Proceedings of Engineering & Technology (PET)
pp. 86-93

2nd International Conference on Automation, Control, Engineering and Computer Science (ACECS-2015)
Proceedings of Engineering & Technology (PET)

The choice Between Two Digital Methods for AC Power Measurement

Ayari Ahlem[1], Mechergui Hfaiedh[1], Haddouk Amira[1] and Hlaili Manel[1]

[1]Laboratory & Research groups: C3S, Ecole Nationale Supérieure d'ingénieurs de Tunis, University of Tunis, Tunisia
E-mail: ayariahlem82@gmail.com, Hfaiedh.Mechergui @esstt.rnu.tn, haddoukamira@yahoo.com, hlaili_manel@yahoo.fr

Abstract— **This paper presents two digital methods for the power measurement in a single-phase network.**
The first method describes the designed energy meter based on the Texas Instruments TMS320F28335 DSP. The energy meter using DSP measures basic electric network parameters such as rms values of voltage and current, active, reactive and apparent power, power factor and consumed energy.
The second method is applied for the accurate determination of the active and reactive power of single phase non linear load, the deformation factor, the phase angle and the load parameters using a Virtual Synchronous Detector (VSD). Here we derive analytical expressions for the precision of both estimators as a function of the number of samples acquired and the amount of additive random noise present. We also compare the two methods and we conclude that the second one is better.

Keywords— **AC power measurement; Method using DSP; Method using VSD; The deformation factor; the active and reactive power due to the first harmonic; Energy.**

I. INTRODUCTION

Electric power systems have been troubled by harmonic distortions due to the wide scope of applications of power electronic equipment and the diversity of nonlinear loads. The problems brought about include malfunction of control devices, data loss of computers, interference to telecommunications, extra power dissipation, and it make difficult and complex to measure the fundamental active and reactive power.

This creates a need for an accurate method for the measurement of the power components in the presence of distortion. There are many basic questions that need to be addressed on this subject. The major question is how these power components are properly defined in non-sinusoidal situations [1].

In this paper two solutions for the measurement of active, reactive, apparent power and the consumed energy of a single linear load and non linear load are proposed. Each method offers the accuracy and direct print-out of results.

II. DEVELOPMENT AND HARDWARE IMPLEMENTATION OF ENERGY METER USING DSP

Nowadays many measurement devices use microprocessors to enhance their capabilities and to increase their flexibility. The basic setup is an analog circuit which is responsible for the signal conditioning. It is followed by an analog-to-digital converter (ADC) to convert the quantities of interest to the digital domain, and finally a microprocessor or microcontroller which treats the performed information. The proposed instrument is able to measure all basic net parameters (rms value of voltage and current, active, reactive and apparent power, power factor, and energy delivered into the load). It can calculate the TDH, as well as graphical representation of the spectral analysis.

Block diagram of the system developed using the hardware implemented of energy meter using DSP is in Figure.1. Analogue part contains circuits for sensing and conditioning of the net voltages and currents. A block of A/D converters digitises the signals from the analogue part. The DSP part with the Texas Instruments TMS320F28335 processor makes necessary calculations and signal processing in digital form.

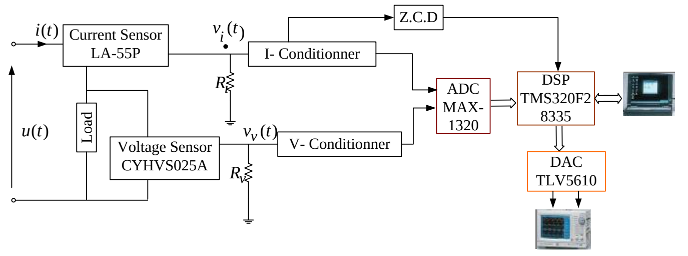


Figure 1. Synoptic diagram of the measurement of the power and energy using a DSP

To increase the accuracy of the energy meter a few precautions must be done. First of all the start of sampling must be synchronized with the input signal. Better accuracy can be achieved if the sampling starts in the instant of crossing the rms value of the sampled signal.

One used two sensors with Hall Effect; the sensor of the current is of type the 55-P to measure the current loads and a voltage sensor is of type CYHVS02A to measure the

ISSN: 2356-5608

terminal voltage of the network. Indeed, the signal on the outlet side of a sensor is generally weak, it is thus necessary to amplify it and condition it at the same time via two conditioners. A numerical analogical converter (ADC MAX-1320) acquires the two signals. The data are sent to a PC via a DSP of the type TMS320F28335. One calculates the true effective value of the voltage and the current by using the following formulas:

$$I_{RMS} = \sqrt{\frac{1}{N}\sum_{m=1}^{N} i(m)^2} \quad \text{and} \quad U_{RMS} = \sqrt{\frac{1}{N}\sum_{m=1}^{N} u(m)^2}$$

The power is calculated as follow:

$$P_n = \sqrt{\frac{1}{N}\sum_{m=1}^{N} u(m).i(m)} \qquad (1)$$

m: is the sample of the current or the voltage in real time ($1 \le m \le 400$).

