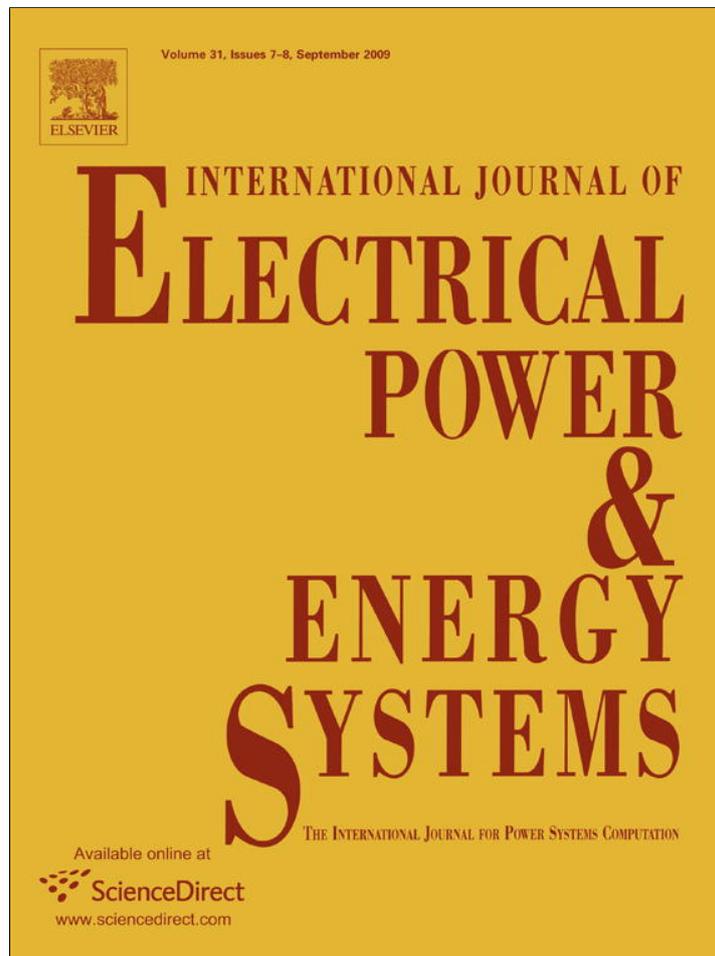


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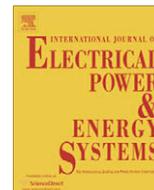
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# Electrical Power and Energy Systems

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## Measurement of a power system nominal voltage, frequency and voltage flicker parameters

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### ABSTRACT

We present, in this paper, an approach for identifying the frequency and amplitude of voltage flicker signal that imposed on the nominal voltage signal, as well as the amplitude and frequency of the nominal signal itself. The proposed algorithm performs the estimation in two steps; in the first step the original voltage signal is shifted forward and backward by an integer number of sample, one sample in this paper. The new generated signals from such a shift together with the original one is used to estimate the amplitude of the original signal voltage that composed of the nominal voltage and flicker voltage. The average of this amplitude gives the amplitude of the nominal voltage; this amplitude is subtracted from the original identified signal amplitude to obtain the samples of the flicker voltage. In the second step, the argument of the signal is calculated by simply dividing the magnitude of signal sample with the estimated amplitude in the first step. Calculating the arccosine of the argument, the frequency of the nominal signal as well as the phase angle can be computing using the least error square estimation algorithm. Simulation examples are given within the text to show the features of the proposed approach.

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### 1. Introduction

Voltage flicker and harmonics are introduced to power system as a result of arc furnace operation, and power utilities are concern about their effects. As such an accurate model for the voltage flicker is needed. The definition of voltage flicker in IEEE standards is the “impression of fluctuating brightness or color, when the frequency observed variation lies between a few hertz and the fusion frequency of image” [1]. The flicker phenomenon may be divided into two general categories, cyclic flicker and non-cyclic flicker. Cyclic flicker is repetitive one and is caused by periodic voltage fluctuations due to the operation of loads such as spot welders, compressors, or arc welders. Non-cyclic flicker corresponds to occasional voltage fluctuations, such as starting of large motors, some of loads will cause both cyclic and non-cyclic flicker, such as arc furnace, welder, and ac choppers.

Over the past three decades, many digital algorithms have been developed and tested to measure power system frequency and rate of change of frequency. Ref. [2] presents the application of the continuous Wavelet transform for power quality analysis. The transform appears to be reliable for detecting and measuring voltage sags, flicker and transients in power quality analysis. Ref. [3] pays attention to the fast Fourier transform and its pitfalls. A low pass

digital filter is used, and the effects of system voltage deviation on the voltage - flicker measurements by direct FFT are studied. The DC component leakage effect on the flicker components in the spectrum analysis of the effective value of the voltage and the windowing effect on the data acquisition of the voltage signal are discussed as well.

