Construction of the Traceability for Electrical Power

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***Abstract*-**The traceability for the calibration of power converters and wattmeters is obtained in primary laboratory starting from the standards of electrical quantities, such as resistance and voltage. The paper shows the path followed at I.N.Ri.M, which is the primary laboratory in Italy for metrology, to built the traceability for the precision measurement of both the single phase and the three-phase active power in the frequency range from 40 Hz to 60 Hz.

I. Introduction

The measurement of electrical power has a high impact in economic transactions. Electrical energy valued to millions of euros is exchanged every day in the international market between different producers and between producers and users. The economical transactions concern a lot of people and it is well known that the energy meter is certainly the more utilised electrical instrument. Furthermore, in the recent years and in many countries, the market liberalisation has expanded more and more the area of the producers that are selling their electrical energy.
For these reasons the request for the measurement of power and energy at 50-60 Hz is constantly increasing and primary laboratories are asked to improve their traceability in this field. At I.N.Ri.M. a gradual evolution has occurred in the last few years and a complete new laboratory has been developed. The traceability, starting from the primary standard, is extended to the measurements of single phase and three-phase power and energy both for internal instruments and for customers' instruments. This construction involves systems and methods that will be described and discussed in the following parts of the paper.

II. Sampling wattmeter and its characterisation

At I.N.Ri.M. the primary standard for electrical power is based on a sampling method [1]. Two high precision sampling voltmeters are used to acquire both the voltage and the current, which is transformed into a proportional voltage by mean of a double stage current transformer and a 1 Ω ac resistor.

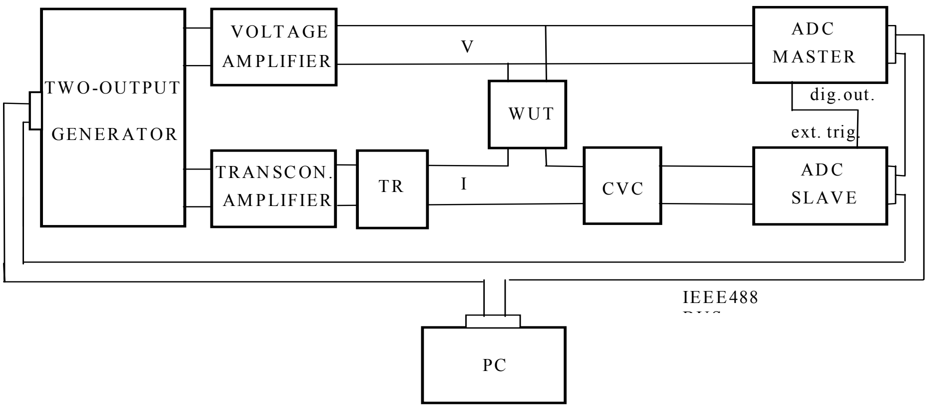

Fig. 1 Basic scheme of the system for the primary measurement of electrical power connected for the calibration of a wattmeter under test (WUT). TR is the transformer for selecting the output current, CVC is the current to voltage converter.

The voltage and the current to be supplied to the sampling system for power measurement and to a power converter under test is generated by a double output generator, able to supply two voltages in the

range from to 120 V variable both in value and phase. One of the voltage can be amplified up to 600 V by means of a voltage amplifier, the other one can be transformed in a relevant current up to 50 A by means of a transconductance amplifier and a transformer.
The generator and the two sampling voltmeters are driven by a computer by a IEEE-488 bus and the automatic system built acquires, for a given period of time, the samples of the voltage and those the current. Then, by special sine-fit algorithm [1], [2], the software program reconstructs the fundamental and the harmonic components of the voltage and the current and evaluates the value of the active power.

Fig 2 Picture of the primary system for the measurement of electrical power

A first part of the program controls the acquisition of the two series of samples from the two multimeters and the resulting data are stored in the memory of the computer. Subsequently the two series of samples are processed to compute the parameters of the voltage and the current: frequency, amplitudes and phases of the harmonic components.
In the reconstruction procedure the voltage and the current are assumed to be described as Fourier functions of time truncated at the M-harmonic component.
The algorithm for the reconstruction of the voltage and current signal is based on the following steps:

- First evaluation of the frequency from the zero-transitions of the voltage from the change of the sign of the samples. To avoid false detection minimum delay between two successive transitions is introduced. The time interval between an entire number of periods of the signal is evaluated. Near to the first and the last transition the samples and the respective times are recorded and the times of the two transitions are evaluated by the intersection at zero of the two segments that best fit these samples. The evaluation of the frequency is then computed as the ratio between the number of periods and this time interval.
- Identification of the parameters that define the harmonics of the voltage signal, by means of a least square adjustment minimising the sum of the squares of the residuals.
- Evaluation of the optimum frequency shift which minimizes the residuals by using the least square adjustment applied to the truncated Fourier expression with the phase shift as additional parameter.
- Repetition of the previous steps for a new approximation until the value of the frequency shift reduces to a negligible amount.
- Determination of the parameters of the current.

The harmonic components of the reconstructed voltage and current are corrected to take into account the not negligible aperture time of the multimeter, by means of the procedure described in detail in [4] and the electrical power is computed as:

$$P = V_0 \cdot I_0 + \cdot \sum_{h=1}^{M} \left[V'c_h \cdot I'c_h + V's_h \cdot I's_h \right] \cdot \qquad (1)$$

where:
V_0, I_0 are the dc components of the voltage and the current, while $V'c_h$, $V's_h$, $I'c_h$, $I's_h$ are respectively the cosine and sine component of the voltage and the current corrected for a not negligible width of the samples.
The primary system for power measurement is calibrated by means of a suitable procedure starting

from the value of a 10 V voltage reference used to calibrate the two voltmeters and the calibration of the 1 Ω shunt, by comparison with a resistance standard.
The values and the phase of all voltage range in the voltmeters are then calibrated by means of an inductive voltage divider and by coaxial resistors by a suitable procedure [3].

