POWER QUALITY MONITORING AND SAMPLE SIZE ANALYSIS BEYOND EN 50160 AND IEC 61000-4-30

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ABSTRACT

Possibility for storing electrical energy in any significant quantity is very limited. Measurement and evaluation of the quality of the supplied Voltage (power) has to be made at the instant of its consumption. Power Quality analysis, monitoring and assessment is a very complex task, since the supplier and user, whose sensitive electrical equipment is also a source of disturbances, have different perspectives.

INTRODUCTION

Power Quality (PQ) is the provision of the voltages and system design so that the user of electric power can utilize the electric energy from the distribution system successfully, without interference or interruption. Maintaining satisfactory PQ is a common responsibility for the supplier and the electricity user. PQ parameters are frequency, magnitude of supply voltage, Flicker, events (dips, swells, and interruptions), transients, unbalance, harmonics and inter-harmonics, and rapid voltage changes. The standard, issued by the International Electrotechnical Commission IEC 61000-3-30 defines for each type of parameters the measurement methods to obtain reliable, repeatable and comparable results regardless the instruments being used and regardless of its environmental condition.

MATEMATICAL BACKGROUND

In order to have the sustainable assessment method of the power quality in a distribution network, an appropriate statistical approach is necessary. For grid planning purpose and trend analysis of voltage quality different classification methods (STAV-method appropriate for benchmarking PCCs, CARCI-method limited on classifying voltage dips) could be used [6]. But if the main target is monitoring the voltage quality against the standard and for purpose of calculating the PCCs performances, the percentile method shows best results.
For the purpose of this Study, a Cochrane's theorem for sample size determination was used to predict the number of measurement locations. Sample size determination is the act of choosing the number of measurement points to include in a statistical sample. The sample size is an important feature of any empirical study in which the goal is to make inferences about a population from a sample. In practice, the sample size used in a study is determined based on the expense of data collection, and the need to have sufficient statistical accuracy.
In this paper, the statistical parameter "quintiles" or "percentile" (5% and 100% for Voltage-; 95% for Flicker-; 95% for THD-; and 95% for Unbalance-percentile) is calculated by means of the program MS Excel.

Determining the size of the sample

The optimal value of n – "size of the sample", can be calculated using various statistical sampling techniques. [1]. In this study size of the sample was determined with the formula of Cochran:

$$n = \frac{\dfrac{Z^2 \cdot p \cdot q}{e^2}}{1 + \dfrac{\dfrac{Z^2 \cdot p \cdot q}{e^2} - 1}{N}} \qquad (1)$$

$$N \to \infty \quad \Rightarrow \quad n = \frac{1{,}96^2 \cdot 0{,}05 \cdot 0{,}95}{0{,}06^2} = 50$$

Where:
Z - from the standard normal distribution for the desired security of the confidence interval, for example, 1.96 for an interval of 95% certainty.
p,q- sample proportion (limit violations), e.g. 0.05, q = 1 – p
e- Exactness e = 0.10 (±10%)
N – Population (number of customers N=948 563 operated by EVN Austria[1])
Measurement probability: 0.000053; Size of sample: n=50

PROPOSED MONITORING PROCESS

The power quality monitoring should be reliable and accurate; therefore the analysis for energy consumption can provide a comprehensive insight of the entire facilities. Actually, monitoring of PQ is assumed to be a key opportunity for a power supply utility to protect its reputation and improve its relationship with customers.
Monitoring the Power Quality and Harmonics should fulfill mainly two tasks. First providing the information of power quality and the causes of power system disturbances, and second, identification of problem condition through the system before they cause widespread customer complaints, equipment malfunction and failures. Measurement and analysis of supply voltage quality, according to EN 50160, requires specialized equipment and measurement methods enabling continuous monitoring over one week of the following parameters:

- three phases voltages and frequency

1 Authors thanks to EVN Austria (Macedonia) for supporting this study

- voltage unbalance factor as a ratio of positive and negative sequence voltage component
- short term and long term flicker as indication of fast and slow voltage variation
- frequency and duration of voltage dips and outages
- harmonics and total harmonic distortion factor (THD)

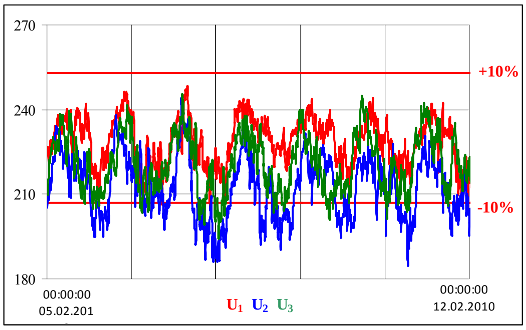
The measurement parameters are processed and recorded as 10 minute time samples (or 1008 samples over 7 days for most parameters, and 2 hours time samples for Flicker). For each sample the mean value of the measured power quality parameter is calculated and after week recording period the sum of the duration of a given distortion level in the observed time period is presented.

