DIGITAL SIGNAL PROCESSING ALGORITHMS FOR POWER QUALITY ASSESSMENT

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Abstract – Power quality assessment requires definition of power quality indicators so that a given power system disturbance and related signal distortion can be quantified and eventually related to a cost criteria. Typical power quality indicators considered so far include harmonics and harmonic power under various types of loads. Due to the various types of loads and power system operating conditions, it is desirable that a wide range of power quality indicators are defined to cover various types of power system disturbances and signal distortions.

This paper introduces new digital signal processing algorithms that can be used to measure various power system indicators which, in turn, may be utilized for power quality assessment.

Keywords: Power Quality, Digital Signal Processing, Digital Measurements, Digital Algorithms

INTRODUCTION

Power quality is an issue that has attracted wide interest in recent years. This is a natural development since introduction of some new types of electronic loads and control equipment have produced a situation where either these devices are very sensitive to the power system disturbances or they create disturbances themselves. As a result, a number of research projects were initiated within academic community [1] and power industry [2]. The IEEE has also been addressing this problem through working groups reports [3], and standards [4].

An interesting observation coming from a recent survey of research directions is that despite significant research results obtained so far, the power quality problem still remains loosely defined and lacks widely adopted agreement on the fundamental concepts involved [5]. Future research will, therefore, still need to continue to concentrate on almost all the different aspects of this problem.

This paper is focusing on a fundamental issue of how to quantify power disturbances so that various indicators for power quality can be established and correlated to a cost criteria for power quality improvement/deterioration. The first step in this consideration is to identify quantities that need to be measured and to define corresponding measurement algorithms that will produce an indicator representing given disturbance. These values can further be used to derive various indexes for power quality assessment.

The problem of defining various measurement algorithms has prompted a need to define processing conditions for power signal analysis since the measurement algorithms are, indeed, clearly defined only under a given set of assumptions about signal characteristics. The authors have dealt, in this paper, with digital techniques for measurement algorithm definition which assume that power system voltages and currents are sampled and processed digitally to produce a defined quantity.

An earlier study of algorithms for power system protection and monitoring, performed by the authors over the past ten years, resulted in a definition of a new digital signal processing form [6]. It can be utilized to define a number of digital algorithms for measurement of well defined quantities such as power, line parameters and frequency [7-9]. Further study indicated that the same digital signal processing approach can be utilized to define algorithms for the power quality related measurements.

The first part of the paper gives discussion of the signal analysis problem by providing classification of the assumptions about signal characteristics. Specific characteristics are a consequence of different power system disturbances. The next two sections introduce two different classes of digital signal processing algorithms. These algorithms can be utilized for measurement of various quantities which may be used to characterize given disturbances. An approach to power quality assessment based on various measurements is illustrated by some examples given in the following section. Conclusions and future research activities are outlined at the end.

SIGNAL ANALYSIS CONSIDERATIONS

In order to emphasize the importance of signal analysis considerations, a block diagram of the signal processing involved in a digital measurement is given in Figure 1.

Figure 1. Signal Processing Steps

It is well known in the signal processing field that all of the processing steps indicated in Figure 1 have to be carefully designed to match given signal characteristics. This requires analysis of signals to determine their characteristics. It is important to indicate that false assumptions may lead to inappropriate design of the signal processing steps which, in turn, may produce measured quantities that do not reflect existing signal characteristics.

It is, therefore, extremely important to understand characteristics of the signal disturbances associated with power quality changes so that appropriate signal processing steps may be designed to allow measurements of the quantities that, indeed, characterize the disturbances.

The authors have analyzed typical signal disturbances associated with power quality indicators such as over voltages, under voltages, power outages, voltage flickers, switching transients, spikes, impulses, current harmonic distortions, etc. The following two classes of assumptions about signal characteristics have been identified as a result of the signal analysis:

Class I: A dominant signal component is a single harmonic whose frequency may slightly vary. This signal may shortly (not on a periodic basis) be corrupted by some other known signal components such as other harmonics and subharmonics, transients and noise.

Class II: The main signal is periodic and may consist of a number of harmonic components that are also periodic.

