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AC TRACEABILITY IN THE MILLIVOLT RANGE UP TO 1 MHz BY MEANS OF A WIDEBAND TRANFORMER

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Abstract − At IEN the application of new procedures for the calibration of ac voltages in the millivolt range is now being developed. In this paper a specific method based on a high precision inductive divider and wideband transformers is analysed.

The experimental determination of the transformer parameters shows that the generation of calibrated ac voltages is possible with an uncertainty better than 50 parts in 10^6 down to 10 mV.

Keywords: Ac low voltages, calibration of ac voltmeters, transformers.

1. INTRODUCTION

At Istituto Elettrotecnico Nazionale (IEN) the traceability for ac voltages in the range from 0.5 V to 1000 V is well established. The standards are single and multijunction thermal converters, which are compared by means of an automatic system [1]. An electrometric ac-dc transfer standard [2] has been recently employed for the traceability in the high voltage range. For low ac voltages the traceability is now being developed by using resistive dividers [3] both to extend the frequency range for calibration and to take part to international comparisons. Beside resistive dividers, other methods such as micropotentiometers and inductive dividers are considered for the maintenance of the traceability and especially for the calibration of ac voltage measuring instruments.

Among these methods the use of transformers and inductive dividers is simple and straightforward for the extension of ac voltages. However, it has been used up to now at IEN only in a limited frequency range (for example from 40 Hz to 20 kHz).

2. METHODS IN LOW VOLTAGE GENERATION

In low voltage ranges, due to the intrinsic limitations of the direct comparison methods based on thermal converters, the systems employed are mainly based on the generation of calibrated voltages. These voltages are then applied to the measuring instruments to be calibrated or are compared to other voltages produced by sources under test.

Different methods and devices have been used for the generation of calibrated low voltages. In all these methods essentially two concepts have been employed. The first principle is the use of a device with a wide and flat frequency response. A specific device based on the application of this principle is the micropotentiometer [4]. In this device a coaxial circular resistor is used as a high frequency shunt affected only slightly by stray inductive parameters. The rms value of the current is kept constant in ac and dc by a thermal element. The ac voltage supplied to the input of the micropotentiometer is adjusted so that the output of the thermal element output has the same electromotive force as in dc.

The same principle can be also applied by building inductive and resistive dividers with flat input-output characteristics.

A different principle is used here, which is based on the relative invariance of the input-output ratio as a function of the applied voltage. The limits of this assumption for transformers is analysed and tested in this paper.

3. ONE STAGE TRANSFORMER

A transformer can be used for the generation ac voltages in different ways, each of them having their own advantages and disadvantages. In this paper two solutions have been considered and experimented. A first solution employs a simple one-stage transformer calibrated at a specific frequency by comparison with an inductive divider. Another solution is based on a double stage transformer that, for the accuracy level of its input-output ratio at intermediate frequency, does not need the calibration.

In both these methods the reference at intermediate frequency is strictly required only if the calibration of the ac voltmeter at intermediate voltages (0.3 V-3 V) is performed as a transfer standard, i.e. by assuming that the ac-dc transfer difference is known for these ranges.

In the first method a simple transformer that can operate in a wide frequency range is used. The calibration of this transformer can be performed by a standard method or directly by an inductive divider and the apparatus for the calibration of the ac voltmeter itself.

In this case the calibration procedure consists of two steps. In the first step an inductive divider calibrated at a specific frequency (for example 1 kHz) is connected to an ac generator and its input is measured by a proper calibrated voltmeter. Then, a transformer suitable to operate in the high frequency range with the input-output frequency ratio measured at intermediate voltages is used for the extension of the traceability in the whole frequency range.

The basic circuit for this calibration is shown in Fig. 1, where ID is the inductive divider and TR the transformer that replaces the inductive divider in the second step of the procedure.

