# Chapter-9
# Non-Destructive Testing and Quality Control of Electrical Equipment

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# Objectives

- High voltage withstand tests of insulation
- Quality of finish of equipment insulation
- Partial breakdown measurement techniques
- Recommended procedures of high voltage testing of electrical apparatus

# Introduction

## Non Destructive Testing of Electrical Equipment

* It implies assessment of the quality of electrical insulation finish provided to the equipment.
* It is required in order to ensure satisfactory service of the equipment over the stipulated life span.
* The measurement techniques adopted are mainly electrical.
* As it implies, the non-destructive test measurements should not cause any damage to the equipment yet reveal the quality and condition of the dielectric performance.
* These tests are done to assess the electrical properties like resistivity, dielectric constant & loss factor over a wide frequency range.

# High-Voltage Withstand Test on Equipment

The high voltage tests on power apparatus are categorized into four types as recommended by specifications. These are:

- **Routine Test** This is performed by the manufacturer, the routine test demonstrates the correct production of the product in conformity of the specifications.
- **Type Test** This is also performed by the manufacturer but on a sample product from the production.
- **Commissioning Test** In this test, very large power equipment are often transported in parts and reassembled at the site. Hence 'quality acceptance tests' need to be performed before commissioning/after installation at the site.
- **Performance Test** The test after installation on 'complete system' is performed at the site of the installation under 'operational conditions'.

## ➢ Testing with AC Power Frequency Voltage

- The individual phase insulation is tested between the phase and the neutral/ ground, which under normal conditions has zero potential.
- If the rated rms voltage of equipment is $U_n$, the voltage between the phase and the neutral $U_o$ is equal to $U_n/\sqrt{3}$.
- The magnitude of power frequency high test voltage for each phase, as prescribed by the standards, vary from $2U_o$ to $3U_o$ for a duration of 1 to 15 minutes depending upon the country or the international (IEC) specifications.

# High-Voltage Withstand Test on Equipment

- ***HVAC Tests Recommendations for Objects having High Inductance***
- Power apparatus such as power transformers, instrument transformers, and high voltage line capacitance compensation reactors offer high inductive loads for the test voltage source (high voltage test transformers). Such apparatuses are tested in two ways:

1. High ac test voltage is applied by a high voltage test transformer. All the HV terminals of the windings are short circuited and the low voltage side of the windings are grounded along with the magnetic core and the container tank. High voltage resonant test systems are quite suitable for such objects.
2. The apparatus having low voltage primary windings like 'transformers' can be tested with HVAC induced voltage. The transformer under test is made to generate its own HVAC test voltage. A three-phase transformer is excited with an appropriate separate three-phase voltage source on the low voltage side. Because of the saturation of the magnetic core, this source is required to produce the voltage at frequency more than twice the rated operational frequency of the test object. Such 'Induced Voltage Tests' are required to follow the induced voltage PB tests too.

The duration of the induced voltage tests '$t_t$' is recommended to be derived by the following relation:

$$t_t = 120\,\frac{f_r}{f_t} \geq 15\ s$$

where, $f_r$ is the rated frequency of the equipment and $f_t$ the test voltage frequency

# High-Voltage Withstand Test on Equipment

## ➢ Impulse Voltage Withstand Tests

- The charge injected into the system by the lightning strikes and switching phenomena is restless on the conductors and it propagates in the form of ‘travelling wave’ at a speed of light producing transient overvoltage whose magnitude depends upon the surge impedance of the conductor it travels.
- These may reach every part of the power network at an attenuated magnitude.
- The overvoltage are superimposed on the network over and above the rated voltage, hence the insulation is excessively stressed.
- Therefore all major high voltage equipment in the power network are put through the impulse voltage withstand tests.
- Impulse voltage tests are performed on the transformers according to IEC-60076-3 and 60060-1 (2010).

$$W_{min\ (impulse\ generator)} > \frac{100.2\pi f.T_2^2.V_t^2.S_r}{Z.V_n^2.\eta^2}$$

$V_n$ - rate line to line voltage in volts;
f - rated frequency in Hz;
Z - short circuit impedance percentage in % at the test terminals;
$S_r$ - three-phase power rating in volt–amperes;
$V_t$ - li test voltage values in volts;
$t_2$ - time to half value of the li impulse voltage in μs;
η - efficiency factor in per unit.

