High Voltage Testing

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Why Testing?

- Demonstrate equipment fulfils standard specs and functional requirements
- Purpose may be type tests to check quality assurance of Equipment Design
- Routine Tests to check quality assurance of the Equipment Manufacture
- Further routine tests ascertain ability of equipment to withstand stresses during entire life

- Test stress should be high enough to be sensitive to withstand but low enough not to cause any defect during the test; which may deteriorate eqpt. later
- Tested condition depends on experience concerning stress and material behavior to the test

Considerations

1. Requirements
2. Regulations or law
3. Mutual agreement on technical specs
4. Economy

- This lecture deals with item 1 only

Recommendations

- IEC60071 – describes relationship of various types of test voltages – ac, dc and impulse
- IEC60060 – specifies Voltage wave shapes, tolerances and measurement un-certainty
- HV apparatus have specific IEC stds.

1. IEC60076 specifies switching impulse for transformer. This is over and above IEC60060
2. IEC60230 specifies additional criteria for impulse tests on cables with front time up to 5 us as opposed to std. 1.2 us. A low front time would result in oscillations. Increase in time enables double exponential

- Precise definitions necessary

Definitions

- Insulation Co-ordination – selecting insulation levels keeping eqpt strength, service environment together with Protective devices
- External Insulation – distance in air, surface in contact with air for solid insulation effected by external conditions such as pollution, humidity and atmospheric conditions

Definitions Contd.

- Internal Insulation – solid, liquid or gaseous parts inside an equipment protected from atmosphere
- Self Restoring Insulation – that which restores after a breakdown eg: Air or gases, liquids to some extent
- Non-self-restoring Insulation – that which loses insulating properties after a breakdown eg:solids

Definitions Contd.

- Nominal System Voltage – the Voltage used to designate a system eg: 400 V, 11 kV, 33 kV, 66 kV, 132 kV, 220 kV, 345 kV, 400 kV, 500 kV, 735 kV, 765 kV, 800 kV and 1200 kV (line to line RMS 50 / 60 Hz)
- Highest System Voltage – Highest value under normal conditions usually $\pm$ 10 %
- Highest Equipment Voltage – highest line to line RMS design voltage according to relevant standards

Definitions Contd.

- Over-voltage – any voltage either line to line or line to earth (ground); whose peak value exceeds peak of the Highest Equipment Voltage ($V \sqrt{2} / \sqrt{3}$)

Voltage Classifications

- Continuous Power Frequency Voltage – PF
- Temporary Over-voltage – few cycles – eg: load throw off
- Transient Over-voltages (OV)

 - slow front OV 20 us $\leq T_f \leq$ 5000 us, $T_2 \leq$ 20 ms

- Fast front OV 0.1 us $\leq T_f \leq$ 20 us, $T_2 \leq$ 300 us

-Very Fast Front OV $T_f \leq$ 0.1 us, total duration < 3 ms, super-imposed oscillations 30 kHZ < f < 100 MHz

Standard Wave-shapes

- PF 48 Hz < f < 62 Hz – duration = 60 s
- Std. SI 250 x 2500 uS
- Std. LI 1.2 x 50 us

Definitions Contd.

- Withstand Voltage – value to be applied specified number of times with a tolerance specified discharges
- Co-ordination withstand voltage (V_{cw})– value of the withstand voltage meeting performance criterion in actual service conditions
- Standard Withstand voltage (V_w) – Std. Voltage as specified in a std. Specifies the rated insulation level. Proves Compliance with std.

Definitions Contd.

- Rated Insulation Level – Characterizes Dielectric strength of the Insulation – std. withstand voltage
- Standard Withstand Voltage Test – Dielectric test performed to comply with a std. by performing any of the following tests:

1. Short Duration PF Voltage Tests
2. SI Voltage Tests 3. LI Voltage Tests

4. Combined Tests

Test Voltages

- Defined by Amplitude, Frequency and/or shape with in certain tolerances.
- IEC60060 specifies std. and preferred test voltages
- Sometimes frequency or shape is modified to enable the tests

Types of Voltages

- DC
- AC
- Impulse Voltage
- Impulse Current

Test Conditions

- Standard Conditions are ambient temperature t_0 = 20 ^{0}C and pressure b_0 = 1013 mbar and absolute humidity of h_0 = 11 g/m^3
- If 'b' be actual pressure and 't' be the temperature – atmospheric correction 'K' has two parts – air density 'k_1' and humidity 'k_2'

Test Conditions Contd.

- k_1 depends relative air density δ

$$k_1 = \delta^m$$

$$\delta = b\,(273 + t_0) / (b_0\,(273+t))$$

and

'm' is a function of 'g'; 'g' depends on pre-discharges and defined as

$$g = V_B / (500\ L\ \delta\ k)$$

Test Conditions Contd.

- V_B is 50 % discharge voltage at actual condition in kV, L minimum discharge path, δ relative air density and k according to figure 16.20 of IET book
- $K_2 = k^w$

Tests on Insulators

- Type Tests and Routine Tests
- Type tests check designs – on samples
- Routine tests check quality of each piece
- HV Tests Include PF tests and Impulse Tests. All the insulators are tested for both the categories of tests.

PF tests on Insulators

- Wet and Dry Flashover Test – HV PF ac test voltage is applied @ a rate 2 % per second up to 75 % of the estimated test voltage to such voltage : breakdown occurs on the Surface of Insulator. When carried out under normal conditions without precipitation – dry flashover. If carried out under wet conditions- wet flashover.

Conditions for Wet Test

- Precipitation rate – 3 $\pm$ 10 % mm/min
- Direction – 45^0 to the vertical
- Conductivity of water – 100 uS $\pm$ 10%
- Water Temperature – ambient $\pm$ 15 ^{0}C
- IEC 42 specifies Precipitation rate

Wet and Dry Withstand Test

- Voltage specified is applied under dry or wet condition as per relevant std. – ANSI/IEEE, IEC, BIS, BS etc – for one minute

Impulse Tests

- Impulse Withstand Voltage Test
- Impulse Flashover Test
- Pollution Testing

Impulse Withstand Voltage Test

- Apply standard specified Impulse under dry condition with both polarities.
- Five Consecutive waves should not cause flashover or puncture – insulator passes the test
- If two applications cause flashover – insulator fails
- If there is only one Flashover ten additional pulses are applied. If it withstands – Insulator Passes

Impulse Flashover Test

- As in withstand test with specified voltage
- Aim is to determine 50 % probability of flashover
- Probability of Flashover for 40 % and 60 % failure or 20 % and 80 % value are determined
- Average of upper and lower limit is taken as Flashover value
- Assuming it follows Gaussian distribution

Types of Pollution

- Dust, micro organisms, bird secretions, flies etc
- Industrial Pollution like smoke, petroleum vapors, dust and other deposits
- Coastal pollution – corrosive and hygroscopic salt deposits
- Desert pollution – storms deposit sand and dust
- Ice and fog @ high altitudes and in Polar countries

Pollution Causes

- Corrosion
- Non-uniform gradients along insulator strings and surface of insulators
- Deteriorate the material
- Cause PD and Radio-interference
- Popular Pollution test is Salt-fog test

Salt-Fog Test

- Apply Maximum Normal withstand Voltage on the insulator and then create an artificial salt fog around by jets of salt solution and compressed air.
- If the flashover occurs with in 1 hour the test is repeated with fog of lower salinity otherwise with a higher salinity
- The maximum salinity at which insulator withstands 3 out of 4 applications without flashover is taken as representative value

PF tests on Bushings

- Power Factor – Voltage Test
- PD test
- Momentary Withstand Test
- One Minute Wet Withstand Test
- Visible Discharge Test

Power Factor – Voltage Test

- Bushing setup as in service or immersed in oil
- Connected with line conductor to HV and tank or earth portion goes to detector side of Schering Bridge or Capacitance Bridge.
- Capacitance and Power Factor (tan δ) is recorded at each step by applying voltage in steps up to rated value and reduced.
- Variation is plotted. Routine Test