N: is the number of the samples to be acquired during one period of time ($N = 400$).

Figure. 2 shows the experimental section to measure the active power and energy by using DSP and the results displayed on PC.

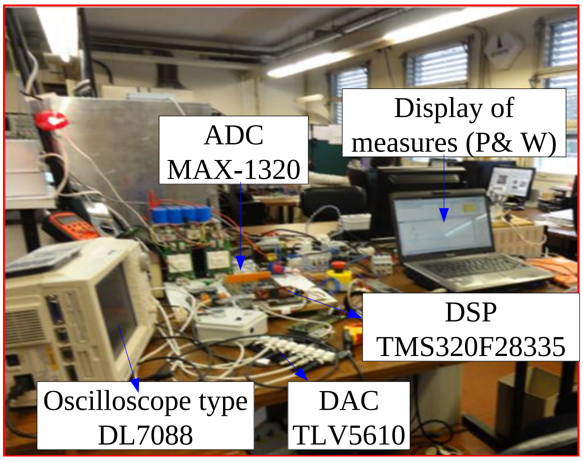


Figure 2. Experimental material to calculate the active power and energy by using a DSP for a linear load and a nonlinear load

Figure 3 shows a flowchart of the proposed measurement procedure using DSP.

III. DEVELOPMENT OF THE SYNCHRONOUS DETECTION METHOD FOR MEASUREMENT OF ACTIVE AND REACTIVE POWER

In general, the synchronous detection method is used when we need to extract a useful signal buried in noise [2]. This method is applied mainly for signals with very low amplitude. The principle of the synchronous detection can be effectively exploited in the field of instrumentation for performing measurement converters [3, 4].

If the signal $x(t)$ obeys to the following conditions:

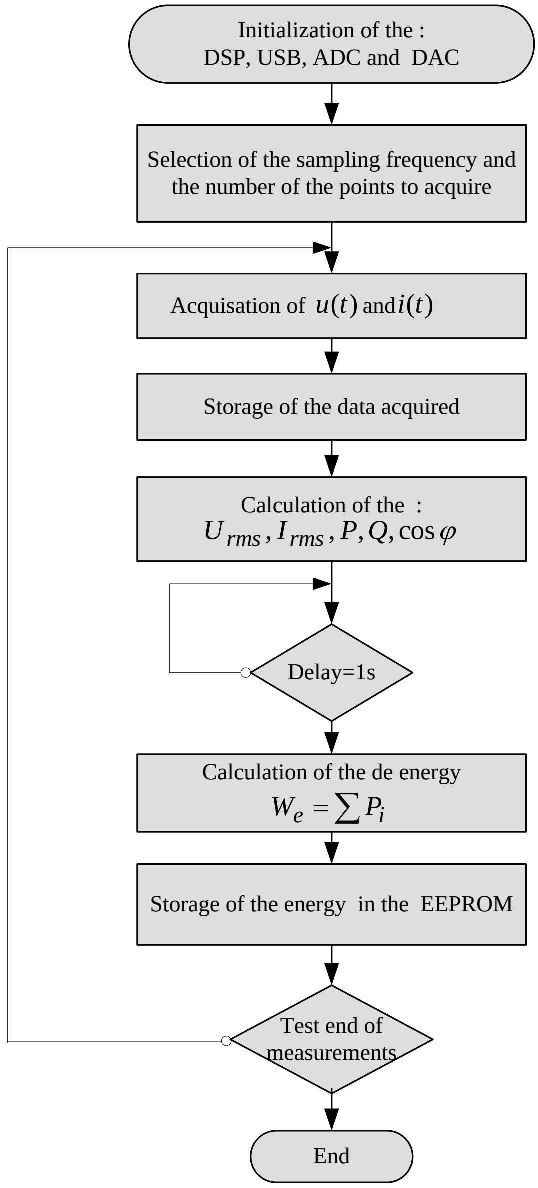


Figure 3. The flow chart of the proposed measurement procudure using DSP.

