MEASUREMENTS IN UNBALANCED LOW VOLTAGE NETWORK AND ON-LINE VOLTAGE MONITORING DEVICE

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INTRODUCTION

Electricity, as the most widely spread and versatile form of energy, able to meet all type of demands and utilizations of the customers, must accomplish specific quality requirements stated by standards and regulations. The european standard EN 50160 is compulsory in Romania, as well as the ANRE (National Regulatory Authority) Performance Standard for the power distribution activity, published by the end of 2007. The Performance Standard defines indicators and sets out the formulas and limits for the supply continuity, power distribution technical quality and trading quality. The distribution operator (DO) has to achieve the goal of the power quality and continuity monitoring in a significant number of substations, by using adequate devices. The devices must allow at least, measurements, recordings and analysis for voltage sags and drops, interruptions, frequency recordings, temporary overvoltages phase to earth or between phases (voltage swells), flicker, harmonic and interharmonic voltage, THD and the voltage unbalance. Any licensed OD must monitor the power quality at least in 5 HV/MV substations, in 2008. The effective voltage monitoring must be accomplished in all the substations. The distribution operator need also to have a number of portable monitoring devices with the same performance, for solving customers' complaints, all costs being supported by the company. It must be said that most of these requirements are not yet effectively implemented.

The paper presents the measurement results achieved during an unbalanced low voltage power network analysis, in an urban area, in Romania, and a monitoring device and software conceived by the authors. The unprecedented proliferation of customers' electronic devices increased the possible damage caused by abnormal voltages non-compliant with the standard limits, and by the disturbances of the public distribution systems.

If, until recently, power network development planners and managers took into consideration, primarily, information from the main consumption points or nodes, the last period failures, and also, their media exposure, unveiled the importance of a proper quality parameter monitoring, especially, to have real time voltage measurements from the consumption points. This becomes very important for the low voltage to, in the last one or two years. Therefore, power quality measurements parameters should be performed systematically, by more diversified and better devices, up-dated to the present requirements. Today's low-cost of the new electronics components, especially for the microcontrollers, and their accuracy and reliability for measurements and data processing, represent great opportunities in this field.

Even in the rural areas, farmers are using now process or climate control equipments, sensitive to voltage variations [1]. The failures of such equipment caused by all type of disturbances can draw significant economic losses for the power customer and, consequently, for the supplier. Modern building electrical installations are becoming more and more sophisticated, not only as functional diversity, but also in terms of cost and power efficiency, flexibility and safety. Actions like the lighting

control, climate and blinds control, security protections and equipments, must operate in a reliable and optimal way, and any error or damage caused by incompliant supply voltage should be rapidly eliminated. For this type of customers, owners of so-called “intelligent buildings”, aspects as the remote control operation, on-line installation monitoring and the integration with other control systems, focus on the importance of new devices and software.
For the supplier, the new power market imposes the obligation to monitor and report to the regulatory authority a greater number of network performance indicators. He is compelled to pursue the contract requirements and maintain the good technical conditions to keep his customers.
The papers deals with unbalanced low voltage network measurements, using the expression of the total distortion factor THD, calculated as follows:

$$\delta_U = \sqrt{\sum_{k=2}^{40} \frac{U_k^2}{U_1^2}} \qquad (1)$$

Negative asymmetry factor:

$$k_U^- \ [\%] = \frac{U_1^-}{U_1^+} \cdot 100 = \left| \frac{\underline{U}_A + \underline{a}^2 \cdot \underline{U}_B + \underline{a} \cdot \underline{U}_C}{\underline{U}_A + \underline{a} \cdot \underline{U}_B + \underline{a}^2 \cdot \underline{U}_C} \right| \cdot 100 \quad [\%] \qquad (2)$$

For a rapid evaluation of the asymmetry in a power node a more simple formula can be used, after the IEEE norms, as follows:

$$k_s = \frac{U_{max} - U_{med}}{U_{med}} \qquad (3)$$

where U_{max} represents the highest value between the phase voltages U_A , U_B and U_C in the analysed node, U_{med} being the average between the three values.
The flicker indicator P_{st} :

$$P_{st} = \sqrt{0{,}0314 P_{0,1} + 0{,}0525 P_{1s} + 0{,}0657 P_{3s} + 0{,}28 P_{10s} + 0{,}08 P_{50s}} \qquad (4)$$