A digital flicker meter is proposed in Ref. [6] based on forward and inverse FFT and on filtering, in the frequency domain, for the implementation of the functional blocks of simulation of lamp-eye-brain response. Refs. [5–7] propose a method based on Kalman filtering algorithms to measure the low frequency modulation of the 50/60 Hz signal. The method used, in these references, allows for random and deterministic variation of the modulation. The approach utilizes a combination of linear and non-linear Kalman filter modes.

Ref. [8] presents a method for direct calculation of flicker level from digital measurements of voltage waveforms. The direct digital implementation uses Fast Fourier transform (FFT) as the first step in computation. A pruned FFT, customized for the flicker level computation, is also proposed. Presented in Ref. [9] is a static state estimation algorithm based on least absolute value error (LAV) for measurement of voltage flicker level. The waveform for the voltage signal is assumed to have, for simplicity, one flicker component. This algorithm estimates accurately the nominal voltage waveform and the voltage flicker component. An application of continuous wavelet transform (CWT) for analysis of voltage flicker-generated signals is proposed in Ref. [10] With the time-frequency

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localization characteristics embedded in the wavelets, the time and frequency information of a waveform can be integrally presented.

Ref. [11] presents an arc furnace model that implemented in the Simulink environment by using chaotic and deterministic elements. This model is obtained by solving the corresponding differential equation, which yields dynamic and multi valued  $v-i$  characteristics of the arc furnace load. In order to evaluate the flicker in the simulated arc furnace voltage, the IEC flicker meter is implemented based on the IEC 1000-4-15 standard in Matlab environment.

Ref. [12] presents an approach to estimate voltage flicker components magnitudes and frequencies, based on  $L_p$  norms ( $p = 1, 2$  and  $\infty$ ) and Taylor's' series linearization. It has been found that it is possible to design an  $L_p$  estimator to identify flicker frequency and amplitude from time series measurements. The Teager energy operator (TEO) and the Hilbert transform (HT) are introduced in Ref. [13] as effective approaches for tracking the voltage flicker levels. It has been found that TEO and HT are capable of tracking the amplitude variations of the voltage flicker and supply frequency in industrial systems with an average error 3%.

Ref. [14] presents a control technique for flicker mitigation. This technique is based on the instantaneous tracking of the measured voltage envelope. The ADALINE (ADaptive LINear) neuron algorithm and the Recursive Least Square (RLS) algorithm are introduced for the flicker envelope tracking. In Ref. [15], an algorithm for tracking the voltage envelope based on calculating the energy operator of a sinusoidal waveform is presented. It is assumed that the frequency of the sinusoidal waveform is known and a lead-lag network with unity gain is used. Ref. [16] develops an enhanced method for estimating the voltage fluctuation ( $\Delta V_{10}$ ) of the electric arc furnace (EAF). The method proposed considers the reactive power variation and also the active power variation in calculating  $\Delta V_{10}$  value of ac and dc EAFs.

Control and protection of power systems requires accurate measurement of system frequency. A system operates at nominal frequency, 50/60 Hz means a balance in the active power, i.e. the power generated equals the demand power plus losses. Imbalance in the active power causes the frequency to change. A frequency less than the nominal frequency means that the demand load plus losses are greater than the power generated, but a frequency greater than nominal frequency means that the system generation is greater than the load demand plus losses. As such, frequency can be used as a measure of system power balance.

Ref. [17] presents a numerical differentiation-based algorithm for high-accuracy, wide-range frequency estimation of power systems. The signal, using this algorithm, includes up to 31st-order harmonic components. Ref. [18] presents a method for estimation of power frequency and its rate of change. The proposed method accommodates the inherent non-linearity of the frequency estimation problem. The estimator is based on a quadrature phase-look loop concept.

An approach for designing a digital algorithm for local system frequency estimation is presented in Ref. [19]. The algorithm is derived using the maximum likelihood method. A recursive Newton-type algorithm suitable for various measurement applications in power system is developed in Ref. [20] and is used for power system frequency and spectra estimation. A precise digital algorithm based on discrete Fourier transforms (DFT) to estimate the frequency of a sinusoid with harmonics in real-time is proposed in Ref. [21]. This algorithm is called smart discrete Fourier transform (SDFT) that avoids the errors due to frequency deviation and keeps all the advantages of the DFT.

Ref. [22] presents an algorithm for frequency estimation from distorted signals. The proposed algorithm is based on the extended complex Kalman filter, which uses discrete values of a three-phase voltage that are transformed into the well-known  $\alpha\beta$ -transform.

Using such a transformation a non-linear state space formulation is obtained for the extended Kalman filter. This algorithm is iterative and complex and needs much computing time and uses the three-phase voltage measurements, to calculate the power system voltage frequency.

Ref. [23] describes design, computational aspect, and implementation aspects of a digital signal processing technique for measuring the operating frequency of a power system. It is suggested this technique produces correct and noise-free estimates for near nominal, nominal and off-nominal frequencies in about 25 ms, and it requires modest computation. The proposed technique uses per-phase digitized voltage samples and applies orthogonal FIR digital filters with the least errors square (LES) algorithm to extract the system frequency.

