# Signal Processing Techniques used in Power Quality Monitoring

Umar Naseem Khan

Abstract— **This paper gives a general review of different signal processing techniques which are widely used for the power quality monitoring. The majority of power quality problems can be characterized through measurements of voltage and current. To distinguish the type of disturbances, monitoring systems require the processing of signals, which concern the extraction of features and information from measured digital signals. In fact, the use of signal processing techniques can influence the way that voltage and current signals are measured and analyzed in power system field.**

***Index Terms*—power quality, signal processing, power quality monitoring, disturbances, variations, events**

## I. Introduction

As it is well known, an ideal three-phase AC supply consists of three phase voltages that are 120 degrees out of phase and have identical magnitudes. Above all, these voltages should be sinusoidal and should be available continuously. Any diversion from these requirements is considered as poor quality of power. One of the major causes of disturbances in AC power system is the electronic switching circuits, which are widely used both in industry and in household systems. Most of the power electronic equipments are manufactured based on the available standards, but due to increase in the numbers of such equipments there are also an increase in disturbances in the power system. While the sources of disturbances in AC power systems increase continuously, the electric utilities and end users of electrical power have become more concerned about the quality issues of the AC power.

The research focuses on power quality monitoring systems are very much involved in the studies of signal-processing techniques applied to the monitored signals to extract valuable information for analyzing and diagnosing the cause of power quality problems. The analysis of this information then help the power quality experts to determine the sources and causes of such events and, thus, possible solutions for avoiding these disturbances can be identified.

The monitoring practice of power quality includes three steps, detecting and extracting the features of the power quality events. classifying these events into known waveform categories, and, if the size of the monitored data is very large, compression methods will be necessary for saving these data for further analysis.

### A. Variations and Event

An important division of power quality disturbances is between variations and events. Variations are small deviations from the normal or desired voltage or current sine wave that can be measured at predefined instances (or more precisely over predefined windows of time), whereas events are larger disturbances that trigger a recording or further processing [1].

The most common origin of variations are: voltage frequency variations, voltage magnitude variations; unbalance; voltage fluctuations or flicker and waveform distortion. While most common origins of events are interruptions, voltage dips, and transients.

The issues to be discussed when measuring power quality variations include: (1) extracting the characteristics; (2) statistics to quantify the performance of the supply at one location; (3) statistics to quantify the performance of a whole system [1].

The issues to be discussed when measuring events include: (1) a method has to be defined to obtain the voltage magnitude from the sampled waveform; (2) threshold levels have to be set for the beginning threshold and for the ending threshold, these two thresholds could be the same or different. In addition, a value has to be chosen for the minimum duration of interruption; (3) characteristics have to be defined for the event, in this case the duration of the interruption [1].

A general scheme for carrying out power quality measurements is shown in Fig. 1. The first step in power quality monitoring is the transformation from analog voltages and currents in the power system to sampled digital values that can be processed automatically. The measurement device block in Fig 1 includes instrument transformers, analog anti-aliasing filters, sampling and digitizing, and digital anti-aliasing and down sampling. In this paper, our concentration will be focused on post processing and we will assume that the sampled and digitized voltage or current waveforms are available for processing.

## II. Detection Methods of Power Quality Disturbances

The disturbance capturing techniques are usually based on detecting the power quality events when a certain threshold level is exceeded. The limits and threshold levels are primarily defined by the standards that provide the acceptable level of disturbance in AC power systems by the end users.

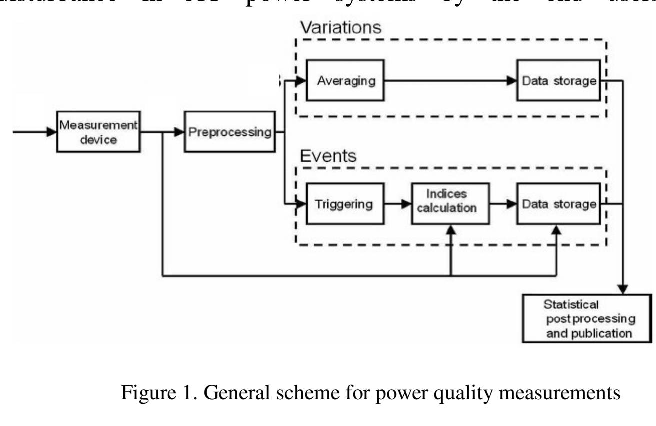


Figure 1. General scheme for power quality measurements

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These methods are divided in two main categories: Detection methods of variations and detection methods of events. Before, going further it is important to know about the stationary and non-stationary signals.

Stationary Signals: A signal is stationary when it is statistical time invariant (or the statistics of the signal are independent of time) [1]. All the variations in the voltage and current sine wave are among the stationary signals.