Description of the proposed measurement method

For performing the one week measurements a state of the art high performance power quality monitoring system OMNI-QUANT, Class I, instrument. Due to its high interference resistance and the integrated UPS, the OMNI-QUANT-*mobile* is suitable for continuous, unsupervised operation. The device was designed to measure the voltage and current in three-phase power systems with neutral conductor. If voltages occur that are higher than the maximum values allowed for the voltage inputs, voltage transformers must be used. Current measurements are generally carried out by means of the Rogowski current probes provided, or alternately by means of the optionally available CT5 current transformers. In connection with the PC software DAMON, which is included with each device, the measured values obtained can be analyzed in accordance with the EN 50160 standards and EN 61000-12 standard for compatibility levels for low-frequency conducted disturbances and signaling in public/industry low/medium-voltage power supply systems. Two measuring systems are integrated in the device. The three-phase main measurement (*L1, L2, L3*) and a single-phase auxiliary measurement (Aux) allow acquisition of 4 voltages and 4 currents. It is possible to acquire or calculate the voltages, star point voltage and asymmetry; frequency (identical for all channels), current, summary current, active reactive and apparent power; power factor; distortion reactive power; current and voltage high order (until 50) harmonics and inter-harmonics; Total harmonic distortion factor (THD); short (*Pst*) - and long (*Plt*)-term flicker severity.

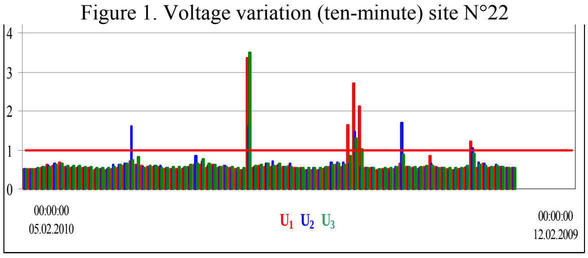
Analysis and Assessment of the Data

According to the proposed statistical sampling method measurements of voltage variation, voltage unbalance, flicker and THD are performed at 52 measurement location out of about 900000 from the Macedonian distribution network operated by EVN Austria. The percentile method because of his transparency and simplicity is used for classifying the power quality against standard EN 50160 and for assessment the performance at specific PCCs.
The reports for the different 52 measurements sites include plots of voltage variation, long term flicker severity, voltage unbalance and THD factor over a one-week period showing 7x24x6=1008 ten-minute average values. All of these 52 Measurements are conducted simultaneously and as an example the measurement plots for only one site N°22 are illustrated on Fig.1 to Fig.4.



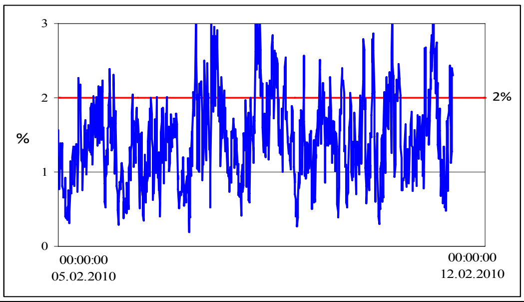
Limit	Parameter for Compliance to Pass	Actual			Result
		U_1 (%)	U_2 (%)	U_3 (%)	
±10 % Un	95% of measurement	99,70	64,29	92,56	Concern

Figure 1. Voltage variation (ten-minute) site N°22



Limit	Parameter for Compliance to Pass	Actual			Result
		U_1 (%)	U_2 (%)	U_3 (%)	
Plt≤1	95% of measurement	94,05	94,05	96,43	Concern

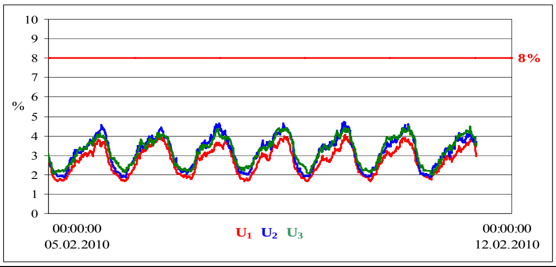
Figure 2. Long-term Flicker severity (ten-minute) site N°22



Limit	Parameter for Compliance to Pass	Actual (%)	Result
≤2%	95% of measurements	82,14	Concern

Figure 3. Voltage unbalance (ten-minute) site N°22

Short-circuit parameters of this measurement site are: *Zk=0,10Ω, Rk=0,095mΩ, Xk=0,025mΩ, Ik=2.01 kA, U=396V.*
For this particular measurement site, parameter status against EN 50630 standard for voltage variation, long term flicker severity and voltage unbalance are classified as "concern" while THD is determinate as "pass".



