APPLICATION OF BRIDGE CIRCUITS TO GENERATOR MAINTENANCE

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SUMMARY

The development of the Schering bridge for insulation measurement has been followed by various modifications and improvements to the original circuit. Lately the transformer-ratio-arm and the current comparator bridge circuits have been used in equipment designed for laboratory or for field testing of electrical insulation. Today there is instrumentation available that can measure the quality of electrical insulation at power frequency and over the full range of test voltage, and can accommodate grounded or ungrounded samples.

INTRODUCTION

The Capacitance Bridge is probably the third oldest instrument employed in the maintenance of generators and other electrical equipment, the first instrument being a low range ohmmeter used to measure the resistance of windings, and the second being a high range ohmmeter, or insulation tester, used to measure the conductivity of the generator insulation. Very early in electrical history it was realized that an ac measurement on insulation would provide invaluable information for the design, operation, and maintenance of electrical equipment such as generators, transformers and others. And so we see the development and exploitation of the Schering bridge for the measurement of electrical insulation (Figure 1). Because much of the in-service insulation used in electrical equipment is grounded and cannot be measured by the Schering bridge, we have the development of the inverted Schering bridge (Figure 2). To this day, we see test sets based on the inverted Schering bridge being used for the measurement of electrical insulation during commissioning or during routine maintenance procedures.

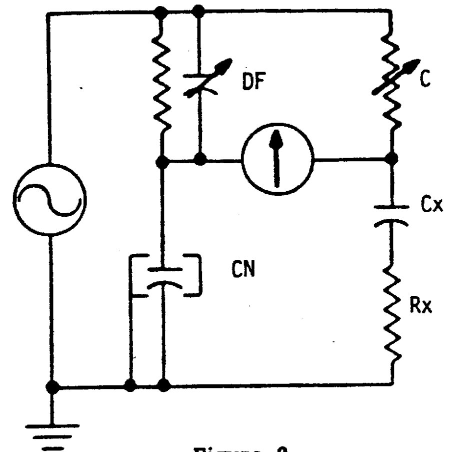

Figure 2

Inverted Schering Bridge

Some of these instruments use unique construction techniques which made them outstanding in their field. One such instrument is the "Cameron Hot Box" developed and pioneered in Ontario Hydro by A.W.W. Cameron and M. Kurtz.

Over the years other bridge circuits were found and applied to these measurements. The more notable ones were the transformer-ratio-arm bridge (Figure 3) and its modification called the current comparator bridge (Figure 4). The transformer-ratio-arm bridge suffered from the same shortcomings as the Schering bridge, namely that it was not very useful for measuring grounded specimens. Modifications to these newer instruments allowed grounded specimen measurements to be made (Figure 5).

