Predrag B. Petrović

Processing, Estimation and Measurement of Signals Parameters in Public Distribution Networks

ACADEMIC MIND
Belgrade, 2019.

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Publisher

ACADEMIC MIND, Belgrade, Serbia

Printed in Serbia by

ACADEMIC MIND, Belgrade

Circulation

200 copies

ISBN 978-86-7466-820-7

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PREFACE

This monograph is the result of a long-term work of the author on the problems of digital processing of complex periodic signals of voltage and current which can be found in the distribution network. This scientific field has been given special attention in the literature abroad through a great number of articles published in the leading journals, textbooks and the other publishing forms.

Over the recent period, the author of the monograph have published a large number of papers in a number of journals and have presented at the leading international conferences, which verifies the results they have achieved in this scientific field.

The problem of the reconstruction and estimation of complex periodic signals, which is in the focus of Chapter three of this monograph, has been given special attention. A completely new protocol, which enables the development of much superior and more efficacious algorithms, has been developed, and the obtained results are unique in global practice.

In other Chapters processing of parameters of ac signals, is performed on basis of Hilbert, Newton-Raphson, Gramm matrix, Taylor-Fourier techniques. The conditions, required for the performance of such a processing, have necessarily been derived. Chapter six proposes a newly developed instrument for the calculation of basic parameters of the processed voltage and current signals. Having being practically verified, this method has demonstrated exceptionally favorable performance.

The authors believe that the monograph will be beneficial to specialists and experts involved in problems of this scientific field, and hope that it will serve as a useful guideline to follow in further investigations.

1. New measurement procedures based on measurements on time interval

As is well known, during the past few years-decades, the major part of electrical loads in common power systems has become nonlinear or parametric (time varying); this is due to the proliferation among industrial, commercial, and residential customers of power-electronic equipment, such as adjustable-speed drives, controlled rectifiers, cycloconverters, electronically ballasted lamps, arc and induction furnaces, and clusters of personal computers. Such loads may create a host of disturbances to the utility and to other customers' equipment. Consequently, electric power quality is a major issue for utilities and for their customers and both is quickly adopting the philosophy and the limits proposed in the new International Standards (such as IEC, EN, BS, IEEE). The quality of electrical power in commercial and industrial installations is undeniably degrading. In addition to external disturbances, such as outages, sags and spikes due to switching and atmospheric phenomena, there are inherent internal problems specific to each site, resulting from the combined use of linear and non-linear loads. For these very reasons it is important to develop measuring systems capable of performing the calculation of basic AC values in the presence of the higher harmonic components, within the processed voltage and current signals [1-4].

Power components such as active, reactive, distortion, nonactive and apparent powers are definied by the IEEE Standard 1459-2000 [5] using fast Fourier transforms (FFT). For the case of stationary wave forms, the FFT can provide accurate results; however, for the case of nonstationary waveforms, the FFT introduces large errors due to spectral leakage and picket fence phenomena [6]. The wavelet transform, which is considered as a time-frequency transform, is capable of handling and accurately representing nonstationary waveforms in too many applications in different disciplines [7, 8]. The power of the wavelet stems from the fact that it can provide variable frequency resolution while preserving time information. This is an important requirement for the analysis and measurement of the nonstationary waveforms which possess time-variant characteristics and this is lost when using the FFT.

The conventional algorithms for the measurement of active power and effective values of voltage and current employ integration or summation over an abruptly limited time interval [9-15]. The synchronous sampling of alternating current (AC) signals enables a highly accurate recalculation of basic electric values in a network. This is possible in the cases when we have a modified signal that is spectrally limited and when we have a sufficient processing time and necessary recalculation capacities. For this method to be effective, it is necessary to precisely measure the period T, as well as to generate the sampling interval $T_S=T/N$, where T is the period of the processed signal, and N is the number of measurements necessary for exact calculation [9, 10]. This method is suitable for sinusoidal signal and complex-periodical signals with low harmonic content.

Some of these methods [13-15] can offer exceptionally high precision in the calculation of basic electrical values, but only after conducting a complex calibration procedure and engaging high processor's power. Consequently, they operate correctly at a periodic input signal only. The voltage and current waveforms of the power network, however, are not strictly periodic, due to their nonharmonic components and stochastic variation. It is for this reason and in order to preserve the high performances of such algorithms that it is necessary to analyse the possible sources of errors in the determination of the integration interval [16], as well as to introduce special estimation procedures [17-21], all of which makes their structure additionally complex. Due to this, the outputs of these algorithms often do not represent the input's instantaneous value, but the input observed over a certain period of time. Based on estimated signal parameters [17-21], we can obtain RMS value of processed signals, and realize precise measurements of other important electrical values such as power and energy.

We developed a new approach in processing analogue signals (most of all AC that can be represented in the form of Fourier series, such as AC signals in public distribution networks), within a twice shorter time interval, compared to other methods in standard use [22, 23]. It is primarily directed towards determining the value of the active power of the signals, or the effective value (RMS) of the signal being processed, without a need for synchronization. This means that the sampling frequency f_s of the used analogue-to-digital converter is not an integer multiple of the signal frequency f. The method suggested here does not depend on complex hardware or intensive numerical calculations, which makes its practical realization highly inexpensive and does not require any special estimation procedure that would enable a subsequent refining of the obtained measuring results.

Let us assume that the system voltage $v_{input}(t)$, and current $i_{input}(t)$ signals can be represented as a sum of their Fourier components as follows:

$$\begin{aligned} v_{input} &= \sqrt{2}V_R \cdot \sum_{r=1}^{M_1} k_r \sin\left(r\omega t + \psi_r\right) = v_{input}\left(t\right), \\ i_{input} &= \sqrt{2}I_R \cdot \sum_{s=1}^{M_2} l_s \sin\left(s\omega t + \varphi_s\right) = i_{input}\left(t\right) \end{aligned} \tag{1.1}$$

where $\omega=2\pi f$ represents the angular frequency, k_rV_R is the RMS voltage value of the rth harmonic, l_sI_R is the RMS current value of the sth harmonic, ψ_r, ϕ_s are the phase angles of the rth and sth harmonic of voltage and current, M_1 and M_2 are the numbers of the highest harmonic components of voltage and current signal, respectively. Using the known spectral limits, it is also possible to specify the frequency of the selection of the processed signals in accordance with the Nyquist criteria. In real environment, the current signal usually possesses a "richer" harmonic content.

By definition, the average power P is calculated as:

$$P = \frac{1}{T}\int_0^T i_{input}\left(t\right) v_{input}\left(t\right) dt = \frac{1}{T}\int_0^T p\left(t\right) dt; T = \frac{1}{f} \tag{1.2}$$

However, the signal of the actual power of the band-limited signals, Figure 1.1 [24], shows the periodicity that enables us to perform the modification of the size of the time interval in which the calculation of the value of the active power is performed.