

## DISCREPANCY IN THE REACTIVE ENERGY MEASUREMENT IN SINGLE PHASE SYSTEMS

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### KEYWORDS

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### ABSTRACT

The increasing amount of loads with low power factor (PF) in the residential consumption, in Argentina, is cause of preoccupation by distribution companies and cooperatives, affected by the increase of the low voltages in the network, increases of losses and the consequent diminution of the capacity of its equipment. The cause of this diminution is not only due to the incorporation of equipment with inductive behavior, but, in a great extent, by the contribution of loads with strong harmonic distortion.

For this reason and in order to monitoring this problem, is usual to replace the conventional measuring devices by other (electronic ones), which are able to register reactive energy.

In present paper, authors show different possibilities to study and interpret the reactive energy. They cause the mentioned differences. The theoretical developments are complemented with simulations and laboratory measurements, on two different single-phase electronic measurement devices, supplied by their manufacturers.

### INTRODUCTION

The Electrical Engineers are familiarized with the handling of the concepts active, reactive and apparent power, as well as of the power factor, in sine regime, single-phase circuits. However, is possible to commit important mistakes when trying to generalize these definitions for circuits with harmonic or unbalanced content in three-phase circuits. Only the definition of the active power has a clearly meaning from the physical point of view, like average value of the instantaneous power, maintaining its validity in all the cases. The lack of a unique and universal definition of the reactive power, results in differences in the measurements when are made with commercial aims. This results in important economic effects.

The energy measurements –in the traditional electromagnetic measurement devices– are according to the well-known physical laws. They are “translated mechanically” in the turn of disc connected to an accounting device. In this case, the reading of the active and reactive power takes place in two separated measuring devices. However, the electronic recorders have transducers that capture instantaneous values of voltage and current are in only one apparatus. This information is processed by means of algorithms and it is accumulated in the memory. These algorithms generally are not known by the customers.

From these data, the mean value of the power factor is obtained by using the formulas (1) or (2) where P and Q are the mean of active and reactive power in the period studied, or directly the active and reactive energies read by the instruments:

$$PF = \cos [\text{arc tg } (Q/P)] \quad (1)$$

$$PF = \frac{P}{\sqrt{P^2 + Q^2}} \quad (2)$$

In the Companies of Argentina exists an “institutional culture” in order to calculate the power factor as is shown in formulas (1) and (2). Also it is very common to see that in some invoices the value of the tangent of Q/P.

### DIFFERENT POSSIBILITIES TO SHOW THE REACTIVE POWER

Just to a few years ago, the discussions about the power definition were quite exclusive in the theoretical levels. Nevertheless, now, and due to the very important presence of loads with distortions has translated the problem to almost all the circuits. In present paper we will speak about sine-voltage and single-phase circuits only.

Many are the proposals for a new definition of power considering the harmonic content. The most accepted in many books of electrical engineering is the one proposed by Budeanu. He defines the active and reactive power according to the formulas (3) and (4).

$$P = \sum_h U_h I_h \cdot \cos \varphi_h \quad (3)$$

$$Q = \sum_h U_h I_h \cdot \sin \varphi_h \quad (4)$$

Where: “h” is the harmonic order.

In order to obtain the apparent power, a term, named “power of deformation” “D” is added, as is shown in formula (5), so:

$$S = \sqrt{P^2 + Q^2 + D^2} \quad (5)$$

This last formula is represented in figure 1, where we can see that the classical triangle of power has become a parallelepiped of powers. The value of “D” is zero for sine regimes.

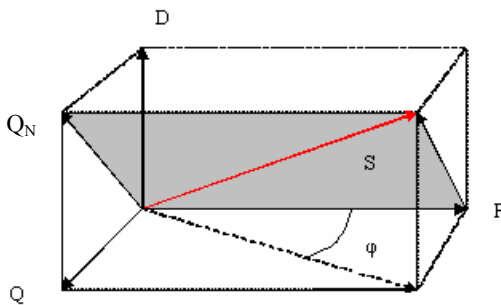


Fig 1. Geometric interpretation of the power.

Fryze proposed a definition, easy to understand with a simple interpretation of the figure 1, where it is possible to see that the vector composition of Q and D gives a new vector, named “non active power”  $Q_N$ , also identified in some books as  $Q_F$ .

$$Q_N = Q_F = \sqrt{Q^2 + D^2} \quad (6)$$

The definition proposed by Fryze is most important than the one than may be inferred of the relationship obtained from the figure, but, with practical aids -for the requirements of present paper- it is enough to show the formula (6). We remark only that the distortion is included by “D” in the formula.

