THE ELECTROMETRIC AC-DC TRANSFER STANDARD AS PRIMARY STANDARD AT IEN FOR AC VOLTAGES FROM 300 V TO 1000 V

U. Pogliano and G.C. Bosco

Istituto Elettrotecnico Nazionale "Galileo Ferraris"
Strada delle Cacce 9, 10135 Torino, Itlaly
Phone (+39) 011 3919 433 Fax: (+39) 011 346384 e-mail: pogliano@me.ien.it

Abstract - *An electrometric AC/DC transfer standard has been built, which compares the equivalence between an AC and a DC voltage by an attracting force sensed by an analytical scale. The functionality and the stability of the instrument have been tested and the electromagnetic and mechanic effects have been analysed. Comparisons with thermal converters have shown that this instrument can be conveniently used to maintain the traceability for voltage beyond 300 V, in the frequency range from 1 kHz up to 100 kHz.*

Keywords - AC measurement, Measurement standards, Transfer standards, Voltmeters.

1. INTRODUCTION

In almost all primary metrological laboratories the AC voltage is measured by means of thermal converters. For voltages in the range from 0.5 V to 3 V the AC/DC transfer difference of multijunction thermal converters is generally lower than 1 part in 10^6 for frequencies from 20 Hz to 100 kHz. For thermal converters with nominal voltage higher than 300 V and frequencies higher than 20 kHz the AC/DC transfer difference raises to more than 100 parts in 10^6. A specific determination of this parameter, with uncertainties at the level of some parts in 10^5, is possible by means of a step-up procedure. Starting from the basic standard maintained by means of multijunction thermal converters and by means of a series of comparisons the AC/DC transfer difference is evaluated at increasing voltages. However, this procedure can be troublesome and includes many steps.

Alternative approaches, such as electrodynamic or electrostatic instruments have been considered in the past; however, the uncertainty level was worst than that of thermal converters, which have been for a long time practically the only devices used at primary level.

In order to have both an improvement of the uncertainties and a simple direct method alternative to thermal converters, an electrometric AC/DC transfer standard [1] has been built at Istituto Elettrotecnico Nazionale "Galileo Ferraris"(IEN).

This instrument is based on the attractive force between two electrodes, which is proportional to the square of the RMS voltage both in AC and in DC.

In fact, from the electrostatics we know that, between two generic conductors at different voltage with a single degree of freedom for the displacement, the mean force F_m is given by the relation:

$$F_m = \frac{\partial C}{\partial s} \cdot U_{RMS}^2$$

where C is the capacitance between the two conductors, s is the displacement along the direction of the degree of freedom and U_{RMS} is the RMS voltage between the two electrodes (a similar relation can be written for the torque as function of the angle).

In the past, electrometric systems were used mainly as quadrant electometers, where, by a suitable geometric construction of the electrodes, the torque for a given voltage is almost independent of the relative position of the mobile electrode. The quadrant electrometers have also some drawbacks, specifically the forces are very weak for voltages up to 1000 V. Instead by the Kelvin type electrometer higher forces can be obtained, even if the force for a given voltage is strongly non linear as function of the distance between the electrodes.

In the instrument the force is used as the transfer quantity, and the comparison between AC and DC voltage is achieved by a measurement procedure identical to that of a thermal converter: applying first the AC voltage to be measured and then, immediately after, a suitable DC voltage in order to reach the same output.

2. PROTOTYPE OF THE INSTRUMENT

The development of prototype based on the electrometric principle has been undertaken at IEN. A picture of this instrument is shown in Fig. 1. The instrument consists of an analytical scale that senses the force between the electrodes and whose main features are: a range of comparison between mass of 22 g and a resolution of 1 μg.

The scale can perform automatic measurement because it is programmable and can be read by a computer at a proper timing by means of a RS-232 interface.

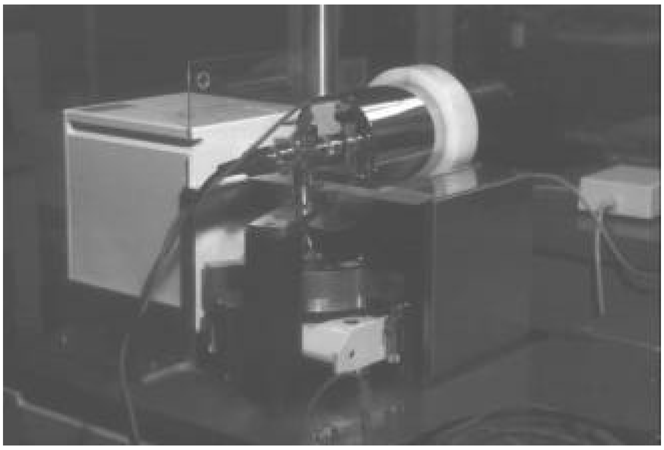

Fig.1 Prototype of the electrometric AC/DC transfer standard.

