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Influence of Current Transformers on the Measurement of Harmonic Active Power

A. Cataliotti[1], D. Di Cara[1], A. E. Emanuel[2], S. Nuccio[1]

[1] Department of Electrical, Electronic and Telecommunication Engineering, Università di Palermo
Viale delle Scienze, 90128 Palermo, Italy. Phone: +39 091 6615270, Fax: +39 091 488452
[2] Department of Electrical and Computer Engineering, Worcester Polytechnic Institute,
100 Institute Road, Worcester MA 01609 USA
e-mail: acataliotti@ieee.org, dicara@dieet.unipa.it, aemanuel@ece.wpi.edu, nuccio@unipa.it

***Abstract*-**The harmonic active power is a useful power quality quantity. For example it is used in many algorithms for the detection of the harmonic source in a complex electrical network. The highest uncertainties in such kind of measurements are introduced by the transducers. In the paper is presented an experimental analysis of the effects of current transformer in the measurement of harmonic power. It is concluded that large phase angle errors can cause as larger errors as the phase shift between harmonic voltage and harmonic current get close to ±90. Moreover if such measurements are used to determine the power flow direction, i.e., if a load or consumer pollutes or is polluted, even high accuracy class CTs may yield unsatisfactory results.

I. Introduction

The modern standards on electrical measurements under distorted conditions, [1], introduce new definitions of harmonic active and "non active" powers. The measurement of these quantities are necessary to evaluate the harmonic-distortion levels in a defined metering section. The key concept of the new definitions is the separation of the fundamental components of voltages and currents from all other components. This allows one to evaluate the performance of a correct measurement of the traditional billing quantities (active, reactive, and apparent powers and power factor). The remaining components of the apparent power can be used to assess the harmonic pollution level at the metering section. One of the defined quantity, which is able to detect the harmonic source, is the harmonic active power P_h, whose value is positive or negative when the harmonic content is due to the network or the load, respectively [2].

The harmonic active power is not easily measurable because usually it is very small if compared to the fundamental power. In medium and low voltage network the impedances of the lines and of the most common loads are usually resistive-inductive. Thus by increasing the frequency the Thevenin equivalent resistance at the metering section become negligible in respect of the reactance. Therefore the phase shift between harmonic voltage and current can be close to ± 90°. A particular attention should be put on the choice of the measurement instrumentation to be used [3]. First of all the P_h should be measured directly [4] and not from the difference $P_h = P–P_1$ [1]. Moreover the power meter has to be able to measure harmonic active power with small power factor. Finally it should be taken into account the errors introduced by the voltage and current transducers. Most of the time this last point is the most important measurement problem. In this paper the attention has been focused on the presence of current transducer. In particular, it was analysed the influence of current transformers, CTs, which are the most widely used current transducers. The results of an experimental analysis of the effects of CT errors in the measure of harmonic power will be presented and discussed.

II. Experimental test system

The harmonic active power, according to the definition given in [1], is:

$$P_{ph}=V_h I_{ph} \cos(\beta_h - \alpha_{ph}) = V_h I_{ph} \cos\theta_h \qquad (1)$$

where: V_h and β_h are the rms amplitude and the phase angle of the h-order harmonic voltage; I_{ph} and α_{ph} are the rms amplitude and the phase angle of the h-order harmonic primary current; θ_h is the phase shift between h-order harmonic of current and voltage.

When a current transformer is used the measured current will be affected by an amplitude and a phase angle error. To characterize the measurement errors for each harmonic of a CT, two basics index can be used [5]:

1. the h-order harmonic ratio error:

$$e_h\% = \frac{k\, I_{sh} - I_{ph}}{I_{ph}} \cdot 100 \qquad (2)$$

where: $k=I_{pn}/I_{sn}$ is the rated transformation ratio (I_{sn} and I_{pn} are the secondary and primary rated current, respectively); I_{sh} is the rms value of the secondary h-order harmonic current;

2. the h-order harmonic phase angle error:

$$\varepsilon_h = \alpha_{sh} - \alpha_{ph} \quad \text{[rad]} \tag{3}$$

where: α_{sh} is the secondary current phase angle.
Thus when the CT is connected between the power meter and the measurement point the harmonic power measured by the instrument will be:

$$P_{sh}=V_h k I_{sh} \cos(\beta_h - \alpha_{sh}) = V_h \left(\frac{e_h \% I_{ph}}{100} + I_{ph} \right) \cos(\theta_h - \varepsilon_h) \tag{4}$$

The error of the harmonic power, by considering (1), (4), can be expressed as:

$$E_{Ph}\% = \frac{P_{sh} - P_{ph}}{P_{ph}} 100 \approx e_h \% + 100 \varepsilon_h \tan(\theta_h) \tag{5}$$

In this expression it was assumed that for practical situations e_h and are close to zero [6].
As said before the phase shift θ_h can be close to ±90°and then, according to expression (5), the error E_{Ph}% can reach higher values as larger is ε_h.