It is important to note that a Class I signal such as the sinusoidal ones is straight forward to handle because measurement quantities such as amplitude, phase, frequency, active power, reactive power

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apparent power, and power factor are well defined for sinusoidal signals. If the signal contains some known disturbances, digital algorithms can be defined to measure either the fundamental signal quantities or the disturbances quite accurately. In this case, the use of only several samples in a cycle may be sufficient to perform the desired measurement. By monitoring the measured quantities one can perform power quality assessment either by determining that the fundamental signal quantities or the disturbance levels caused by superposition of some other signals are different from the expected values.

The Class II signals are more difficult to handle since the quantities that are well defined for Class I signals are not that well defined for this case. Since the standard quantities are not directly applicable to Class II signals, there is a disagreement about their definitions for the Class II signal conditions. Typical examples are definitions of the power and the power factor for nonlinear and unbalanced situations [10–12]. Further characteristic of Class II signals is that measurement of these quantities requires synchronized samples taken in the entire cycle of the periodic signal. Both signals in Class I and Class II may be polluted by a noise.

Before different algorithms for measurement of various quantities for the two signal classes are introduced, Figure 2 is presented to illustrate typical signal disturbances for both of the classes [13].

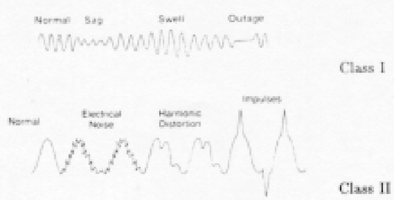

Figure 2. Typical Signal Classes [13]

ALGORITHMS FOR CLASS I SIGNALS

Let us assume that samples of signals $x(n)$ and $y(n)$ are available at time instances Δt. In that case, for a pure harmonic signal, the discrete forms are equal to:

$$x(n) = X \cos n\delta \qquad y(n) = Y \cos(n\delta + \phi) \tag{1}$$

where: $\delta = \frac{2\pi}{T} \cdot \Delta t \qquad \phi-$ phase difference.

A definition of the new signal processing algorithm form has been introduced earlier to denote a quadratic form (Q–Form) as follows [6]:

$$QFXH(n) = \sum_{k=0}^{N-1} \sum_{m=0}^{N-1} h_{km} X(n-k) X(n-m) \tag{2}$$

and a bilinear form (B–Form) as follows [6]:

$$BFXYH(n) = \sum_{k=0}^{N-1} \sum_{m=0}^{N-1} h_{km} x(n-k) y(n-m) \tag{3}$$

where h_{km} are elements of the weight matrix H.

If the signal is a pure harmonic described by (1), then the value of the quadratic form is equal to [6]:

$$\begin{aligned} QFXH(n) = & \frac{X^2}{2} |H^c(e^{-j\delta})| \cos[arg H^c(e^{-j\delta})] + \\ & + \frac{X^2}{2} |H^v(e^{-j\delta})| \cdot \cos[2n\delta + arg H^v(e^{-j\delta})] \end{aligned} \tag{4}$$

Similarly, the value of the bilinear form is equal to [6]:

$$\begin{aligned} BFXYH(n) = & |H^c(e^{-j\delta})| \frac{X \cdot Y}{2} \cos[\phi + arg H^c(e^{-j\delta})] + \\ & + |H^v(e^{-j\delta})| \frac{X \cdot Y}{2} \cos[\phi + 2n\delta + arg H^v(e^{-j\delta})] \end{aligned} \tag{5}$$

where $H^c(e^{-j\delta})$ has a constant value defined as:

$$H^c(e^{-j\delta}) = \sum_{k=0}^{N-1} \sum_{m=0}^{N-1} h_{km} e^{-j(k-m)\delta} \tag{6}$$

and $H^v(e^{-j\delta})$ also has a constant value expressed as:

$$H^v(e^{-j\delta}) = \sum_{k=0}^{N-1} \sum_{m=0}^{N-1} h_{km} e^{-j(k+m)\delta} \tag{7}$$