$x(t) = x(t+T)$ (periodic signal) and $x(t) = -x(t+T/2)$ (Anti-symmetric signal) then $x(t)$ can be written as:

$$x(t) = \frac{dX(t)}{dt} \qquad (2)$$

Where $X(t)$ is the primitive of $x(t)$. Then the conversion function of the synchronous detector can be written as

$$Y(t_i) = \frac{1}{T}\int_{t_i}^{t_i+\frac{T}{2}} x(t)dt = \frac{2}{T}X(t_i) = 2.f.X(t_i) \qquad (3)$$

With:

t_i: The initial time synchronized to the reference signal.

$X(t_i)$: Value of the $x(t)$ primitive and f is the frequency of periodic signal ($x(t) = X_m.\sin(\omega t + \varphi)$).

The block diagram of the synchronous detector is shown in figure 4.

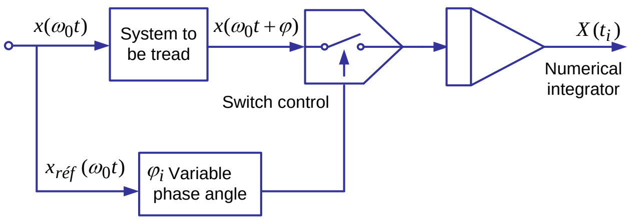


Figure 4. Block diagram of the instrumental synchronous detector

It includes:

- A source providing a sinusoidal reference signal
- A variable phase shifter for selecting the time control t_i or a phase angle φ_i .
- A control logic multiplier
- A digital integrator

According to figure 3, we note that by varying the phase φ_i , we can identify the useful information of a deterministic signal. Moreover, using the equation (3), we can extract the active and the reactive component denoted Y_a and Y_r of the useful signal:

$$Y_a = \frac{1}{T}\int_0^{\frac{T}{2}} x(t)dt = \frac{X_m}{\pi}\cos\varphi \quad (4)$$

$$Y_r = \frac{1}{T}\int_{\frac{T}{4}}^{\frac{3T}{4}} x(t)dt = \frac{X_m}{\pi}\sin\varphi \quad (5)$$

The synchronous detector is used to determine the active and reactive power of a non linear load. So for a non linear load, the voltage network is [2]:

$$u_L(t) = U_m \sin(\omega t) \quad (6)$$

And the current across the load is not linear:

$$i_L(t) = I_{1m}\sin(\omega t + \varphi_1) + \sum_{k=1}^{\infty} I_{(2k+1)m}\sin((2k+1)\omega t + \varphi_{2k+1}) \quad (7)$$

$k = 1,2,....,\infty$

Therefore the total power consumed by the load is:

$$p_L(t) = u_L(t) \times i_L(t)$$

$$p_L(t) = U_m \sin(\omega t) \times \left[I_{1m}\sin(\omega t + \varphi_1) + \sum_{k=1}^{\infty} I_{(2k+1)m}\sin((2k+1)\omega t + \varphi_{2k+1})\right]$$

$$p_L(t) = U_m I_{1m}\sin^2(\omega t)\cos\varphi_1 + U_m I_{1m}\sin(\omega t)\cos(\omega t)\sin\varphi_1 + U_m\sin(\omega t)\times\sum_{k=1}^{\infty} I_{(2k+1)m}\sin((2k+1)\omega t + \varphi_{2k+1}) \quad (8)$$

According to the expression (8) we obtain the instantaneous active and the reactive power due to the current of the first harmonic:

$$p_{ac}(t) = U_m I_{1m}\sin^2(\omega t)\cos\varphi_1 \quad (9)$$

$$q_{ac}(t) = U_m I_{1m}\sin(\omega t)\cos(\omega t)\sin\varphi_1 \quad (10)$$

So the power due to the harmonics is:

$$p_{har} = \sum_{k=1}^{\infty} I_{(2k+1)m}\sin((2k+1)\omega t + \varphi_{2k+1}) \times U_m\sin(\omega t) \quad (11)$$

When the harmonics of the current and the voltage are not isochrones, the power is null. To extract the active and reactive component we make recourse to the expression (3).