Ref. [24] presents an iterative technique for measuring power system frequency to a resolution of 0.01–0.02 Hz for near nominal, nominal and off-nominal frequencies in about 20 ms. The algorithm in this reference uses per-phase digitized voltage samples together with a FIR filter and the LES algorithm to extract iteratively the signal frequency. This algorithm has beneficial features including fixed sampling rate, fixed data window size and easy implementation.

Refs. [25,26] present a new pair of orthogonal filters for phasor computation; the technique proposed extracts accurately the fundamental component of fault voltage and current signal. Ref. [27] describes an algorithm for power system frequency estimation. The algorithm, applies orthogonal signal component obtained with use of two orthogonal FIR filters. The essential property of the algorithm proposed is outstanding immunity to both signals orthogonal component magnitudes and FIR filter gain variations. Again this algorithm uses the per-phase digitized voltage samples.

Ref. [28] presents a method of measuring the power system frequency, based on digital filtering and Prony's estimation. The discrete Fourier transform with a variable data window is used to filter out the noise and harmonics associated with the signal. The results obtained using this algorithm are more accurate than when applying the method based on the measurement of angular velocity of the rotating voltage phasor. The response time of the proposed method equals to three to four periods of the fundamental components. This method uses also per phase digitized voltage samples to compute the system frequency from harmonics polluted voltage signal. Ref. [29] implements a digital technique for the evaluation of power system frequency. The algorithm is suitable for microprocessor implementation and uses only standard hardware. The algorithm works with any relative phase of the input signal and produces a new frequency estimate for every new input sample. This algorithm uses the orthogonal sine and cosine-filtering algorithm.

A frequency relay, which is capable of under/over frequency and rate of change of frequency measurements using an instantaneous frequency-measuring algorithm, is presented in Ref. [30]. It has been shown that filtering the relay input signal could adversely affect the dynamic frequency evaluation response. Misleading frequency behavior is observed in this method, and an algorithm has been developed to improve this behavior. The under/over frequency function of the relay will cause it to operate within 30 ms.

Digital state estimation is implemented to estimate the power system voltage amplitude and normal frequency and its rate of change. The techniques employed for static state estimation are least errors square technique [31–33], least absolute value technique [34–36]. While linear and non-linear Kalman filtering algorithms are implemented for tracking the system operating frequency, rate of change of frequency and power system voltage magnitude from a harmonic polluted environment of the system voltage at the relay location. Most of these techniques use the per-phase digitized voltage samples, and assume that the three-

phase voltages are balanced and contain the same noise and harmonics, which is not the case in real-time, especially in the distribution systems, where different single phase loads are supplied from different phases.

An approach for identifying the frequency and amplitude of flicker signal that imposed on the nominal voltage signal, as well as the amplitude and frequency of the nominal signal itself is presented in this text. The proposed algorithm performs the estimation in two steps. While, in the first step the original signal is shifted forward and backward by an integer number of sample, one sample in this paper. The generated signals from such shift together with the original one are used to estimate the amplitude of the original voltage signal that composed of the nominal voltage and the flicker voltage, the average of this amplitude gives the amplitude of the nominal voltage. This amplitude is subtracted from the original identified amplitude to obtain the samples of the flicker voltage. In the second step, the argument of the signal is calculated by simply dividing the magnitude of signal sample with the estimated amplitude in step one. Computing the arccosine of the argument, the frequency of the nominal signal as well as the phase angle can be calculated using the least error square estimation algorithm. Simulation examples are given within the text to show the features of the proposed approach.

## 2. Flicker voltage identification

Generally speaking, the voltage during the time of flicker can be expressed as [2]:

$$v(t) = \left\{ A_0 + \sum_{i=1}^M A_i \cos(\omega_{fi}t + \phi_{fi}) \right\} \cos(\omega_0t + \phi_0) \quad (1)$$

where  $A_0$  is the amplitude of the nominal power system voltage,  $\omega_0$  is the nominal power frequency, and  $\phi_0$  is the nominal phase angle. Furthermore,  $A_i$  is the amplitude of the flicker voltage,  $\omega_{fi}$  its frequency, and  $\phi_{fi}$  its phase angle and  $M$  is the expected number of flicker voltage signal in the voltage waveform. This type of voltage signal is called amplitude modulated (AM) signal.

### 2.1. Signal amplitude measurement

The first bracket in Eq. (1) is the amplitude of the signal,  $A(t)$  which can be written as:

$$A(t) = \left\{ A_0 + \sum_{i=1}^M A_i \cos(\omega_{fi}t + \phi_{fi}) \right\} \quad (2)$$

As such Eq. (1) can be rewritten as:

$$v(t) = A(t) \cos(\omega_0t + \phi_0) \quad (3)$$

Assume that the signal is given forward and backward shift by an angle equals an integral number of the sampling angle. Then Eq. (3) can be written in the forward direction as:

$$v_f(t) = A(t) \cos(\omega_0t + \phi_0 + \theta) \quad (4)$$

While for the backward direction, it can be written as:

$$v_b(t) = A(t) \cos(\omega_0t + \phi_0 - \theta) \quad (5)$$

where  $\theta$  is the shift angle and is given by

$$\theta = N \frac{2\pi}{N_c}, \quad \text{and} \quad N_c = \frac{m\Delta T}{T} = \frac{mf_0}{F_s} \quad (6)$$

