Methods of Measuring Current Shunts

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1 Abstract

The purpose of this paper is to describe some of the various methods used at NPL for measuring current shunts Four methods are described, covering different frequency and current ranges. Depending on the method measurements can be made at 20 A up to 100 kHz and up to 1000 A at 50 Hz. A comparison of these methods, when performing typical calibrations of current shunts of different values and current ratings, is provided where possible.

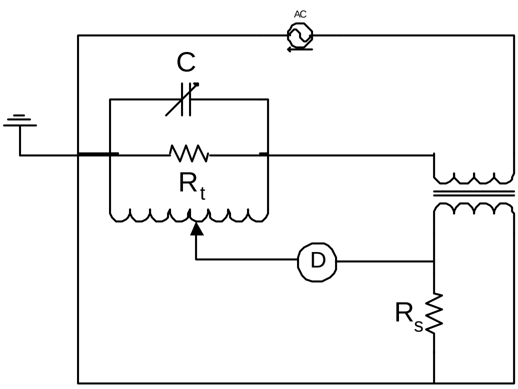
2 Introduction

There is a demand in industry for the measurement of current shunts of varying current ratings and frequency ranges. There are a number of ways to carry out these measurements. It is possible to measure both the imaginary and real parts of impedance by some methods, alternatively only the modulus of the impedance may be required. In most cases a given range of current and frequency will determine the choice of method.

Certain methods are more suitable for different current and frequency ranges. It is useful to compare the different methods where the frequency and current ranges overlap. These comparisons can give greater confidence in the use of the described techniques for the measurement of current shunts. The shunts used for the measurements in this paper were not necessarily designed for use at high frequencies. They have high time constants and serve to highlight some of the problems that can occur with current shunt measurements.

The four methods of measuring current shunts examined here are the Current Transformer (CT) Bridge, the Four Terminal Pair Bridge, AC/DC Transfer and the Direct Voltage Measurement System (DVMS). The CT bridge and 4 Terminal Pair Bridge both measure the in phase and quadrature components of impedance separately. No phase information can be obtained using the DVMS and AC/DC Transfer methods, only modulus.

3 The Current Transformer Bridge



The measurement circuit is shown in Figure 1. Connections to the bridge are made using screened twisted pair leads. The cases of the shunts under comparison are also connected to the screen. The measurement circuit is kept at a distance of > 2 m from the supply transformer, in order to minimise interference from the supply transformer, which is also screened. The shunt under test, R_t, is measured against a standard shunt, R_S, of known resistance, which is designed to have a low frequency dependence [1]. The current circuit is set up so that the test shunt is connected in series with a current transformer, which supplies a stepped down current to the standard shunt.

Figure 1 – The Current Transformer Bridge

An inductive voltage divider (IVD) is placed across the potential terminals of the appropriate shunt, with the output of the IVD connected across the other shunt, via a null detector, D. The IVD is set to null the detector. The ratio of the potentials across the two shunts is then given by the required IVD setting. A variable capacitance, C, placed across the potential terminals of one of the shunts, is used to cancel the quadrature signal. Where possible a substitution measurement is made to cancel out any errors in the bridge. A standard of similar value to the test shunt can be measured against another standard shunt and then substituted for the test shunt. The value of the test shunt can then be calculated from the ratio of the two IVD settings. The CT ratio and other conditions are the same in both measurements and so any in phase errors should cancel.

