LOW VOLTAGE CAPACITANCE & TAN DELTA TESTING, MEASUREMENT METHOD & APPLICATION

The quality of Electrical apparatus insulation is something normally taken for granted. However that same insulation can unnecessarily be the cause of equipment failure resulting in costly replacement or repairs and downtime. To avoid this situation one should monitor the quality of insulation by periodically testing the apparatus. One such test is a Capacitance and Dissipation Factor Test, which can detect moisture, contamination or deterioration of insulation (shorts, open circuits etc.). These tests may be done in shop or fields on bushings, breakers, transformers, cables, rotating machinery, insulating oils etc.

The basic requirements of equipment for Capacitance and Dissipation Factor Testing of electrical insulation are :-

a) Measure Capacitance
b) Measure Dissipation Factor
c) Perform measurement at power frequency
d) Operate on Grounded or Ungrounded samples
e) Provide required guarding

The first two are the quantities we are interested in measuring. Since all the specimen under test work at power frequency, the test are to be done at power frequency. Since in some cases testing is done on multi-terminal pieces of equipments (for example, transformer with two winding and case which may have one of the terminal grounded). It is desirable to have an equipment which can do measurements on both grounded and ungrounded specimens. Finally, in order to effectively measure separately each of capacitances associated with multi-terminal pieces of equipment, an effective guard terminal is necessary.

Over the years a number of instruments and test systems have been developed to meet the above requirements. Among them the Schering Bridge (Fig. 1) is the oldest bridge used for insulation measurements. As we can see the Schering Bridge fails to meet two of the basic requirements, the capability to do the tests on grounded specimens and provision of a guard terminal. A modified Schering Bridge called an “Inverted Schering Bridge” can be used for tests on ground terminals (Fig. 2). The main disadvantage of this bridge being, the controls and null detector are located at high voltage and so the operator has to do the adjustments by use of insulated rods or the operator should be actually situated at a high voltage in a screened cage.

Then came the Transformer Ratio Arm Bridge, where the resistance arm of the Schering Bridge are sub situated by transformer windings (Fig. 3). This results in the dramatic reduction in the impedance of these arms, so that the inter-winding corners of the bridge can be used as a guard terminal. This is because at balance, the transformer winding offers very low impedance. For the normal configuration of the bridge the ground becomes a guard which makes accurate and repeatable measurements possible. To measure grounded specimen, the transformer bridge can be operated inverted, (Fig. 4) or grounded on one side. When operated inverted the guard potential is a test voltage and therefore the bridge is often called a hot guard bridge. Such bridges are always usually available at low test voltages only. When operated with one side grounded it is called a Cold Guard Bridge, because guard is very close to ground potential (Fig. 5). One complication of Cold Guard Bridge is, an ungrounded supply is required. To operate free from external influences the supply transformer should be double shielded.

Other advantages of transformer arm bridge are :

a) A very high sensitivity can be obtained by using high permeability alloys for the transformer core.
b) The null detector can be matched to the bridge by simply varying the number of turns of the detector winding.
c) The ratio accuracy is very stable because it depends only on number of turns on the core.

Modern electronics had made possible the detectors that are not only tuned but are synchronous; i.e. they respond to only one frequency. By making a synchronous detector phase sensitive, the task of balancing the bridge is easier, because we can balance separately for capacitance and dissipation factor. When testing equipments in the field, especially on grounded specimen type, one encounters interference from energised lines or nearby equipments. In an effort to overcome these errors many bridges are equipped with supply reversal switches. By means of making two measurements and averaging the results, much of the effects of the interference is eliminated. This can also be done by injection on a separate winding in a transformer ratio arm bridge, a signal that is equal in magnitude, but opposite in phase to the interference.

Using a low voltage source in place of high voltage makes the bridge safer for operation, and makes precautions usually associated with high voltage instruments unnecessary. Since for most maintenance purposes, what we look for in tan delta measurement, is change in tan delta value with respect to a value originally recorded, making measurements at low voltage is more than adequate.

This simple diagram of a typical low voltage test is given in (Fig. 6).

The low voltage source is an oscillator at a frequency away from the power frequency such that strong power frequency currents do not interfere with the operation of the instrument and the frequency is close enough to the power frequency so that the bridge indicates capacitance and tan delta value close to the measurements done at power frequency. This makes the measurements possible in high voltage yards without the use of high voltage equipments to overcome interference or the use of complex interference suppressors. For 50 Hz power frequency a typical oscillator frequency can be 80 Hz.

