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Development of a System for the Accurate Measurement of Power with Distorted Signals

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Abstract- This paper describes the development, at INRIM, Italy, of a system for the accurate measurement of the power with distorted signals. This system consists of a six input high resolution acquisition system and suitable shunts and voltage dividers. The first version of the system has been tested for its functionality and in comparison with the primary system for the measurement of electrical power showing a good agreement, when the same devices are used as signal conditioners. Instead, not negligible differences arise in the direct comparison of the two systems, mainly due to the instability of the voltage dividers.

I. Introduction

In the last few years, in the field of the power and energy measurements, there has been an increasing request for the determination of the power quality and of the power with non sinusoidal waveforms. This is mainly due to the application of renewable generation sources (photovoltaic generators and wind turbines), which, for the use of power electronic, produce generally distortions larger than that those of the traditional generators. Furthermore, the commercial availability of more flexible instruments for the measurement of the power and energy with distorted waveforms has increased the request for the traceability in this field. National Metrological Institutes have faced this request by developing specific measurement systems and methods for these measurements and, in 2011, the Consultative Committee for Electricity and Magnetism (CCEM) has decided to organise an international comparison between National Institutes.

In Italy, INRIM is now developing a system for sampling and reconstructing the electrical signals for the accurate determination of the power and the other important parameters (distortion, energy contents of the harmonics, interruptions,….) for periodical not sinusoidal waveforms and for power quality. This system is a part of a project developed in co-operation with the universities of Cassino, Palermo and Napoli, supported by the Italian Ministry of Research for the "Implementation and characterisation of measuring systems with metrology reference at primary level for electrical energy and power in non sinusoidal conditions". The research activity developed at INRIM aims at the creation of the traceability at primary level for the electrical power and energy measurement for periodical distorted signals.

The traceability is obtained by means of a calibrator for the generation of the distorted voltages and currents and by a system for their measurement and for the determination of the electrical power and energy. The measurement system is implemented by a three-phase digitizer integrated by voltage dividers and shunts able to convert the signals at the input of the measurement system into voltage signals at a level suitable to be sampled. The traceability for this system is derived from the standard of voltage and electrical resistance and from the temporal relation between the relevant signals.

II. Hardware

A. The acquisition system

The acquisition system has been developed for three-phase power and energy measurements. It has been assembled by a National Instrument PXI chassis with express bus, where three high resolution double channel digitizer boards (NI PXI-5922) are inserted. Each of them acquires a voltage and a current of one phase. The controller is connected to a computer through a fibre optic link, so allowing the separation from the supply and ground system of the computer and that of the acquisition system. A further board (NI PXI-6682) has been preliminarily used for the time synchronisation of the acquisition system, which has the capability of tracking the GSP signals for labelling in time the power quality events. Now a new timing and multichassis synchronizing board having and accuracy of $50 \cdot 10^{-9}$ at 10 MHz (NI PXIe 6674T), has replaced the previous one, so increasing the time consistency between the three acquisition boards.

B. The signal conditioners

The acquisition system can digitize voltage signals in ranges that can be selected by the program. For the best accuracy these ranges are from 1 V to 10 V and, in a first version of the system:

- The nominal currents are converted into a voltage of about 1 V rms by shunts. The devices used are those employed in the ac-dc transfer standards of current that can be well characterized both in ac/dc difference and in phase by proper methods previously developed at INRIM [1], [2].
- The nominal voltages (up to 300 V) are converted by means of voltage dividers, built by connecting at the input of the voltage sections range resistors for ac-dc transfer standards in series to low current (10 mA) shunts.

A photograph of the acquisition system, one of the shunts and one of the voltage dividers are shown in Fig. 1 a) b) and c).

