REACTIVE POWER DIFFICULTIES MEASUREMENT UNDER NON SINUSOIDAL CONDITIONS

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Abstract: *In a liberalized market context, measures performed on an electric systems becomes crucial in terms of energy invoicing, and for the provision quality assessment in electric energy for a given network zone. Among different nuisances, the harmonic distortion has the most considerable weight, because of the non linear loads proliferation, which leads non sinusoidal currents and voltages. Among the different problems provoqued by harmonic distortion, there is two important aspects and bounds to which ultimately one must cope with: the measure instrumentation synchronization and the reactive energy numbering with the electronic meters. With regard to the sizes measure defined by the IEEE norm, a virtual tool has been imagined, while using a technique in the domain time for the voltage and current fundamental extraction, on the basis of these works we led a survey on reactive energy electronic counters behaviour in harmonic distortion presence. The first results underline, that in sinusoidal regime the different methods with which are driven the reactive energy measure lead to the same result, while for the diet disrupted the electronic counters bring to a different answer.*

Keywords: *reactive power, harmonics, phase locked loop, energy measure*

I. Introduction

In the liberalized market context, the measures done on the electric systems not only, assume a crucial role for the invoicing of the energy but also provide quality assessment in electric energy in a given network zone to ends of evaluation as well as for identification between consumers and distributors, for the involvement to the nuisances and pollution creation.

Among the nuisances, harmonic distortion is of paramount importance, because of the non linear loads proliferation, which leads the non sinusoidal currents and voltages. Among the different problems led by the harmonic distortion, there are two important aspects and bound to which intimately one must cope: the measure instrumentation synchronization and the reactive energy numbering with the electronic meters.

Concerning the first aspect, the CEI norm EN 61000-4-30 [1] imposes itself, currently as the main reference as a quality measure because it describes the general specifications, the measure methods and the precision degrees of the instrumentation as for the voltage characteristics determination. For the harmonic and inter harmonic measures, one refers to the CEI norm EN 61000-4-7 [2] which defines the parameters to measure for the harmonic distortion level assessment in a measure data zone, through the harmonic voltages and currents amplitude, as well as global parameters as the harmonic distortion rate (THD), calculated in relation to the totality of the harmonic; or while selecting the groups and the harmonic subgroups.

For the instrumentation class 1, the norm imposes to perform signal measures in permanent regime through Discreet Fourier Transformed (DFT). With regard to the sampling, we adjust the observation window to 200 ms (10 cycles of the fundamental to 50 Hz) and impose the synchronization, with a maximal error of ± 0, 03%, in a frequency interval ± 5% around the nominal system frequency.

However the norm given in [2] doesn't provide any specific indications on the techniques to use for the synchronization and the tests to be done for the synchronization error assessment, especially with regard to the permanent or transient disruptions possible presence in the measure instrument entry signal. In this configuration we developed an innovative synchronization system that behaves correctly in the presence of disturbances either permanent or transient. The characterization has been developed on the tests appropriate basis conditions.

The other difficulty to which we are confronted concerns the behaviour of the reactive energy electronic counters in harmonic distortion presence. This counter type replacing now the traditional counters, provide better stability and a bigger precision, they allow a perfect integration with the active energy counters and concerning the electric sizes measure permit to plan for the future tele-reading and multiple pricing.

As definite by the norms, the reactive electronic energy counters able to be conceived and made in several different manners are planned for sinusoidal regime applications, where reactive power and power factor are defined in a univocal manner. In practice, on the other hand, they operate in harmonic presence, because of the non linear loads proliferation.

It is why, their performances assessment in the unsettled regimes is of fundamental importance; nevertheless, the trial protocol foreseen by the norms in force CEI EN 62053-23 and 62052-11 [3-4] don't hold on no account of the harmonic presence. It results some that in harmonic presence, the meters performances could prove to be appreciably different in relation to those valued in sinusoidal. Besides, the quoted norms only make reference to the static meters class 2 and 3; whereas for that class lower the norm is again at the project state.
According to the standards [1-2], all the solutions for the measurement of the reactive energy are developed for the sinusoidal state condition; thus they work correctly for the fundamental frequency. On the other hand, they can lead to different results in the same working condition when harmonic components are present [5, 6].

