Wavelet-based of Electrical Power Measurement

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Abstract

Power and power quality are of most importance in modern energy systems. The analysis of electrical power measurement is an important consideration to electrical utilities and industrial customers so that diagnosis and mitigation of such disturbances can be implemented quickly. This paper presents the development of a computer based data acquisition system that provides practical measurement of power components (apparent, active, and reactive) under sinusoidal, non sinusoidal, stationary and non stationary conditions by using continuous wavelet transform. Wavelet transform measuring technique is the more accurate as it has a position analytic ability (analytic of a specified position from the signal of non sinusoidal waveforms). This method is fast, efficient and overcomes limitations of the current techniques. The practical results of the mentioned technique have been compared with the practical results obtained using AC/DC clamp power meter device.

الملخص

ان القدرة الكهربائية و نوعيتها هي الأهم في نظم الطاقة الكهربائية الحديثة. ان تحليل قياس القدرة الكهربائية ذات اهمية و فوائد في القطاع الصناعي و غيره، لهذا فان تشخيص و تخفيف الأضطرابات يمكن انجازه و بسرعة. يقدم هذا البحث تطوير نظام الحصول على البيانات معتمدا على الحاسبة لينفذ قياسات عملية لمكونات القدرة الكهربائية (الظاهرة، الفعالة وغير الفعالة) تحت ظروف الموجة الجيبية، غير الجيبية، المستقرة و غير المستقرة. ان تقنية القياس باستخدام تحويل المويجة هو الأكثر دقة لكونه ذات قابلية تحليلية معتمدا على الموقع (تحليل موقع محدد من الأشارة ذات الموجة غير الجيبية). تمتاز هذه الطريقة بانها سريعة، كفوءة و تتغلب على المحددات التي تعاني منها التقنيات المتبعة حاليا. تمت مقارنة النتائج العملية للتقنية المشار اليها في اعلاه مع النتائج العملية باستخدام جهاز مقياس مكونات القدرة.

1. Introduction

In parallel with the technological developments, the number and complexity of loads fed by energy networks have been growing. The nonlinear characteristics of the added loads focus attention on the concept of ‘‘energy quality”. Power and power factor are the primary factors determining energy quality [Vatansever2009].

The time-frequency domain wavelet transform shows a lot of possibilities when used in the multi-resolution analysis of voltage and current waveforms in the presence of non-linear loads, causing or subject to power quality problems .This transform proves to have some advantages when compared to the classical Fast Fourier Transform (FFT) -based algorithms. One of the basic assumptions of the FFT, the periodicity of the signal, is required in order to avoid erroneous results.

The wavelet methods solve this problem by decomposing the measured signal into a family of time finite signals through a filter-bank resulting in multi-scale wavelet decomposition. Harmonics of the fundamental frequency, sub-harmonics and inter harmonics are considered, disregarding the length of their occurrence in time. Especially the harmonics of rather low order, usually occurring with the highest amplitudes, are observed in detail. Since the set of basic functions is not restricted to sine and cosine waveforms, there is a freedom in choosing the basic functions (the wavelets), offering the best results in output and/or calculation speed. The applications of the proposed analysis technique can be found in the field of evaluating the electric power quality using previously recorded waveforms. Currently, the use of wavelet transforms in the registration of power quantities is explored. For this purpose, novel power definitions in the time-frequency domain are derived by making use of complex wavelet transformations. This technique is being implemented in a Digital Signal Processing (DSP) system allowing real-time analysis [Al-Dabagh2006].

2. Theoretical aspect

2.1 Basic wavelet constraints

The wavelet transform replaces the Fourier transform's sinusoidal waves by a family generated by translations and dilations of a window called a Wavelet. It takes two arrangements: time and scale.

- The wavelet is a non – zero in a limited interval.
- Integral of the wavelet must be zero :

$$\int \psi(x)dx = 0 \tag{1}$$

- A wavelet $\psi_{s,\tau}$, with the mother wavelet ψ , can be described as :

$$\psi_{s,\tau}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-\tau}{s}\right) \tag{2}$$

Where s is the scale and τ is the shift factor. The previous function is centered around τ, like the windowed Fourier atom. If the frequency center of ψ is τ, then the frequency center of the dilated function is τ/s [Al-Dabagh2006].

