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EXCELLENCE IN MAINTENANCE

Indian Railways
Centre for Advanced Maintenance Technology

CONDITION MONITORING

OF

ELECTRICAL EQUIPMENT

Phase I – Module No. FC - 02

CONDITION BASED MAINTENANCE

It is a type of Preventive Maintenance, initiated as a result of the knowledge of the condition of selected parameters (such as insulation resistance, dissipation factor, polarization, temperature, vibration, material hardness, mechanical stress etc.), obtained through routine or continuous monitoring of such parameters.

CONDITION MONITORING

Continuous or periodical measurement and interpretation of data to indicate the healthy condition of selected item (or of a critical parameter) to determine the need for maintenance.

NEED FOR CONDITION MONITORING

- To optimizing safety standards, maximizing operational efficiency, and enhancing profitability through careful monitoring of system parameters.
- To predict maintenance needs well in advance, thus enabling better planning and support services through monitoring real time data.
- To save money, time, and resources.
- Close observation helps engineer to understand the equipment better.

STEPS IN CONDITION MONITORING

- Selection of critical parameters, most indicative of the health of the equipment.
- Decide the ideal reference values or norms and service-limits of these parameters.
- Decide the frequency of measurement of the value of these critical parameters.
- Interpret the observation readings with respect to the norms.
- Decide the maintenance action & initiate.

ADVANTAGES OF CONDITION MONITORING

- Reduced forced outage
- Reduced number of maintenance operation
- Reduced human error influence
- Better plan for repair / maintenance/ overhauling activities
- Better plan for procurement of spares
- Decrease maintenance cost
- Better plan for unit exchange spares

DISADVANTAGES OF CONDITION MONITORING

- High cost of purchasing, installation of condition monitoring equipment & instruments.
- Unpredictable maintenance period affects cost sharing.
- Increased number of checking, maintenance, calibration of additional condition monitoring equipment & instruments.

CONDITION MONITORING OF ELECTRICAL EQUIPMENT

Two basic component of any electrical equipment are:

- Conductors and
- Insulation

STRESSES ON INSULATION

Insulating material properties generally get degraded as it is subjected to following stresses :-

- Electrical
- Thermal
- Mechanical
- Environmental
- Combined

1. *Electrical Stressing Factors*

- Voltage variation beyond the permissible limits for prolonged periods.

- Switching and impulse voltages e.g. frequent start / stop duty. These are generally 3-4 times the normal stress levels.

$$\text{LIFE of Insulation} = \frac{1}{E^n}$$

where, E = Stress Voltage level

n = A Constant whose value varies from 5-20.

Thus, there is logarithmic fall in life with increase in electrical stress.

2. *Thermal Stressing Factors*

Temperature variations of conductors, beyond the permissible limits for prolonged periods.

Mechanism:

Resistance at temperature ‘t’ is, $R_t = R_o(1+\alpha_o t)$

Since, Copper Loss $P = I^2R$

Temperature ↑ → Resistance ↑

Resistance ↑ → Power Loss ↑

Power Loss ↑ → Temperature ↑

Poor joints in conductors can cause hot spots and in worst case thermal runaway.

3. Mechanical Stressing Factors

- Permanent Stresses - As in case of rotating machines.

- Occasional Stresses - As a result of sudden load-changes, short circuit or thermal creepage, as found in transformers.

- *Basically involves physical wear and tear of the insulating material leading to its deterioration.*

4. *Environmental Stressing Factors*

- Humidity – More humidity affects badly the life of insulating material

- Pollution – Air pollution also affects the life

- Radiation - the effect of deterioration.

5. *Combined Stressing Factors*

- Normally all stressing factors are present simultaneously (Multi-Stress Condition).

- Usually this would lead to accelerated deterioration of the insulating material.

SYMPTOMS OF POOR INSULATION-CONDITION

- Increase in resistance of conductor
- Excessive temperature rise
- Reduction in insulation resistance (IR)
- Increase in dielectric loss (tanδ)
- Change in dielectric absorption
- Visual, Audible and Ultra Violet (UV) discharges

- Ultrasonic emission

- Gas evolution

It is the object of diagnostic testing to measure and assess these symptoms using non destructive testing techniques as part of the condition-monitoring maintenance.

Result of Insulation Failure

Result of Insulation Failure

Result of Insulation Failure

Result of Insulation Failure

Result of Insulation Failure

Result of Insulation Failure

DIAGNOSTIC TESTING

- Conductor – Generally no problems, except Joints.
- Insulation is weak link.
- Generally failures are on account of insulation.
- Electrical insulation constitutes only a small proportion (10%) of the cost of equipment but on failure can lead to total loss of the equipment.
- Thus insulation testing / diagnosis is a vital parameter and most techniques involve Dielectric Diagnosis / Dielectric monitoring.

SIMPLE INSULATION- DIAGNOSTIC TESTS

(A) DC Tests :-

- Insulation Resistance test (IR)
- Polarization Index (PI)
- Dielectric Absorption Ratio (DAR)
- Step Voltage (SV)
- Dielectric Discharge (DD)
- Recovery Voltage (RV) Measurement
- Polarization Depolarization Current (PDC)

(B) AC Tests :-

- Tan-Delta test
- Hipot or HI-Voltage Test
- Surge Comparison Test
- Partial Discharge Test

Why DC test is preferred over AC test for IR Test

1. Leakage Current is sufficient to give information on IR value.

2. In AC testing, since polarity changes every half-cycle (10 ms) frequent charging current will be predominant, and **Dielectric Absorption Current** will never die down. Compared to both these, the Leakage current will be insignificant.

3. For appreciable leakage-current to flow & measure, test-voltage will have to be increased, which will require larger size of equipment for AC test.

4. Larger size of AC equipment will be costlier & difficult to transport & handle easily.

जो कार्य तुम आज कर सकते हो, उसे कल पर कदापि मत छोड़ो।

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DC TESTS FOR CONDITION MONITORING OF ELECTRICAL EQUIPMENT

Phase I – Module No. FC – 02

(A) DC Test

1. Insulation Resistance test (IR)
2. Polarization Index (PI)
3. Dielectric Absorption Ratio (DAR)
4. Step Voltage (SV)
5. Dielectric Discharge (DD)
6. Recovery Voltage (RV) Measurement
7. Polarization Depolarization Current (PDC)

Insulation Resistance Test (IR)

- Simplest insulation test.
- DC Voltage is connected across the insulation under test for 1 minute.
- Reading is not taken immediately, because there are 3 types of currents (capacitive charging current, leakage current and the dielectric absorption current) at start, which gradually decay and stabilize with time.
- The resistance is then calculated using the Ohm's law.
- Insulation Resistance R = V/I

- ***Some key points related to IR test:***

  For Rotating Machine = (KV+1) MΩ

- ***Test Voltage for Meggering of electrical equipment:***

  AC Voltage = (2 X Name Plate Voltage) +1000 volt

  DC voltage = (2 X Name Plate Voltage) volt

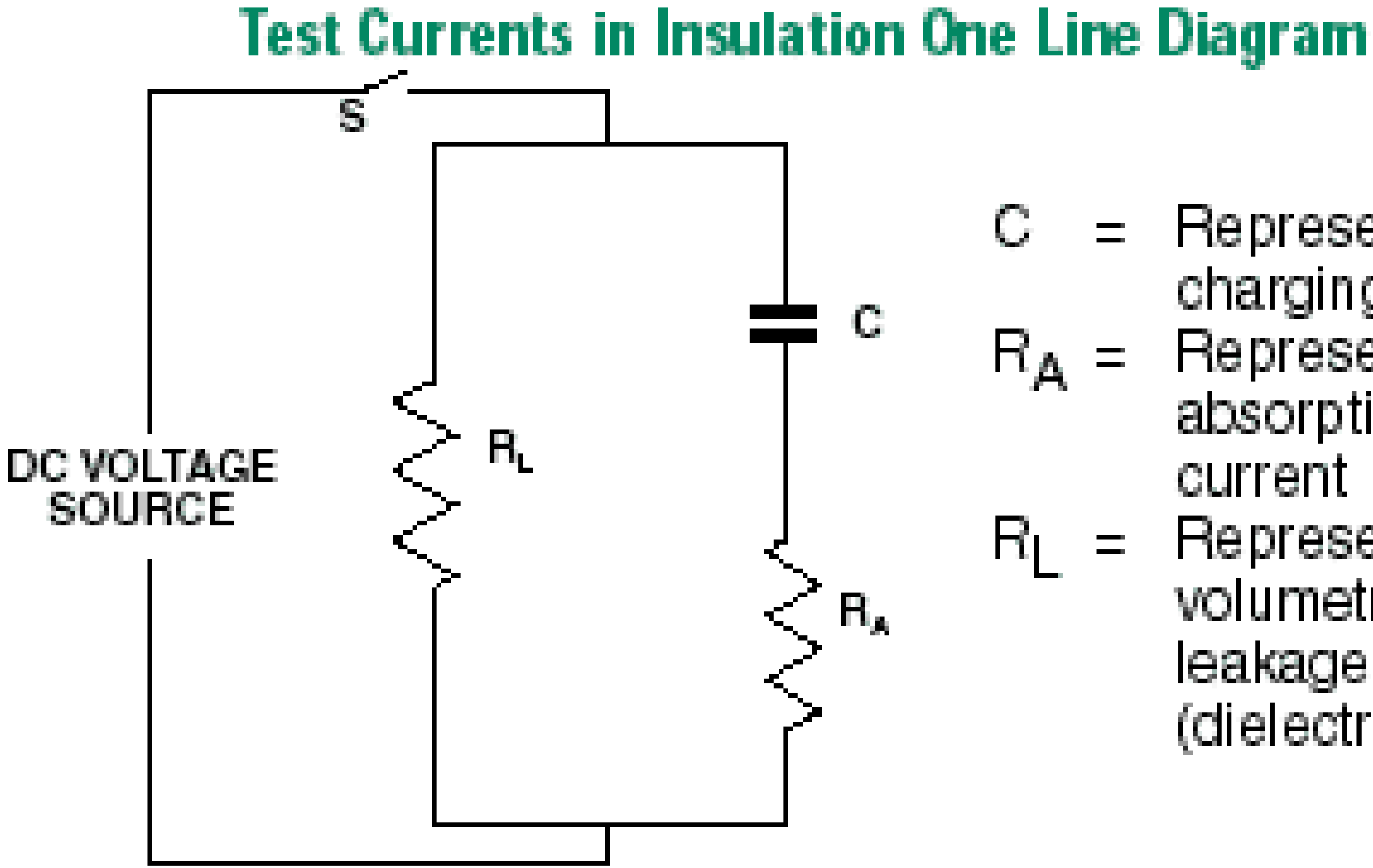
- IR value is dependent on temperature. Every 10^0C rise in temperature reduces the IR value by half.

Limitation:-

1. Highly temperature dependent, therefore should be corrected to value at 27^0C.

2. Measurement values are affected by moisture & surface contamination.

Circuit diagram of Insulation Test

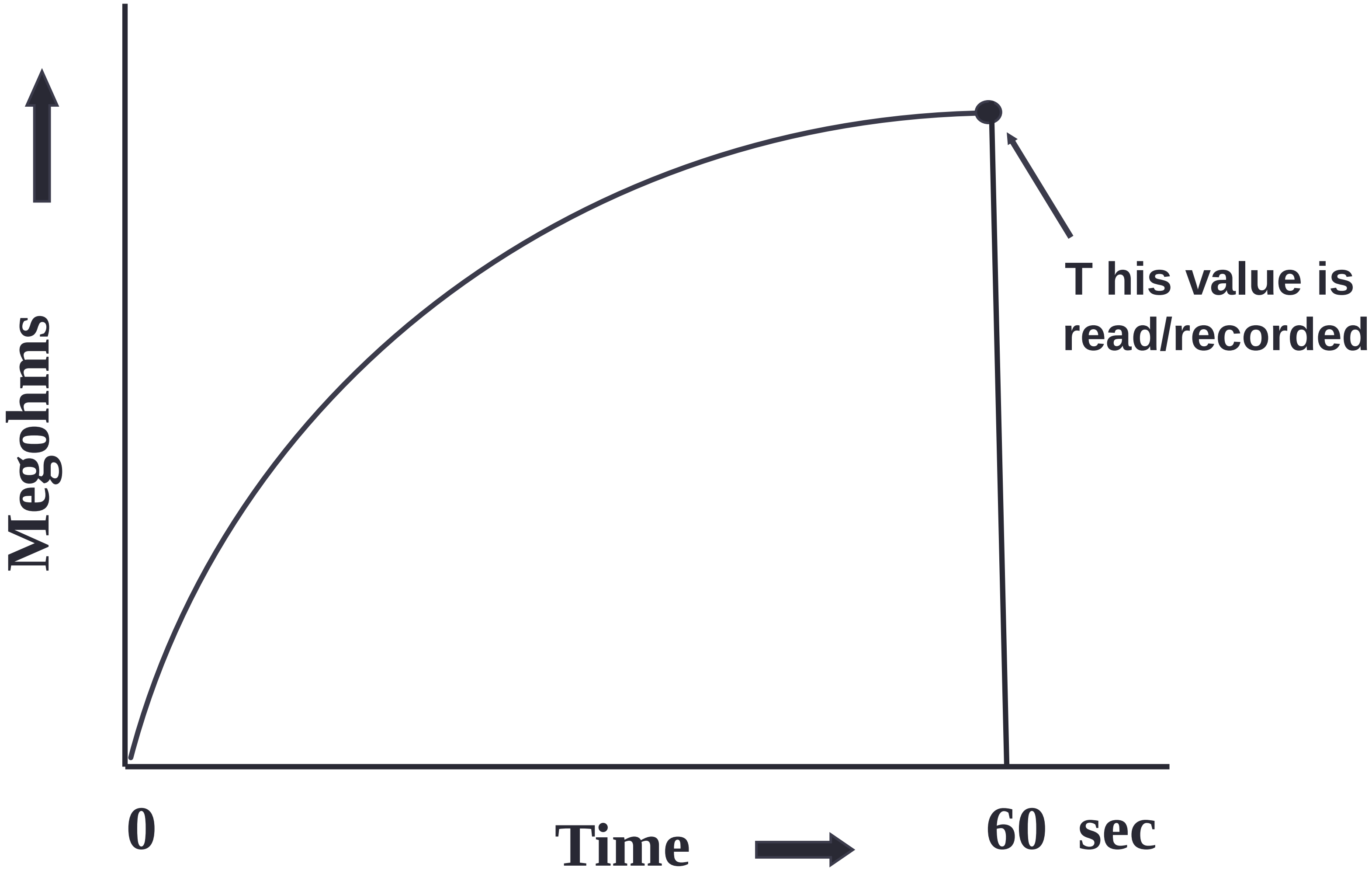


C = Represents charging current

R_A = Represents absorption current

R_L = Represents volumetric leakage current (dielectric loss)

Short-Time / Spot Reading - IR Test



Minimum Recommended IR Values

Maxiumum Rating of Equipment in Volts	Minimum Test Voltage dc	Recommended Minimum Insulation Resistance in MegOhms
250	500	25
600	1000	100
5000	2500	1000
8000	2500	2000
15000	2500	5000

Maxiumum Rating of Equipment in Volts	Minimum Test Voltage dc	Recommended Minimum Insulation Resistance in MegOhms
25000	5000	20000
35000	15000	100000
46000	15000	100000
69000	15000	100000

Current Responses in Insulation Test

- Leakage Current is resistive (contamination or severe internal problems if magnitude is high).

- Charging Current is Capacitive in nature & initially higher in magnitude.

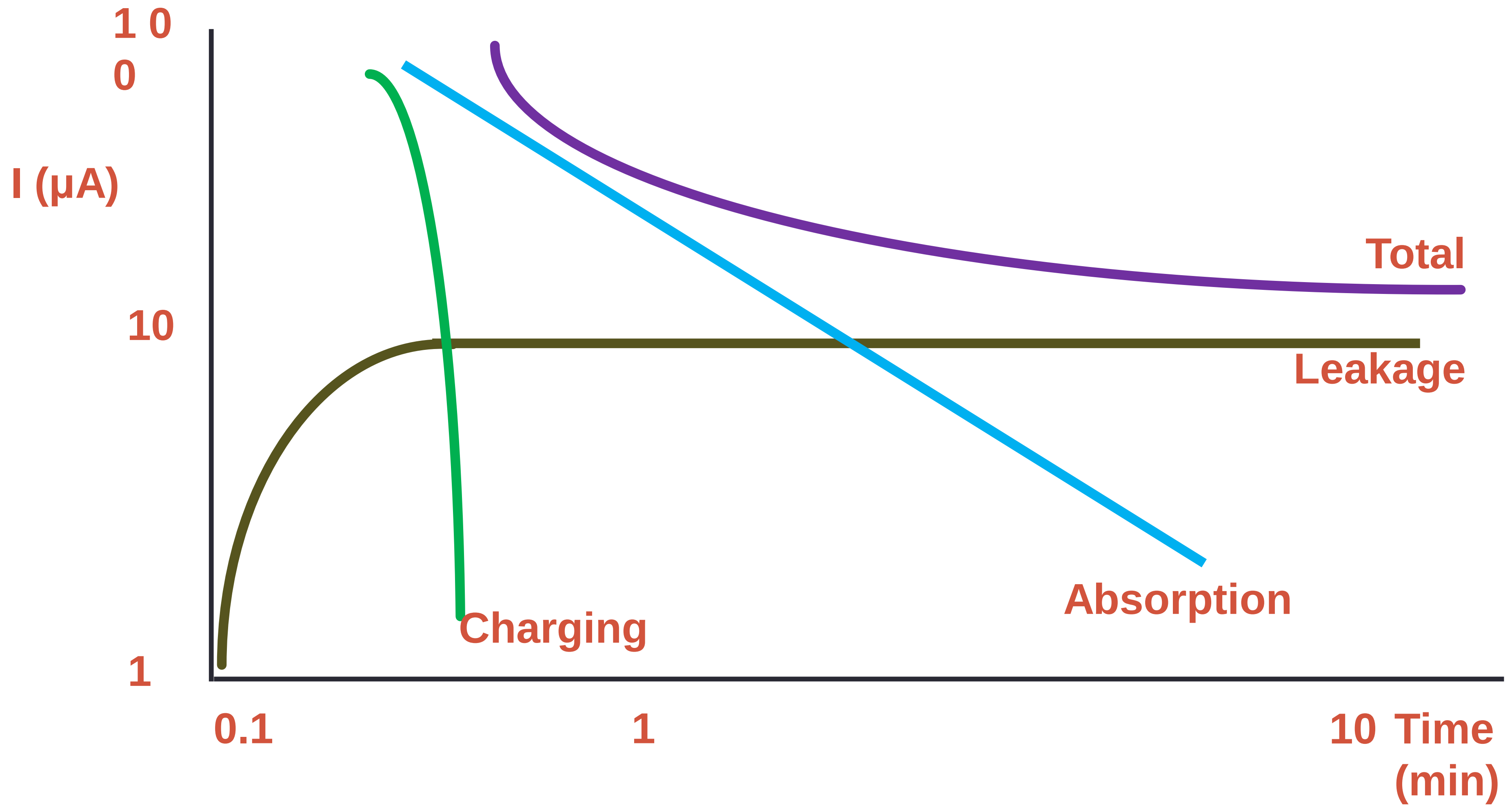
- Polarization/ absorption Current :

  - Directional polarization increases with absorbed moisture

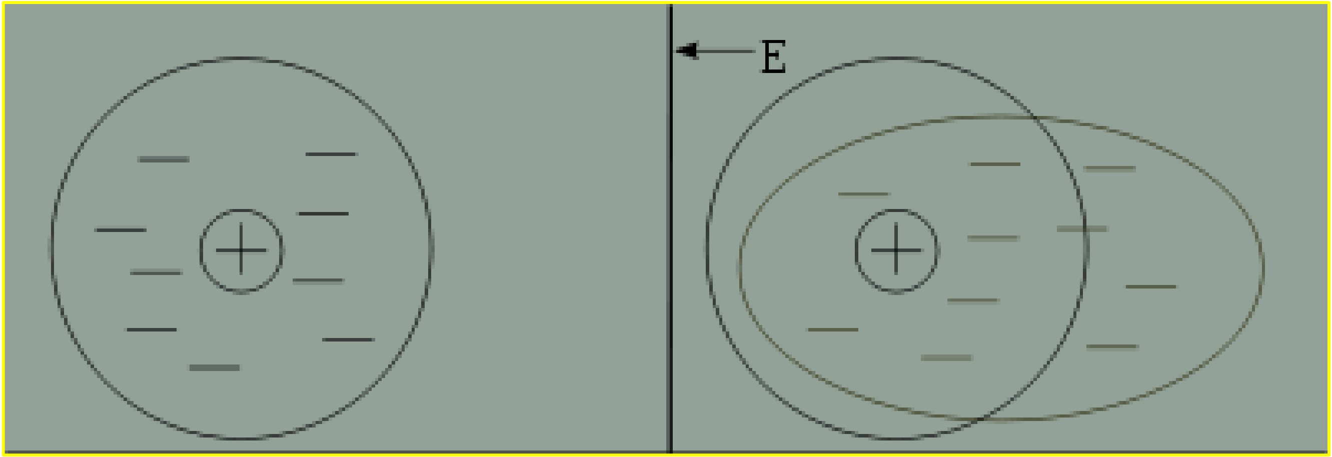
  - Contaminated materials get more polarized

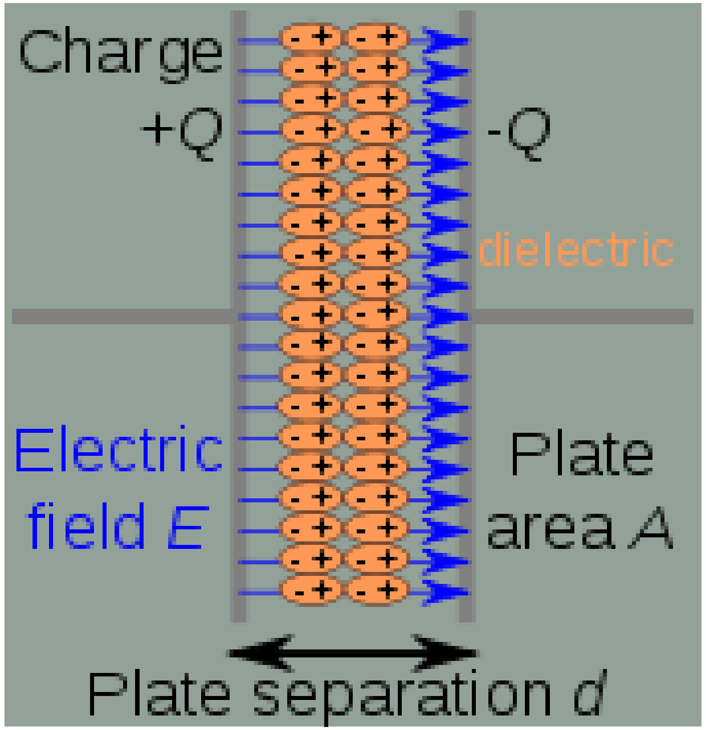
  - De-polymerization increases polarization

Insulation Currents in DC Test



Dielectric Polarization Absorption Current

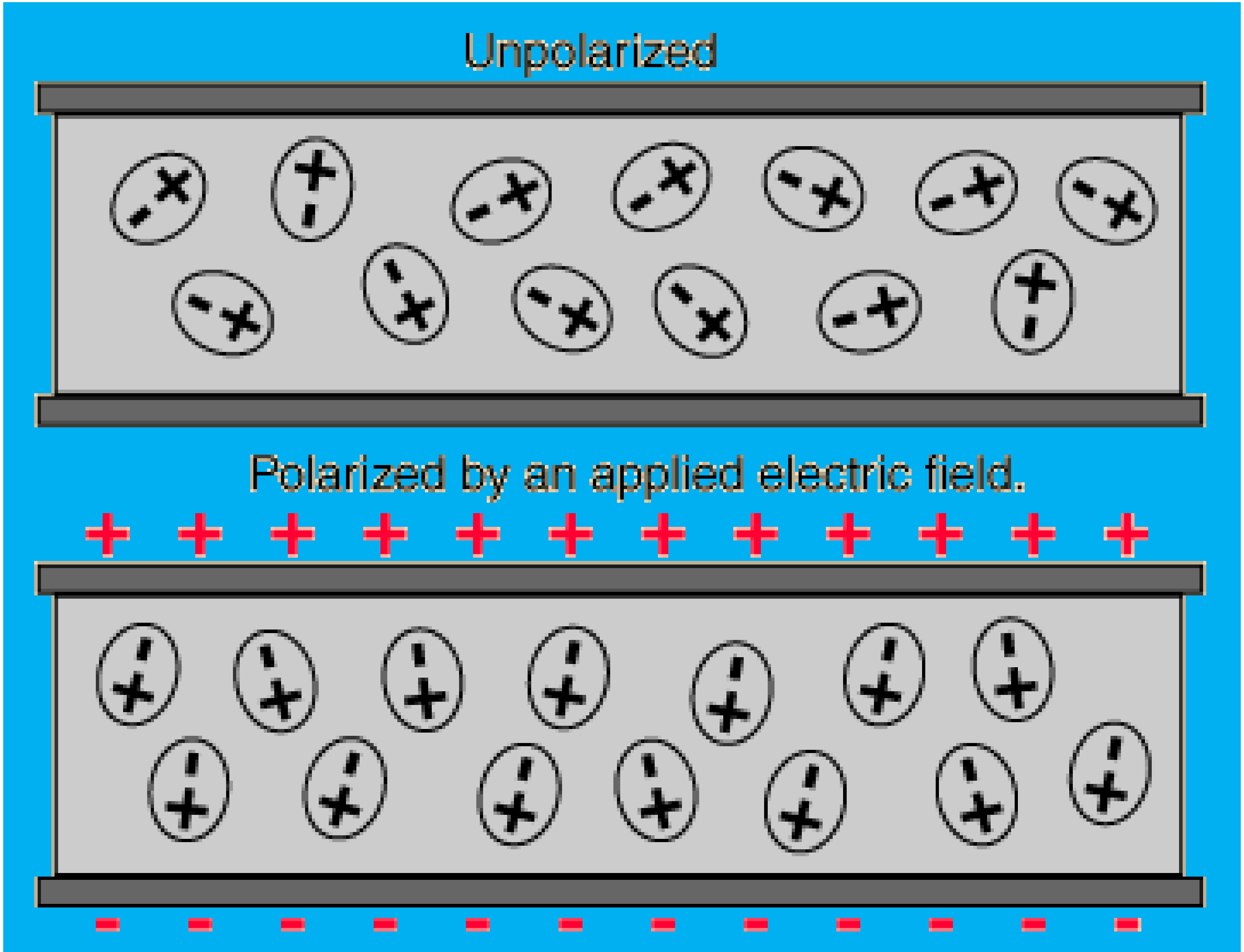




When dielectrics are placed in an electric field, practically no current flows in them because, unlike metals, they have no loosely bound, or free electrons that may drift through the material.

- Instead, electric polarization occurs.
- The positive charges within the dielectric are displaced minutely in the direction of the electric field, and the negative charges are displaced minutely in the direction opposite to the electric field.

Dielectric Polarization by applying external field



Measurement of IR for trend-analysis over time

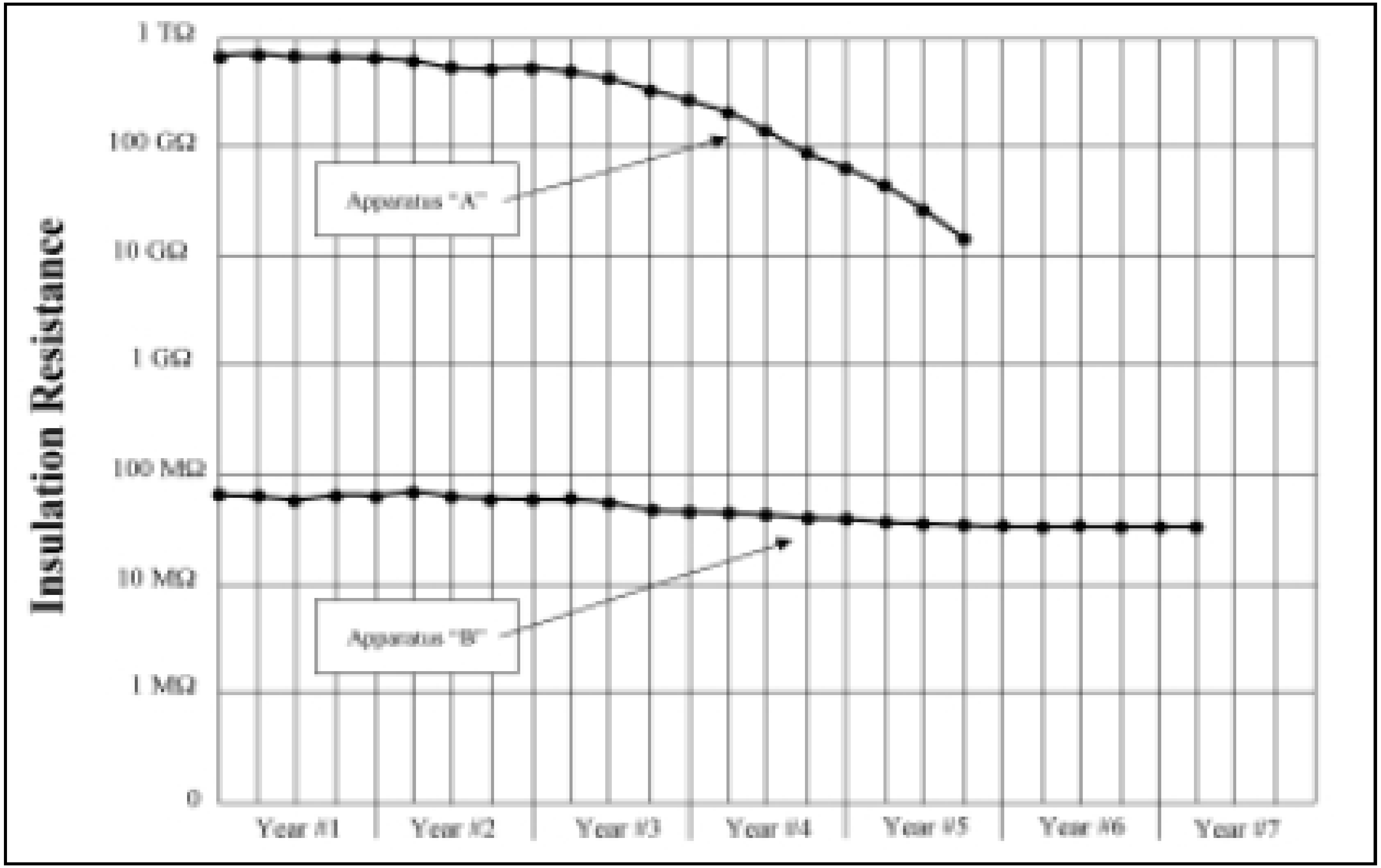


Figure 12: Comparison of Trended Test Results

Insulation of Apparatus " B " (lower curve) is better than "A"

Observing the trend of IR Values over many years

Condition	*What to Do*
(a) Fair to high values and well maintained	• No cause for concern
(b) Fair to high values, but showing a constant tendency towards lower values	• Locate and remedy the cause and check the downward trend

Condition	*What to Do*
(c) Low but well maintained	• Condition is probably all right but cause of low values should be checked. May simply be the type of insulation in use.
(d) Fair or high values previously well maintained but showing sudden lowering	• Make tests at frequent intervals until the cause of low values is located and remedied or, • Until the values have become steady at a lower level but safe for operation or, • Until values become so low that it is unsafe to keep the equipment in operation.