III. Measurement of power converters by means of the sampling wattmeter

After calibration the sampling measurement system is employed to calibrate the power converters, which are the reference for the power laboratory. The calibration is performed by means of the same program used for the calibration of the primary system.
The power converter under test is connected at the primary system as in Fig. 1 and the proper voltage and current at the selected phase difference are supplied. The program evaluates the harmonic components and then the active power and at the same time reads the multimeter connected to output of the power converter. All parameters of the virtual power supplied and the value of power read by the power converter are measured and the corrections are evaluated.
The power converters are calibrated at the uncertainty level depended on the value of the voltage, current and phase and ranging from 30 to 60 parts in 10^6 (expanded uncertainty). At the moment this operation is made by setting manually the two outputs of the calibrator to obtain the correct value of voltage, current and phase and by measuring with the program for the acquisition and reconstruction of the voltage and current signals.

IV. Comparison of power converters

The next step is the calibration of the customers' power to voltage or power to frequency converters. This calibration can be made in two possible ways. A first method is the direct comparison against the national standard with the same system and procedure previously described. By this method the uncertainty given to the customer is at its best level, but the price is higher for the time required. A second method is based instead on the comparison with another calibrated power converter.

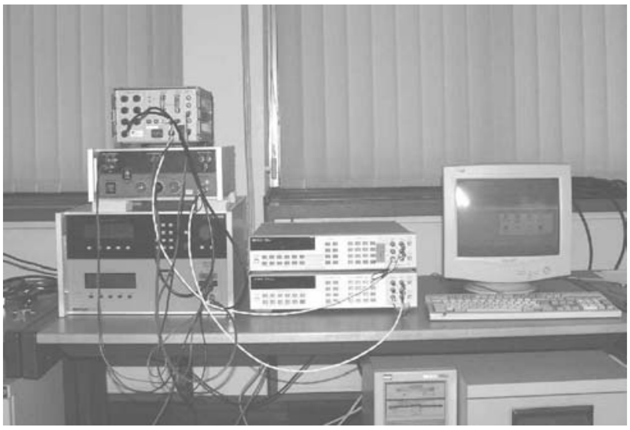

Fig 4 Picture of the system for the comparison of power converters

This last method uses either the generator previously described or a single phase power calibrator. The voltage and the current are applied to the power converter already calibrated acting as a reference and to the one under test. The procedure is automatically driven by a computer by means of a IEEE-4888 interface. On the basis of the model of the power converter chosen, the software selects the calibration process to be performed and displays the correct connections, controls the response of the converters to be employed and checks the correctness of the procedure. For each measurement point, the means and the standard deviation of the comparisons between the two power converters are evaluated and corrected from the calibration data of the reference converters. Tests on the data obtained verify the repeatability and the stability of the results. The data are then stored in the hard disk of the computer where they can be compared with the previous calibration data obtained on the same converter and utilised for the certification of the converter under test.
By using this method the uncertainties are a bit worse than with the previous method, for the contribution of the stability of the reference power converter, but the reduction of the time employed allows a reduction in the price of such calibration.

V. Calibration of the three-phase measurement system and comparison of three-phase

The measurement system for three-phase measurements is built with a three-phase generator and a wattmeter of the same manufacturer (MTE). This system works for frequencies between 45 Hz and 60 Hz, in the voltage range from 30 V to 500 V, a current range from 1 mA and 160 A. For each phase the phase difference between the voltage and the current can be adjusted.
The calibration of the system is obtained by means of three single-phase power converters, whose outputs are read by precision multimeters. A program developed in Visual basic performs automatically the calibration of the system data in a set of suitable points. It acts on the generator and on the three-phase wattmeter selecting the proper ranges of these instruments, while for the monophase power converter only an indication of how to connect their inputs is given. Then, the program acquires and processes the data. The instruments are synchronised and in every measurement point a selected number of measurement is taken. The voltages of the power converters are converted in power and compared with the power measured by three-phase wattmeter obtaining the correction of the instrument to be used in the next step for the calibration.

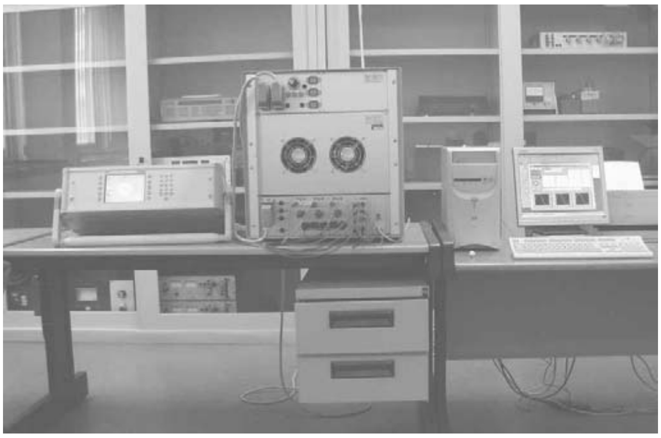

Fig 4 Picture of the system for the comparison of three-phase wattmeters

Another program allows the calibration of customers' three-phase wattmeters by comparison with the reference.

VI. Conclusions

The systems for the construction and for the measurements of both the single-phase and the three-phase power have been described. They have been completed now and allow to the laboratory to perform high quality measurement of active power for single phase or three-phase wattmeter or power converters.

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