Harmonic number	Parameter for Compliance to Pass 95% of measurement	Actual			Result
		U1 %	U2 %	U3 %	
THD	≤8%	100	100	100	Pass
3	≤5%	100	100	100	Pass
5	≤6%	100	100	100	Pass
7	≤5%	100	100	100	Pass

Figure 4. THD (3-th, 5-th and 7-th harmonic) (ten-minute) site N°22

On the Fig. 5 and Fig.6, the probability density of 100% and 5% voltage percentiles frequency distribution for entire electrical grid are presented. The maximum expected probability density of ***100% voltage percentiles*** are between 102% (e.g. 234,6V) and 107% of the nominal voltage of 230V, while the maximum probability density of ***5% voltage percentiles*** are between 98% and 102% of the nominal 230V voltage value.

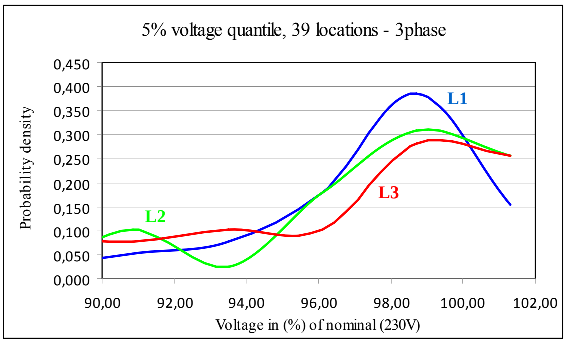


Figure 5. Frequency distribution of 5% voltage quantiles

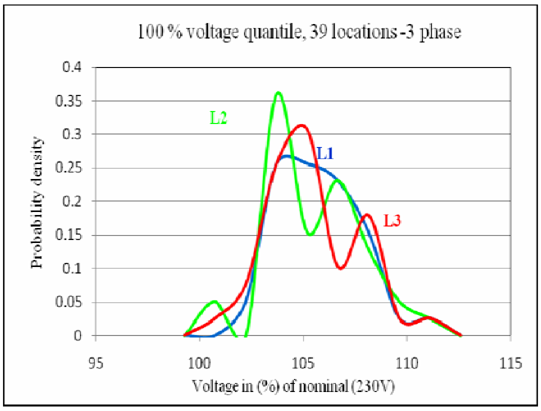


Figure 6. Frequency distribution of 100% voltage quantiles

Furthermore according to the data in the table I, it is evident that 4 out of 39 measuring sites have voltages under the lower limit of 207 (V), and only one out of 39 measuring sites has voltage over the upper limit of 253 (V).

The Fig. 7 gives the probability density of the 95% long term flicker severity frequency distribution for all 39 three phase sites measuring locations. According to the data in the table and from the graphical presentation, one can conclude that almost 30% or 11 out of 39 three phase measuring sites have flicker which level is above the upper limit of 1.

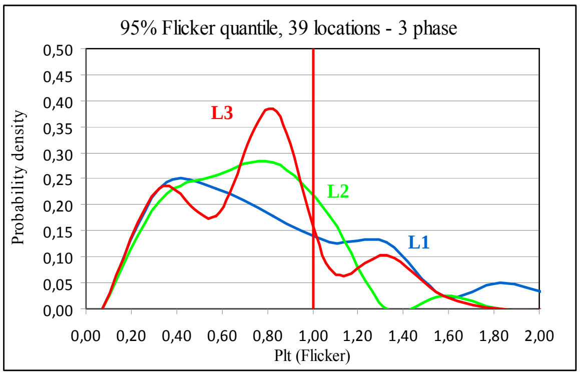


Figure 7. Frequency distribution of 95% Flicker quantiles

The Fig.8 gives the graphical presentation of probability density for 95% THD frequency distribution for all 39 three phase measuring sites.

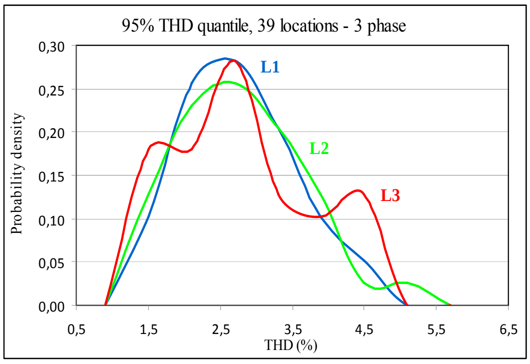


Figure 8. Frequency distribution of 95% THD quantiles

According to the data in the table I and from the graphical presentation, evidently all 39 three phase measuring sites have THD level in the prescribed limits according EN 60150.