The test set uses a high μ core transformer ratio arm bridge to have a high sensitivity and has all the advantages of the transformer arm bridge we have seen. The detector winding is tuned to the oscillator frequency for providing maximum sensitivity at the oscillator frequency. Connected to the bridge is a three terminal capacitor with dissipation factor represented by Rx. This could be transformer with low windings (L) high windings (H) and tank grounded (G). The voltage supply energises Cs (Standard capacitor in the test set) and Cx (specimen under test). Current of Cs. travels through the transformer winding and returns to the voltage supply. Current of Cx does the same but in opposite direction, thus generating an opposite polarity magnetic flux.

The output winding (or the detector winding) of the ratio transformer detects the difference in Cs current Vs the Cx current. The difference is displayed as an unbalanced null meter in the figure.

To balance the null meter both the magnetic fluxes (Cs and Cx) must cancel each other out. This is achieved by choosing different taps on the Ns and Nx through which the current of Cs and Cx are directed. Cs, Ns and Nx are so selected that when balanced the front panel dials directly read the capacitance.

The null meter is then made sensitive to only dissipation factor and balance is achieved by adjusting Rs (Resistance added to standard capacitance). Rs is caliberated directly to read dissipation factor when the bridge is balanced.

The null detector is an electronic null detector (Fig. 7)

The detector winding, which is tuned to the oscillator frequency is fed to a high input impedance follower. The output of the follower goes to a notch filter for power line frequency filtering followed by tuned amplifiers tuned to oscillator frequency. A reference output is generated from the oscillator and this is in synchronization with the capacitive current. The reference is phase shifted by 90 degrees to generate a reference synchronised to the resistive current. These two signals are multiplied with the tuned amplifier output such that only the in-phase signals produce a DC component for capacitance and dissipation factor. The multiplier outputs can be selected one at a time to the balance indicating meter, to balance capacitance and dissipation factors separately.

The bridge has other advantages : Because the bridge has a low voltage source which is locally generated, the bridge can be easily operated from a low voltage DC source and it is not necessary to have a mains power to operate the instrument. Being a low voltage bridge, it is small, so portable, and suitable for field use. The use of a frequency other than mains frequency makes it immune to mains frequency interference in high voltage yards.

By providing a proper switching network and by using a guard terminal the bridge can be used for both grounded and ungrounded measurements so that it can directly measure different capacitance associated with measurements.

APPLICATION

We have described the ratio arm bridge method which has made possible accurate testing at low voltages and the function of test equipment in general. This development has made it possible testing to use this test for maintenance of expensive vital electrical equipment. The same can also be used for manufacturing process testing and quality assurance.

The capacitance and more so Tan Delta values provide a definite clue to the condition of the apparatus before a breakdown occurs and thus avert costly unscheduled shutdowns. Insulating materials used in electrical apparatus, such as transformers, motors, generators, instrument transformers etc. deteriorate due to normal ageing, chemicals, moisture, dirt, unavoidable leakages and discharge during service. These conditions can be checked by several tests starting from insulation resistance measurement right upto measurement of integrated discharge energy values. However the basic features of a maintenance test are :

1) The test should indicate the overall quality of the insulation and its structural integrity.

2) The test should reflect any change in surface conditions.

3) The test should not take unduly long time.

4) The test should be easy to conduct and the interpretation of results should be practical and straight forward.

5) It should be possible to conduct the test in manufacturers work/repair shop and sites under similar conditions.

6) The equipment should be light and portable.

An examination of the above reveals that such tests can be :

a) Insulation resistance measurement at terminal voltage of the order of 2.5 or 5 KV DC and with instruments with resolutions to make readings in the range of 5000 M ohms and above meaningful.

b) Low voltage capacitance and Tan Delta measurement.

Insulation resistance measurement fulfills all requirement except that it does not indicate overall quality of the insulation. It mainly reflects surface conditions. Moreover the readings obtained are cramped, as resolution in the range which is vital viz. above 5000 M ohms is very poor.

On the other hand low voltage Tan Delta and Capacitance measurement fulfills all the conditions. By the very nature of measurement, overall insulation condition is assessed as it takes into account not only surface condition but also the internal voids, deterioration, moisture absorption and changes in dielectric constant due to ageing of insulation. The resolution of readings is excellent.

The concept is however new in our country although the few organisations are known to be doing this test for quite sometime now. Therefore it is necessary to elaborate a few aspects of this test.