PD test

- To assess internal deterioration of Composite Insulation of Bushing
- PD measurement is carried out. Method will be discussed in Cable Testing
- Voltage vs PD level plotted
- Index of performance of bushing in service
- A routine test

Momentary Withstand Test

- As per IS 2099 – IEC 60137
- Specified ac PF Voltage is applied
- Bushing should withstand the voltage for a minimum time of 30 s
- Replaced by Impulse Test

One Minute Wet Withstand Test

- Common and routine test – one minute wet and dry PF withstand tests
- Wet test as specified earlier by mounting bushing as in service
- Should withstand specified voltage for one minute
- No indication of performance during service
- Better tests are Impulse and PD

Visible Discharge Test

- This indicates possibility of Radio Interference in service at voltage specified by IS 2099
- No discharge – except from arcing horns or grading rings should be visible in a dark room
- All conditions remain as before

Impulse Tests

- Full Wave Withstand Test
- Chopped Wave Withstand and Switching Surge Test

Full Wave Withstand Test

- Tested as per specified impulse voltage of either polarity.
- Five consecutive pulses of full wave are applied
- If 2 of them cause Flashover – bushing is deemed to have failed
- If 1 of them causes flashover – 10 additional pulses are applied.
- Bushing passes when no further flashover occurs

Chopped Wave Withstand and Switching Surge Test

- Chopped wave test is done for Bushings over 220 kV
- Switching Surge Tests are important for EHV bushings
- Similar to full wave withstand tests

Thermal Tests

- Temperature rise tests is carried out in free air (below 40 ^{0}C) at rated PF ac current.
- Steady temperature rise above ambient should not exceed 45 ^{0}C on any part of the bushing.
- It is carried out for long duration : temperature remains substantially constant i.e. 1 ^{0}C/h
- This is carried at voltages above 132 kV
- A type test

Isolators & Circuit Breakers (CB)

- Isolators interrupt @ best .5 A @ 420 kV and below essentially capacitive currents
- IS 9921 defines Isolator/dis- connector as mechanical switching device, that provides in open position an isolation distance in accordance with system voltage.
- It is capable of opening and closing a circuit when either current interrupted is negligible or insignificant change in voltage occurs across the poles. Capable of carrying Short Circuit currents for a very short duration and normal currents.

Circuit Breakers

- Evaluation of Constructional and operational characteristics
- Evaluation of Electrical Characteristics of the circuit to be interrupted or made

Tests on CBs

- Dielectric tests or over-voltage tests
- Temperature rise tests
- Mechanical Tests and
- Short Circuit tests

Dielectric Tests

- Power Frequency Withstand
- Lightning Impulse Voltage Test
- Switching Impulse Voltage Test
- Carried out for both internal and external insulation with switch/CB open and closed
- Test Voltages are 15% higher in open position
- LI tests similar to Insulators of std wave shape
- SI tests are carried out to assess OV withstand ability under Switching operations

Short Circuit Tests

- Most important test on CBs
- They assess ability to interrupt fault currents
- Determination of making and breaking capacities at various load currents at rated voltages
- In Isolators, rated short circuit current for given duration. No making and breaking tests are done

Short Circuit Tests Contd.

- Direct Tests:

1. Using Short Circuit Generator @ the source
2. Using Utility as the source

- Synthetic Tests

1. Direct Test on Field
2. Direct Test in the Laboratory
3. Synthetic Tests of CBs

Direct Tests on field

- Some times tested under normal load conditions or sc conditions in the NW itself
- Carried out during limited energy consumption.

Advantages of Field Tests

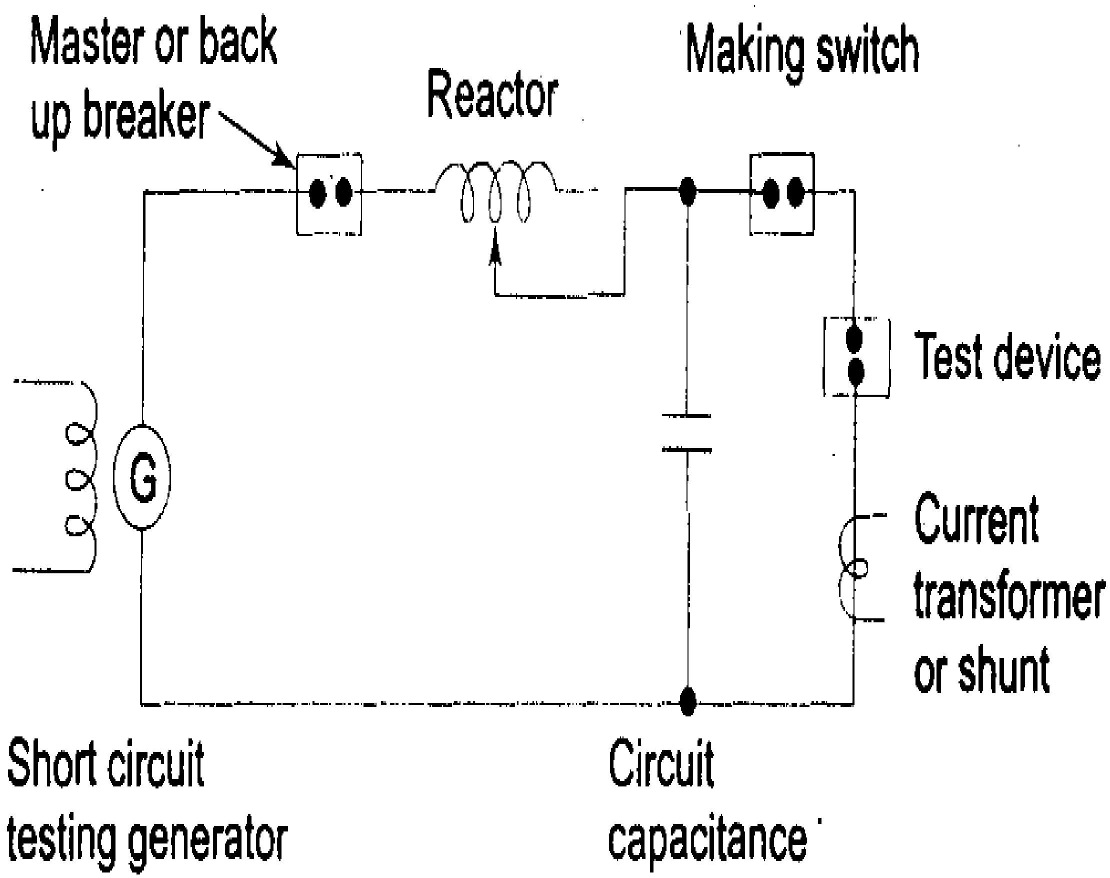
- Tested under actual conditions that occur in a NW
- Special situations like breaking of charging currents of long lines, short line faults and interruption of small inductive currents
- Assesses the thermal and dynamic effects of SC Currents to study application of safety devises

Disadvantages of Field Tests

- Can be tested at rated voltage and NW capacity only
- Need to interrupt normal services and tests only light load conditions
- Extra inconvenience and expenses of installing controlling and measuring eqpt. On field

Direct Testing in Laboratory

- SC generator along with a master CB. Resistors, Reactors and measuring devices
- A make switch initiates the SC and master CB isolates the test device from the source after a pre-determined time on a test sequence controller
- Master CB can be tripped if the test breaker fails to operate.