If $H^v(e^{-j\delta})$ is zero for $\delta = \delta_0$, where $\delta_0 = \frac{2\pi}{T_0} \cdot \Delta t$, then the value of the quadratic form given by equation (4) is equal to:

$$QFXH(n) = \alpha(\delta) \cdot \frac{X^2}{2} \tag{8}$$

and the value of the bilinear form given by equation (5) is equal to:

$$BFXYH(n) = \alpha(\delta) \cdot P + \beta(\delta) \cdot Q \tag{9}$$

where:

$$P = \frac{XY}{2} \cos\phi \qquad Q = \frac{XY}{2} \sin\phi \tag{10}$$

and:

$$\alpha(\delta) = \sum_{k=0}^{N-1} \sum_{m=0}^{N-1} h_{km} \cos(k-m)\delta \tag{11}$$

$$\beta(\delta) = \sum_{k=0}^{N-1} \sum_{m=0}^{N-1} h_{km} \sin(k-m)\delta \tag{12}$$

Finally, if $x(n)$ designates voltage samples and $y(n)$ current samples, expressions (8) – (12) can be used to define several algorithms for measurement of phasor quantities. Table I gives a summary of these algorithms.

Table I. Algorithms for Calculation of Phasor Quantities

Quantity	Algorithm	Form	Coefficients
Active Power	$P = \frac{VI}{2}\cos\phi$	$BFVIH(n)$	$\alpha(\delta_0) = 1,\ \beta(\delta_0) = 0$
Reactive Power	$Q = \frac{VI}{2}\sin\phi$	$BFVIH(n)$	$\alpha(\delta_0) = 0,\ \beta(\delta_0) = 1$
Voltage RMS^2	$V_{RMS}^2 = \frac{V^2}{2}$	$QFVH(n)$	$\alpha(\delta_0) = 0$
Current RMS^2	$I_{RMS}^2 = \frac{I^2}{2}$	$QFIH(n)$	$\alpha(\delta_0) = 0$

Besides obtaining the basic quantities given in Table I, the following derived quantities can also be obtained using the same expressions. The apparent power is derived as:

$$S = \sqrt{V_{RMS}^2 \cdot I_{RMS}^2} \tag{13}$$

and the power factor is derived as:

$$PF = \frac{P}{\sqrt{V_{RMS}^2 \cdot I_{RMS}^2}} \tag{14}$$

Finally, appropriate selection of two different weight matrices A and B can also give an algorithm for frequency deviation measurement using the same basic expressions. In that case, frequency deviation given as:

$$\delta - \delta_0 = \Delta t(\omega - \omega_0) \tag{15}$$

can be estimated by using the following expression [9]:

$$\widetilde{\Delta}\delta = \delta - \delta_0 \cong \frac{QFVA(n)}{QFVB(n)} \tag{16}$$

Further discussion of the measurement algorithms that are designed to measure the fundamental harmonic quantities while eliminating influences of known harmonics, DC offset and variation in frequency of the fundamental harmonic is given in reference [14].

As a result of this brief overview of various algorithms, it is obvious that the signal processing form discussed in this paper can be used to define algorithms that will measure some main indicators of the signal characteristics for Class I si[illegible] for power quality assessment may be implemented by monitoring deviations in the measured quantities, which in turn, indicate departure from the well defined steady state conditions.

It is important to note that the distortion may appear in the fundamental harmonic either as a change in amplitude and/or phase or as an addition of short bursts of superimposed harmonics, subharmonics and noise. Algorithms discussed for Class I signal measurement applications can be designed to measure the fundamental signal quantities by taking into account disturbances in various ways.

In one case, algorithms can be designed to measure some well defined quantities while the effect of the disturbances is included. By doing this, the change in the fundamental quantities caused by the disturbances can be detected.

The algorithms can also be designed to measure the fundamental signal quantity while being insensitive to the well defined disturbances. In this case, the changes in the fundamental signal alone can be detected.

Finally, algorithms can be defined to extrapolate only the disturbances while the fundamental signal quantities are not measured. This discussion illustrates that methodology for power quality assessment may be defined in different ways depending on how one wants to relate measured quantities to the power quality indicators.

ALGORITHMS FOR CLASS II SIGNALS

If one deals with a periodic signal, situations with measurement of standard quantities related to power quality becomes difficult because standard quantities do not have the original meaning under these circumstances. Typical examples are power and power factor quantities under a presence of harmonics [10–12]. Further discussion will illustrate that a number of digital algorithms can be implemented under these conditions to calculate various quantities once they are well defined.