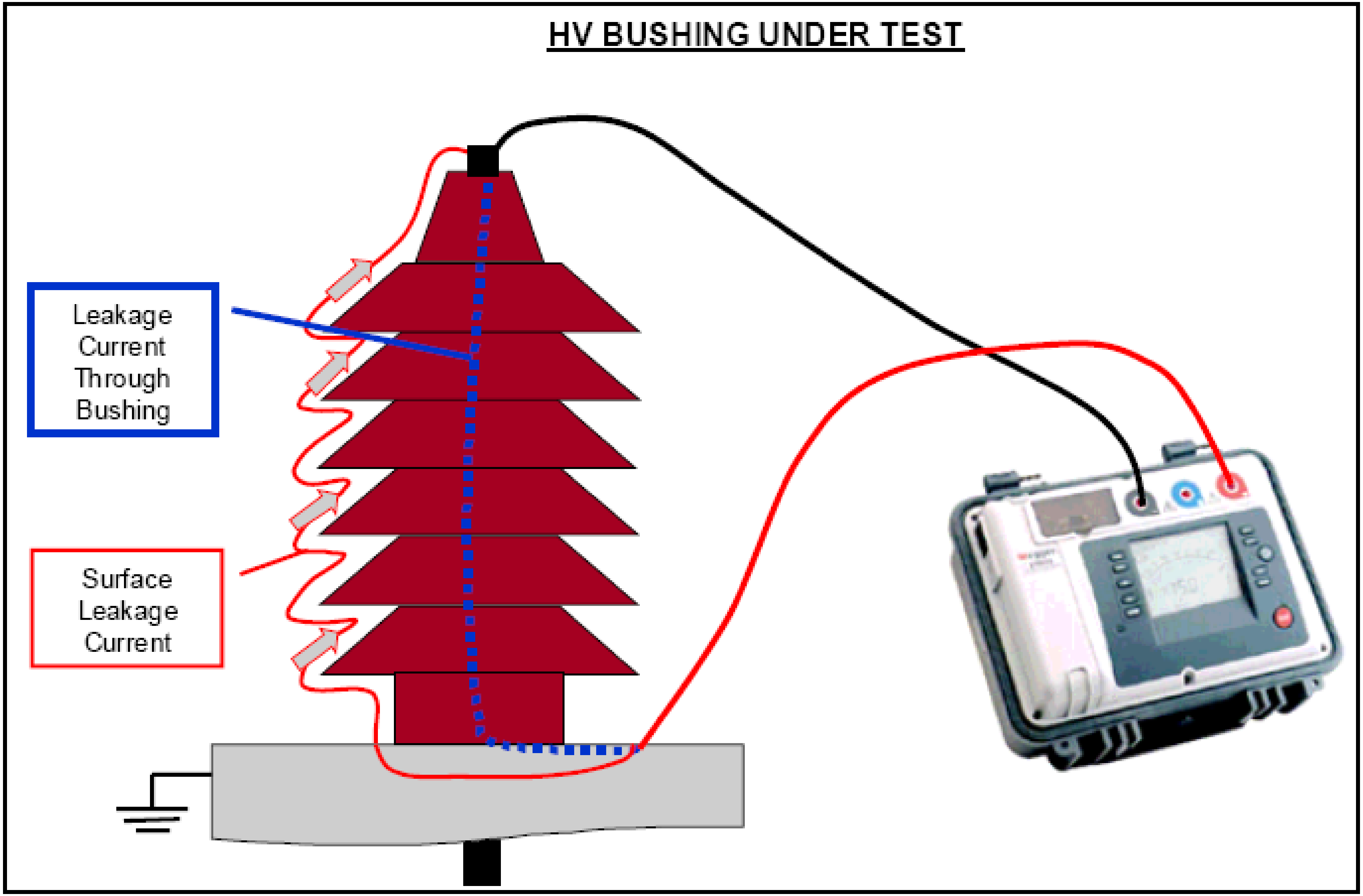
Terminals on IR Tester

L or (-) ve Terminal -------------- Connected to Line to test

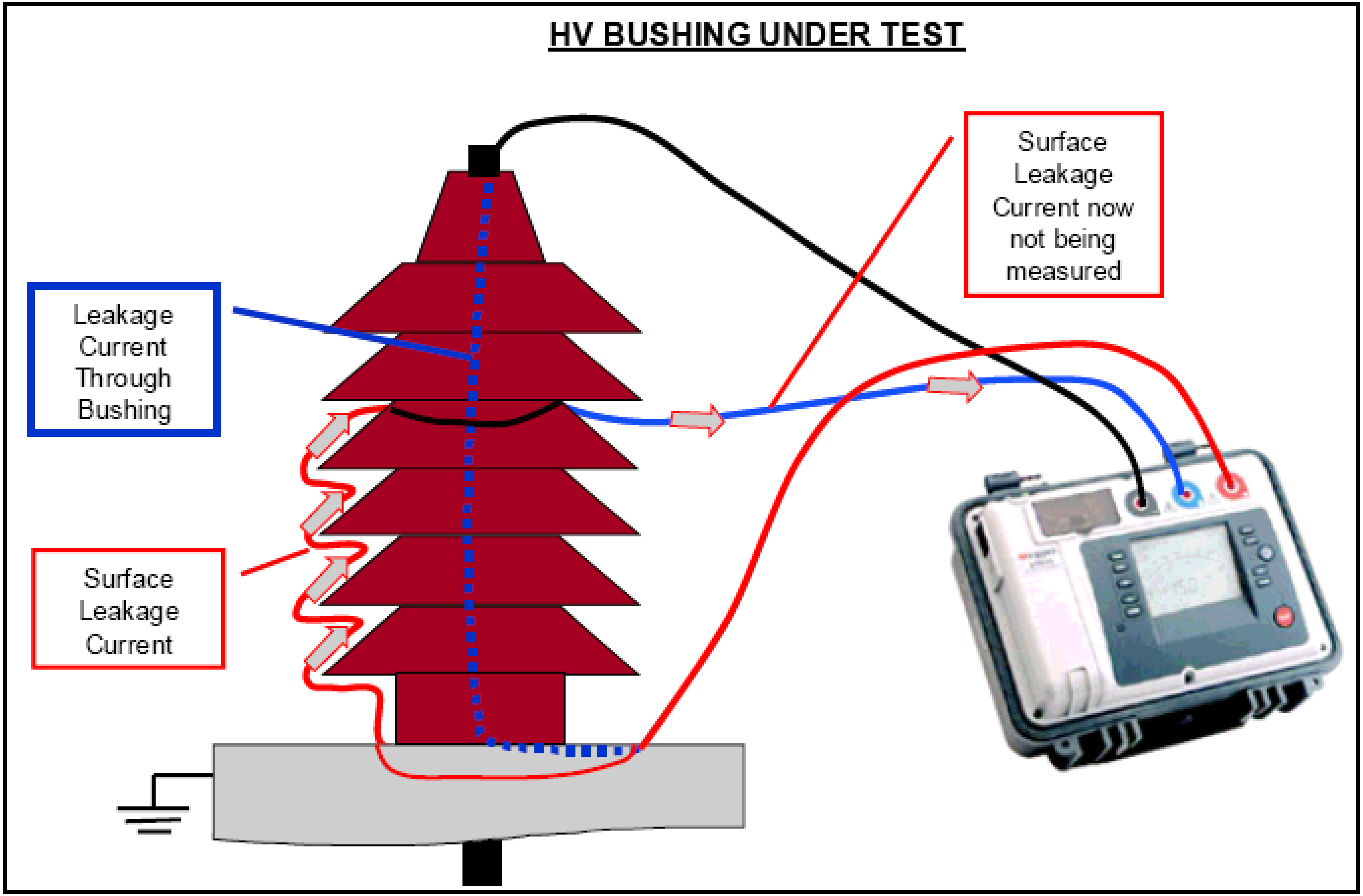
E or (+) ve Terminal -------------- Connected to Ground/Earth

G or Guard Terminal ----------- Connected to Guard Wire

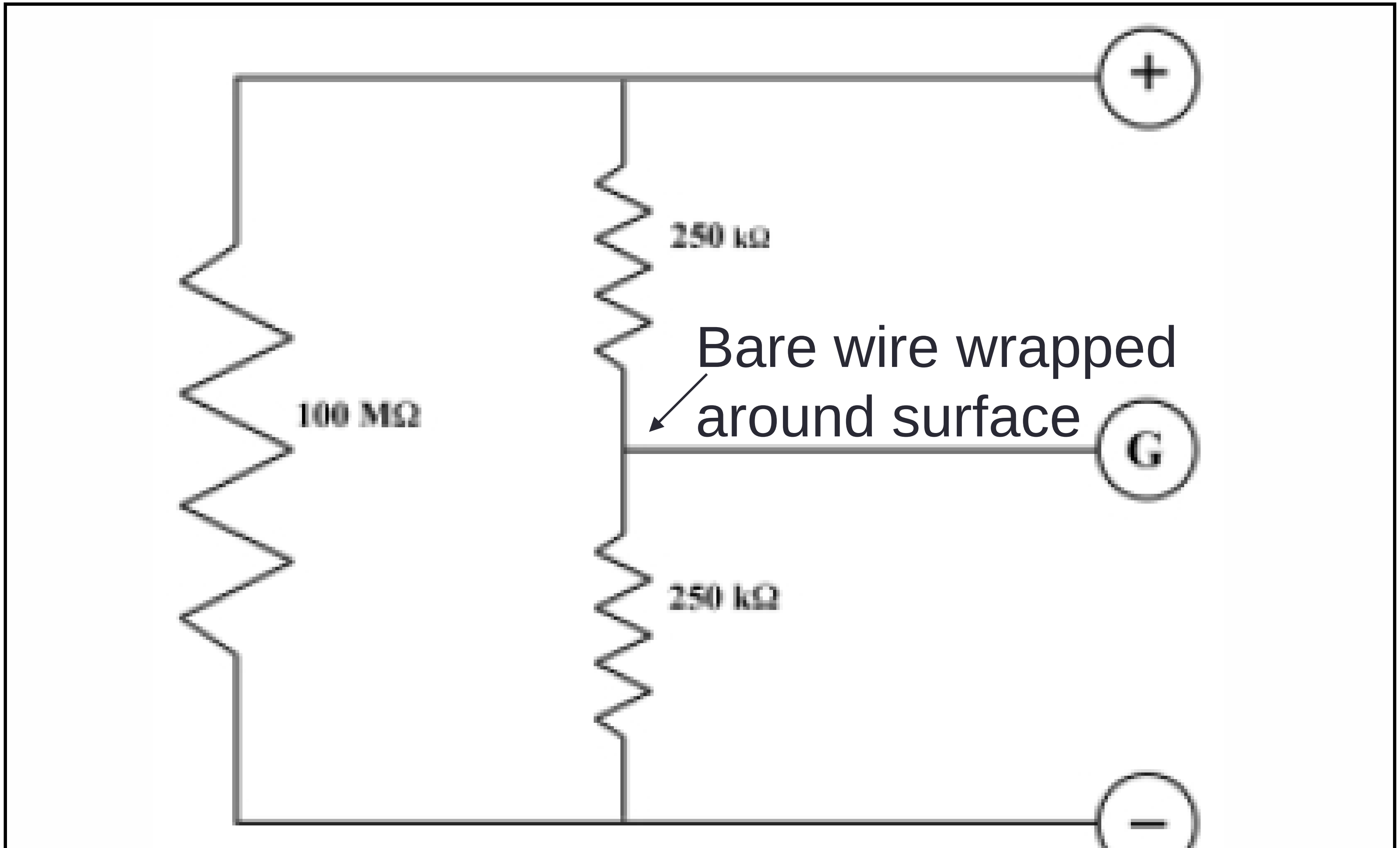
- Surface Leakage Current due to dirt etc. on the outer surface of an insulation, may be quite high, and may give erroneous results of IR value, therefore Guard Wire should be connected from Guard Terminal of IR Tester and is left bare-wrapped around the outer surface of insulation. The use of Guard Wire & Terminal, allows by-passing of the surface-leakage current.



WITHOUT GUARD WIRE



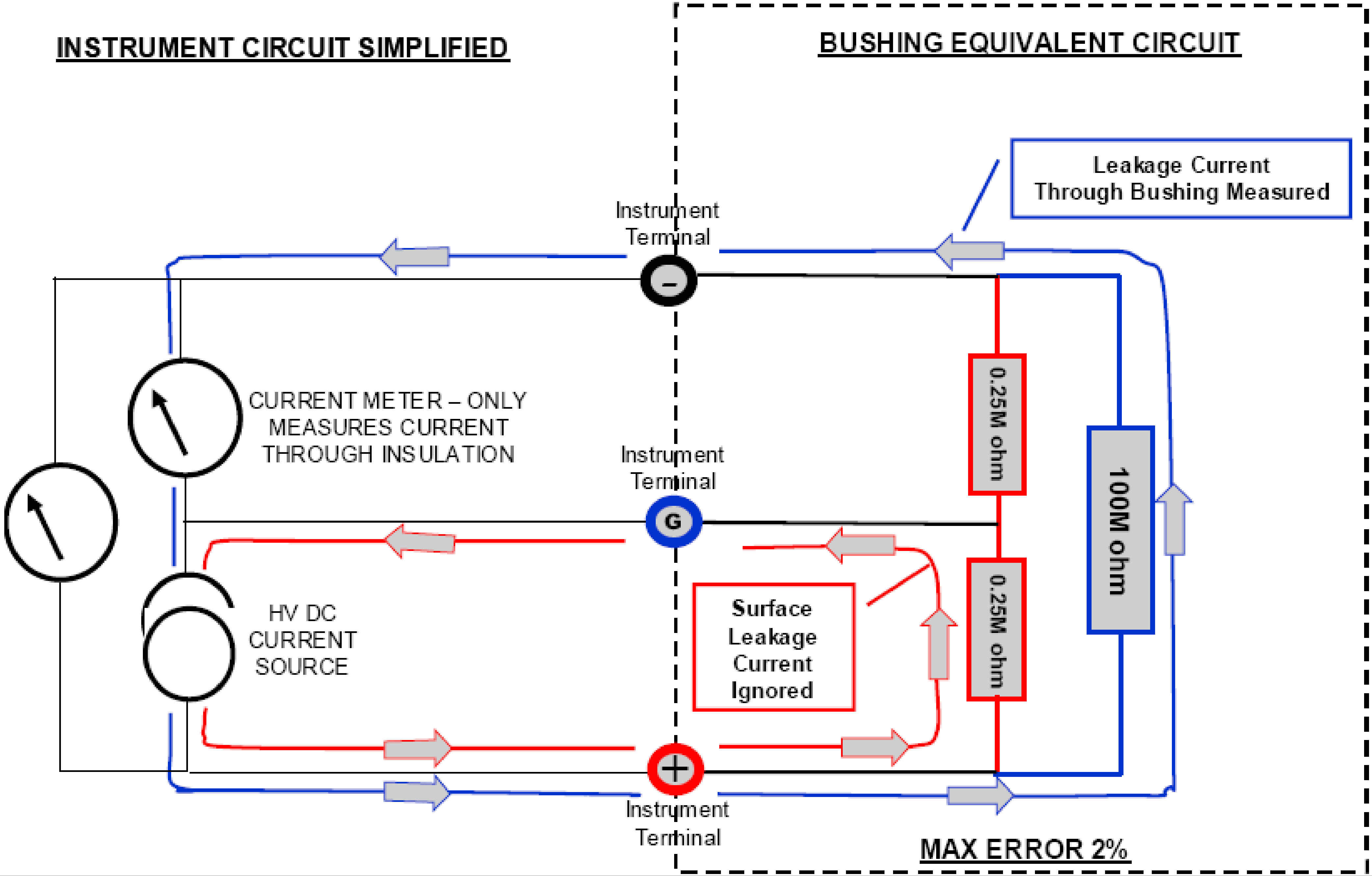
WITH GUARD WIRE

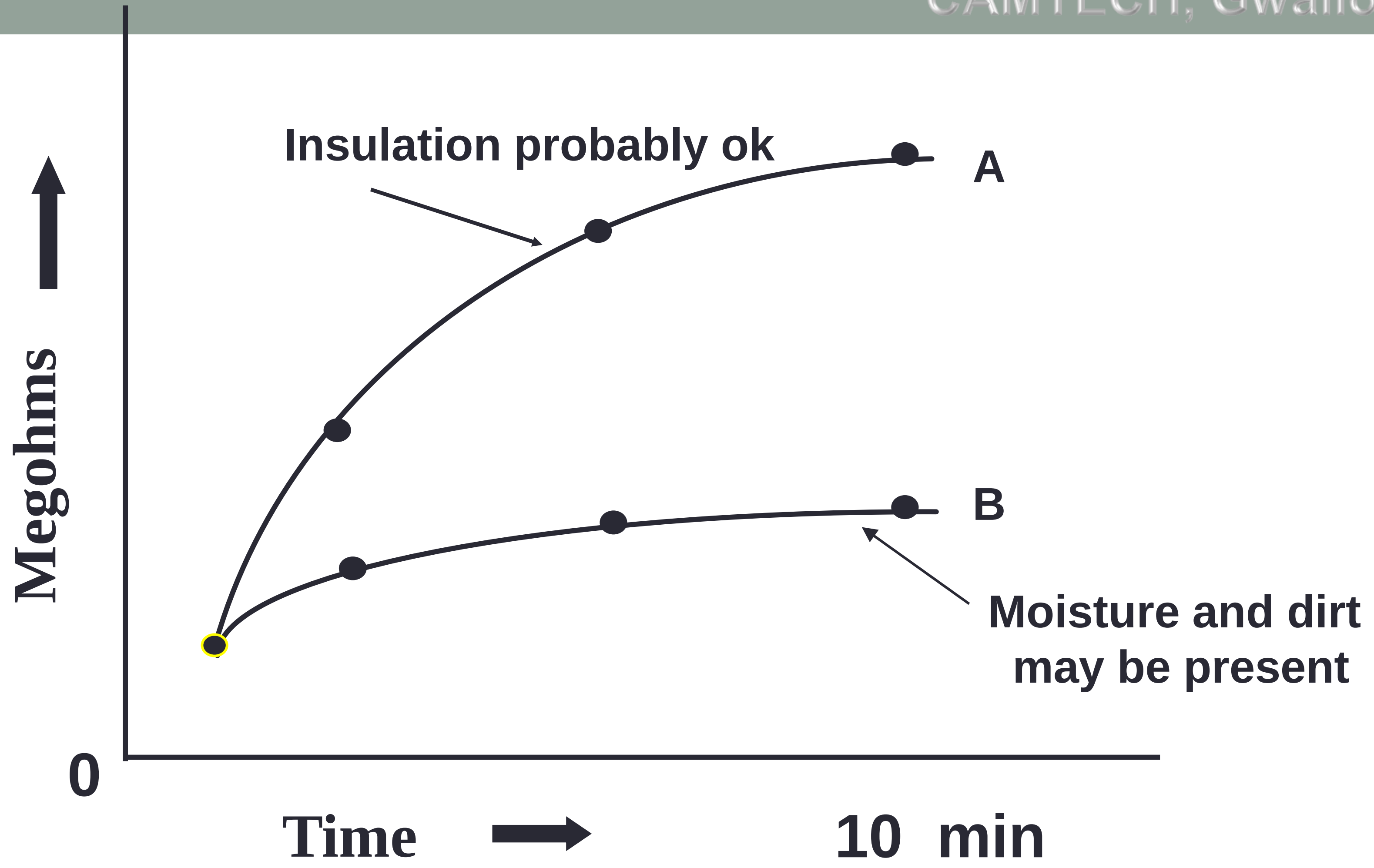


Guard terminal diagram

Here we show an insulator of value 100 MΩ that we wish to measure. It is dirty and contaminated and so it has a surface leakage path of 500 k Ω. If we apply our test voltage from the positive and negative terminals without guarding the circuit, 20 times as much current will flow through the surface leakage compared with the current flowing through the insulation we wish to measure and we will read a resistance of only 497 k Ω

Significance of Guard wire





Good insulation shows a continual increase in resistance (curve A) over a period of time (about 10 minutes). This is caused by the absorption; and continues for a longer time than to charge the capacitance of the insulation. If the insulation contains moisture/ contaminants, the absorption effect is masked by high leakage current.

Polarization Index Test

(PI)

- Ratio of IR Reading taken at 10 minute, to that taken at 1 minute. $PI = IR_{10\ minutes} / IR_{1\ minute}$

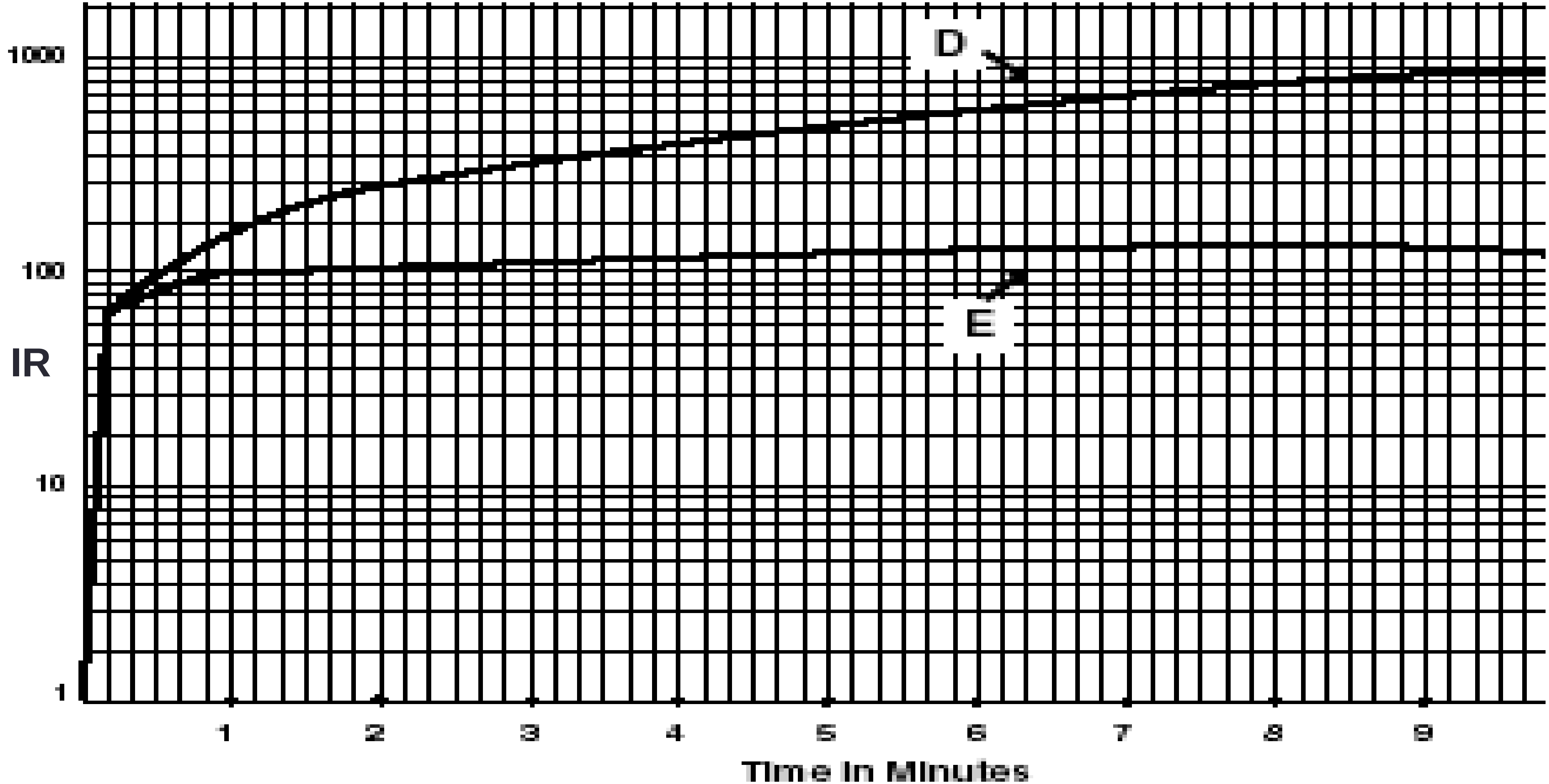
- Generally used on insulations of large systems, having high capacitance, since the readings in such systems, do not stabilize quickly.

- PI test is not recommended **for liquid insulation**, due to convection currents.

- It indicates presence of surface dirt & moisture, since both Charging & Absorption Currents die down at 10 minutes.

- Proves insulation**, before applying HV a.c**. test.

Importance of PI Value



Curve **D** indicates a good insulation with an excellent Polarization Index of (1000/200)=5. Curve **E** indicates a potential problem, as the PI value is only 140/95, or 1.47. Insulation of curve “D” is better than that of curve “E”.

Dielectric Absorption Ratio

- DAR = (IR in 60 sec. / IR in 30 sec.)

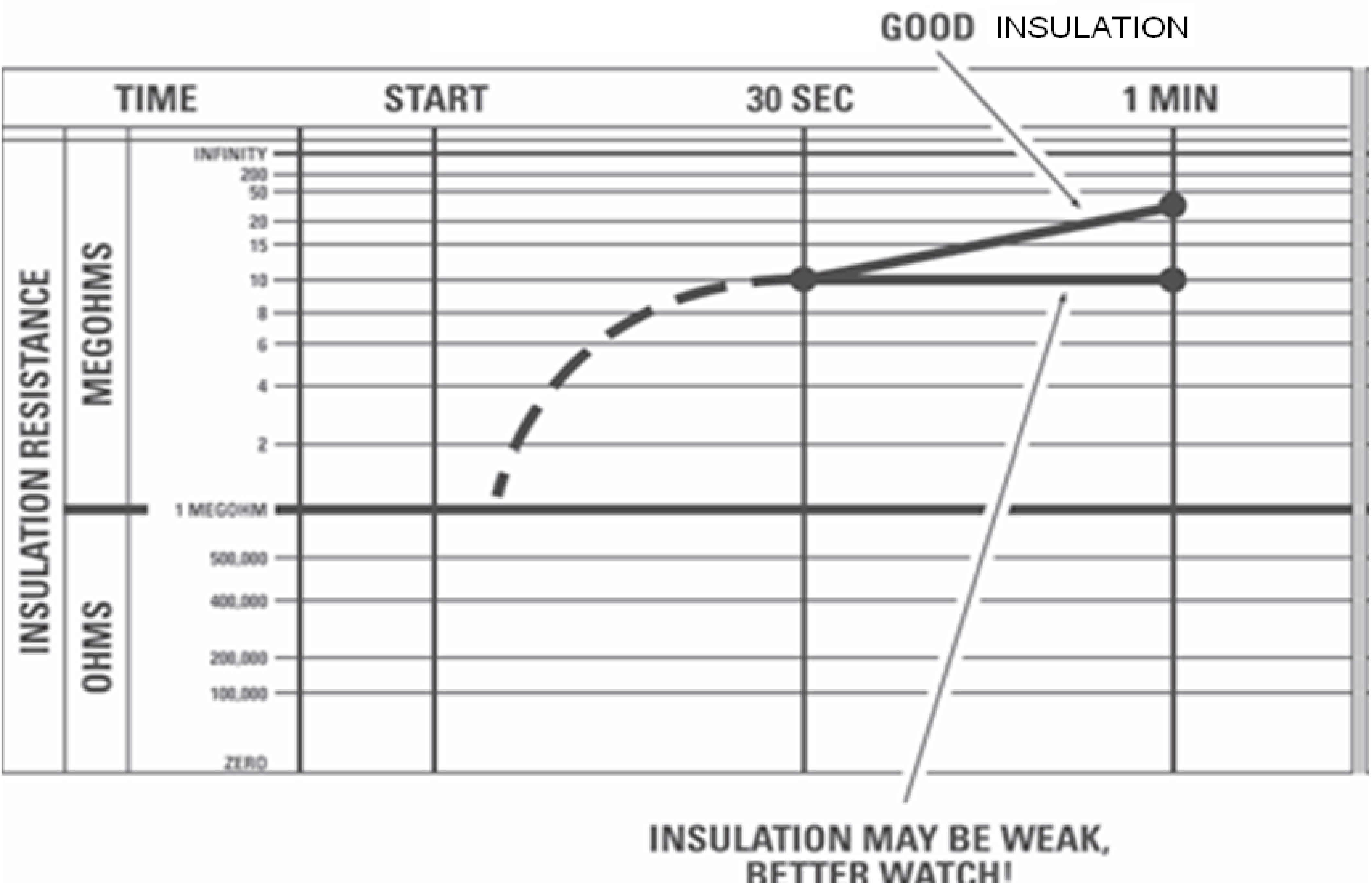
- Good insulation will show gradual increase in IR, as test voltage is applied.

- In good insulation, leakage current rapidly increases (before 30 sec) & then stabilizes at low value.

- In good insulation, absorption current should begin at 30 sec. and should reduce gradually, so IR value should increase after 30 sec.

- Charging Current should ideally die down before 30 sec.

Concept of DAR



PI and DAR Values

Insulation Condition	PI Result	DAR
Poor	Less than 1	Less than 1
Questionable	1 – 2	1.0 to 1.4
Good	2 – 4	1.4 to 1.6
Excellent	Greater than 4	Above 1.6

Thermal Class	PI Value
Class "A"	1.5
Class "B, F or H"	2.0

Step Voltage Test

(SV)

- Multi-voltage test: involves applying two or more voltages in steps (like 500 V and 1 kV).