Where the values $P_{0,1}$, P_1, P_3, P_{10} and P_{50} represents flicker levels exceeded for 0,1; 1; 3; 10 and 50% of the total observation time, within the specified observation interval. The *s* index shows that the smooth values should be used. These values are obtained with the formulas:

$$P_{50s} = (P_{30} + P_{50} + P_{80})/3; P_{10s} = (P_6 + P_8 + P_{10} + P_{13} + P_{17})/5;$$
$$P_{3s} = (P_{2,2} + P_3 + P_4)/3; P_{1s} = (P_{0,7} + P_1 + P_{1,5})/3. \qquad (5)$$

VOLTAGE RECORDINGS IN LV NETWORK

The company periodically proceeds to power quality measurements in the distribution networks, medium and low voltage, some of the recent results being stated below. The recordings were made in a urban area, a 6/0,4 kV substation (Figure1÷8 and Tables 1÷6), on 0.4 cables, with a power quality analyzer. The two feeders were monitored for couples of houres on 26 and 31 october 2007.

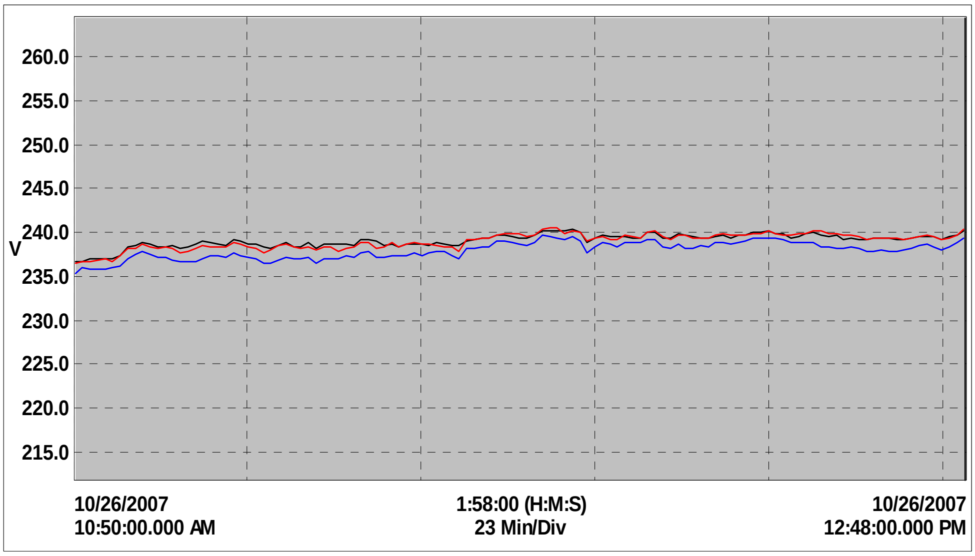

Figure 1. Phase to earth voltage on Feeder 1 (supplying gas station)

TABLE 1 – PHASE TO EARTH VOLTAGE, FEEDER 1

	Average voltage (V)	Minimum voltage (V)	Maximum voltage (V)
U_{ph-e} phase1	239.05	236.60	240.40
U_{ph-e} phase2	238.97	236.60	240.50
U_{ph-e} phase3	237.91	235.30	239.60

