POWER SUPPLIES AND MEASUREMENT TECHNIQUES FOR THE CALIBRATION OF HIGH CURRENT DC SHUNTS

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Abstract

A DC supply for the measurement of DC shunts at currents of up to 3000 A has been developed. The supply uses 12-pole rectification of the output of a 3-phase star:delta/star step-down transformer to produce an output with a ripple of about 2%. The design of the supply together with its use at NPL is described.

Introduction

For many years, a bank of rechargeable lead-acid batteries was used at the National Physical Laboratory to provide the current source for calibration of DC resistive shunts at currents of up to several thousand amperes. Such batteries are physically large and very heavy, occupy substantial space and require regular maintenance. Although batteries supply current with low ripple, they also have substantial disadvantages such as drift in the output voltage with time, the requirement for high power series resistors to control the output current and switches for disconnection and reversal of the current which need to be able to make and break the full load current. The performance of the batteries at NPL had gradually decreased over a number of years and so alternative sources of high current were investigated. At the time, replacement batteries and electronic switched-mode supplies were prohibitively expensive so an alternative approach proposed by one of the authors (WL), based on a 3-phase transformer and rectifier system was chosen instead.

Transformer-Rectifier

A 3-phase full wave rectifier ('6-pole') provides an inherent ripple of approx 5%, the lowest ripple frequency being 6 times the supply frequency (50 Hz) or 300 Hz. During the design phase, it was realised [1] that if a 12-pole rectifier system were used, driven by star and delta windings on the step-down transformer, the fundamental ripple frequency could be increased to 600 Hz and the nominal ripple reduced to 2%. This is possible because the outputs of the star and delta windings have a nominal phase angle difference of 30°.

A diagram of the power circuit is shown in Figure 1. A step-down transformer T2 converts the 415 V 3-phase input to two 4.3 V 3-phase outputs. The voltage to the input of the transformer is controlled by a star-connected assembly of three ganged variable transformers VT1, each rated at 25 A/phase. These main variable transformers, which have 295 turns on the winding, do not provide sufficient control resolution, and therefore a fine control is provided by three further 4 A/phase variable transformers VT2 which feed a "buck-and-boost transformer" T1. Further details of the design of transformer T2 are given in the Appendix.