III. Experimental results

A series of tests have been settled up on a CT whose rated values are reported in Table 1. The test bench used to measure $E_{Ph}\%$, $e_h\%$ and ε_h is shown in Fig. 1.
The voltage and the primary current were generated by a reference calibrator, whose accuracy specifications are available in [7], and acquired by a DAQ PCMCIA card with a 16 bits A/D converter and a maximum sampling rate of 200 kS/s (single-channel). By means of LabVIEW software, a PC-based instrument was realized: it performs a frequency analysis of the acquired signals in order to evaluate the harmonic power, ratio and phase angle errors. To acquire the currents were used two 0.1 Ω non inductive shunts, R_{sp} for the primary current and R_{ss} for the secondary current. The secondary burden, $Z_b=R_b+j\omega L_b$, is a standard burden for current transformers, according to IEC 60044-1. The calibrator was settled up to generate a voltage with a rms value of 1 V, which was directly acquired by the PC-based instrument. Since the acquisition card has only one A/D converter and a multiplexer, the interchannel delay was corrected. To verify the accuracy of the acquisition system several tests were performed comparing the values of P_{ph} measured by the PC-based instrument with the values of $P_{hcalibr.}$ declared by the calibrator. In these tests the errors $E_{Ph}\%$ were always below 1/10 of the errors obtained in the tests with the CT.

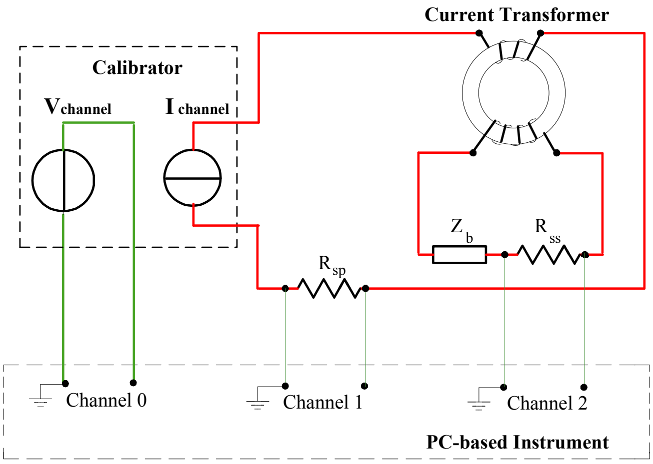

Fig. 1: Test bench used to measure $E_{Ph}\%$, $e_h\%$ and ε_h.

Table 1: Current transformer nominal data.

	CT1 (400 V)
$K_n=I_{pn}/I_{sn}$	10/5 A/A
Standard burden.	10 VA
Class	1
Frequency	50 Hz

The calibrator was settled up to generate a voltage and a current composed from a fundamental, with amplitude respectively of 1 V and 10 A and frequency f=50 Hz, and a harmonic, with an amplitude equal to 10% of the fundamental. The phase angles were settled up at $\alpha_{p1}=\beta_1=\beta_h=0°$, only α_{ph} was varied from -100° to -80° and from 80° to 100° in order to focus the attention on θ_h close to ±90°.
The harmonic power errors, E_{Ph}%, for 2nd, 3rd, 5th and 7th harmonic are shown in Fig. 2: in every graph are reported the results for four different tests, one for each harmonic. As can be seen for some harmonics the error E_{Ph}% is larger than 10% even for θ_h = ±80° or ±100°. Moreover as expected, the error strongly increases when θ_h gets close to ±90°. The

phase angle errors measured in the same conditions are shown in Fig 3. Comparing Fig .2 and 3 an exact correspondence can be found by means of the expression (5). For example for 80°<θ_h<90° the phase angle errors are negative and so are the harmonic power errors, because tan(θ_h)>0. Moreover as higher is the absolute value of phase angle error as higher is the harmonic power error. In the example for 80°<θ_h<90° the smallest phase angle errors was found for the 2nd harmonic and so also was found for power harmonic errors; the biggest errors instead were found for the 3rd harmonic.