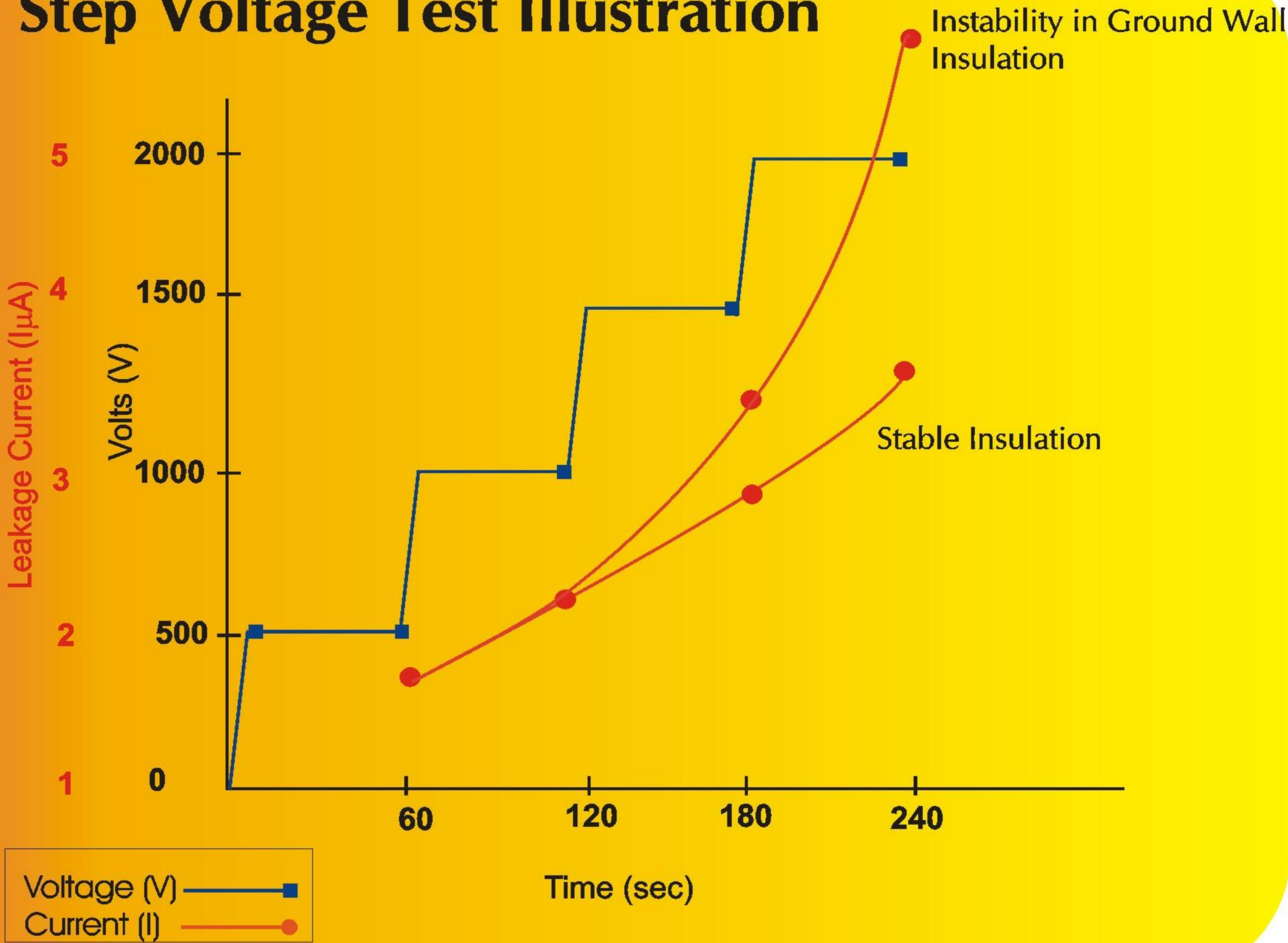
- Test voltage remains constant between steps for about 60 seconds.

- Between two consecutive test-steps, insulator is allowed to discharge.

- Monitor insulation resistance at each level.

- Any marked or unusual reduction in IR value of more than 25%, is an indication of incipient weakness, or ageing.

Step Voltage Test Illustration



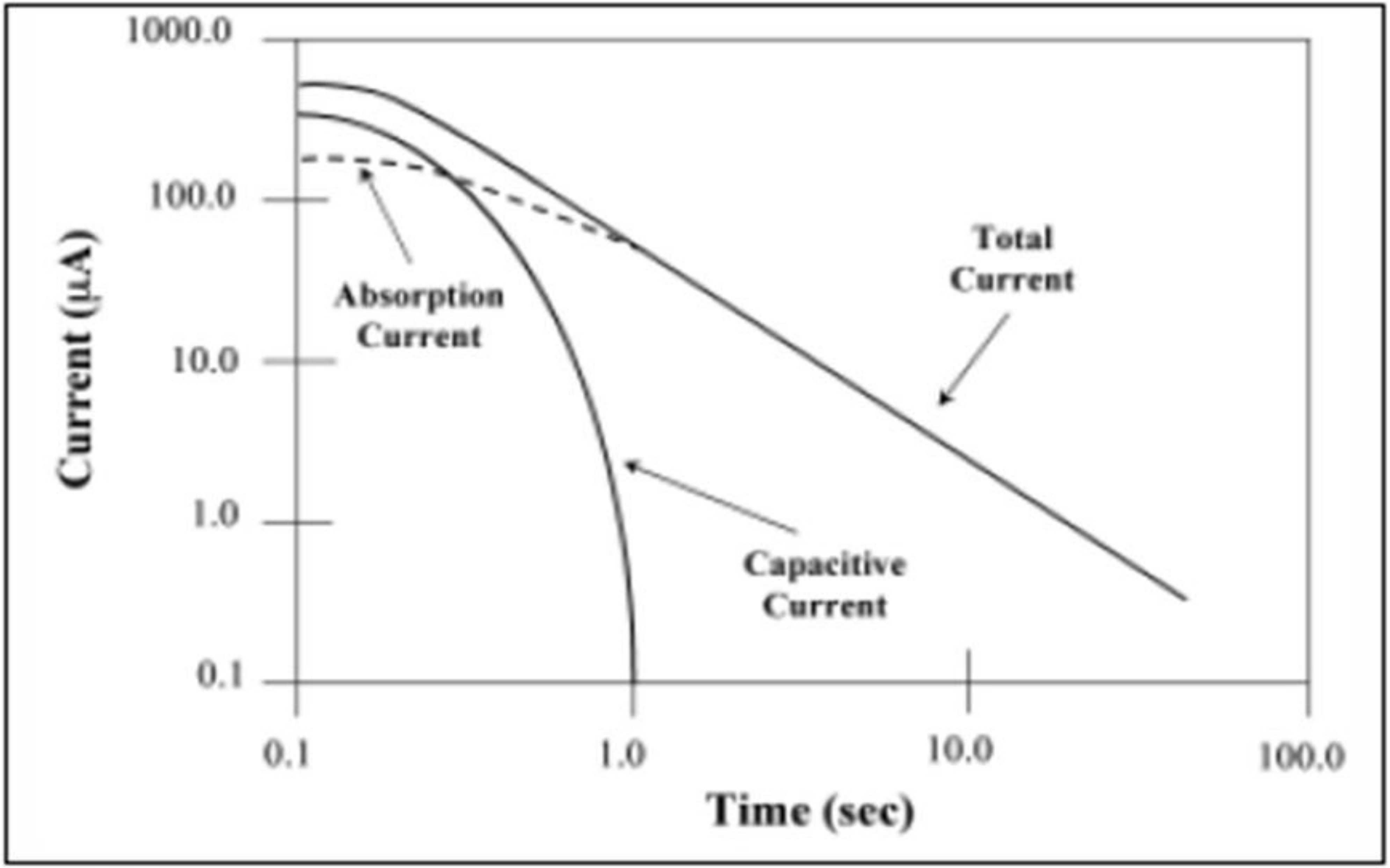
Diagnosis From Polarisation Effects

- Polarisation can give information about
  - Absorbed moisture
  - Aging
- But is difficult to measure directly due to masking by Capacitance / leakage effects.
- So let us look at the DISCHARGE based tests.

Dielectric Discharge Test (DD)

- Charge the insulation with test-voltage for 30 min.
- Discharge the insulation through known “resistance” of the Tester.
- Measure the discharge current after 60 seconds of applying discharge-resistor of the Tester.
- Level of re-absorption after this time, shows the state of the insulating material.
- The re-absorption current is dependent on the following:
  - overall capacitance.
  - final test voltage.
  - degree of polarization of the dielectric.

Currents during Dielectric Discharge Test



Reabsorption Currents

Why Measure Dielectric Discharge

- The DD test result can show how similar the layers of insulation are in a multi-layer insulation.
- Goal is for each layer to share the voltage stress equally.
- If an internal layer is damaged, mismatch in its (RC) value w.r.t. other layers, gives higher values of current.
- Can show when the resistance-capacitance characteristic is incorrect.

- DD is given by:
$$DD = \frac{\text{Discharge current flowing after 1min (nA)}}{\text{Test voltage (Volts) x Capacitance (µF)}}$$

- Availability of absorbed moisture affects absorption current, and this current can be correctly measured in “Dielectric Discharge Test”.

Dielectric Discharge (DD) Test

Insulation Condition	DD Value (in $mAV^{-1}F^{-1}$)
Bad	Greater than 7
Poor	4 – 7
Questionable	2 – 4
Ok	Less than 2

Recovery Voltage Measurement

(RVM)

- DC voltage is applied to dielectric material (polar molecular structure) & electric dipoles are oriented in the direction of applied electric field.

- Polarization charge is induced by dipole movement and realignment & this gives voltage across capacitance.

- If dielectric is short circuited, the stored charge in dielectric capacitance is dissipated with time constant (time constant is calculated by effective intrinsic resistance & capacitance).

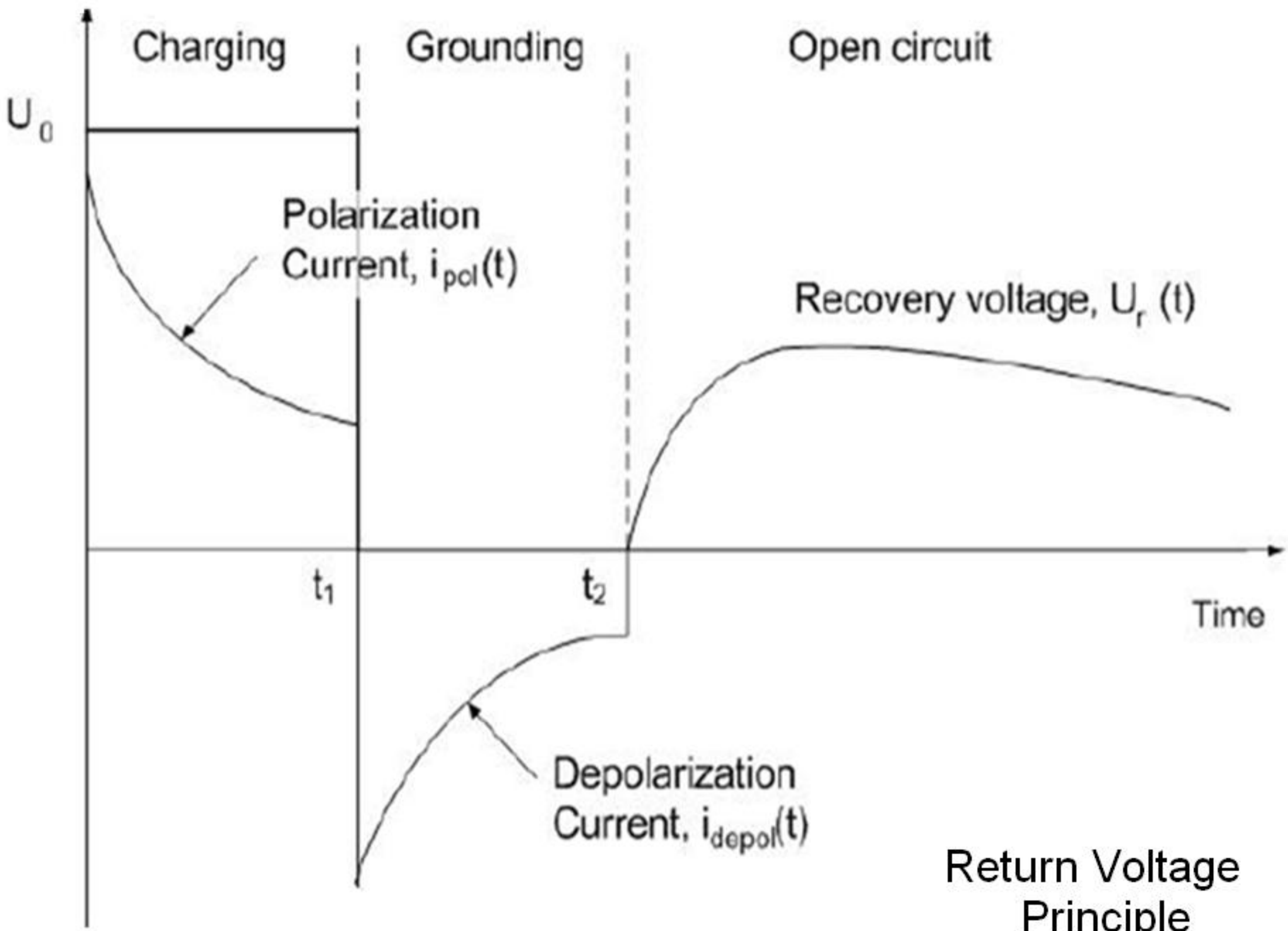
- During short circuit voltage across dielectric is zero but if short circuit is removed before the equilibrium condition of total stored charge, some voltage is remain across the dielectric & known as Recovery voltage.

Method for RVM

- The spectrum of the return voltage is plotted by changing the charging and discharging time until the peak value of the maximum return voltage was obtained.

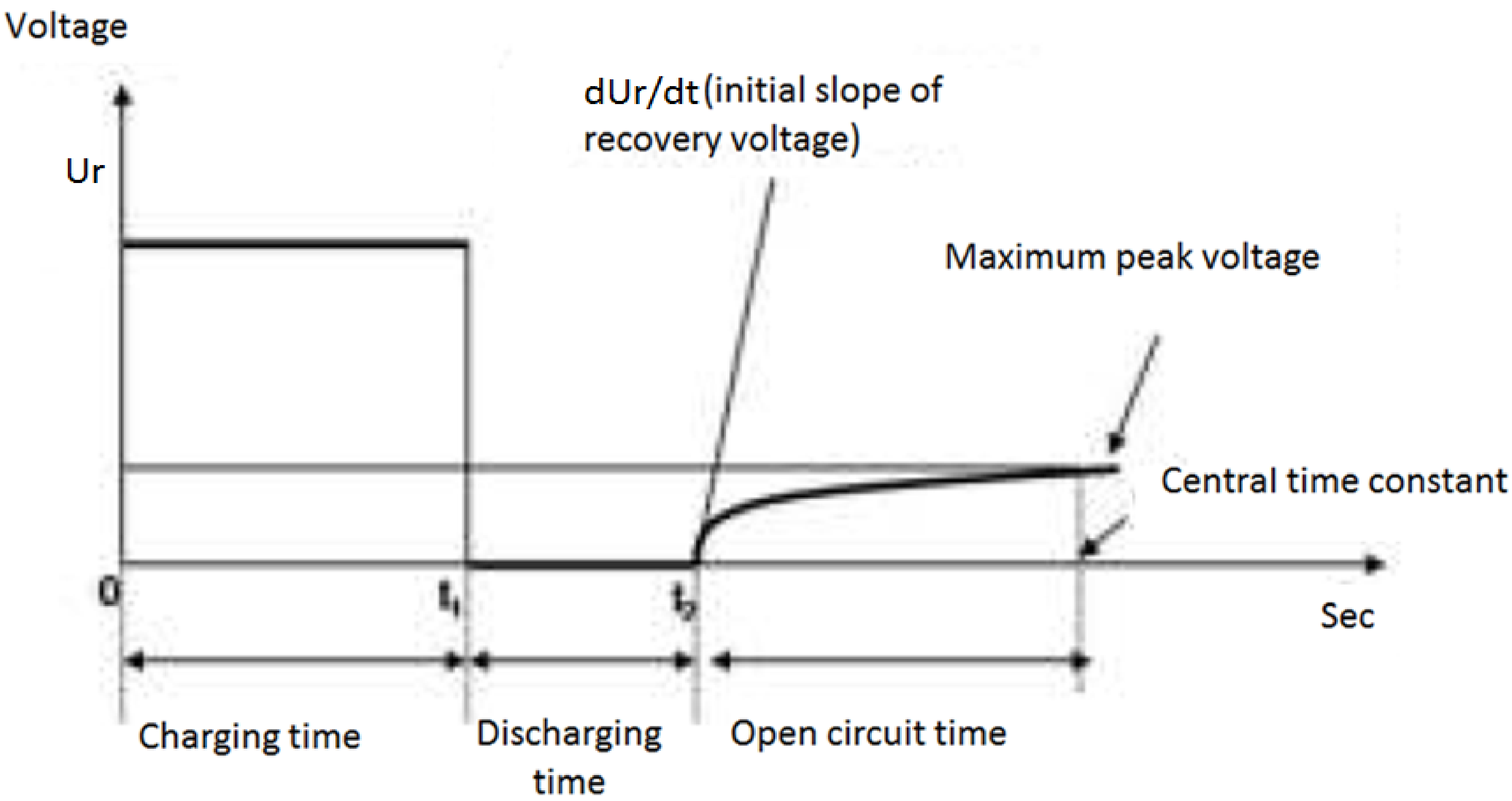
- Then the spectra of maximum return voltage and initial slope or "rate of rise of Return Voltage" are plotted in Y-axis versus the central-time constant (the time at which the return voltage is max.) on X-axis.

- Insulation with absorbed moisture, will show early arrival of Recovery Voltage Peak in a lesser central time-constant.

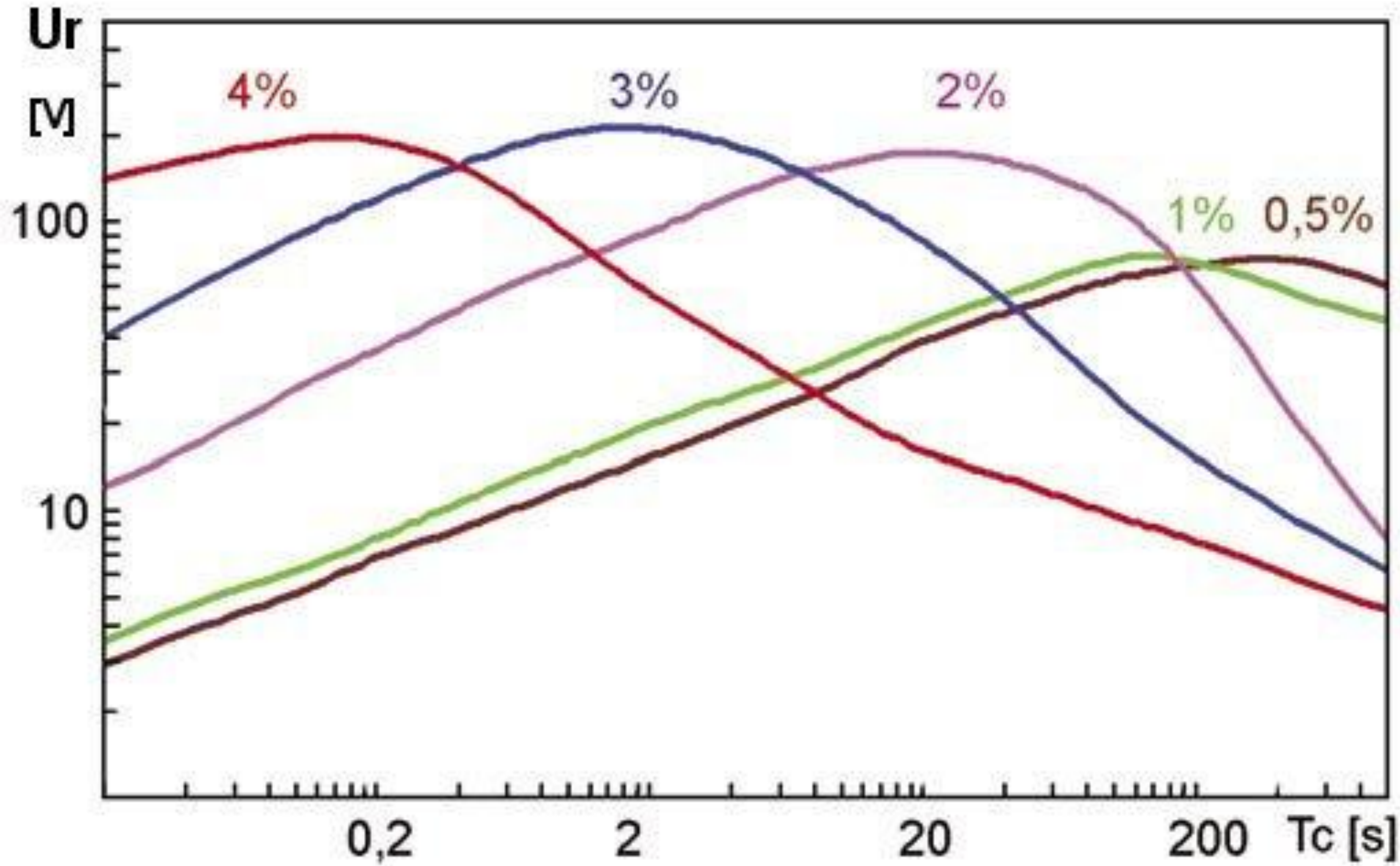


Return Voltage Principle

Recovery Voltage Measurement (RVM)

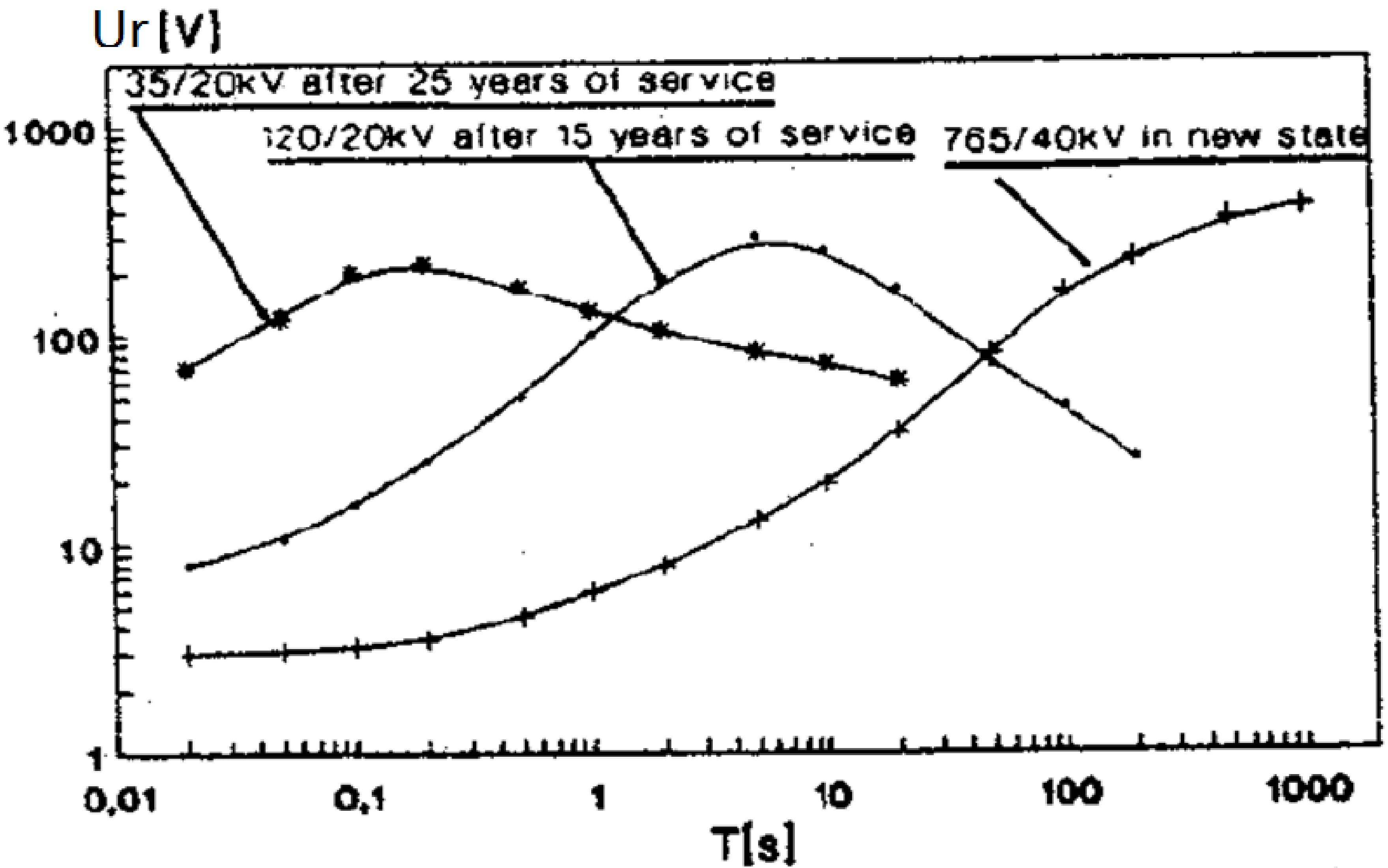


The process of charging, waiting, discharging through short circuit and open circuiting at different times is done to get maximum Recovery Voltage.



Water content in %M/dw in cellulose by RVM method

Some findings from other researchers:-The closer the return voltage peak is towards the small time constant the worse is the condition of the transformer



Polarisation – Depolarisation – Current (PDC) Method

- PDC method gives the information of insulation condition through predicting the moisture content & also developing the ageing phenomenon.

- The polarizing current pulse has peak magnitude, final steady state level, time constant & duration that are determined by the quality of the moisture level and electrical conductivity.

- Electrical conductivity affects the peak current in the first 100 seconds or so of the current pulse.

- The moisture in the insulation affects the polarization current level after 1000 seconds.

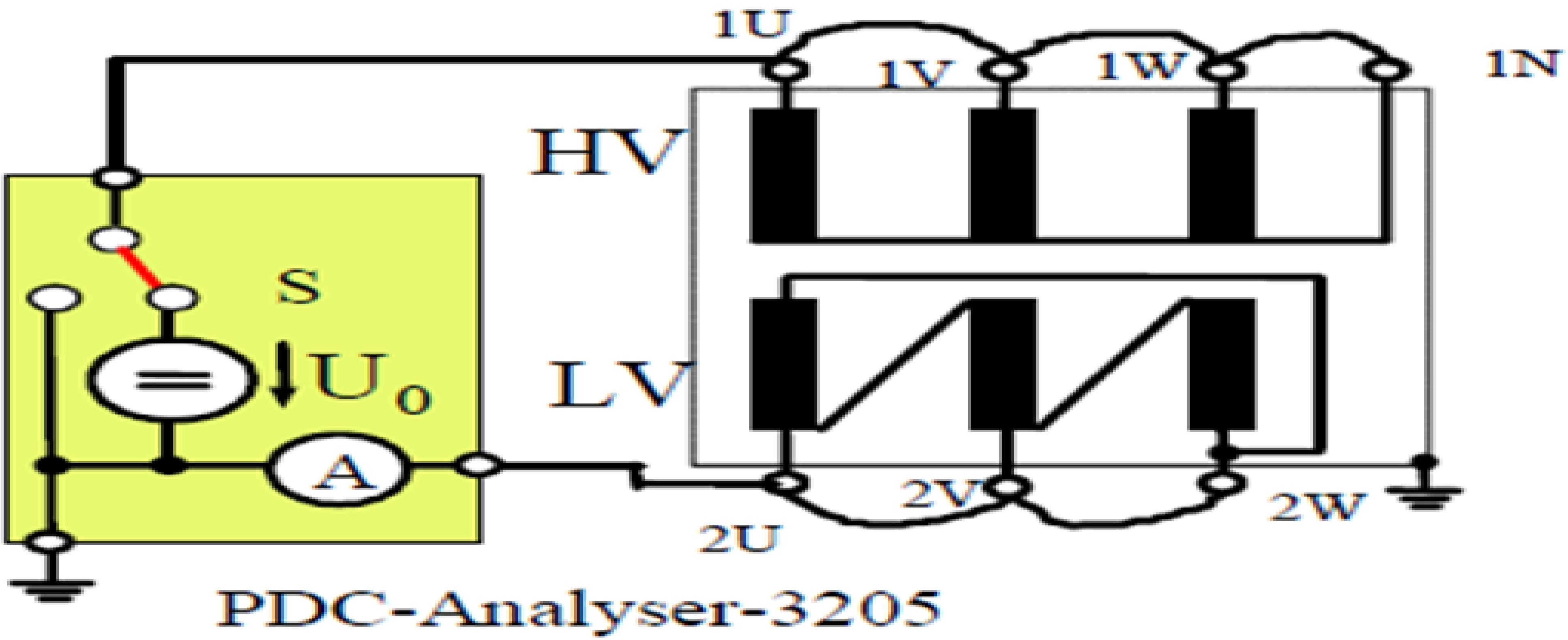
- The magnitude and nature of the PDC currents were found to be a good indication of the equivalent ageing and moisture content of the paper and of oil insulation.