If the interval integration is: $t_i \in \left[\frac{T}{12}, \frac{5T}{12}\right]$, we can determine the active component of the first harmonic I_{1a} :

$$I_{1a} = \frac{1}{T}\int_{t_i}^{t_i+T/3} i_L(t)dt = \frac{I_{1m}\sqrt{3}}{2\pi}\cos\varphi_1 = \frac{I_{1am}\sqrt{3}}{2\pi} \quad (12)$$

If the integration interval is: $t_i \in \left[\frac{T}{3}, \frac{2T}{3}\right]$, we can determine the reactive component I_{1r} :

$$I_{1r} = \frac{1}{T}\int_{t_i}^{t_i+T/3} i_L(t)dt = \frac{I_{1m}\sqrt{3}}{2\pi}\sin\varphi_1 = \frac{I_{1rm}\sqrt{3}}{2\pi} \quad (13)$$

Using expression (12) and expression (13), one determines the amplitude of the first harmonic,

$$I_{1m} = \sqrt{I_{1am}^2 + I_{1rm}^2} \quad (14)$$

Moreover, the active and the reactive power, for the first harmonic, are given as:

$P_1 = U_{rms}.\frac{I_{1am}}{\sqrt{2}}$ and $Q_1 = U_{rms}.\frac{I_{1rm}}{\sqrt{2}}$.

This study allows us to built a synchronous filter with a sensibility of $\frac{\sqrt{3}}{2\pi}$. One determines also the active, the reactive, the apparent power ($S_t = U_{rms}I_{rms}$) and the deformation factor $D = \frac{P_1}{S_t}$.

$$\text{With : } I_{rms} = \sqrt{\sum_{i=1}^{\infty}\frac{I_{1m}^2 + I_{2m}^2 + ...}{2}} \quad (15)$$

Once the acquisitions samples of $u_L(t)$ and $i_L(t)$ are taken, one calculates U_{rms} and I_{rms} which they need to be multiplied together and added to yield real power over the stated interval of time. The power P_n is calculated, with a numerical integration method [3, 5], as:

$$P_n = \frac{\sum_{j=1}^{N} u_L(jTe) \times i_L(jTe)}{N} \quad (16)$$

With N: the number of samples.

The voltage network and the current load are applied to two Hall-effect sensors to provide respectively a voltage adapted to the network or a voltage adapted to the current load. These two last are applied to a PC via a PCI-6024E as illustrated in figure.5.

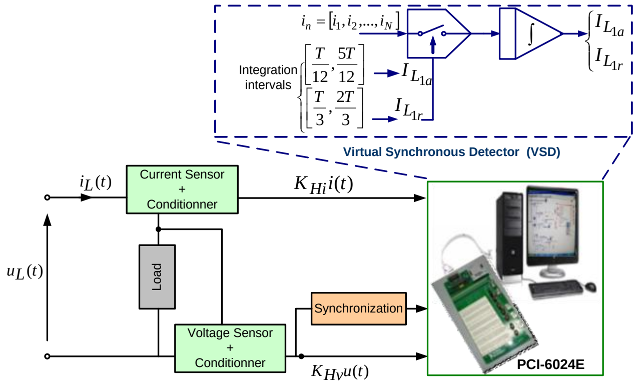


Figure 5. Block diagram of a power measuring instrument

One exploits the LabVIEW software to build an instrumental platform which works as a virtual synchronous detector. A digital processing algorithm performing a VSD with LabVIEW, manages: the measurement sequences, the calculation of U_{rms}, I_{rms}, I_{1a}, I_{1r}, the determination of different measurement parameters of the load and displays P_1, Q_1, S_t, φ_1, D and the consumed energy of a single phase non linear load.

The Instrumental platform using a synchronous detector performed via LabVIEW, for the measurement of Active, reactive Power and energy is given in figure.6.

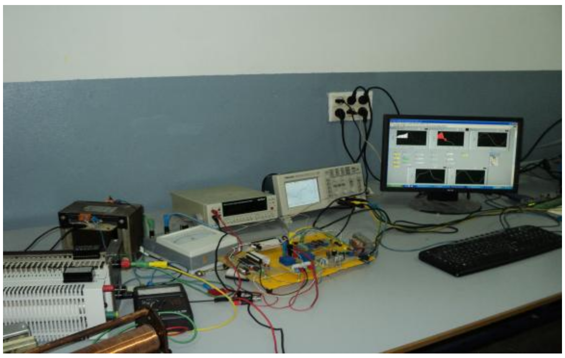


Figure 6. Instrumental platform using a synchronous detector, performed via LabVIEW, for the measurement of Active, reactive Power and energy.

The operation sequences are illustrated by the following chart of figure 7.

