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POWER QUALITY IN OFFICE BUILDINGS - CASE STUDY

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***Abstract* - According to statistics, approximately 40% of electricity produced in the European Union it is used to power commercial and residential buildings. Commercial buildings include hospitals, office buildings and apartments, hotels, schools, churches, stores, theaters and sports facilities. In these buildings, air conditioning equipment, computers, fax and copying equipment, printers are using the same power network as fluorescent lighting and various electronic communications equipment.. In most cases the energy is supplied at their nominal operating value to the consumer, but the overvoltages, voltage variations, gaps and interruptions of voltage represent factors that may have a harmful impact on the equipment. Another issue of power quality represents the magnitude of harmonic currents, induced by non-linear equipment.**

Keywords: *Power Quality, office buildings, measurement analysis, harmonic distortion, power factor.*

1. TYPES OF NONLINEAR EQUIPMENT IN THE ELECTRICAL DISTRIBUTION NETWORK OF AN OFFICE BUILDING

1.1 Fluorescent Lamps

The fluorescent lamps are one of the major sources of harmonic pollution of electrical distribution networks in office buildings. Despite the advantages they present, they often raise serious problems considering the current harmonics introduced by them into the supply network. Moreover, their supply with non-sinusoidal voltages, as it happens frequently due to other non-linear equipment placed in neighboring nodes, may cause further deterioration of their electrical performance.
The supplying of the lighting systems with fluorescent lamps leads to the emergence of current of large amplitudes through the earth phase conductor determined by the summing of third harmonic phase currents. These currents are amplified by the zero sequence components, if these lighting sources are placed unevenly on the phases of the power network. These additional loads form a serious degradation jeopardy of the zero phase conductor by overheating, the greater their cross section it is lower than the phase conductors (with rare exceptions). Electronic ballasts used for fluorescent lamps have become popular in recent years due to the need of greater effectiveness. In general, they are only slightly more effective than the best magnetic ballasts and, in fact, the biggest gain is that the fluorescent lamp is more effective when powered at high frequency. The main advantage of the electronic ballast is that the light level can be maintained for a greater lifetime period by controlling the lamp currents, but this practice leads to a decrease of the overall efficiency. Their biggest inconvenience is that the electronic ballast generates harmonics in the power supply network [2].

1.2 Switched-mode power supply

Most of the modern electronic equipments are using switched-mode power supplies. These sources are different from the old power sources, in which the downward transformer and the rectifier are replaced by a direct command rectifier of the power supply to charge a capacitor battery, from which the direct current used at the load it is achieved through an adequate method, at the required voltage and current. The advantages for the equipment manufacturer - size, cost and weight - are significantly reduced and the switched-mode power supply can be achieved for virtually any required form factor. The disadvantage is that, instead of direct current, the source absorbs from the power supply network current as wave current containing a large amount of third and higher harmonics and also high frequency harmonic components.

2. THE USE OF NON-LINEAR EQUIPMENT

Modern household appliances (color TV receivers, fluorescent lamps, microwave ovens, audio-video equipment, air conditioning units) and utilities business (personal computers, fax machines, drives, photocopying equipment, printers) represent for the electrical power network loads with non-linear characteristic. These devices, although of low power demand, if connected in a large number, represent the main polluting source for the low voltage power networks. The disturbances introduced by them deteriorate the power quality of the network, existing a possible damage to consumers connected to the same electricity network, when the disturbances exceed the level of immunity of the equipment. It is required the verification and the maintaining of harmonic disturbance levels in the point of common coupling at levels below the accepted ones, according to the StandardIEC1000-2-2.

The main use of non-linear equipment favors the circulation of high harmonic currents throughout the power systems, with harmful effects on electrical installations, designed to operate in the sinusoidal system. The deformation of the voltage and power waves will be spread throughout the system and will be preponderant in the connection points of capacitors used for reactive power compensation.