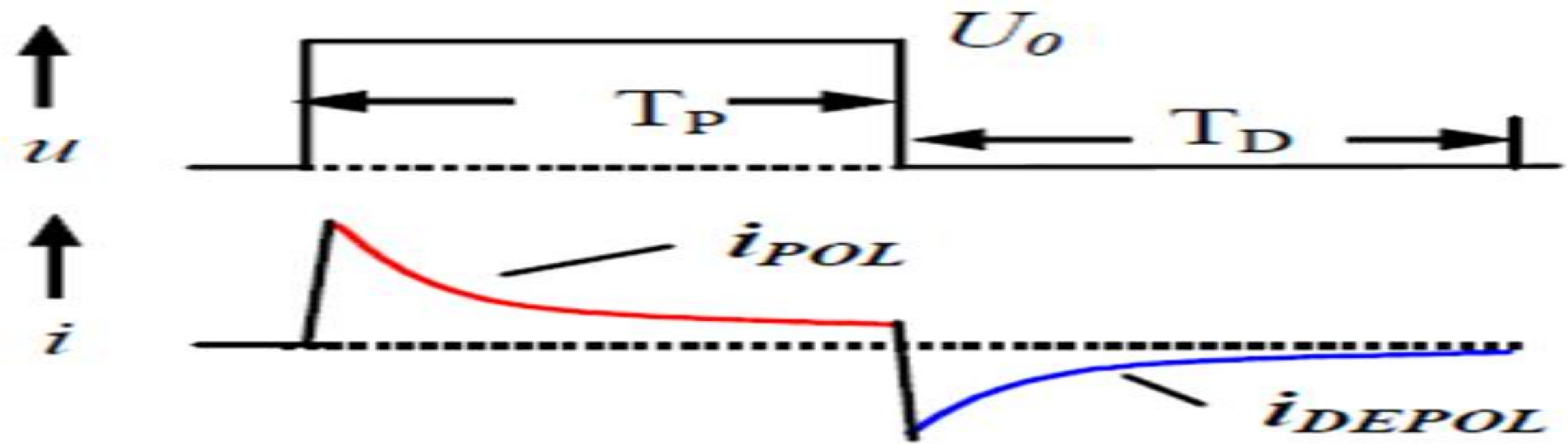
- The initial part of the polarization current was found to be dependent on the condition of the oil, whereas the long term stationary value of this current was governed by the condition of the solid insulation.

- Oil conductivity and paper conductivity can be separately estimated from the polarization current.

- Oil and paper conductivity can be empirically related to equivalent ageing and moisture level of the oil and paper insulation respectively.

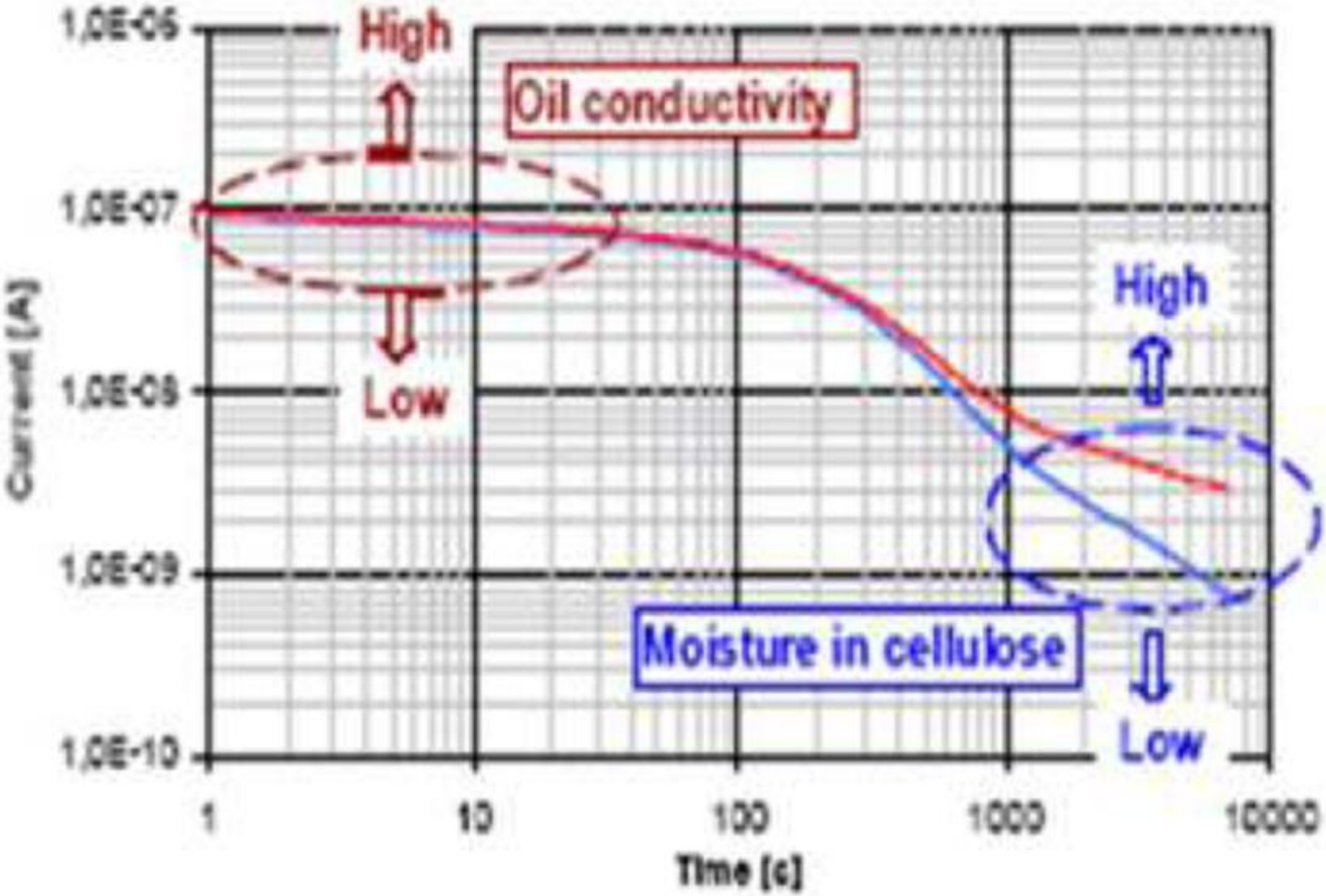
Polarization-Depolarization Current (PDC) Method

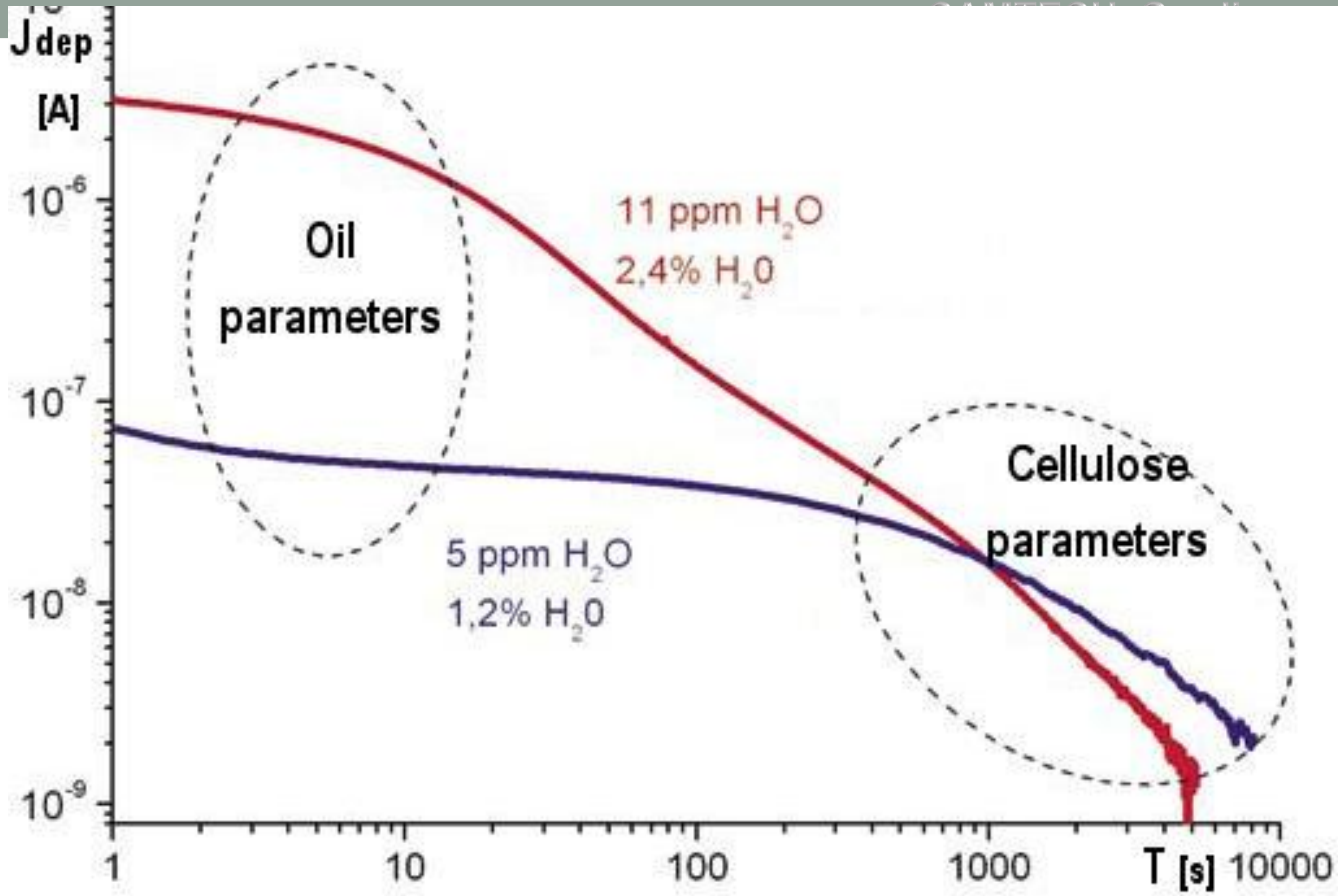




Polarization & Depolarization Current (PDC)

- Effect of moisture in oil and cellulose paper on the polarization depolarization current measurement





Water Content in oil & cellulose by PDC Method

योग्य नहीं बनोगे, तो योग्यता का पारितोषिक (रिवार्ड) तुम्हें कौन देगा ?

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AC TESTS FOR CONDITION MONITORING OF ELECTRICAL EQUIPMENT

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AC Tests

1. Tan-Delta test
2. Hipot or Hi-Voltage Test
3. Surge Comparison Test
4. Partial Discharge Test

1. TAN-DELTA TESTING

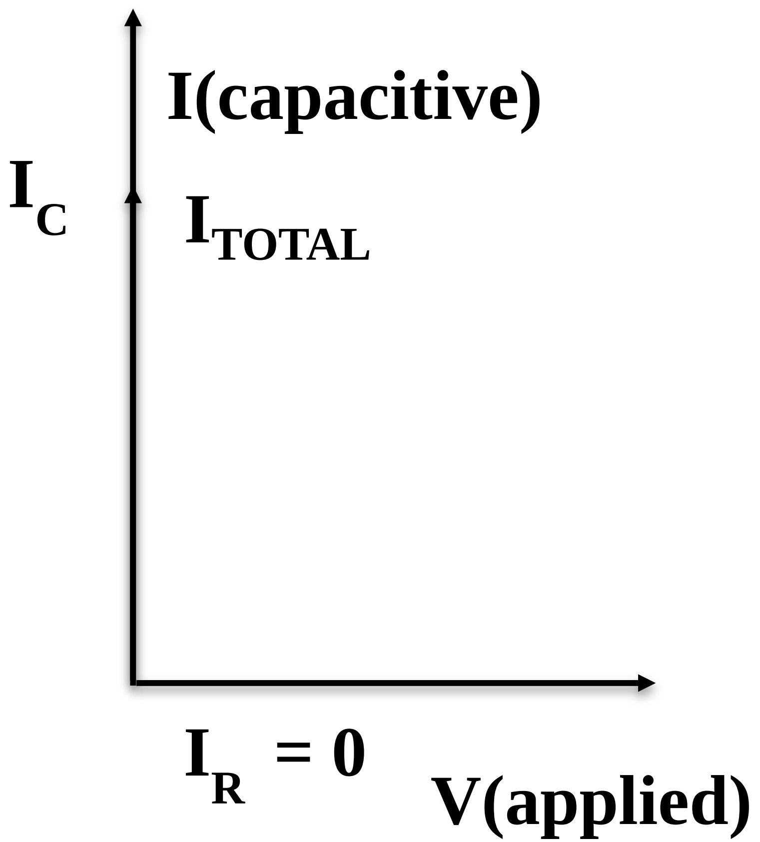
(Capacitance & Dielectric Dissipation Factor Testing)

1. Tan-Delta testing (Capacitance & Dielectric Dissipation Factor Testing)

- AC test to evaluate the integrity of electrical insulation
- Dielectric Loss Angle.
- Dissipation Factor.
- Applies HV AC and measures losses within test object.

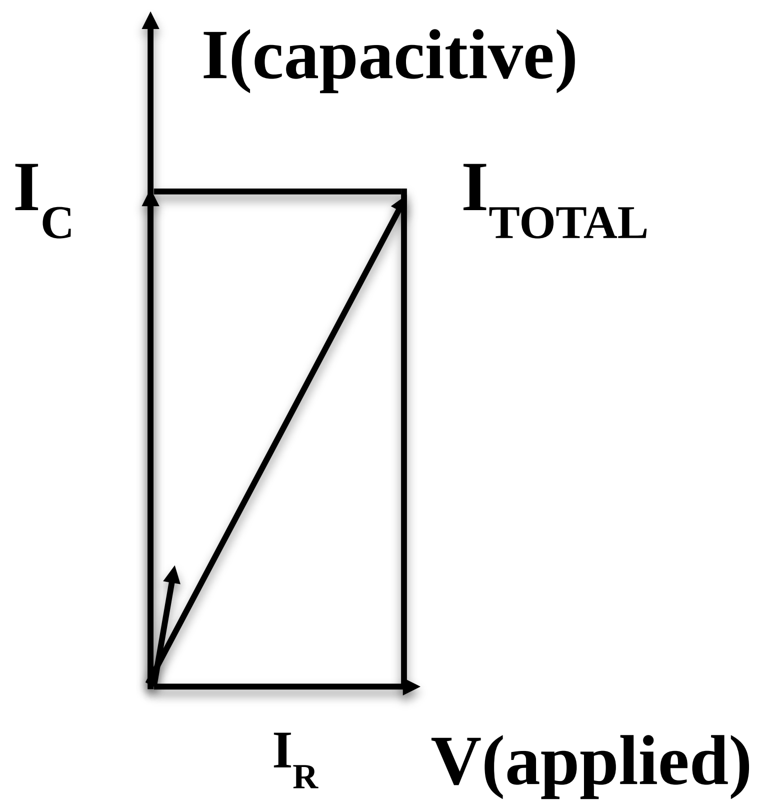
Perfect Insulation

- In an “ideal insulation system”, the current flowing will be purely capacitive.



Real Insulation

In a “REAL insulation system” there is also a loss current flowing in-phase with the voltage.



What is Tan Delta ?

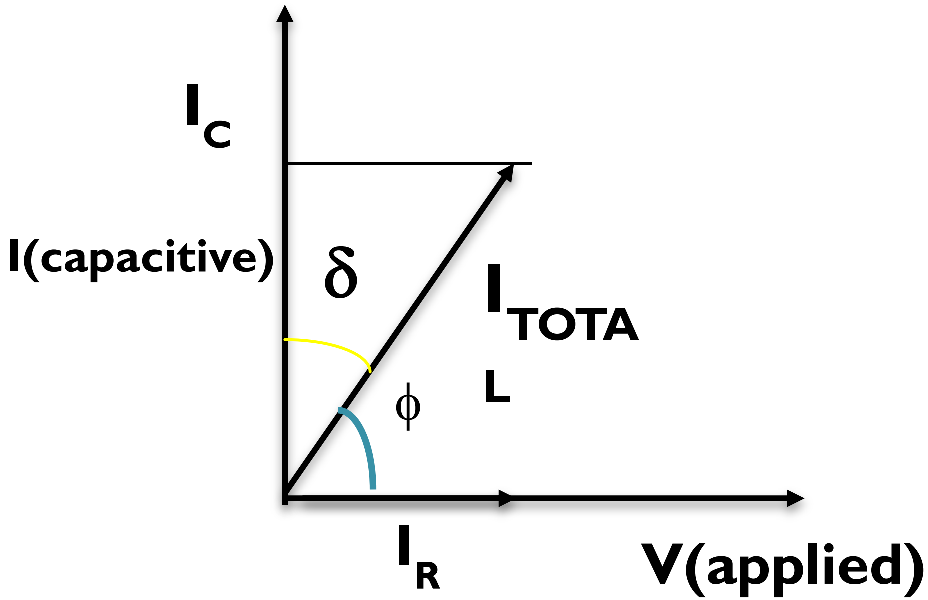
- Tan Delta is the ratio of in-phase (resistive) current to the 90 degree (capacitive) current.

  $$\tan\delta = I_R / I_C$$

- Tan Delta is also called Dissipation Factor or Loss Angle

  Tanδ = [Watt-loss (Active) Power / Reactive Power]

- Hence tan delta is considered as the measure of quality of insulation in dielectric material.



$$\tan\delta = \frac{I_R}{I_C}$$

$$P.F. = \cos\phi$$

Facts about Insulation

- In practice No insulation is perfect.
- Resistive loss current is always present.
- Total current lags the capacitive current by an angle δ.
- This angle, by which total current in a real-life insulation deviates from its ideal position, is called loss-angle δ.

Why perform the Tan-Delta Test?

- Normal insulation resistance testing limited to 5kV dc.
- Tan Delta is usually on 11kV ac or operating voltage.
- Most test specimens normally operate with AC voltage.
- Much closer resemblance to the normal operating condition of the insulation.

- Current research indicates **AC testing is less destructive** than over voltage DC testing.

- Isolate sections of the specimen to identify problems areas.

- Dielectric Loss Factor = $\tan\delta$ x Dielectric Constant is used to compare different insulating materials

Applications of Tan Delta Testing

- Evaluating quality of electrical insulation materials & systems.
- Revealing contamination, fractures and punctures.
- Detection of defects that accompany aging of insulation.
- Estimating health of delicate insulation like enamel of winding copper wire.

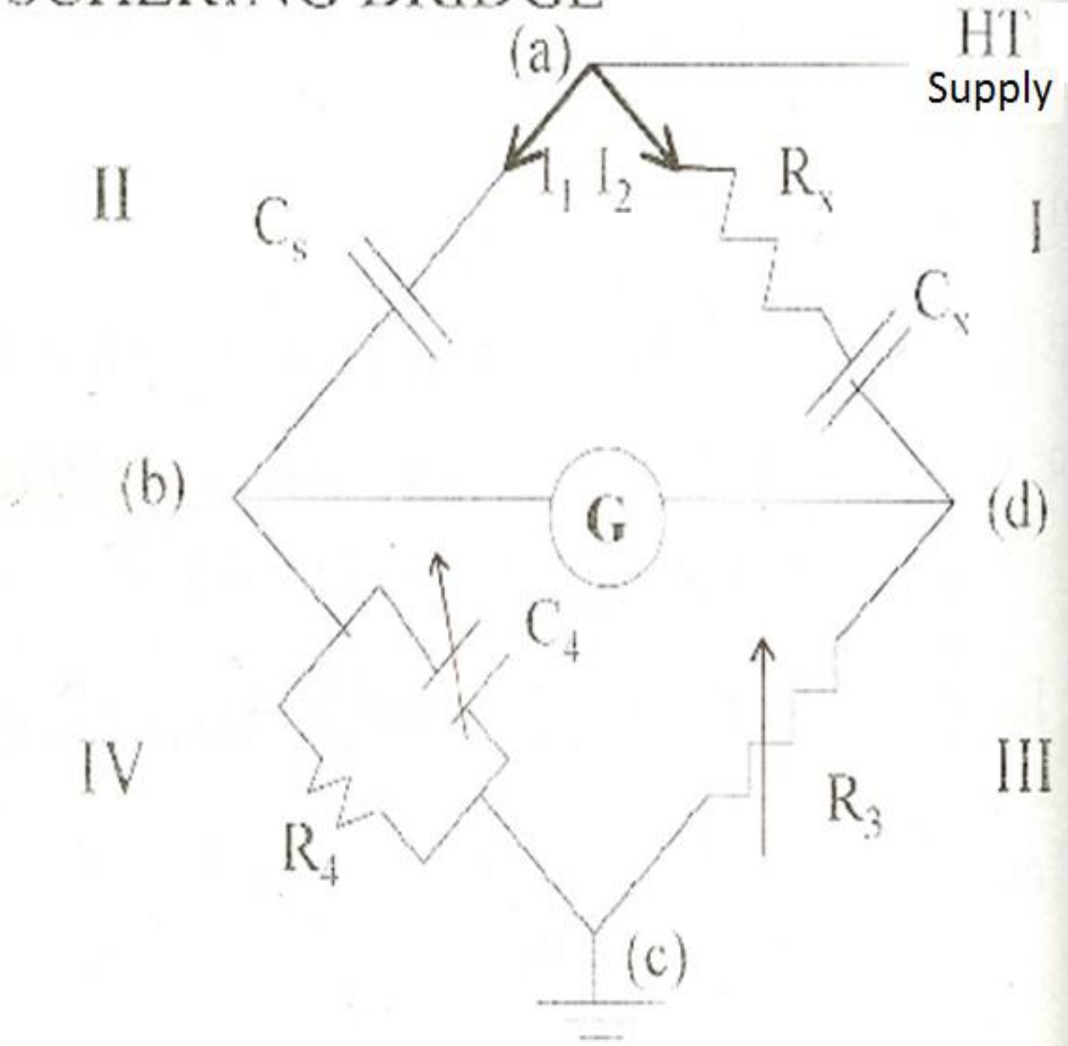
Indicative values of tan-delta of different Elect. appliances

Equipment	Tanδ for Fresh equipment	Tanδ for Old equipment	Capacitance range
Power Capacitor	0.0002	As agreed up on between Mfr and Purchaser	10 uF… 2000 uF
Power Cable (XLPE)	0.0005	0.01	Approx 250 pF/ Mtr
Power Cable (PVC)	0.01	0.1	Approx 500 pF/ Mtr

Equipment	Tanδ for Fresh equipment	Tanδ for Old equipment	Capacitance range
Insulating Oil (Capacitor)	< 0.0001	0.001	Depends on Cell as per IEC250
Insulating Oil (others)	0.0001	0.001	
Insulating Board	0.01	0.05	
Power Transformer	0.01	0.05	500 pF … 5 nF
Bushing	0.003	0.01	200 pF … 1500 pF
Rotating Machines	0.01	Δ tan delta is considered	10 nF. ..1 uF

MEASUREMENT OF TAN δ CAPACITANCE

SCHERING BRIDGE



C_S = Standard Capacitor

C_X = Test Capacitor

R_X = Losses of C_X

R_4 = Fixed Resistor

C_4 = Variable Capacitor

R_3 = Variable Resistor

On balancing or Null Condition :-

$I_1.Z_{ab} = I_2.Z_{ad}$ & $I_1.Z_{bc} = I_2.Z_{dc}$

which gives :-

$R_X = R_3.(C_4/C_S)$

$C_X = C_S.(R_4/R_3)$

and $\underline{\tan \delta = \omega.R_4.C_4}$

2. HI VOLTAGE OR HIPOT TEST

OR

DIELECTRIC WITHSTAND TEST

HI VOLTAGE OR HIPOT TEST OR DIELECTRIC WITHSTAND TEST

1. A Hipot test (also called Dielectric Withstand test) verifies that the insulation of a product or component is sufficient to protect the operator from electric shock.

2. In a typical Hipot test, high voltage is applied between a product's current-carrying conductors and its metallic chassis. The resulting current that flows through the insulation, known as leakage current, is monitored by the tester.

3. The theory behind the test is that, if a deliberate over-application of test voltage does not cause the insulation to break down, the product will be safe to use under normal operating conditions -hence the name, Dielectric Withstand test.

4. In addition to over-stressing the insulation, the test can also be performed to detect material and workmanship defects, most importantly small gap or spacing between current-carrying conductors and earth ground. Dirt, vibration, shock and contaminants can close these small gaps and allow leakage current to flow. This condition can create a shock hazard if the defects are not corrected at the factory. No other test can uncover this type of defect .

5. A standard test voltage is applied (2xSys.Vol.+1KV for 1min. in AC test or 1.414 x AC test voltage For DC) and the resulting leakage current is monitored. The leakage current must be below a preset limit or otherwise the test is considered to have failed. **This test is a non-destructive test, but not a routine test.**

Hipot Test or Proof Test Voltages for Equipment:

Factory AC Test = 2 x Nameplate Rating + 1000 volts

DC Proof Test on Installation = 0.8 x Factory AC Test x 1.6

DC Proof Test After Service = 0.6 x Factory AC Test x 1.6

<u>Example:</u>

Motor with 2400 V AC nameplate rating–

Factory AC Test = 2x(2400) +1000 = 5800 VAC

Max. DC Test on Installation = 0.8x(5800)x1.6 = 7424 VDC

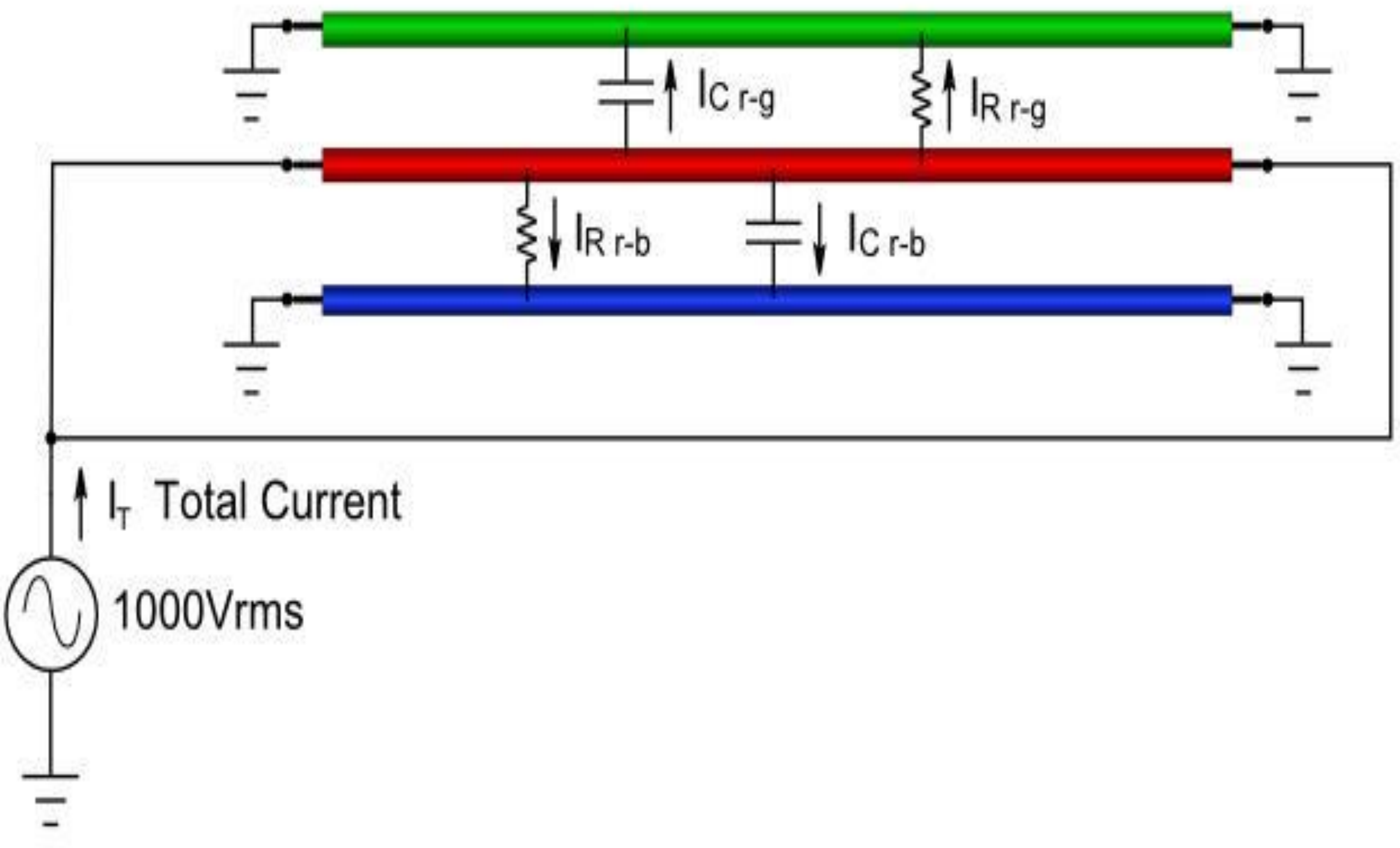
Max. DC Test After Service = 0.6x(5800)x1.6 = 5568 VDC

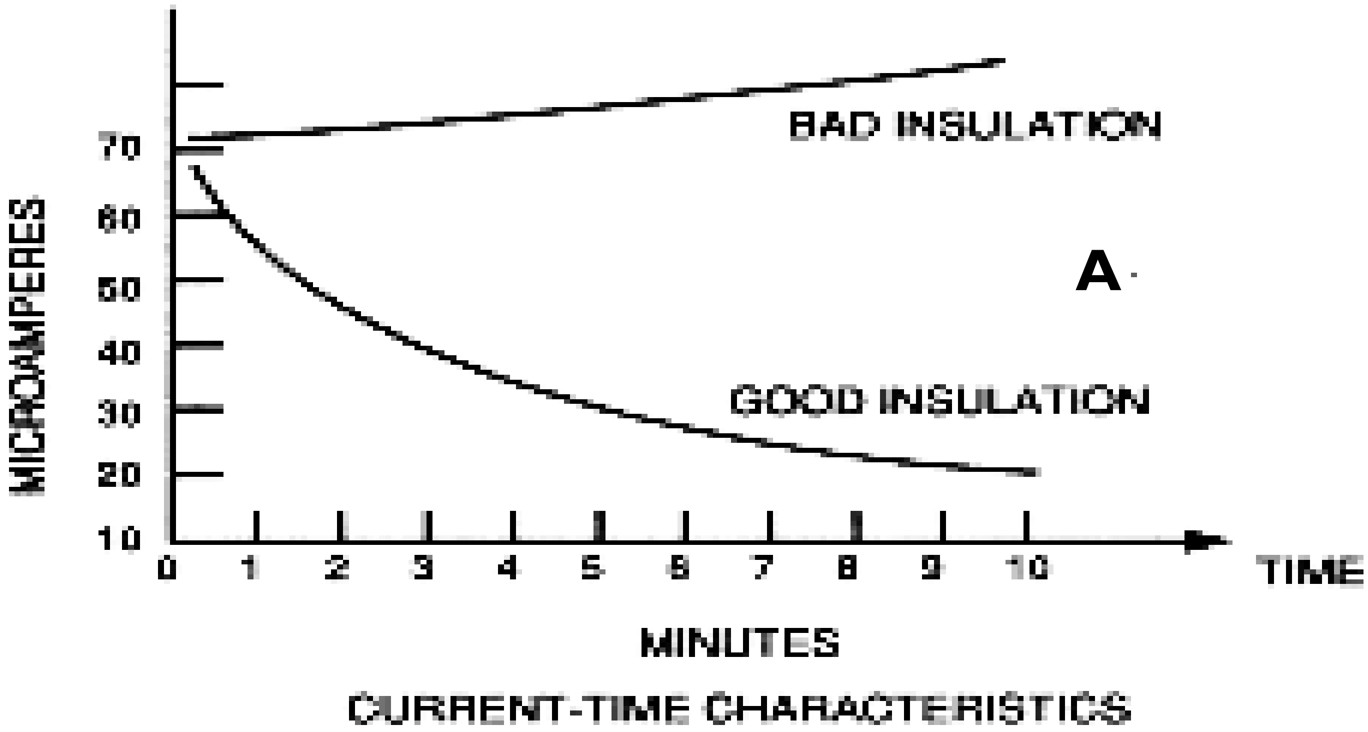
PRECAUTIONS FOR HIPOT TEST

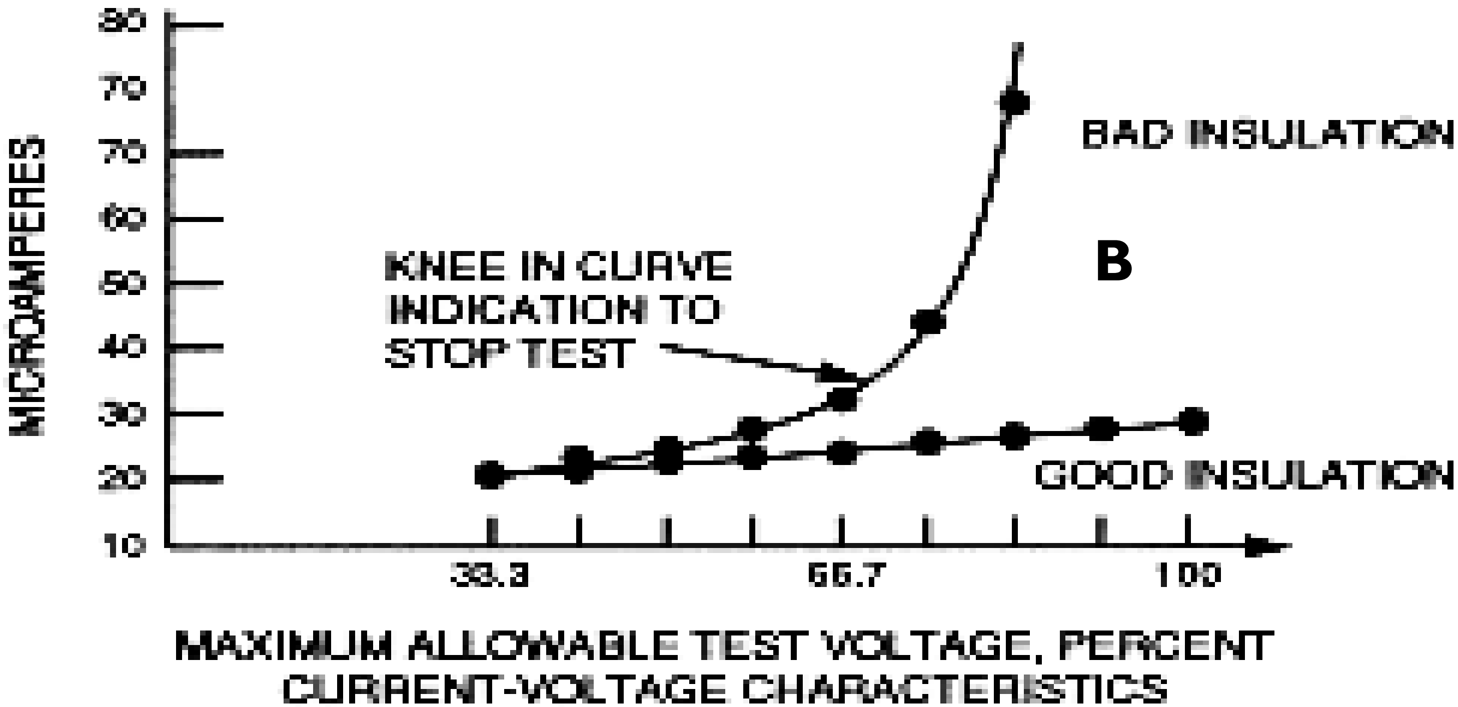
- To minimize risk of injury to operator from electrical shock make sure that hipot equipment follows these guidelines:
  - The total charge one can receive safely in a shock should not exceed *45 μC.*
  - The total hipot energy should not exceed *350 mJ*.
  - The total current should not exceed *5 mA peak (3.5 mA rms).*
  - The fault current should not stay on longer than *10 mS*.