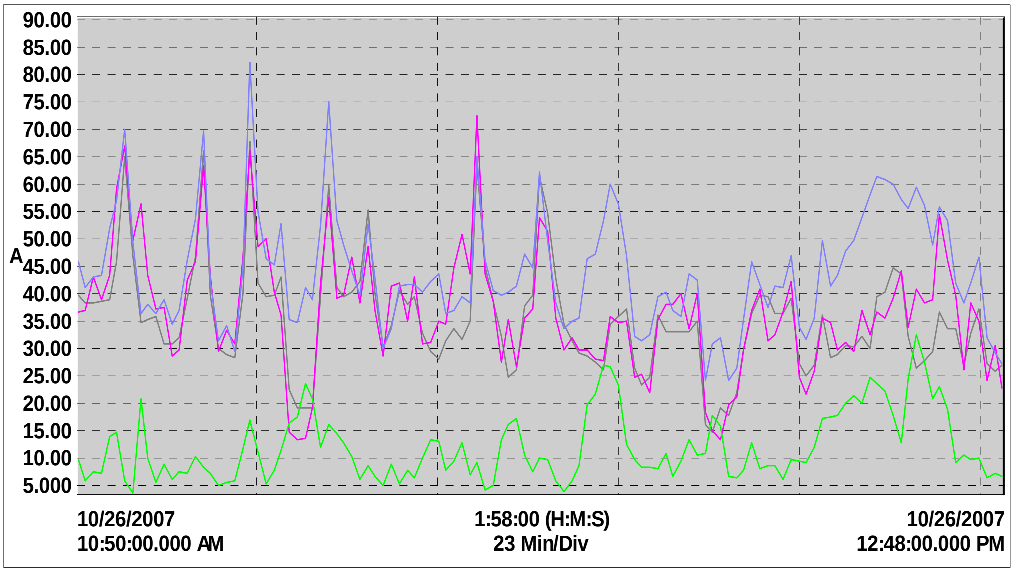

Figure 2. Phase and neutral currents

TABLE 2 – PHASE AND NEUTRAL CURRENTS

	Average current (A)	Minimum current (A)	Maximum current (A)
I_{ph} phase 1	35.01	14.60	67.70
I_{ph} phase 2	36.48	13.10	72.50
I_{ph} phase 3	43.93	24.00	82.20
$I_{neutral}$	11.89	3.60	32.30

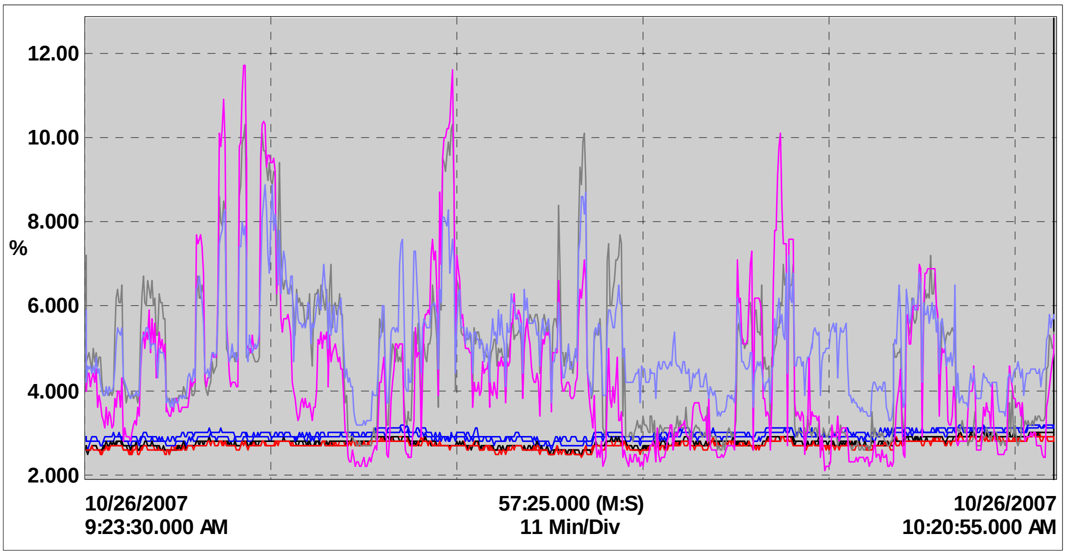

Figure 3. Total distorsion factor for current and voltage

TABLE 3 – THD FOR CURRENT AND VOLTAGE

	Average value (%)	Minimal value (%)	Maximal value (%)
I_{thd} (δ_I) phase1	4.650000	2.600000	10.300000
I_{thd} (δ_I) phase2	4.301304	2.100000	11.700000
I_{thd} (δ_I) phase3	5.003333	3.200000	8.900000
U_{thd} (δ_U) phase12	2.746087	2.500000	3.000000
U_{thd} (δ_U) phase23	2.739275	2.500000	3.000000
U_{thd} (δ_U) phase31	2.894058	2.600000	3.200000
V_{thd} (δ_V) phase1	2.774058	2.500000	3.000000
V_{thd} (δ_V) phase2	2.702174	2.400000	3.000000
V_{thd} (δ_V) phase3	2.979275	2.700000	3.200000