The active elements of the instrument are two circular electrodes, whose cross section is schematically represented in Fig. 2. One of the electrodes (electrode A) is placed on the plate of a scale and the other one (electrode B) is sustained by the internal shafts of three positioners joined to a rigid support. Each shaft is adjustable by means of a micrometer screw, so that electrode B can be placed parallel to the other at a distance that can be adjusted from 0.5 mm to 5 mm. The electrode A is made of gold plated silicon 0.6 mm thick and its diameter is 114 mm. Its total mass is only about 17 g. The other electrode is a coaxial pair, the high voltage is supplied to the internal part, whose diameter is 75 mm, while the external part at zero potential is connected to the electrode A by means of three gold strips 3 mm wide and about 20 µm thick.

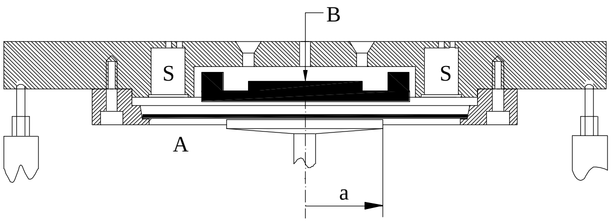

Fig. 2 View of the two electrodes of the electrometric AC/DC transfer standard. A is the electrode on the plate of the scale (a is the radius of the support where the electrode is placed), B is the electrode that is supported by the positioners, while S is the location of the sensors for measuring the distance between the electrodes

The input of the instrument where the AC and the DC voltages under comparison are applied is a GR 874 T-connector joined by means of a rigid support to the base where the scale is placed. The input connector is electrically linked by a short flexible coaxial cable to the internal and the external parts of the electrode B.

3. ANALISYS OF THE ELECTROGNETIC EFFECTS

The electrometric AC/DC transfer standard can be characterised by its AC/DC transfer difference, which accounts for the different behaviour in DC and AC. Possible components of the AC/DC transfer difference due to electromagnetic effects on the electrodes have been evaluated [2] by means of computation.

In fact, when a DC voltage is applied only the currents due to dispersion are present, while the application of an AC voltage produces AC currents on the electrodes, due to the capacitive load.

These currents, which are function of the frequency, induce different effects on the coaxial structure:

- generation of a magnetic field and its dynamic interaction with the current on the electrodes;
- resistive voltage drop on the electrodes;
- partition error due to both the input resistance and inductance.

The dynamic effect due to the magnetic field can be computed by evaluating the magnetic field at every point between the electrodes the electrometer from the current due to the variation of the electric field. Then the magnetic energy stored in the space between the electrodes is computed and the force is evaluated by deriving of the magnetic field energy with respect to the displacement of the electrode.

An interesting result of this calculation is that the ratio between the forces due to the magnetic field and due to the electric field is independent of the distance d between the electrodes and the potential difference U [2].

The resistive effect on the surface was computed, from the distribution of the capacitive currents and from the surface resistance, by determining the potential difference between every point of the surface and the input. The RMS of the voltage at every point of the surface of the electrode is then computed. The difference between the mean value on the surface and the input voltage represents the contribution of the resistive effect to the transfer difference.

The error due to the resistive effect depends on all the geometrical parameters of the electrometer and also on the surface resistance of the electrodes, and is almost proportional to the square of the frequency.

Within the electromagnetic effects, the major contribution is due to the impedance of the conductor, which is connected in series to the capacitance of the electrodes. The influence of this effect can be evaluated by means of a simple model in Fig.3.

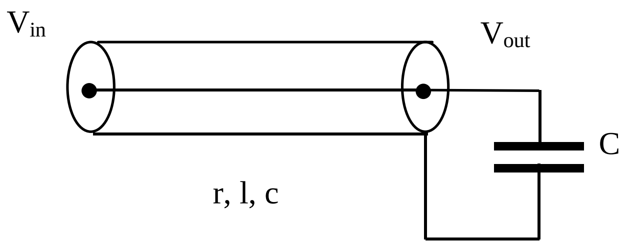

Fig 3. Model used to compute the error on the AC/DC transfer difference due the impedance of the connector and conductor represented by a coaxial cable (r,l.c are respectively the resistance, the inductance and the capacitance for unit of length) instead C is the capacitance between the electrodes.