The deficiencies found at a normative level are due to a lack of consensus at the academic level concerning the reactive energy in the presence of harmonics. Therefore the only norm that impose itself when confronted to a wide academic debate remains the IEEE 1459-2000 norm, which doesn't provide a specific reactive power definition in deformed regime [7].

In fact, it introduces a set of definitions of non active powers, destined to quantify the harmonic distortion and/or the unbalance severity in a measure data zone .The approach made by the norm is essentially founded on the fundamental components separation in relation to the voltages and currents others composing. This approach permits to measure the contractual quantities traditionally used (fundamental active, reactive and obvious power as well as the power factor that return itself of it) in order to highlights the sizes able to estimate the harmonic distortion and the unbalance order in a measure zone.
With regard to the sizes measure defined by the IEEE norm, a virtual tool has been imagined, while using a technique in the domain time for the voltage and current fundamental extraction [8], on the basis of these works we led a survey the reactive energy electronic counters behaviour in harmonic distortion presence.
The first results underline, that in sinusoidal regime the different methods with which are driven the reactive energy measure lead to the same result, while for the diet disrupted the electronic counters bring to a different answer. At the opposite, the induction counters, as even in harmonic distortion presence, practically measure the reactive energy associated to the fundamental.
If we consider that the invoicing of the energy is bound intimately worthy of the reactive energy, we understand that the adoption of different meters by their construction can imply, in the unsettled regime, a consumer's penalty difference, to load conditions equality.

II. A System for the Power Quality Instrumentation Measure Synchronization in Permanent and Transient Disturbs Presence

The synchronization used solutions may be classified in the zero-crossing techniques, Phase Locked analogical or numeric Loops (PLL) and the systems based on the spectral analysis, generally through the Fourier Fast Transformed (FFT). The answer speed PLL technical allows their application until including at the transient disturbs, in the variations frequency, phase and amplitude.
More precisely, at the advent time transient disturb in the observation window, the synchronizer must be able to signal its presence. It may heppened, as we will show it thereafter, that the synchronization error is maintained between certain limits even though the signal is affected by transient disturbance.
The PLL proposed permits to do the entry signal fundamental frequency measure synchronization as well as in the presence of permanent or transient disturbances, with the coordinate's transformation in the time domain and a new strategy phase error assessment. In addition, a new parameter is proposed to detect the transient disturb presence in order to avoid analyzing with the DFT the non steady signal portion.

III. Synchronization Technique

The software PLL developed is founded on a technique described in [8, 9], from the Park and Clarke coordinates transformations.
The sampled entry signal $v(n)$ will be a quarter period deemphasize by means of Hilbert transformed, so that we gets a two-phase system (v_α, v_β); we will make the transformation therefore [Tpq] on a coordinates system turning to the speed corresponding to the fundamental frequency f_0, generated by a software oscillator.
The quadratic signal in $v'(n)$ is given by:

$$v'(n) = \frac{v(n-1) - v(n)\cos\Omega_0}{\sin\Omega_0} \quad (1)$$

Having $\Omega_0 = 2\pi f_0/f_s$, the software generating oscillation frequency used for the rotating system realization (f_s is the sampling frequency).
The transformation in polar coordinates is the following:

$$v_p = \begin{bmatrix} s_\alpha s_\beta \end{bmatrix} \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} T_{pq} \end{bmatrix} \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} \qquad (2)$$