# High-Voltage Withstand Test on Equipment

## ➢ Tests Performed with High DC Voltages

- Tests with dc high voltage need to be performed on HVDC equipment, insulators, etc.
- The high dc test voltage generators normally have a very low current ratings, in mA.
- It is because with dc a dielectric behaves like an open circuit and hence no charging current is required by the capacitance formed by the dielectric.
- The high voltage tests with dc on transformers is performed as part of the commissioning and/or performance test at site.

**Table 1. Recommended test on power transformers for different rated voltages, IEC 60076-3**

| Rated voltage, $U_n$ | $\leq$ 72.5 kV | 72.5 kV $\geq$ $U_n$ $\leq$ 170kV | $\geq$ 170 kV |
|---|---|---|---|
| Full lightning impulse voltage , li | Type test | Routine test | Included in li (chopped) test |
| Chopped lighting impulse | Special test | Special test | Routine test |
| Switching impulse test, si | Not applicable | Special test | Routine test |
| Applied voltage test | Routine test | Routine test | Routine test |
| Induced voltage withstand test | Routine test | Routine test | Replaced by si and induced voltage test with pd measurement |
| Induced voltage test with PD measurement | Special test | Special orroutine test | Routine test |

# Measurement of Dielectric Properties with Schering Bridge

For the measurement of active power loss in the dielectric on applying ac voltage, this bridge circuit was developed by H. Schering in 1919. Since then it is used widely for HV measurements and non-destructive testing for quality assessment of the factory finish and working state of dielectrics in different equipment. Figure below shows circuit of Schering bridge.

$R_x$, Cx -Test object
$C_2$ – Loss free Standard HV capacitor
$R_3$,$C_4$ - Balancing elements
$R_4$ - Fixed resistor
N - Null indicator
S - Screening