The signals $x(n)$ and $y(n)$ are now defined as:

$$x(n) = \sum_{l=1}^{M} X_l \cos(ln\delta + \phi_l) + X_0 \tag{17}$$

$$y(n) = \sum_{l=1}^{M} Y_l \cos(ln\delta + \Psi_l) + Y_0 \tag{18}$$

These signal expressions are known as geometrical polynomials and can be obtained by filtering a periodic signal. The number of harmonics left in the signal, denoted as M, will depend on the number of samples N that are taken in the signal period. This dependence is defined by a well known sampling theorem which states the following relationship between the number of harmonics M and the number of samples N:

$$M < \frac{N}{2} \tag{19}$$

This means that with a given number of samples N, available in the signal period, only l number of harmonics can be measured, where $l < \frac{N}{2}$.

Since our interest relates to digital algorithms for measurements, it is important to understand what are the properties of quadratic and bilinear forms under these conditions. In an earlier paper [7], conditions for the weight matrix H have been discussed for a case when the forms have a constant value. It has been shown that quadratic and bilinear forms of periodic signals, under particular conditions imposed on weight matrix H, do not depend on $\underline{n}$ as long as their periodicity is undistrubed. The conditions are that matrix elements on the main diagonal and the sub diagonals are the same. This also means that h_{km} is a function of $(k - m)$. This class of matrices is called Toeplitz's matrices. Under these conditions, the quadratic form can be expressed as:

$$QFXH(n) = \sum_{l=1}^{M} \alpha_l \cdot \frac{X_l^2}{2} + \alpha_0 X_0^2 \tag{20}$$

while the bilinear form can be expressed as:

$$BFXYH(n) = \sum_{l=1}^{M} \alpha_l P_l + \beta_l Q_l + \alpha_0 P_0 \tag{21}$$

If $x(n)$ denotes current and $y(n)$ voltage, then coefficients P_l and Q_l can be defined as active and reactive harmonic power, respectively. The expressions for their calculation are:

$$P_l = \frac{X_l Y_l}{2} \cos(\phi_l - \Psi_l) \tag{22}$$

$$Q_l = \frac{X_l Y_l}{2} \sin(\phi_l - \Psi_l) \tag{23}$$

while

$$P_0 = V_0 \cdot I_0 \quad \text{and} \quad Q_0 = 0 \tag{24}$$

Analysis of expressions (20) and (21) indicates that their value represents linear combination of squares of RMS values of all harmonics in the case of the quadratic form and linear combination of active and reactive powers for all harmonics in the case of bilinear form. This property of the forms can be utilized to measure various signal quantities under harmonic conditions. By properly defining various power quality indicators based on these quantities, and by establishing a criterion for power quality assessment, one may be able to monitor power quality indexes and, ultimately, the power quality through a measurement procedure. However, the main obstacle in this approach is lack of definitions for the quantities to be measured under harmonic distortions. Our discussion relates to capabilities of quadratic and bilinear forms when used for measurement of well defined quantites. To illustrate how powerful the algorithm implementation approach is, different definitions of various quantities are adopted from the literature [10–12]. It is understood that there is no agreement, at present, on the physical meaning of some of these definitions. This will need to be resolved if a power quality assessment is to be based on these definitions. However, for the prupose of demonstrating various approaches to algorithm implementation, the existing definitions can be used as an example.

The possibilities of various algorithm implementations based on the use of quadratic and bilinear forms are summarized in Tables II