The Tan Delta value changes with the temperature and therefore it is necessary to correct it to a given temperature say 20 or 30 degrees Centigrade. Then only any comparisons will be meaningful. There is no possibility of calculating such correction factors and these have to be evolved from field tests. The factors change from equipment to equipment and even the same equipment of different designs of same manufacture can show different pattern as illustrated in (Fig.8). Temperature correction factors for transformer are given in (Fig. 9). It may be noted here that the factors are taken from foreign publications and pertain to American equipment. These will not directly be applicable to indigenous equipment.

Several consulting firms specify measurement of excitation current and watt loss at 400/433 volts for transformers. The values so obtained are used as a check at the time of commissioning, which is important but essentially is a one time usage of the data. On the other hand low voltage measurement of Tan Delta at manufacturers works will provide data for life long maintenance of transformer. Tan Delta values for an equipment will naturally depend upon state of each component of insulation system and also the fittings/accessories of the equipment. For example, for a transformer it is paper, oil and other materials in the transformer assembly and OLTC and bushings, which are separate accessories or fittings. Where possible, accessories and insulation components should be checked individually to obtain a thorough assessment. Guidelines for an acceptable value have to be evolved by compiling data over a period. A typical example is given below for oil filled bushings.

Voltage Class		Tan Delta		
		Good	Investigate	Bad
Upto	76 KV	0-2.5%	2.51-3.5%	above 3.51%
	76 to 145 KV	0-2.0%	2.01-3.0%	above 3.01%
Above	145 KV	0-1.5%	1.51-2.5%	above 2.51%

Even if no base value or guideline is available, regular monitoring and recording of Tan Delta for a given piece of equipment will show up a point at which the value increases more rapidly. We can take this point for investigation and remedial action before a costly break down takes place.

It is acknowledge that measurement of Tan Delta at operating voltage does take into account conditions of stress and ionisation, which a low voltage measurement does not. However, the fact remains that an equipment having high Tan Delta will necessarily show a high value even at low voltages, though the value will be lower due to absence of electrical stress and ionisation. As a maintenance check test a low voltage measurement positively indicates state of insulation. High values indicate imminent trouble and a significant change in rate of increase gives warning that equipment needs attention.

Low voltage Tan Delta measurement can be used for monitoring health of insulation in any equipment like generators, motors, circuit breakers, instrument transformers etc. It will be valuable check for sealed transformers. It can be used to monitor condition of insulating oil as it reflects ageing unlike a BDV test. Transformer manufacturers can use it with advantage for controlling dry-out process through the vaccum cycles.

CONCLUSION

The paper deals with significance of Capacitance and Tan Delta values from view point of maintenance test. It is observed that Schering Bridge is not really suitable for measurement but ratio arm bridge provides the answer. The values of Tan Delta at low voltages will be certainly lower than those obtained at high voltages, but they provide a positive and definite indication of health of the insulation system / equipment. Such a test can be very logically included as a routine test in Indian Standards for transformers, motors, breakers etc., along with insulation resistance measurement. There is need to establish data by factory and field tests to derive full benefit of low voltage Tan Delta test.