Fig.9 gives the frequency distribution of 95% unbalance percentile for 38 three phase measurement locations.

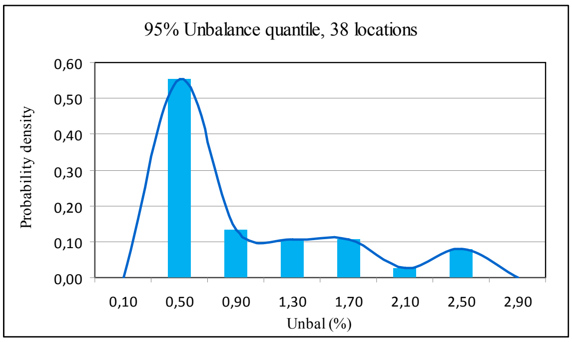


Figure 9. Frequency distribution of 95% Unbalance quantiles

The data from the table and from graphical presentation, one can conclude that 3 out of 38 measuring sites have 95% Unbalance parameter which is over the allowed upper limit of 2(%), and the maximal value for 95% percentile unbalance is 2.53 (%). One measuring site has had no appropriate conditions for conducting the unbalance measurement, so instead on 39 measuring sites, there were only on 38 sites such measurements conducted.

As a summary from statistical calculation On Fig.10 number of measurement points with PQ parameters out of limit are presented. Table I gives summarized statistical overview of voltage quality parameters according the percentile classification method for all 52 measurement sites (13 one phase consumers, 39 three phase consumers)

- **Voltage Variation:** 4 out of 13 one phase measuring locations and 5 out of three phase locations have voltages which are below low level limit of 207 (V), and only 2 out of 39 three phase locations have voltages above upper limit of 253 (V). The measurement and data processing results show the one phase consumers have lower voltages in comparison with three phase consumers. The reason may be the load unbalance of the three phase feeders with one phase consumers.

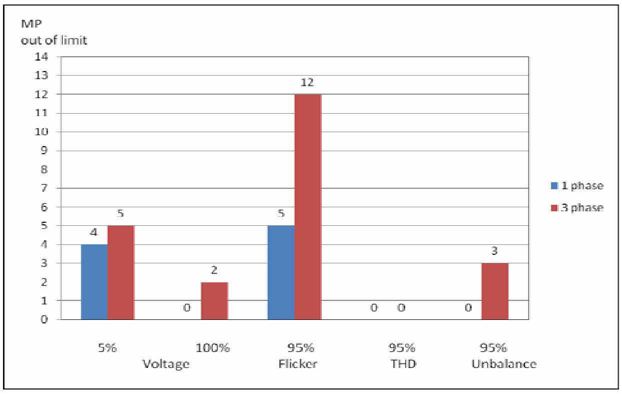


Figure 10. Measurement points with PQ parameters out of limit

- **Flicker severity:** 5 out of 13 one phase and 12 out of 39 measuring locations have long term flicker severity level $P_{\ell t}$ above prescribed limit (1) and they do not conform to the demands of the standard EN50160. This makes altogether 32,7 (%) of all measuring locations. In many cases was registered “occasional flicker” rather than “continuous flicker” mainly due load switching and due events in the power system.

- **THD:** All measuring locations have values in prescribed limits of the standard EN50160. Concerning the voltage distortion (THD) it is evident that entire distribution grids have enough capacity for additional connection of industrial or households nonlinear loads based on power electronics

- **Voltage Unbalance:** 3 out of 38 measuring locations (unbalance as a voltage quality parameter is possible only for three phase locations) have unbalance above prescribed limit of 2 (%).

TABLE I

		Voltage		Flicker	THD	Unbalance
Limit	-	±10%Un		<1	<8%	<2%
Quantile	(%)	5%	100%	95%	95%	95%
Out of limit	1 phase	4	0	5	0	0
	3 phase	5	2	12	0	3
Total	-	**9**	**2**	**17**	**0**	**3**
Measured locations	-	52	52	52	52	38
Out	(%)	**17,3**	**3,85**	**32,7**	**0**	**7,9**

CONCLUSION

The power quality monitoring should be reliable and accurate, therefore for calculating the performance of the specific PCCs as well for planning purposes and trend analysis an appropriate classification method should be used.

The aim of this paper is by means of percentile classification method, to make reliable and sustainable PQ assessment to entire distribution network. Using Cochran’s theory for sample size determination, 52 measurement sites was determinate with random access procedure.

Some authors considered that percentile method is very time-consuming and not convenient for planning purposes and trend analysis. According our experience this method is very simple and with good measurement preparation, planning and data procession gives not only reliable results for monitoring against standard and calculating the performance of particular PCCs, but also allowed comprehensive planning of the entire grid including all four PQ parameters voltage variation, voltage unbalance, flicker severity and total harmonic distortion.

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