with $s_\alpha = sin2\pi f_0 t$ et $s_\beta = -cos2\pi f_0 t$

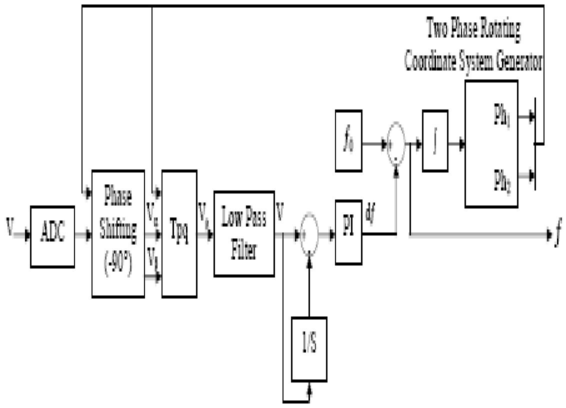


Figure 1: PLL Diagram block

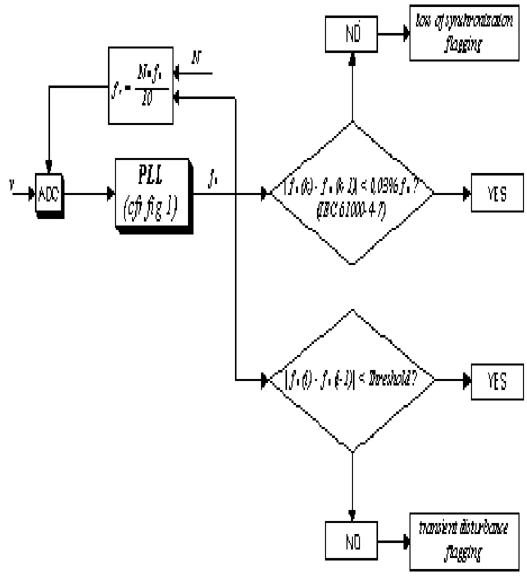
A low pass-filter extracts the corresponding *vp* entry signal fundamental component, which constitutes the feedback signal for the signal entry regulating frequency f_0: in fact, if the rotating system is perfectly synchronized to the fundamental frequency, the filtered signal is continuous; on the other hand if this signal is not then continuous it would mean that the generated rotating system frequency doesn't coincide with the entry signal fundamental frequency.

Consequently, while affecting initially to the generated signal oscillator the nominal frequency, if the filter exit signal is not continuous, this will be corrected and controlled to f_0 (fig 1).

In agreement with [2], the synchronizer determines the sampling frequency f_s, according to the frequency f_0 and the number of points sampled N:

$$f_s = \frac{N.f_0}{10} \qquad (3)$$

The values of f_0 gotten on 200ms will be compared to those gotten to the previous cycle and will be modified, if the synchronization error doesn't match with the allowed limits.
Finally, since the PLL puts up to date the frequency f_0 at every sampling step, the transient disturb existence will be raised by the comparison between two successive sampling steps: $f_0(i) - f_0(i-1)$
We can see on figure 2 the synchronizer functional diagram



[$f_0(k)$: frequency values on 200ms ;
$f_0(i)$: frequency values at sampling pass]

Figure 2: Synchronizer functional diagram

IV. Implementation and Characterization

The PLL software was implemented on the control card DS1103 dSPACE IBM microprocessor PC 604th, programmed with MATLAB SIMULINK. Voltage has been acquired through an effect Hall probe (width of strip 100kHz DC, precision ± 0,8%) and a converter A/D to 14 bits. The experiences have been done using a Fluke calibre 6100A Electrical Power Standard (precision in frequency 50 ppm, resolution 0,1 Hz); to introduce variations of frequency, phase and size on the signal produces, the calibre has been controlled in remote fashion, USB GPIB, by a special signals generator, programmed on a PC with LabVIEW 6.1. The synchronizer has been compared with a material PLL CMOS 4046 [9].
The tests conditions have been chosen according to the three tests states of class *A* as recommended by the IEC 61000-4-30 norm [1], introducing in the entry signal the flicker, amplitude disturbance, harmonic and inter harmonic; especially for the trial condition 1. Whereas the norm doesn't specify harmonic or inter harmonic order and amplitude, in particular, we kept those that are the nearest to the fundamental because they prove to be the most harmful on the synchronizer outputs (2nd and 3rd harmonic and the inter harmonic to 1.1 f_0).
According to the norms [1] and [2] we verified that the synchronization error is well kept in the limits (± 0.03% f_0, i.e. ± 15mHz for f_0=50Hz) in disturb

presence foreseen by the test states; contrarily of the forecasts of [1] we took into account the transduction.
The tests have been done for five frequency values distributed in an uniform and linear manner over the interval (47.5-52.5 Hz, $\pm$5% f_0) [2].
On the tests set done, the proposed PLL displayed a synchronization error lower to the maximal limit foreseen by the norm [2] (limit equal to $\pm$14mHz in the worse of the cases corresponds to $\pm$ 0.03% of 47.5Hz); whereas on the contrary the PLL 4046 displayed a synchronization error superior to the limits know-indicated, in harmonic and inter harmonic presence (to see figure 3).
With regard to the tests done in presence of transient disturbance, we took in consideration frequency variations in steps and in rails, in addition to the voltage entry phase and amplitude variations. The tests have been done with and without harmonic and inter harmonic, in conformity to the conditions of quoted tests in the norm [1].