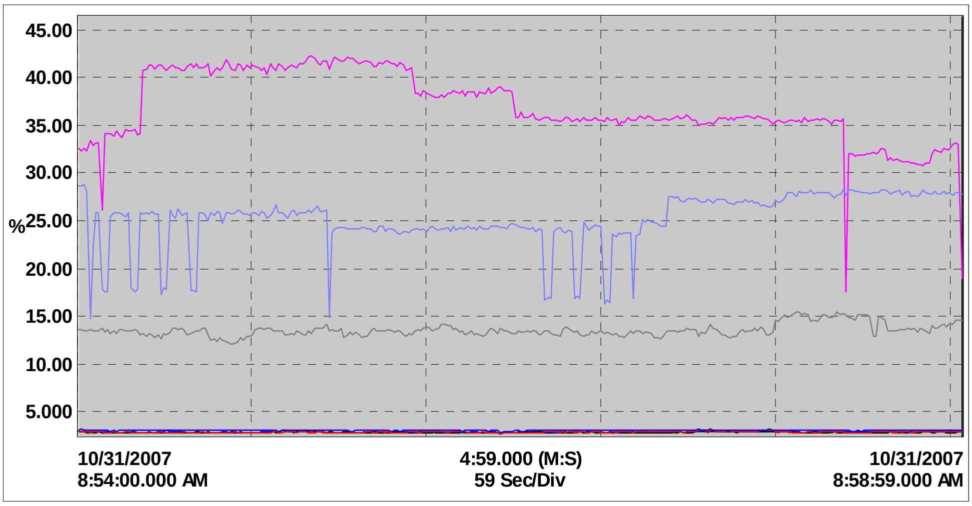

Figure 4. Total distorsion factor for current and voltage

TABLE 4 – THD FOR CURRENT AND VOLTAGE

	Average value (%)	Minimal value (%)	Maximal value (%)
I_{thd} (δ_I) phase1	13.545000	12.100000	15.400000
I_{thd} (δ_I) phase2	36.923000	17.500000	42.300000
I_{thd} (δ_I) phase3	25.152667	14.700000	28.800000
V_{thd} (δ_V) phase1	2.832333	2.700000	3.000000
V_{thd} (δ_V) phase2	2.853667	2.600000	3.000000
V_{thd} (δ_V) phase3	3.031667	2.800000	3.200000