Table II. Some Quantities Directly Measured Using Quadratic and Bilinear Forms

Quantity	Algorithm	Coefficients
Active Harmonic Power	$P_k =$ $= \frac{V_k I_k}{2}\cos(\phi_k - \Psi_k)$ $k \neq 0$	$\alpha_k = 1$ All other $\alpha_k, \beta_k = 0$
Reactive Harmonic Power	$Q_k =$ $= \frac{V_k I_k}{2}\sin(\phi_k - \Psi_k)$ $k \neq 0$	$\beta_k = 1$ All other $\alpha_k, \beta_k = 0$
Total Active Power	$\sum_{k=0}^{M} P_k = P_T$	All $\alpha_k = 1$ All $\beta_k = 0$
Boudenau Reactive Power	$Q_B = \sum_{k=1}^{M} Q_k$	All $\alpha_k = 0$ All $\beta_k = 1$
RMS^2 for Voltage Harmonics	$\frac{V_k^2}{2} = V_{kRMS}^2$	$\alpha_k = 1$ All other $\alpha_k, \beta_k = 0$
Total RMS^2 for All Voltage Harmonics	$V_T^2 = \sum_{k=0}^{M} V_{kRMS}^2$	All $\alpha_k = 1$ All $\beta_k = 1$
Losses	$L = \sum_{k=2}^{M} c_k V_{km}^2$	All $\alpha_k = c_k$ $k \neq 0,\ k \neq 1$ $\alpha_0 = 0,\ \alpha_1 = 0$ All $\beta_k = 0$

and III. The quantities that can be measured by an algoritm which directly uses either a quadratic or bilinear form are given in Table II. Other quantities that can be defined as a combination of the quantities given in Table II, are outlined in Table III. Each of the tables contains indication of the quantity measured, definition of the signal processing form implemented for that measurement, and values of the coefficients used in the processing form for a given quantity. Again, it shall be noted that definitions of quantities for reactive power and power factor used in Tables II and III are only some examples of the many definitions introduced so far [10-12].

After all of the algorithms in Tables I, II, and III are derived, the question of how to use the measured quantities for the power quality assessment remains yet to be answered. The following section gives some examples of possible approaches in this direction.

POSSIBLE APPLICATIONS OF Q-FORMS IN POWER QUALITY ASSESSMENT

Examples in this section fall into two groups

- Class I Signals
- Class II Signals

Class I signal characteristics can be measured, as discussed earlier, in three different ways. One approach is to measure the fundamental quantities, under the presence of disturbances. This issue has extensively been studied for standard power meters and will not be discussed here [10]. The other approach is to measure the fundamental quantities making measurements insensitive to known disturbances. This approach has been discussed by the authors in their earlier references [14]. The third approach is to measure the disturbances only. An example of algorithms used for this approach is discussed below.

As an example of a disturbance of short duration, the signal given in Figure 3a is considered. It shall be observed that the signal also has a slight variation in the fundamental frequency.

Table III. Quantities Derived from the ones given in Table II.

Quantity	Algorithm	Coefficients
RMS for Harmonics	$\sqrt{V_{kRMS}^2}$	See Table II
Apparent Harmonic Power	$S_k = \sqrt{V_{kRMS}^2 I_{kRMS}^2}$	See Table II
Harmonic Power Factor	$PF_k = \frac{P_k}{S_k}$	See Table II
Total Apparent Power	$S_T = \sqrt{V_T^2 \cdot I_T^2}$	See Table II
Total Power Factor	$PF_T = \frac{P_T}{S_T}$	See Table II
Fryze Reactive Power	$Q_F = \sqrt{S_T^2 - P_T^2}$	See Table II
Budenau Distortion Power	$D = \sqrt{S_T^2 - P_T^2 - Q_B^2}$	See Table II
Total Harm. Distortion (TMD)	$\frac{\sum_{k=2}^{M} V_{kRMS}^2}{V_{1RMS}^2} = \frac{A}{B}$	A : Q-Form $\alpha_0 = \alpha_1 = 0$, $\alpha_k = 1$ B : Q-Form for RMS of the 1^{st} Harmonic
Kusters Reactive Power	$\frac{\sum_{k=1}^{M} kQ_k}{\sum_{k=1}^{M} k^2 V_{kRMS}^2} \cdot V_T = \frac{A}{\sqrt{B}} \cdot V_T$	A : B-Form $\beta_k = k,\ \alpha_k = 0$ B : Q-Form $\alpha_k = k^2,\ \alpha_0 = 0$
Reactive Current	$i_q = i(t) - \frac{P_T}{V_{TRMS}^2} u(t)$	See Table II

