MONITORING POWER QUALITY IN A DISTRIBUTION SYSTEM

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Summary – Utilities have been making efforts in order to diagnose and control Power Quality (PQ), since PQ has become a competitivity issue in electric power business. COELCE has been developing a PQ monitoring program aiming to determine indicators which could characterize its system power quality levels. The program involves monitoring several strategical sites. The parameters being observed include interruptions, voltage sags, harmonics, voltage imbalances, undervoltages, overvoltages, frequency deviations and power factor. The results are compared to those levels and limits currently set by legal acts, normative procedures, and recommendations. This paper presents the preliminary results from this Power Quality monitoring program.

KEYWORDS

Power quality, monitoring program, voltage sags.

I. INTRODUCTION

In order to achieve quality and productivity gerencial goals, the modern industrial processes are, more and more, using control devices based on microprocessed technology. In consequence, the loads have become exremely sensitive to phenomena associated to Power Quality (PQ). Processes interruptions are very expensive, causing production and input losses and demanding extra costs with equipament reparing and workmanship.

The power utilities, in its turn, are suffering with its worn down image and high costs, due to refunds requested by consumers to whom a poor quality power has caused damages.

COELCE, the Ceara State load serving entity, has developed a research program with the objective to determine qualitative and quantitative Power Quality indicators at the conection and delivering points. The stabilishment of the cause-effect relationship can help in choosing the preventive and corrective actions, as well as in planning the operation and expansion of the power system.

II. MONITORING PROGRAM

The monitoring program was divided into eight phases: definition of the monitoring sites; specification and aquisition of the disturbance monitors (RDP); selection of the measuring parameters; disturbance monitors installation; measurement and data collection; simulation and voltage sag data comparison; technical report elaboration.

Voltage and current informations were given by voltage transformers and current transformers placed at the 69kV and 13,8 kV buses (Figure 1).

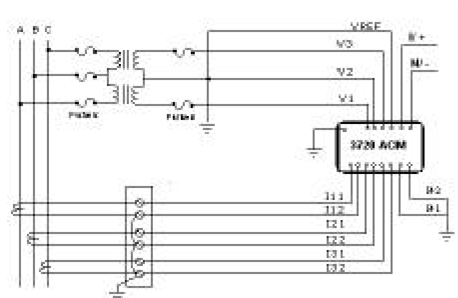

Figure 1- 3 Wire Delta System: Connection Using 2 PTs and 3 CTs.

The following parameters were monitored and analysed: interruptions, voltage sags, harmonics, voltage unbalances, undervoltages, overvoltages, frequency and power factor.

Eigh sites were selected considering the importance of the load and the power system characteristics. All the monitoring sites were installed in substations of the COELCE's power system.

The disturbance monitor used was ACM 3720 from the Canadian supplier Power Measurements Ltd. The unit is based around a 13.5 MHz, 16 bitmicrocontroller chip. This provides very high computational throughput, allowing the unit's sophisticated software to process information in real time. The unit is self-contained and its readings and set up parameters are maintained in nonvolatile memory. An internal 16-bit CPU gives the instrument the processing capability to be used as a stand-alone power monitoring in a large energy monitoring network.

The compatibility levels were taken from DNAEE's Governmental Decree 47, ANEEL's Resolution 505 and ONS (the Brazilian ISO) Network Procedures. Although the Network Procedures are not aplicable to distribution systems, we decided to use them because they set PQ indicators limits to the 13.8kV and 69 kV voltage levels.

It was used a commercially avaiable power quality database analysis software system, PEGASYS, to collect and analyse the data. This software, which runs in Windows NT, allows the storage of data in a relational database. Parameters like short-duration variations and harmonic distortion can be acquired and stored for posterior analysis. On the waveform capture mode (Figure 2), the harmonic content of a waveform can be analysed in detail. PEGASYS is also able to show or print all min/max snapshot logs from all the disturbance monitors, which are automatically stored in the hard disk of the data acquisition computer. Figure 3 shows long duration voltage variation for one monitoring site.

