consumer who are connected to the same 110 kV network; verification of intervention times, interruptions, switching, respectively trigger times, triggering - various switching and protection equipment, plus other complaints that existed in the area (on IT and MT) during this monitoring period (but also before).	With specialists or with the knowledge of the Zonal Electricity Distributor	external

Legend: Red = with maximum priority; Yellow = priority.

Table 5.

- by passing through the transformer of 110/20 kV that supplies the electric arc furnace; in case of mounting these SVC devices on the 110 kV side, it is to be taken into account only the design data of the SVC system (this additional attenuation is almost null at 110 kV).
4. However, in this case, compared to the compensation of the flicker level on the 20 kV side, we can also consider a slightly lower level of short-term and long-term flicker indicators on the 110 kV bar, compared to their level on the 20 kV, which may or may not influence the final price (depending on the manufacturer/equipment used).
5. Although the solution using SVC ensures the limitation of the flicker level to the users in the area, in the current configuration of the Electric Station at Zonal Electricity Distributor and Electric Station at Electricity Transporter with Electric Station at Consumer, the open coupling at 110 kV bus bar does not provide the necessary conditions for using a backup transformer for the user (a transformer will be dedicated to the analyzed user).

Thus, using FACTS devices (SVC or STATCOM) implies [9–11]:

- Flicker

It is a random variation caused by rapid fluctuations of the reactive power in the common power supply point of the steel enterprise. The human eye perceives voltage fluctuation as the change in brightness of light sources.

- Voltage stabilization

The operation of the electric arc can lead to a strong unbalance, especially in the initial stage of starting the melting process. The three-phase asynchronous motors are affected by voltage unbalance. The unbalance of the voltage causes the reduction of the installation's yield, overheating, loud noises, vibrations

and variations of motors' speed. That is why the use of SVC in control mode on each phase of the steel company's power supply system ensures the voltage symmetry and stabilization.

- Reactive power compensation (Q)

The transport of reactive power leads to significant voltage drops and the increase of electric currents in the supply network, decreasing the transport capacity of the active power (P). Public network operators maximize the transport capacity, encouraging users to use local reactive power compensation. SVC maintains the required reactive power (Q) within the limits imposed by the operator, thus avoiding penalties, as well as increasing the efficiency of user activities.

- Harmonic currents reduction

Users with non-linear characteristics such as electric arc furnaces generate harmonic electric currents. Harmonic currents charge the network and lead to voltage distortion. Distorted voltages can cause IT equipment (computers, etc.), control equipment, and other sensitive equipment to malfunction. SVC filter circuits are designed to absorb harmonic load-generated currents such as thyristor-controlled coils (TCRs). THD (Distortion Factor) and the individual level of harmonic currents are limited below the specified (normed) values.

- Energy saving

Reactive power compensation (Q) and increased electricity quality lead to increased active power transmission capacity (P) and reduced active energy losses. Thus, overloading of the power supply network can be avoided. This fact brings benefits for both the company and the environment by a more efficient use of electricity, and a reduction of the need for electricity. It is known that, for every 1 kWh saved, produced in a thermal power plant, the amount of pollutants released into the atmosphere is smaller with about 1 kg of CO₂.

- Productivity increase

The SVC system can ensure a practically constant voltage level at the company's power supply bars. This way, it decreases the duration of the melting process and increases productivity. A SVC system limits production interruptions and restarts that require long durations. The electric arc furnaces stabilized by SVC have an important effect on reducing electrode consumption, heat loss and the life of the furnace liner. By increasing the quality of electricity, the demand for equipment is reduced, the lifespan is increased and the costs of maintenance and replacement of some components are reduced.

5. Conclusions

Conclusions resulting from the analysis of the monitored data on the 110 kV – T1 side (power station) as well as the main observations that emerge from the analysis of the electrical measurements performed are:

- there is an unbalance of charge in the three phases of the analyzed electrical circuit;

- the power factor level shows variations outside the range 0.90 ... 1.00; these values are not considered optimal (correctly compensated); there are penalties to the Electricity Invoice for not falling between the mentioned values, according to ANRE (National Energy Regulatory Authority) order only if those from PCC (Common Connection Point – CCP) to the electric meter;
- the flicker level varies strongly, but is maintained between optimal values in 90% from 90% of the monitoring time (Obs. The values in the CCP matter the most);
- the level of electric harmonics is relatively high; it is noticed that the harmonics of electric current 5, 7 have high values, with significant variations.

Under these conditions, the aim is: balanced charging of the three phases, improved power factor compensation, improved flicker level and operation with an improved harmonic regime (electric harmonics).

There is a good classification of the voltage level on phases and between phases, in the normed parameters (framing in the normed limits).