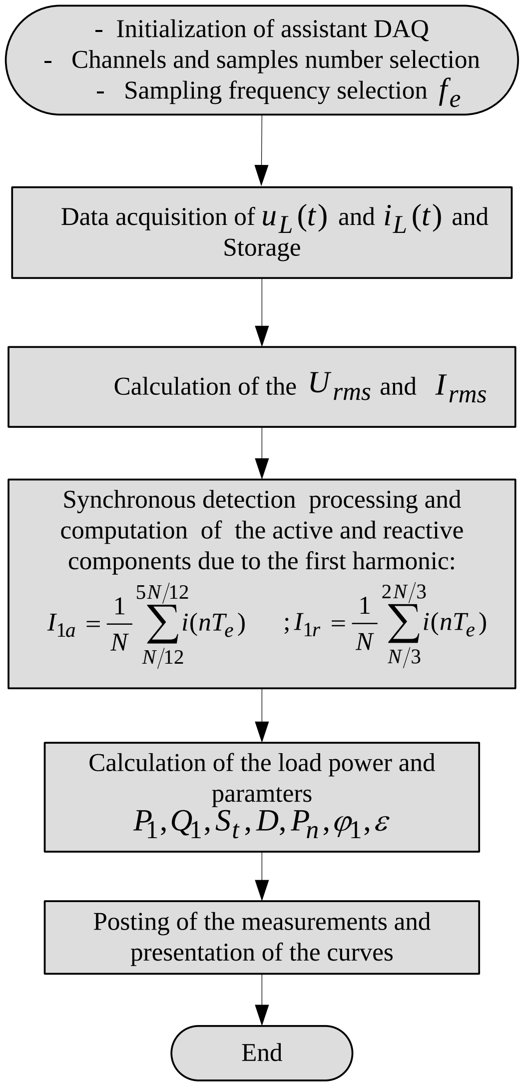


Figure 7. Flow chart illustrating the system operation principle using VSD

IV. EXPERIMENTAL RESULTS

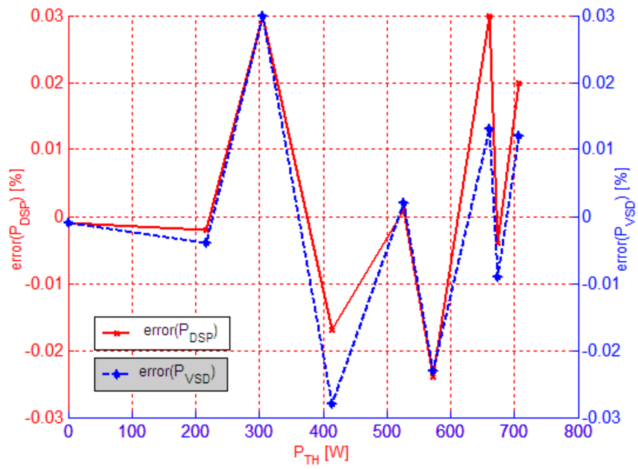
A. *Power Measurement*

In this experimental work, the power measurement is made both with the method using the DSP and with the method using virtual synchronous detector (VSD); the results are given comparatively. All measurements are made under sinusoidal conditions loads. The experimental results of the active and reactive power are given in table.1 for a linear load.