Cancelling the phase errors in the bridge can also be achieved with substitution. Since the time constants of the two standard shunts are very small, any quadrature components cancelled by the capacitance during the standard against standard measurement, will be due to phase errors in the bridge. The capacitance needed to balance the bridge during the standard against standard measurement is kept in circuit when the substitution is made. Any phase errors resulting from the CT and connecting leads are therefore cancelled and a second capacitance box can be used to balance the quadrature signal caused by the test shunt.For shunts of high time constant, where a large capacitance would be needed to balance the bridge, a resistor, r, is placed in the potential circuit as shown in Figure 2. The resistance has the effect of reducing the capacitance needed to null the detector by a calculable factor. Since the resistor is connected in the potential circuit it does not affect the in phase measurement. The IVD, resistor and detector are kept > 2 m away from the shunts to avoid any unwanted interactions due to mutual inductance effects

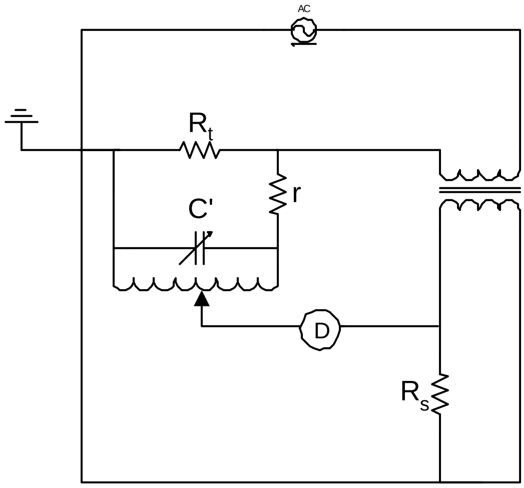


Figure 2 – Using a resistor to reduce the required capacitance.

4 The Four Terminal Pair Bridge

This bridge is used for low power (≤ 1 mW) measurements of AC resistances above 100 mΩ, at frequencies of up to 20 kHz. All connections on the bridge are made with coaxial cables, the outers of which are connected together and act as a screen. The cases of the shunts under test are connected to this screen. The main bridge balance is obtained using an IVD for the in-phase component and a variable capacitor connected across the more inductive of the two shunts being compared, This shunt is usually the device being tested. A number of secondary circuits are used on this bridge to prevent various sources of error. A detailed description of the bridge is given in[2](Chapter 6).

5 AC/DC Transfer 'Digital Bridge'

The AC/DC difference of a shunt can be measured against thermal transfer standards using the technique described in [3] and shown in Figure 3. This method gives the difference between AC and DC voltages across the shunt under test, when a sequence of AC and DC currents are applied to the test and standard shunts. The current is supplied by a transconductance amplifier, capable of delivering currents of up to 20 A at frequencies up to 100 kHz.

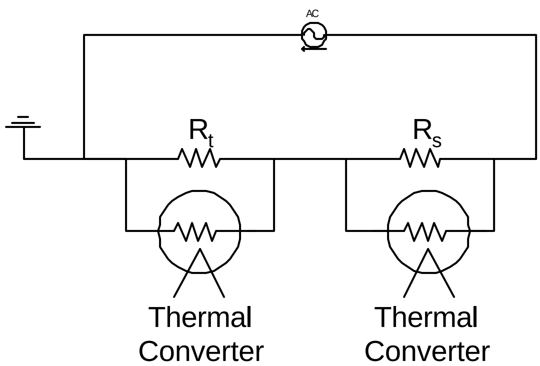


Figure 3 – AC/DC Transfer 'Digital Bridge'

The result of the measurement is the ac/dc difference of the combination of the thermal converter, the shunt and the circuit joining the two components. The effect of the circuit can be assessed by changing the configuration and is usually only a few ppm. The ac/dc difference of the thermal converter is known and is usually small, less than 5 ppm.

6 Direct Voltage Measurement System

In this method a stable current is passed through the DUT and the standard when connected in series, and the voltage developed across each is measured. If the current rating of the two shunts are very different then the circuit can be changed to that shown in Figure 4. Here a current transformer is used to provide the two different currents required. The current can be sourced from a transconductance amplifier or a power amplifier and supply transformer as appropriate.

The voltages across the test and standard shunts are measured using two calibrated voltmeters. The voltages are monitored by a computer, which takes a number of readings from the voltmeters and calculates an average ratio. In the case shown in Figure 4 a knowledge of the ratio of the current transformer is also required. This requirement can be dispensed with if a substitution method can be used.