The two proposed performance solutions (in this case):

A. The connection of a STATCOM to the 110 kV bus bars of the user (**Figure 22**) leads to a factor of reduction of the flicker level between 3 and 6 (they multiply). The control block BC receives the information regarding the voltage level at the 110 kV bus bars and determines its maintenance by injection of real-time capacitive reactive power from capacitor C via the appropriate controlled inverter.

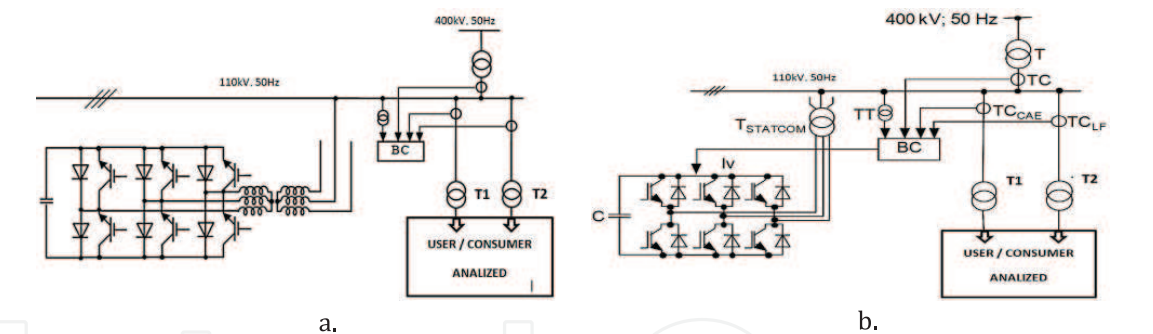


Figure 22. Scheme of a STATCOM (for analyze) [3–7, 12]. a. Scheme of a STATCOM for voltage control at 110 kV bus bars. b. Functioning scheme/diagram of a STATCOM equipment.

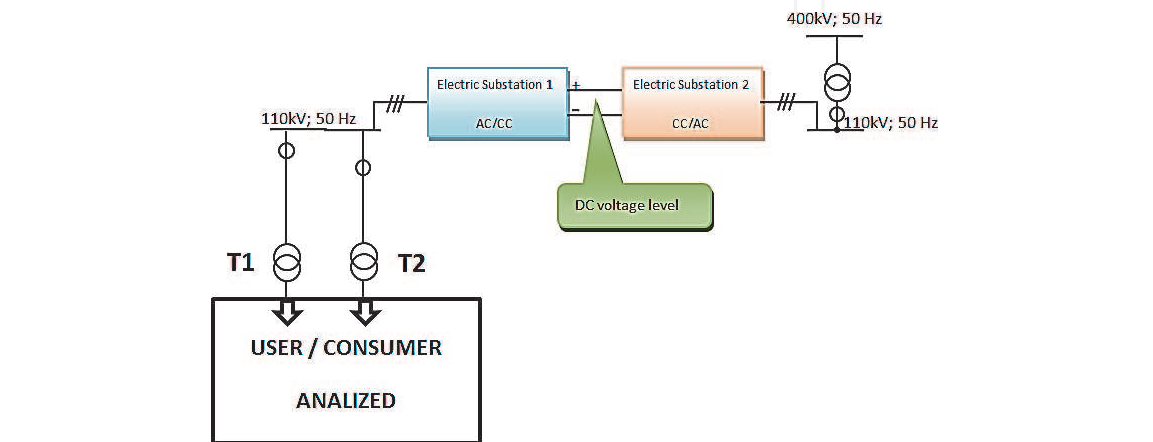


Figure 23. The functioning diagram of a back-to-back FACTS system [15, 16].

Connecting SVC or STATCOM to the user's 110 kV bus bars, along with using a dedicated 400/110 kV transformer, enables a reduction of practically 1.5 ... 2 times (in case of using SVC), and 3 ... 6 times (in the case of using STATCOM), of the disturbance level at the 110 kV bars of the Electrical Station [3–7, 12]. In this way, the problems related to the disturbance of the users in the area are completely solved as well [13].

In CIGRE study [12, 14] regarding a STATCOM type FACTS device to improve the flicker level in the case of an ELECTRIC ARC OVEN, it is said that the reduction of the flicker level in a single installation was reduced from an initial factor of $P_{st95\%} = 3,75$ without STATCOM, to $P_{st95\%} = 0.76$ with STATCOM in operation, for a short-term probability of 95% [3–7, 12]. This fact indicates that the flicker level has improved about five times with the introduction of the compensator.

B. “Back-to-Back System” - By using this type of system/equipment, the level of flicker indicators on the bar on which it is mounted is eliminated, in the sense that it can be fully controlled [3–7, 12]. This is due to the well-known fact that any type of disturbance is eliminated from the arc furnace to the Power Station by passing through a DC voltage level (**Figure 23**) [15, 16]. Obs. Back-to-back equipment has high-power thyristor electronic devices, which can themselves produce/generate system disturbances, if they are not correctly chosen and calculated with great accuracy.


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