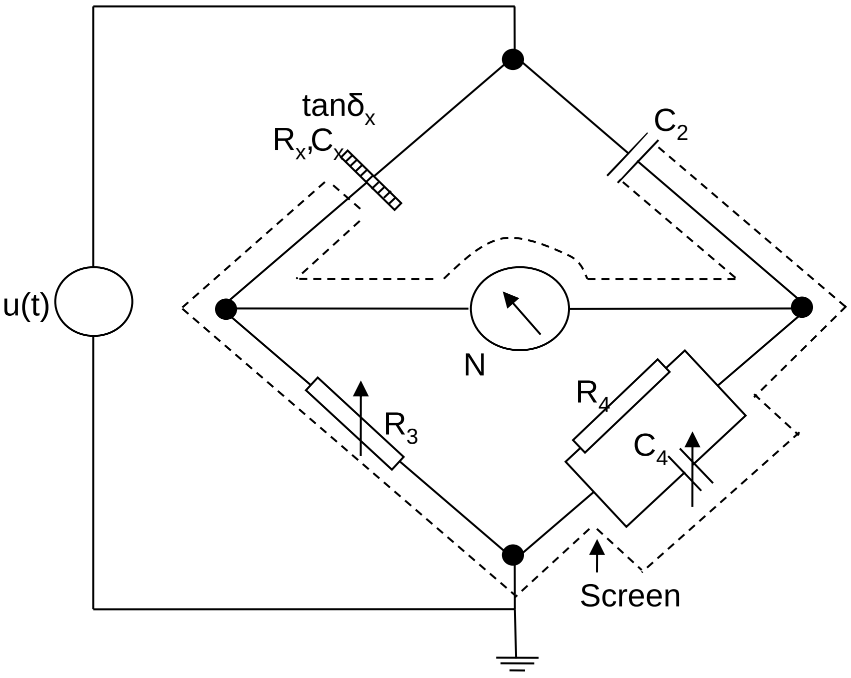



Fig. 1. Circuit diagram of a Schering Bridge

# Measurement of Dielectric Properties with Schering Bridge

The portions of the circuit shown under screening are all at low voltage. Only the test object $C_x$ and the standard capacitor $C_2$ are at high voltage. $C_2$ must be an active power loss free ($R_2$ = infinity) capacitor. The bridge is equipped with over voltage protective devices. By adjusting resistor $R_3$ and the capacitor $C_4$ the bridge can be balanced. When the bridge is balanced, the following relation holds good, considering $R_x$ and $C_x$ to be in parallel

$$\bar{Y}_4 \bar{Y}_x = \bar{Y}_2 \bar{Y}_3$$

$$\left(\frac{1}{R_4} + j\omega C_4\right)\left(\frac{1}{R_x} + j\omega C_x\right) = \frac{j\omega C_2}{R_3}$$

On comparing the real and imaginary parts of the equation, we obtain:

$$tan\delta_x = \frac{1}{\omega R_x C_x} = \omega R_4 C_4$$

The other quantities required to be determined can also be derived as follows;

$$C_x = C_2 \frac{R_4/R_3}{1 + tan^2\delta_x} = C_2 \frac{R_4}{R_3}$$

$$\varepsilon_r = \frac{C_x}{C_0} \quad and \quad R_x = \frac{1}{\omega C_x tan\delta_x}$$

For the power frequency of 50 Hz, $\omega = 100\pi$. If $R_4$ is chosen to be equal to $1000/\pi$, and since $\tan\delta = \omega R_4 C_4$, It is measured directly on balancing the bridge by varying $C_4$ and putting its value in Farads.

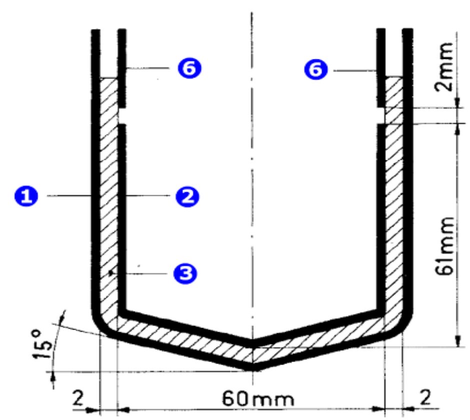
# Measurement of Dielectric Properties with Schering Bridge

## ➢ Standard Guard-ring Capacitor for Measuring tan $\delta$ of Liquid Dielectrics

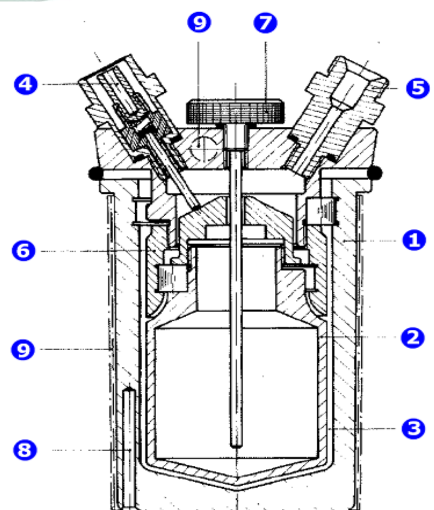
- This is a standard apparatus known as ‘test cell’, especially designed according to VDE-0370 Specifications, Germany for measuring dielectric properties of liquid dielectrics, shown in Fig. 2.