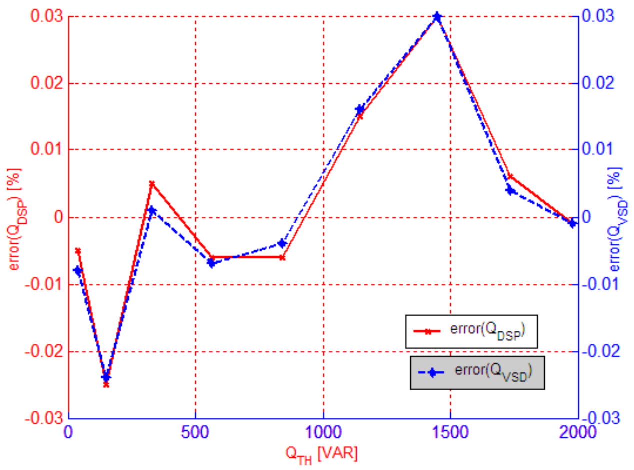
TABLE I. MEASUREMENT RESULTS OF POWER PARAMETERS OF LINEAR LOAD

Phase angle	Values	P $[W]$	Q $[VAR]$	ε_P [%]	ε_Q [%]
10°	Theoretical values	216.657	38.202		
	Method using DSP	216.720	38.321	-0.002	-0.005
	Method using VSD	216.752	38.382	-0.004	-0.008
20°	Theoretical values	413.464	150.488		
	Method using DSP	413.851	151.038	-0.017	-0.025
	Method using VSD	414.080	151.020	-0.028	-0.024
30°	Theoretical values	571.576	330.000		
	Method using DSP	572.070	329.890	-0.024	0.005
	Method using VSD	572.100	330.200	-0.023	0.001
40°	Theoretical values	674.119	565.653		
	Method using DSP	674.213	565.783	-0.004	-0.006
	Method using VSD	674.323	565.812	-0.009	-0.007
50°	Theoretical values	707.066	842.648		
	Method using DSP	706.626	842.800	0.02	-0.006
	Method using VSD	706.729	842.754	0.012	-0.004
60°	Theoretical values	660.000	1143.153		
	Method using DSP	659.200	1142.827	0.030	0.015
	Method using VSD	659.712	1142.786	0.013	0.016
70°	Theoretical values	526.711	1447.126		
	Method using DSP	526.678	1447.466	0.001	0.03
	Method using VSD	526.708	1447.465	0.002	0.03
80°	Theoretical values	305.620	1733.261		
	Method using DSP	304.929	1733.126	0.03	0.005
	Method using VSD	304.925	1733.172	0.03	0.004
90°	Theoretical values	0.000	1980.000		
	Method using DSP	0.034	1980.021	-0.001	-0.001
	Method using VSD	0.024	1980.022	-0.001	-0.001

So the linearity errors between two methods are given in figure 8.a and figure 8.b.



(a)



(b)

Figure 8. The linearity error for linear load.

We notice that this error is less than 0.03%.

In the second part of experiments, we take the case of a non-linear load, measuring the effective values of voltage and current, the phase angle; and power due to the first harmonic, the total power and the deformation factor. The results are given in Table 2.

TABLE II. MEASUREMENT RESULTS OF POWER PARAMETERS OF NONLINEAR LOAD

Method using VSD		
U_m [V]	I_m [A]	φ [°]
233.5	0.657	33.471
233.3	0.893	61.213
233.4	1.132	70.147
233.6	1.380	74.343
233.5	1.621	77.757
P_1 [W]	P_n [W]	D
92.692	92.693	0.604
146.69	146.68	0.703
193.95	193.96	0.734
239.56	239.55	0.743
282.87	282.87	0.747

B. *Analysis of the Measurement Errors*

To evaluate the standard deviation of the estimated active power using the method using a virtual synchronous detector and method using DSP, so each input channel of the DAQ, there is a voltage signal that is proportional to the signal of the voltage and current.

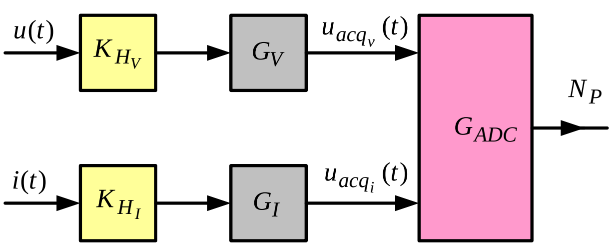


Figure 9. Schematic diagram of error estimation.

$$u_{acq_v}(t) = V_M k_{H_V} G_V \cos(\omega t + \varphi_V) + n_{cond_v}(t) + n_{acq_v}(t)$$
$$u_{acq_i}(t) = I_M R_{mi}.k_{H_I} G_I \cos(\omega t + \varphi_I) + n_{cond_i}(t) + n_{acq_i}(t) \quad (17)$$

Where:

k_{H_V} : Voltage sensor constant.

k_{H_I} : Current sensor constant.

G_V : Gain of the conditioning circuit used to adapt the voltage of the sensor signal.

G_I : Gain of the conditioning circuit used to adapt the current sensor signal.

We set: $k_I = R_{mi}.k_{H_I}$

The instantaneous product $u_{acq_v}(t)$ and $u_{acq_i}(t)$ is:

$$\begin{aligned} u_{acq_v}(t) \times u_{acq_i}(t) &= \frac{1}{2} V_M I_M k_{H_V} k_I G_V G_I \cos(\varphi_V - \varphi_I) + \\ &\frac{1}{2} V_M I_M k_{H_V} k_I G_V G_I \cos(2\omega t + \varphi_V + \varphi_I) + n_{cond_v}(t) \times n_{cond_i}(t) + \\ &V_M k_{H_V} G_V \cos(\omega t + \varphi_V) \times n_{acq_i}(t) + V_M k_{H_V} G_V \cos(\omega t + \varphi_V) \times n_{cond_i}(t) + \\ &I_M k_I G_I \cos(\omega t + \varphi_I) \times n_{acq_v}(t) + n_{acq_v}(t) \times n_{acq_i}(t) + n_{acq_v}(t) \times n_{cond_i}(t) + \\ &I_M k_I G_I \cos(\omega t + \varphi_I) \times n_{cond_v}(t) + n_{cond_v}(t) \times n_{acq_i}(t) \end{aligned} \quad (18)$$