The electronic equipments are based on the use of semiconductors, and they determined non-linear voltage-current characteristics being thus sources of harmonics in the power network.

There are several known effects of harmonics on the power network. These effects depend on the shape and location (position) of the higher harmonic source, as well as on the configuration and characteristics of the power network where they are propagated. The most important of these adverse effects are: occurrence of the resonance phenomenon in higher harmonic frequencies, which can produce currents and voltages over the standard admission limits; overdemand and the possible damage of the capacitors used for reactive power compensation; perforation of the insulation of cables and cable plugs because of overvoltages; influence on the accuracy and veracity indications of the standardized measuring devices; greater loss and the increased heat of the transmission cables, transformers and rotating machines; mechanical oscillation of synchronous and asynchronous machines; phenomenon of interference with the microprocessor system managements and relay protection; phenomenon of interference with telecommunications signals; phenomenon of interference with the devices command throughout thyristors [3].

3. MEASUREMENT ANALYSIS [4]

In this paper there are presented some results of specific measurements at an office building with the purpose of signaling the power quality problems caused by increasing use of nonlinear receivers.

The degradation of power quality consists both in the changing of the basic power parameters and in the distortion of the wave form. In the basic parameters category there are specified the effective voltage and frequency, also the asymmetry phenomena of the electrical network, the deviations being defined by correspondent Standards.

The measurements analyzed in the following were performed on a segment of the building, corresponding to the electric panel TP1 (floor panel 1). The three phase electrical distribution network supplies electrical energy both to lighting equipment equipped with fluorescent lamps with electronic ballast that uses power factor corrector and to computing devices (personal computers, laptops, printers, photocopying equipment). Measurements were performed on a 30 minutes interval, respectively at 31 March 2009 between 14:00-14:30, storing data being made per second. A Power Logic ION 8800 analyzer device was used, the data being transferred and processed on a computer. To better distinguish the electrical parameters of the network it has been achieved both an analysis at the entire range of time and an analysis at the instant time, at 14:15. For the analysis of the results, there were used the Standards SR EN 50160 and SR EN 61000-3-2.

There are first examined the corresponding electrical parameters of the distribution network:

3.1 Frequency

According to standard EN 50160, voltage frequency limits are:

- low voltage, medium voltage: average value of the fundamental wave measured at 10 s is ± 1% (48,5 – 50,5 Hz), for 99,5% in the week;
- -6% / + 4% (47 - 52 Hz) for 100% of the week [5]

The instantaneous frequency was 49,990 Hz. During the measurements made at this electrical panel (at 14:00-14:30) the minimum frequency was 49,946 Hz and a maximum of 50,021 Hz. These values are within the limits of the allowable frequency, compliant to EN 50160.

3.2 Voltage variations

a) Variations of voltage amplitude

According to standard EN 50160, the variations of voltage amplitude must be within the limits:

- low voltage, medium voltage: ± 10% for 95% of the week, 10 minute average of actual values. Thus, at U=230 V, the permissible variation domain of voltage is U=207... 253V.

b) Fast voltage variations

According to standard EN 50160, the fast voltage variations must be within the limits:

- low voltage: 5% normal (U=218,5 .. 241,5 V), 10% uncommon (U=207 .. 253 V); $P_{lt} \leq 1$ for 95% of the week, where the P_{lt} represents the long-term flicker severity;
- medium voltage: 4% normal, 6% uncommon; $P_{lt} \leq 1$ for 95% of the week;

Analyzing the measurements, the voltage amplitude value at 14:15 and for the period of time for which measurement was made:

1. U_1=244,816 V at 14:15, during the measurement period of time (14:00-14:30): U_{1max}=244,934 V; U_{1min}=220,144 V; U_{1med}=231,375 V.
2. U_2=243,660 V at 14:15, during the measurement period of time (14:00-14:30): U_{2max}=244,010 V; U_{2min}=220, 065 V; U_{2med}=230, 840 V.
3. U_3=244,023 V at 14:15, during the measurement period of time (14:00-14:30): U_{3max}=244,332 V; U_{2min}=219, 438 V; U_{2med}=230, 682 V.