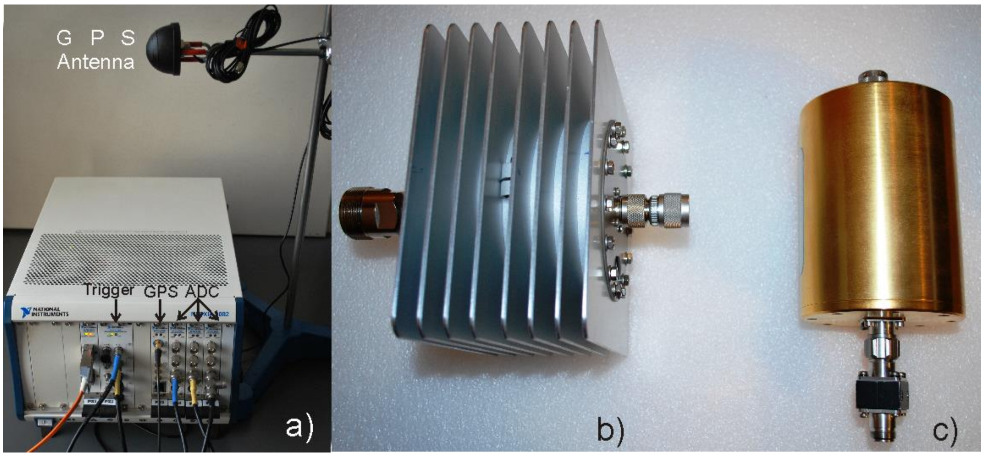

Fig. 1. Pictures of some components of the INRIM system for the measurement of power and energy with distorted waveform a) the digitizer b) one of the shunts (5A) c) one of the voltage dividers.

III. Software

As the system is mainly intended to be employed for the characterisation of calibrators and measurement instruments in laboratory and it does not need real time processing, the software program is divided into two parts: one for the acquisition and the other for the processing.
The acquisition program was built in NI Labwindows^{TM}/CVI and, after setting the parameters of the digitizers for the adequate range, the sampling period, aperture time and the trigger event configuration, starts the simultaneous sampling data acquisition from three ADC boards. The acquired data are stored in a matrix form, into the computer; in the first column is stored the acquisition time, whereas in the later columns are stored the values of the digitizers for the voltage and current signals.
Two software programs for the data processing have been developed in Matlab^{TM}. The first program has been built for the accurate determination of the harmonic components when the frequency can be considered stable during the whole measurement time. The algorithm is asynchronous and the frequency of the signal assumed as a reference (a selected voltage) is evaluated by an iterative sequence. A number of cycles for the frequency determination can be set by the operator who can use respectively a phase shift interpolation algorithm and/or a multi harmonic frequency estimator.
The phase interpolation algorithm evaluates, starting from the guessed value of the frequency, the equivalent phase in sections of the signals. These phases are put in a sequence and from the rate of variation a new guessed frequency is evaluated.
The multiharmonic frequecy estimator is described in detail in [3] and is very accurate. Typical accuracy for the determination of the relative frequency are of the order of 10^{-9}, when more than twenty periods of the

fundamental harmonic are used. However, in order to converge this algorithm needs an inital guessing, which must be within a maximun relative error of:

$$\text{maxerr} < \frac{1}{4 \cdot n_{\mathrm{P}} \cdot n_{\mathrm{H}}} \tag{1}$$

where n_{P} is the number of periods and n_{H} the number of harmonic considered in the determination. Eventually, the sine and cosine harmonic components are evaluated by the harmonic best fit [3].
The second program has been implemented for a fast processing of large quantity of data, for the determination of the power quality parameters. This program evaluates most of the parameters defined in the standard EN 61000-4-30. In a preliminary stage evaluates the frequency as a time function, by the zero transitions of the reference signal. Then, the program evaluates for each voltage the rms values, the interruptions, the sags and swells. The evaluation of the frequency for groups of ten periods is then improved by the phase shift evaluated by FFT with a Hamming window. The signals are resampled for an exact number of periods and the values of the harmonic and interharmonic components are evaluated by means of FFT.

IV. Algorithm tests

Some preliminary tests have been already made on the system and on the algorithms.
The functionality of the digitizer and the acquisition program have been verified, besides the functionality of the algorithms for processing the data. The algorithm for the accurate determination of the harmonic components has been tested by streams of computed samples of distorted signals and for all harmonics the differences between the theoretical and the reconstructed components were generally under a few parts in 10^7.
The resulted phase instability, in the hypothesis of perfect input signals, with the additional noise has been derived [4] from the specifications of the digitizers. For the frequencies of interest (up to the 50th harmonic) the dominant term appear to be the noise (about –85 dB), while for example the jitter gives a significant contribution only of higher harmonics. The reconstruction of the phase in each channels of the digitizers has been showing that the repeatability of the phase difference is under 0.1 μrad for frequencies up to 10 kHz [2], [4].

V. Preliminary tests on the system

The three-phase acquisition system has been tested for its functionality by supplying each section independently by a two output voltage generator.
The accuracy of the complete system has been preliminarily tested only for one section (a single phase voltage and a current).
For each shunt used as signal conditioners:

- the transresistance has been measured in comparison with a proper calibrated dc shunts;
- phase has been evaluated as function of the frequency by means of the phase comparator [2];
- the ac-dc transfer difference, when the shunt is used with a thermal converter, has been evaluated in comparison with the national standard.