- Hipot tests are helpful in finding nicked or crushed insulation, stray wire strands or braided shielding, conductive or corrosive contaminants around the conductors, terminal spacing problems, and tolerance errors in cables. All of these conditions might cause a device to fail.

HIPOT TEST ON 3-CORE CABLE







Leakage Current Vs.

A)Time

B)Voltage

3. SURGE COMPARISON TEST

Basic Principle

- The Surge Tester uses the Comparison Technique to detect faults in the windings.
- Two identical High Voltage Capacitors of known value are electronically discharged through the two windings (Inductances) under comparison test to produce voltage decay waveforms. These waveforms are displayed on CRO screen.
- If the two windings are exactly similar in all respect, each of them will produce a waveform which is exactly similar to that of the other.

- Visually, the two waveforms will perfectly match or superimpose each other. Thus, A Single waveform will be seen on the screen.

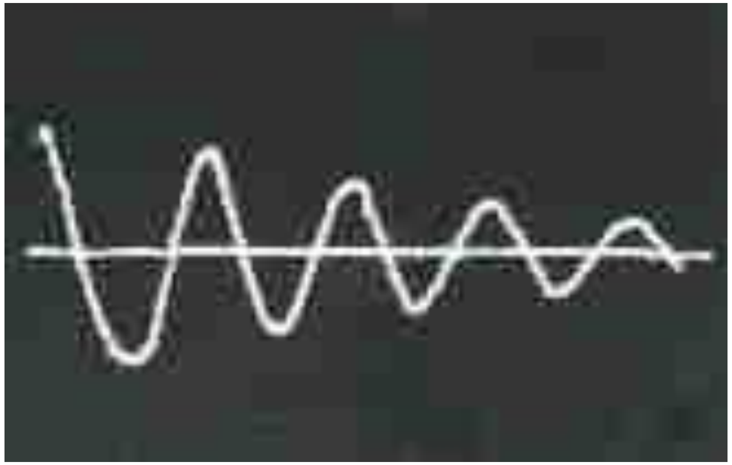
- In case the two windings are not same due to any reason, their waveforms will also be of different type.

- Thus two separate waveforms will appear on the screen.

SURGE - COMPARISON TEST ON WINDING

(2 coils at a time)

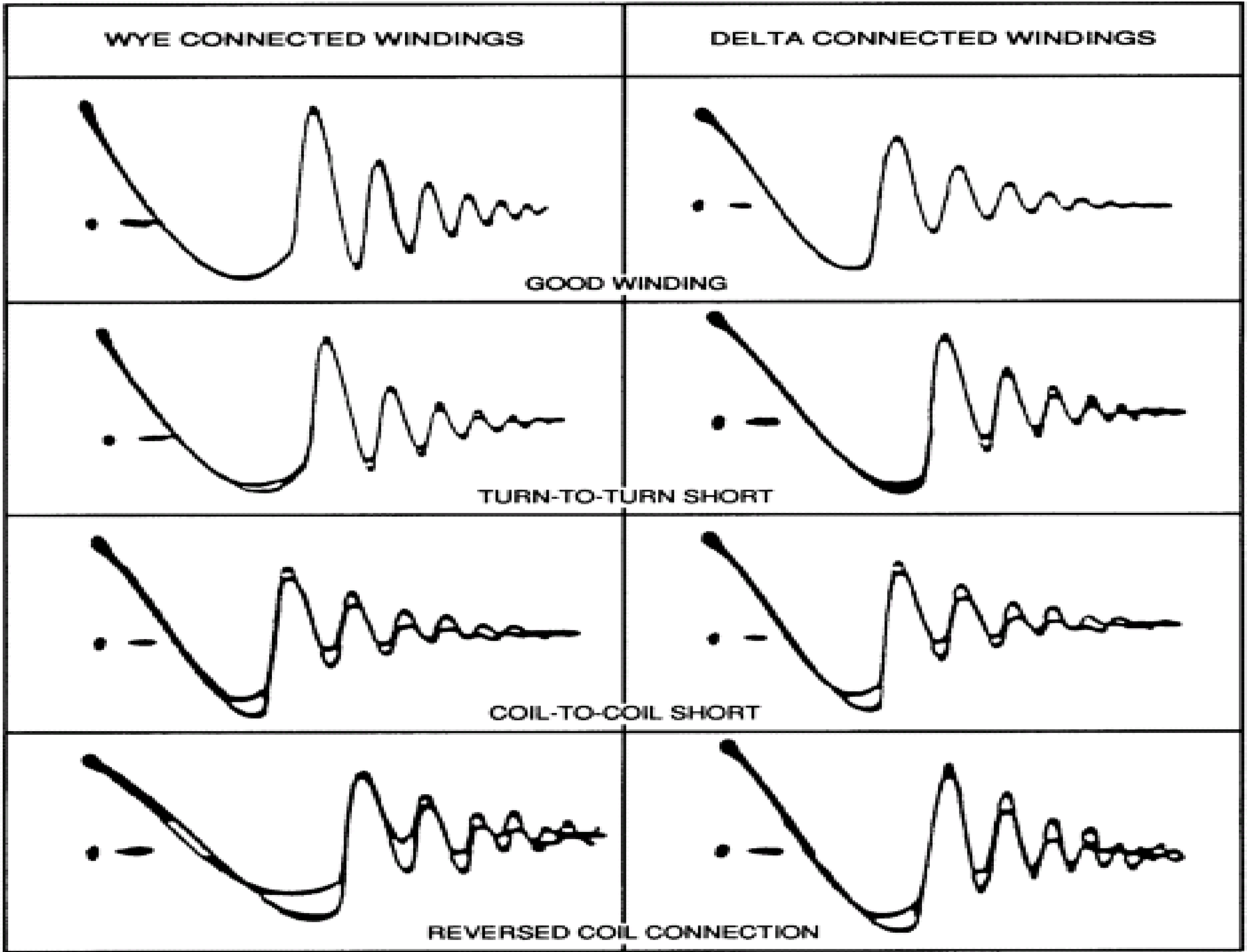
Good Winding

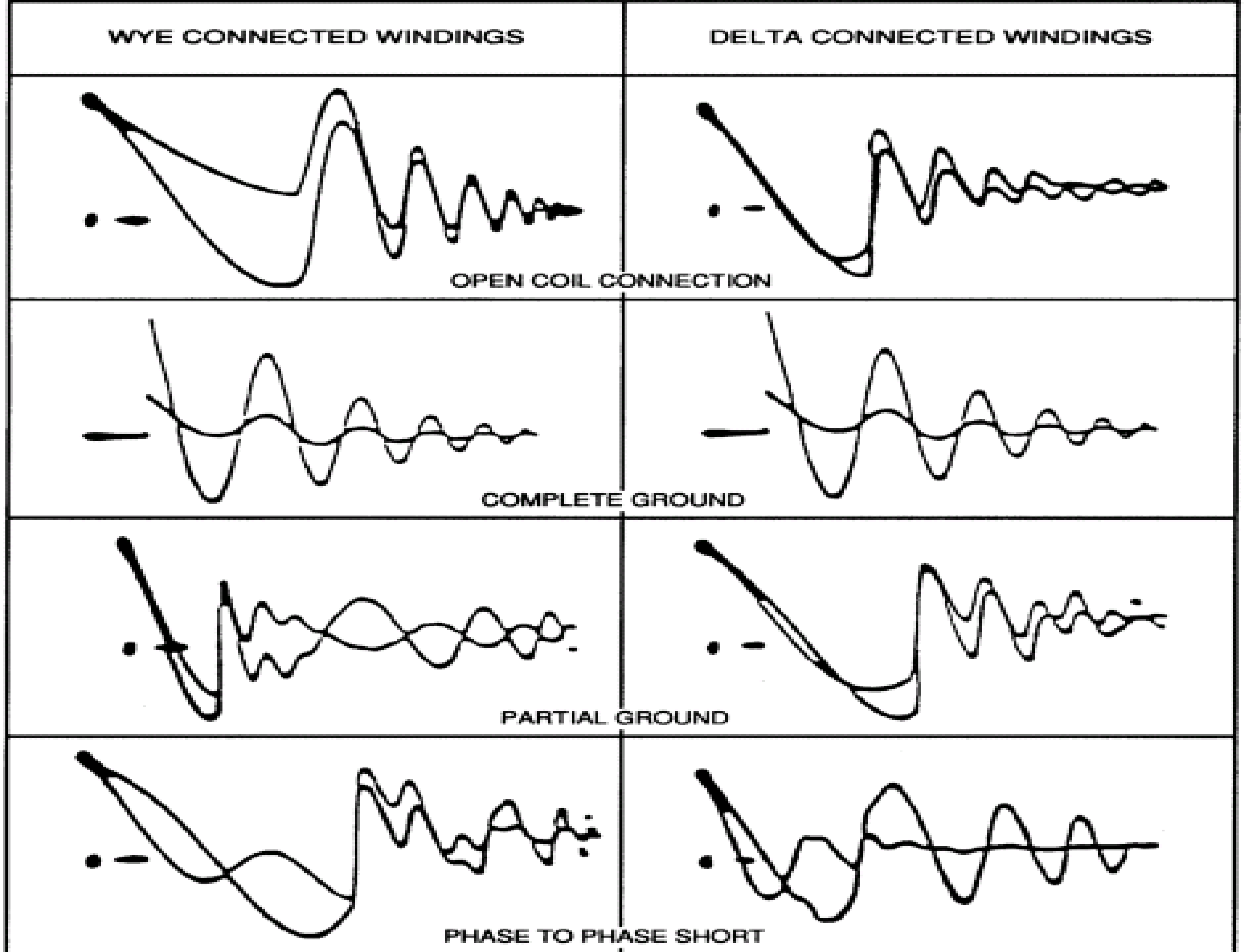


Coil Earth Fault

Inter Turn Short

Coil Open

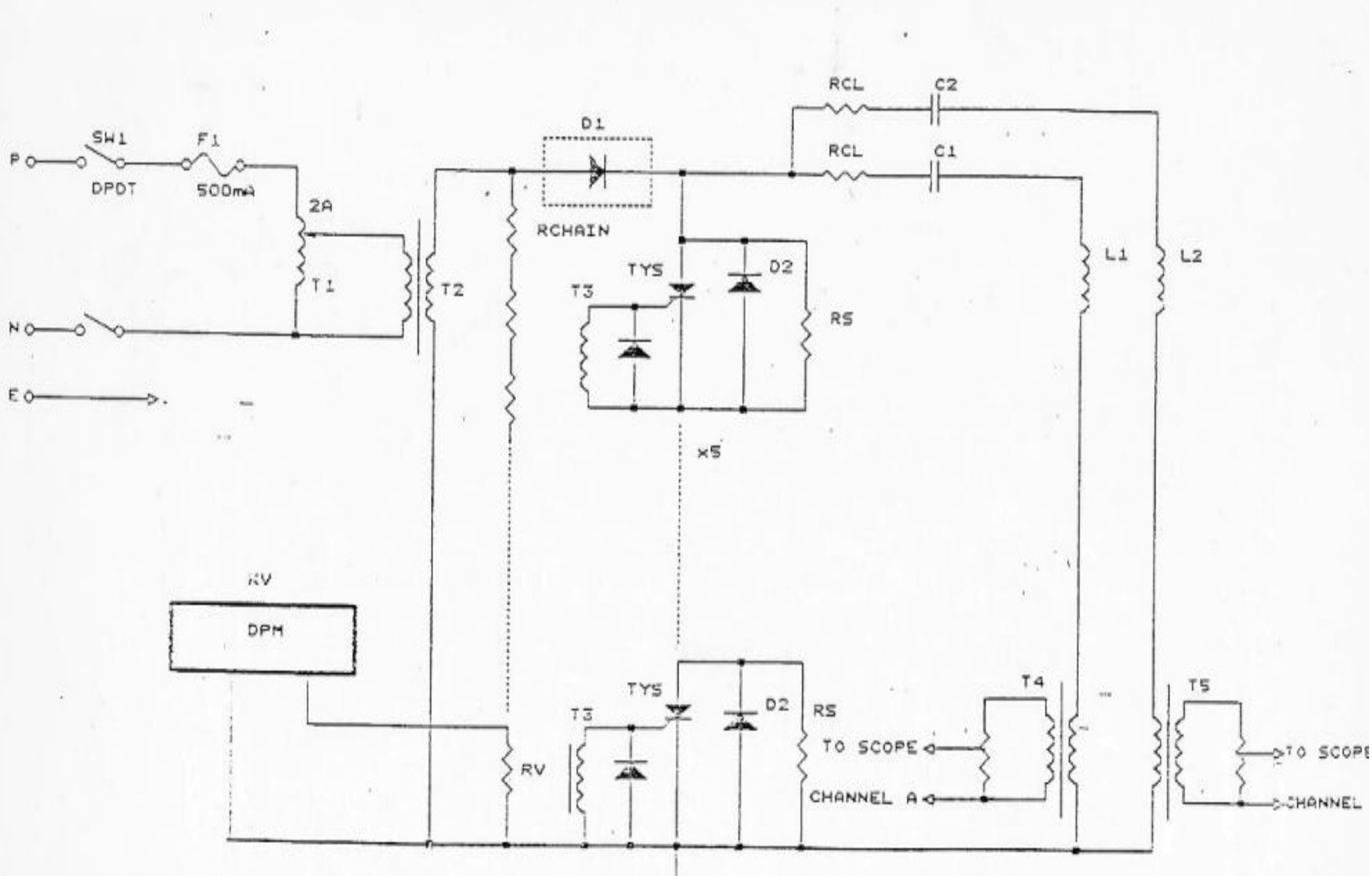

WYE CONNECTED WINDINGS
DELTA CONNECTED WINDINGS
GOOD WINDING
TURN-TO-TURN SHORT
COIL-TO-COIL SHORT
REVERSED COIL CONNECTION


WYE CONNECTED WINDINGS
DELTA CONNECTED WINDINGS
OPEN COIL CONNECTION
COMPLETE GROUND
PARTIAL GROUND
PHASE TO PHASE SHORT

SURGE COMPARISON TESTER

Surge comparison testing is used for checking defective coils, or coils after motor-rewinding, and for checking solenoid-coils of Electro Magnetic Contactors of electric locos.

SURGE COMPARISON TESTER



4. Partial Discharge (PD) Test

Basic Description

- Partial discharges are small electrical sparks that occur within the electric insulation of electrical equipment. Various stresses cause air pockets or voids to be developed inside the insulation.

- The air in the void has a different permittivity and therefore faces increased voltage stress. When this voltage-stress increases beyond PDIV/CIV (PD Inception Voltage/Corona Inception Voltage) value, electrical breakdown occurs in the form of PD.

- Electrical breakdown in air causes an extremely brief period (ns) electric current to flow through the air pocket. The measurement of partial discharge is, in fact, the measurement of these breakdown currents, in form of pulses. PD results are used to reliably predict which HV electrical equipment is in need of maintenance. Partial discharge levels provide early warning of imminent equipment failure.

Partial Discharge is defined as :-

"Localized electrical discharges that only partially bridges the insulation between conductors and which can or cannot occur adjacent to a conductor. Partial discharges are in general a consequence of local electrical stress concentrations in the insulation or on the surface of the insulation. Generally, such discharges appear as pulses having a duration of much less than 1 μs."

- *“Corona is a form of partial discharge that occurs in gaseous media around conductors which are remote from solid or liquid insulation…”*

- *“Partial discharges are often accompanied by emission of sound, light, heat and chemical reactions…”*

PARTIAL DISCHARGE EMISSIONS

Partial discharges emit energy as:

1. Electromagnetic emissions, in the form of radio waves, light and heat.

2. Acoustic emissions, in the audible and ultrasonic ranges.

3. Ozone and nitrous oxide gases.

CAUSES OF PARTIAL DISCHARGES

- Insufficient design margins.
- Improper choice of insulating materials.
- Bad processing.
- Bad workmanship.
- Faulty manufacturing procedures.
- Loose connections.
- Improper shielding inside and outside the equipment.

Where Partial Discharge can occur in Elect Equipment?

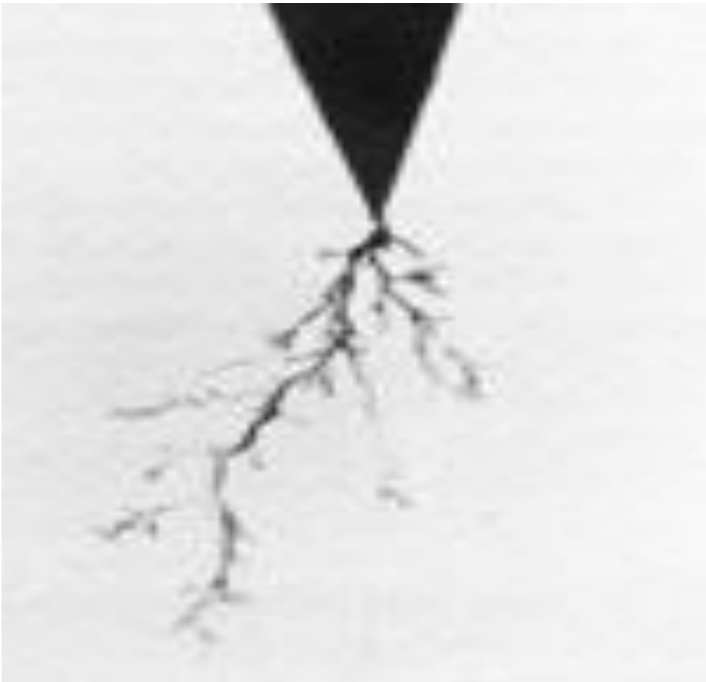
- Cavities in an insulation layer
- Metal electrodes at boundaries of these insulation layers (surface discharges)
- Electrode edges of a foil in an insulation layer (e.g. bushings, capacitors)
- Electrodes in- the air
- Metal parts at free potential

- Loose contact at high voltage points
- Bad earthing
- Solid particles in oil (DC equipment)

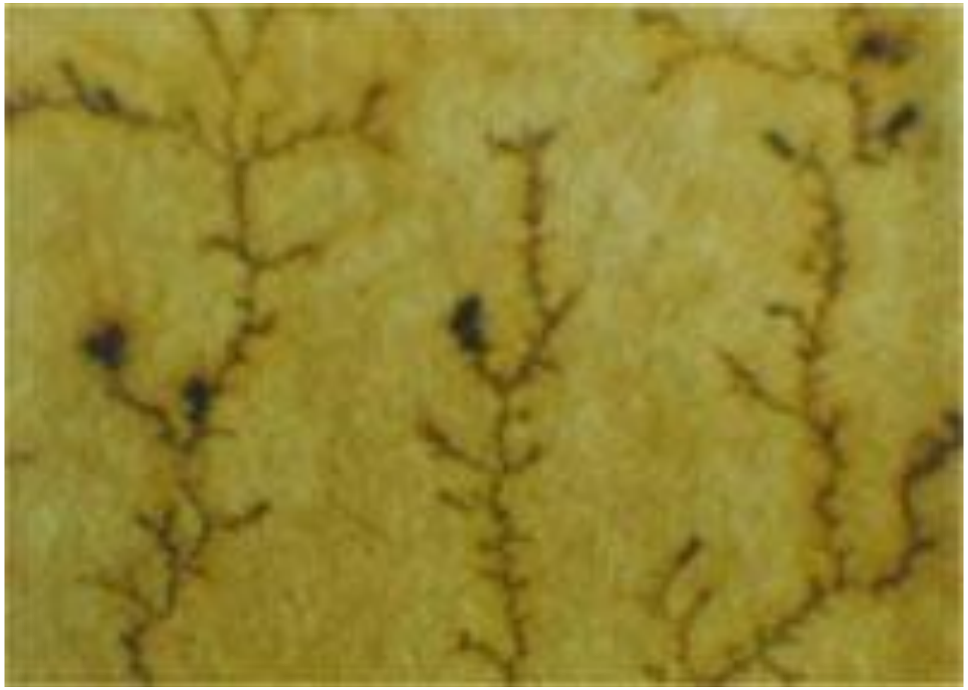
Damaging Effects of Partial Discharge

- Erosion on the surfaces/walls.
- Chemical degradation.
- Formation of pits.
- Tracking / Treeing.
- Loss of mechanical strength.
- Local heating.
- Interference with radio communication.
- Partial discharges of high magnitude may lead to accelerated aging, causing a complete damage of the insulation within a short period of time.

Damaging Effects of Partial Discharge



Electrical Tree



Tracking in paper-insulation

After initiation, the Partial Discharge can propagate and develop into electrical trees until the insulation is so weakened that it fails completely with breakdown to earth or short circuit between the phases.

Purpose of Partial Discharge measurement

- ❖ To verify that the test object does not exhibit partial discharge greater than a specified magnitude, at a specified voltage.

- ❖ To determine :

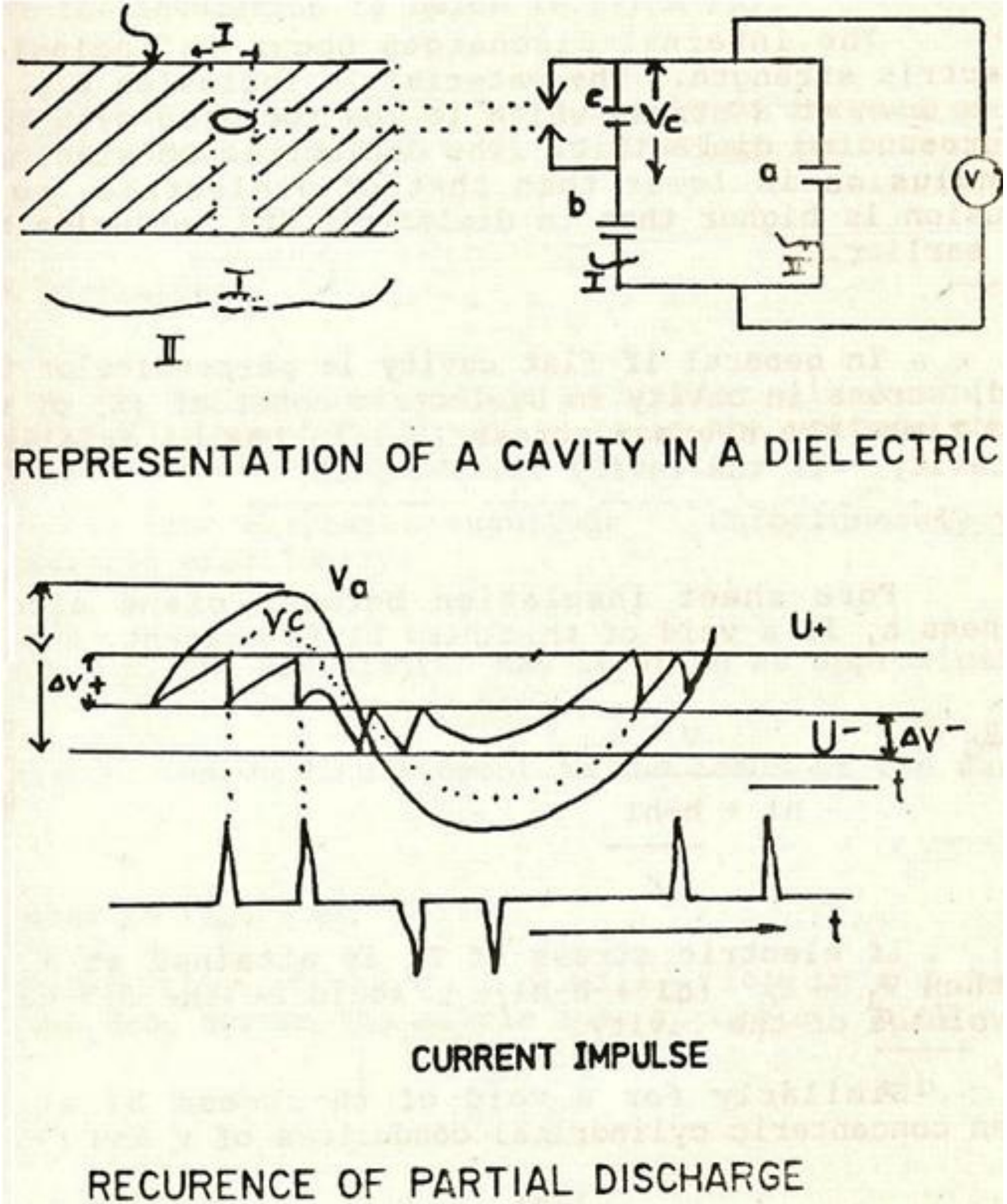
  - Inception Voltage - voltage at which Partial Discharge starts (PDIV/ CIV)

  - Extinction Voltage – voltage at which Partial Discharge ends (PDEV/CIV)

  - Partial Discharge level at the test voltage (Height of Pulse in pc)

Presentation of PD by capacitance circuit

1. Capacitance of void = **c**
2. Capacitance of healthy part in portion-I = **b**
3. Capacitance of healthy part shown in portion-II = **a**



V_a = Voltage across specimen

V_c = Voltage Across cavity or void

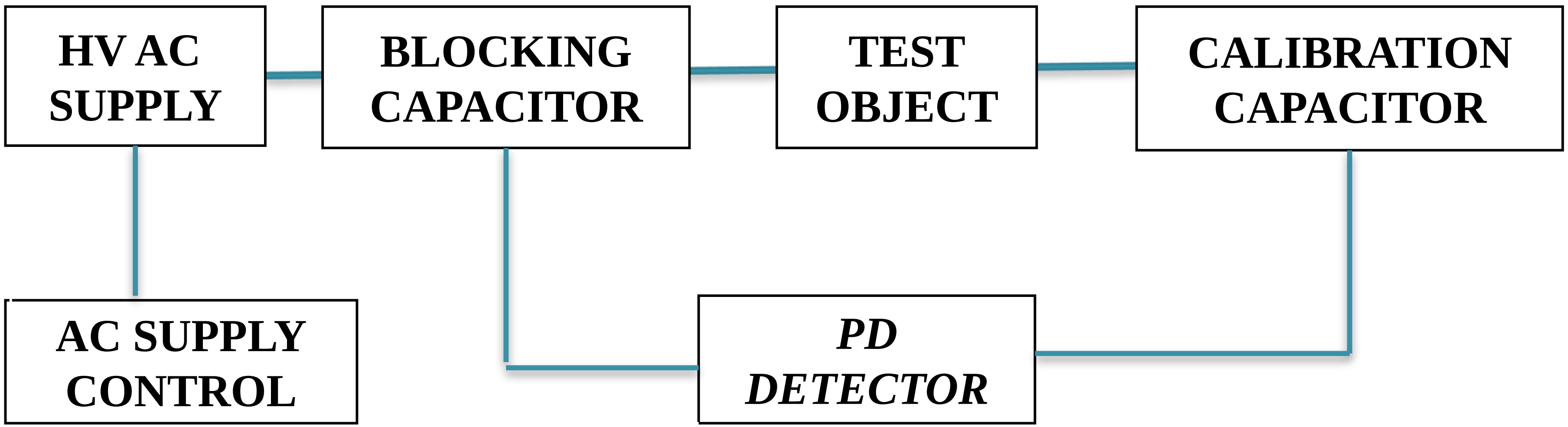
U+ = DIV in +ve half cycle

U- = DIV in –ve half cycle

DIV = Discharge Inception Voltage

- Similar PD pulse repeats in both +ve and –ve half cycles.