The AC/DC transfer difference attributed to all the electromagnetic effects taken into consideration is less than 2 part in 10^6 for a frequency up to 100 kHz.

4. ANALISYS OF THE MECHANICAL EFFECTS

The mechanical effects, such as deformation and free vibration frequencies, have been analysed.

The attractive forces on the electrodes due to the application of the input voltage are of the order of 20 mN with an electric field of 1 kV/mm. However, for the delicate construction of the electrode on the plate of the scale, there can be non negligible deformations of the electrode surface. The static transversal displacement of the electrode has been computed by means of a finite element program as a function of the radius *r*, and is shown in Fig. 4. For a generic voltage and distance between the electrode, the displacement, which is proportional to the square of the electric field, can be easily evaluated.

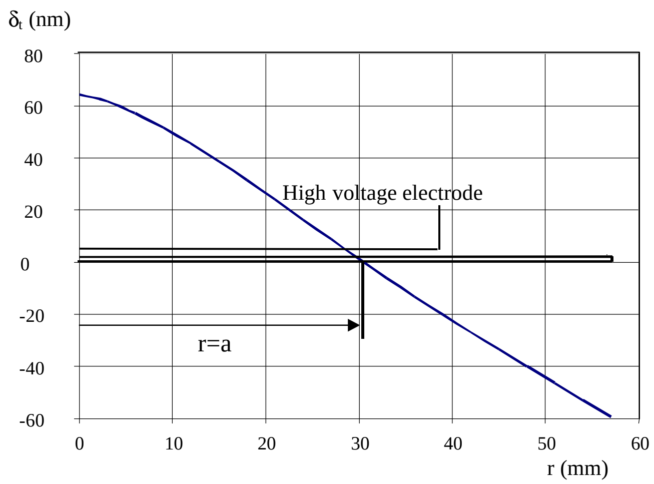

Fig. 4 Transversal displacement δ_t as a function of the radius r produced by a static electric field of 1 kV/mm on the electrode on the plate of the scale.

For very low frequencies the deformation is variable in time and it is proportional to the applied force. In DC there is a fix deformation while with the application of the AC voltage the deformation is variable in time. As a result of these different deformations over the surface of the electrode and negletting the edge effect, the ratio between the force with respectively the AC voltage and the DC voltage applied is:

$$\frac{F_{ac}}{F_{dc}} \cong 1 + \int_S \frac{d_t(P)}{d} dS ,$$

where d is the distance between the electrodes without voltage, $d_t(P)$ the displacement at the position P on the electrode when the nominal voltage is applied in DC.

At higher frequencies the proportionality between the deformation and applied force is not maintained. Furthermore, the electrode can be affected, at specific resonant frequencies, by large deformations driven by the pulsing force, whose frequency is double of that of the applied voltage. These resonant frequencies have been theoretically evaluated considering the equation that links the transversal displacement to the mechanical parameters.

This equation can be solved for the electrode on the plate of the scale by imposing proper conditions and the free vibration frequencies can be then computed.

The resulting vibration frequencies inside the working band of the electrometric AC/DC transfer standard are more than 50. However, as the applied force is axially symmetrical, the frequencies more likely to be excited are those following such a condition and are given in Table 1.

TABLE 1: Computed vibration frequencies in the electrode A (kHz)

i=0	i=1	i=2	i=3	i=4	i=5	i=6	i=7	i=8	i=9
1.10	6.7	16.4	30.5	49	72	99	130	166	206

5. TESTS ON THE INSTRUMENT

The functionality of the AC/DC transfer standard has been tested by applying to the input voltages up to 1200 V, both in DC and AC, and different frequencies in the operating range of the instrument (up to 100 kHz) with the electrodes placed at a distance of about 1 mm. In all this experiment the instrument worked as expected.

However, for frequencies lower than 200-300 Hz the readings of the instrument are not stable, possibly because the mass of both the electrode and the plate of the scale does not attenuate enough the vibrations induced by the application of a pulsing force and so there is interference with the sampling system.

The electrometric AC/DC transfer standard has been tested by applying increasing voltages and it has been found that there is a slight modification of the quadratic law between the attracting force and the applied voltage. This can be justified by a displacement of the electrode on the plate of the scale of about 200 nm for a variation of 1 mN in the attracting force.