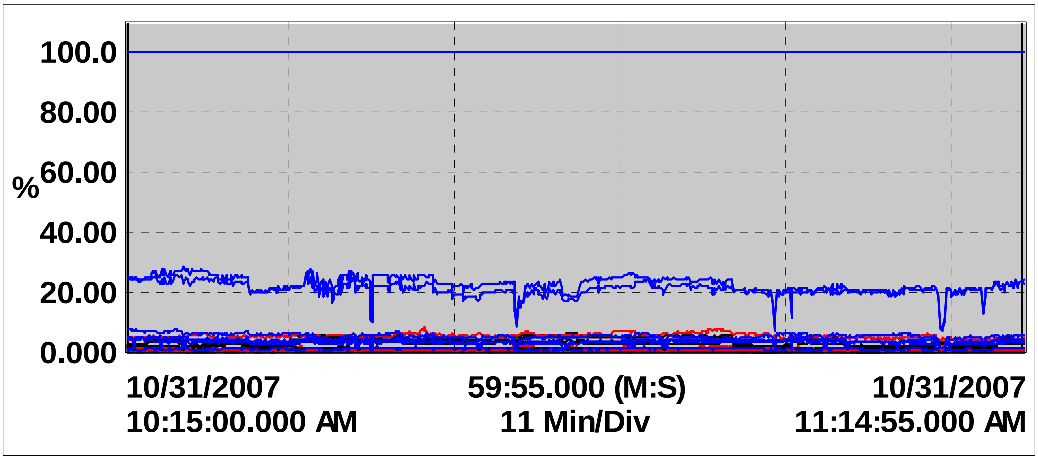

Figure 5. Current harmonics

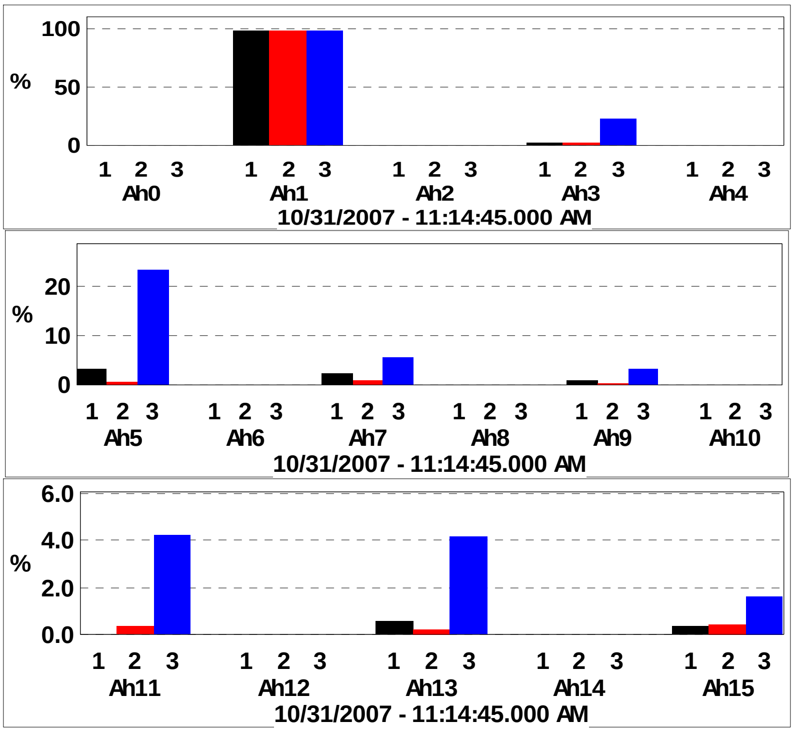

Figure 6. Current harmonics

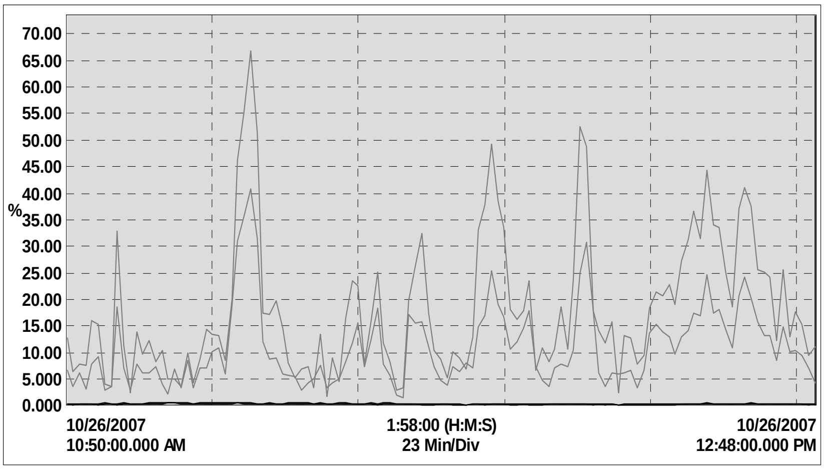

Figure 7. Asymmetry factor

Table 5 – ASYMMETRY FACTOR

	Average value (%)	Minimal value (%)	Maximal value (%)
k_I^- (IEC)	10.93	1.50	40.80
k_U^- (IEC)	0.40	0.20	0.60

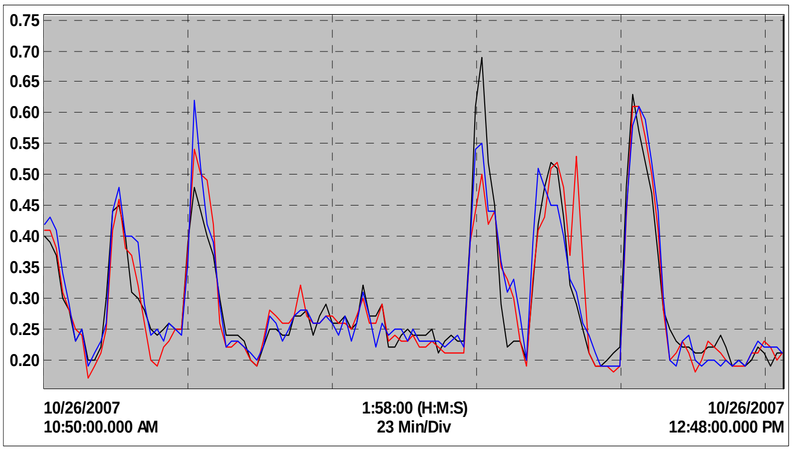

Figure 8. Flicker indication

Table 6 – FLICKER INDICATION

	Average value	Minimal value	Maximal value
P_{st} phase1	0.292	0.190	0.690
P_{st} phase2	0.292	0.170	0.610
P_{st} phase3	0.296	0.190	0.620