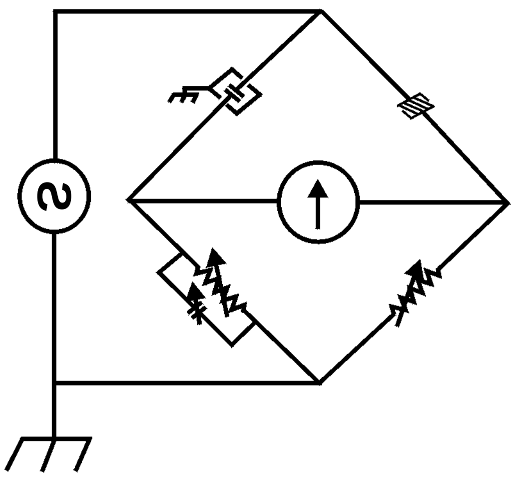


FIG. 1

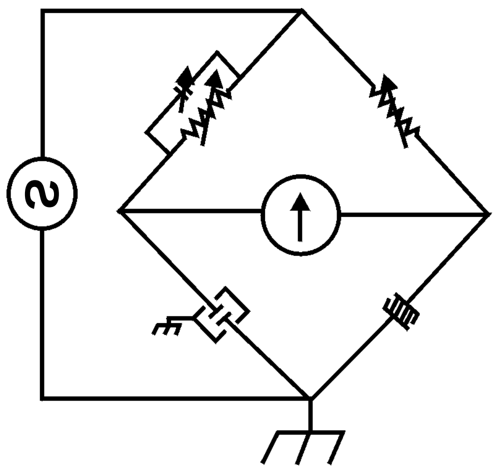


FIG. 2

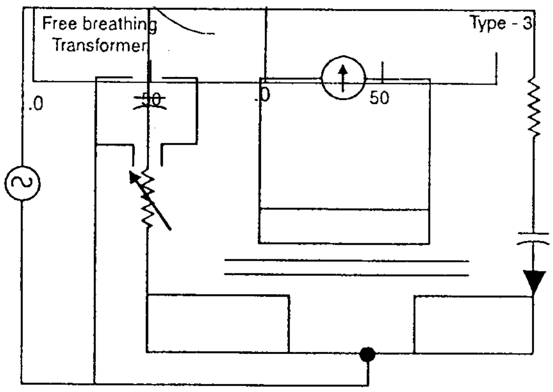


FIG. 3

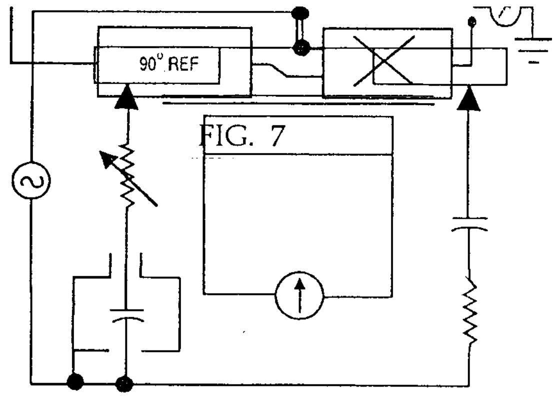


FIG. 4

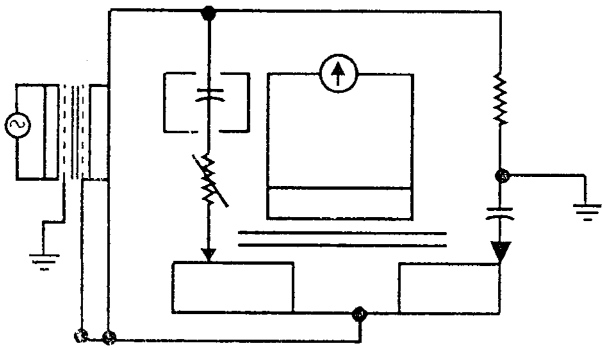


FIG. 5

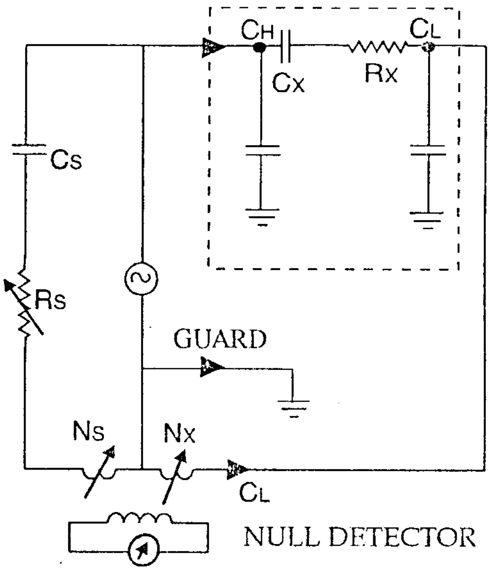
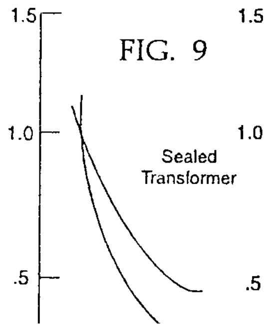
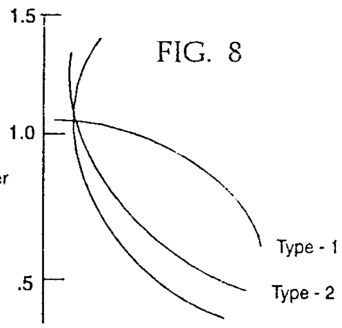
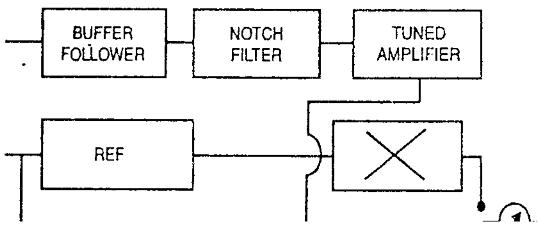


FIG. 6







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