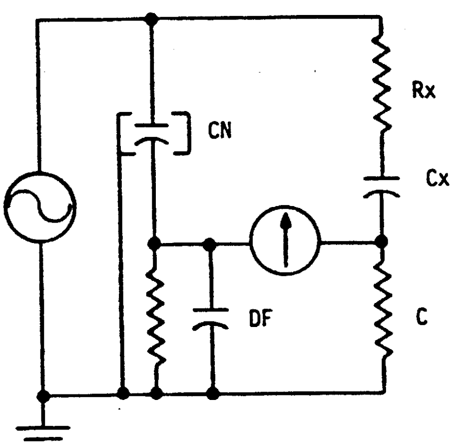

Figure 1

Schering Bridge

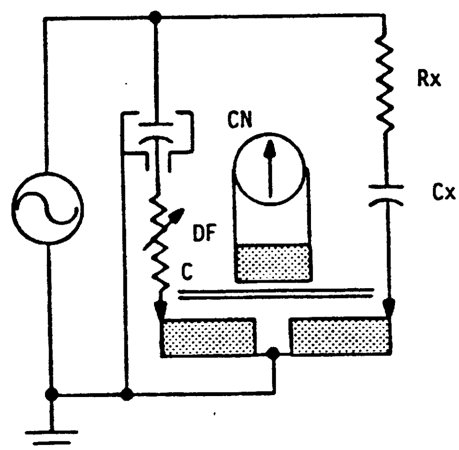

Figure 3

Transformer-Ratio-Arm Bridge

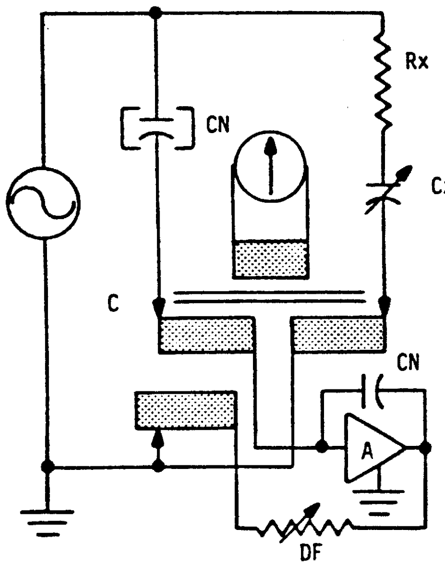

Figure 4

Current Comparator Bridge

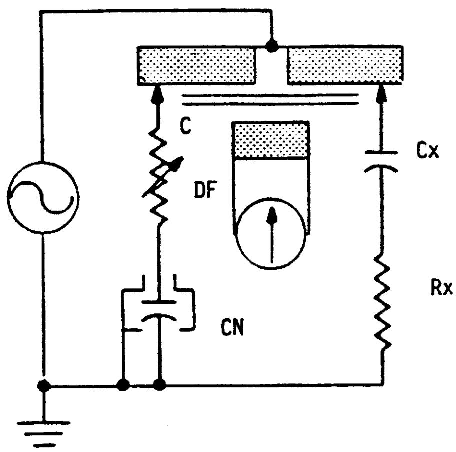

Figure 5

Inverted Transformer-Ratio-Arm Bridge

COMPARISON OF BRIDGE CIRCUITS

Some comparison of the basic bridges is in order. The advantage of the Schering bridge (Figure 1) is that it could be readily assembled from calibrated components such as resistors and capacitors. Its shortcoming is the finite resistance of bridge arms which makes guarding necessary if high accuracy is to be obtained. A guarded measurement requires two complex balances, one for the unknown and one for the guard circuit (Figure 6). The basic advantage of the transformer-ratio-arm bridge is that at balance the impedance of the transformer arm is very low. This feature provides a guard terminal which does not require a balance (Figure 3). Examination of the basic transformer-arm bridge circuit indicates that stray capacitance that is usually associated with a test sample is eliminated from the measurement by appearing across the supply (where it draws additional exciting current), or by appearing across the detector (where it reduces the sensitivity of the detector by shunting it). When stray capacitance appears across the supply, no errors are created. When stray capacitance appears across the transformer windings, a phase error (loss angle) results. This phase error is related to the ratio of the winding resistance to the impedance of the shunting capacitance. Thus for example, if the winding resistance is one ohm and it is shunted by 0.1 μF of stray capacitance, (26500 ohms at 60 Hz) an apparent loss angle of 4×10^{-5} radian results. Properly designed instruments can tolerate stray capacitances of ten times the range without generating errors larger than ten microradians.

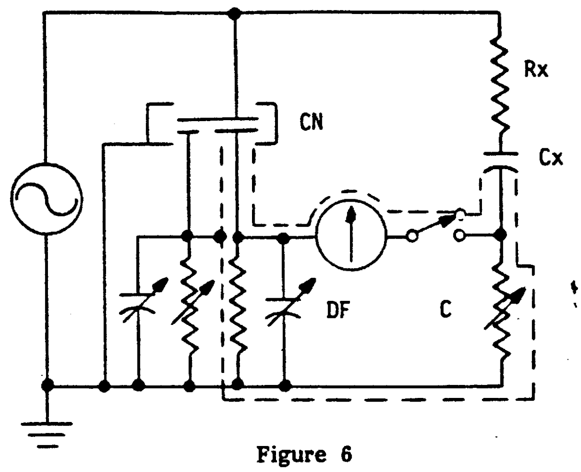

Figure 6

Schering Bridge with guard balance

The main advantages of the transformer-ratio-arm bridge can be summarized as follows:

1) Very low impedance of ratio arms resulting in a guard terminal being available.