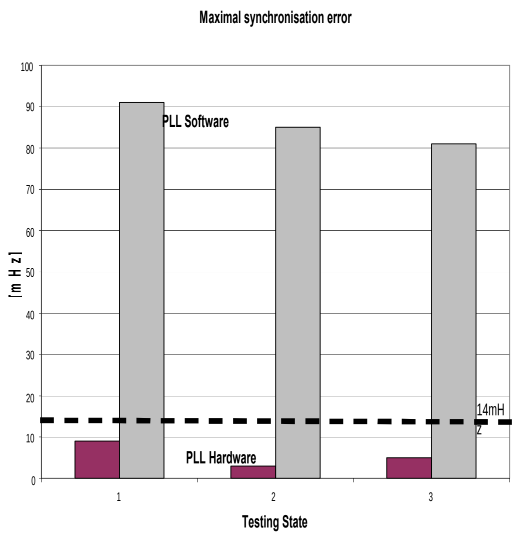
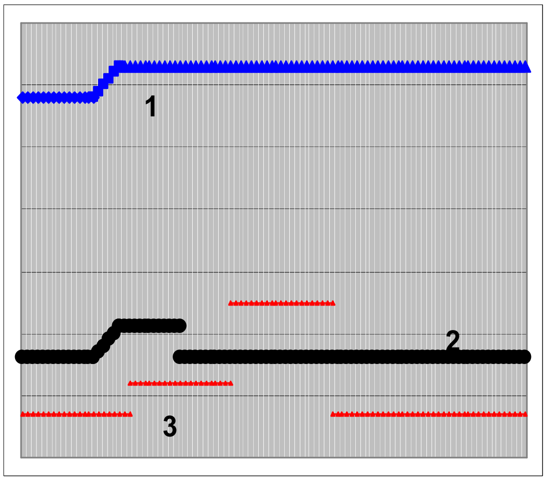


Figure 3: Synchronization error in permanent regime (experimental results)

Figure 4 regroups the results obtained with a frequency variation in steps of 47.5 HZ to 52.5 Hz, with the harmonic and inter harmonic presence on the entry signal .So that the difference of frequency f_0 *(i)* - f_0 *(i-1)* is more meaningful than the synchronization error for the transient disturbs existence identification .
In fact the synchronization error is maintained in the limits during the transient, while it passes them when the transient is exhausted. As for the value of f_0 *(i)* - f_0 *(i-1)* this one varies in the same context that the transient.



["**1**" measured frequency,"**2**" difference $f_0(i)$-$f_0(i$-$1)$ "**3**" synchronisation error]

Figure 4: PLL characterization in transient

At the light of the experiments, it is clearly shown that: even in transient disturb presence, the PLL is not sensitive to harmonic and inter harmonic presence on the entry signal and therefore is able to perform the synchronization before the 200ms. Some analogous results have been obtained in other tests conditions [9]

V. The Reactive Energy Electronic Counters in Harmonic Distortion Presence

On the construction view point, the reactive energy electronic meters can be achieved through a current signals and voltage analogical or numeric multiplier (the latter out diphase with a value of 90°).

It is known that the static meters available on the market can be constructed with different solutions.

For single-phase applications, the measurement of reactive energy (or power) can be obtained by means of an analogue or digital multiplication of current and voltage; the voltage (or the current) is preliminarily shifted by 90° by means of an integrator circuit, a time shifting of a quarter of a period, a filtering stage or another numeric technique.
The different implementations correspond to different mathematical models in which, in non sinusoidal condition, the various harmonics give different contributions to the reactive power. As an example, three different metrics can be considered [5, 6].
Moreover, digital meters, which are based on the numerical conversion of voltage and current signals, can also implement the mathematical definition of reactive power, for example, the expression corresponding to the "non active power"

of the IEEE Std. 1459-2000 (or to the Fryze's reactive power), but many other formulations can be adopted, which have been already proposed in literature [10-12]

All the aforesaid metrics can be implemented for the construction of a commercial meter or a reference standard meter for reactive energy and in sinusoidal conditions these solutions lead to the same result. On the contrary, in the presence of harmonics on voltage and current, the solutions are not equivalent anymore. This fact was confirmed in papers [5, 10, and 12], by means of several experimental tests, which were carried out on different meters, both commercial and standard.