The monitors were set to collect min/max data of several disturbance of interest, adjusting the setpoints that indicate the storage limits in the Waveform Capture mode (Figure 4) and log events screen (Figure 5).

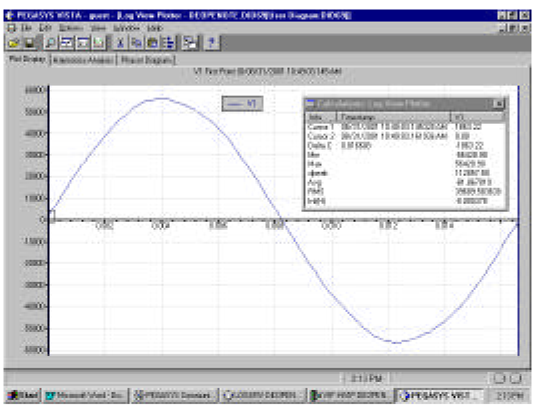

Figure 2 – Voltage *waveform capture*.

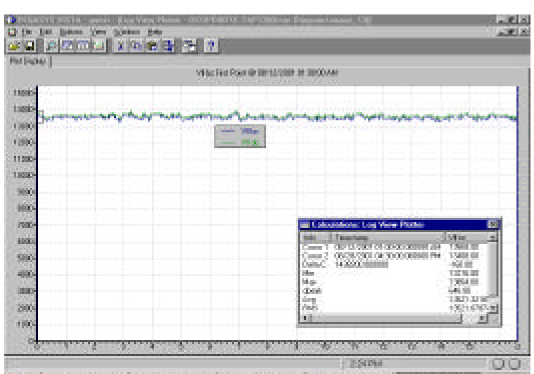

Figura 3 – Long duration voltage variation – Substation Tauape

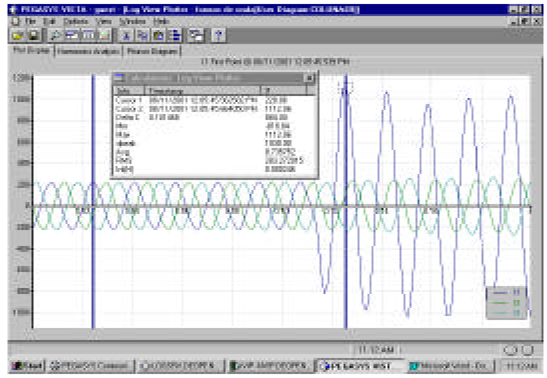

Figure 4 – Current at a fault event.

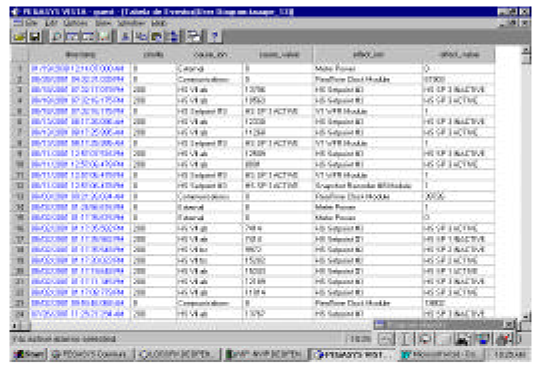

Figure 5 – Log events screen – Substation Tauape – 13.8kV

III. RESULTS

Measurements of long-duration voltage, power factor, harmonic distortion and frequency were recorded every half hour. For the first two, measurement were taken over two 24 periods: a normal week day and a 9weekend day, representing maximun and minimun consumption respectively.

Long-duration voltage measurements were presented in histograms (Figure 6), tables with minimun and maximum values, the average and 95th percentile (Table 1) and graphics showing the daily voltage profile (Figure 7).

