

# Power Quality Indices for Electrical Power Systems under Non-Stationary Disturbances

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**Abstract.** This paper presents a methodology to evaluate power quality indices using Wavelet Packet Transforms in electrical power systems, in the presence of harmonics, under stationary, non-stationary and short-circuit occurrence conditions, in order to achieve efficient monitoring of power systems. Results on several test systems and various disturbances simulated by Matlab/Simulink, demonstrate the effectiveness and robustness of the proposed method.

## I. INTRODUCTION

The term power quality (PQ) indicates the deviation of both voltage and current from their ideal waveforms. An ideal waveform is considered to be sinusoidal, with fixed frequency and amplitude, any deviation from which is considered a disturbance. With the increased use of nonlinear loads, as well as due to time-varying single-phase and three-phase loads, the deformation of voltage and current from their ideal waveforms has increased to a large extent. Therefore, the quantification of these deformations, using appropriate power quality indices (PQIs), has become a quite important issue in modern electrical power systems and offers the opportunity of efficient monitoring of power system quality. Total harmonic distortion of voltage and current, distortion index of voltage and current, as well as power factor, are worldwide established PQIs capable of compressing raw information, usually multidimensional in nature, into a single value [1].

Most PQIs currently used, are based on the analysis of voltage and current waveforms in their individual harmonic components. In order to analyze these disturbances and extract their spectrum, Fourier Transform (FT) is widely used [2]–[3]. However, using FT, signals can be described exclusively in the time or frequency domain, failing to provide information about time tracing of different frequencies within the signal. Thus, FT is no longer considered as the most suitable method for analyzing non-stationary disturbances containing time-varying frequency spectrum, such as short circuits. To address these problems, as well as to improve the existing PQIs and monitoring services, the wavelet transform (WT) is investigated. WT provides simultaneous time-frequency information of a signal, and as a result is more accurate in evaluating PQIs in electrical power systems with non-stationary disturbances [4]–[8].

In the present paper, Wavelet Packet Transforms (WPT) is proposed to evaluate the PQ performance of single-phase and three-phase electrical power systems, operating under both

stationary and non-stationary conditions. Typical PQ components, such as voltage, current and power, are reformulated by WPT and the most critical PQIs are calculated. Their values are presented and compared with their true values and those calculated with FT, in order to validate: 1) the ability of WPT to provide very accurate results in electrical power systems operating under both stationary and non-stationary conditions, 2) the advantage of WPT over FT to assess PQ performance in electrical power systems operating under non-stationary conditions, 3) the inability of FT to recognize short time disturbances.

This paper is organized as follows. Section II presents the WPT based mathematical approach to calculate PQIs. In Section III, the test cases and scenarios considered are described and the obtained results are presented. Conclusions are drawn in Section IV.

## II. MATHEMATICAL APPROACH

### A. Wavelet Packet Transform

Using a pair of filters, a low-pass  $[L^j]$  and a high-pass  $[H^j]$ , the initial waveforms given by the matrix  $sC[0]$ , is analyzed into  $j$  decomposition levels. The initial matrix  $sC[0]$  contains  $2^N$  samples and at each level  $j$  and node  $i$ , the WPT coefficients are derived from those of the previous level, by the convolution of the coefficients of the previous level with the low pass and the high pass filter, by the following equations, respectively:

$$sC^j[1] = \sum_k sC^{j-1}[k] G_{L^j}[2^j n - k] \quad (1)$$

$$sC^j[2] = \sum_k sC^{j-1}[k] G_{H^j}[2^j n - k] \quad (2)$$

where  $n$  is an integer variable of the convolution mathematical operation. Thus, in the final decomposition level, the signals  $sC^j[1]$  contain  $2^{N-j}$  WPT coefficients and a frequency range of  $\frac{f_{max}}{2^j}$ , where  $f_{max}$  is the maximum frequency of the original signal. The maximum frequency is calculated using the sampling frequency  $f_s$  of the signal, based on the sampling theorem, by:

$$f_{max} = \frac{f_s}{2} \quad (3)$$

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