In figures 2 and 3 are represented diagrams with possible algorithms. From the instantaneous values of voltage and current, the reactive power is calculated by different ways. With these Q values, the different values of the power factor are calculated. It is interesting to highlight

that the PF is calculated, in both cases, in the conventional form, as the cosine of the arc tangent of relation  $Q/P$ . In figure 2 we proceed according to Fryze, and in the figure 3 we proceed according to the conventional method.

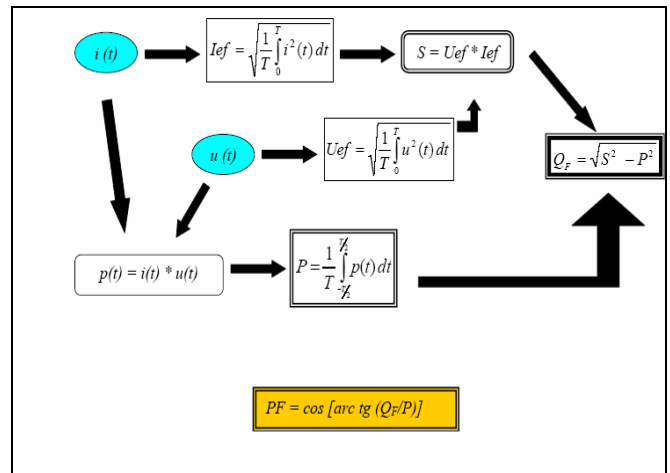


Fig 2. Operations flow for the calculation of PF with the use of  $Q_F$

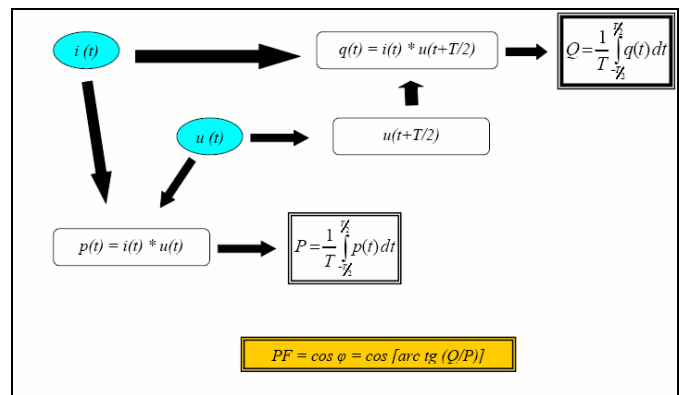


Fig 3. Operation flow for the calculation of the PF = cos  $\varphi$  by conventional method.

**SIMULATIONS**

In the laboratories of the GEA group of the Buenos Aires University, we have been tested two measuring devices whose algorithms were according to the diagrams shown in the figures 2 and 3. The results obtained were replicated by means of the simulation tool Mat-Lab, Simulink ®. The source -of sine characteristic- was connected, in both cases, to different loads, one of them with strong harmonic currents, see figure 4. The models and results are shown in figures 5 and 6.

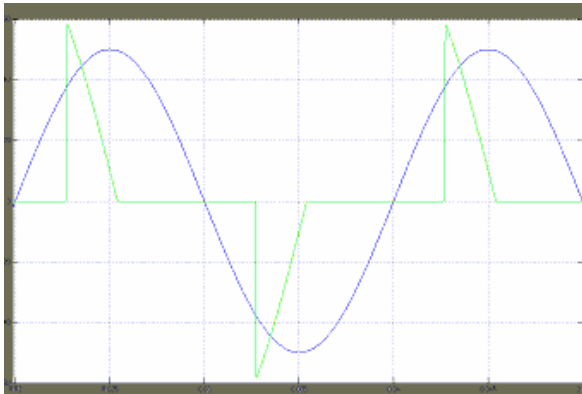


Fig.4 Voltage and current of the non linear load used for present paper

We have simulated also lineal loads. In table 1 we compare the obtained values. In the left column we show the results when the circuit of figure 6 is considered. In the right column we show the values according to the circuit of figure 5. Thus we can say that only in the non linear case we can see interesting differences, when the current has important harmonic contents. Simulations were carried up connecting different loads, in order to have the same apparent power.

We highlight that the negative sign of  $Q$ , in the case of non linear load is according to the angle between current and voltage. In correct way we must speak about the “fundamental component of the current” compared with the voltage. Is not the same case with the  $Q_{Frize}$ , always positive.