The inductive divider is used to transfer the calibration in the range of a few volts of the first ac voltmeter, calibrated by the thermal converters, to the second ac voltmeter operating in millivolt range. In the frequency range from 50 Hz to 1 kHz the additional relative uncertainty introduced by the ratio of a two stage inductive divider can be less of 1 part in 10^6 for 0.1 ratio and less than 10 parts in 10^6 for the 0.01 ratio. So, the precision of the method for the extended frequency range mainly depends on the precision of the first ac voltmeter and on the stability of transformer ratio as function of the applied voltage.

The second step of the procedure is, in fact, based on the stability of the transformer ratio as a function of the applied voltage. The ratio between the voltage amplitudes at the input and at the output of the transformer is calibrated in the whole frequency range by means of the two voltmeters. Then this ratio is employed to extend the traceability down to the other ranges.

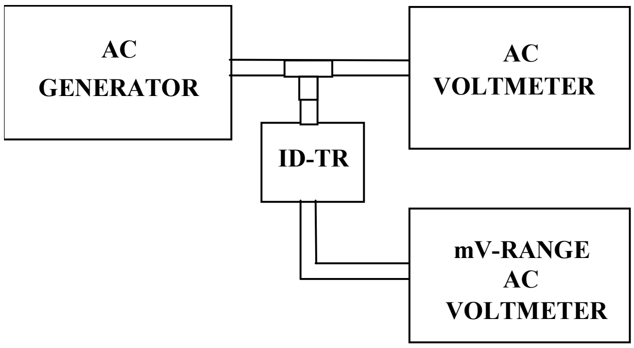

Fig. 1. Calibration of an ac voltmeter in the millivolt range by comparison with another ac voltmeter and an inductive divider and a wide frequency transformer

A transformer has been designed for the 0.1 ratio and has been built and tested for operation in the range from 10 mV to 300 mV

The magnetic core is amorphous and so it is suitable for application in high frequency. Taking into account the value of the measured parameters, the optimal turn number has been evaluated to be 30 for the primary windings and 3 for the secondary one.

Another transformer of ratio 0.1 has been built for the extension of the procedure to lower ac voltages.

4. EXPERIMENTAL TESTS ON THE PARAMETERS AND MODEL OF THE TRANSFORMER

The parameters of the high frequency transformer have been measured in the condition of 10 turns at both the primary and the secondary winding. This condition can be more easily tested because the voltage at both windings is almost the same. Extrapolation to the real operative conditions is made by means of the assumption that the series impedance grows approximately as function of the turn number, while the parallel impedance grows as a function of the square of this number.

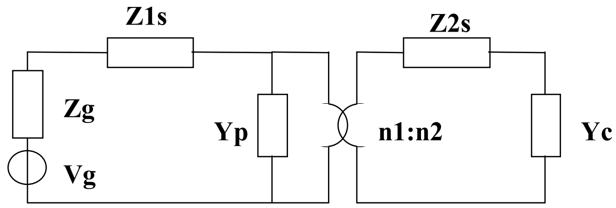

Fig. 2. Simplified model of the transformer used for the determination of the variation of the input-output ratio as a function of the voltage and frequency.

Evaluation of the serial impedances Z1s and Z2s shown on Fig. 2 has been made by closing in short circuit the secondary winding, while the parallel admittance Yp was measured with the secondary winding open. These measurements have been performed as a frequency function by an automatic impedance bridge. Three voltages of respectively 20 mV, 100 mV and 1 V have been applied in the tests. Using the parameters extrapolated to the real condition the amplitude error, evaluated as the difference between the obtained and the nominal values, is shown in Fig. 3 as a frequency function. The same figure also shows the differences between the error at the voltage of 100 mV and that of the other two voltages.