In the tri phased meters case, to two or to three crews, to get the reactive energy measure from the active, we can use the symmetrical systems simple and composed voltages properties, through the intermediary of connecting artificial volt metrics.

The power measure and therefore reactive energy can be done using the active power definition numeric implementation. In that sens, it can be observed that in unsettled regime, the reactive power is not defined in a univocal manner and in the bibliography there exist a lot of different approaches [8].

In sinusoidal regime, the different constructive topologies, work in conformity with the norms, while, in harmonic distortion presence, their working is not known a priori.

With this anomaly light, a survey has been led on the behaviour of the electronic counters in harmonic distortion presence; to reach this goal, some comparisons have been done by the simulation and the experimentation, on different topologies of meters, in presence of harmonic distortion of voltage and current [13].

In particular, in this survey we will show the results of the tests done on a commercial electronic counter and on other "virtual" electronic counters, achieved in the MATLAB environment that implementing the different modes of the reactive energy measure; In particular, we have implemented a counter with numeric quarter voltage period deemphasize and a counter with deemphasize through the intermediary of an integrated circuit.

With the use of the Fluke calibre 6100A Electric Power Standard, a known harmonic content has been introduced on voltage and current, chosen in agreement to the CEI norms EN 50160 [14] and CEI EN 61000-3-2 [15].

Reading provided by the commercial counter , translated as for the reactive power, has been compared with the reactive powers gotten according to Fryze, Budeanu, Kusters-Moore, Shepherd-Zakikani and Sharon (raised by the same calibre) and with the reactive powers measured by the virtual counters with numeric deemphasize of a quarter period and with deemphasize through integrated circuit (calculated by simulation).

The comparison has been made by the difference in percents:

$$\Delta Qi\% = \frac{Qi - Q1}{Q1} 100 \qquad (4)$$

From the error in defined percent in [6], and having Q_i the measured reactive power in any case and Q_1 the reactive power associated to the fundamental.

The choice of this parameter is motivated by the fact that the meters are conceived to work in sinusoidal regime; in this sense. *ΔQ%*, assumes as reference reactive power, the power associated to the fundamental which, corresponds practically, in energy term, to the measure done by the induction meter in harmonic distortion presence.

The choice parameter *ΔQ%* is otherwise in accordance with the IEEE 1459-2000 norm formulation, which doesn't introduce a reactive power univocal definition in harmonic presence, but separates the relative power components to the fundamental in relation to the remaining components, due to the harmonic.

From the obtained results, we deduct that in sinusoidal regime as foreseen, the different counters lead to compatible results.

On the other hand, in the disturbed regime the *ΔQ* %values are extremely different for different meters. As opposed, the traditional induction counters, even in distortion presence, continue to measure the reactive energy associated to the fundamental practically [13].

A set of obtained results are shown in the table 1; in which, the conditions of tests are synthesized in term of harmonic distortion total factors making reference to the deemphasize enters voltage and current; the angle between the fundamental voltage and the fundamental current in the case of load *RL* [13]; in the (b) cases and (c) the different values of the THDI are due to the limitations for the current harmonic indicated in [15]. From results analysis we can conclude that the commercial counters submitted to the tests, show a very near reactive energy when compared to the one measured of the meter that implement the Fryze definition; and the values there pertaining of *ΔQ%*, are raised; while the values of. *ΔQ%*, relative to the counter with integrated circuit and those with a voltage quarter period deemphasize are very weak, so that this counters type, and in spite of the harmonic presence, measure a reactive energy in the neighbourhood of the one associated to the fundamental, with a behaviour therefore very similar to the one of the induction counters.