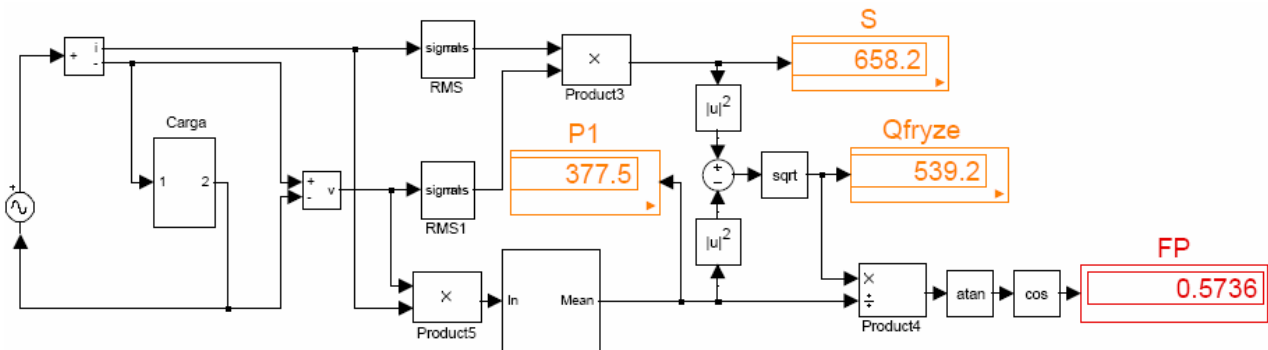


Fig 5. Calculation of Power Factor by the use of  $Q_F$

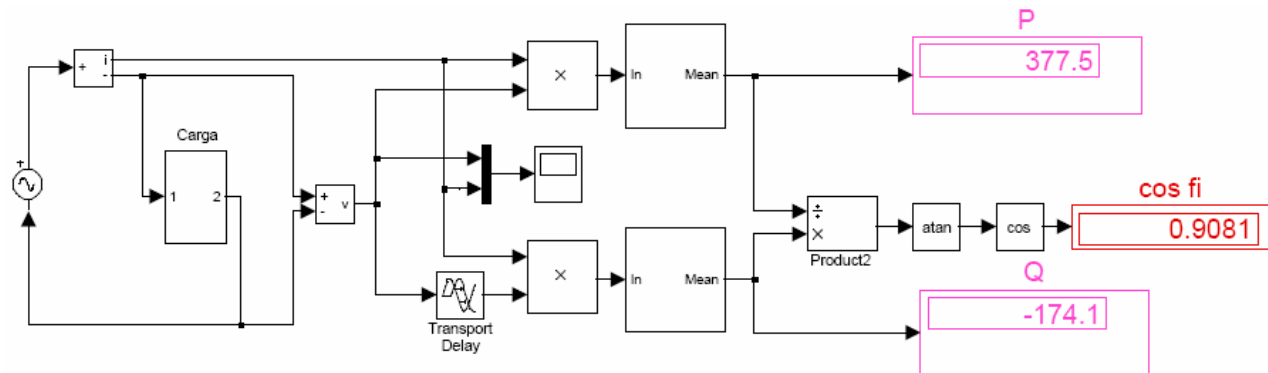


Fig. 6. Calculation of the Power Factor by the traditional method.

Table 1. Comparison of different loads

	Inductive Reactive load		Resistive load		Non linear load	
S[VA]	658.2	658.2	658.2	658.2	658.2	658.2
P[W]	346.6	346.6	658.2	658.2	377.5	377.5
Q[var]	559.6	559.6	-9.548e-013	3.738e-005	-174.1	539.1
PF	0.5266	0.5266	1	1	0.9081	0.5736

## CONCLUSIONS

The excess of reactive power in the loads, taken into account since the power factor calculation, is penalized but many tariff arrangements. It is the methodology used by the utilities in order to avoid the saturation of their networks with energy not paid by customers.

In this paper we have compared two different possibilities to consider the reactive power. They lead to very different results in the calculation of the PF, when the circuits do not have a sine behavior.

In the residential sector of Argentina, the consumption shows a high harmonic content. In this case the traditional methodology of measurement leads to a value of the PF equal to the cosine of the angle formed by the fundamental component of the current and the voltage. This value is very near to one for all the distorted loads. The PF value is very different when, for the calculation, the "reactive power non active" is considered, procedure that leads to a number that normally is below the penalized limits. In the first case the measurement does not take into account the harmonic content, thus the client is benefited in the invoicing.

The measurement of reactive energy, and the power factor calculated using the traditional methodology, is not translated into signals that can warn to the clients on their inefficiency in the energy demand.

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