PD Test Set-up



Controlled High Voltage is gradually increased, which applies on Test Object, through a Blocking or Coupling Capacitor, which blocks supply-harmonics to enter the Specimen. It also diverts the PD pulses towards the PD Detector, which is a CRO Screen. The current pulses produce measurable voltage pulses after passing through impedance of Calibrating or Measuring Capacitor. Pulse height is calibrated and measured and gives charge in pC.

TEST SET-UP FOR MEASURING PD

IS : 10810 (Part 46) - 1984

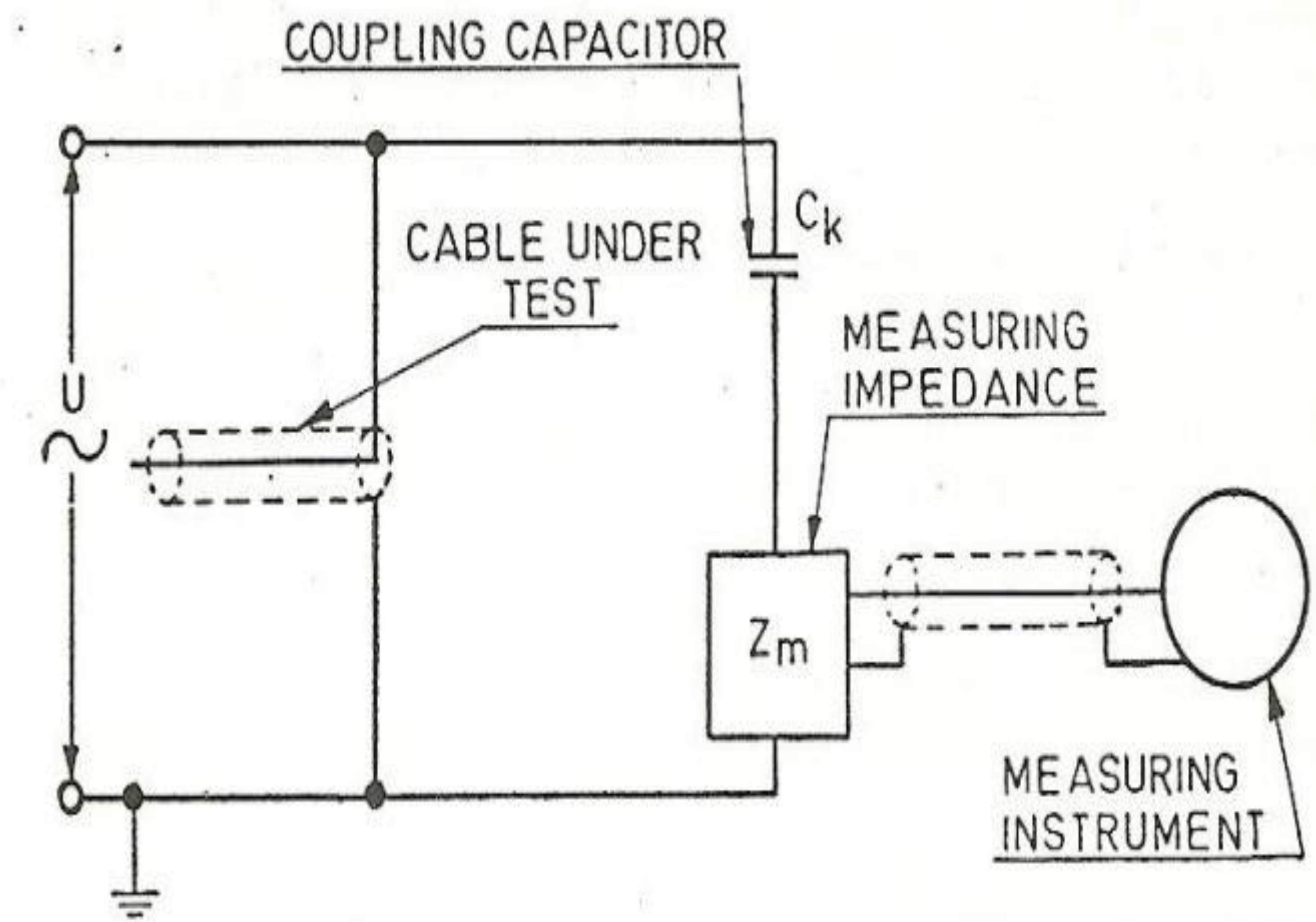
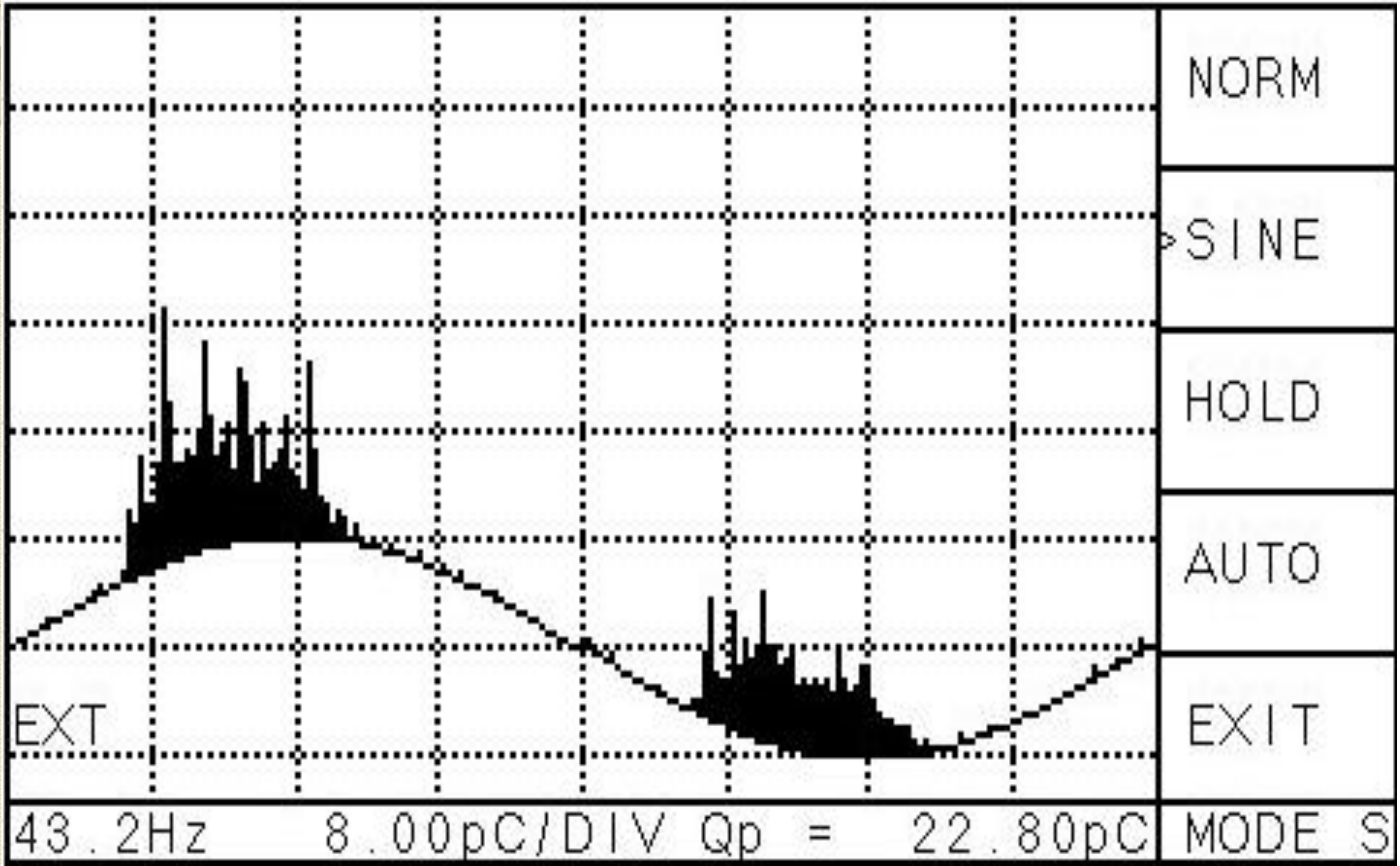
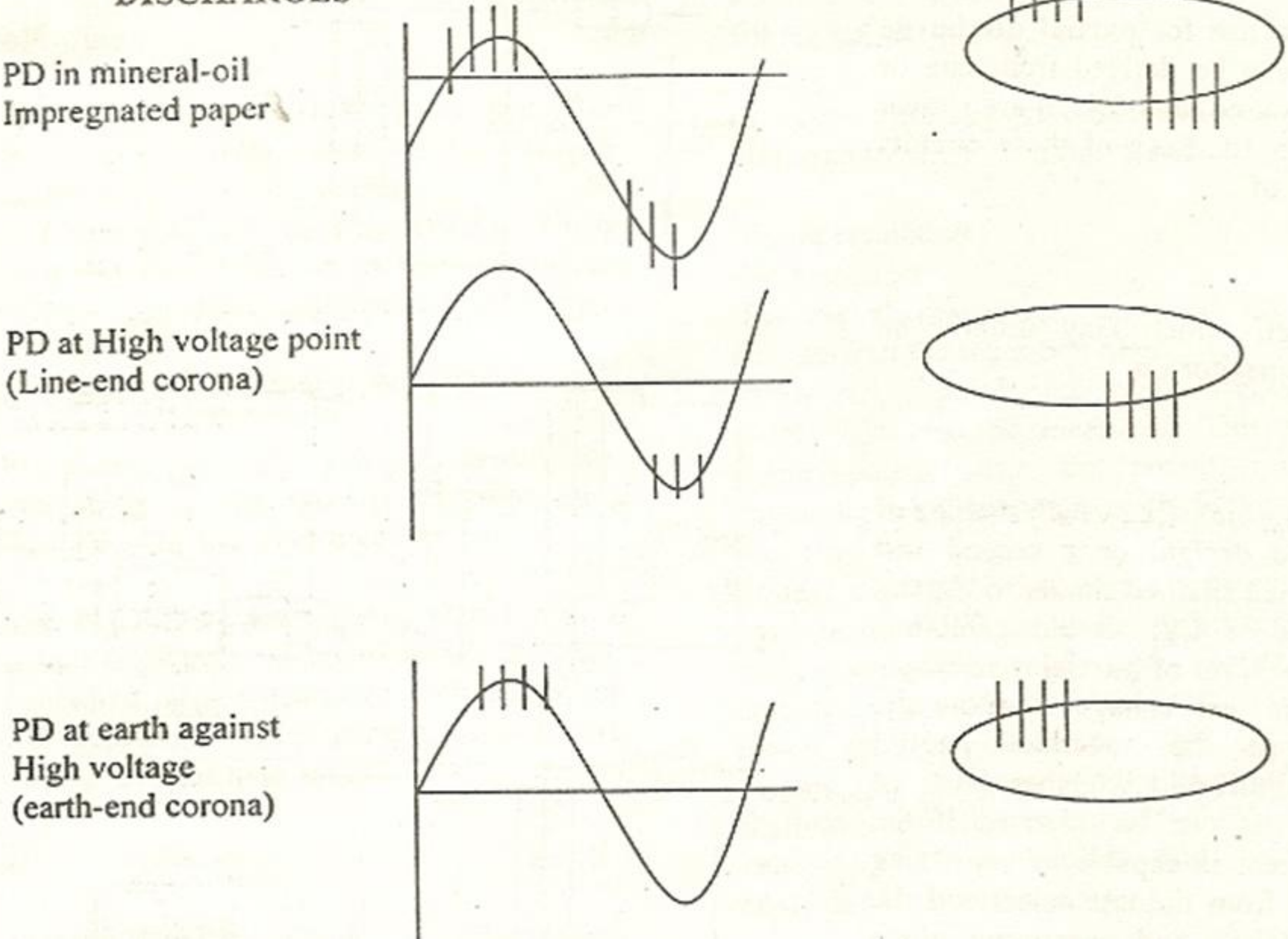


FIG. 1 TEST CIRCUIT FOR TESTING SHORT LENGTHS OF CABLE (UP TO 300 m)

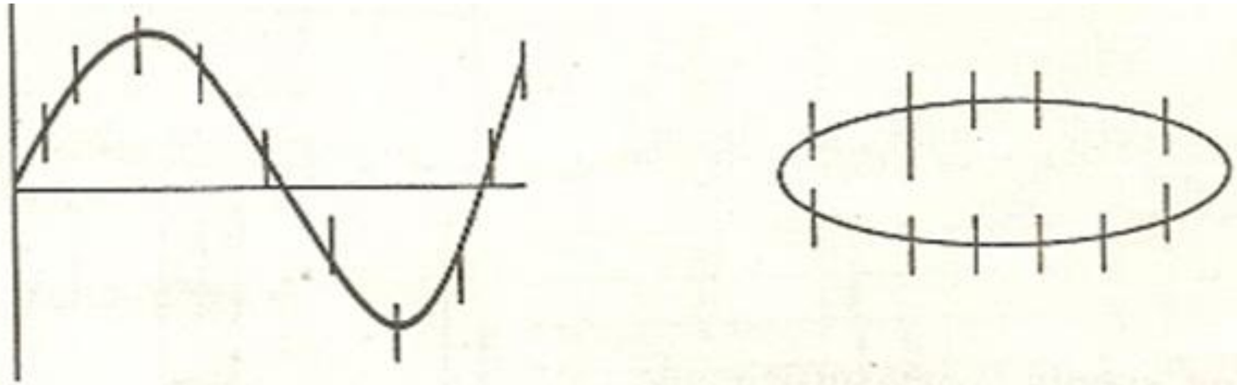
PARTIAL DISCHARGE PULSES



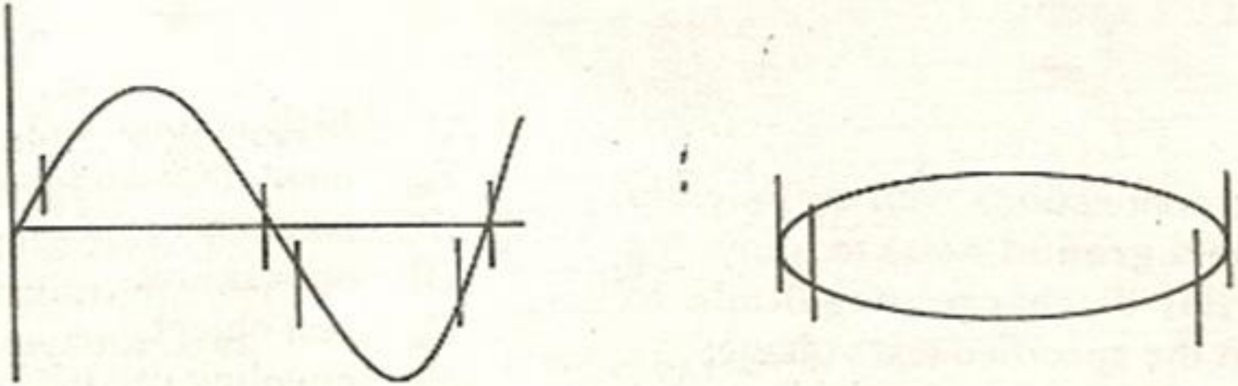
RECOGNITION OF PARTIAL DISCHARGES



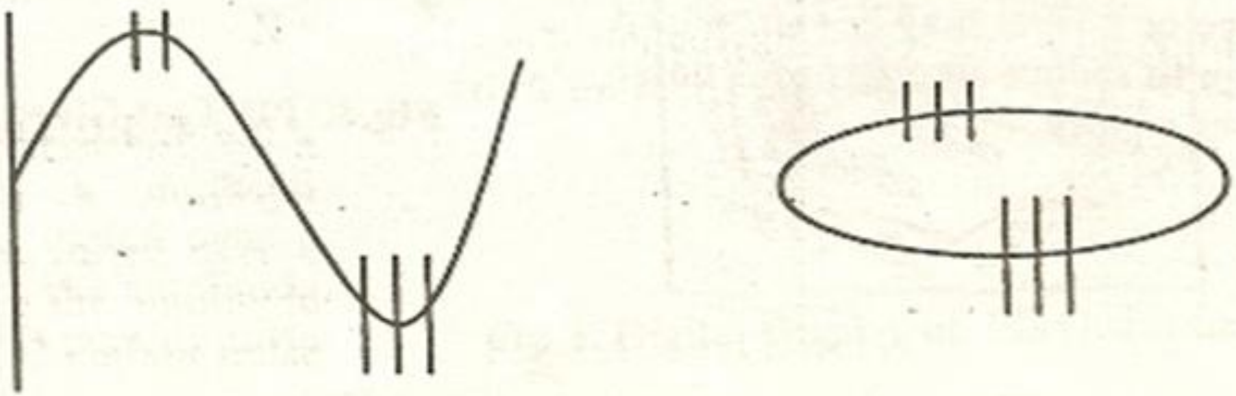
PD caused by metallic
Parts at free potential



PD due to bad contacts



Surface discharges



PRECAUTIONS WHILE PD TESTING

- Surrounding must be clean.
- Metallic object should be earthed (vicinity).
- Capacitive object shall be shorted & earthed.
- No high voltage test in vicinity.
- No switching operation.
- No crane operation.
- No faulty tube light (switched off if any).
- Test object should be earthed.
- Surface of test object - clean and dry.
- Should be at ambient temperature.

PD AS A CONDITION MONITORING TOOL

It can be used to assess and locate Fault on line.

- Avoids shutdown of system.
- Indicates fault at very early stage.

Sophisticated digital measuring & analyzing system is used. This system is based on :-

- Digital counting of discharge pulses.
- Evaluation of no. of pulses.
- Amplitude and phase of pulses with respect to applied voltage.

Techniques of PD Measurement :-

- Acoustic
- Electrical
- Optical

(a) Acoustic detection :

A partial discharge results in a localized release of energy creating a small explosion. Hence acoustic waves are generated and propagate from the source to the outer surface. The amplitude and frequency components of acoustic waves are both factors in detecting the PD. They can be caused by geometrical spreading of the wave, interface between materials, absorption of the material, frequency-dependent propagation etc.

Acoustic detection of PD on metallic wall of test equipment

(e.g. transformers and reactors)

- Sensor mounted on tank wall.

- Hand held detector detects the PD activity within the equipment.

  ☞ For finding location of PD three sensors are used in triangular position.

  ☞ Time consuming but precise location can be obtained.

ACOUSTIC EMISSION TESTS

Acoustic transducers detect and capture energy

Acoustic energy radiates from discharge source

Data Interpretation

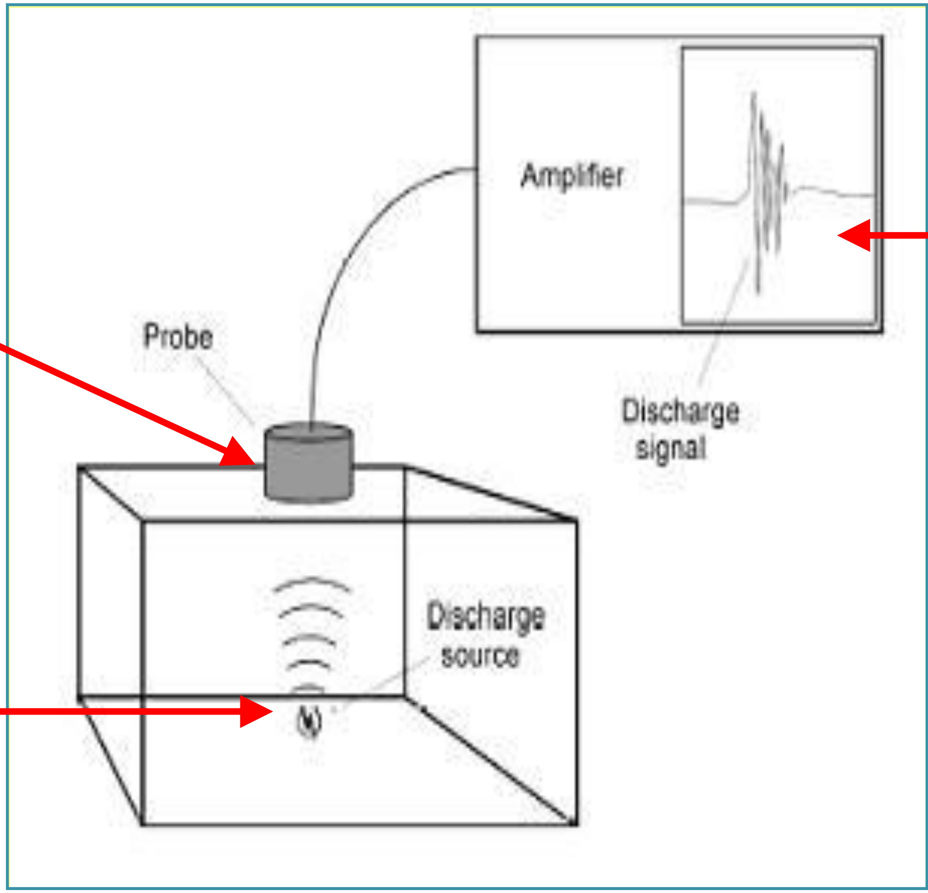


Figure 1: Sound Energy from a Discharge Source

Acoustical PD sensor installed on transformer tank:

Acoustic emissions (AE) are transient elastic waves in the range of ultrasound, usually between 20 kHz and 1 MHz, generated by the rapid release of energy from a source. Partial discharges are pulse-like stress waves, propagate to the transformer tank wall, where they may be detected with a transducer that is tuned to the right frequency.

Discharge tracking

FINDINGS

Surface Discharge
on the
Current Transformer

Figure : Surface Tracking on CT

Corona Detectors

Used for (Cables, Connectors, insulators, & Bushings)

- Measures Air Discharge

- Acoustic emission from a PD source of 100 pc (pico-Coulombs) can be detected from a distance of 5m.

Common PD levels

Category	PD level – Pico-Coulombs
Defect Free	10 – 100 pC
Normal deterioration	< 500 pC
Developing Defects (irreversible damage to paper)	1,000 – 3,000 pC
Breakdown of oil	10,000 – 100,000 pC

(b) Electrical detection

- Based on PD probing by field coupling of the test object with the sensor.

Basic techniques are :

<u>PD probe measurement technique</u>

- The detection of signal is done using electro-magnetic radiation field.

- Used for cables Transformers, Generators, Bushing etc.

(c) Optical Detection of PD

Optical sensing is a method of partial discharge measurement using advances in optical fiber technology. Partial discharges can produce ultrasonic pressure waves which can be detected with suitable pressure optical transducers. The optical fiber sensor system can be safely immersed inside the transformer.

The perturbation caused by pressure wave induces stress on the fiber core and affects the light beam traversing the fiber. By using interferometer techniques, the optical phase shift caused by the perturbation can be detected accurately with a phase-modulated type optical sensor. One advantage of the optical sensor is there is no power requirement at its site.

SUMMARY

- PD is curtain raiser to dielectric breakdown.
- Different electrical equipment have different critical PD levels.
- PD measurement is a technique for quality assessment of High Voltage insulation.
- PD detection can be done at site.
  - But not accurate for quantitative measurement of PD.
  - Useful for detection of PD & localizing.
- PD is a good condition monitoring tool for preventive measures.

सफलता और उन्नति के लिए एक भी क्षण व्यर्थ न गँवाओ।

रेल अग्रदूत Transforming Railways

EXCELLENCE IN MAINTENANCE

Indian Railways

Centre for Advanced Maintenance Technology

TESTING TECHNIQUES

FOR

TRANSFORMERS

Phase I – Module No. FC - 02

Transformer Testing

Transformer tests fall broadly into three categories:

A. Type Tests (Factory tests):

- These tests are perform to prove that the transformer meets the customer specifications and basic design expectations.

B. Routine Tests:

- These tests are mainly for confirming operational performance of individual unit in a production lot.
- These tests are carried out on every unit manufactured & when the transformer is ready to deliver.

C. Field Tests:

For maintenance and diagnostic purposes. These are also categorized as **Condition Monitoring** tests.

A. Type Tests (Factory Tests):

1. Winding resistance measurement
2. Ratio test
3. Losses test
4. IR Test
5. Dielectric test
6. Magnetic balance test
7. Magnetizing current test
8. Temperature rise test
9. HV test
10. Breakdown Voltage (BDV) Test
11. Vector group test

B. Routine tests:

- Routine tests of transformer include all the type tests except temperature rise test.

1. Winding Resistance Measurement

- It is carried out as a type test as well as routine test.
- Winding resistance measurement is carried out to calculate the I^2R losses & winding temperature at the end of a temperature rise test.
- It is also done at site to ensure healthiness of a transformer that is to check for loose connections, broken strands of conductor, high contact resistance in tap changers, high voltage leads and bushings etc.

➢ To calculate resistance of a coil per phase resistance by no. of coil.

Procedure of Transformer Winding Resistance Measurement

For star connected winding, the resistance shall be measured between the line and neutral terminal. For star connected auto-transformers the resistance of the HV side is measured between HV terminal and IV terminal, then between IV terminal and the neutral.

For delta connected windings, measurement of winding resistance shall be done between pairs of line terminals. As in delta connection the resistance of individual winding can not be measured separately, the resistance per winding shall be calculated as per the formula:

Resistance per winding = 1.5 x Measured value

(For delta connected windings)

The resistance is measured at ambient temperature and then converted to resistance at 75°C for all practical purposes of comparison with specified design values, previous results and diagnostics.

Winding Resistance at standard temperature of 75° C

$$R_{75} = R_t \frac{235 + 75}{235 + t}$$

R_t = Winding resistance at temperature t
t = Winding temperature in degree centigrade

2. Transformation Ratio Test

- The performance of a transformer largely depends upon perfection of specific turns or voltage ratio. So ratio test is an essential type test of transformer.
- This test also performed as **routine test** of transformer.

Procedure of Transformer Ratio Test

First, the tap changer of transformer is kept in the lowest position and LV terminals are kept open.

Then apply 3-phase 415 V supply on HV terminals.
Measure the voltages applied on each phase (Phase-phase) on HV and induced voltages at LV terminals simultaneously.

After measuring the voltages at HV and LV terminals, the tap changer of transformer should be raised by one position and repeat test.

Repeat the same for each of the tap position separately.

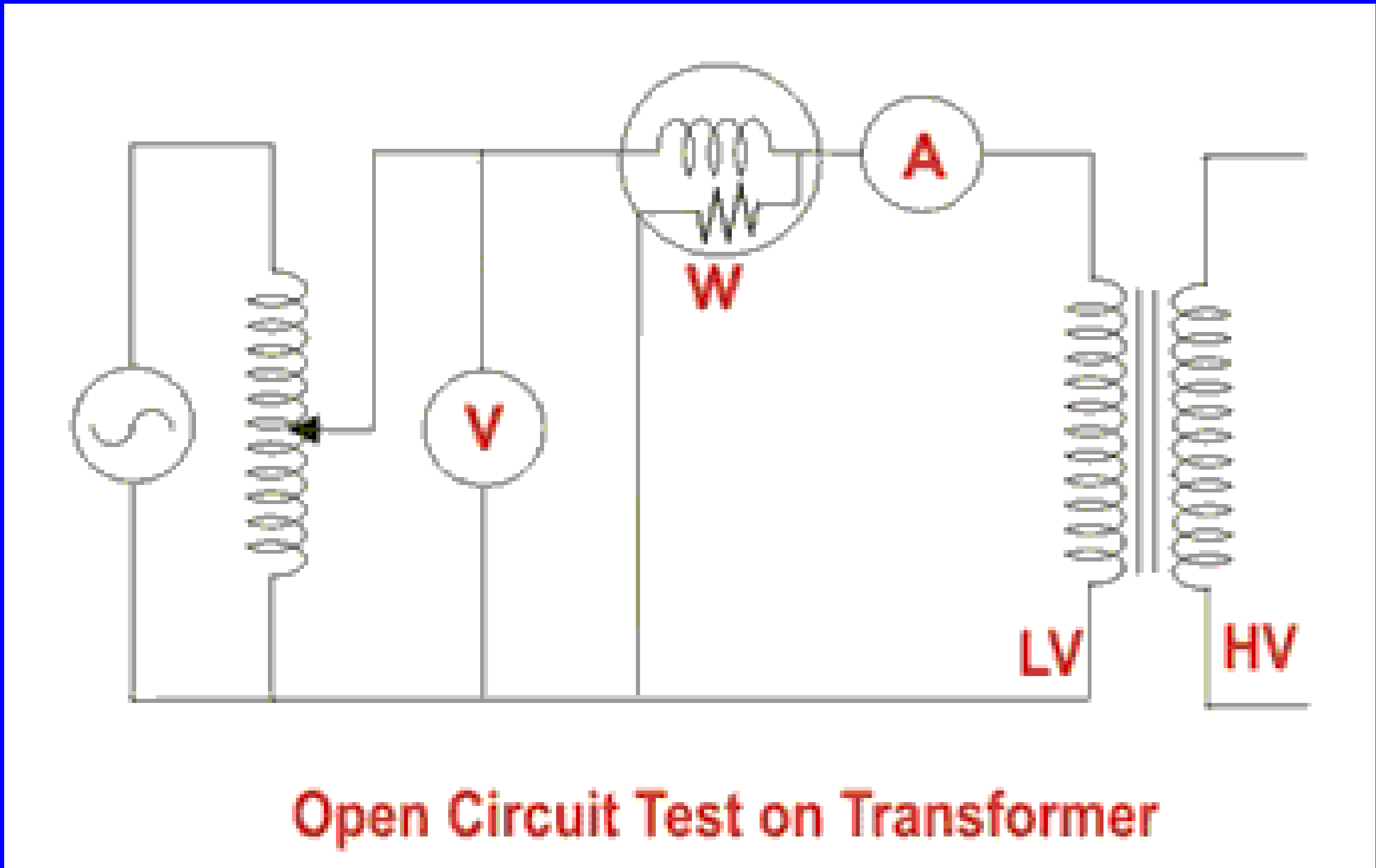
3. Losses test

(i) Open Circuit Test:

This test is used to get, no load losses of transformer at no load operation.