The effect of the vibration has been tested near the frequency of the first vibration frequency $f_{0,0}$ where, there seems to be a transition between two states and a resonant peak.

Tests to detect possible mechanical effects for higher frequencies have also been performed by checking the continuity of the characteristics near some of the vibration frequencies but no significant discontinuities in the AC-DC transfer difference function have been found.

6. STABILITY

The short-term stability has been tested by applying a stable voltage to the input of the instrument and by acquiring the readings of the scale. The drift is usually less than 10 parts in 10^6 for periods of time of about 5 minutes for the instrument alone, while it doubles when a 10 W thermal converter is connected to it, for the heat produced by the range resistor. However, the drift is quite regular and its contribution to the determination of the AC/DC transfer difference, which can be computed by a relation that eliminates the linear drift, is less than 1 part in 10^6 (rms value) for a switching time less than 40 s.

So, a comparisons of the electrometric transfer standard with thermal converters has almost the same dispersion than the comparisons between two thermal converters.

The long term stability was tested by a set of repeated comparisons, in a time of about six months, with a special thermal converter with a low thermal effect range resistor. The resulting difference between the results was within 15 parts in 10^6. Furthermore, in comparison with this thermal converter the relative transfer difference changes for less than 10 parts in 10^6 as the voltage changes from 600 V to 1000 V.

7. COMPARISON WITH THERMAL CONVERTERS

The comparisons made in the last two years have shown that for thermal converters under investigation, the AC/DC transfer difference obtained by direct comparison with the instrument was compatible (within 2σ) with that obtained by means of the traditional step-up procedure, in all the frequency band from 1 kHz to 100 kHz.

A further investigation, in order to test the correctness of the direct measurement of AC/DC transfer difference, has been performed recently in an international comparison organised by CCEM in which the IEN took part. The extensive measurements performed for this comparison, with the use of an improved scheme of the step-up procedure confirmed a full compatibility of the measurements with the two methods and has been a further step in the characterisation of the instrument.

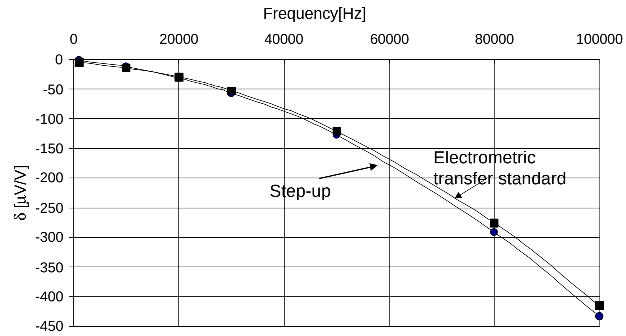

Fig.4 AC/DC transfer difference obtained by means of the step-up and that of obtained by the direct measurement with the electrometric transfer standard as a function of the frequency.

8. CONCLUSION

The prototype of an electrometric AC-DC transfer standard for voltages up to 1000 V built at IEN. The experiments confirm its regular behaviour.

Some possible electromagnetic effects have been computed. The AC/DC transfer difference due to all these effects is less than 2 part in 10^6 for a frequency up to 100 kHz

The mechanical effects, such as displacements and free vibration frequencies, have been taken into consideration. Experimental tests have found a discontinuity in the characteristic placed approximately at the first vibration frequency, while no other significant perturbations in the AC/DC transfer difference function have been found.

The comparisons with thermal converters have almost the same dispersion than the comparisons between two thermal converters. These comparisons have also shown that for thermal converters under investigation, the AC/DC transfer difference obtained by direct comparison with the instrument is almost compatible (within 2σ) with that obtained by means of the traditional step-up procedure, in all the frequency band from 1 kHz to 100 kHz. Furthermore a long term stability and absence of voltage effects have been verified in comparison with a thermal converter with a precision resistor.

For these reasons there is now sufficient experimental support for using the electrometric transfer in conjunction with thermal converters to maintain the traceability for voltage beyond 300 V and for frequencies from 1 kHz up to 100 kHz.

ACKNOWLEDGMENTS

Acknowledgments, if any, should be included before the references in a separate section.

REFERENCES

[1] U. Pogliano, G. C. Bosco, D. Serazio, "Development of a New Type of Electrometric ac-dc Transfer Standard", *Proceeding of IMTC/99*, vol. 3, 1999, pp. 1888-1893.

[2] U. Pogliano, "An electrometric method for precise ac/dc transfer measurements," *Digest CPEM'94*, 1994, pp. 363-364.