In order to measure such a disturbance, an algorithm having zero output for sinusoidal part has been implemented. This algorithm needs only 4 samples taken in $\frac{1}{6}$ fraction of a cycle. The expression for this algorithm is equal to:

$$QFV(n) = X_n Z_{n-1} - Z_n X_{n-1} \quad (25)$$

where:

$$Z_n = aX_{n-2} + bX_{n-3} + cX_{n-4} \quad (26)$$

Coefficients a, b and c are determined by the following expressions:

$$H^v(e^{-j\delta}) = 0 \quad (27)$$

$$H^c(e^{-j\delta_0}) = 0 \qquad \delta_0 = \frac{1}{24} \quad (28)$$

$$\frac{dH^c(e^{-j\delta_0})}{d\delta} = 0 \qquad \delta_0 = \frac{1}{24} \quad (29)$$

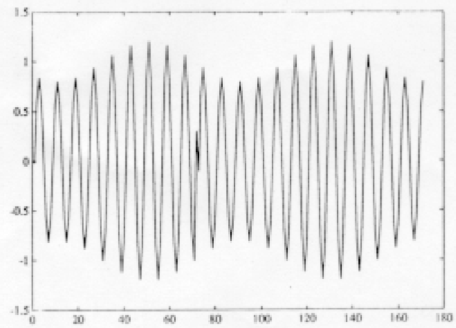

Figure 3a. Signal with a Disturbance of Short Duration

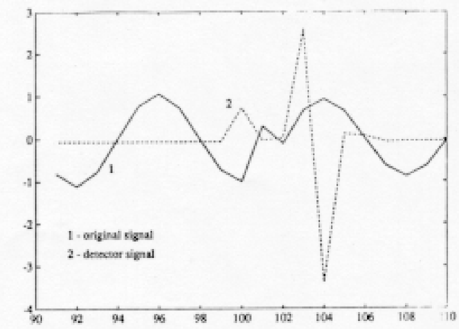

Figure 3b. Output of the Disturbance Detection Algorithm

Conditions given by the above expressions can be explained as follows: expression (27) – assures that QFV is constant; expression (28) – assures that the value of QFV is zero at the fundamental frequency; expression (29) – assures that the value of QFV is zero for slight variations of the fundamental frequency.

The algorithm given by expressions (25) and (26) is tested using the following expression for the signal given in Figure 3:

$$X(n) = \left[1 + 0.2\cos\frac{\delta_n}{2}\right]\cos\left[\delta_n + 0.25\sin\frac{\delta_n}{s}\right] \qquad (30)$$

The results are showing algorithm output being zero for all times except when the disturbance is present. This is quite impressive since the result was not affected by the variations in both amplitude [20%] and frequency [5%] of the fundamental harmonic. The results are shown in Figure 3b. It can be observed that a significant departure of the algorithm output from zero value is present when a disturbance is encountered.

Yet another test of this algorithm was done with a signal having impulses as disturbances. The signal is shown in Figure 4 and the algorithm output for this case is also shown in Figure 4. The output is squared to give positive indicators of the disturbances. Again, a sharp indication of the disturbance is obtained.

The example of this algorithm [illegible] of a short disturbance for Class I signals [illegible] to be defined what action shall be taken in this case to assess power quality in this case but the fact that a disturbance can easily be detected is considered a necessary step in this direction.

Class II signal characteristics can be measured in a number of different ways, depending on definitions of the quantities of interest. This section gives an example of how an indicator for voltage flicker intensity can be measured.

Voltage flicker is a disturbance which is characterized by the fundamental harmonic being modulated with a periodic signal having frequency that is lower than the fundamental harmonic's one.

As an indicator of the voltage flicker disturbance, an intensity index is defined as [15]:

$$I_{FL} = \sum_{r=1}^{R} 2W_r^2 c_r^2 \qquad (31)$$

where: W_r – weight coefficients
c_r – amplitudes of harmonics present in the voltage signal envelope

The voltage signal in the case of a flicker can be represented as:

$$x(n) = A\left[1 + \sum_{r=1}^{R} c_r \cos rn\delta\right] \cdot \cos[mn\delta] \qquad (32)$$

where: $m\delta = \omega_0 \Delta t$ $\quad \omega_0$ – nominal frequency
$\delta = \omega_1 \Delta t$ $\quad \Delta t$ – interval between samples

The voltage signal, given by equation (32), can also be represented in the following form.

$$X(n) = A\cos[mn\delta] + \sum_{r=1}^{M} Ac_r[\cos(m-r)n\delta + \cos(m+r)n\delta] \quad (33)$$

The expression (33) can be developed as a Fourier series of a periodic signal with freqeuncy ω_1. By doing this, expression for the intensity becomes a special case of the algorithm $\sum_{k=0}^{M} \alpha_k V_k^2$, given in Table II.