For each resistive divider:

- the voltage ratio has been measured by means of two precision multimeters in dc;
- the frequency band has been evaluated at low voltage by supplying with a fast pulse generator a rectangular waveform and observing the output by a wide-band oscilloscope.

These measurements have been employed to derive the corrective parameters to be introduced in the software for the power measurement.

Two tests have then been performed at the frequency of 53 Hz in comparison with the reference system for power measurement [5], which operates in quasi-sinusoidal conditions or with the presence of a limited number of harmonic components (maximum of 10).
In the first test the acquisition system of the system under development was connected in parallel to the multimeters of the primary system for power measurement: The resulting power of the two systems has been measured at the same time and Fig. 2 shows the results in a sequence of measurements for a nominal voltage of 120V and a nominal current of 5 A.

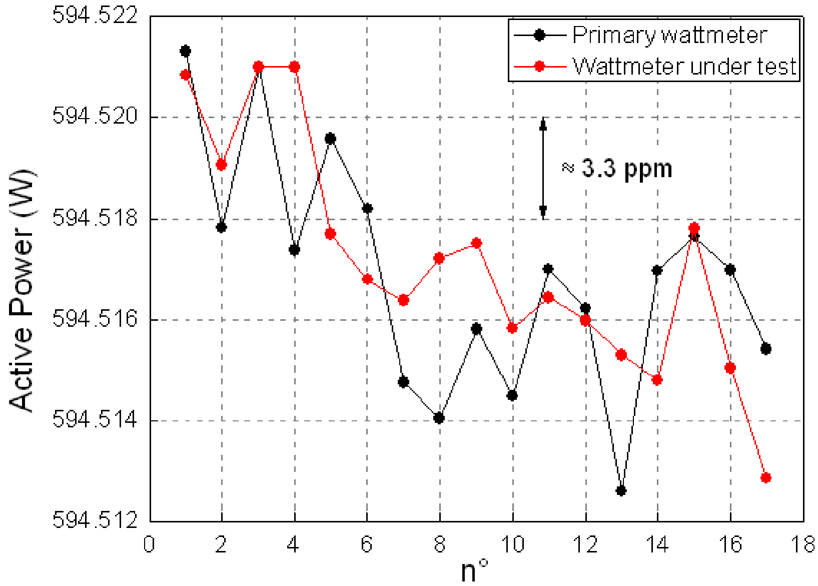

Fig. 2 Comparison of the systems for the power measurement with the two acquisition systems using the same transducers, connected in parallel (nominal voltage 120 V, nominal current 5 A).

In the second tests the two systems with the respective signal conditioners have been compared, connecting the supplied voltage in parallel and the current in series (see Fig. 3).

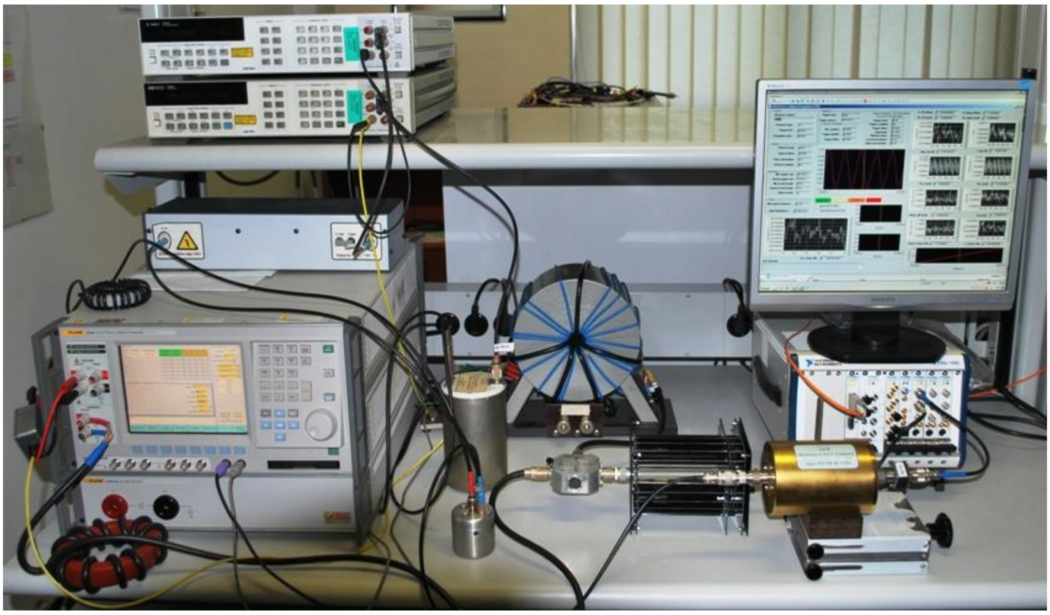

Fig. 3 View of the connection of the two systems in parallel for their comparison.