These values are within the standard limits given by EN 50160 for fast voltage variations. During the measurements at the electrical panel there were not reported overvoltages or gaps of the voltage supply.

3.3 Harmonic voltages

Individual harmonic distortion (HD) is defined as the ratio between the actual values of the n[th] harmonic and the fundamental harmonic (50 Hz) [5]:

$$HDU = (U_n/U_1) * 100\% \quad (1)$$

where HDU is the individual harmonic distortion factor of the voltage; U_n- actual-value of the n[th] harmonic voltage; U_1- effective value of the fundamental voltage. Total harmonic distortion (THD) is defined according to [5]:

$$THDU = \sqrt{\sum_{n=2}^{\infty} U_n^2 / U_1^2} * 100 = \sqrt{\sum_{n=2}^{\infty} HDU^2} (\%) \quad (2)$$

where THDU is the total harmonic distortion factor of voltage.

The total harmonic distortion factor of the current (THDI) is defined by [5]:

$$THDI = \sqrt{\sum_{n=2}^{\infty} I_n^2 / I_1^2} * 100 = \sqrt{\sum_{n=2}^{\infty} HDI^2} (\%) \quad (3)$$

where THDI is the total harmonic distortion factor of the current; I_n - the actual current amplitude of the n[th] harmonic; I_1 - the actual current amplitude of the fundamental; HDI - current individual harmonic distortion factor.

According to standard EN 60160, THDU must be equal or less than 8%. The measurements made indicate a value of THD in the standard limit, respectively:

- $THDU_1$=2,202%; $THDU_2$=2,301%; $THDU_3$=2,144% at 14:15.

In the period of time when the measurements were made, the maximum THDU was:

$THDU_1$=2,321%; $THDU_2$=2,395%; $THDU_3$=2,227%.

Analyzing these results it can be concluded that the supply voltage at the electric panel TP1 it is in the standard limits given by the EN 50160.

An analysis of power, currents and phase angle between currents and voltages is made.

Following the measurements of conductors that leave the electrical panel TP1 at 14:15 there were recorded the following dates:

- P_1=1,288 kW, S_1=1,681 kVA, Q_1=-0,189 kVAr; I_1=6,868 A; PF=76,596%; phase angle U_1=0°, I_1=8,984°; $THDI_1$=81,501%.
- P_2=1,781 kW, S_2=1,863 kVA, Q_2=-0,422 kVAr; I_2=7,644 A; PF=95,611%; phase angle U_2=-119,641°; phase angle I_2=-106,134°; $THDI_2$=18,341%.
- P_3=2,483 kW, S_3=2,513 kVA, Q_3=-0,347 kVAr; I_3=10,298 A; FP=98,818%; phase angle U_3=120,211°; phase angle I_3=128,507°; $THDI_3$=6,194%.

Three phase power factor is equal to 98,545%. On the earth phase conductor there were recorded the following dates:

I_4=6,381 A, $THDI_4$=149,577 %.

An analysis of these results is attempted:

- Reactive power values are negative, the measured parameters (U, I) being situated in the 4[th] quadrant, according to calculation mode of the Power Logic ION 8800 [6].
- On the L_1 phase conductor there can be seen a low power factor, PF=76,596% (below the required 92% of the power network supplier), a high current harmonic distortion factor, $THDI_1$=81,501% a K-factor of 11,494 (K-factor is a weighting of the harmonic load currents according to their effects on transformer heating, as derived from IEEE C57.110. A K-factor of 1.0 indicates a linear load (no harmonics). The higher the K-factor, the greater the harmonic heating effects), and a crest factor of 2,496 (by definition, the crest factor of a voltage is equal to the peak value divided by the effective (rms) value - in the case of a sinusoidal voltage the crest factor is 1,41).

