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Proposal of a Power Quality Analyzer for the new Brazilian Distribution Procedures (PRODIST)

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Abstract. This paper presents the analysis of the requirements of the new Brazilian regulation of Power Quality. The Electric Distribution Procedures (PRODIST), that includes power quality regulation, stipulates the references and methods of measurements to the Electrical Utilities that soon will become a standard that will have limits that must be achieved. The main target of this paper is to propose a methodology for a Power Quality Analyzer to calculate all the parameters requested in the PRODIST. The PQ Analyzer complies PRODIST technical specifications and the International Standard IEC61000-4-30 for some aspects that PRODIST is not clear. The weak points that are not specified in the PRODIST are also analyzed, showing that they should be more precise, otherwise if different manufactures choose distinct methods, procedures and algorithms, they will not reach the same results. Therefore, power quality measurements could not be compared using equipment of different manufacturers.

Key words

Power Quality Analyzer, Brazilian Power Quality Standard (Prodist), Energy Measurement

1. Introduction

The concerns about aspects related to Power Quality are increasing in Brazil and in the World. The Brazilian Energy Regulation Agency (ANEEL) has been looking for solutions to do the correct measurement and monitoring of power quality indices. The Brazilian Electric Distribution Procedures (PRODIST)[1] is really important and has contributed significantly to the interest in this area. The power consumption in Brazil is constantly increasing, all electrical equipments connected to an electric power system are designed to work in a particular nominal voltage. Their useful life and performance will change the greater is the difference between the voltage supplied by the utility and their nominal voltage. Of course, for the utility, the greater the permissible range of voltage is, the lower are the costs of energy supply. For consumers and manufactures of these devices, the situation is reversed. The smaller is the permissible range of voltage variation, the cheaper it will be the manufacture costs of such equipment[2]. Also the efficiency of industrial processes is directly related to the Power Quality (PQ) delivered to customers, since most of the equipments that compose these processes have different levels of vulnerability in relation to disturbances in the Power Quality[3]. Non-compliance of the electric power standards results in losses of materials and specialized manpower, causing damages to the industrial sector[4]. The recent standard PRODIST forces all utilities to meet the requirements.
This paper presents an analysis regarding the power quality parameters covered by Prodist: steady state voltage magnitude, power factor, voltage harmonics, voltage unbalance, voltage fluctuation (flicker), voltage variation and frequency variation.
The goal is to present aspects to be observed in the measurement of each parameter indicating the standard in which the measurement is based, technical characteristics, measurement methodology and criteria accuracy that must be observed.

2. Prodist Analysis

The Prodist shows how to determine and characterize the disturbances parameters and reference values to the power quality compliance.
The minimum hardware requirements for the measurement system according to the regulation are:

1) *Digital sampling of 16 samples per cycle*
2) *Analog to Digital converter of 12 bits*
3) *Precision: 1% of the reading value*

The following items will only present the parameters stated by Prodist.

A. Steady State Voltage Magnitude

According to the Prodist the Steady State Voltage Magnitude classifies the levels of voltage integrated in 10 minute periods. Three voltage levels are defined: Adequate,, Precarious and Critical Voltage.

B. Power Factor

The Power Factor according to Prodist should be calculated as:

$$\boldsymbol{PF = \frac{P}{\sqrt{P^2+Q^2}}} \quad (1)$$

Where P is the Active Power and Q is the Reactive Power. It is not defined how to measure P and Q considering harmonic distortion.

C. Voltage Harmonics

According to Prodist, the Voltage Harmonics should be calculated till the 25th harmonic. There is no standard method that should be used. The following expressions should be used to calculate the Individual Voltage Distortion (**IHD**) and the Total Voltage Harmonic Distortion (**THD**):

$$\boldsymbol{IHD\% = \frac{V_h}{V_1}100} \quad (2)$$

$$\boldsymbol{THD\% = \frac{\sqrt{\sum_{h=2}^{hmax} V_h^2}}{V_1}100} \quad (3)$$

Where V_h is is the h-th harmonic magnitude and V_1 is the fundamental voltage magnitude.

Voltage Unbalance

The following methodology is specified by Prodist to calculate the Voltage Unbalance:

$$\boldsymbol{VU\% = 100\sqrt{\frac{1-\sqrt{3-6\beta}}{1+\sqrt{3-6\beta}}}} \quad (4)$$

Where:

$$\boldsymbol{\beta = \frac{V_{ab}^4+V_{bc}^4+V_{ca}^4}{(V_{ab}^2+V_{bc}^2+V_{ca}^2)^2}} \quad (5)$$

Where V_{ab}, V_{bc} and V_{ca} are the phase to phase voltages.