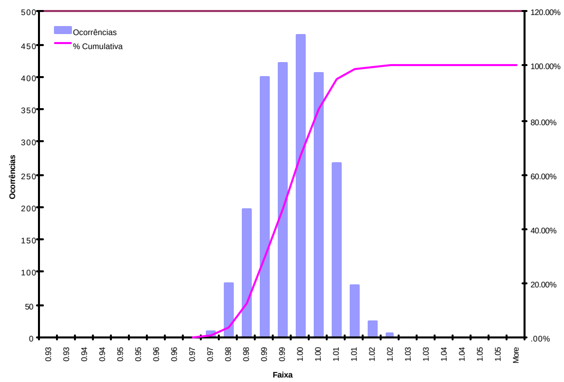

Figure 6 – Long-duration histogram for one monitoring site

Table 1- Voltage summary – Substation Coluna

Site	Line-to-neutral voltage (p.u.)		
	A	B	C
Minimum	0.966	0.968	0.974
Maximum	1.010	1.015	1.018
Average	0.986	0.991	0.995
95%	0.999	1.003	1.009

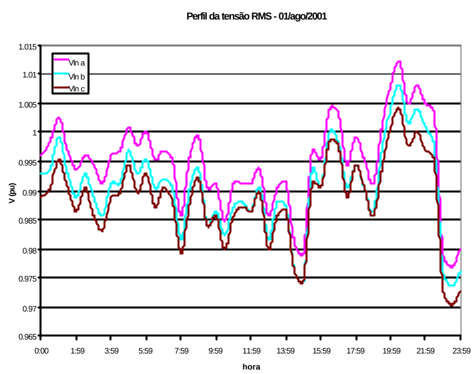

Figura 7 – One-day period voltage profile - Substation Coluna 69 KV

Total harmonic distortion (THD) results were also presented in histograms (Figure 8) and tables (Table 2). The 5th harmonic were also analysed (Table 3, Figure 9) as it was the only individual harmonic that showed significative content in all sites. Overlaid on the histogram is a cumulative probability line, which can be used to determine the sample's 5th and 95th percentile values.

Figures 10 and 11 show the 95th percentile values for the THD and 5th harmonioc, respectively, for each monitoring site. The lighter bars correspond to the 13.8 kV substations. These graphics also show the 69 and 13.8 kV limits established by ISO Network Procedures.

The voltage sags were presented by histograms and cumulative frequency (Figure 12). Figure 13 is a scatter plot of event magnitude versus duration. Overlaid on it are the tolerance limits sugested by ITIC. In this particular site (Substation Distrito Industrial) several events fell off the curve.

Table 2. THD summary

	Fase A	Fase B	Fase C
	SE Coluna		
Minimum	0,70 %	0,90 %	0,80 %
Maximum	3,10 %	3,50 %	3,20 %
95 %	2,20 %	2,60 %	2,40 %
Average	1,53 %	1,82 %	1,66 %

Table 3. 5th Harmonic summary

	Fase A	Fase B	Fase C
	SE Coluna		
Minimum	0.50 %	0.70 %	0.60 %
Maximum	2.90 %	3.40 %	3.10 %
95 %	2.07 %	2.50 %	2.20 %
Average	1.40 %	1.72 %	1.50 %