$N$  is the number of samples required for the shift,  $f_0$  is the signal frequency and  $m$  is the total number of samples over the data window size. Using Eqs. (4)–(6), one obtains

$$v^2(t) - v_f(t)v_b(t) = A^2(t) \sin^2 \theta \quad (7)$$

The recursive equation for the amplitude  $A(k)$  is given by:

$$A(k) = \frac{1}{\sin \theta} [v^2(k) - v_f(k)v_b(k)]^{\frac{1}{2}} \quad (8)$$

Having identified the amplitude  $A(k)$ , the amplitude of the nominal voltage signal of frequency  $\omega_0$  can be calculated, just by taking the average over complete data window size as:

$$A_0 = \frac{1}{m} \sum_{k=1}^m A(k) \quad (9)$$

Having identified the power signal amplitude  $A_0$ , then the flicker voltage components can be determined by;

$$V_f(k) = A(k) - A_0 \quad (10)$$

This voltage flicker signal can be written as;

$$v_f(k) = \sum_{i=1}^M V_{fi}(k) \cos(k\omega_{fi}\Delta T + \phi_{fi}); \quad k = 1, 2, \dots, m \quad (11)$$

where  $\Delta T$  is the sampling time that is the reciprocal of the sampling frequency.

### 2.2. Measurement of flicker frequency

Without loss of generality, we assume that the voltage flicker signal has only one component given by,  $i = 1$

$$v_f(k) = V_{f1}(k) \cos(k\omega_{f1}\Delta T); \quad k = 1, 2, \dots, m \quad (12)$$

To determine the flicker amplitude  $V_{f1}(k)$  and the frequency  $\omega_{f1}$  from the available  $m$  samples, we may use the algorithm explained in Ref. [9]. The frequency is calculated from

$$\omega_{f1}(k) = \left[ \frac{-v'_f(k)}{v_f(k)} \right]^{\frac{1}{2}} \quad (13)$$

While the amplitude can be calculated as:

$$V_{f1}^2(k) = v_f^2(k) + \left( \frac{v'_f(k)}{\omega_{f1}(k)} \right)^2 \quad (14)$$

In the above equations  $v'_f(k)$  and  $v''_f(k)$  are the first and second derivative of the flicker signal, they can be calculated, using the central forward and backward difference [9] as:

$$v'_f(k) = \frac{F_s}{12} [-v_f(k+2) + 8v_f(k+1) - 8v_f(k-1) + v_f(k-2)] \quad (15)$$

and

$$v''_f(k) = \frac{F_s^2}{12} [-v_f(k+2) + 16v_f(k+1) - 30v_f(k) + 16v_f(k-1) - v_f(k-2)] \quad (16)$$

### 2.3. Nominal voltage signal frequency and phase angle

The signal argument can be calculated from

$$AR(k) = \cos^{-1} \left( \frac{v(k)}{A(k)} \right), \quad k = 1, 2, \dots, m \quad (17)$$

where  $AR(k)$  is given by

$$AR(k) = \omega_0(k\Delta T) + \varphi \quad (18)$$

In the above equation  $\omega_0$ ,  $\varphi$  are the two parameters to be estimated from the available  $m$  samples of the argument  $AR(k)$ . At least two samples are required for such a linear estimation.

Eq. (17) can be written, for  $m$  samples, as

$$\begin{bmatrix} AR(1) \\ AR(2) \\ AR(3) \\ \vdots \\ AR(m) \end{bmatrix} = \begin{bmatrix} \Delta T & 1 \\ 2\Delta T & 1 \\ 3\Delta T & 1 \\ \vdots & \vdots \\ m\Delta T & 1 \end{bmatrix} \begin{bmatrix} \omega_0 \\ \varphi \end{bmatrix} \quad (19)$$

In vector form, Eq. (19) can be written as:

$$\underline{Z} = H\underline{X} + \underline{\zeta} \quad (20)$$

where  $\underline{Z}$  is  $m \times 1$  measurements vector for the argument samples,  $H$  is  $m \times 2$  measurements matrix the element of this matrix depend on the sampling time, sampling frequency,  $\underline{X}$  is the  $2 \times 1$  parameters vector to be estimated and  $\underline{\zeta}$  is  $m \times 1$  error vector to be minimized. The minimum of  $\underline{\zeta}$  based on least error squares occurs when:

$$\underline{X}^* = [H^T H]^{-1} H^T \underline{Z} \quad (21)$$

Perform the matrix multiplications in Eq. (21); one obtains the signal frequency as;

$$\omega_0 = \frac{m \sum_{k=1}^m k AR(k) \Delta T - \sum_{k=1}^m k \Delta T \sum_{k=1}^m AR(k)}{m \sum_{k=1}^m (k \Delta T)^2 - (\sum_{k=1}^m k \Delta T) (\sum_{k=1}^m k \Delta T)} \quad (22)$$