(a)

| | |
|---|---|
| Spacing between the HV and Ground electrodes | 2 mm |
| No-load capacitance $C_o$, with air/vacuum | ≈ 60 pF |
| Maximum voltage application | 2 kV |
| Amount of liquid required for measurement | ~ 40 cm$^3$ |
| Dimensions | 240 mm dia. x 220 mm high |
| Total net weight | ~ 10 kg |




(b)




(c)

**Legend**
1 High-voltage electrode
2 Measuring electrode
3 Oil to be measured
4 Connection for measuring electrode
5 Vacuum connection
6 Guard electrode
7 Temperature sensor with indicating instrument
8 Pt-temperature sensor
9 Heating

**Fig.2. (a) Oil test cell (b) Cross-sectional sketch of a standard guard-ring capacitor as per VDE specifications, courtesy Haefely Hipotronics, Germany**

# Mega-ohm Meter for Dielectric Measurement of Insulation Resistance

- The dc resistance $R_{dc}$ or $R_{ins}$ offered by the insulation of any gadget can also be measured directly with the help of a measuring instrument known as 'MΩ Meter'.
- The dc insulation resistance, $R_{dc}$ and the specific insulation resistance of a dielectric are related as;

$$R_{dc} = \rho_{ins} \frac{d}{A}$$

- Considering a uniform field the capacitance of the test cell with vacuum or air ($\varepsilon_r = 1$), $C_o$ is equal to $\varepsilon_o . A/d$. Therefore $\rho_{ins} = R_{dc}$. If the measurement is performed with the test cell described.

$$\rho_{ins} = \frac{R_{ins} . C_0}{\varepsilon_0} \quad \Omega m \quad = \frac{R_{ins} . 60 \times 10^{-12}}{8.854 \times 10^{-12}} \quad = \frac{R_{ins} \times 60}{8.854} \quad \Omega m$$

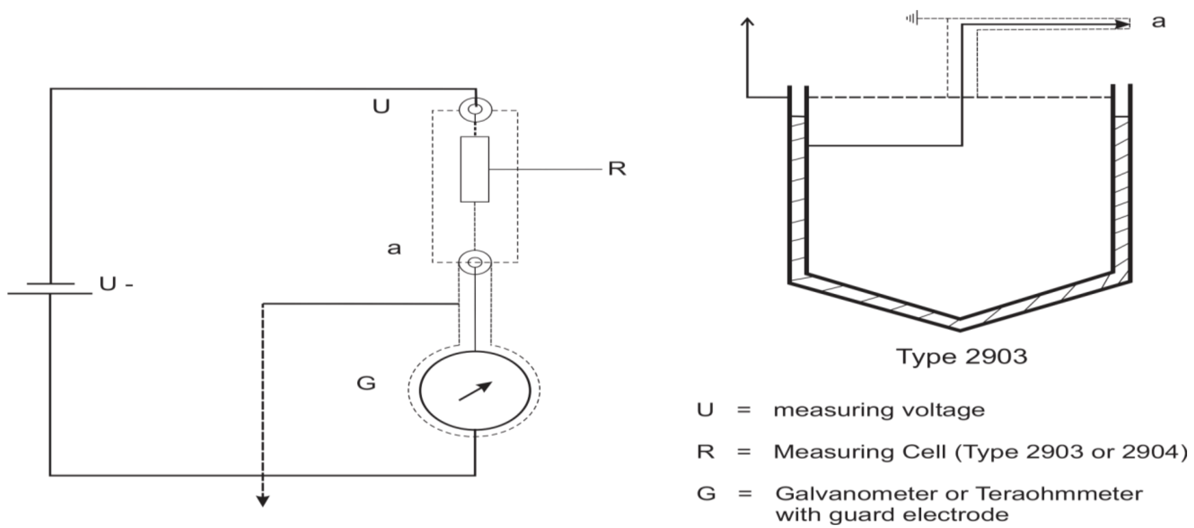



Fig.3. Connection details for the measurement of Insulation Resistance with standard cell

# Partial Breakdown Measurement Technique in Dielectrics

- PB in solid dielectrics are most damaging. These may reduce the life of the equipment drastically.
- The damage not only depends upon the intensity of PB but also upon the location and the time required for the formation of conducting path (treeing process).