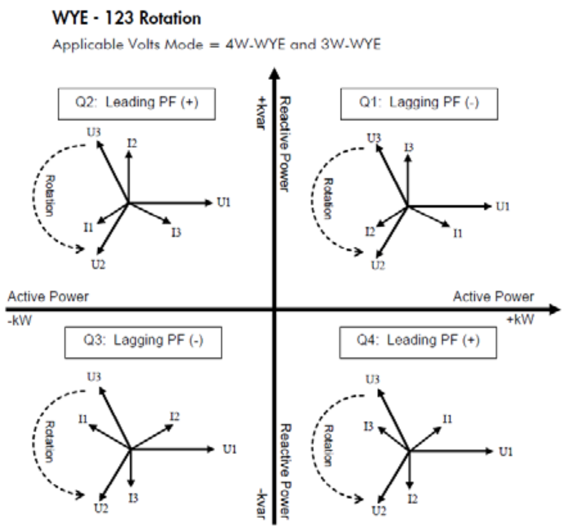

Figure 1: The distribution on quadrants of the phase diagrams, regarding the active power and the reactive power.

To reach a conclusion in this case it was conducted a more detailed analysis which shows the correlation between the low power factor and the harmonic pollution of the electrical network. In Table 1 there are listed the values of the amplitudes of each harmonic current till the rank of 25, at 14:15.

- Throughout the measurements, the minimum value of the power factor is PF=74,890% and the maximum current total harmonic distortion factor is $THDI_1$=83,288%. For the calculation of the power factor, the Power Logic ION 8800 uses an algorithm based on the equation [6]:

$$PF_\alpha = P_\alpha / S_\alpha * 100\%, \tag{4}$$

where PF_α represents the read power factor values on each phase; P_α, S_α – the active power and the reactive power for each phase.

The power factor of the corresponding pure sinusoidal system is being calculated. Thus, with U_1=244,816 V, I_1=6,868 A, phase angle between voltage and current being φ=8,984°, the resulting active power is P=1,6607 kW, apparent power S= 1,6814 kVA and power factor PF=98,77 %. The difference between this factor and the initial power factor is given by the harmonic pollution of the power network. This correlation between the current harmonic distortion factor (THDI), the K-factor and the power factor it is observed throughout the measurements:

-minimum value $THDI_1$=48,911%, with a K-factor equal to 5,274 corresponds to a power factor PF=86,085 %;

-maximum value $THDI_1$=83,288%, with a K-factor equal to 11,290 corresponds to a power factor PF=79,637 %

The high value of the current total harmonic distortion factor $THDI_1$=81,501% and also the value of the K-factor equal to 11,494 indicates a high percent of harmonics, due to lighting devices equipped with fluorescent lamps with electronic ballast and to modern electric equipment. The values allowed for the current amplitude wave are:

THDI ≤ (5 ... 20)%, depending on the size of short-circuit current at the point of delimitation I_{sc} considered as multiple of nominal current corresponding to the load I_s ($<20 \cdot I_s$ ... $>1000 \cdot I_s$). [7].

It can be noted that the current total harmonic distortion factor exceeds far the standard limits. It is known the fact that the fluorescent lamps are equipped with capacitors to increase the power factor, these capacitors amplifying the harmonic distortion.

Analyzing the phase conductors L_2 and L_3 there can be observed values of the current harmonic distortion factor, $THDI_2$=18,341 %, respectively $THDI_3$=6,194 %, values which fall within the standard limits. There can be also observed the increased values of power factor (PF_2=95,611 %, PF_3=98,818 %).

The neutral conductor requires to be analyzed due to the high current harmonic distortion factor $THDI_4$, $THDI_4$=194.577 % and a K-factor equal to 16,459. The maximum value of $THDI_4$ on the entire range of time of measurements it is $THDI_4$=484.893 %, corresponding to a K-factor of 21,554. These values do not fall within acceptable standard limits. The values of amplitudes of each harmonic current till the rank of 25, at 14:15, will be listed in Tables 2 and 3. Results shown indicate an increased percentage of odd harmonics, especially harmonics of rank 3 and 5.