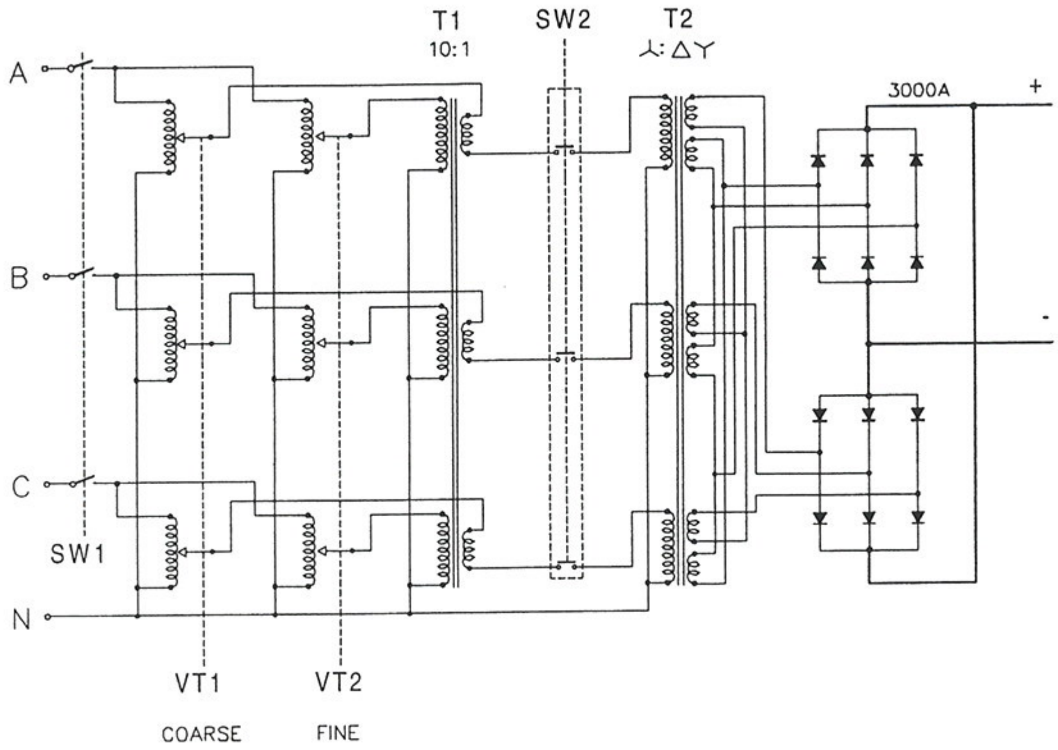

Figure 1

Switching and Current Reversal

In measurements of resistance with direct current, it is conventional to take the value of a resistor as the mean of readings with forward and reverse current and therefore provision must be made for reversing the test current. However, this is not always appropriate, as some high current shunts are used to measure the current in uni-directional power supplies and so should be calibrated with uni-directional current also.

In measuring systems using batteries there is no alternative but to cut the current and then switch back on with connections reversed. At NPL a large knife switch with a "centre off" position was used. If an electronic power supply is used, the current can be reduced to near zero and reversed by a switch which has adequate current carrying capacity but does not need the ability to make or break under load. For the supply described here, a simple strategy is adopted, whereby the three-phase AC supply is interrupted by SW2, the reversing switch operated, and the AC supply re-applied. The current controls are not disturbed so that, if the circuit resistance is the same in the forward and reverse case, the current value after restoration would be the same as before, but in the reverse polarity. In practice, this is not precisely the case, because the resistance of the reversing switch will be slightly different.

Measurement Systems

All resistance calibrations are essentially comparisons in which the ratio of the test resistance to that of an already traceably calibrated standard is determined. At NPL, high current shunts are calibrated using either a current comparator bridge or a potentiometric method using two voltmeters [2]. In both cases, the stability of the test current is not critical although the value must be approximately known and sufficiently stable as to not affect the measurement due to changes in device temperature.

(a) Direct current comparator.

The direct current comparator is particularly suited to calibrations of resistors carrying high currents because a current ratio, typically 1000:1, is used to scale the power dissipation down to a value appropriate to a precision reference standard. Many descriptions are available in published papers [3]. In brief, the principle is that of a self-balancing DC current transformer in which the absence of an ampere-turns balance between the primary and secondary is sensed by a magnetic core. The core is modulated with a superimposed alternating current and when a direct current magnetising force is present, even harmonic components of the modulation are generated. The even harmonic components are converted to an error signal by the detector electronics. Figure 2 shows how a current comparator is used in a resistance ratio bridge. The bridge is energised by a master current source S_1 and a slave current source S_2. The turns ratio N_1/N_2 on the comparator is chosen to be equal to the nominal ratio of the resistors R_X/R_Y. The current ratio I_1/I_2 is set equal to the reciprocal of the turns ratio so that there is no magnetic flux in the comparator and the voltages across the two resistors are approximately equal. The output from the comparator is used to correct the slave current source, S_2, by negative feedback. The resistor ratio can then be deduced from the voltage, V, on the null detector from the equation

$$\frac{R_Y}{R_X} = \frac{N_2}{N_1}\left[1 - \frac{V}{V_0}\right]$$

where V_0 is the voltage across the resistors. The great advantage of this method is that each resistor operates at its rated current, for example a 1 mΩ shunt carrying 1000 A can be directly compared with a 1 Ω standard carrying 1 A.