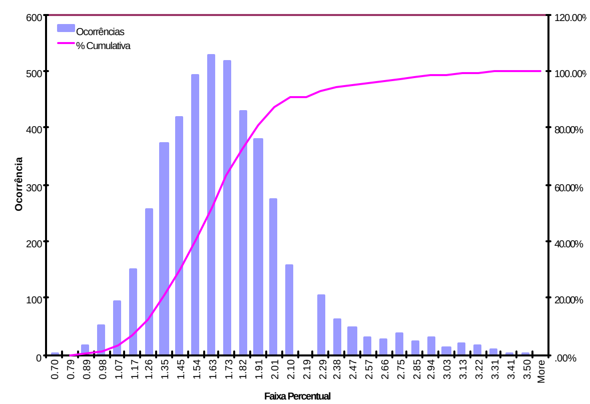

Figure 8 – Distribution of line-to-neutral voltage THD, Substation Coluna 69 kV

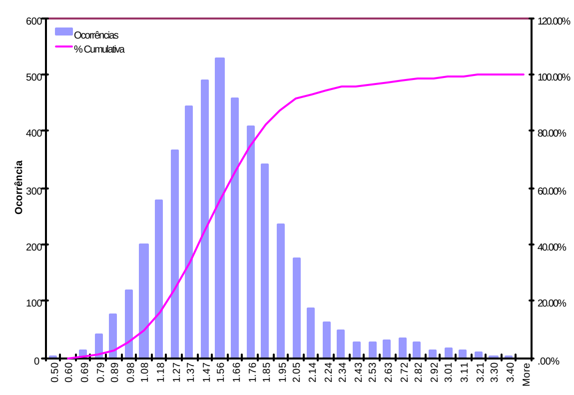

Figure 9 – Disribution of the 5th harmonic, SE Coluna 69 kV.

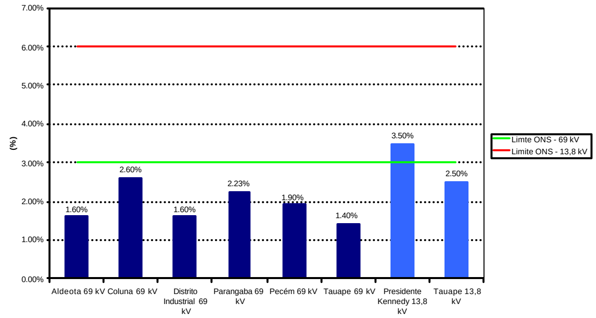

Figure 10 – 95th percentile of THD value for each substation.

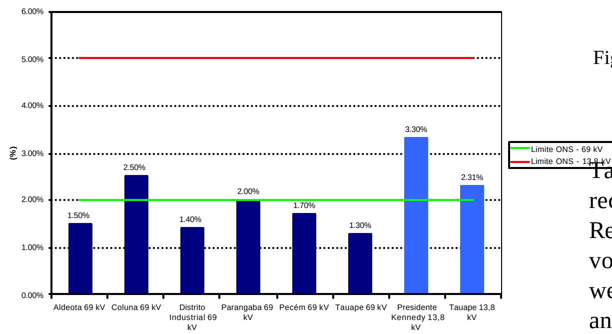

Figure 11: 95th percentile of the 5th Harmonic for each substation.

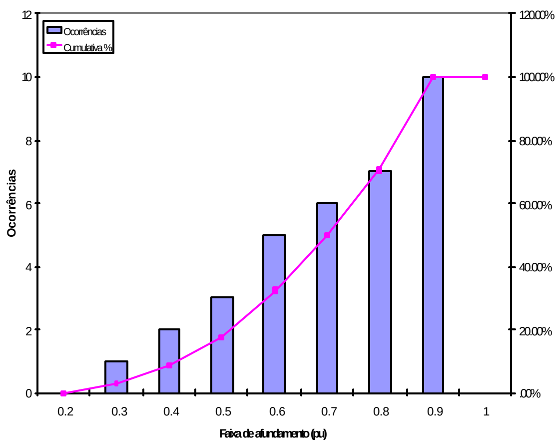

Figure 12 – Voltage Sag magnitude histogram - Substation Distrito Industrial

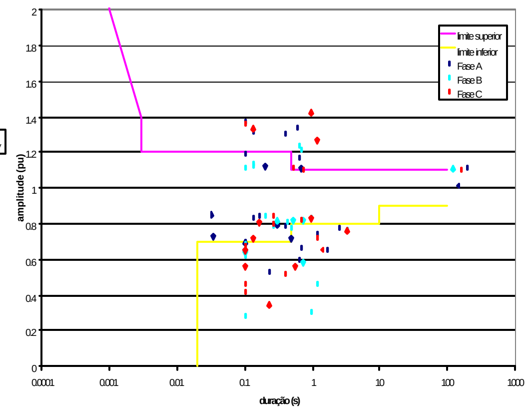

Figure 13 – Voltage variation magnitude-duration scatter plot – Substation Distrito Industrial.