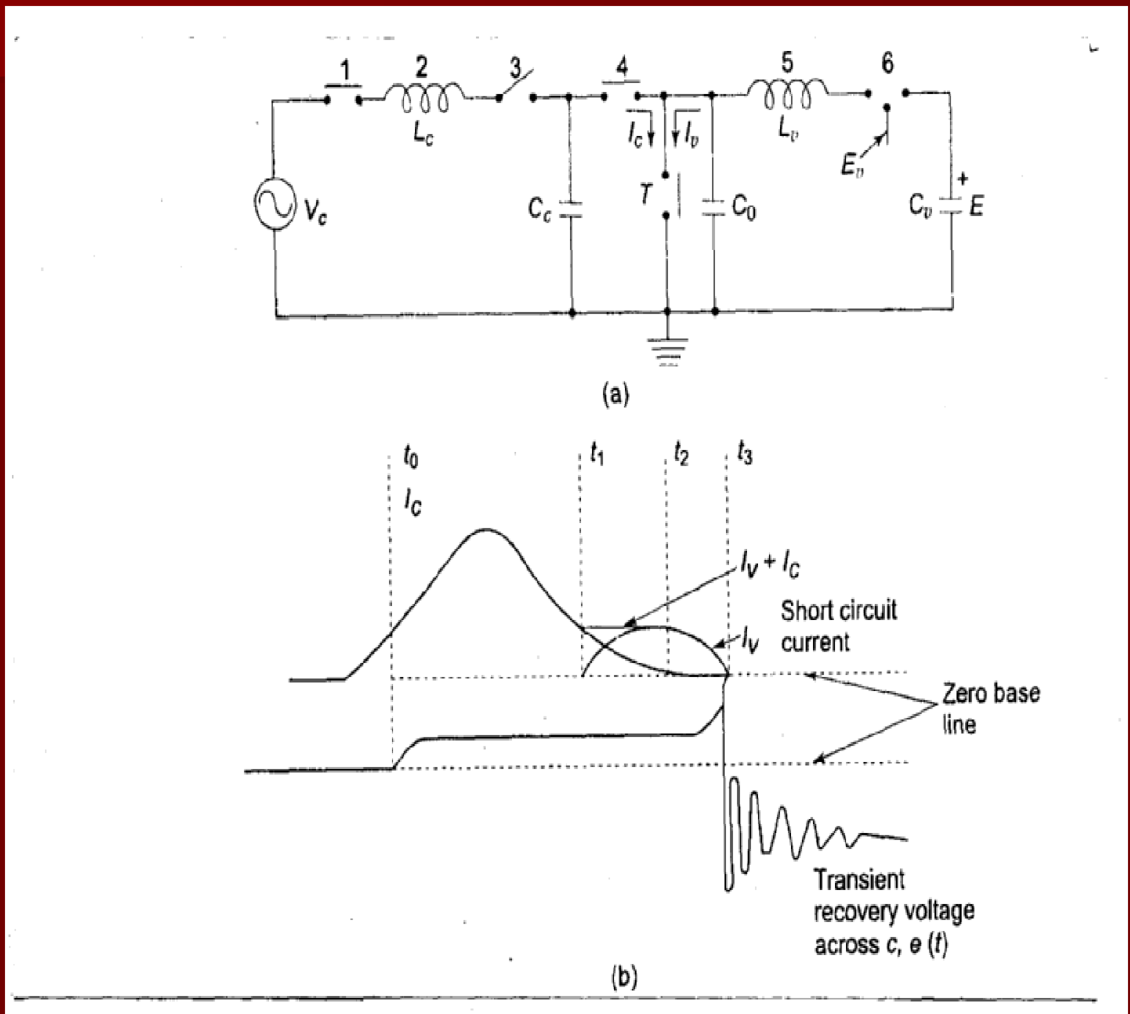

Master or back up breaker
Reactor
Making switch
Test device
G
Current transformer or shunt
Short circuit testing generator
Circuit capacitance

Synthetic Testing of CBs

- Uneconomical to have a single source to provide required SC current @ the rated voltage due to high interrupting capacity of CBs
- Effect of Short Circuit and recovery voltage are obtained separately by combining two sources
- Initial period is SC test period -high current source supplies the current @ a low voltage
- Later recovery voltage simulated by a High Voltage source of low current

Synthetic Testing of CBs Contd.

- Auxiliary breaker(3) and test breaker (T) are closed by closing making switch (1) – thereby current flows
- At a time t_0 T begins to operate and the master breaker (1) clears the generator
- Just prior to current zero trigger gap (6) closes : full voltage is applied at current zero



1
2
3
4
5
6
L_c
I_c
I_v
L_v
E_v
V_c
C_c
T
C_0
C_v
+
E
(a)
t_0
t_1
t_2
t_3
I_C
I_V + I_C
Short circuit current
I_V
Zero base line
Transient recovery voltage across c, e (t)
(b)

Composite Testing

- First tested rated breaking capacity@ reduced voltage
- Later @ rated Voltage @ a low current
- May not assess adequately performance of the breaker

Unit Testing

- When CB has more than one break per pole specially @ EHV levels
- One break is tested @ rated current and estimated voltage
- Arc characteristics may differ from break to break
- Further Voltage Distribution may not be uniform

Test Procedure

- Tested for Breaking Capacity (B) and making capacity (M) After calibration of SC Generator typical test consist :

1. B-3-B-3 @ 10 % rated breaking capacity
2. B-3-B-3 @ 30 % rated breaking capacity
3. B-3-B-3 @ 60 % rated breaking capacity
4. B-3-MB-3-MB-3-MB @ 100 % rated breaking capacity with a recovery voltage > 95 %of rated service voltage

Power factor is kept between 0.15 to 0.3. In the sequence 3 is time in minutes. Currents are symmetrical.

Asymmetrical Tests

- One test cycle repeated for asymmetrical breaking capacity that has dc component @ the instant of contact separation > 50 % of the ac component.