Fig. 4 shows the measurement of the power by means of both systems. There are evident differences, which with a more careful investigation appear to be due mainly to the drift of the voltage dividers. In fact, while the frequency responses of the voltage dividers are satisfactory, with a natural bandwidth of more than 10 MHz, the range resistors, that are suitable for the ac-dc transfer standards, are not sufficiently stable with the temperature and the voltage applied.

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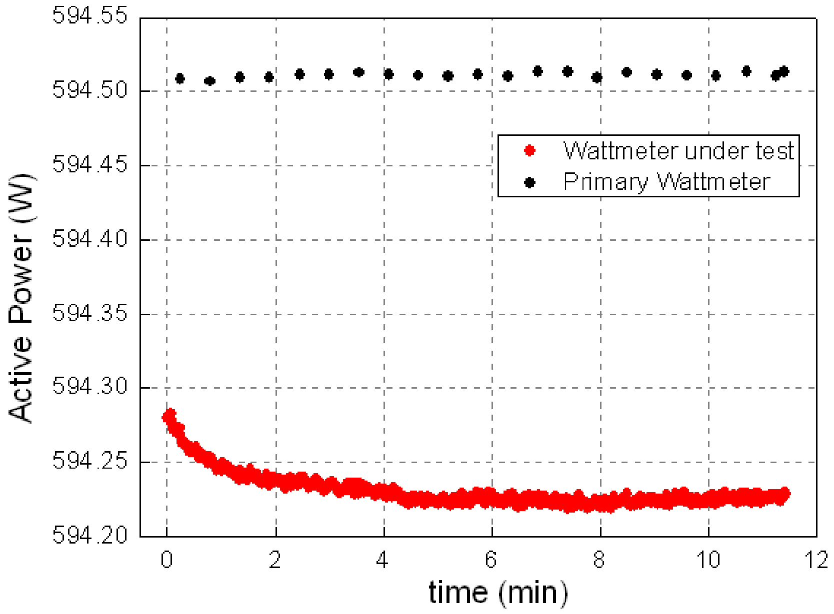

Fig. 4 Difference between the power measurement in the two systems. The difference could be compensated by using proper corrective parameters, but it depends on the voltage applied and the stabilization time.

V. Conclusions and future work

A first version of a system for the accurate measurement of power with distorted signals has been set up and tested for its functionality and in comparison with the primary system for the measurement of power. The acquisition system has shown a good agreement, when the same devices are used as signal conditioners. However, there are not negligible differences, due to the instability of the voltage dividers. Consequently, a new type of voltage divider has been designed and it is now under construction. This new type of divider, while maintaning a wideband, employs a network of high accuracy resistors in order to reduce the power in each components for maintaining a reduced voltage effect.

References

[1] U. Pogliano, G. C. Bosco, G. La Paglia, G. Zago, "Flexible System for Precision and Automatic Comparison of AC Measuring Devices", *IEEE Trans. on Instrum. and Meas.*, vol. IM-42, no. 2, pp. 295-300, 1993.
[2] U. Pogliano, B. Trinchera and D. Serazio, "Wideband digital phase comparator for high current shunts," *Metrologia* , vol. 49, no. 3, pp. 349-358, 2012.
[3] U. Pogliano, "Precision Measurement of AC Voltage below 20 Hz at IEN", *IEEE Trans. on Instrumentation and Measurement*, vol. IM-46, no. 2, pp. 396-372, 1997.
[4] U. Pogliano, B. Trinchera "Uncertainty characterization of two channels digital analyzer as a wideband phase comparator," *CPEM 2012 digest*, Washington DC, USA, Jul 2012, pp. 286-287.
[5] U. Pogliano, "Use of Integrative Analog to Digital Converters for High Precision Measurement of Electrical Power", *IEEE Trans. on Instrumentation and Measurement*, vol. 50, no. 5, pp.1315-1318, 2001.