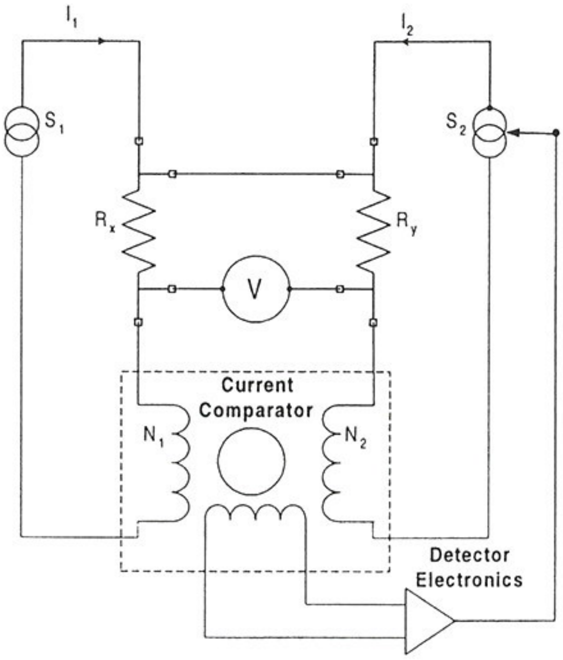

Figure 2

This technique is used at NPL for currents of up to 1000 A, which is the limit of the current comparators. The supply ripple from S_1 is coupled into the circuit of S_2 by transformer action so there is virtually no ripple flux present in the core. Also, the null detector, which is a photocell galvanometer, is unaffected by signals at the ripple frequency. A typical measurement uncertainty for this measurement system is 15 ppm at 700 A, expressed at a confidence interval of 95%.

(b) Two voltmeter method.

In this method, simultaneous measurements of the voltage drops across the test resistor and a reference resistor of similar value are made with two nominally identical digital voltmeters. Differences in the gain of the two voltmeters can be evaluated by interchanging them. The voltmeters are triggered simultaneously so that they are measuring the voltages across the resistors at the same time. This means that any short term drift in the supply current and also the supply ripple can be eliminated.

The disadvantage of this method is that the unknown and reference resistor carry the same current and therefore have the same power dissipation (if they have the same resistance). In order to characterise the unknown resistor, it is necessary to know the power coefficient of the reference device. At NPL, this problem is overcome by using reference resistors with a higher power rating than the test devices and calculating a power coefficient correction from measurements of the element temperature at the operating current. Measurements are made with this technique up to 3000 A and a typical measurement uncertainty is 100 ppm at 2250 A, expressed at a confidence interval of 95%.

Summary

A transformer-rectifier power supply having inherently low ripple has been developed suitable for providing a reversible and controllable test current for the calibration of resistive shunts at currents up to 3000 A DC under measurement conditions where stability of the current source is unimportant, e.g. where the comparison of the test resistor is via a direct current comparator to a standard resistor, or where the voltage drops across a test and a calibrated reference shunt are measured simultaneously.

Appendix

Transformer iron core Constructed as a five limb iron core design, to give a high zero phase sequence reactance, with the three centre limbs used for mounting the coils. Core material UNISIL 27M5. This avoids the need for an interphase transformer (IPT). Core weight 88 kg.

Transformer windings Coils are concentrically wound with NOMEX covered copper strip. Between the input and output windings is a copper earthed screen. All coils are insulated with class "F" insulation and varnish vacuum impregnated. Total copper 123 kg.

Input winding (Mains voltage) 3 phase 50 Hz star 4 wire. Each winding comprises 194 turns of 6.35 x 2.54 mm copper strip.

Output 1 (4·3 volts AC minimum) 3 phase star 4 wire, 1731 A line current. Each winding rated 2·5 V 1731 A comprising 2 turns 12·7 x 2·54 mm copper strip, 5 in parallel.

Output 2 (4·3 volts AC minimum) 3 phase delta 3 wire, 1731 A line current. Each winding rated 4·3 V 1000 A comprising 3½ turns 8·89 x 2·54 mm copper strip, 5 in parallel.

General Overall weight 250 kg. Iron losses 100 W (measured). Copper losses 890 W (calculated).

References

[1] Homard, J V (personal communication)

[2] A Guide to measuring resistance and impedance below 1 MHz, *The Institute of Measurement and Control*, ISBN 0 904457 31.1

[3] Kusters, N L, W J M Moore and P J Miljanic, "A current comparator for the precision measurement of D-C ratios", *IEEE Trans. Communications and Electronics,* pp 22-27, January 1964.
MacMartin, M P and N L Kusters, "A self-balancing direct current comparator for four-terminal resistance measurements", *IEEE Trans. Instrumentation and Measurement,* vol IM-15, pp 212-220, Dec. 1966.

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