Non-stationary Signals: If a signal is statistical time varying, then it is a non-stationary signal.

### *A. Root Mean Square value (RMS)*

The RMS of a signal is not an analysis technique in its own right, but it gives some basic information about an electrical system, and is used widely. The main disadvantage of this algorithm is its dependence on the size of the sample window. A small window makes the RMS parameter less relevant, as it follows the tendency of the temporal signal, and loses the meaning of mean value of power. A large window hides the events [3].

The deviation of the voltage or current signal from the ideal sine wave is characterized through a number of parameters (or features): magnitude, frequency, distortion, unbalance, Flicker Severity and very short variations. We will briefly discuss the different detection methods for these parameters.

#### *1) Voltage Magnitude Variations*

The vast majority of voltage (magnitude) variation studies use the rms value to quantify the voltage magnitude. In IEC 61000-4-30, a basic measurement window of 10 or 12 cycles (in 50- and 60-Hz systems, respectively) is prescribed: The measurement window shall be synchronized to the actual power system frequency. Non-synchronization leads to a small error in the estimated rms value, where the relative error in rms value is half the relative error in frequency. A number of alternative methods are introduced: among others, voltage amplitude, fundamental component, instantaneous three-phase rms, and positive-sequence voltage. The latter two values are suitable alternatives in a three-phase system.

For monitoring purpose, the point-by-point RMS values of PQ signals have to be calculated, which is defined as

$$V_{rms}(n_k + i) = \sqrt{\frac{1}{n_k}\sum_{k=i}^{n_k+i} v[k]^2} \qquad (1)$$

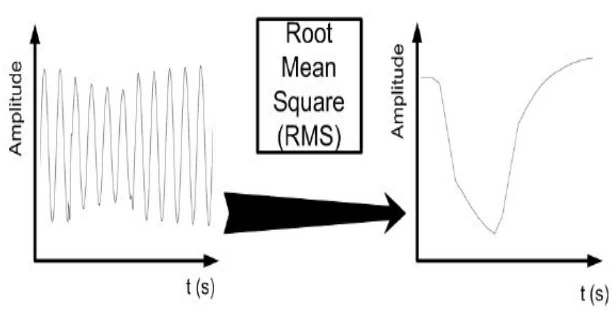


Figure 2. RMS calculation of a signal [4]

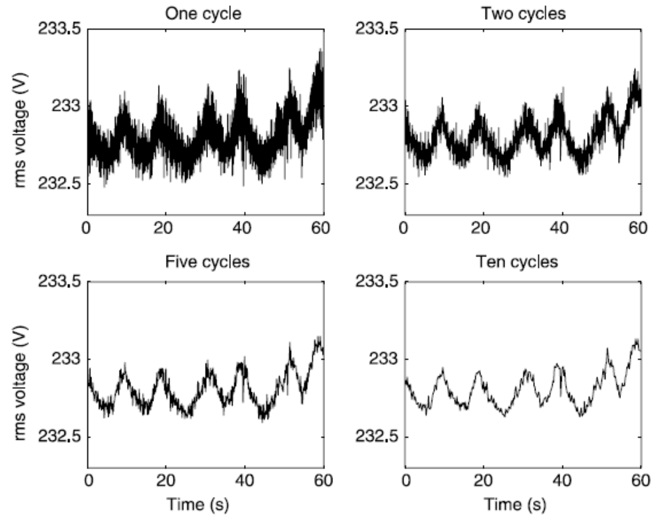


Figure 3. Effect of window size on the rms voltage-time waveform [1]

The effect of changing the length of the window is shown in Fig 3 for a 1-min window of the phase a voltage of the normal case. In all four cases, one value per window has been calculated. For a one- or two-cycle window, the rms voltage has a rather noisy appearance. Applying a longer window gives a more smooth function of time.

For the three-phase measurement, three methods are mostly used:

*Average of the magnitude values of the three phases:*

$$V = mean(V_a, V_b, V_c) \qquad (2)$$

*The rms value of the amplitudes from three phases:*

$$V = \sqrt{\frac{1}{3}(V_a{}^2 + V_b{}^2 + V_c{}^2)} \qquad (3)$$

*The absolute value of the positive-sequence voltage:*

$$V = |V_p| \qquad (4)$$

*The instantaneous three-phase rms:*

$$V = \sqrt{\frac{1}{3}(v_a{}^2(t) + v_b{}^2(t) + v_c{}^2(t))} \qquad (5)$$

#### *2) Voltage Frequency Variations*

The standard method to characterize frequency variations consists of counting the voltage zero crossings during a time- period with an accurately known length (10 s according to IEC 61000-4-30). The high accuracy of this method is based on the very high accuracy for time measurements. The high accuracy that can be obtained by the standard method also limits the need for more advanced methods. Despite this, an alternative method is introduced, based on the dq-transform that is better suited to present short-time changes in frequency.