4. CONCLUSIONS

Fluorescent lamps (both the compact and fluorescent tubes) with electronic ballast and the modern electric equipment, while providing an increased efficiency, their use imply a decrease in the electrical power quality of the network.

Analyzing the results it can be concluded that the designing of electrical installations in an office building must take account of the existence and the positioning of the non-linear receivers, their existence in the electrical distribution network causing the amplification of the harmonic current, the decrease of the power factor of the electrical network, the rising current harmonic distortion of the neutral conductor. must take account of the existence and the positioning of the non-linear receivers, their existence in the electrical distribution network causing the amplification of the harmonic current, the decrease of the power factor of the electrical network, the rising current harmonic distortion of the neutral conductor.

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		Odd harmonics				Even harmonics	
Time	31.03.2009 @14:15:00	Not multiples of 3		Multiples of 3			
I_1	6.868 A	Order	Relative current (%)	Order	Relative current (%)	Order	Relative current (%)
$THDI_1$	81.501%	5	40.521	3	61.957	2	2.282
		7	27.215	9	16.009	4	1.446
		11	7.667	15	5.460	6	1.195
		13	2.416	21	1.950	8	1.182
		17	4.796			10	1.324
		19	3.715			12	0.689
		23	0.760			14	0.189
		25	1.973			16	0.539
						18	0.262
						20	0.244
						22	0.664
						24	0.373

Table 1: The amplitudes of harmonic current in phase conductor L_1, at 14:15.

		Odd harmonics				Even harmonics	
Time	31.03.2009 @14:15:00	Not multiples of 3		Multiples of 3			
		Order	Relative current (%)	Order	Relative current (%)	Order	Relative current (%)
I1	6.868 A	5	52.383	3	130.629	2	4.152
THDI1	81.501 %	7	37.848	9	27.437	4	1.948
I2	7.644 A	11	5.170	15	10.429	6	2.741
THDI2	18.341 %	13	6.009	21	4.860	8	1.211
I3	10.298 A	17	5.077			10	1.838
THDI3	6.194 %	19	4.966			12	2.215
I4	6.381 A	23	3.471			14	0.893
THDI4	149.577 %	25	1.568			16	0.665
						18	1.073
						20	1.322
						22	1.504
						24	1.546

Table 2: The amplitudes of harmonic current in earth phase conductor, at 14:15.

		Odd harmonics				Even harmonics	
Time	31.03.2009 @14:15:55	Not multiples of 3		Multiples of 3			
		Order	Relative current (%)	Order	Relative current (%)	Order	Relative current (%)
I1	8.297 A	5	166.124	3	424.799	2	18.498
THDI1	54,678 %	7	125.105	9	86.000	4	7.534
I2	7.652 A	11	18.473	15	30.149	6	9.936
THDI2	18,400 %	13	18.959	21	14.067	8	4.551
I3	9.752 A	17	17.020			10	3.924
THDI3	6,435 %	19	18.982			12	5.358
I4	5.979 A	23	16.698			14	1.197
THDI4	484,141 %	25	3.315			16	3.404
						18	4.526
						20	6.586
						22	4.213
						24	4.468

Table 3: The amplitudes of harmonic current in earth phase conductor, at THDI maximum value.