2) The sensitivity of the transformer-ratio-arm bridge can be several order of magnitude higher than the Schering bridge and depends on the permeability of the iron used in the transformer.

3) The transformer can be readily used to match the impedance of the detector to the impedance of the bridge.

4) The capacitance read-out on the bridge depends on the ratio of transformer turns and therefore provides permanent accuracy.

Additional advantages of the current-comparator version of the transformer-ratio-arm bridge are:

5) Dissipation factor (loss angle) readings are independent of external cable connections.

6) The bridge can measure a negative as well as a positive loss.

BRIDGE CONNECTIONS

The bridge connections to be discussed here are theoretical and may or may not be possible with a particular make or model of instrument used. The intention is to show the different theoretical possibilities and to point out their special features and shortcomings.

1) The Basic Bridge Connection

The basic Schering or transformer-ratio-arm bridge circuit (Figures 1, 3) is intended for measuring ungrounded specimens and uses a grounded HV supply. Ground for the transformer-ratio-arm bridge serves as a guard and anything connected to ground is automatically eliminated from the measurement. For proper guarding the Schering bridge must use a guard circuit where additional balances, or an automatic guard amplifier are required (Figure 7). This basic connection is ideal for shop or laboratory testing of equipment before it is installed.

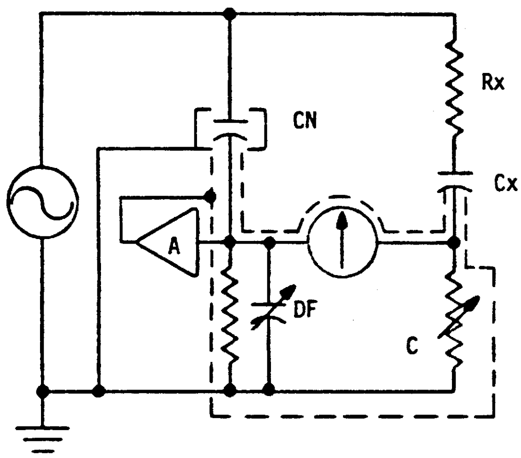

Figure 7

Schering Bridge with guard amplifier

2) The Inverted Bridge Connection

This circuit (Figures 2, 5) is intended primarily for grounded specimen such as generators, cables, transformers, and the like. It also uses a grounded supply. In many circles this configuration is referred to as the "Hot Guard" bridge because the guard voltage is the bridge supply voltage. Similarly to the basic bridge connection, anything connected to the bridge HV supply is eliminated from the measurement. The problems with this connection are that all the controls are at high voltage and therefore must be insulated for operator access. Bridges of this type are typically limited to voltages in the vicinity of 10 kV because of the insulation problems. This bridge connection is intended for maintenance testing of installed equipment. This connection presents additional safety problems because the bridge supply voltage appears both on the measuring and the guard leads.

3) Bridge Grounded on its Side

An examination of the bridge will indicate that a third configuration, that of grounding the bridge on its "side", exists (Figure 8). This configuration appears ideal for testing grounded specimens, and furthermore, furnishes a guard which is very close to ground potential. This circuit is referred to as the "Cold Guard" bridge by the people in the trade. Unfortunately this configuration does suffer from some shortcomings which include:

a) The supply is no longer directly grounded.

b) The bridge suffers from interference due to stray capacitance from the power supply leads.

The effect of both of these shortcomings can be greatly reduced by using a specially designed supply transformer. The transformer must be double shielded. One shield surrounds the primary winding and is grounded; the other shield surrounds the high voltage winding and is connected to the guard (Figure 9).