2.2 The Morlet

The most commonly used Continuous Wavelet Transform (CWT) wavelet is the Morlet wavelet, a Gaussian-windowed complex sinusoid that is defined as following in the time and frequency domains:

$$\psi_0(\eta) = \pi^{-1/4} e^{jm\eta} e^{-\eta^2/2} \tag{3}$$

$$\hat{\psi}_0(s\omega) = \pi^{-1/4} H(\omega) e^{-(a\omega - m)^2/2} \tag{4}$$

In equations (3) and (4), η is a non-dimensional time parameter, m is the wave number, and H is the Heaviside function [Torrence1998].

2.3 Calculation of the Complex wavelet based power definitions

The relevant voltages and currents are transformed to the time and frequency domain using a well-chosen complex wavelet ψ (t), with scaling parameter s (setting the frequency range) and translation parameter t (determining the time localization) [Johan2002]:

$$fw(t,s) = \left\langle f, \psi^*_{t,s} \right\rangle = \int_{-\infty}^{+\infty} f(t').\frac{1}{\sqrt{s}}\psi^*\left(\frac{t'-t}{s}\right)dt' \tag{5}$$

In a single-phase system this yields two series of complex wavelet coefficients for the voltage V and for the current I, indicated by a subscript W: V_W and I_W. From these coefficients, instantaneous amplitude and phase values are derived for the different sub bands.

$$V_w(t,s) = V_w(t,s)\angle\varphi_{V,w}(t,s) \tag{6}$$

$$I_w(t,s) = I_w(t,s)\angle\varphi_{I,w}(t,s) \tag{7}$$

For most power measurement applications, the most interesting subband is the one covering the fundamental frequency, here indicated as S_f. A complex-wavelet based power quantity is then defined in a way analogous to the Fourier-based active power definition [Yoon1998], now using the instantaneous voltage and current amplitude and the instantaneous phase difference between voltage and current then the complex wavelet power is:

$$P_w(t,s_f)=V_w(t,s_f).I_w(t,s_f).\cos(\varphi_w(t,s_f)) \qquad (8)$$

With the phase difference, based on the difference of the instantaneous phases:

$$\varphi_w(t,s_f)=\varphi_{V,w}(t,s_f)-\varphi_{i,w}(t,s_f) \qquad (9)$$

Similarly, a complex wavelet based reactive power quantity can be defined as well:

$$Q_w(t,s_f)=V_w(t,s_f).I_w(t,s_f).\sin(\varphi_w(t,s_f)) \qquad (10)$$

Both P_w and q_w can be obtained immediately by:

$$P_w(t,s_f)=P_w+jq_w=V_w(t,s_f)conj(I_w(t,s_f)) \qquad (11)$$

A ‘momentary’ power factor can be defined using the instantaneous phases.

$$dPF(t)=\cos(\varphi_w(t,s_f)) \qquad (12)$$

An apparent power-like quantity is obtained as well:

$$S_w(t,s_f)=\sqrt{P_w(t,s_f)+q_w(t,s_f)} \qquad (13)$$

It is possible to follow the philosophy of [Johan2002] to define additional power quantities for higher frequency phenomena and multiple phases. The development of all definitions is not possible here due to lack of space. Therefore only the wavelet based high frequency power is given as an illustration:

$$P_w(t,s_f)=\sum_{s>s_f}V_w(t,s_f).I_w(t,s_f).\cos(\varphi_w(t,s_f)) \qquad (14)$$

The previous derivation is mainly theoretical as it uses continuous transformations .A practical calculation will have to use discrete transforms [Yoon1998].The power components using complex wavelet are calculated as shown in Figure (1) [Al-Dabagh2006].