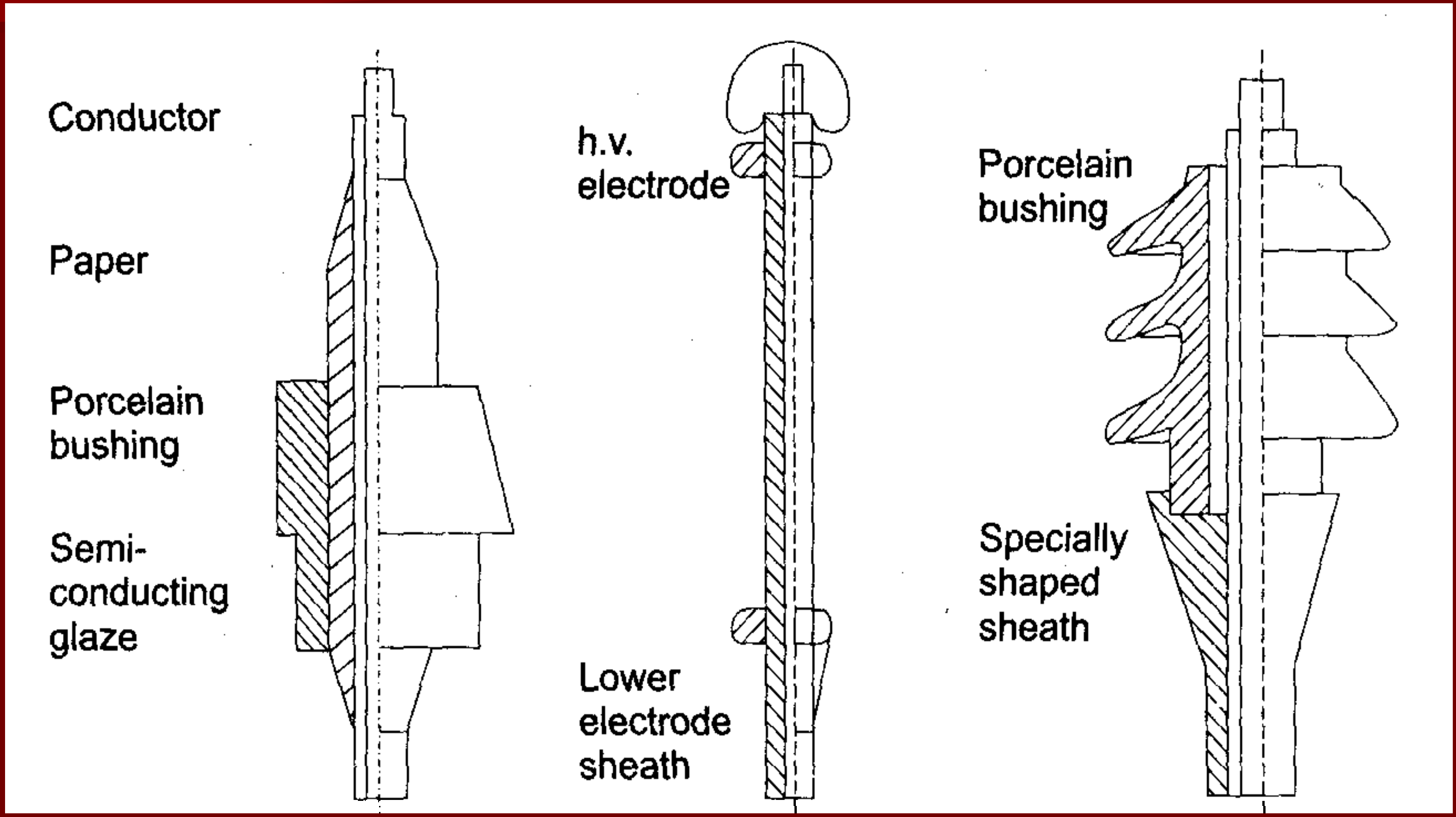
Cable Testing

- Important for Underground transmission
- Mechanical Tests: bending, dripping and drainage, fire resistance and Corrosion
- Thermal Duty Tests
- Dielectric power factor tests
- PF withstand voltage tests
- PD tests
- Life Expectancy tests
- Focus on electrical tests

Sample Preparation

- To be prepared carefully to avoid leakage and end flashover
- Length varies from 50 cm to 10 m
- Termination prepared by shielding the end conductor with stress shield

Terminations



Dielectric Power Factor Test

- Employs HV Schering Bridge or Transformer Ratio arm bridge
- Tanδ – Loss Tangent or Dielectric Power Factor is measured @ 0.5,1.0,1.66 and 2.0 times rated voltage phase to ground (Ig)
- Max. value difference in power factor to normal value @ 1.66 and that @ 2.00 is specified

- At times difficult to supply charging VA from the source available
- At such times a reactor is used with the cable to form a resonant circuit
- Thus enabling improvement in Power Factor of test circuit and test voltage magnitude
- Capacitance bridge should have appropriate protection

HV tests on Cables

- Withstand tests against ac, dc and impulse voltages
- During manufacture entire cable is tested @ rated HV to check the continuity of insulation in the cable – a routine test
- This is done @ 2.5 times normal rated voltage for 10 minutes
- Type tests are carried out on samples

HV tests on Cables Contd.

- Type tests consist of both dc and impulse tests
- dc voltage applied is 1.8 times the rated value of negative polarity for 30 minutes
- Impulse test as specified 5 positive 5 negative pulses are applied
- This is followed by a Dielectric Power Factor measurement.

Partial Discharges

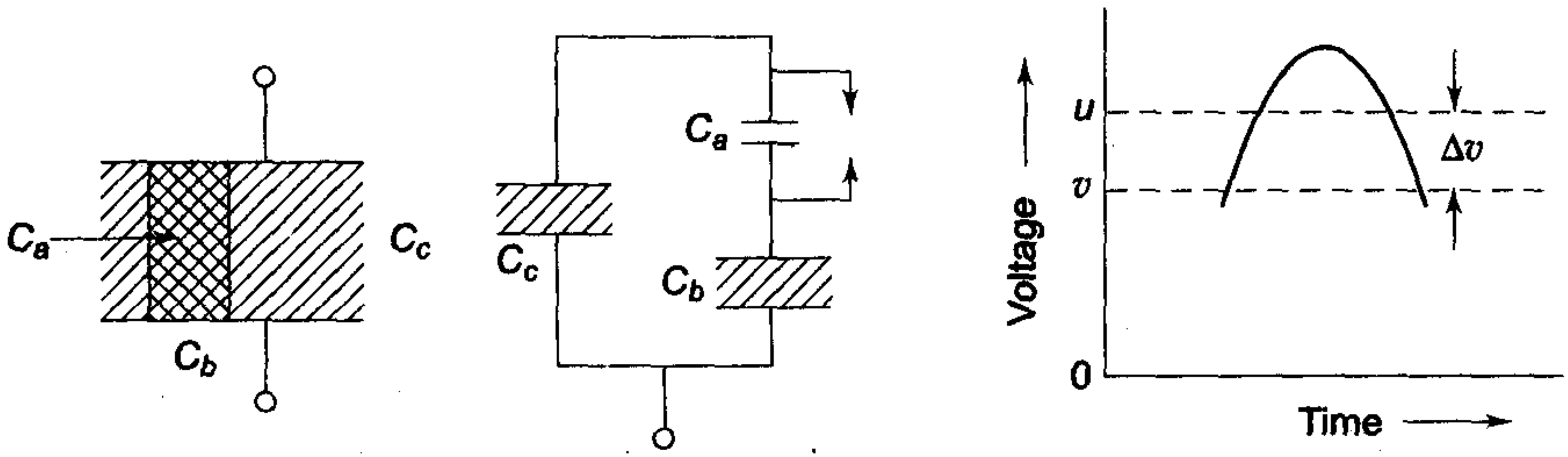
- Discharge Measurement
- Location
- Scanning

Discharge Measurement

- Important for cables as life depends on discharge level
- A very good index of weakness of cable insulation

PD Measurements

- Earlier Loss Tangent or Dissipation factor or Dielectric power factor were indices of condition of insulation
- As it was voltage dependant
- Voids cracks or imperfections lead to internal intermittent discharges termed PD without bridging electrodes
- Usually not revealed in capacitance measurements



(a) (b)

C_a – Capacitance of the void acting as a spark gap

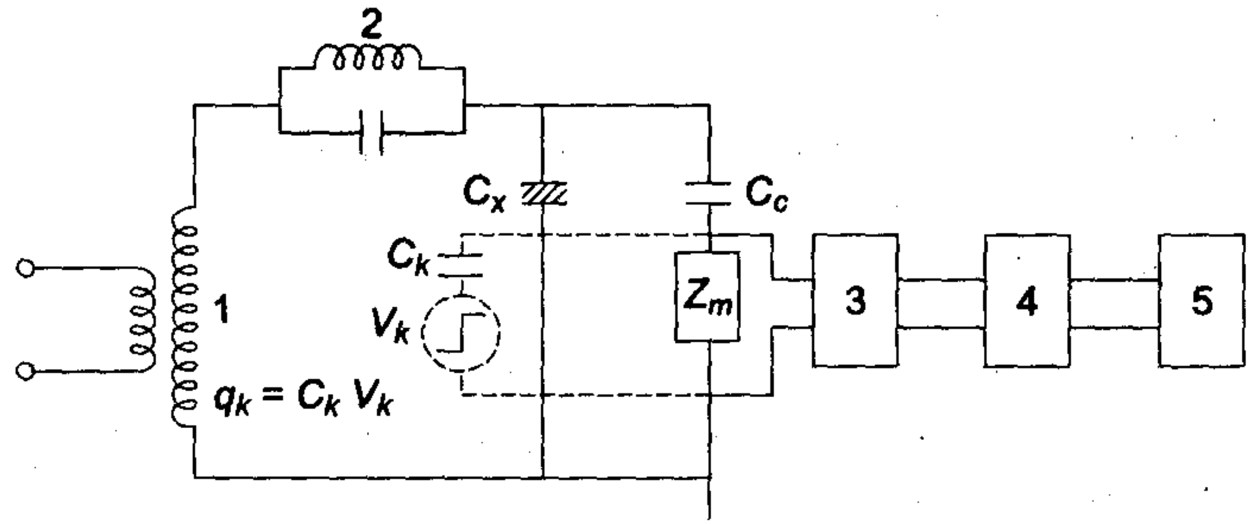
C_b – Capacitance of the remaining series insulation with the void

C_c – Remaining part of the discharge free insulation of the test object

PD Measurements Contd.