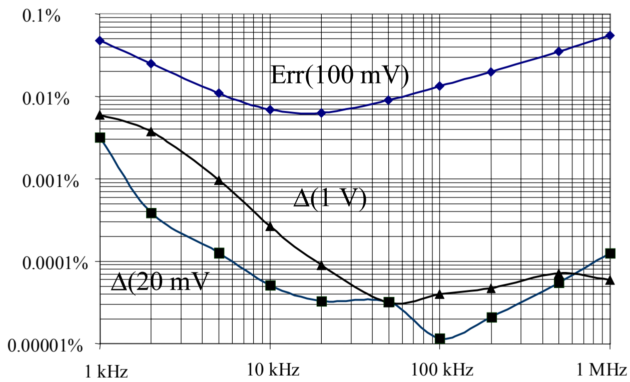

Fig. 3. Error in the input-output transfer function of the transformer (Yc=0) with an input voltage of 100 mV (Err(100 mV) and absolute value of the difference in this error when the input is respectively 20 mV (Δ(20 mV)) and 1 V (Δ(1 V)).

The results shown in Fig. 3 indicate that, for all frequencies the difference between the ratio with two different voltages is lower than 50 parts in 10^6.

5. DOUBLE STAGE TRANSFORMER

In order to avoid the calibration of the transformer at intermediate frequency a different solution based on a double stage transformer has also been investigated. The double stage transformer is made with two cores with common windings. The first core is employed to generate the main part of the magnetic flux necessary to support the electromotive force. The additional magnetic flux for reaching a more precise electromotive force, which reproduces exactly the applied input voltage, is supplied to the other core by a second stage winded around both cores. Fig. 4 shows a simplified equivalent circuit useful to derive theoretically the transformer ratio as a function of the frequency.

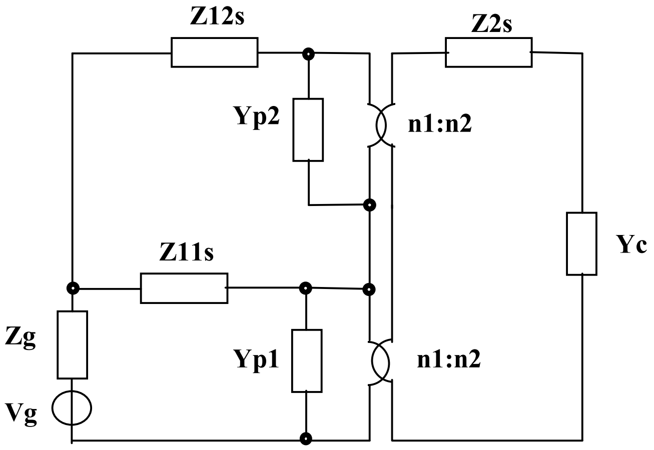

Fig. 4. Simplified model of the two-stage transformer used for the evaluation of the input-output ratio as a function of the frequency.

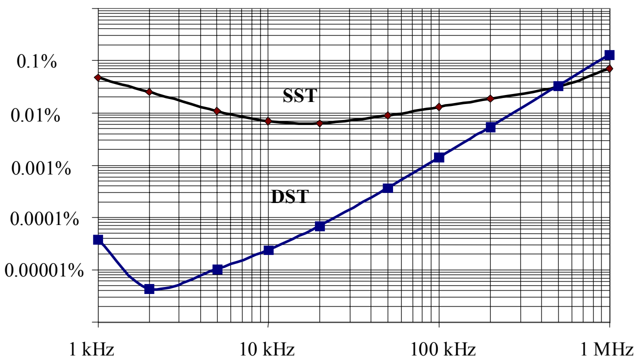

Fig. 5. Comparison between the errors in the input-output transfer functions of the single stage transformer (SST) and the double stage transformer (DST) the input voltage is 100 mV and for both Yc is a capacitance of 40 pF connected in parallel with a 1 MΩ resistor.

By applying to the model of the transformer given in Fig. 4 the values of the parameters evaluated by extrapolation from the measurements made with 10 turns, the error of the double stage transformer can be evaluated. The absolute value of this error is shown in Fig. 5 as a function of the frequency in comparison with that of the single stage transformer.