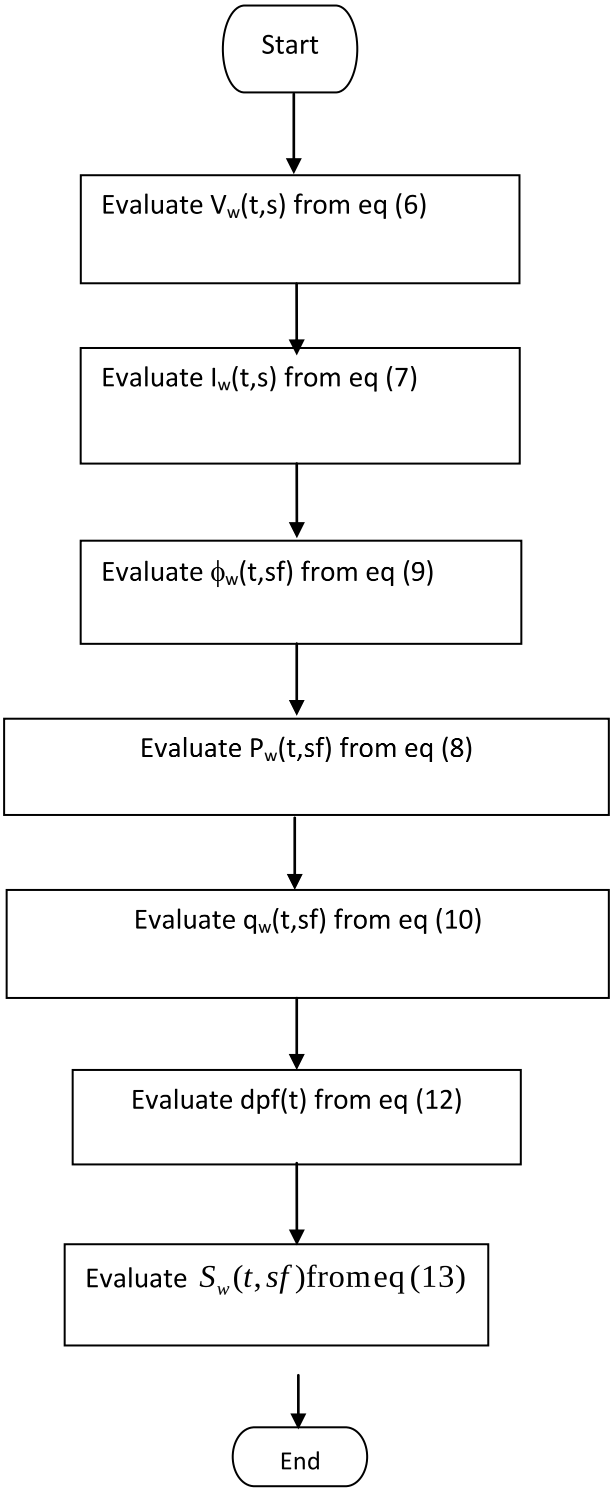

Figure (1) Flowchart of the computer program using complex wavelet.

3. Practical measurements and results

3.1 Practical connection for power measurement

The source shown in Figure (2) is a source inverter of 50Hz that supplies a load through a 1:1 isolating transformer. The output of this transformer is attenuated to (5V, 50Hz), and supplies to channel No.1 (ch1) of interfacing circuit. The output of the attenuator represents the voltage parameter (V). A current transformer, with ferrite core, 100/20 and up to 5kHz is connected to generate the second parameter (I) which is applied to channel No.2 (ch2) of the interface circuit. The interface circuit was designed and applied to communicate with Mat lab environment [Al-Dabagh2006].

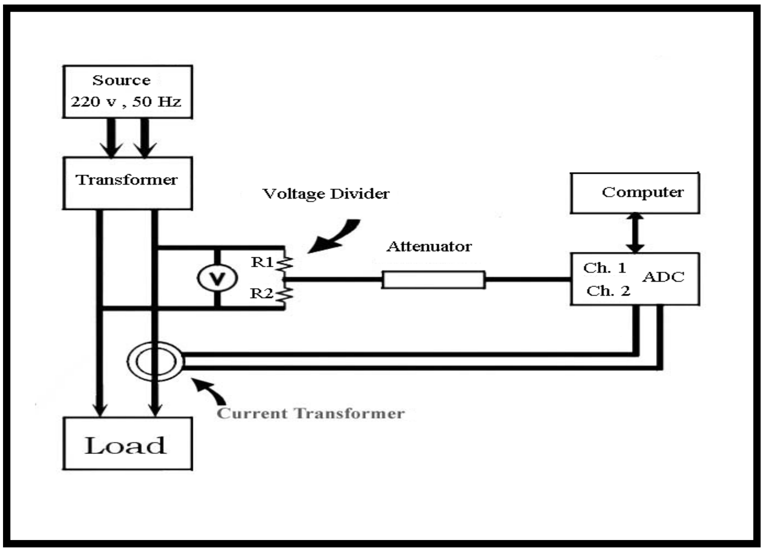

Figure (2) Block-Diagram of the Designed System.