In order to obtain such an expression, the following has to be recognized:

$$V_m = A \qquad V_{m+r} = Ac_r \qquad m + r = k$$

Therefore:

$$c_r = \frac{V_{m+r}}{V_m}$$

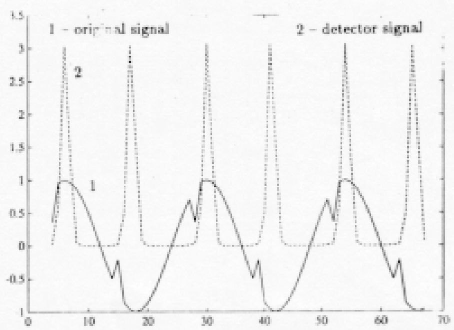

Figure 4. Signal with an Impulse Disturbance and Output of the Disturbance Detection Algorithm

The intensity is then equal to:

$$I_{FL} = \sum_{r=1}^{R} 2 \cdot W_r^2 \frac{V_{m+r}^2}{V_m^2} = \sum_{k=m+1}^{m+M} 2W_{k-m}^2 \frac{V_k^2}{V_m^2} = \frac{\sum_{k=m+1}^{m+M} 2W_{k-m}^2 V_k^2}{V_m^2} \quad (36)$$

From equation (36) it can be observed that intensity I_{FL} can be obtained as a quotient of two quadratic forms QFV_1 and QFV_2. Coefficients for QFV_1 are equal to:

$$\alpha_k = 2W_{k-m}^2 \quad k = m+1, \quad ..., \; m+M$$
$$\alpha_k = 0 \quad \text{otherwise} \quad (37)$$

Coefficients for QV_2 are as follows:

$$\alpha_k = 1 \quad k = m \qquad \alpha_k = 0 \quad k \neq m \quad (38)$$

It shall also be noted that the sampling rate for both forms needs to be greater than $2(m+M)$.

In order to demonstrate the use of the algorithms for calculation of the flicker intensity, the following voltage signal has been simulated as an example of a flicker disturbance:

$$V(n) = 2\left[1 + \cos 15 \cdot \frac{2\pi}{180} + \cos 5 \cdot \frac{2\pi n}{180}\right] \cdot \cos \frac{60n}{180} \quad (39)$$

This signal is shown in Figure 5. Coefficient α_k has been assigned the following value in the simulations:

$$\alpha_k = 4 \cdot \frac{60(k-60)}{15} \quad (40)$$

The results obtained for the intensity are within the expected error.

CONCLUSIONS

- Q–forms and B–forms can be used to define a number of algorithms that may be useful for power quality assessment
- Examples of the algorithms for disturbance monitoring, intensity of the harmonics, and voltage flicker demonstrate how measurements of possible power quality indicators can be implemented using Q–forms
- Future algorithm developments using Q–forms and B–forms need to concentrate on definition of some additional power quality indicators
- Methodology for power quality assessment using various algorithms for the power quality indicators also needs to be developed in the future.

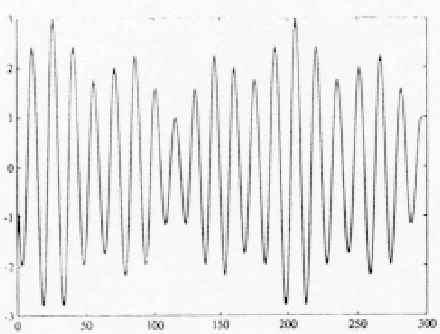

Figure 5. Voltage Flicker Signal

ACKNOWLEDGEMENTS

The authors would like to extend their thanks to Mr. Predrag Spasojević for performing simulations given the this paper. Thanks are also due to the Electric Power Institute of the Department of Electrical Engineering at Texas A&M University for providing a graduate student research assistantship for Mr. Spasojević.

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