While the signal phase angle is given by

$$\varphi = \frac{\sum_{k=1}^m AR(k) \sum_{k=1}^m (k \Delta T)^2 - \sum_{k=1}^m k \Delta T \sum_{k=1}^m k AR(k) \Delta T}{m \sum_{k=1}^m (k \Delta T)^2 - (\sum_{k=1}^m k \Delta T) (\sum_{k=1}^m k \Delta T)} \quad (23)$$

The above two equations give directly the frequency and phase angle, in closed forms, for the signal under study. To have a practical approach those formulas should not be sensitive to noise and harmonics. One way to reduce those sensitivities is to use of least error squares algorithm, as we explained in Eq. (21), for the frequency estimation in the paper. In the following section we offer examples from the area of power system voltage flickers that can be considered as amplitude modulated signals.

### 3. Computer experiments

The above algorithm is tested using amplitude modulated signal with one voltage flicker signal given by;

$$v(t) = [1 + 0.2 \cos 20\pi t] \cos(314t + 10^\circ) \quad (24)$$

The signal is sampled at 10000 Hz and is giving a forward shift and backward shift by one sample,  $\theta = 7.2^\circ$  and 1000 samples are used. The power system voltage, 50 Hz signal, amplitude is estimated using the algorithm explained earlier, using Eqs. (8) and (9), and it has been found to that the proposed algorithm is succeeded in estimating this amplitude with great accuracy and is found be  $A_0 = 1.0$ . Fig. 1 gives the actual voltage signal, the tracked signal and the voltage signal amplitude. Examining this figure reveals the following:

- The power voltage signal amplitude, 50 Hz, is almost 1 p.u., the average value of  $A(t)$ , as that calculated using Eq. (9).
- The proposed technique tracked the actual signal exactly.

The flicker signal frequency is estimated using 200 samples only with Eq. (13). Fig. 2 gives the estimated flicker voltage frequency at each sampling step. Examining this figure reveals that the proposed algorithm estimates the flicker frequency with great accuracy. The spikes in these curves, are due to the value of the voltage flicker signal at this time of sampling which is very small, and looking to Eq. (13) one can notice that to calculate the frequency we divide by this value

Fig. 3 gives the estimated flicker amplitude at different samples. Examining this figure reveals that the proposed algorithm is suc-

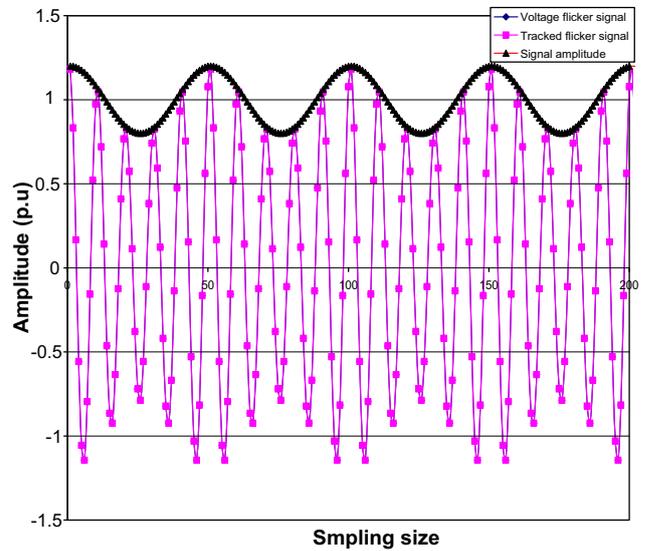


Fig. 1. Actual and tracked signal with the signal amplitude.

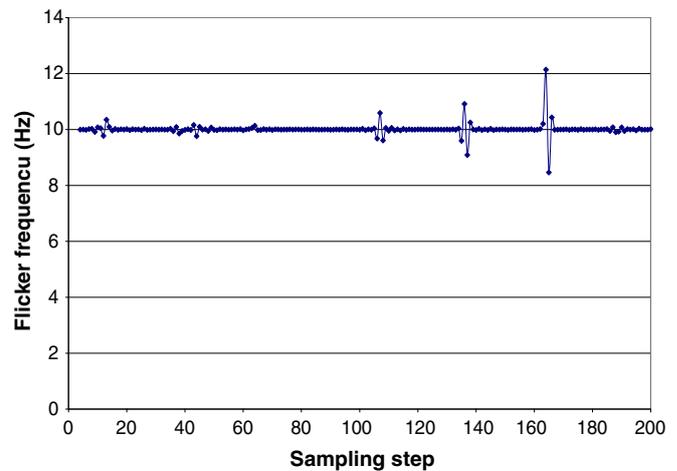


Fig. 2. Estimated flicker signal frequency.