- Location of site is valuable
- Enables strengthening insulation and improving the design
- Equivalent Circuit in previous slide
- On voltage reaching critical value discharge takes place can be simulated by shorting gap across void capacitance Ca
- Ca << Cb << Cc

- Charge $\Delta q0$ present in the void flows through the rest of insulation giving rise to a pulse
- A measure of voltage pulse gives discharge quantity
- Difficult hence apparent charge across a detecting impedance as a terminal measurement is made

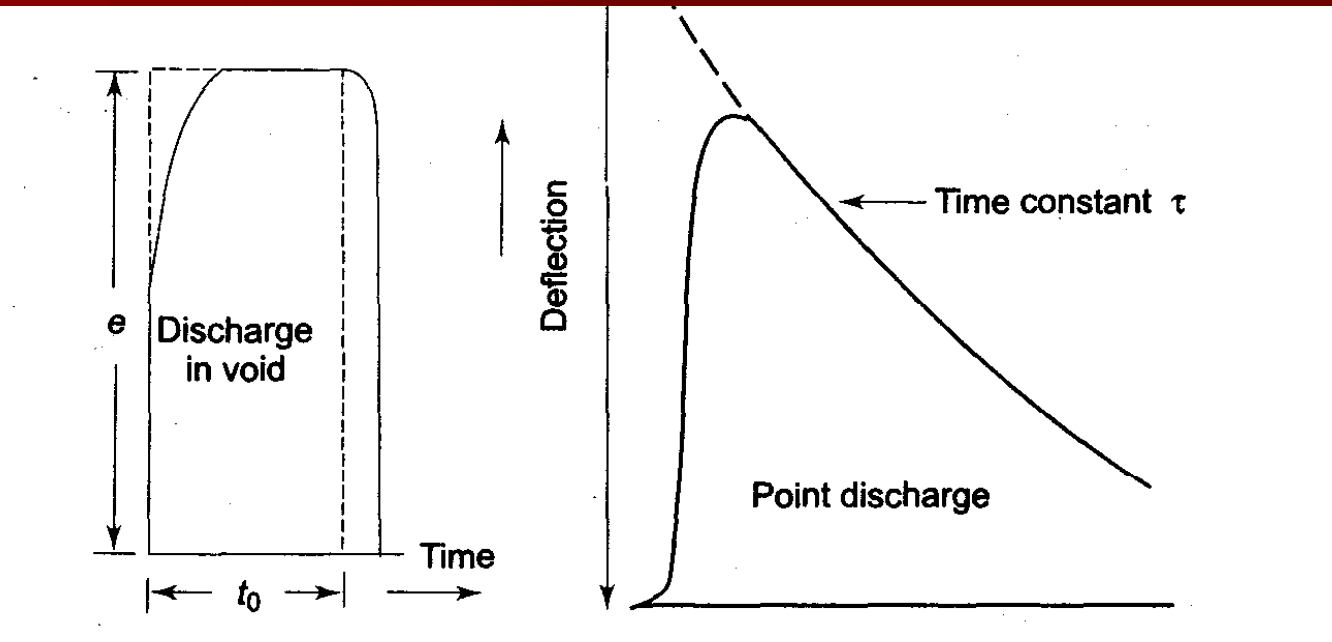


1 — H.V. testing transformer
2 — Filter
3 — Band pass filter
4 — Amplifier
5 — Display unit (CRO or pulse counter or multi-channel analyser unit)

C_x — Sample or testpiece
C_c — Coupling condenser
Z_m — Detector impedance
V_k — Calibrating pulse
C_k — Calibrating capacitor
q_k — Calibrator charge

Discharge Location

- Voltage dip due to a PD propagates as a travelling wave
- Can be detected as a pulse at the terminals at the end of the cable
- By measuring time difference between pulses distance can be determined



(a) Internal discharge
$t_0 = 20 - 40$ ns

(b) Corona discharge
$\tau = 50 - 500$ ns

Scanning

- In order to scan entire length bare core of cable passed through high field and discharge location is done
- Cable is passed through insulating tube containing distilled water
- Four electrodes in ring form are mounted at two ends and at middle
- Middle electrodes are energised @ High Voltage

- Other two electrodes and cable conductor are grounded
- As a result the discharge occurring between middle electrodes is detected
- If the cable is passed through the electrode system discharge location is spotted
- Very Convenient for isolating the defects while manufacturing

Life Tests

- Intended for reliability studies
- Life is assessed through accelerated life tests applying increased voltages

Transformer Testing

- Important and costly
- They should not be damaged during test
- Focus on Insulation tests
- Other tests include temperature rise, short circuit test
- IS 2026 – IEC 60076

Induced OV test

- Tested by exciting the Secondary from a high frequency (100-400 Hz) @ twice the rated voltage
- Reduces the core saturation
- Limits the charging current in large power transformers
- Thus checking insulation withstand check

PD Test

- PD test on windings are carried out to assess discharge level and the RI level
- Transformer can be connected as discussed earlier
- Location can be done by using Traveling wave technique
- Discharge measurements are carried out on all terminals
- Under PF excitation discharges > 10^4 pC are considered severe

Impulse Testing

- Ability to withstand over-voltages
- Short rise time – voltage distribution along the winding is non-uniform
- Carried out employing Full and Chopped waves chopped between 2-6 us
- Windings not tested are short circuited and grounded to avoid induced OVs
- This reduces impedance of transformers and hence adjusting wave-shape becomes difficult

Test Procedure

- Test level in the std. is termed BIL
- One pulse @ 50 – 75 % BIL
- One pulse @ 100 % BIL

- One Chopped pulse @ 50 – 75 % BIL
- Two Chopped Pulses @ 100 % BIL
- Two Pulses @ 100 % BIL

Fault Detection During Test

- General Observations – Noise in the tank or smoke or bubbles in the breather or external flashover
- Voltage Oscillogram – Fault appears as a collapse of voltage wave – can not detect faults within 5 % of one end of the winding
- Neutral Current Method – Current flowing from neutral to ground monitored by a non-inductive shunt CVR

- Neutral Current has three components – High Frequency Oscillations, Low Frequency Disturbance and a current rise
- In case of arcing due to turn to turn or between turn to ground train of HF pulses are seen and waveshape gets altered
- In case of a PD only HF oscillations without change in Voltage waveshape are seen

Transfer Function Approach

- Change in Transfer Function before chopping to after chopping is examined
- Convert applied Voltage waveform and neutral current in to frequency domain
- Take the ratio of I(f)/V(f) and compare from pulse to pulse.

Surge Arrester (SA) Testing

- SA – employed towards OV protection
- It is non-conducting in normal situation under PF
- Behaves as a Short Circuit for Over Voltages – there by discharging associated energy without any power follow currents

SA Voltages and Currents

SA Class	Rating	Impulse Current (8 x 20 us) (kA)	High Current (4 x 10 us) (kA)	Long Duration us (A)
A	230 V to 600 V	1.5, 2.5	10, 25	50, (500us)
B	400 V to 33 kV (distribution)	5	65	75 (1000us)
C	>11 kV Station	10, 20	100	150 (2000us)

Tests

- Power Frequency Spark over test
- Standard Impulse Spark over test
- Front of wave spark over test
- Residual voltage test
- High Current test
- Long Duration Impulse Current test
- Operating Duty Cycle test

Power Frequency Spark over test

- Routine Test
- Current limiting resistor is used
- SA to withstand 1.5 times rated voltage at least for 5 successive applications
- Carried out under dry as well as wet conditions

Standard Impulse Spark over test

- To check the operation of SA to act upon over voltages
- IVG is set for standard Lightning Impulse as specified in the standard
- Both polarities of 10 pulses each
- Alternative way of performing is to start from a low level, increase in steps till 100 % flashover occurs

Front of wave spark over test

- Tests efficacy for steep fronted over voltages
- An Impulse with a rate of rise at least 100 kV/us per 12 kV is applied – specified in the standard
- Test is conducted @ 100 % SOV test for increasing test levels while measuring time to spark over
- Voltage vs time are plotted
- Intersection of V-t curve with slope of virtual steepness of the pulse gives front of wave SOV