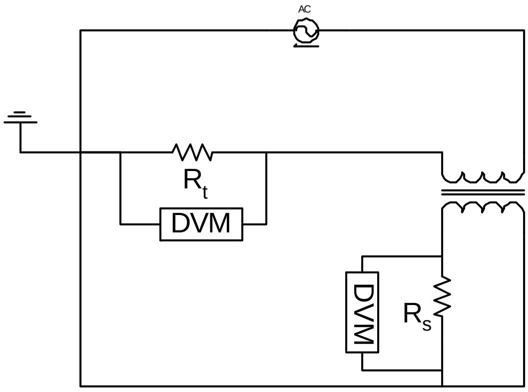


Figure 4 – Using a current transformer for high current measurements

7 Results and Comparisons

Comparison measurements are presented here on current shunts having a nominal resistance of 10 mΩ and 1 Ω. The shunts have current ratings of 140 A and 3 A respectively. Note that the particular current transformer used for these measurements had a frequency range from 400 Hz to 20 kHz and so no measurement was made at 100 Hz on the current transformer bridge, or on the DVMS method at 10 mΩ.

7.1 7.1 1 Ω Shunt Results

The variation of impedance with frequency of the 1 Ω shunt as measured by the applicable methods is given in Table 1.

Frequency (Hz)	Impedance (Ω)			
	CT Bridge	4 Terminal Pair Bridge	AC/DC Transfer	DVMS
100	-	1.000007	1.000011	1.000011
400	1.000060	1.000054	1.000060	1.000067
500	1.000081	1.000072	1.000079	1.000093
1000	1.000177	1.000165	1.000180	1.000196
2000	1.000383	1.000372	1.000391	1.000409
4000	1.000824	1.000791	1.000834	1.000842
5000	1.001077	1.001021	1.001080	1.001088
10000	1.002737	1.002510	1.002716	1.002711

The CT bridge measurements were made using the circuit shown in Figure 1. For the CT bridge and 4 Terminal Pair Bridge, the impedance is calculated from the real and imaginary parts, whereas the modulus is given directly by the AC/DC transfer and DVMS methods.

Table 1 – 1 Ω Shunt impedance comparisons

7.2 10 mΩ Shunt Results

The variation of impedance with frequency of the 10 mΩ shunt as measured by the applicable methods is given in Table 2.

Frequency (Hz)	Impedance (mΩ)		
	CT Bridge	AC/DC Transfer	DVMS
400	10.00043	9.99964	10.00001
500	10.00052	9.99969	10.00006
1000	10.00084	10.00006	10.00046
2000	10.00252	10.00198	10.00226
4000	10.00962	10.00936	10.00944
5000	10.01508	10.01489	10.01415
10000	10.06158	10.06167	10.05893

For the CT bridge method, the 10 mΩ shunt was measured using the circuit shown in Figure 2 directly against a standard shunt. No substitution measurement was made, as no 10 mΩ standard shunt was available. Hence the bridge was calibrated and the results are shown with relevant corrections made.

Table 2 – 10 mΩ Shunt impedance comparisons

8 Conclusions

Comparisons of the four methods have been shown to give reasonable agreement where their frequency and current ranges overlap. Suitable methods for measuring shunts up to 10 kHz at currents of up to 100 A have been described. Necessary modifications needed for the measurement of shunts with large time constants have been described. It is important to use substitution measurements wherever possible to cancel any errors in the bridge measurements.

Acknowledgement

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9 References

[1] Laug O. L., “A wide band transconductance amplifier for current calibrations”, IEEE Trans. Instrum.

[2] Kibble B. P. and Rayner G. H., “Coaxial AC Bridges", Adam Hilger, Bristol, 1984. See Chapter 6

[3] R B D Knight, D J Legg and P Martin, “Digital “bridge” for comparison of AC/DC transfer standards”, IEE Proceedings-A, v. 138, p 169-175 (1991).