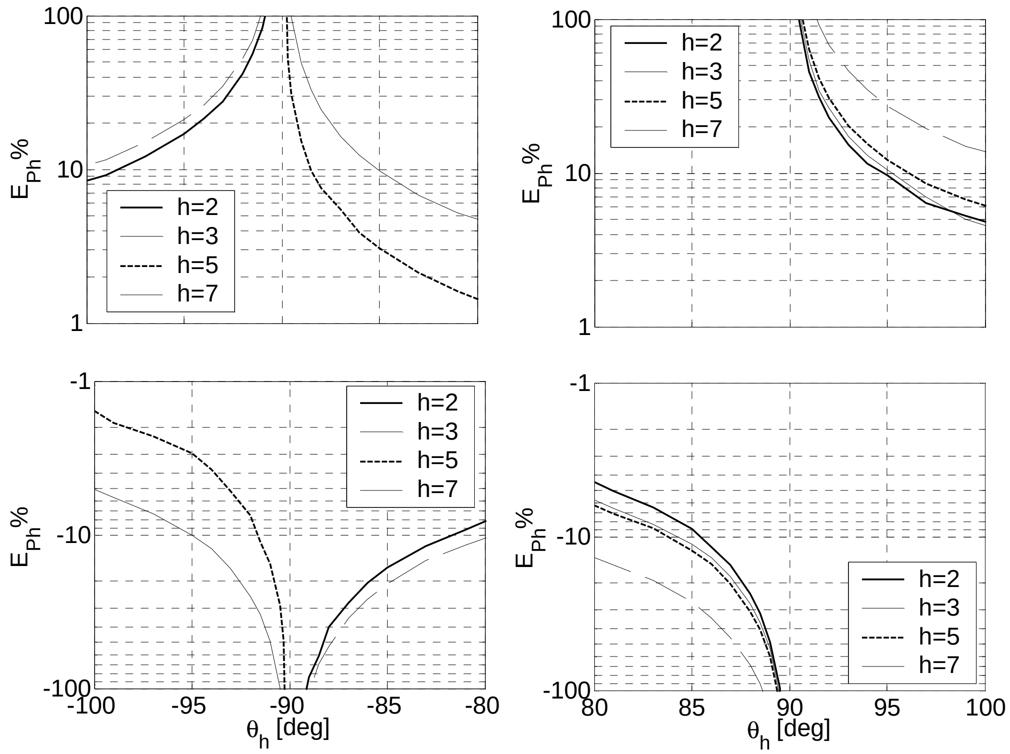

Figure 2: Harmonic active power errors for θ_h close to ±90°.

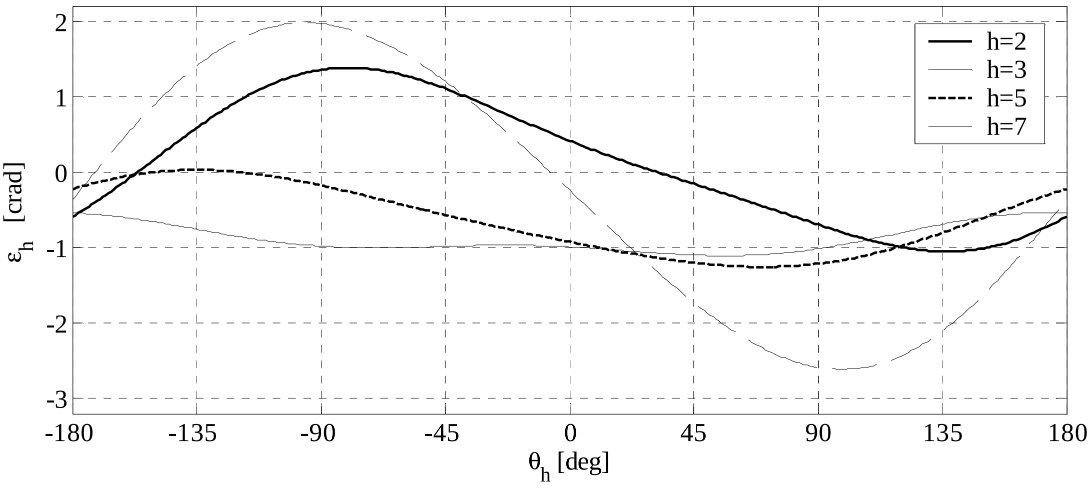

Figure 3: Harmonic phase angle errors.