The commercial counter submitted to the experimental tests would seem, therefore, to be based on the Fryze reactive power definition, although its constructor doesn't states anything in that sense; on the other hand, the use of such a definition is probably commercially a choice and

technically justifiable, within sight of its extreme implementation simplicity.
Nevertheless, the counter, in harmonic pollution presence, measure a reactive energy relatively superior to the one measured by a counter with integrated circuit and with a quarter period delay.
We understand, therefore, how the adoption of different counters can imply, in the unsettled regimes, a different consumers penalty, as for cost of the invoiced energy, to equal load conditions. In this measure, the constructors should be held to specify the principle according to which their counter are conceived so that one is able to identify the size measured in harmonic distortion presence; it especially in the specific indications absence an reactive energy operational definition to which to conform for the counter realization themselves.

Since, the measure done by the counter depends on their construction, it would be necessary, in the normative setting, to define appropriate tests conditions to characterize the counter performances in the unsettled regimes.
These tests, put aside the reference nominal conditions, must be executed in conditions that best represent the ream operative conditions.
Besides, when for the measure the insertion of transduction voltage and/or current is necessary, it agrees to take in consideration the whole measure chain (meter + transduction system), because the behaviour of the transduction (generally TA and TV) can also be influenced by the harmonic disturbances presence on voltage and/or the current.

Table 1: *ΔQ %* experimental results (IEC EN 50160 and 61000-3-2 Norms)

Test with harmonics impairs non multiple of 3										
sin Φ	***THDv%***	***THDi%***	***ΔQ_{cont}%***	***ΔQ_B%***	***ΔQ_F%***	***ΔQ_{KM}%***	***ΔQ_{SZ}%***	***ΔQ_{SH}%***	***ΔQ_{in}%***	***ΔQ_{90}%***
1.00	7.90	13.90	+1.50	+0.20	+1.40	+0.50	+1.40	+1.40	0.00	0.00
0.50			+6.30	+0.20	+7.90	+0.50	+1.40	+1.40	0.00	0.00
0.25			+20.4	+3.30	+21.50	+1.10	+12.40	+12.40	0.00	0.00
Test with harmonics impairs multiples of 3										
sin Φ	***THDv%***	***THDi%***	***ΔQ_{cont}%***	***ΔQ_B%***	***ΔQ_F%***	***ΔQ_{KM}%***	***ΔQ_{SZ}%***	***ΔQ_{SH}%***	***ΔQ_{in}%***	***ΔQ_{90}%***
1.00	5.30	6.60	+0.30	0.00	+0.40	+0.10	+0.10	+0.10	0.00	0.00
0.50		25.90	+10.80	-2.30	+12.40	-0.70	+11.10	+11.10	-0.40	+1.00
0.25		29.05	+56.00	-5.50	+61.30	-1.80	-48.30	-48.30	-0.90	+2.20
Test with harmonics pairs et impairs until 24										
sin Φ	***THDv%***	***THDi%***	***ΔQ_{cont}%***	***ΔQ_B%***	***ΔQ_F%***	***ΔQ_{KM}%***	***ΔQ_{SZ}%***	***ΔQ_{SH}%***	***ΔQ_{in}%***	***ΔQ_{90}%***
1.00	7.90	17.30	+1.60	-0.30	+1.80	+0.20	+1.20	+1.20	0.00	-0.10
0.50		31.20	+14.7	+1.60	+15.90	+0.70	+5.50	+5.50	-0.30	+0.50
0.25		33.80	+53.50	-2.50	+59.80	-0.20	+20.6	+20.6	-0.60	+1.20

Φ : deemphasise fundamental voltage-current, cont = electronic counter commercial, B = Budeanu, F=Fryze, KM=Kusters-Moore, SZ=Shepherd- Zakikani, SH=Sharon, in=counter with deemphasize by integrated circuit, 90=counter with deemphasize by a quarter period delay.

VI. Conclusion

From the above study, we will finally keep on the one hand, that the parameter *ΔQ%* could be used for the completed study, since it makes reference to the fundamental reactive power permitting to estimate the counter performances in relation with the present norms. Presenting a penalty fashion that doesn't take into account the distortion presence referring to the sinusoidal case.
On the other hand, it is necessary to continue the studies in the same optic in relation with the parameters definition that permits the harmonic costs correct repercussion.

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