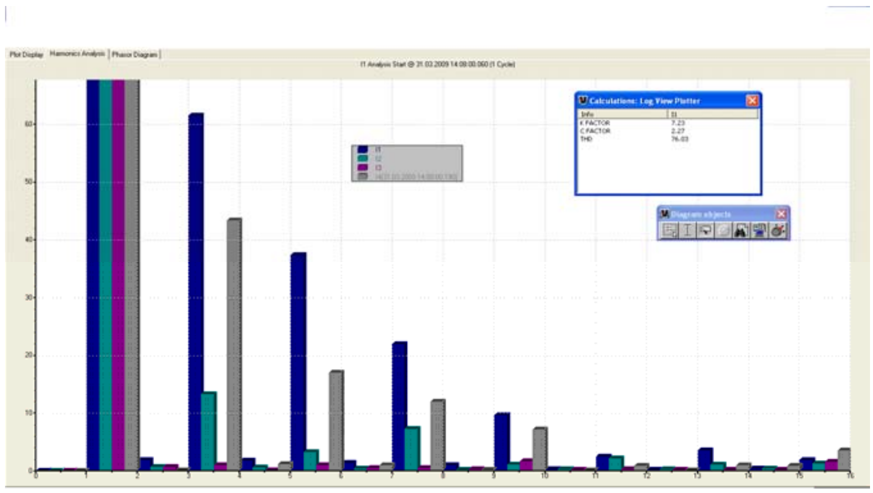

Figure 3: The amplitudes of current wave harmonics, where it can be seen the high value of the harmonic distortion coefficient of the L1 phase and earth phase conductors (I_1-dark blue, I_2-blue, I_3- violet, I_4-gray).

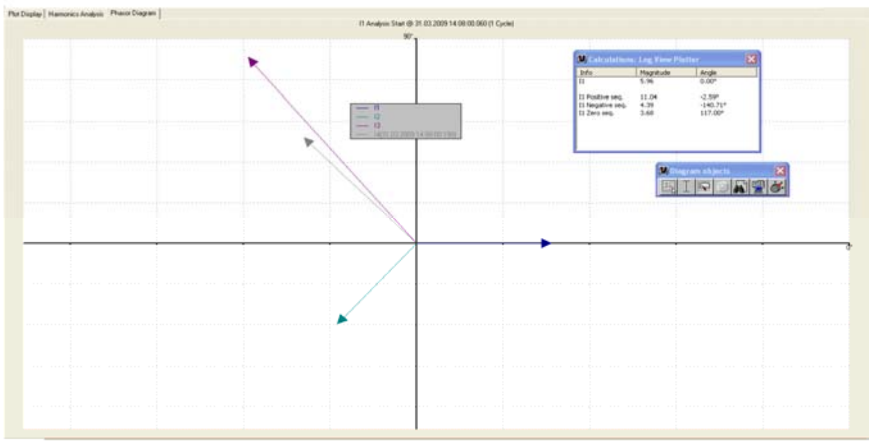

Figure 4: The phase current diagram (I_1-dark blue, I_2- light blue, I_3-purple, I_4 -gray).

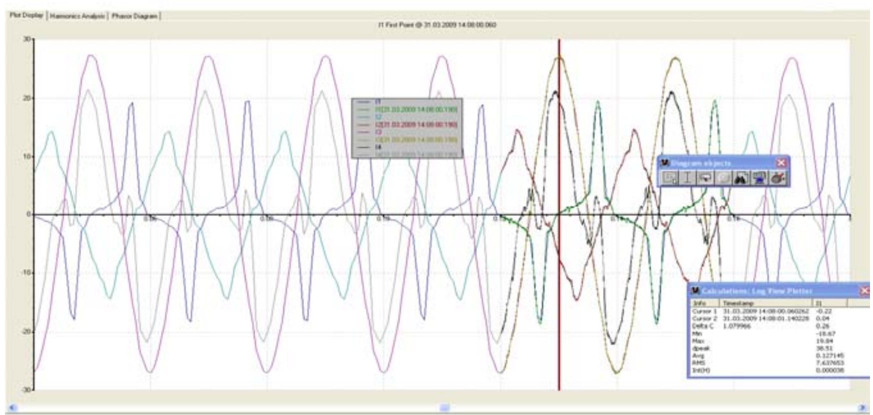

Figure 5: The current wave forms (I_1-dark blue, green, I_2-blue, red, I_3-purple, brown, I_4-black, gray).