Taking the average value of this product, the estimated active power is divided the equation (18) by the term $k_{H_V} k_I G_V G_I$, which gives:

$$P_t = \frac{1}{k_{H_V} k_I G_V G_I} \frac{1}{2} V_M I_M k_{H_V} k_I G_V G_I \cos(\varphi_V - \varphi_I) \quad (19)$$

We set : $\beta_V = k_{H_V} G_I V_M$, $\beta_I = k_I G_I I_M$, $K_V = k_{H_V} G_V$ and $K_I = k_I G_I$

The equation (19) becomes:

$$P_t = \frac{1}{2} \frac{\beta_V}{K_V} \frac{\beta_I}{K_I} \cos(\varphi_V - \varphi_I) \quad (20)$$

The standard deviation of the estimated active power is simply the square root of the variance:

$$\sigma_{P_t} = \sqrt{V\{P_t\}} \quad (21)$$

With: $V\{P_t\} = E\{P_t^2\} - E^2\{P_t\}$

We calculate $E\{P_t^2\}$:

$$E\{P_t^2\} = E\left\{\left[\frac{1}{2} \frac{\beta_V}{K_V} \frac{\beta_I}{K_I} \cos(\varphi_V - \varphi_I)\right]^2\right\}$$

$$E\{P_t^2\} = E\left\{\begin{array}{l} \frac{1}{4} \frac{\beta_V^2}{K_V^2} \frac{\beta_I^2}{K_I^2} \cos^2\varphi_V \cos^2\varphi_I + \\ \frac{1}{4} \frac{\beta_V^2}{K_V^2} \frac{\beta_I^2}{K_I^2} \sin^2\varphi_V \sin^2\varphi_I + \\ \frac{1}{2} \frac{\beta_V^2}{K_V^2} \frac{\beta_I^2}{K_I^2} \cos\varphi_V \cos\varphi_I \sin\varphi_V \sin\varphi_I \end{array}\right\}$$

Using the calculated value of properties, we obtain [6]:

$$E\{P_t^2\} = \left\{\begin{array}{l} \frac{1}{4K_V^2 K_I^2} E\{\beta_V^2 \cos^2\varphi_V\} \times E\{\beta_I^2 \cos^2\varphi_I\} + \\ \frac{1}{4K_V^2 K_I^2} E\{\beta_V^2 \sin^2\varphi_V\} \times E\{\beta_I^2 \sin^2\varphi_I\} + \\ \frac{1}{2K_V^2 K_I^2} E\{\beta_V^2 \cos\varphi_V \sin\varphi_V\} \times E\{\beta_I^2 \cos\varphi_I \sin\varphi_I\} \end{array}\right\}$$

$$E\left\{P_t^2\right\}=\left\{\begin{array}{l}\frac{1}{4K_V^2K_I^2}\left[\beta_V^2\cos^2\varphi_V+\frac{4}{N}\sigma_V^2\right]\times\left[\beta_I^2\cos^2\varphi_I+\frac{4}{N}\sigma_I^2\right]\\+\frac{1}{4K_V^2K_I^2}\left[\beta_V^2\sin^2\varphi_V+\frac{4}{N}\sigma_V^2\right]\times\left[\beta_I^2\sin^2\varphi_I+\frac{4}{N}\sigma_I^2\right]\\+\frac{1}{2K_V^2K_I^2}\left[\beta_V^2\cos\varphi_V\sin\varphi_V\right]\times\left[\beta_I^2\cos\varphi_I\sin\varphi_I\right]\end{array}\right\} \quad (22)$$

Substituting equation (22) in (21), we obtain:

$$\sigma_{P_t}^2=\frac{1}{4K_V^2K_I^2}\left(\begin{array}{l}\beta_V^2\beta_I^2\cos^2\varphi_V\cos^2\varphi_I+\frac{4}{N}\beta_V^2\cos^2\varphi_V\sigma_I^2+\\\frac{4}{N}\beta_I^2\cos^2\varphi_I\sigma_V^2+\beta_V^2\beta_I^2\sin^2\varphi_V\sin^2\varphi_I+\\\frac{4}{N}\beta_V^2\sin^2\varphi_V\sigma_I^2+\frac{4}{N}\beta_I^2\sin^2\varphi_I\sigma_V^2+\\2\beta_V^2\beta_I^2\cos\varphi_V\sin\varphi_V\cos\varphi_I\sin\varphi_I+\frac{32}{N^2}\sigma_I^2\sigma_V^2\end{array}\right)$$

$$-\frac{1}{4K_V^2K_I^2}\left(\begin{array}{l}\beta_V^2\beta_I^2\cos^2\varphi_V\cos^2\varphi_I+\\\beta_V^2\beta_I^2\sin^2\varphi_V\sin^2\varphi_I+\\2\beta_V^2\beta_I^2\cos\varphi_V\sin\varphi_V\cos\varphi_I\sin\varphi_I\end{array}\right) \quad (23)$$