3.2 Practical test and results [Al-Dabagh2006]

The data acquisition card (NI-DAC 7) received both voltage and current signals from the source inverter of 50Hz.The output signals are displayed by the softscope which are shown in Figures (3) and (4) respectively. The practical result: by using AC/DC clamp power meter device ANALYST 2060:-

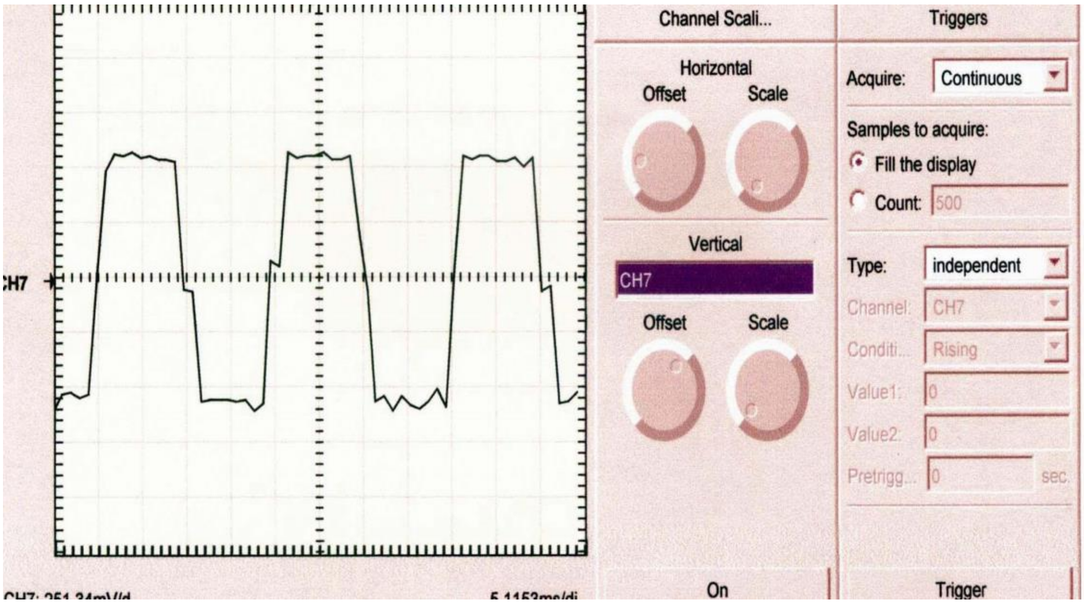

Figure (3) Output signal of channel 1.

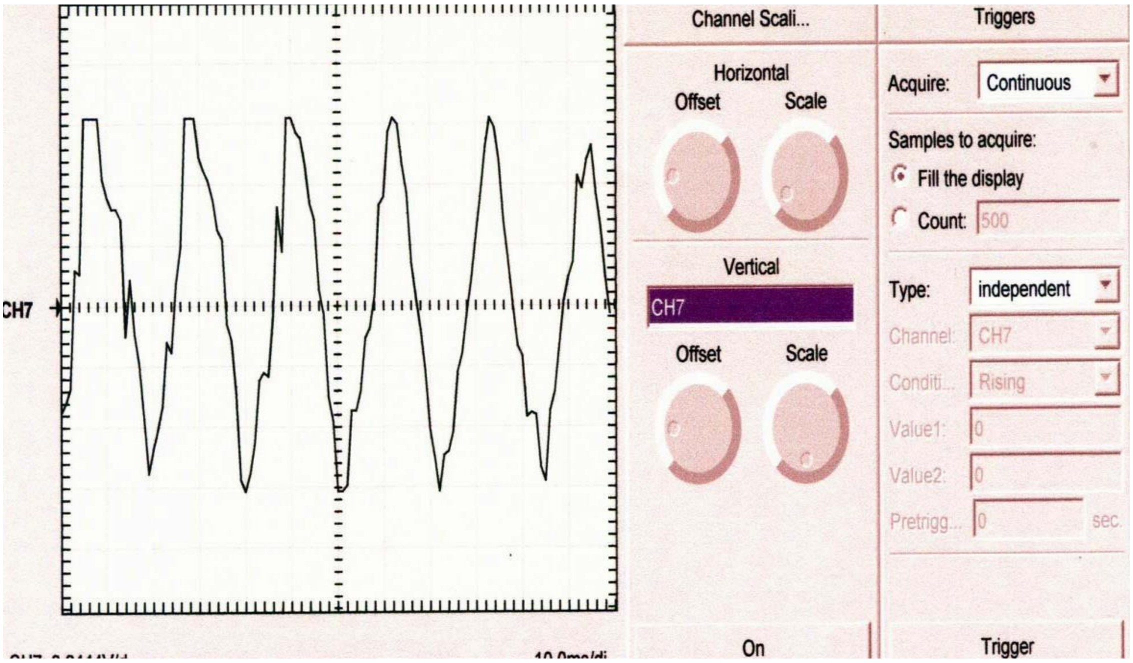

Figure (4) Output signal of channel 2.