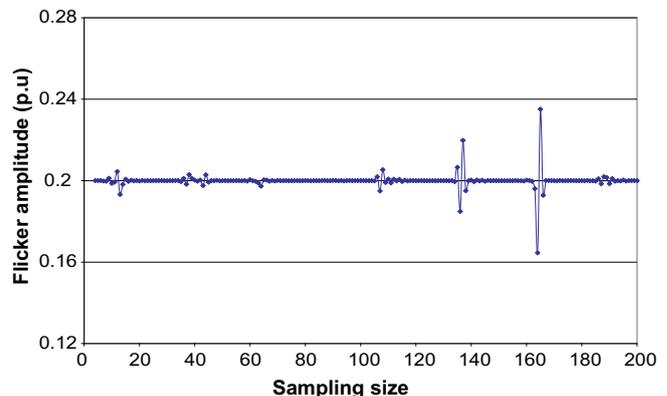


Fig. 3. Flicker amplitude.

ceeded to estimate the flicker amplitude, except at the points of spikes, as we explained earlier in the frequency estimation.

Another example has been solved, where the voltage signal has two flicker signals with different amplitude and frequency. The voltage signal in this case is given by

$$v(t) = [1 + 0.1 \cos(2\pi 2t) + 0.5 \cos(2\pi 5t)] \cos(2\pi 50t)$$

The signal is sampled at 500 Hz and is giving a forward shift and backward shift by one sample,  $\theta = 7.2^\circ$  and 500 samples are used. The voltage nominal amplitude is estimated using the technique explained earlier and has found to be one per unit, and the tracking voltage, using this technique, tracks the signal exactly as shown in Fig. 4.

### 3.1. Signals with nominal frequency (50 Hz)

In this section, we offer a signal of amplitude modulated, and frequently happens in power system. This is the voltage flicker signal and is given by

$$v(t) = [1 + 0.1 \cos(2\pi 2t) + 0.5 \cos(2\pi 5t)] \cos(2\pi 50t + 10)$$

Fig. 5 gives the time domain presentation of this signal. The signal is sampled at 1000 Hz and 200 samples are used in the calculation of the frequency and phase angle of the nominal voltage. Note that in this example  $\omega_0 = 314.159$  and  $\varphi = 10^\circ = 0.1745$  rad. Furthermore, the nominal voltage amplitude  $A_0$ , equals one.

Fig. 6 gives the variation of the argument with the time. Using the LES estimation algorithm explained earlier for linear best fit, the following estimation for the angular frequency and phase angle is obtained. The dashed line is the best fit.

$$\omega_0 = 314.2 \text{ rad/s}, \quad \varphi = 0.1745 \text{ rad}$$

It has been shown from this figure and the degree of fitness,  $R$ , that the proposed technique is greatly succeeded in estimating the frequency and phase angle of the signal in about 10 ms (half cycle) data window size. Furthermore it has been shown that the proposed algorithm estimates exactly the amplitude of the nominal signal.

Another example is offered in this section, where the amplitude of the signal has a lot of voltage flicker signal as

$$v(t) = [1 + 0.05 \cos(2\pi 2.5t) + 0.333 \cos(2\pi 7.5t) + 0.2 \cos(2\pi 12.5) + 0.14 \cos(2\pi 17.5) + 0.11 \cos(2\pi 22.5) + 0.09 \cos(2\pi 27.5)] \times \cos(2\pi 50t + 10^\circ)$$

The signal in the time domain is shown in Fig. 7.

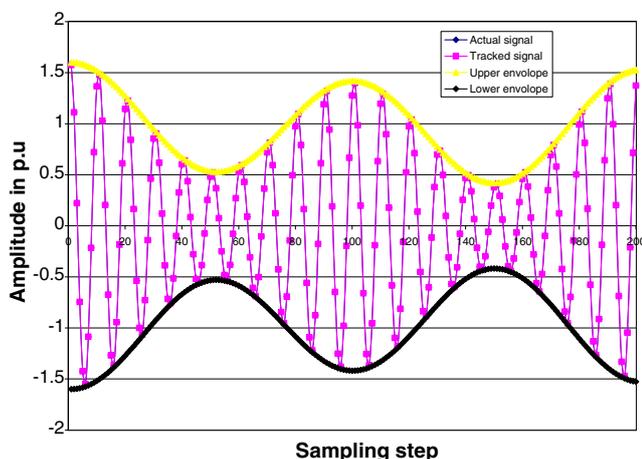


Fig. 4. Original and tracked signal.

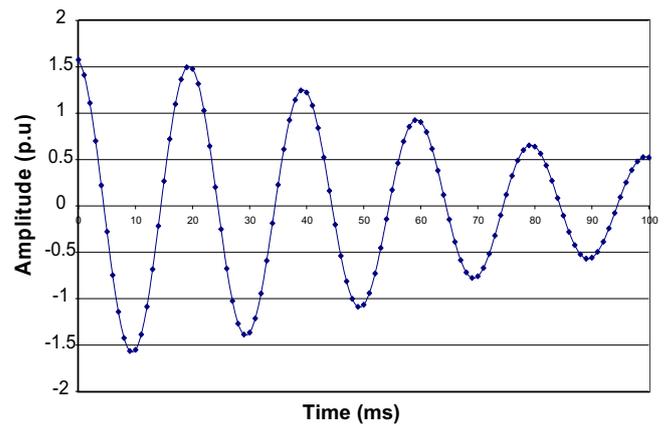


Fig. 5. Amplitude modulated signal.