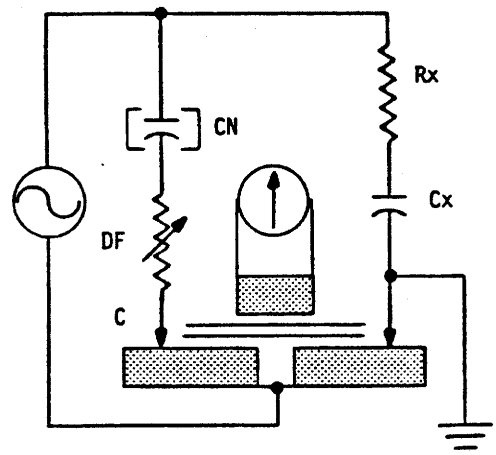

Figure 8

Transformer-Ratio-Bridge with side ground

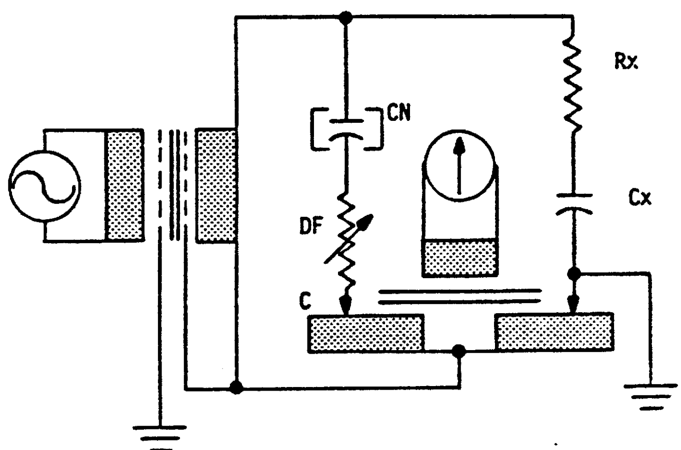

Figure 9

Transformer-Ratio-Bridge with side ground and double shielded supply Transformer

4) Special Features

Much of the test equipment available today has special features which make it easier or more convenient to use than equipment available one or two decades ago. Many of these features are discussed below.

Most bridges are now equipped with synchronous and phase-sensitive null detectors. This type of detector is sensitive only to the fundamental frequency and, provides the operator with a sense of direction (up or down) and allows for the separation of capacitance balance from the loss angle balance.

Some bridges are equipped with interference suppression equipment. This feature is especially useful when performing measurements in the field on grounded specimen. This feature allows the operator to cancel the effects of interference currents on the bridge permitting meaningful measurements.

Some test sets are designed to operate at frequencies which may be above or below the power frequency. The advantage of such equipment is that it can perform measurements in the presence of power frequency interference without the complication of having to balance out such interference.

BRIDGE USES

There are many uses for a bridge during the manufacture, installation and maintenance procedures for electrical equipment such as generators, motors, transformers and cables. The bridge may be used for tip-up measurements on generator or motor stator bars/1/. This test determines if the void content and insulation losses are below an agreed upon value, and if the insulation is not overstressed by the voltage. The tests are typically performed at two test voltages. One test voltage is somewhat higher than the line-to-ground operating voltage of the equipment, while the other voltage might be one-half of the above value. Suppliers and purchasers of equipment will agree as to the largest acceptable difference between the two measurements. Factors affecting the difference are the type of insulation used, and the operating voltage of the equipment. Modern insulating materials exhibit very little if any tip-up, when in good condition.

A second time that the bridge may be used is during the installation of bars in the slots of the stator. It is always a good policy to test small numbers of bars or coils prior to them being connected together. It is also a very good practice to measure the capacitance and dissipation factor of each phase of the machine separately as well as all phases together. Machines which have parallel windings should have each path measured separately before paralleling.

During the life of the equipment, the dissipation factor of the winding should be measured at regular intervals. It is a good practice to split the winding into several sections and measure these separately. The reason for this is that the coils near the top of the winding, operating at full machine voltage, will deteriorate faster than coils further down the winding, which operate at reduced voltage. By measuring smaller sections the deterioration of a small portion of the insulation can be detected. It should be stressed that the bridge measurement is capable of assessing the general condition of the insulation. It will detect degradation of insulation due to aging, overheating, contamination and other reasons. The bridge measurement is incapable of detecting very small or localized problems. This is due to the averaging affect of the measurement.

REFERENCE

1. IEEE Std. 286-1975. IEEE Recommended Practice for Measurement of Power-Factor Tip-up of Rotating Machinery Stator Coil Insulation.