There are three basic circuits which can be employed for the measurement of PB measurable quantities suitable to convenience or specific requirement

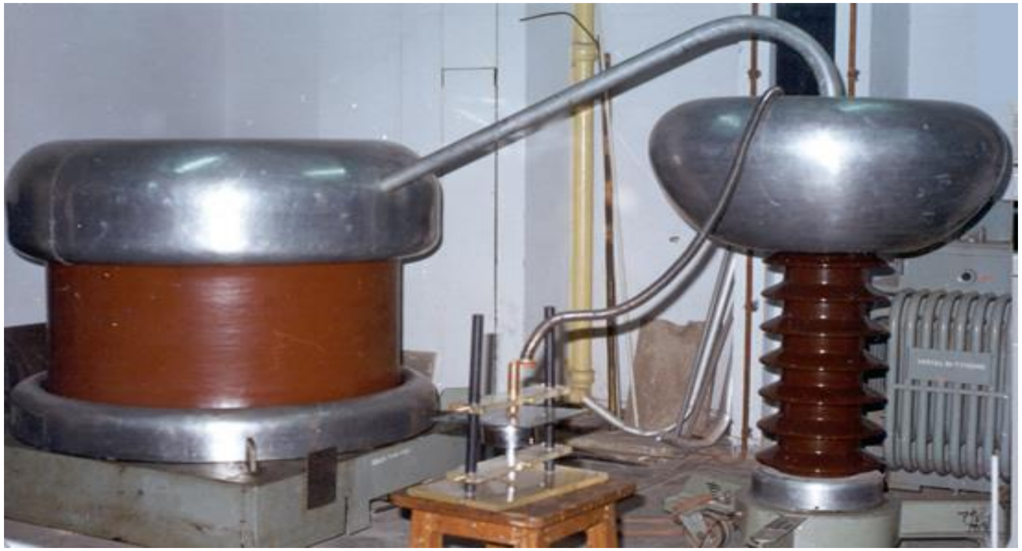


**Fig. 4 A PB free 100 kV Transformer and 1.1 nF Coupling Capacitor setup in HV Laboratory at IIT Kanpur**

# Partial Breakdown Measurement Technique in Dielectrics

- If a global breakdown or complete rupture of dielectric is expected to take place during the PB measurements, it is advisable to chose the circuit shown in Fig. 5 (a) below in order to protect the measuring impedance $Z_m$ and the voltage measuring unit from over-voltages developed at breakdown.