D. Flicker

Flicker is the only voltage disturbance in Prodist that has a determined standard related, the IEC 61000-4-15[5]. In summary the important values are the Short Duration Severity PST, the Long Duration Severity PLT and the Transference Factor TF.

E. Short Duration Voltage Variations

The short duration voltage variations are determined by the RMS value and the duration of the disturbances is between one cycle and 3 minutes. They are classified by Prodist in six types:

Type	Duration	Voltage Magnitude
Momentary Voltage Interruption	<= 3 min	< 0,1 p.u.
Momentary Voltage Sag	>= one cycle and <= 3 seconds	> 0,1 p.u. and < 0,9 p.u.
Momentary Voltage Swell	> one cycle and < 3 seconds	> 1,1 p.u.
Temporary Voltage Interruption	>= 3 seconds and < 3 minutes	< 0,1 p.u.
Temporary Voltage Sag	>= 3 seconds and < 3 minutes	> 0,1 p.u. and < 0,9 p.u.
Temporary Voltage Swell	>= 3 seconds and < 3 minutes	> 1,1 p.u

Table 1 – Short Duration Voltage Variation

F. Frequency Variation

The voltage frequency must not exceed during steady state the following reference values: 59,9Hz < system frequency < 60,1Hz. Prodist does not specify the method for calculating the frequency.

3. Power Quality Analyser Proposal

The block diagram showed in (Figure 1) presents a proposal of methods that are used to calculate the parameters discussed in the last session.

A. Signal Conditioning

Block 1 (Figure 1) is responsible for conditioning signals from the current and voltage sensors to the voltage levels of the analog to digital converter (ADC), and serves as an anti-aliasing filter.

B. Analog Digital Converter

Block 2 (Figure 1) consists of an acquisition system and a digital encoding. The primary sampling frequency of 250 kHz, allows a more relaxed anti-aliasing analog filter, and at the same time ensures a high enough temporal resolution to detect high-frequency transients. Although not mandatory in Prodist, high frequency transients can be useful for a more complete power quality analysis.

C. Digital Filtering + Downsampling

Block 3 consists of a series of Finite Impulse Response (FIR) digital filters followed by downsampling, responsible for the reduction of existing spectral content above the 50th harmonic order. The Prodist specifies that harmonics up to the 25-th have to be measured, however, extending the analysis up to 50th harmonics can use the Fourier spectrum as a basis for the calculations of voltage, current and power, more precisely. The computational cost of this increase in the number of harmonics evaluated is also justified for reasons of code compatibility between advanced and simple Power Quality Analysers.