THE LV MONITORING DEVICE

The higher number of automation processes and equipments sensitive to voltage disturbances, together with a higher number of disturbing industries, requires distributed monitoring devices, both for the network as for consumers. It would be ideal for the supplier to have real time feedback from the consumer's connection point and for the consumer to be able to monitor his electrical installation and power quality parameters. Also, it is obvious the need for a rapid reaction in case of poor power quality or disturbances, from the operational side, for optimal intervention, maintenance or repair, and the need for a more rapid adjustment of the operation or the development plans. For the power quality measurements and monitoring principles, some of the last period' papers sustain one or more of the following concepts [2]:

1. One option is to use currently a cheap monitoring or measurement device, with limited technical performance, and only in case of threshold values or periodically the basic instrument will be replaced with a performance device. This allows a more accurate analysis when is needed.

2. Another option would be when the measurements or monitoring functions are implemented mainly on expensive instruments, (i.e. power quality analyzer), with high resolution and data processing capabilities.

3. An intermediate solution is when measurements or monitoring functions are distributed on medium performance sensors, but fully integrated in an on-line information or control system. In this case, the processing capability would be entirely supplied by the computer and the application software.

The authors identified a fourth possibility which is, basically, a compound of the first and third option and, at the same time, proposed and tested a monitoring component. For the low voltage network, we consider that maximum of results can be obtained with a high number of relatively cheap devices, easily to integrate in a distributed control system. In this case the device is not only a sensor, but a basic IED with a microcontroller. By this system we should be able to determine an optimal parameters' set to collect for a user. The cost will be always a limitation. Therefore, the new distributed monitoring system may enhance the power distribution process with a help of a large number of "basic devices", simple and cheap IEDs, integrated via communication links. A great deal of the new customers, including the most demanding, appears to have rather a "monitoring deficit" than surplus, therefore, affordable and flexible modules easily to integrate in a control system will bring a step forward for the goal of the quality power distribution. The accuracy analyses remains to be treated periodically or in case of frequent threshold values, as the performance standard already requires. As a result of these ideas, the authors achieved a simple IED for the voltage monitoring of in a costumer installation, the block-diagram being presented in Figure10. The device, as a first step of a concept, is made with analogue/digital measurement circuit and an 8 bits microcontroller. Its manufacture price is planned to remain bellow 100 €/device (except the computer).

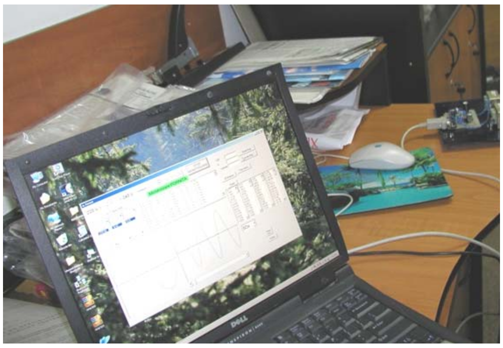

Figure 9. Testing the device interface

The main components are:

I. A measurement circuit – supplies a 20 bits sampled waveform data, with a 0.5 V voltage input and temperature compensation. This component is achieving also frequency measurement by the zero point crossing detection.

II. The Central Unit (CU) is an 8 bits microcontroller with a 16 Kbytes programmable flash memory. The voltage wave is detected and sampled in 140 samples, with maximum points (positive or negative) detection. Also, through the microcontroller are achieved the device settings, the controls, on-request measurements, data preparation for archive.

III. Data are transmitted through a RS 232 serial interface to a computer, were the measurements are processed and displayed. The HMI interface was achieved in Visual Basic.