The calculations of apparent power, active power and reactive power using wavelet are shown in the Figures (5) to (10). These figures have a relationship to the time-varying scale and frequency structure of the signals (voltage, current and power components):-

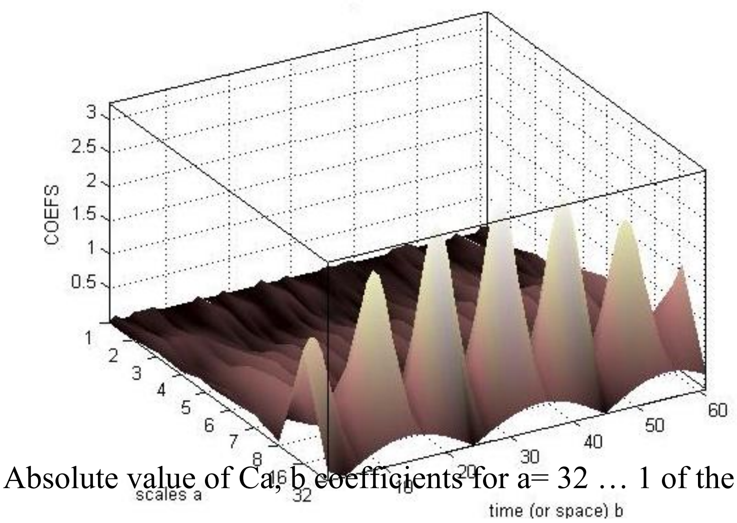

Figure (5) Absolute value of Ca, b coefficients for a= 32 … 1 of the voltage 3D.

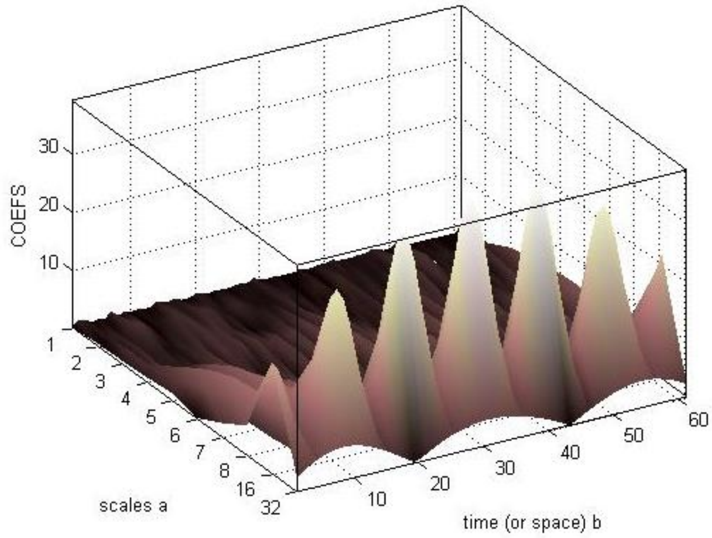

Figure (6) Absolute value of Ca, b coefficients for a= 32 … 1 of the current 3D.

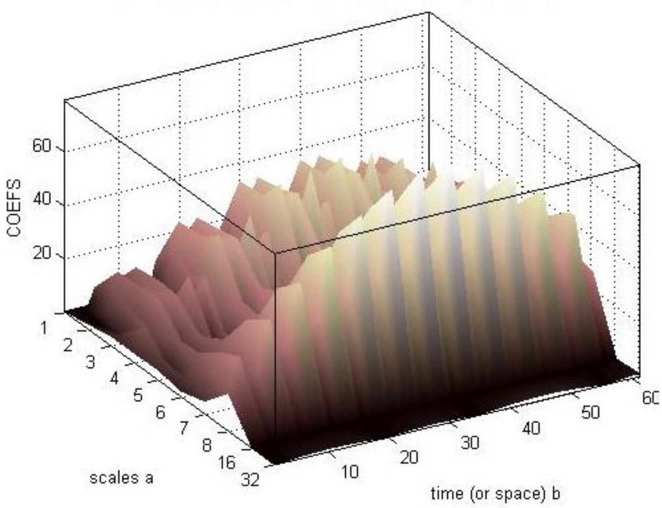

Figure (7) Absolute value of Ca, b coefficients for a= 32 … 1 of the apparent power 3D.