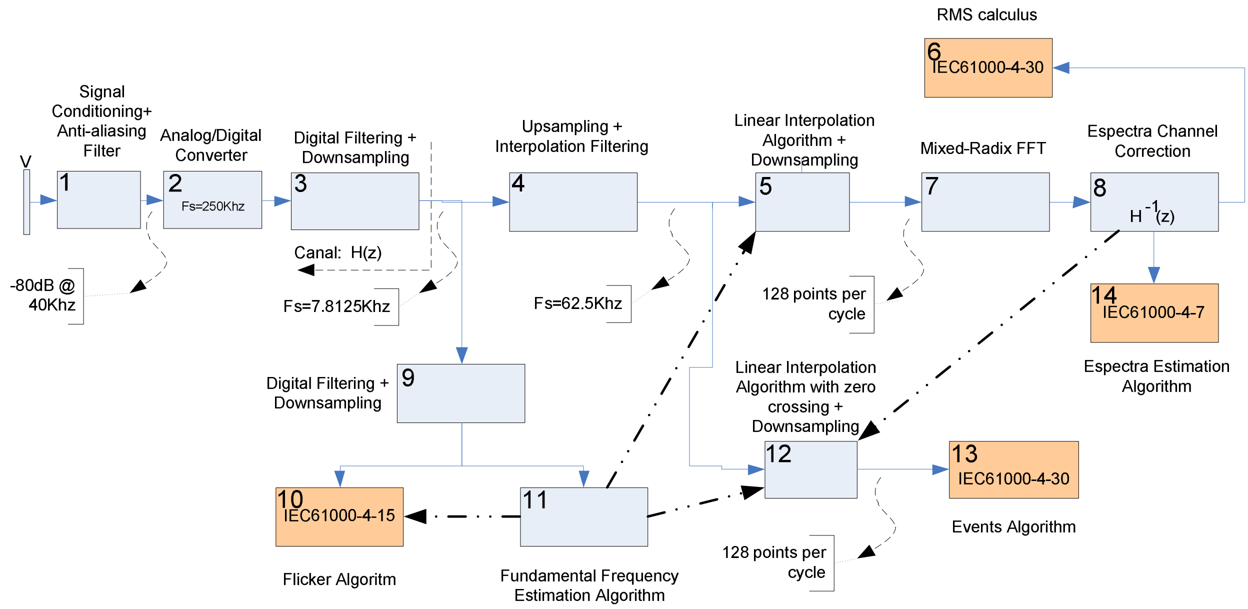

Figure 1 – Block diagram proposal

D. Upsampling and filtering interpolator

Block 4 is responsible for raising the sample rate without changing the frequency response, in order to subsequently apply a linear interpolation algorithm, which has the characteristic of low aliasing. The need for this block is because after filtering and downsampling of Block 3, the interpolation will cause excessive distortion because the sampling rate is too low for a linear interpolation.

E. Linear Interpolation Algorithm + Downsampling

Block 5 is responsible for converting the sampling rate of 62.5Khz to a sampling rate that has 128 points per cycle of the fundamental frequency. Therefore, it will be possible with further algorithms such as mixed radix FFT to estimate the spectrum with 5 Hz bins such as IEC 61000-4-7[6] and Prodist specify.

F. Linear Interpolation Algorithm / Zero Crossing + Downsampling

Block 12 ensures that the signal is interpolated to 128 points per cycle of the fundamental frequency and at the same time has the beginning of the buffer samples started by the zero crossing. The IEC61000-4-30 determines that this procedure must be followed to measure events such as voltage sags and swells. The Prodist does not specify the measurement method of such events, because it is still a regulation in progress, so it will probably follow the international standards.

G. Digital filtering – Downsampling

Block 9 is required to reduce the spectral content and the sampling rate for subsequent calculation of Flicker, and determination of the fundamental frequency of the system.

As for the Flicker, the Prodist is clear in stipulating the IEC61000-4-15 and the calculation methodology. The Prodist is not clear about the calculation of the system frequency, stating only that it should be a representative value of 10 minutes of observation. In this regard, IEC 61000-4-30[7] establishes the frequency of every 10 seconds, without aggregation. However, for proper functioning of Block 12, the frequency must be updated each cycle.

H. Channel Correction Measurement

Block 8 is responsible for making the necessary adjustments to reduce the effects of linear distortion introduced by analog and digital filters on the channels of voltage (or current). The correction is made based on the results of Block 7, using a Look-up table of correction factors in spectrum.

I. Calculation of Estimated Spectrum

Once the channels have been corrected, the groups of harmonics and inter-harmonics are applied according to IEC61000-4-7 in Block 14. Prodist does not specify that these groups should be used, it only says that the measures must represent the spectrum of 10 minutes of observation. This is another aspect in Prodist that is not clear enough. The authors suggest that the groups of harmonics should be calculated over the 10 minutes of FFTs quadratically accumulated, according to (6).

$$V_h = \sqrt{\sum_{i=1}^{n} V_i^2} \qquad (6)$$

J. Calculation of Fundamental Frequency

In Block 11, to determine the fundamental frequency, only Phase A will be used as a reference. A sequence of FIR digital filters will be applied in order to reduce the spectral content of the signal to achieve only the fundamental frequency of the power system. The counts of zero crossings will be started, beginning at 10 seconds tick from the real time clock (or GPS). The number of zero crossings counts will be recorded for the interval of 10 seconds, and it will be used for the estimation of the fundamental frequency. That frequency feeds the algorithms given in Block 5 and 12. However, for Prodist, the frequency is a 10 minutes representative value, and then the authors suggest calculating the mean over 10min.

4. Conclusion

The main features of power quality standard Prodist have been discussed. A Power Quality Analyzer that complies Prodist standard was introduced. With this proposal it will be possible that Power Quality Analyzers manufactures start to discuss the methodology that should be used according to Prodist. Moreover, the issues where Prodist is not clear, other standard should be considered or Prodist should be updated.

If different manufactures use distinct methods and procedures to calculate the parameters the results will not converge so that the analysis of the power quality disturbances will not be accurate.

Prodist is not a clear regulation yet, opening the possibility to international standards such as the IEC 61000-4-30 to be seen as a solution to the unanswered questions.

Acknowledgement

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