Table 4 summarizes the main power quality indicators recorded over the monitoring period. For Voltage Regulation, the ISO column refers to the percentage of voltage samples, measured at the three phases, that were in agreement to the ISO limits (higher than 0.95 pu and lower than 1.05 pu). This way, a 90% value indicates that 10% of the samples were under 0.95 pu or over 1.05 pu. The P95% column shows the 95th percentile values of the voltage measurement samples . The Unbalance column values refer to the maximum value. The values presented in the columns THDV and 5th harmonic refer to the 95th percentile of the phase with the highest harmonic distortion.

Because of space limitations, results of some parameters like frequency variation and power factor will not be presented in this paper.

IV. COMPARATIVE ANALYSIS

Simulations were carried out in oder to estimate the number of voltage sags over a one-year period at the monitoring sites. The estimative values were compared to the real measured ones, aiming to evaluate the accuracy of the estimation procedure. Reliable estimation methods are essential for determining the preventive or corrective actions, even during planning phase or yet during the power system operation.

Figures 14 and 15 show the estimation of the vulnerability areas for one-phase and three-phase faults, respectively.

The number of voltage sags observed for each type of fault and voltage class, for each monitoring site, are also presented (Figures 16 and 17).

In Table 5, the number of voltage sags per year, obtained by measurements can be compared to those calculated by simulation for every monitoring site. The number of voltage sags per year showed in the measurement column were extrapolated from a five-month-period data. The simulation column values were obtained from a short-circuit calculation software, using typical COELCE's failure rate data.

Table 4 - Summary of COELCE's PQ indicators

Site	Voltage Regulation		Imbalance	THDV	5^{th} Harmonic
	ONS	P95%			
Aldeota 69 kV	54%	1.01 pu	4.00%	1.60%	1.50%
Coluna 69 kV	100%	1.01 pu	1.02%	2.60%	2.50%
Distrito Industrial 69 kV	100%	1.02 pu	1.06%	1.60%	1.40%
Parangaba 69 kV	100%	1.01 pu	0.61%	2.23%	2.00%
Pecém 69 kV	100%	1.03 pu	1.31%	1.90%	1.70%
Tauape 69 kV	100%	1.01 pu	0.67%	1.40%	1.30%
Pres. Kennedy 13.8 kV	99.7%	1.04 pu	-	3.50%	3.30%
Tauape 13.8 kV	100%	1.03 pu	-	2.50%	2.31%

Table 5: Comparision of voltage sags per year measured vs. estimated

Site	Measurements		Simulations	
	V < 50%	V < 70%	V < 50%	V < 70%
Aldeota 69 kV	7.2	12	25.1	59.2
Coluna 69 kV	21.6	50.4	40.4	71.5
Distrito Industrial 69 kV	14.4	40.8	35.1	58.5
Parangaba 69 kV	4.8	21.6	34.0	57.3
Pecém 69 kV	ND	24	8.99	26.0
Tauape 69 kV	12	15	25.0	59.2
Pres. Kennedy 13.8 kV	9	30	-	-
Tauape 13.8 kV	ND	4	-	-

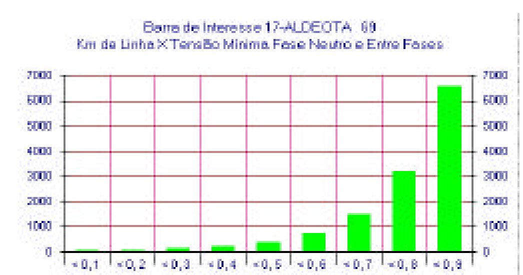

Figure 14: Vulnerability areas for one-phase faults – Substation Aldeota

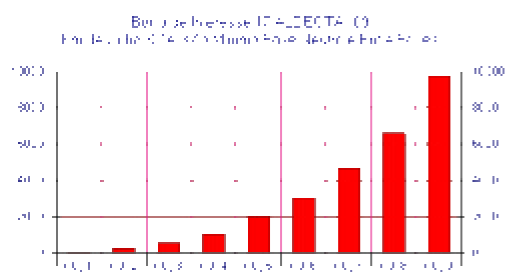

Figure 15:12 Vulnerability areas for thre-phase faults – Substation Aldeota