After simplification, equation (23) is:

$$\sigma_{P_t}^2=\frac{1}{N}\left(V_M^2\left(\frac{\sigma_I}{K_I}\right)^2+I_M^2\left(\frac{\sigma_V}{K_V}\right)^2+\frac{8}{N}\left(\frac{\sigma_I}{K_I}\right)^2\left(\frac{\sigma_V}{K_V}\right)^2\right) \quad (24)$$

Finally, the standard deviation of the estimated power is:

$$\sigma_{P_t}=\frac{1}{\sqrt{N}}\sqrt{V_M^2\left(\frac{\sigma_I}{K_I}\right)^2+I_M^2\left(\frac{\sigma_V}{K_V}\right)^2+\frac{8}{N}\left(\frac{\sigma_I}{K_I}\right)^2\left(\frac{\sigma_V}{K_V}\right)^2} \quad (25)$$

Each channel in the DAQ acquires samples ($N=400$) after all computing the standard deviation of the estimated active power is:

$$\sigma_{P_t}=\frac{1}{\sqrt{N}}\sqrt{V_M^2\left(\frac{\sigma_I}{K_I}\right)^2+I_M^2\left(\frac{\sigma_V}{K_V}\right)^2}=0.03\ [\text{W}] \quad (26)$$

If the power range is $P_t=2200$[W] than the relative error

$\varepsilon_{P_t}=\frac{\sigma_{P_t}}{P_t}$ is less than $1.4.10^{-3}$ [%]

We analysed, from the point of view of measurement uncertainty, two solutions for AC power measurement: a method using DSP and the other using VSD. We considered two sources of uncertainty, namely, the noise introduced by the current sensor and voltage sensor. Taking that into account we derived analytical expressions for the standard deviation of the active power estimation using both methods.

V. Conclusion

The paper proposes two digital methods for measurement of the electrical power of single phase in sinusoidal and non-sinusoidal regime.

The method using DSP measures the active, reactive apparent power, power factor and energy consumed. But the method using VSD measures all basic parameters in linear and non linear load (the total active, reactive and apparent power, the active and reactive power due to the first harmonic, the deformation factor and energy delivered consumed by the load).

Comparing the two measurement solutions, we can conclude that both have a common advantage is to measure the energy consumed by a single phase linear and non linear load and to control the power factor in order to reduce the effect of the load in the residence.

The more advantage in the second method using VSD is firstly the calculating the deformation factor which informs us of the degree of nonlinearity of the load and then we can control it. On the other hand, the identification of the deformation factor helps us to act to reduce power losses and consequently improve the power factor.

References

[1] Ozdemir and A. Ferikoglu : « Low cost mixed-signal microcontroller based power measurement technique », IEE Proc.-Sci. Meas. Technol., Vol. 151, No. 4, July 2004.

[2] Ayari Ahlem, Amira Haddouk and Hfaiedh Mechergui: «REACTIVE POWER MEASUREMENT USING A VIRTUAL SYNCHRONOUS DETECTOR», Electronics World, Issue 1939, Volume 120, ISSN: 1365-4675, July 2014.

[3] A.Haddouk, H. Mechergui, A. Ayari. Instrumental platform controlled by Labview for the power measurement and electric circuit characterisation. (reference: 1569385619). Eighth International Multi-Conference on Systems. Signals & Devices March 22-25. (2011). SSD'2011 - Sousse. Tunisia 978-1-4577-0411-6/11/$26.00 ©(2011) IEEE.

[4] Antonio Cataliotti,, Valentina Cosentino, Dario Di Cara, A PC-Based Wattmetter for Accurate Measurements in Sinusoidal and Distrorted Conditions: Setup and Experiment Characterisation, IEEE Transactions on instrumentation and measurement, vol.61, No.5 May (2012).

[5] A. Ayari, H. Mechergui, A.Haddouk, "ACTIVE POWER MEASUREMENT COMPARISON BETWEEN ANALOG AND DIGITAL METHODS" International Conference on Electrical Engineering and Software Applications (ICEESA) Hammamet - Tunisia, 21 – 23 March 2013, ISBN : 978-1-4673-6302-0, doi : 10.1109/ICEESA.2013.6578416 (2013) IEEE.

[6] F. Corrêa Alegria, « Bias of amplitude estimation using three-parameter sine fitting in the presence of additive noise », Measurement, vol. 42, 2009, pp. 748–756.