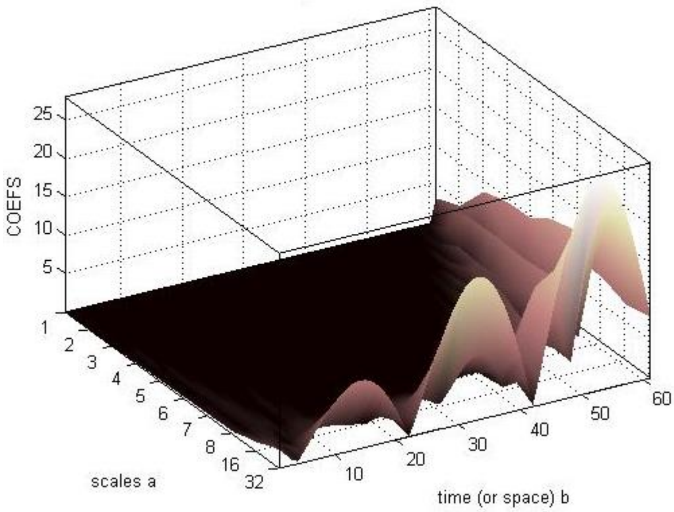

Figure (8) Absolute value of Ca, b coefficients for a= 32 … 1 of the difference angle between voltage and current 3D.

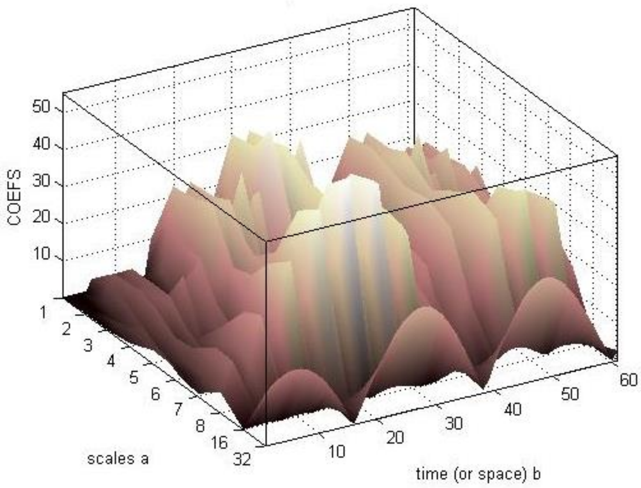

Figure (9) Absolute value of Ca, b coefficients for a= 32 … 1 of the active power 3D.

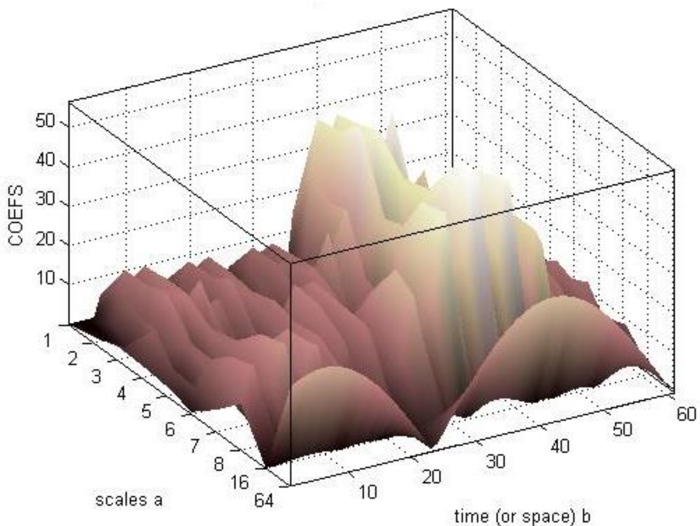

Figure (10) Absolute value of Ca, b coefficients for a= 32 … 1 of the reactive power 3D.