IV. Power source (continuous current from batteries is recommended);

V. Usual PC on Windows Xp, even Windows XpHE is good. The computer permits subsequent data processing, diagrams drawings, tabulation and archiving. In this stage of the concept was analyzed and processed the voltage signal in different locations within a building (fig.9).

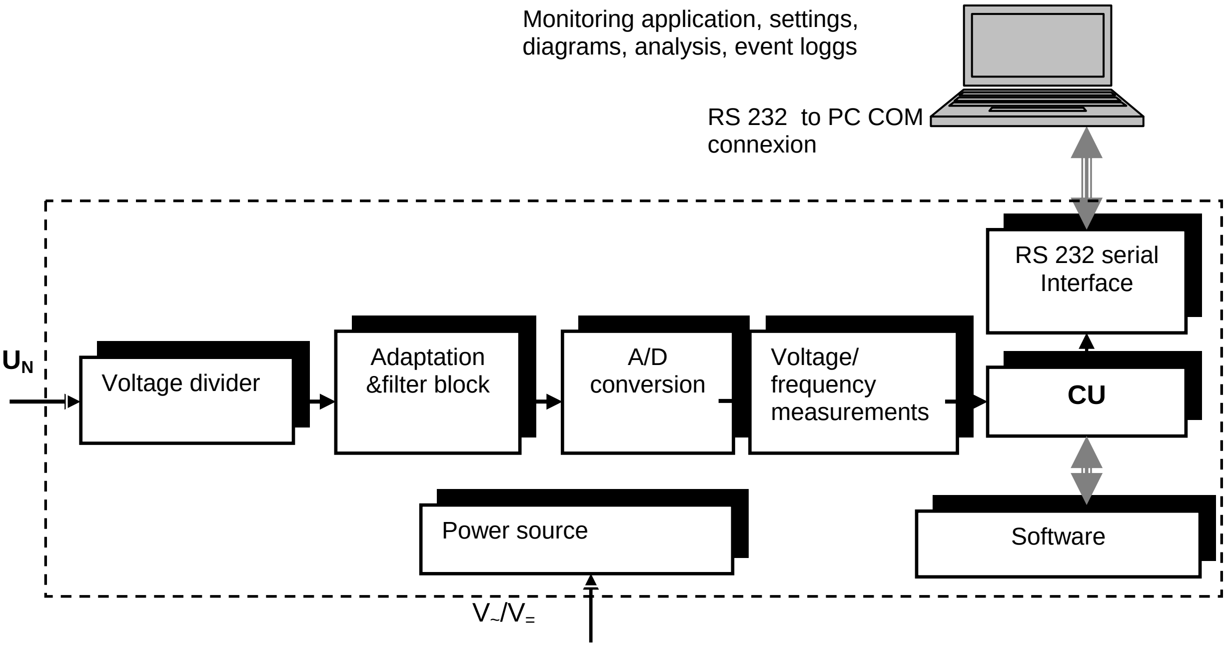

Figure 10. Block-diagram of the of the voltage monitoring device

CONCLUSIONS

The authors assume that the most effective power monitoring system, having the highest performance/cost ratio, will be obtained with simple measurement and monitoring devices easily to integrate in a distributed system. The concept putted in the lead with the achievement of the device and the software application was to allow to an individual customer with minimal data processing equipment and know-how to perform an efficient voltage monitoring, offering him a tool in the possible disputes with the supplier. A cost limitation of the conceived module is also a target, so the device and the monitoring software become accessible for a large number of users. As a concept in development, the power monitoring can be achieved in different configurations, both by the supplier or by the low voltage customer, in this case in buildings with an informatic surveillance and control system, like business centres, offices, banks, administration buildings, upper-level residences, etc.
LV recordings in power distribution installations, presented in Figure1÷8 and the Tables, indicate that even in case of compliant operation, disturbances can occur any moment, therefore being important to have up-date information and an on-line feedback of the power quality parameters. The new availability of measurements circuits and microcontrollers and, also, GPRS communication and Internet technologies, allow extending power quality monitoring with devices adaptable for applications within the buildings, in customer's installations, or in MV/LV substations. The device conceived by the authors can monitor the voltage, the frequency, voltage variation and rapid change, fluctuations and dips. In three-phase system, the voltage unbalance can be monitored. The device is a step in testing the on-line monitoring concept in low voltage, both for distributors' as for customers' purposes.

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