*Use of dq-Transform in Three-Phase System*

With most power quality measurements, the three phases or line voltages are available for processing. Despite this, the frequency is typically only obtained from one channel, the so-called reference channel. It is however possible to consider all three phases in the calculation of the frequency by using the dq-transform, the dq-transform is defined as follows:

$$v_{dq}(t) = e^{-j2\pi f0t}\frac{1}{3}\sqrt{2}(v_a(t)e_a + v_b(t)e_b + v_c(t)e_c) \tag{6}$$

Where,

$$e_a = 1$$

$$e_b = a = -\frac{1}{2} + \frac{1}{2}j\sqrt{3}$$

$$e_c = a^2 = -\frac{1}{2} - \frac{1}{2}j\sqrt{3}$$

*3) Three-Phase Unbalance*

The standard method for quantifying three-phase unbalance is as the ratio between negative- and positive-sequence voltage.

$$u_n = \frac{U^-}{U^+} \tag{7}$$

Alternative definitions for the three-phase unbalance are given in a number of IEEE standards. When the fundamental components of the phase-to-phase voltages Uab, Ubc, and Uca are known, the unbalance can be calculated from the expression

$$u_n = \sqrt{\frac{1-\sqrt{3-6Q}}{1+\sqrt{1-3Q}}}$$
$$where \tag{8}$$
$$Q = \frac{{U_{ab}}^4 + {U_{bc}}^4 + {U_{ca}}^4}{({U_{ab}}^2 + {U_{bc}}^2 + {U_{ca}}^2)^2}$$

Under IEC 61000-4-30, the basic measurement window used to calculate the unbalance is the same as for voltage magnitude and harmonic distortion: 10 cycles in a 50-Hz system, 12 cycles in a 60-Hz system, about 200 ms in each case. Next to the negative-sequence unbalance, a "zero-sequence unbalance" may be calculated as the ratio between zero- and positive-sequence voltages.

*B. Fourier Analysis*

One of the most widely used tools in signal processing is Fourier analysis. This consists of the decomposition of the signal into a sum of sinusoidal signals of different frequencies. The signal in the frequency domain is characterized by the angle and the module of each sinusoidal wave. So this analysis can be viewed as a mathematical transformation from the time domain to the frequency domain, as shown in the Fig 4.

The Fourier transform in continuous time of an integrable function *f* can be expressed as follows:

$$f(\xi) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{+\infty} f(x)e^{-j\xi x}dx \tag{9}$$

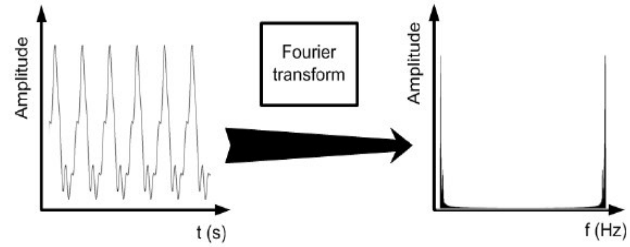


Figure 4. Transformation of time signal in its Fourier Transform

The discrete Fourier transform is thus:

$$f_k = \sum_{n=0}^{N-1} x_n e^{-\frac{2\pi j}{N}kn}$$
$$where \tag{10}$$
$$k = 0,....., N-1$$

The Fourier Transform is very useful in the analysis of harmonics, and is an essential tool for filter design. However, there are some disadvantages, such as losses of temporal information, so that it can only be used in the steady state, and cannot show the moment when the event is produced.

The DFT (Discrete Fourier Transform) has been applied with great success, thanks to its implementation through its calculus algorithm, FFT (Fast Fourier Transform), which provides very efficient and quick calculations.

*C. Short Time Fourier Transform analysis*

The short-time Fourier transform-m has been used in power quality analysis due to its applicability to non-stationary signals, as in the case of most power quality signals [3]. The advantage of the STFT technique is its ability to give the harmonic content of the signal at every time-period specified by a defined window. The STFT *($V_{STFT}$)* of a sampled signal ,*v[k],* is defined as [2]:

$$V_{STFT}(\omega, n) = \sum_k v[k].w[k-n].e^{-j\omega k} \tag{11}$$

Where $w = 2\pi n/N$, N is the length of v[k]; n= 1,.., N; and w[k- n] is a selected window that slides over the analyzed signal. The main disadvantage of this technique is that the greater the temporal resolution required, the worse the frequency resolution will be, and vice versa. For a chosen a window size, this will be equal for all frequencies.