Residual voltage test

- Carried out on Prorated arrester units in 3-12 kV range
- Voltage developed across the block due to the flow of over currents
- Standard Impulse Currents of rated magnitude and applied and voltage developed across the block is recorded using a voltage divider and a CRO
- Test levels being approx. 0.5, 1.0 and 2.0 times rated level. Residual voltages are plotted

High Current Test

- Performed on Pro-rated units in the range of 3 – 12 kV
- High Current impulse of 4 x 10 us as per std applied on a spare unit
- Two such pulses are applied
- Then the tested units are allowed to cool

Unit passes

- PF SOV test before and after High Current test does not differ by more than 10 %
- Voltage and current waveforms do not change due to this test
- NLR should not show any sign of Puncture or external flashover

Long Duration Impulse Current test

- Also performed on Pro-rated unit of 3-12 kV
- Rectangular Pulse Current Generator is employed
- 20 pulses as per standard in groups of 5 are applied
- Interval between successive applications is 1 min
- Waveforms of first 2 and last 2 are recorded

Arrester passes

- PF SOV does not differ by 10 %
- Residual voltage across SA at the first and last application does not differ by more than 8 %
- No sign of puncture or any other damage

Operating Duty Cycle Test

- Again performed on pro-rated units close to field conditions
- SA is energised @ rated PF voltage. At about a phase of 30^0 rated impulse current is applied – power frequency follow on current is observed.
- If there is no follow on current angle is advanced by 10^0 in steps up to 90^0 till the power follow on current is established

- During the follow on peak voltage should be less than or equal to rated peak voltage
- 20 Impulse Current pulses @ the point of the wave selected are applied in four groups with an interval of 1 minute between pulses
- Interval between successive groups is 30 minutes

SA passes

- PF SOV does not differ by 10 %
- Residual voltage across SA at the rated current doe not differ by more than 10 %
- Follow on current is interrupted each time
- No sign of puncture or any other damage

Other Tests

- Mechanical Tests – porosity, temperature cycle tests and others
- Pressure relief tests
- Voltage withstand test of SA housing
- Switching Surge FO test
- Pollution Test

RI or EMI Measurements

- Power Apparatus produce unwanted noise in radio, tv , u wave and other high frequency ranges
- Arise due to Corona in air, PD in the insulation, sparking at commutators and brushes in rotating machines
- Noise generated must be acceptable
- Surface conditions of OH conductors @ High Voltages under varying Atmospheric Conditions influence EMI
- Bonding between porcelain and metal in a insulator, conductor and insulator surface and surface pollution cause EMI

RI Measurement

- Radio Frequency line to ground voltage RIV a conducted measurement
- Interfering field measured by an antenna RI
- RIV is measured in Laboratories
- RI is measured on field

Radio Noise Meter comprises

- Portable radio receiver with a local oscillator
- A radio frequency amplifier
- A mixer
- Intermediate Frequency Amplifier
- Detector similar to radio receiver operating 15 kHz to 30 MHz
- Voltmeter has i/p impedance of 50 to 75 ohm

Test Circuit

- Radio Frequency Choke to limit loss of RIV Voltage and to conduct energy from the sample. Impedance < 1500 Ω
- Coupling Capacitor C , 0.001 uF and a resistor equal to 800 Ω. Conducted RI from test sample
- Coaxial cable of 185 Ω

Loss Tangent Measurement

- Normally Dielectric Constant > 1; shows loss on application of ac voltage depending on frequency
- These are combined and termed Complex Permittivity and are determined over a range of frequencies
- Capacitor excited by ac i.e. $v = v_0\ \varepsilon^{(j\omega t)}$ where $\omega = 2\pi$ stores charge $Q = C_0 v$ drawing a charging current $I_c = dQ/dt = j\omega C_0 v$
- When dielectric is vacuum C_0 is Vacuum Capacitance or Geometric Capacitance. I_c leads v by 90^0

- If the capacitor be filled by a dielectric material of ε′; the capacitance changes to $C = C_0\, \varepsilon'/\varepsilon_0 = C_0 K'$ (termed relative dielectric constant)
- If a voltage V is applied; it results in Charging Current I_c and a loss component I_l
- $I_l = GV$; G is Conductance
- $\mathbf{I = I_c + I_l = (j\omega C + G)\, V}$
- **I** leads **V** by **θ** less than 90^0
- Angle $(90^0 - \theta)$ is termed loss angle $(= \delta)$

- $\tan \delta = D = I_l / I_c = 1/ \omega CR$ assuming a parallel RC Circuit
- D may not agree with our measurement it may include energy consuming processes in addition to migration of charge carriers
- Better represented by complex permittivity

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

- $I = (j\omega\varepsilon' + \omega\varepsilon'')C_0/\varepsilon_0 V = j\omega C_0 \varepsilon^* V$
- $\varepsilon^* = (\varepsilon' - j\varepsilon'')/\varepsilon_0 = K' - j K''$
- $\tan \delta = \varepsilon''/\varepsilon' = K''/K'$
- $\sigma = \omega\varepsilon''$ sums dissipative effects, actual conductivity and loss dependant on frequency i.e. dipole orientation in dielectric
- Measurements look @ Geometric Capacitance and capacitance with Dielectric

Measurement Ranges

- Lumped circuits employed over dc – 100 MHz
- Neither dielectric constant or tanδ are not measured directly
- They are determined using a null method
- Bridge methods are difficult over 0-10 Hz. They are estimated from Current Time Curves

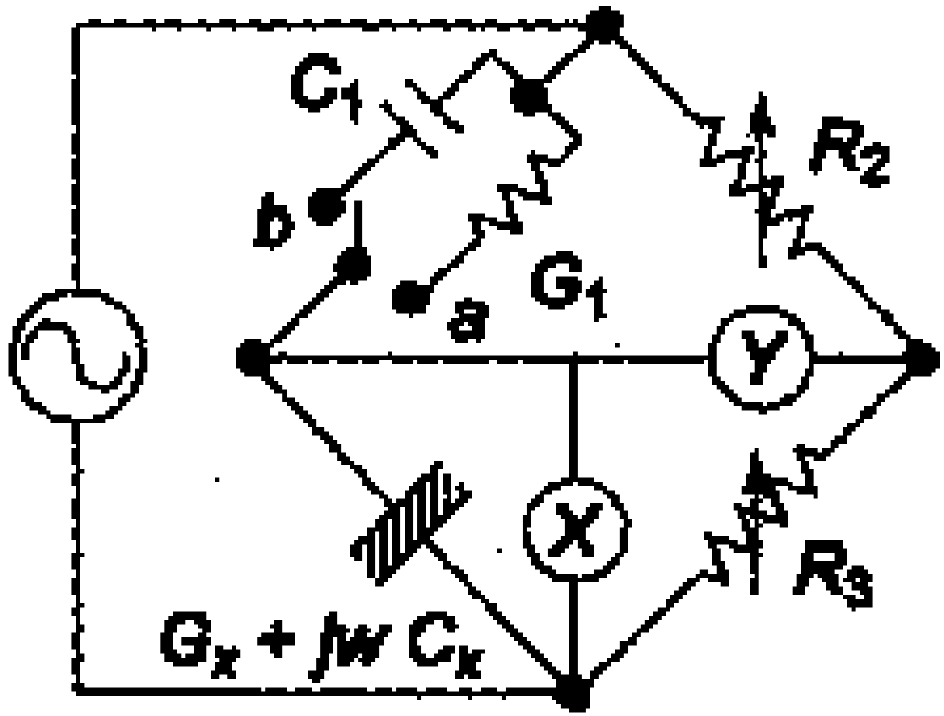
- Over median frequency range 10 Hz to 1 MHz bridge methods are employed.
- Common bridge being four arm Schering bridge from 50 Hz to 100 kHz – HV Schering Bridge when effect of voltage needs to be assessed
- Over 100 kHz to 100 MHz additional problem of shielding and errors become excessive

- At frequencies above 100 MHz lumped circuit approximation is not valid as wavelength of the frequency approaches that of the specimen thickness

- Variation of sudden change in tanδ with applied voltage indicates inception of PD
- Variation of Dielectric Properties enable knowing point of dispersion or reduction in permittivity with rise in frequency