There is an evident improvement of the characteristics at low frequencies, while for frequencies beyond 200 kHz the error is higher. The double stage also reduces the variation of the ratio due to the variation of the parameters, so there is an additional benefit at low frequencies in the ratio stability as a frequency function.

6. PROTOTYPE OF A DOUBLE STAGE TRANSFORMER AND PRELIMINARY RESULTS

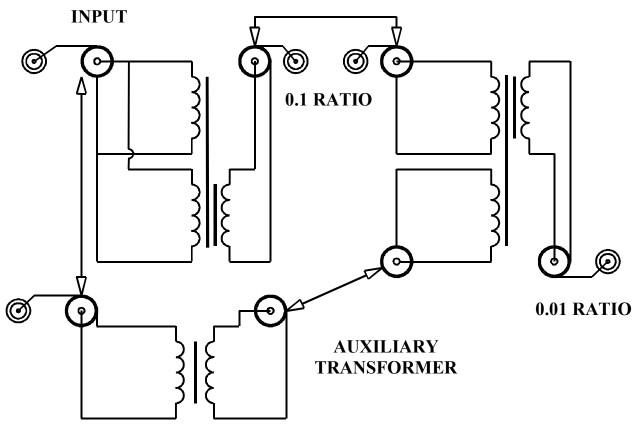

Fig. 6. Internal circuit of the prototype of the double stage composite transformer.

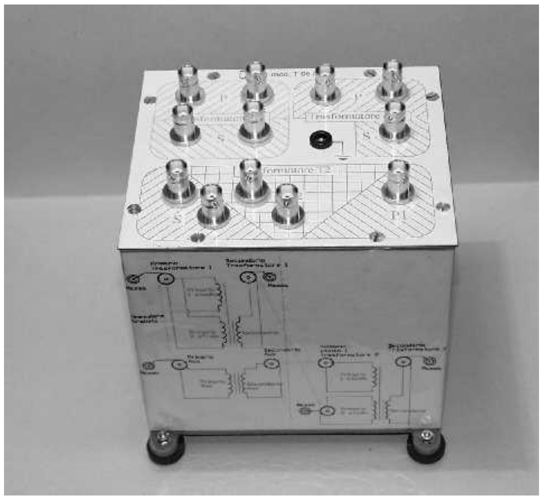

Fig. 7. Photograph of the composite transformer used for the extension of the traceability of ac voltages in the millivolt ranges for frequency up to 1 MHz.

A prototype of a composite transformer that can be configured as 0.1 ratio and 0.01ratio transformer has been built. The composite transformer is made of two double stage 0.1 ratio transformers, and an auxiliary transformer all enclosed in a screen. The transformers can be connected by means of suitable coaxial cables in the proper configuration. The scheme of the internal connections is represented in Fig. 6, while Fig. 7 shows a picture of this prototype.

Two specific tests have been performed on the double stage transformer. The first one has been about the ratio at intermediate frequency and the second is the evaluation of the error in the whole frequency band. The first test was performed at 1 kHz by the system developed at IEN for the ac ratio measurement [5] and the 0.1 ratio error resulted about 1.5 parts in 10^6. For the 0.01 ratio the total ratio error was less that 1 part in 10^7. The second test was performed by means of two ac voltmeters calibrated as ac-dc transfer standards by means of resistive dividers. The uncertainty of the calibration at intermediate level is not comparable to that of the previous system, however the resulting error of the transformer at 1 MHz is less than 0.5%, as expected by the computation from the parameters. The variation with the applied voltage of the transformer ratio has been verified to be zero within the uncertainty of the calibration of the voltmeters.

7. CONCLUSIONS

The analysis and the experimental results on the prototype of single and double stage wideband transformers show that the methods described are suitable for the calibration of the ac voltage in the range from 10 mV to 300 mV for frequencies from 1 kHz to 1 MHz. In these ranges the uncertainty can be better than 50 parts in 10^6. Further investigations are now being performed in order to extend the method in the range from 1 mV to 10 mV.

ACKNOWLEDGMENTS

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