- A voltmeter, wattmeter, and an ammeter are connected in LV side of the transformer. The voltage at rated frequency is applied to LV side with the help of a variac (Auto transformer).
- The HV side of the transformer is kept open. Now with the help of variac, applied voltage gets slowly increased until the voltmeter gives reading equal to the rated voltage of the LV side (440 V). After reaching at rated LV side voltage, all three instruments reading (Voltmeter, Ammeter and Wattmeter readings) are recorded.

(i) Open Circuit test circuit diagram



The ammeter reading gives the no load current. As no load current is quite small compared to rated current of the transformer, the voltage drops due to this current that can be taken as negligible.

Since, voltmeter reading V can be considered equal to secondary induced voltage of the transformer, the input power during test is indicated by watt-meter reading.

As the transformer is open circuited, there is no output, hence the input power here consists of core losses in transformer and copper loss in transformer during no load condition.

But as said earlier, the no load current in the transformer is quite small compared to full load current, so copper loss due to the small no load current can be neglected.

Hence, the wattmeter reading can be taken as equal to **core losses in transformer.**

(ii) Short Circuit Test:

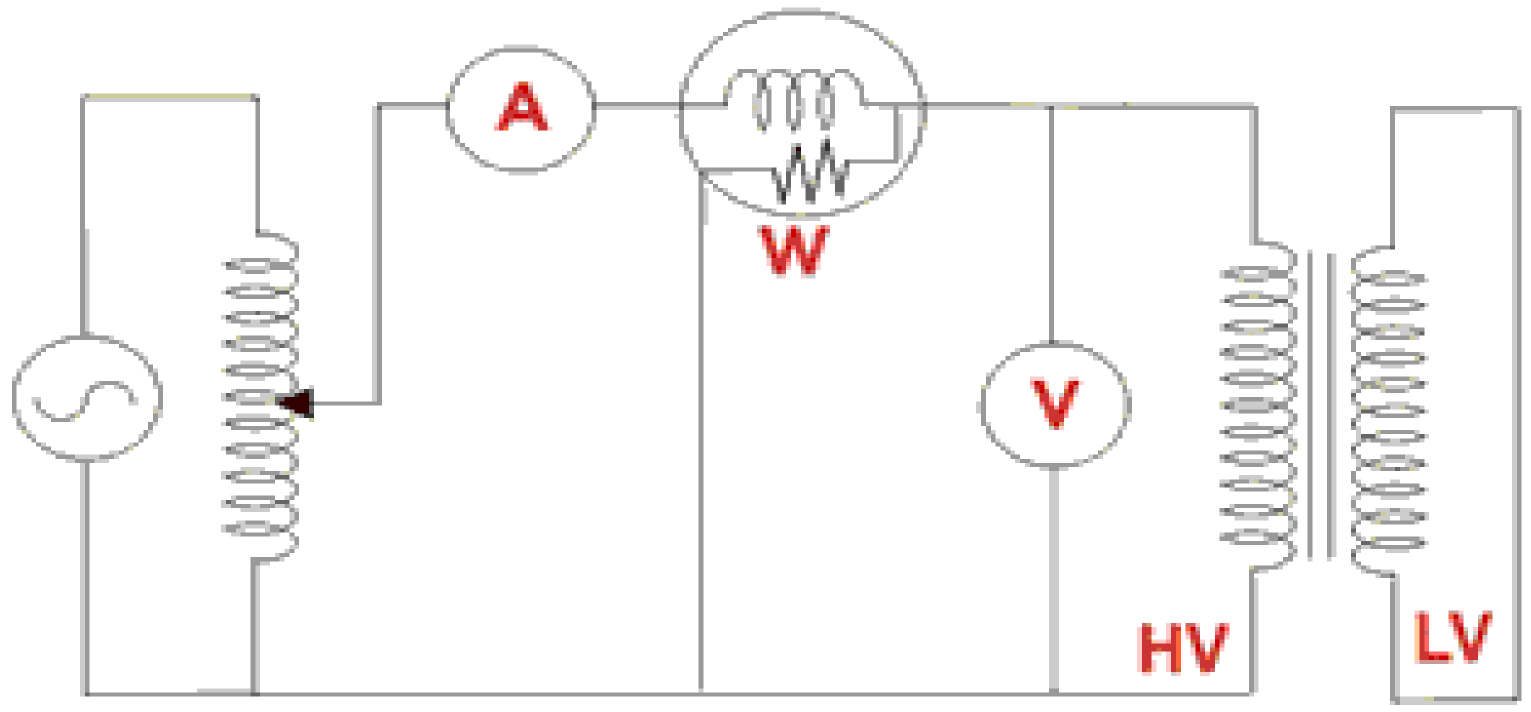
In this test we get, copper losses of transformer at full load.

A voltmeter, wattmeter, and an ammeter are connected in HV side of the transformer as shown on next slide. The voltage at rated frequency is applied to that HV side with the help of a variac of variable ratio auto transformer.

The LV side of the transformer is short circuited. Now with the help of variac applied voltage is slowly increased until the ammeter gives reading equal to the rated current of the HV side.

After reaching at rated current of HV side, all three instruments reading are recorded. The ammeter reading gives the primary equivalent of full load current.

(ii) S.C. test circuit diagram



Short Circuit Test on Transformer

As the voltage applied for full load current in short circuit test on transformer is quite small compared to the rated primary voltage of the transformer, the core losses in transformer can be taken as negligible.

Therefore it is seen that the **short circuit test on transformer** is used to determine copper loss in transformer at full load.

And if full load current is not possible to measure in secondary than we can use following formula to get full load losses.

<u>Conversion Formulae's for losses measured at low load:</u>

Losses at full load current = $(Ifl / Im)^2 \times$ losses at low load

Where; Ifl = full load current,
Im = current at which loss is measured.

4. IR Test or Megger Test

- Insulation resistance is essential type test & carried out to ensure the healthiness of over all insulation system of an electrical power transformer.

Procedure:-

- First disconnect all the line and neutral terminals of the transformer.
- Megger leads to be connected to LV and HV bushing studs to measure insulation resistance IR value in between the LV and HV windings.
- Megger leads to be connected to HV bushing studs and transformer tank earth point to measure insulation resistance IR value in between the HV windings and earth.

- Megger leads to be connected to LV bushing studs and transformer tank earth point to measure IR value in between the LV windings and earth.

- Measurements are to be taken as follows:
- For auto transformer: HV-IV to LV, HV-IV to E, LV to E.
- For two winding transformer: HV to LV, HV to E, LV to E.
- Three winding transformer: HV to IV, HV to LV, IV to LV, HV to E, IV to E, LV to E
- Oil temperature should be noted at the time of insulation resistance test of transformer.

- Since the IR value of transformer oil may vary with temperature.

- IR values to be recorded at intervals of 15 seconds, 1 minute and 10 minutes.

IR value increases with the duration of applied voltage.

Increase in IR is an indication of dryness of insulation.

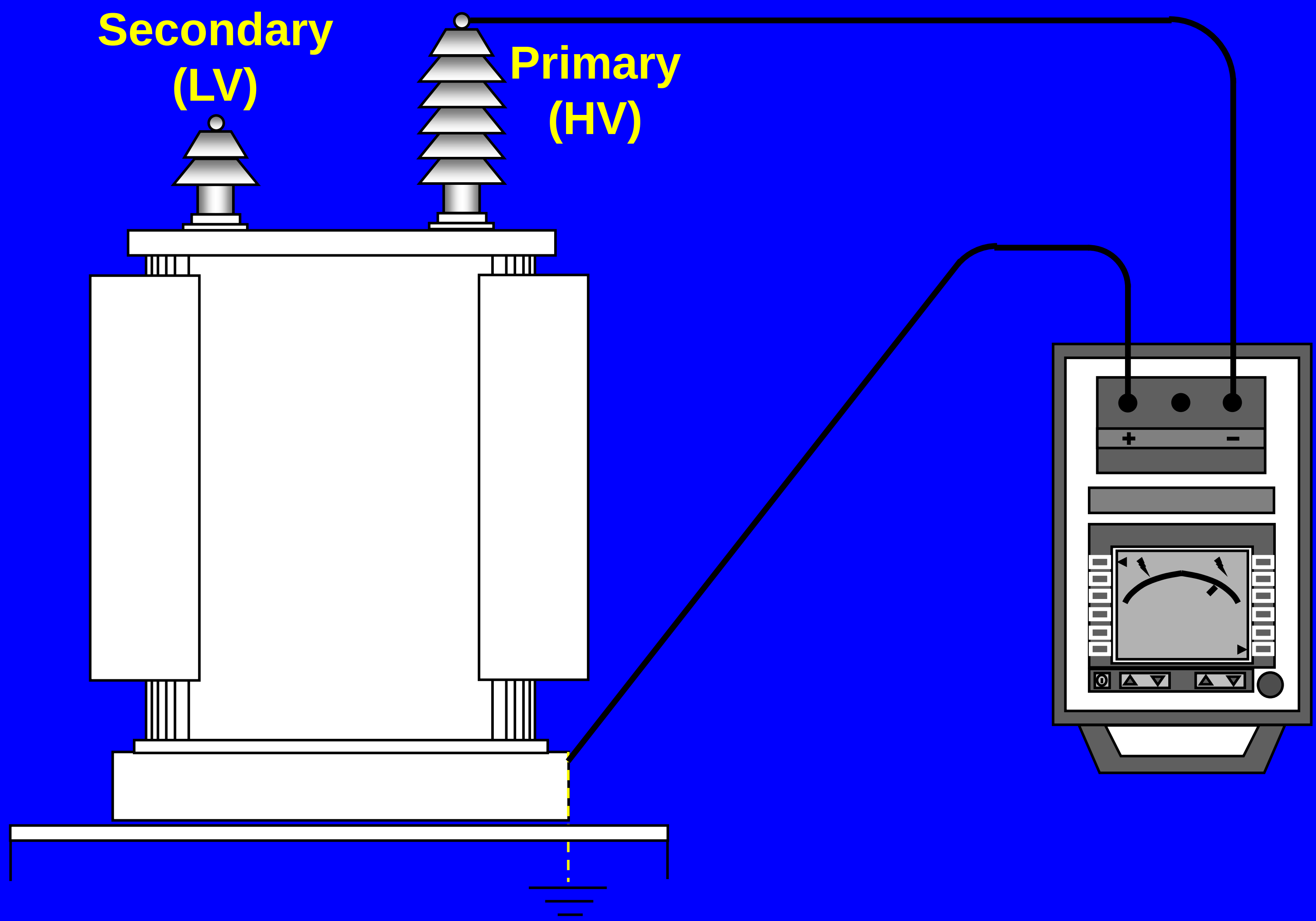
Absorption coefficient = 1 minute value/ 15 sec value.
Polarization index = 10 minutes value / 1 minute value.

Note:
It is un-necessary to perform insulation resistance test of transformer per phase wise in three phase transformer. IR values are taken between the windings collectively as because all the windings on HV side are internally connected together to form either star or delta and also all the windings on LV side are internally connected together to form either star or delta.

IR Test Voltages

Winding's Rated Voltage	IR Test Voltage (DC)
< 1000 V	500 V
1000 – 2500	500 – 1000
2501 – 5000	1000 – 2500
5001 – 12000	2500 – 5000
> 12000 V	5000 – 10000 V

IR Test Connection to Transformer



5. Dielectric Tests

- This test is performed to ensure the expected over all insulation strength of transformer.
- Dielectric test is performed in two different steps:

  (i) Separate source voltage withstand test and

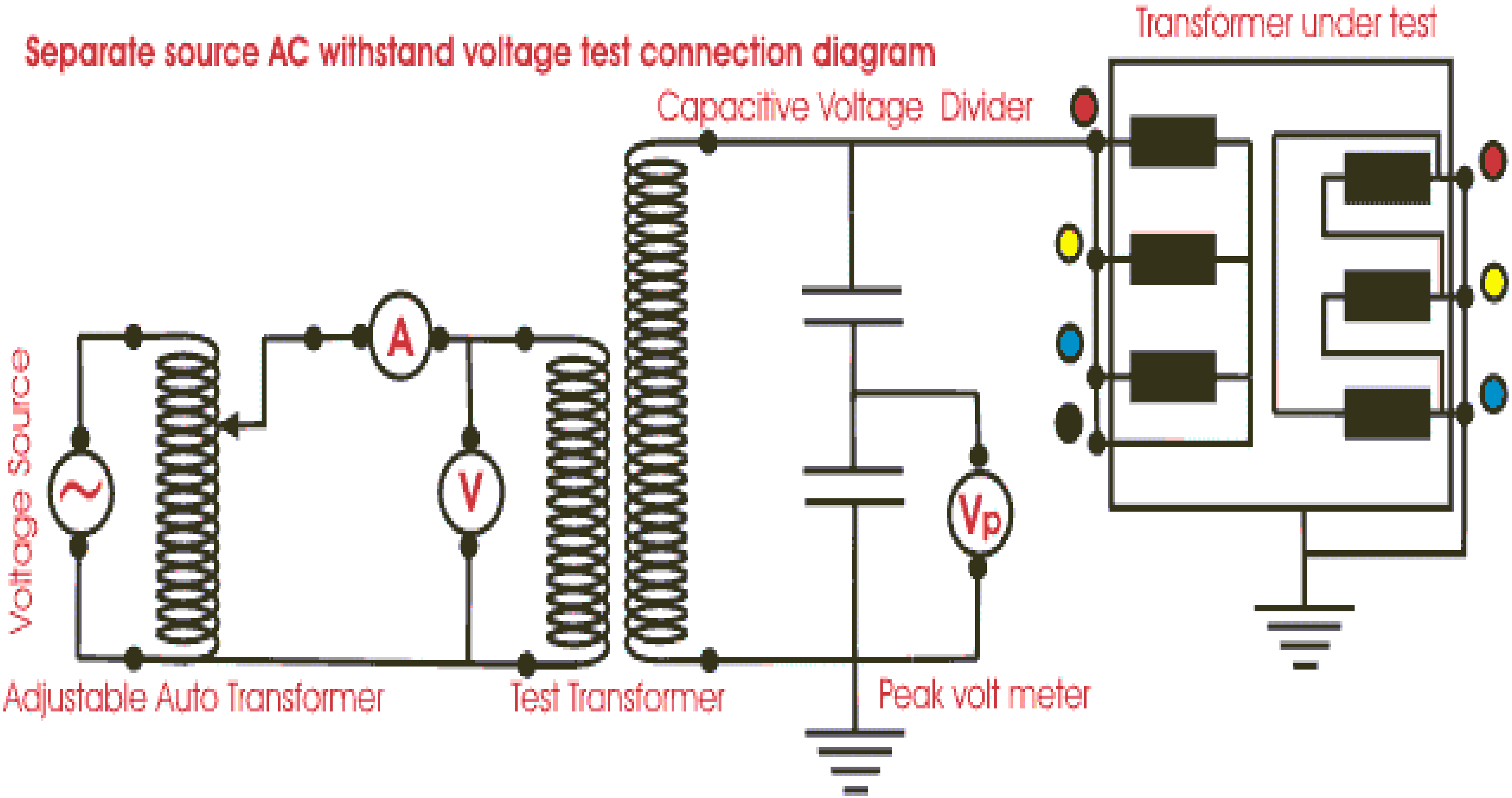
  (ii) Induced Voltage Test

(i) Separate source voltage withstand test:

This **dielectric test** is intended to check the ability of main insulation to earth and between winding.

- **Procedure:**

- Keep the primary winding (HV) of transformer short circuited to earth as shown in figure on next slide.
- In this test a single phase power frequency voltage of prescribed level, is applied on transformer winding under test for 60 seconds while the other windings and tank are connected to the earth.



- In this transformer testing, the peak value of voltage is measured, that is why the capacitor voltage divider with digital peak voltmeter is employed as shown in the diagram above. The peak value multiplied by 0.707 ($1/\sqrt{2}$) is the test voltage.

- The values of test voltage for different fully insulated winding are furnished below in the table:

S No	Nominal system voltage rating for equipment	Highest system voltage rating for equipment	Rated short duration power frequency withstand voltage
1.	415V	1.1 KV	3 KV
2.	11 KV	12 KV	28 KV
3.	33 KV	36 KV	70 KV
4.	132 KV	145 KV	230 / 275 KV
5.	220 KV	245 KV	360 / 395 KV
6.	400 KV	420 KV	570 / 630 KV

- Winding with graded insulation, which has neutral intended for direct earthing, is tested at 38 kV.

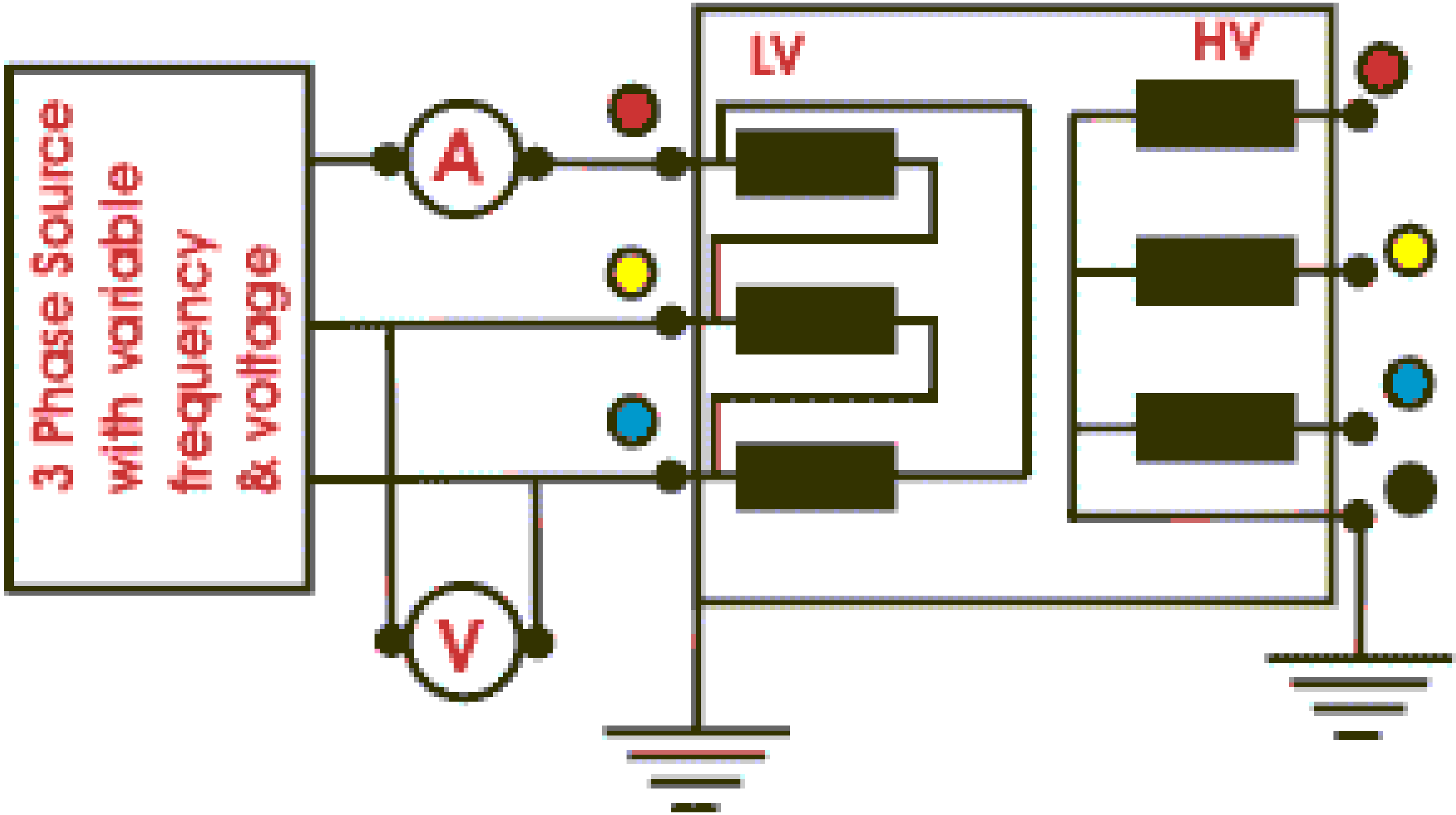
(ii) Induced Voltage Test:

The induced voltage test of transformer is intended to check the inter turn and line end insulation as well as main insulation to earth and between windings.

- **Procedure:-**

- Keep the primary winding (HV) of transformer open circuited as shown in next slide.
- Apply three phase voltage to the secondary winding & the applied voltage should be twice of rated voltage of secondary winding in magnitude and frequency.
- The duration of the test shall be 60 second.
- The test shall start with a voltage lower than 1/3 the full test voltage, and it shall be quickly increased up to desired value.

• The test is successful if no break down occurs at full test voltage during test.



Induced AC voltage test connection diagram

6. Magnetizing Current Test

- This test is performed to locate defects in the magnetic core structure, shifting of windings, failure in turn to turn insulation or problem in tap changers.
- These conditions change the effective reluctance of the magnetic circuit, thus affecting the current required to establish flux in the core.

➢ **Procedure:-**

- First of all keep the tap changer in the lowest position and open all IV & LV terminals.
- Then apply three phase 415 V supply on the line terminals for three phase transformers and single phase 230 V supply on single phase transformers.
- Measure the supply voltage and current in each phase.

- Now repeat this test with keeping tap changer in normal position.
- And repeat also test with keeping the tap at highest position.
- Generally there are two similar higher readings on two outer limb phases on transformer core and one lower reading on the centre limb phase, in case of three phase transformers.
- An agreement to within 30% of the measured exciting current with the previous test is usually considered satisfactory. If the measured exciting current value is 50 times higher than the value measured during factory test, there is likelihood of a fault in the winding which needs further analysis.

➢ **Caution: Magnetizing current test of transformer is to be carried out before DC resistance measurement.**

7. Temperature Rise Test

- In this test we check whether the temperature rising limit of the transformer oil and winding as per specification or not.
- If the temperature rise is above the Insulation of transformer winding heat class tolerance limit then this overheating leads to an accelerated ageing of insulation and, in excessive cases could damage the transformer.

➢ Types of Temperature rise test:

(i) For Transformer oil

(ii) For Transformer winding

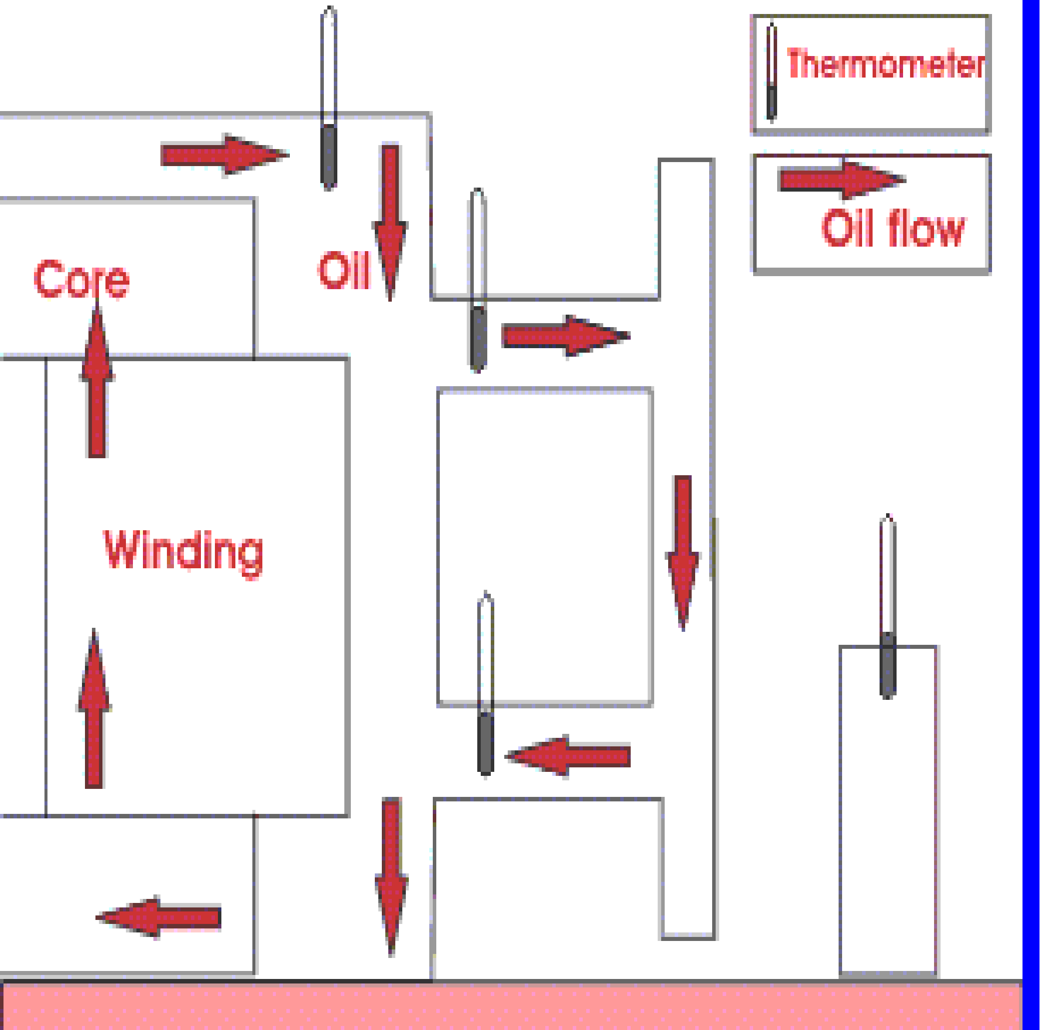
(i) Temperature Rise Test for Transformer Oil

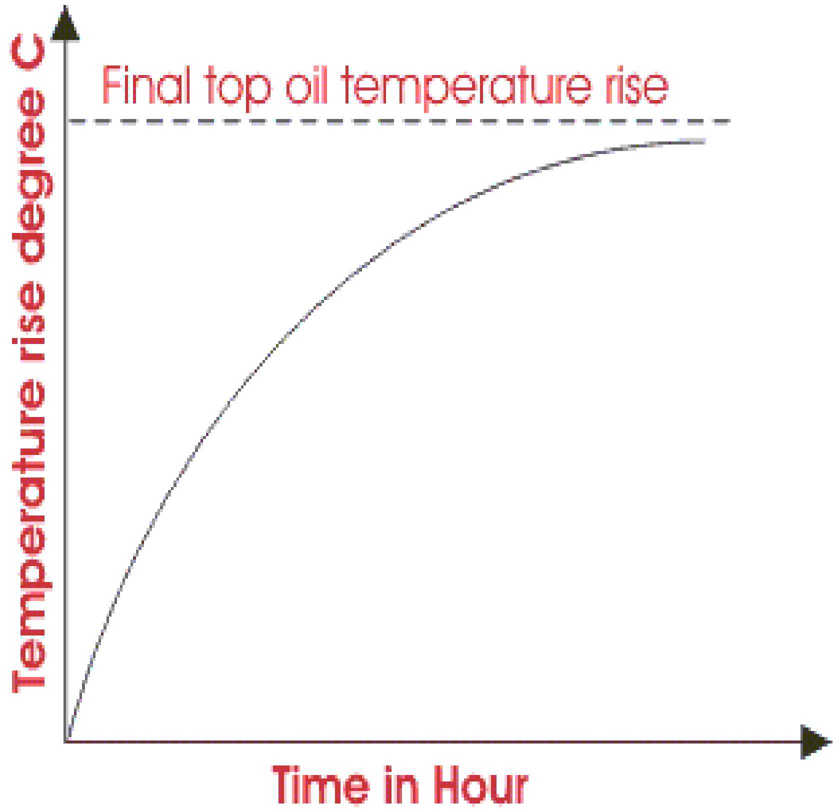
- **Procedure:-**

- First the LV winding of the transformer is short circuited.
- Then one thermometer is placed in transformer top cover. Other two thermometers are placed at the inlet and outlet of the cooler bank respectively.
- The voltage of such value is applied to the HV winding that power input is equal to no load losses plus load losses corrected to a reference temperature of 75°C.
- Measure total losses by 3 watt meter method.
- During the test, hourly readings of top oil temperature are taken from the thermometer already placed in the pocket of top cover.

- Hourly readings of the thermometers placed at inlet and outlet of the cooler bank are also noted to calculate the mean temperature of the oil.
- Ambient temperature is measured by means of thermometer placed around the transformer at three or four points situated at a distance of 1 to 2 meter from and half-way up the cooling surface of the transformer.
- Temperature rise test for top oil of transformer should be continued until the top oil temperature has reached an approximate steady value that means testing would be continued until the temperature increment of the top oil becomes less than 3°C in one hour. This steady value of top oil is determined as final temperature rise of transformer insulating oil.

➢ There is another method of determination of oil temperature. Here the test is allowed to be continued until the top oil temperature rise does not vary more than 1°C per hour for four consecutive hours. The least reading is taken as final temperature rise of the oil.





Method for determining the final temperature rise of oil

(ii) Temperature Rise Test for Winding

1. After completion of temperature rise test for top oil of transformer the electric current is reduced to its rated value for transformer and is maintained for one hour.
2. After one hour the supply is switch off and short circuit and supply connection to the HV side and short circuit connection to the LV side are opened.
3. But, the fans and pumps are kept running (if any).
4. Then resistance of the windings are measured quickly.
5. But there is always a minimum 3 to 4 minutes time gap between first measurement of resistance and the instant of switching off the transformer, which can not be avoided.