Low Freq Measurement (0-10 Hz)

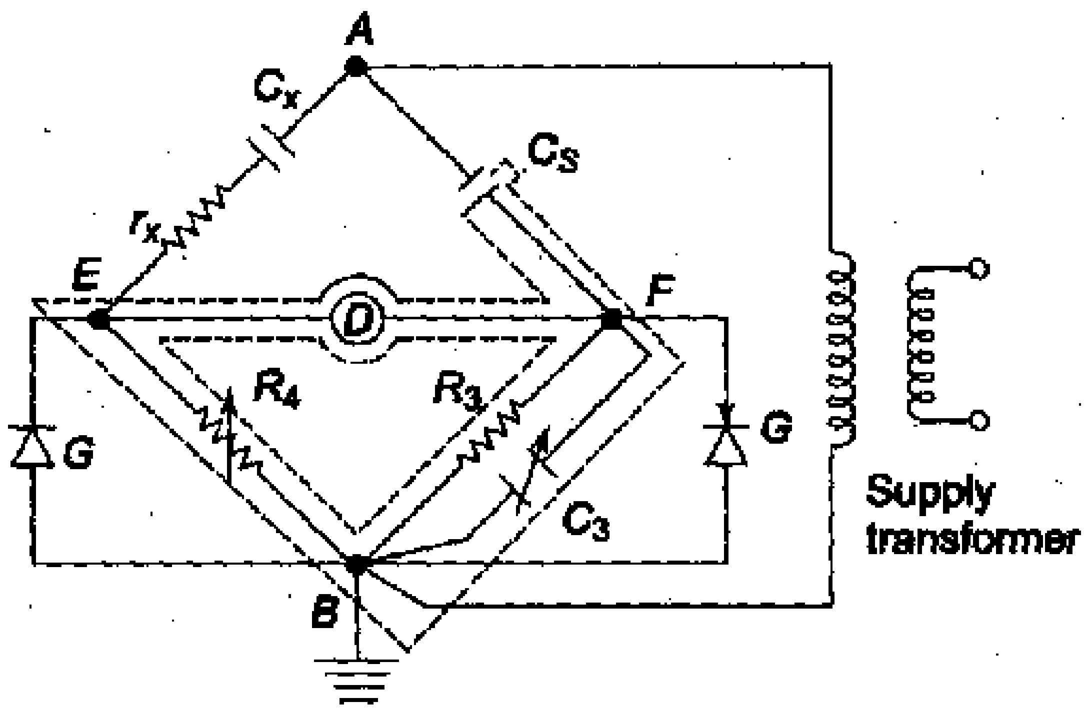
- Moles bridge is suitable
- Used for measuring dispersion in installed eqpt. A reliable measure of Moisture
- Dispersion increases with decrease in freq.
- Usually a CRO is used as Detector. Bridge is balanced if v_y in quadrature with v_x



[redacted] *Mole's bridge*

Power Frequency – HV Schering Bridge

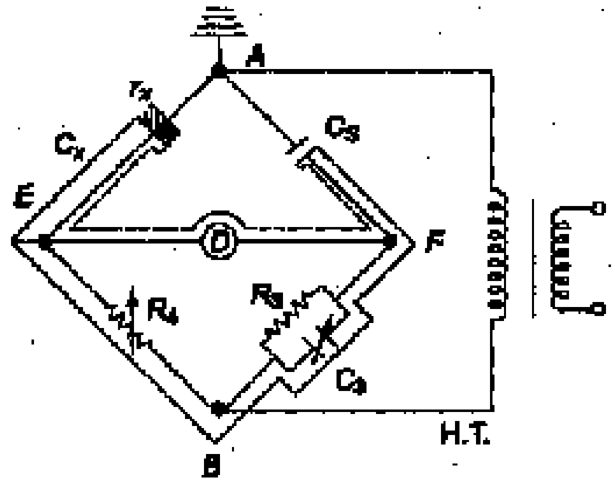
- 25 – 100 Hz Schering Bridge is very sensitive
- Standard Capacitor has Capacitance of 50 to 500 pF
- For High Capacitance test objects Shunt is used



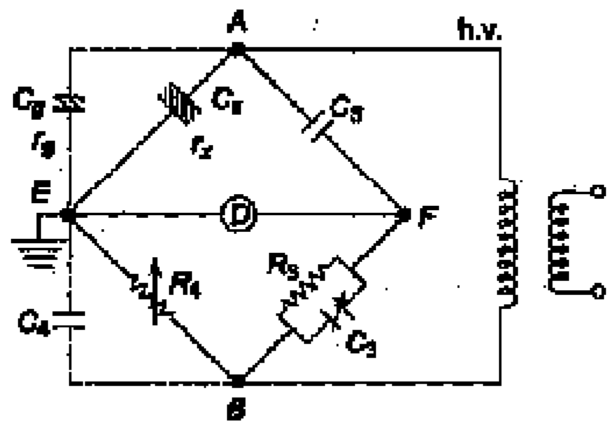
... dotted line is the shielding arrangement. Shield is connected to B

G: Protective device for Z_3, R_4 arms.