The result after executing the software in Matlab:-

Voltage rms	3.9720	V
Current rms	10.02	Amp.
Apparent power	39.817	VA
Active power	34.519	W
Reactive power	19.49	VAR
Power factor	0.8720	

4. Conclusions

A multi-channel measuring system was designed in this work based on the powerful properties of Matlab Package using PC. The signals to be measured are received from voltage and current transformers, and then these signals are processed via interface connection of the PC. The selection of the power measuring techniques depends on the type of the signals, some are useful for sinusoidal and others are useful for non–sinusoidal; stationary or non stationary signals.

Wavelet Transform technique is the most useful one for measuring power components of sinusoidal and non – sinusoidal uniform and non – uniform waveforms, due to its high ability of position analysis of waveforms. The Morlet family of the wavelet was adoptive, since it was the more suitable one of Continues Wavelet Transform family for power measurement.

The voltage rms, current rms, apparent power, active power, reactive power and power factor of non–uniform power waveforms were measured , and results were compared with these measured by the AC/DC clamp power meter. The practical result of using wavelet differs from that of using AC/DC clamp power meter because the clamp power meter is not so sensitive for measuring non-stationary signals.

References

Al-Dabagh M.T.M., 2006 “Techniques of precise measurement of electrical power” MSC, Technical College/Mosul, PP. 5,13, 53, 44, 74, 78, 79.

Johan Driesen and Ronnie Belmans, 2002 "Time frequency analysis in power measurement using complex wavelet ", Circuits and Systems, ISCAS 2002. IEEE International Symposium on ISBN: 07803744, Vol.5, PP. V-681-V-684.

Torrence C. and Compo G. P. 1988, “A practical guide to wavelet analysis”, Bulletin of the American Meteorological Society, Vol. 79, No. 1, PP.61-78.

Vatansever F. and Ozdemir A., 2009 “Power parameters calculations based on wavelet packet transform”, Electrical Power and Energy Systems No.31, pp.596–603.

Yoon W.K. & Devancy M.J., 1998 " Power measurement using wavelet transform " The IEEE Trans. Inst. and Meas. Vol. 47, No.5, pp.1205–1210.

Bibliography

Munoz-Galeano N. et al, 2011,” Non-fundamental effective apparent power defined through an instantaneous power approach”, Electrical Power and Energy Systems, 33 (2011), PP. 1711–1720.

Sudipta Nath, Pampa Sinha, and Swapan Kumar Goswami, 2012, “A wavelet based novel method for the detection of harmonic sources in power systems”, Electrical Power and Energy Systems, 40 (2012), PP. 54–61.

Marcelo A.A. Lima et al, 2012, “A novel method for power quality multiple disturbance decomposition based on Independent Component Analysis”, Electrical Power and Energy Systems, 42 (2012), PP. 593–604.

Pereira L.E.S., Da Costa V.M., Rosa A.L.S., 2012,” Interval arithmetic in current injection power flow analysis”, Electrical Power and Energy Systems, 43 (2012), PP. 1106–1113.

Christy J., Jeno Vedamani X. and Karthikeyan S., 2011, “Wavelet Based Detection of Power Quality Disturbance - A Case Study” Proceedings of 2011 International Conference on Signal Processing, Communication, Computing and Networking Technologies (ICSCCN 2011), PP. 157-162.

Kocaman, C. and Ozdemir, M., 2009, ” Comparison of statistical methods and wavelet energy coefficients for determining two common PQ disturbances: Sag and swell”, International Conference on Electrical and Electronics Engineering - ELECO 2009 Provider: IEEE Publisher: IEEE, PP. I-80-I-84.

Ghaemi A.H., Askarian Abyaneh H., Mazlumi K., 2011,” Harmonic indices assessment by Wavelet Transform”, Electrical Power and Energy Systems, 33 (2011), PP. 1399–1409.

Mário Oleskovicz et al, 2009,” Power quality analysis applying a hybrid methodology with wavelet transforms and neural networks”, Electrical Power and Energy Systems, 31 (2009), PP. 206–212.

Zhengyou He, et al,2011,” Study of a new method for power system transients classification based on wavelet entropy and neural network”, Electrical Power and Energy Systems, 33 (2011), PP. 402–410.

Ozgur Gencer, Semra Ozturk and Tarık Erfidan, 2010,” A new approach to voltage sag detection based on wavelet transform”, Electrical Power and Energy Systems, 32 (2010), PP. 133–140.