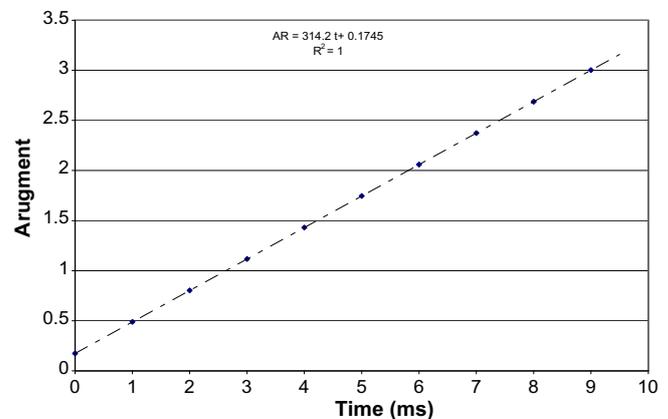


Fig. 6. Variation of argument with time.

Fig. 8 gives the estimated argument and the best fit based on LES estimation algorithm. Examining these figures one can conclude the following remarks:

- The estimated argument based on LES is given by  $AR = 314.3t + 0.1745$

This gives exactly the signal nominal frequency as well as the phase angle.

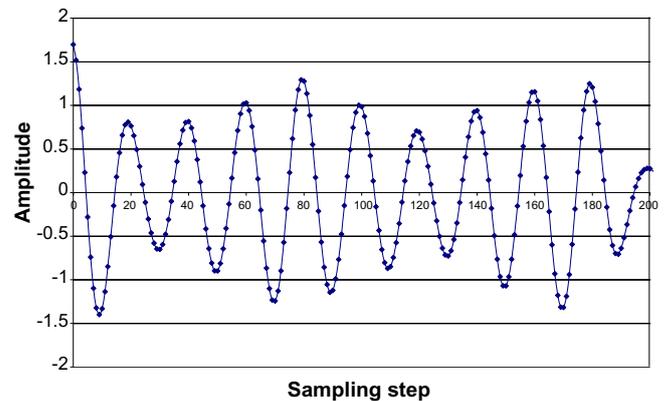


Fig. 7. Amplitude modulated signal.

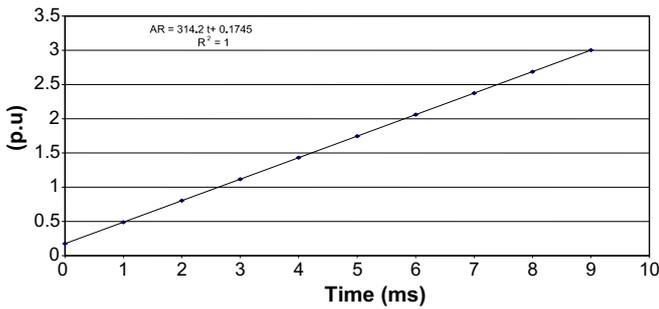


Fig. 8. Argument variations with time.

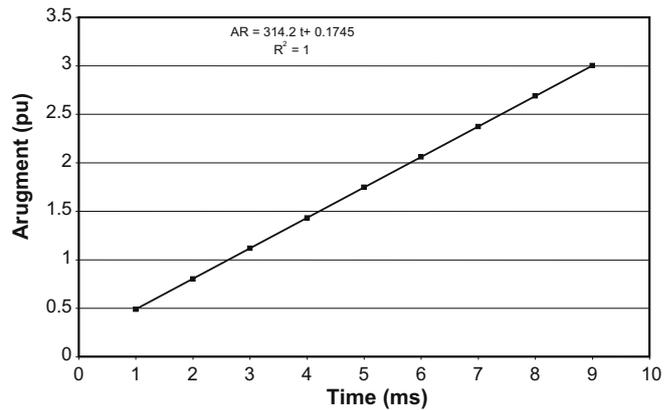


Fig. 10. The signal argument.

The last example is a sinusoidal signal with a decade dc. Fig. 9 gives the waveform of such type of signal, while Fig. 10 gives the argument of the signal and the LES best fit for the argument examining this Figure reveals the following:

- The estimated argument based on LES is given by  $AR = 314.3t + 0.1745$  which gives  $\omega_0 = 314.2$  rad/s and  $\varphi = 0.1745 = 10^\circ$ .
- The proposed algorithm estimates exactly the signal frequency and phase angle with a great accuracy from such polluted signal.

### 3.2. Effects of the frequency drifts

Effects of the frequency drift on the estimated frequency is being tested in the section, where the forwards and backward shift is assumed at 50 Hz and the nominal frequency of the signal is assumed to be 49.5 Hz, frequency drift =  $-0.5$  Hz. Fig. 11 gives the actual signal as well as the tracked signal. Examining this figure reveals:

- The actual signal and the tracked signal are having different frequency, as expected since the first one has 50 Hz, while the second one has 49.5 Hz. As such, there is a phase shift between the tracked signal and the actual signal.
- The estimated amplitude is tracked the exactly both signal.

