VI Semetro
6º Seminário Internacional de Metrologia Elétrica
De 21 a 23 de setembro de 2005 · Copacabana, Rio de Janeiro, Brasil

REVIEW OF DESIGN-METHODS FOR HIGH PRECISION MEASURING TRANSFORMERS

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Abstract: This paper reviews many proposed methods to design high precision current and voltage transformers. Some of them are based on electromagnetic devices (passive), and others on electronic ones (active). A comparison between them is performed, taking into account different parameters as: accuracy, size and weight, cost, and construction troubles.

Key words: transformer, current, voltage, electronic compensation, error.

1. INTRODUCTION

Current and voltage transformers, and inductive voltage dividers (IVD) for high precision measurements, have been used for many decades. The principal problem for obtaining low errors is the behavior of the iron core. The relative permeability of commercial iron is not so high to get accuracies in the order of few parts in 10^6, but this value and betters are needed in many fields, as power, capacitance and ratio measurements.

Some methods were proposed to avoid that limitation. The first was based on a technique that uses double cores and double windings. One of the couples (core plus winding) is dedicated to supply the main magnetic flux, and the other to measurements purposes. When electronic devices became more powerful, from the last decades of the last century, other methods appeared. Only one winding and core is used, but an electronic circuit compensates for the non-ideal behavior of the electromagnetic components.

In the next sections most relevant compensation methods will be analyzed and compared.

2. CURRENT TRANSFORMERS

The main error source, at low frequencies, is the effect of the magnetizing current necessary to maintain the magnetic flux, because this current flows through the magnetizing branch, reducing in this way the output current. This effect produces ratio errors and phase displacement errors as well. Conventional transformer design technique is based on the reduction of the maximum value of that current using large magnetic cores to get a high magnetizing impedance [1]. Big wire cross-sections are also used to reduce the series resistance of the windings, reducing in this way the total load. Although the errors can be reduced without limit from a theoretical point of view, in practice class 0.1 (errors around 0.1%) is the best transformer that can be done with this designing technique.

Another technique uses two cores and two secondary windings (two stages) [2]. One of the core-winding sets is used for magnetizing purposes, and the other for measuring. Errors lower than 10 μA/A and 10 μrad can be achieved [3], while using only one stage, errors increase up to 350 μA/A and 500 μrad for the same example. This technique has the disadvantage that it leads to large, heavy, and costly transformers, if high accuracy is needed. Also, the construction procedures are complicated and manual manufacture is required.

Other authors proposed electronic methods to reduce the magnetizing current. In reference [4], an auxiliary winding is used to measure the magnetic flux, and an electronic control device reduces it to zero (ideally). Thus, the magnetizing voltage is zero, as well as the magnetizing current. This method has been widely used since the 60s [5]. Very small size and high precision transformers can be constructed based on it. Accuracies in the order of few parts in 10^6 can be obtained. Other electronic compensating method that mixes electronic devices and two stages has been presented in [6].

The main disadvantage of these methods is that they need a special transformer design with auxiliary windings and special cores, so that it is not possible to apply it to commercial current transformers. To work with conventional current transformers and clamp-on transformers, in [7] a different method was proposed. It computes the value of the magnetizing current only from the external secondary voltage and current. In this way, no auxiliary winding is necessary. Anyway, a limitation still exists; the electronic device must supply all the burden power. This can be a costly and cumbersome solution in cases were high power is needed, i.e. transformers with 5 A of secondary current with nominal power greater than 10 VA. To avoid this restriction, in [8] the electronic device only supplies a small current to the load of an equal value than the magnetizing current (in amplitude and in phase). In this way, the electronic amplifier can be a simple OpAmp driving currents of some milliamps. An accuracy improvement of more than a factor of 10 can be obtained with a small and cheap electronic device.

With the previous mentioned methods, the influence of the magnetizing current on the transformer error can be reduced at values lower than 1 part in 10^6. However, at this point, the stray capacitance effects cannot be ignored, in the audio frequency range. In [9] it is proposed to use a shielded cable for the secondary winding. Generally, shields are connected to some guard potential, but this proposal leaves the shield potential floating.

3. VOLTAGE TRANSFORMERS

In this case, measuring errors arrive because of the voltage drops in the series impedances. If no load is applied to the output (as in case of IVD), the voltage drop occurs only in the primary winding caused by the magnetizing current. Again, many compensating methods try to reduce that current. In this case, it is not possible to use the same principle than in current transformers because the main idea for them was to reduce the magnetic flux to zero. Voltage transformers need a substantial magnetic flux related to the applied voltages. Anyway, the technique of double core and double winding can be also applied. In [10], a two-stage IVD achieved errors as low as 5 parts in 10^9 in a single-decade divider. On the other hand, this technique leads to large and heavy transformers, as it was for current transformers.

Regarding electronic methods, many ideas have been proposed. A method that reduces the error caused by the output current was presented in [11]. It works well, but does not compensate for the error produced by the magnetizing current. In [12], a technique that compensates the voltage drops produced by the output and the magnetizing current, proved to reduced errors 50 times, varying the load between 0 VA and 10 VA, and the voltage between 40% and 100% of the nominal one. It uses a simple and low-power electronic device. However, it cannot be applied if high voltage exists between primary and secondary windings. For this case, proposal [13] can be used.

However, to apply these last proposals to an IVD would be very cumbersome because many values of the compensating device components depend on the selected ratio. To solve this limitation, in [14] a device that greatly increases the input impedance was showed. An error reduction by a factor of 170 was achieved in its experimental evaluation on a three decade IVD.

4. CONCLUSIONS

Two main ideas have been applied to reduce errors in measuring transformers: two-stage and electronic assistance. In the middle, some authors have proposed a mixture of them. While most transformers designed some decades ago were made according to the two-stage proposal, the electronic option is raising, due to the decrease of costs and low hand-made work that it requires. Cheaper, smaller and lighter transformers and voltage dividers can be done by this way.

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