*D. Wavelet Transform (WT)*

The next logical step is to obtain a window that can vary in time, so as to be able to get better frequency or time resolution where necessary[3]. The wavelet transform is based on the ecompostion of a signal in terms of small waves (daughter wavelets) derived from translation (shifting in time) and dilation (sealing) of a fixed wavelet function called the "mother wavelet". The

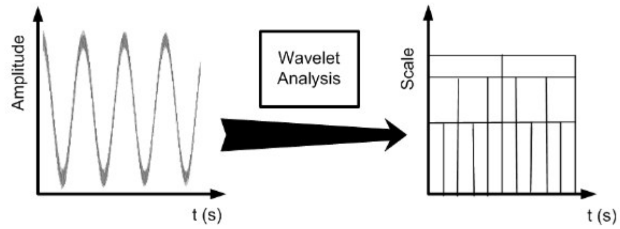


Figure 5. Analysis of signal with a possible scaled by means of wavelet.

main advantage of the wavelet transform is its varying-length window. The general formula of the continuous wavelet transform *($V_{WT}$)* of a signal *v(k)* is given by

$$V_{WT}(a,b) = \int_{-\infty}^{+\infty} v(t).\varphi^{*}{}_{a,b}(t)dt \tag{12}$$

Where $\varphi_{a,b}(t)$ is the mother wavelet (the window function, and the "*" denotes the complex conjugate), and *a* and *b* are the scaling and the translation, respectively [2]. The wavelet allows the use of long intervals of time where it is necessary a high resolution in low frequencies and a small intervals where is required a high frequency information, as it is shown in figure 5[3].

Wavelets have been very useful in electrical transients' analysis. According to the type of disturbance, a different type of wavelet is used. This renders its application less general.

### E. S-Transform (ST)

The S-Transform technique is defined by convolving the analyzed signal, v[k], with a window function. The window function is chosen to be a function of time and frequency, which gives this technique the advantage over the wavelet technique. The convolution is performed in the frequency domain by multiplying the Fourier transforms of the analyzed signal and the window function. Then taking the inverse Fourier transform to obtain the analyzed signal in the ST domain. For the discrete signal with a Gaussian window, the ST of a signal v[k] is calculated as [2]:

$$V_{ST}[k,\frac{n}{N}] = \sum_{m=0}^{N-1} V[\frac{m+n}{N}]e^{-\frac{2\pi^2}{n^2}}.e^{j\omega k} \tag{13}$$

Where *k, m,* and *n =0, , … ,N-1*, and *V[m+n/N ]* is the Fourier transform of the analyzed signal *v[k]*.

### F. Park's Vector Approach

The Park's vector approach is based on the locus of the instantaneous spatial vector sum of the three-phase vectors *($v_1$, $v_2$, $v_3$)*. The Park's vector component, *($v_D$, $v_Q$)* are given by [2]:

$$V_D = \sqrt{\frac{2}{3}}v_1 - \sqrt{\frac{1}{6}}v_2 - \sqrt{\frac{1}{6}}v_3 \tag{14}$$

$$V_Q = \sqrt{\frac{1}{2}}v_2 - \sqrt{\frac{1}{6}}v_3 \tag{15}$$

### G. Kalman filters

Kalman filters are special types of filters. Their solutions are based on a set of state-space equations. Kalman filters are useful tools for many power system applications, for example, real-time tracking harmonics, estimating voltage and current parameters in power system protection, and estimating the parameters of transients. Give the observation data *z(n),* a Kalman filter is described by a set of state equations and a set of observation equations as follows[1]:

State equations:

$$x(n) = A(n-1)x(n-1) + w(n) \tag{16}$$

Observation equations:

$$z(n) = C(n)x(n) + v(n) \tag{17}$$

where x(n) is a vector of state variables, A(n -1) is the state transition matrix, w(n) is a vector of model; C(n) connects the measurement z(n) with the state vector x(n); v(n) is a vector of observation. For stationary data, A(n) and C(n) are time independent, that is, A(n)= A and C(n) = C.

## III. Conclusion

Different signal processing techniques has been discussed in this paper. In terms of calculation RMS techniques is simple, fast, and much sensitive in sags, swells, and interruptions in the signals.

Comparison between signal processing techniques

| | STFT | Wavelet | S Transform | Park's Vector |
|---|---|---|---|---|
| Speed | Moderate | Moderate | Low | High |
| Sensitivity | Low | Moderate | High | High |
| Implementation | Difficult | Difficult | Difficult | Easy |

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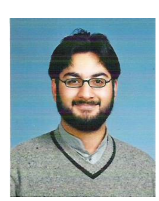
## V. Biography



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