Another important conclusion can be observed from Fig. 4, where the third harmonic power (P_3) is shown. For -90°<θ_h<-89° it can be seen that the harmonic power generated, P_{ph}, was positive and, due to the phase angle errors, the harmonic power measured, P_{sh} , is negative. If the sign of the P_h was used for the detection of the source of harmonic distortion, a misleading indication would be obtained because the load absorbs harmonic power. Moreover Fig. 4 shows how the values of P_{ph} are almost equals to the values declared by the calibrator $P_{h\ calibr.}$ thus confirming the negligible influence of the acquisition system on the evaluation of the harmonic power, ratio and phase angle errors.

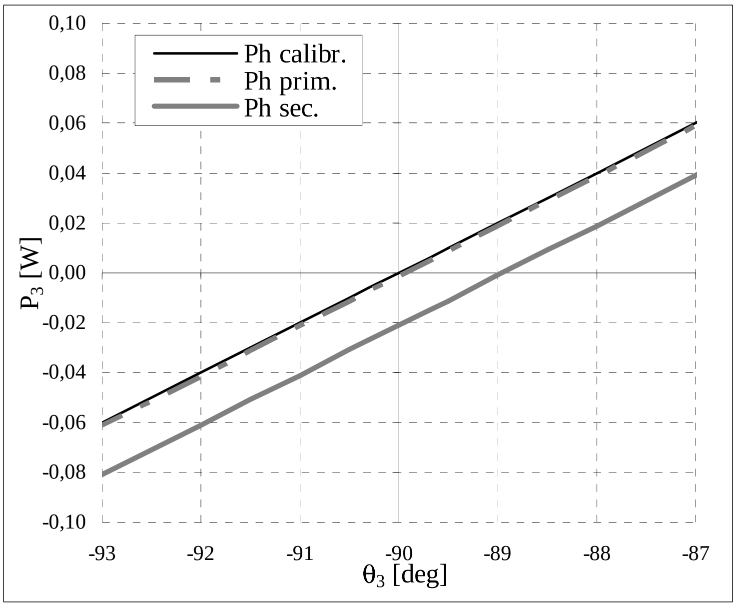

Fig. 4: Harmonic active power measured when the current and the voltage was composed of the fundamental and the third harmonic. For -90°<θ_h<-89° the sign of P_{sh} is the opposite of P_{ph}.

II. Conclusions

The current transformer can introduce large uncertainties on the measure of harmonic active power. This was proved in the paper with some experimental test on a current transformer. The errors introduced are as higher as the phase shift between harmonic voltage and current get close to ±90°. The harmonic active power errors depend mainly on the CT harmonic phase angle errors. When these errors are too large the P_h measured can have opposite sign of the P_h generated. If the sign of the P_h was used for the detection of the source of harmonic distortion, a misleading indication would be obtained indicating that a load absorbs harmonic power when in reality generates or vice versa.

References

[1] IEEE Trial-Use Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Condition, *IEEE Std. 1459-2000*.
[2] P.V. Barbaro, A. Cataliotti, V. Cosentino, S.Nuccio “A Novel Approach Based on Nonactive Power for the Identification of Disturbing Loads in Power Systems” *IEEE Transaction on Power Delivery* Vol.22, No.3, July 2005, pp. 1782-89.
[3] Transformers and Instruments for Measuring Harmonics CIGRE Working Group 05, Study Committee 36, Electra, No. 124.
[4] A. Cataliotti, V. Cosentino, S. Nuccio: “A virtual instrument for the measurement of IEEE Std 1459-2000 power quantities”, IEEE TRANS. ON INSTRUMENTATION AND MEASUREMENT Jan. 2008 Vol.57 N°1 pp. 85 -94.
[5] A. Cataliotti, D. Di Cara, A. E. Emanuel, S. Nuccio “Characterization of Current Transformers in the Presence of Harmonic Distortion” IEEE Instrumentation And Measurement Technology Conference I2MTC 2008, Victoria, Vancouver Island, Canada, May 12–15, 2008.
[6] A.E.Emanuel, J.A.Orr, “Current Harmonics Measurement by Means of Current Transformer” IEEE Transaction on Power Delivery, Vol.22, No.3, July 2007, pp. 1318-25.
[7] Fluke 6100A electrical power standard, accuracy specifications online available at: http://assets.fluke.com/download/6100A_Brochure_2003.pdf.