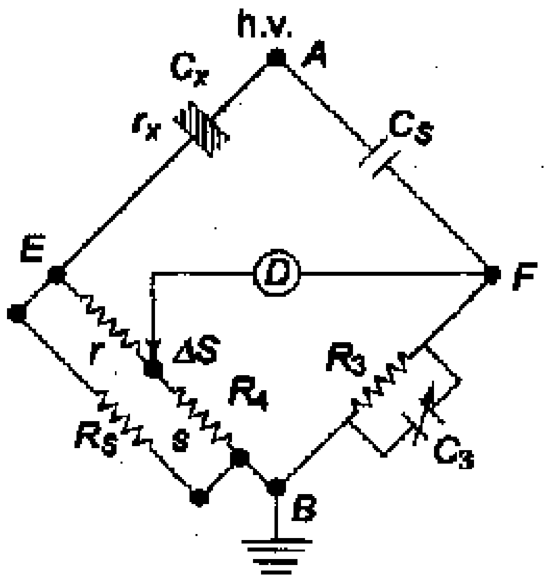
Schematic diagram of a Schering bridge



[redacted] *Inverted Schering bridge for grounded capacitors*



[redacted] *Schering bridge for grounded objects*



R_s — Shunt resistance

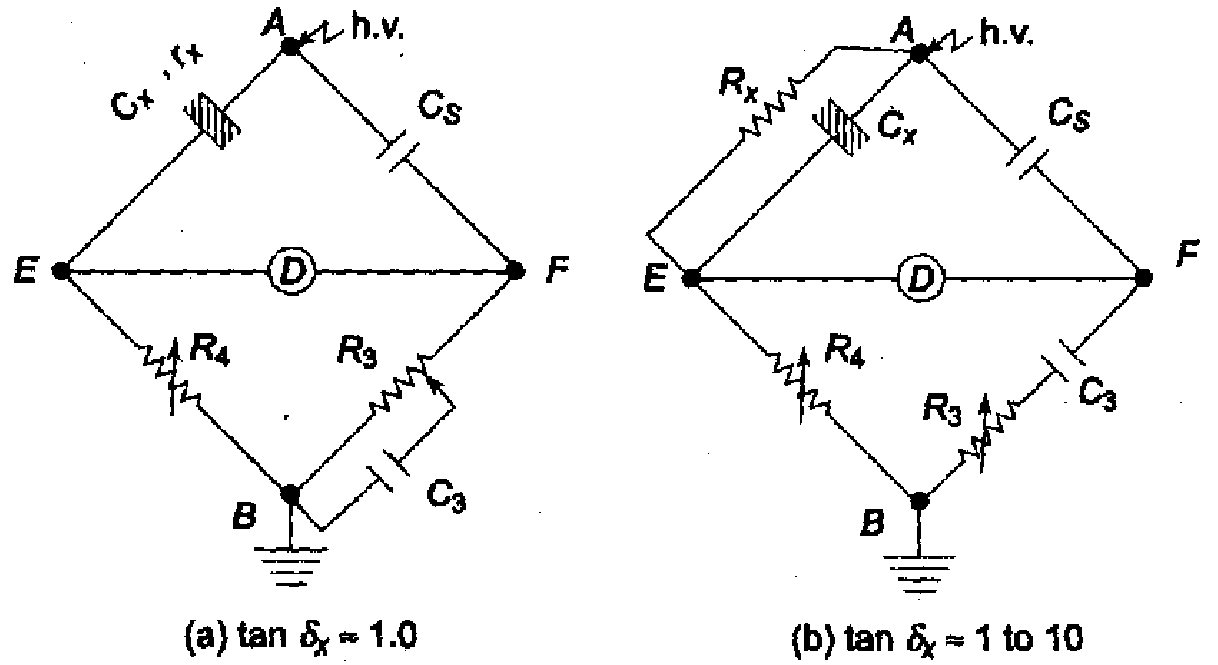
S — Slide wire

ΔS — Tapped portion of slide wire

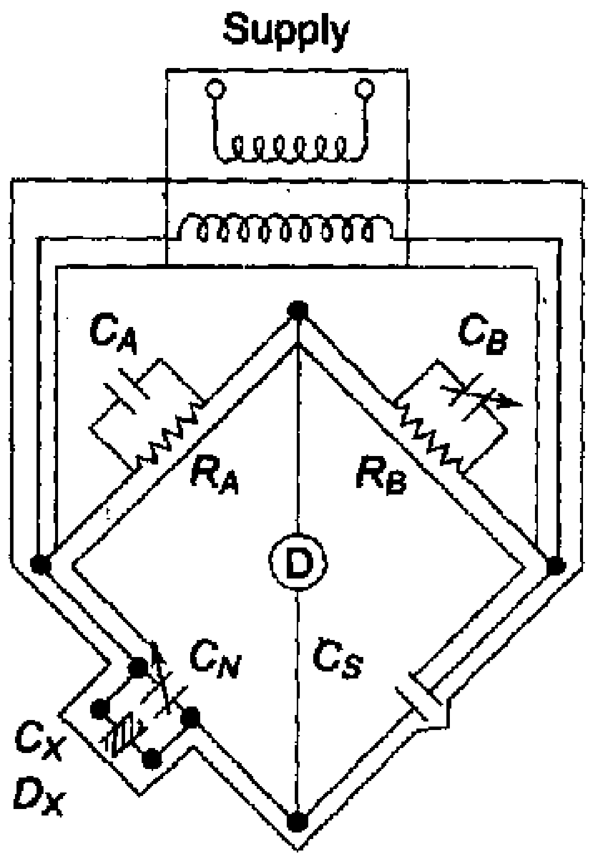
r — Fixed small resistance

R_4 — Decade resistance box

[redacted] *Modified Schering bridge for large charging currents*



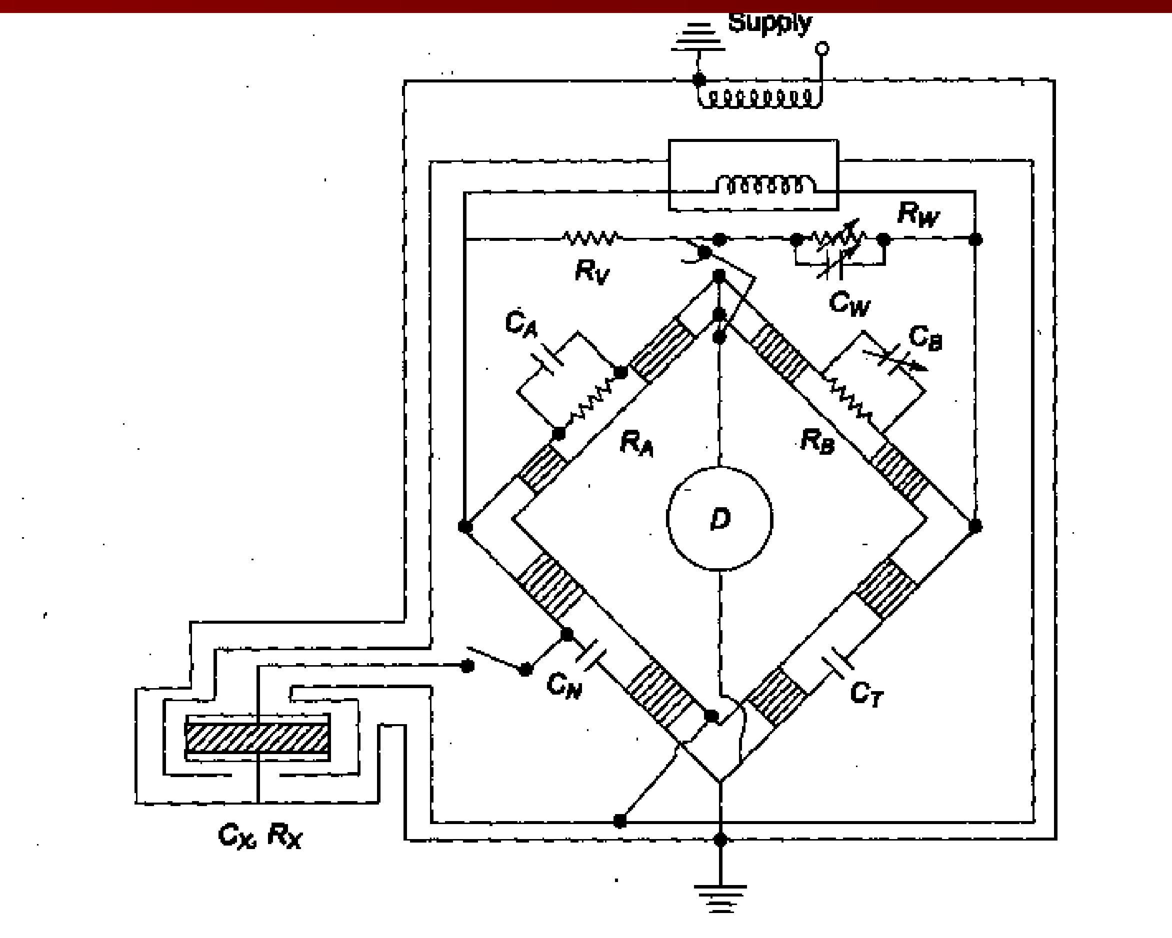
Schering bridge for large dissipation factors



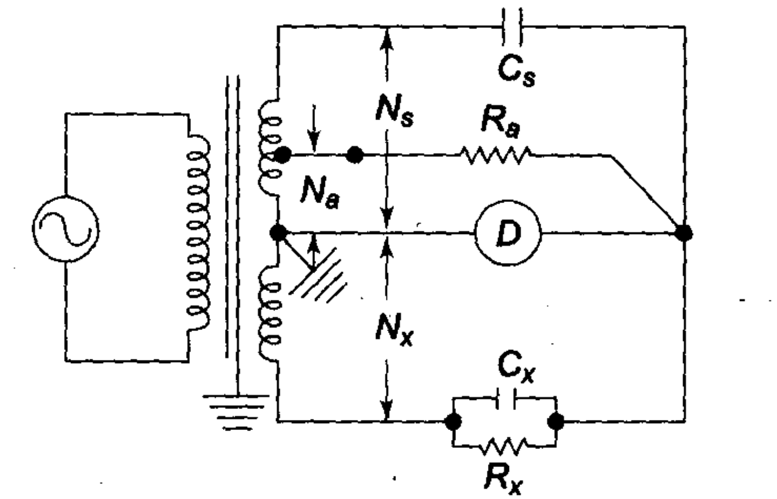
Schering bridge for audio frequency measurements with shields and source transformer

Transformer Ratio Arm Bridge

- @ High Frequencies arms with high resistance pose difficulties due to residual inductances and skin effect
- Shielding and grounding of large arms is difficult
- @ High Frequencies Transformer Ratio Arm bridge is preferred it eliminates two arms



[redacted] *Schering bridge for three terminal measurements with Wagner's earthing device*



Transformer voltage ratio arm bridge