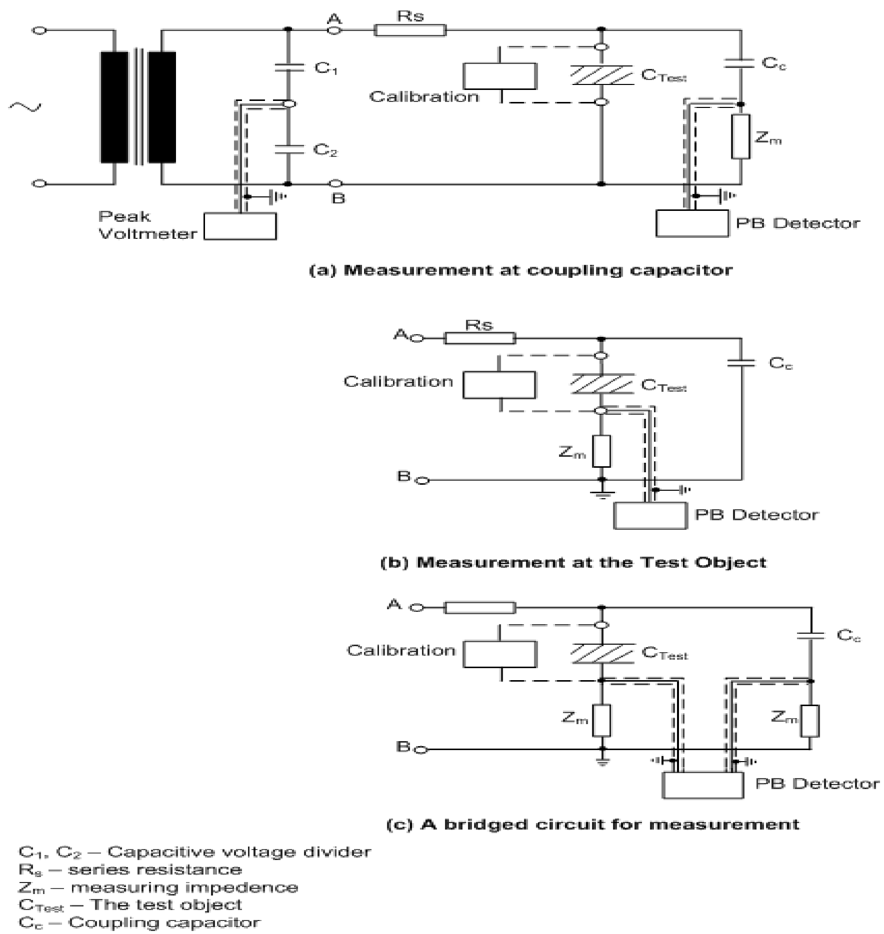



Fig. 5 Partial Breakdown Measurement Circuits

# Partial Breakdown Measurement Technique in Dielectrics

- If the capacitance of the coupling capacitor $C_c$ is smaller than the capacitance of the test object, the sensitivity of the measurement with circuit shown in Fig 5(b) is higher than with the circuit discussed with measurement at coupling capacitor.

- The bridge circuit in Fig 5(c) is more suitable for the measurement at sites having high electromagnetic interference (EMI). Some times it is difficult to make distinction between the PB pulse generated within the test object and the external interference. However, incorporation of suitable filters in modern PB detection facilitate the measurement even under external EMI.

- Calibration of the measuring circuit is required to be done with"standard calibrating charge generator". The measurable quantity of the apparent charge and the sensitivity of the measurement depend largely upon the calibration.

# Testing of Selective Electrical Apparatus

## ➢High-Voltage Tests on Surge Arresters

✓***Power Frequency Spark-over Test:*** This is routine test The test is conducted using a series resistance to limit the current in case a sparkover occurs. The arrester has to withstand at least 1.5 times the rated value of the voltage for five successive applications. The test is generally done also under dry and wet conditions.

✓***Impulse Sparkover Test:*** These tests are conducted on same samples used for power –frequency sparkover tests. These test made to ensure that arrester operates successfully each time for a standard impulse of specified voltage.

✓***Front of Wave Sparkover Test :*** These tests are conducted to make sure that flashover occurs for every steep rising wavefornt of high peak values when applied on surge arresters. This test is performed with an impulse having a rate of rise of 100 kV/μs.

## ➢High-Voltage Tests on Power Cables

Cables are tested for withstand voltages using the power frequency a.c., d.c., and impulse voltages. At the time of manufacture, the entire cable is passed through a high voltage test at the rated voltage to check the continuity of the cable. As a routine test, the cable is tested applying an a.c. voltage of 2.5 times the rated value for 10 min. No damage to the cable insulation should occur. Type tests arc done on cable samples using both high voltage d.c. and impulse voltages. The d.c. test consists of applying 1.8 times the rated d.c. voltage of negative polarity for 30 min., and the cable system is said to be fit, if it withstands the test. For impulse tests, impulse voltage of the prescribed magnitude as per specifications is applied, and the cable has to withstand five applications without any damage.

# Summary

- In order to ensure the quality of finish product in the manufacturing process, it must undergo a number of tests.
- These tests in no way should cause any damage to the product itself. Hence their specifications are derived collectively with utmost care.
- The concept of ‘non-destructive testing and quality control’ has developed in the industry over the time.
- For high voltage power apparatus, most countries in the world, including India, follow today the recommended specifications developed by a consortium of nations known as ‘International Electrotechnical Commission, (IEC).
- In this chapter, main non-destructive high voltage withstands tests of insulation provided on power apparatuses have been discussed.
- Several techniques and test set-up for the measurement of dielectric properties have been presented in details like, Schering bridge, guard ring capacitor, mega-ohm meter and for partial breakdown test.
- Recommended procedures of high voltage testing of selective electrical apparatus has been presented like surge arrestors and power cables.

# Thank You
# &
# References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