Note that there is a phase shift between the two signals, since one signal, original signal has a 50 Hz frequency, while the second one has 49.5 Hz. Fig. 12 gives the estimated argument of the nominal signal as well as the best estimate based on LES to this argument. Examining this figure reveals:

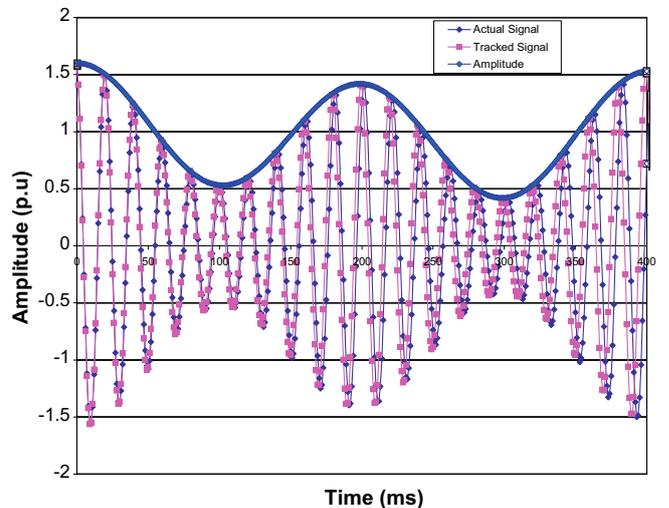


Fig. 11. Actual and tracked signal as well as the amplitude.

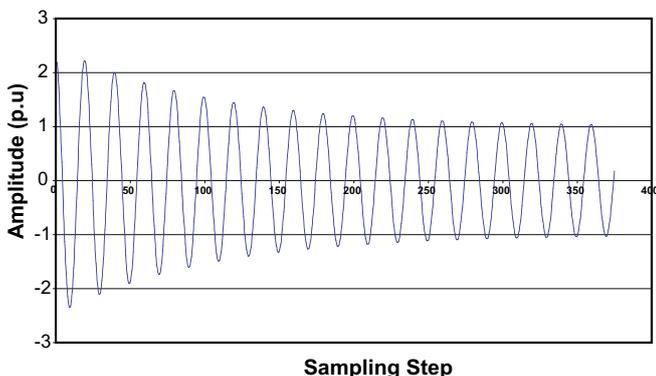


Fig. 9. The voltage signal with dc decade.

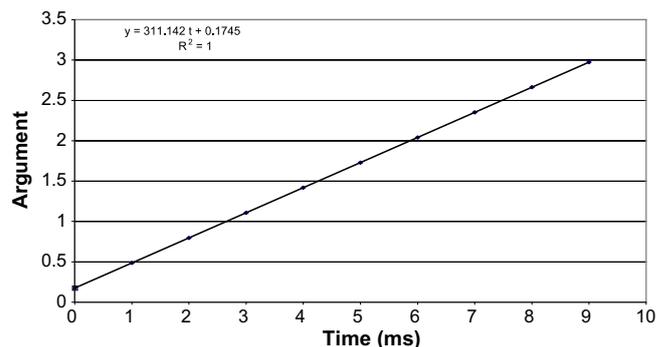


Fig. 12. The estimated argument and the estimated on based on LES.

- The estimated argument is  $AR(t) = 311.42t + 0.1745$  It does mean that the nominal estimated angular frequency is  $\omega = 311.42$  rad/s. This gives  $f_0 = 49.5$  Hz which is exactly the signal nominal frequency.
- The estimated phase angle  $\phi = 0.1745$  rad =  $10^\circ$ , that is exactly equal the phase angle of the signal.

#### 4. Conclusions

An approach for identifying the frequency and amplitude of flicker signal that imposed on the nominal voltage signal, as well as the amplitude and frequency of the nominal signal itself is presented in this paper. The proposed algorithm performs the estimation in two steps; in the first step the original signal is shifted forward and backward by an integer number of sample, at least one sample. The new generated signals from such a shift together with the original one is used to estimate the amplitude of the original voltage signal that composed of the nominal voltage and the flicker voltage. The average of this amplitude gives the amplitude of the nominal voltage; this amplitude is subtracted from the original identified amplitude to obtain the samples of the flicker voltage. The frequency of the flicker voltage is calculated using the forward and backward difference for the first and second derivatives for the voltage flicker signal.

In the second step, the argument of the signal is calculated by simply dividing the magnitude of signal sample with the estimated amplitude in step one. Calculating the arccosine of the argument, the frequency of the nominal signal as well as the phase angle can be calculated using the least error square estimation algorithm. Simulation examples are given. It has been shown that the proposed algorithm is succeeded in estimating the voltage flicker frequency and amplitude as well as the amplitude and frequency of the power voltage signal.

The proposed algorithm can be used off-line as well as on-line. In the on-line mode we recommend the usage of a digital lead-lag circuit. While in the off-line mode; just shift the registration counter on sample in the backward direction and another on in the forward direction to obtain the required sample of the data window size.

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