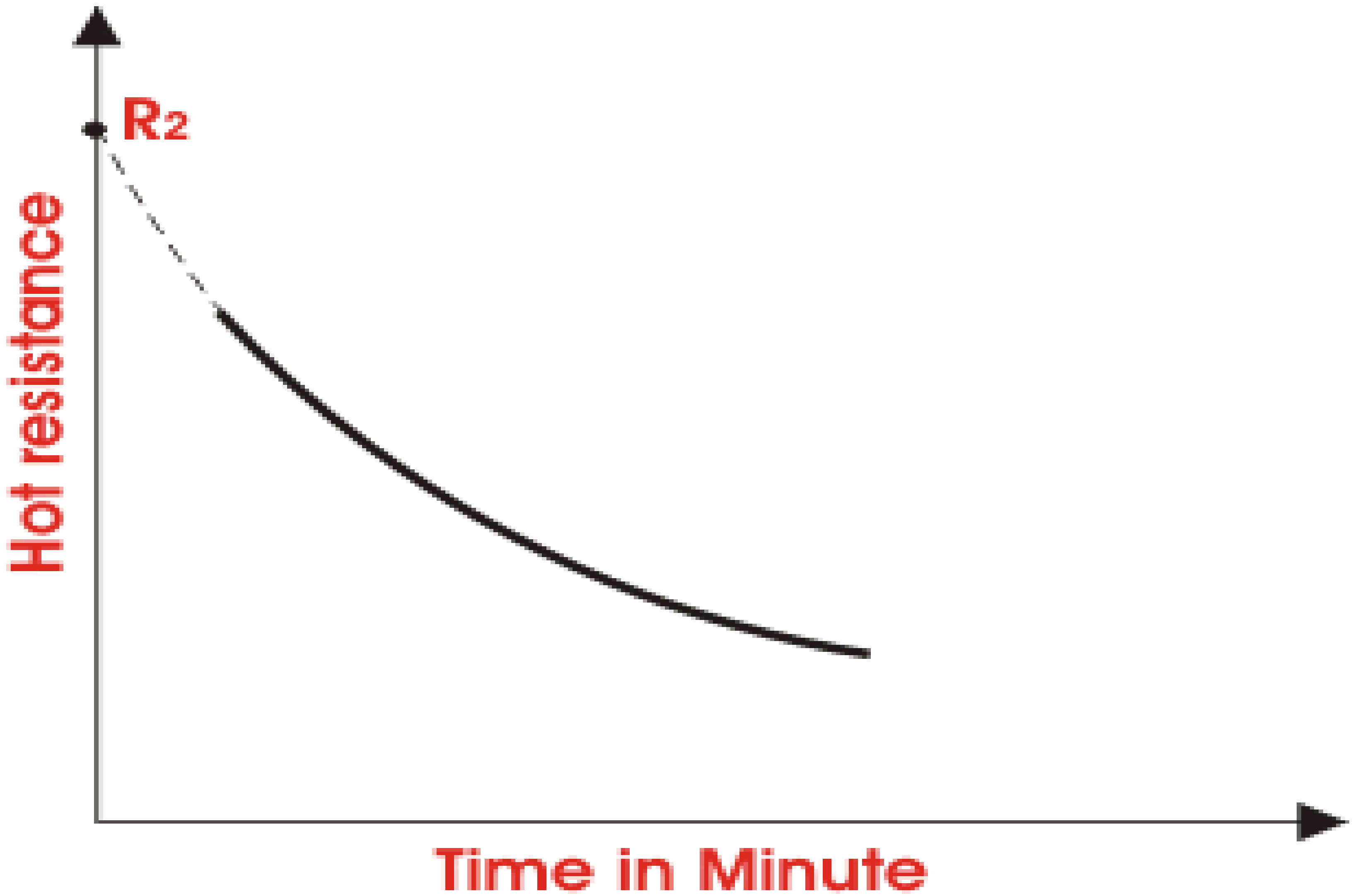
6. Then the resistances are measured at the same 3 to 4 minutes time intervals over a period of 15 minutes.
7. Graph of hot resistance versus time is plotted, from which winding resistance (R_2) at the instant of shut down can be extrapolated.
8. From this value, θ_2, the winding temperature at the instant of shut down can be determined by the formula given below,

$$\boxed{\theta_2 = \frac{R_2}{R_1}(235 + t_1) - 235}$$

Where,

R_1 is the cold resistance of the winding at temperature t_1.

Calculation of R_2 (Hot winding resistance):



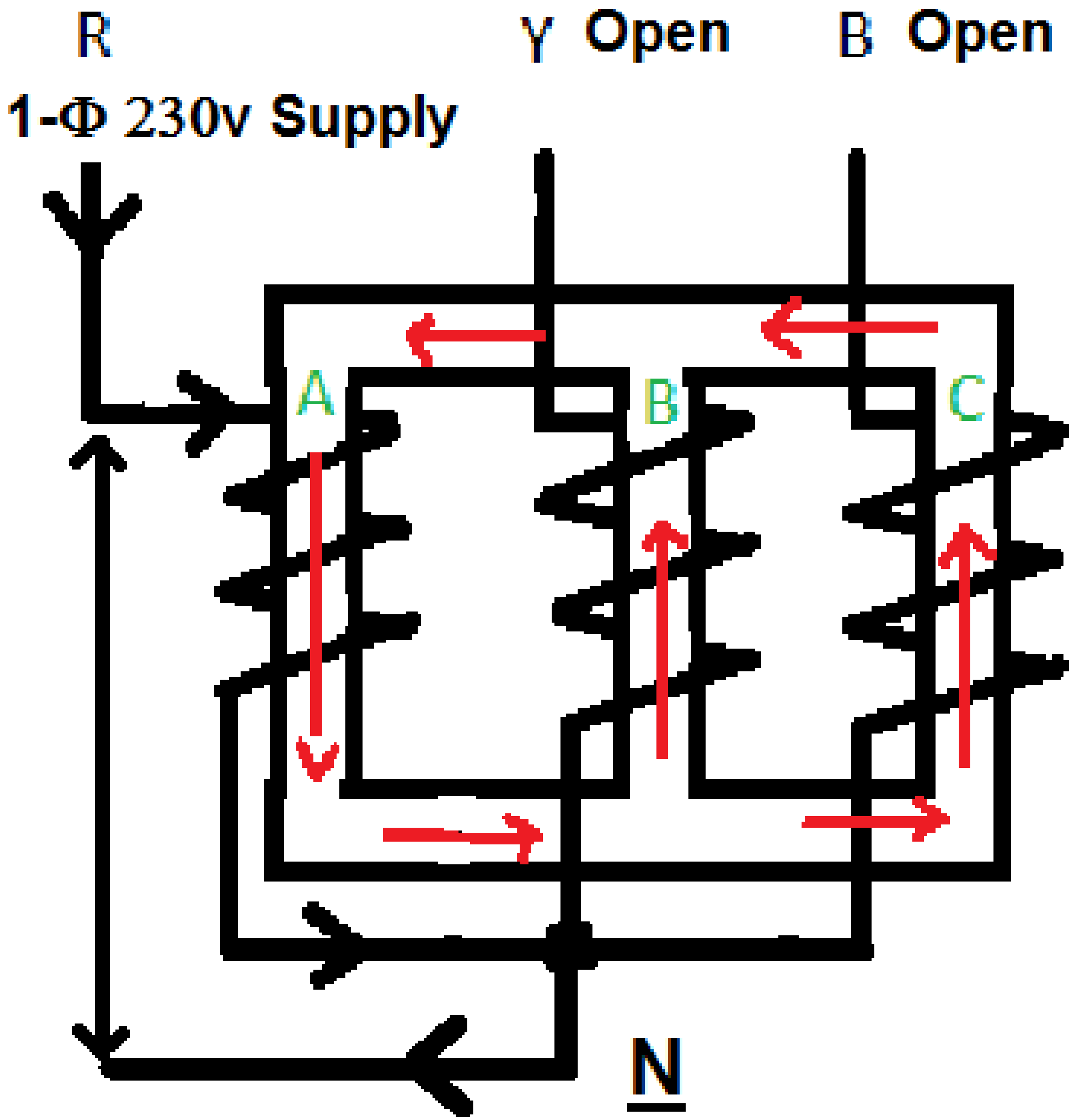
8. Magnetic Balance Test

- Magnetic balance test of transformer is conducted only on three phase transformers to check the imbalance in the magnetic circuit.

➢ Procedure:-

- First keep the tap changer of transformer in normal position.
- Now disconnect the transformer neutral from ground.
- Then apply single phase 230 V AC supply across one of the HV winding terminals and neutral terminal.
- Measure the voltage in two other HV terminals in respect of neutral terminal.
- Repeat the test for each of the three phases.

Magnetic balance test circuit diagram



Let us assume that flux

in limb A= ϕA

in limb B= ϕB

in limb C= ϕC

$$\phi A = \phi B + \phi C$$

100%=60-80% + 40-20%

- There are three limbs side by side in a core of transformer.
- One phase winding is wound in one limb.
- The voltage induced in different phases depends upon the respective position of the limb in the core.
- The voltage induced in different phases of transformer in respect to neutral terminals given in the table below:

➢ **Test Result:-**

Applied Voltage	Measured Voltage(V1)	Measured Voltage(V2)	Result
RY	YB	BR	V=V1+V2
YB	RY	BR	V=V1+V2
BR	YB	RY	V=V1+V2

9. High Voltage (HV) Test

- **Test Purpose:-**

To checks the insulation property between Primary to earth, Secondary to earth and between Primary & Secondary.

- **High Voltage Test Supply:-**

- For 433 V Winding = 3KV High Voltage
- For 11 KV Winding = 28KV High Voltage
- For 22 KV Winding = 50KV High Voltage
- For 33 KV Winding = 70KV High Voltage.

➢ Procedure:- (Connect Supply for 1 min.)

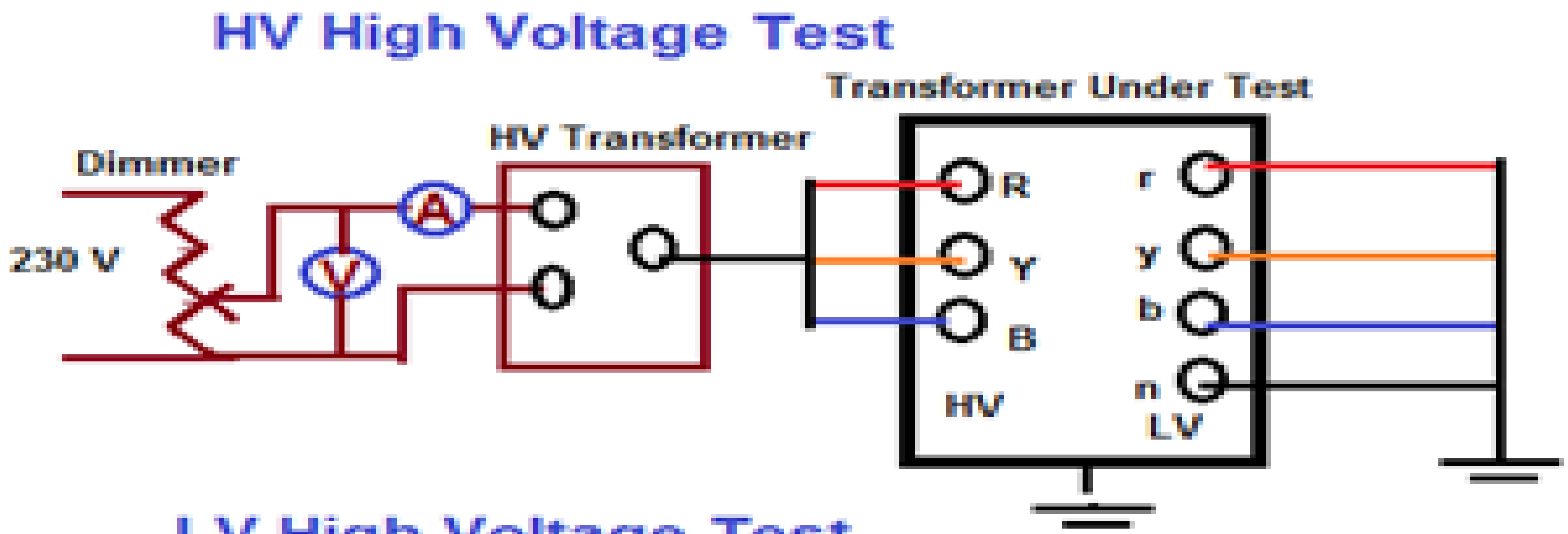
(i) HV winding high voltage test:

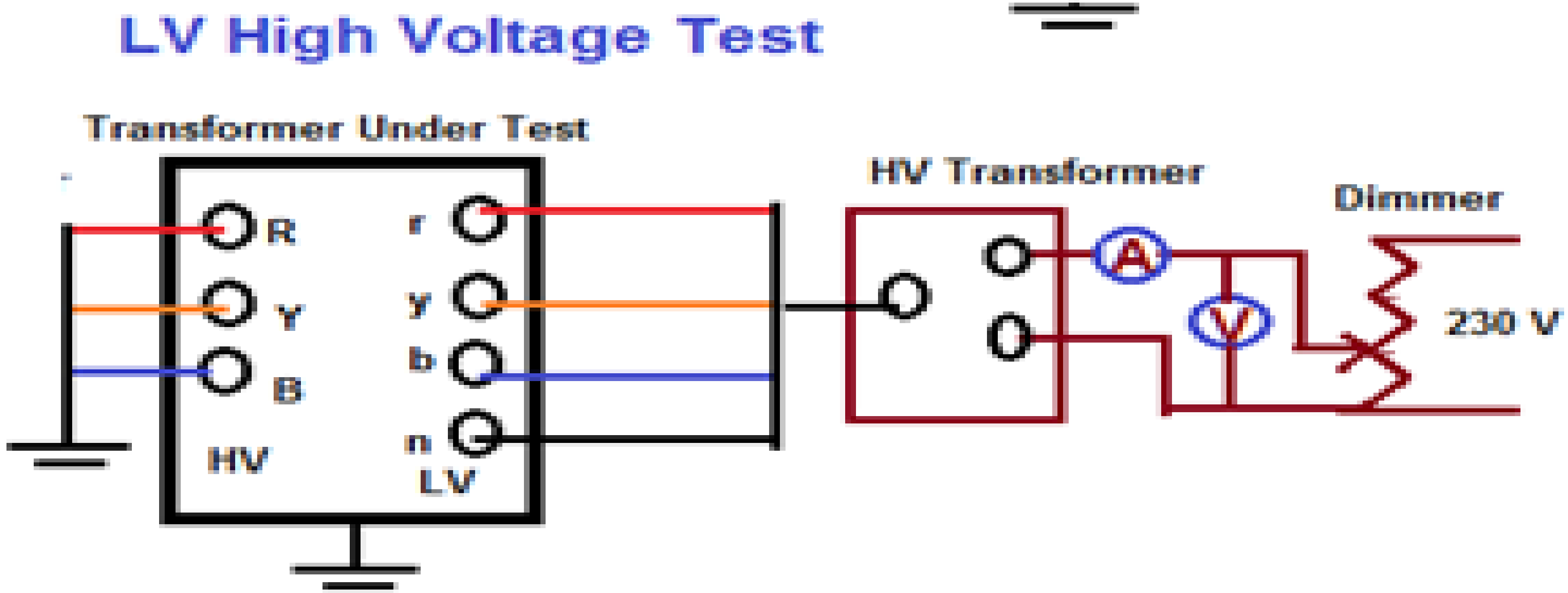
- LV winding connected together and earthed.
- HV winding connected together and connect HV Supply for 1 minute.

(ii) LV winding high Voltage test:

- HV winding connected together and earthed.
- LV winding connected together and connect HV Supply for 1 minute.

HV Test circuit diagram:





10. Breakdown Voltage (BDV) Test:

This test is used to find the breakdown voltage of transformer oil.

Breakdown Voltage:

Value Depends on:

- Presence of dirt
- Moisture
- Foreign particle
- Gap between electrodes
- Alignment of Electrodes
- Environmental conditions

Breakdown Voltage (BDV)

- IS : 6792-1972 prescribes method for test

"Electrodes (Spherical or Hemi-spherical) with a dia. of 12.5 mm, separated by 2.5 mm, with axis dipped at least 40 mm below top oil level, is applied with voltage increasing at uniform rate of 2 KV/Sec, till breakdown occurs. Average of 6 readings is taken for same sample, and oil is stirred after every test."

Breakdown Voltage (BDV)

- Recommended Limits
  - Unused oil filled in new transformer (min)
    - 40 kV for equipment voltage upto 72.5 KV
    - 50 kV for equipment voltage between 72.5 KV & 170 KV
  - Oil in service

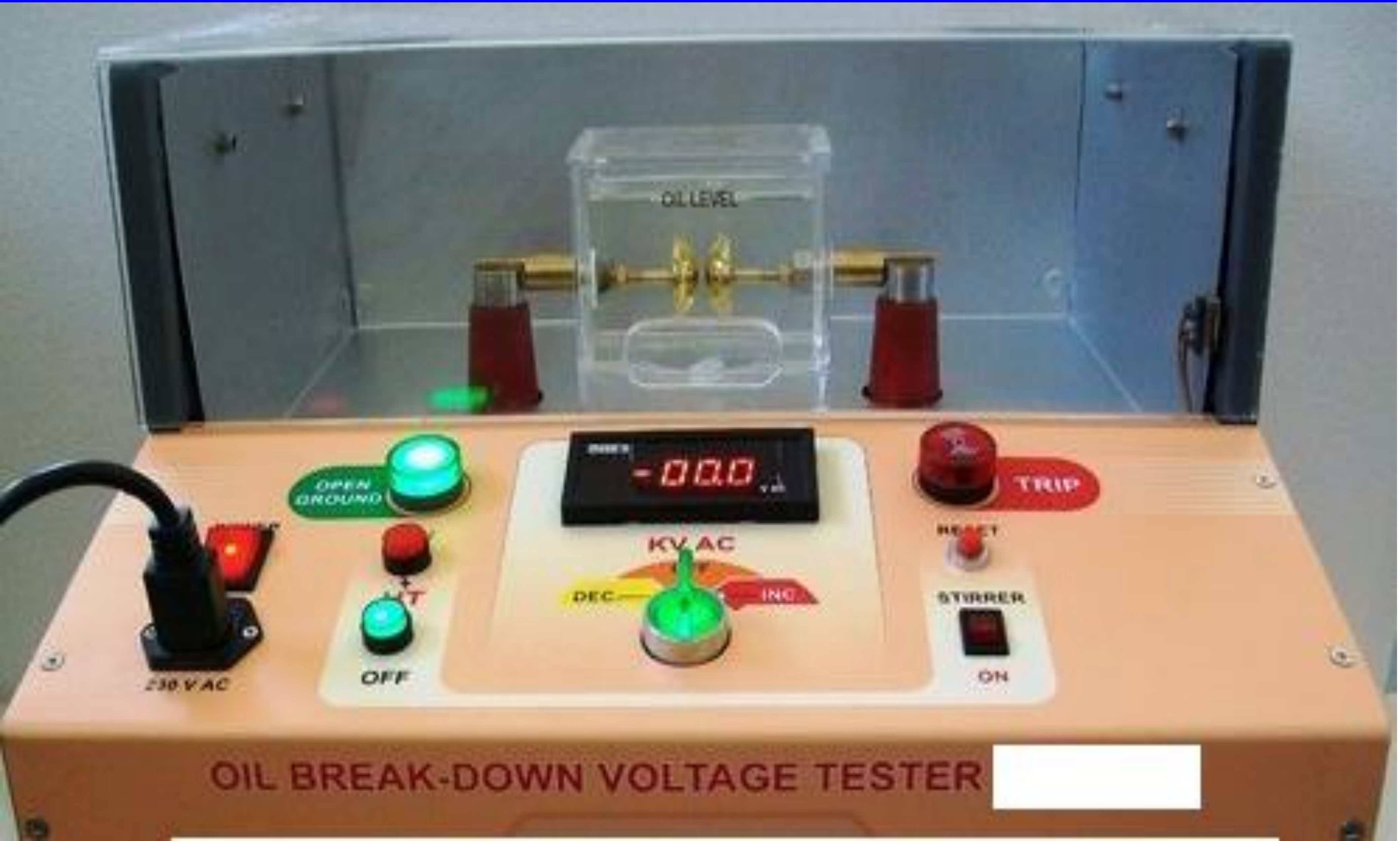
    > 30 KV for equipment Voltage upto 72.5KV

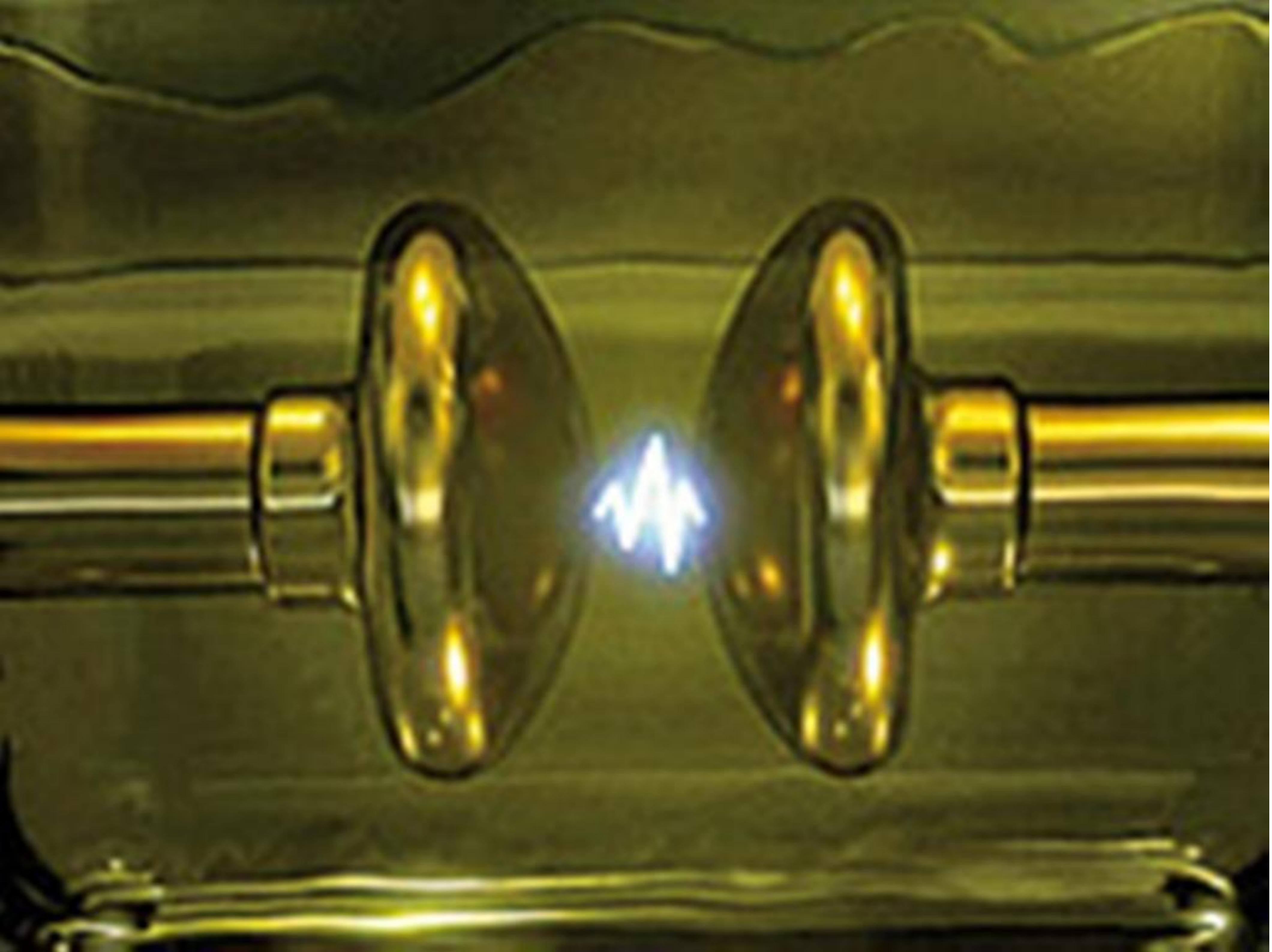
    > 40 KV for equipment Voltage more than 72.5KV & less than 170 KV

BDV procedure:-

- BDV of oil is the voltage at which the transformer oil will break its dielectric Strength and start conducting.
- In this test, one bowl containing transformer oil is taken and put in the test kit.
- Test kit is having provision of 2 electrodes which is maintained at 2.5 mm apart and these electrodes are placed in the bowl containing transformer oil, and voltage is increased slowly.
- At some voltage the flash will appear in the oil. This is voltage is known as Break Down Voltage (BDV).

BDV Test Kit:


OIL LEVEL
OPEN GROUND
-00.0
KV AC
DEC
INC
TRIP
STIRRER
OFF
ON
230 V AC
OIL BREAK-DOWN VOLTAGE TESTER



11. Vector Group Test

- Proper vector grouping in a 3-phase transformer is an essential criteria for parallel operation of transformers.
- There are several internal connection of three phase transformer & these connections gives various magnitudes and phase of the secondary voltage.
- The magnitude can be adjusted for parallel operation by suitable choice of turn ratio, but the phase divergence can not be compensated. So we have to choose those transformer for parallel operation whose phase sequence and phase divergence are same.
- All the transformers with same vector ground have same phase sequence and phase divergence between primary and secondary.

व्यक्ति अपने जन्म से नहीं अपितु अपने कर्म से महान होता है।

Indian Railways
Centre for Advanced Maintenance Technology

CONDITION MONITORING TECHNIQUES FOR TRANSFORMERS

Phase I – Module No. FC - 02

Condition Monitoring techniques for Transformers

1. Sweep Frequency Response Analysis (SFRA)
2. Thermal Analysis
3. Vibration Analysis
4. Partial Discharge Analysis
5. Dissolved Gas Analysis (DGA)

1. Sweep Frequency Response Analysis (SFRA) Test

Need & purpose:

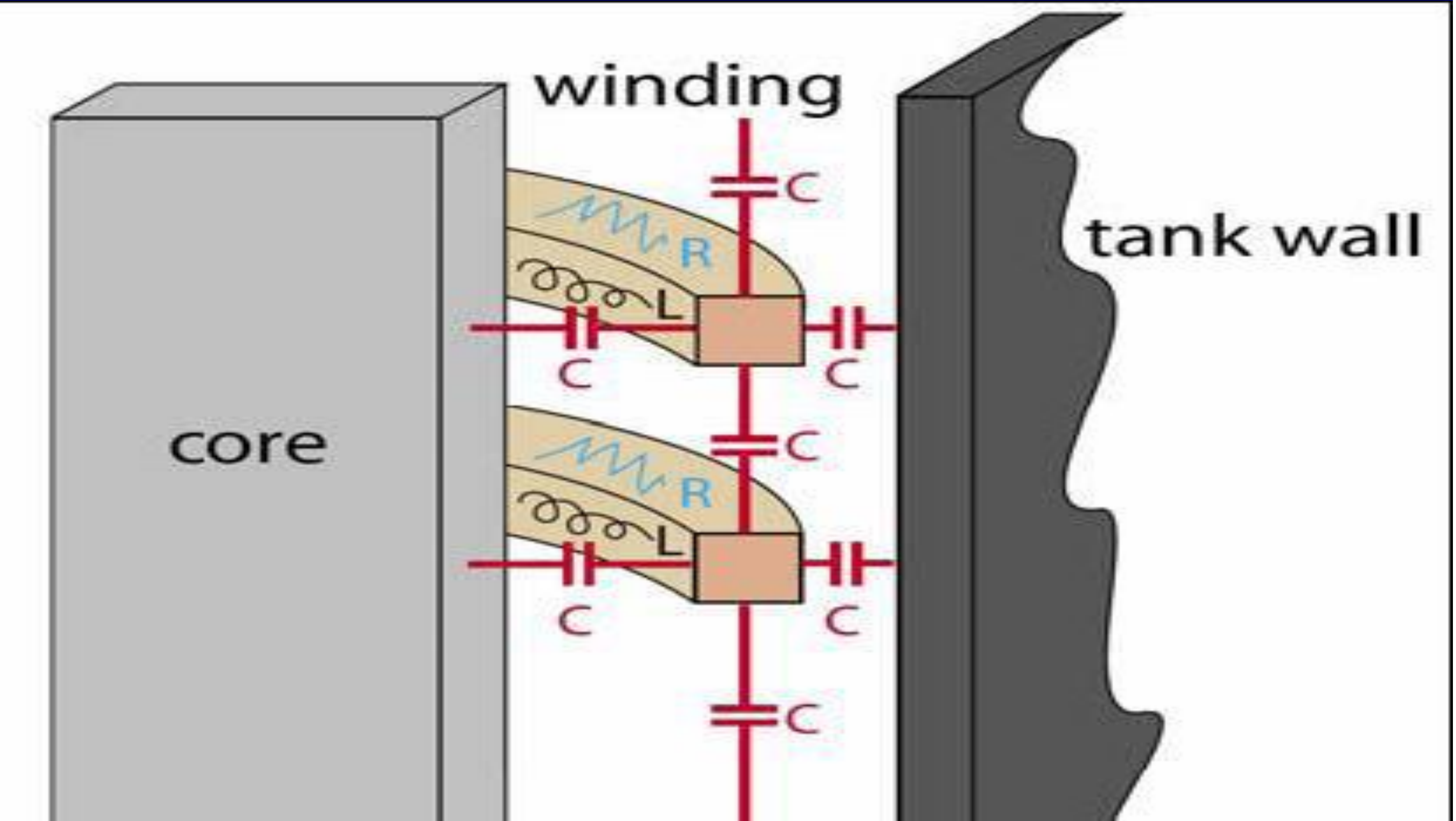
- This is very reliable and sensitive method or tool for condition monitoring of the physical condition of transformer windings.
- The transformer windings may be subjected to mechanical stresses during transportation, heavy short circuit faults, transient switching impulses & lightening impulses etc.
- These mechanical stresses may cause displacement of windings from their position and may also cause deformation of these windings.
- Such physical defects eventually lead to insulation failure or dielectric faults in the windings.

- SFRA can detect efficiently, displacement of transformer core, deformation and displacement of winding, faulty core grounds, collapse of partial winding, broken or loosen clamp connections, short circuited turns, open winding conditions etc.
- Each winding of a transformer exhibits a particular frequency response.
- A frequency response measured directly by injecting a sinusoidal voltage signal V_i of a variable frequency at one terminal and measuring the response at another (Other windings are kept open).
- If we plot these output voltages against the corresponding frequencies we will get a particular pattern for a particular winding.

- But after transportation, heavy short circuit faults, transient switching impulses and lightening impulses etc, if we do same SFRA and super-impose the present pattern with the earlier patterns.
- Observe some deviation between these two graphs, we can asses that there is mechanical displacement and deformation occurred in the winding.

Basic principle OF SFRA Test

Equivalent Geometry of Transformer



Frequency Response of transformer circuit

- **Low frequency response:**

1) Winding behaves as a simple RL circuit formed by series inductance and resistance of the winding (At low frequencies capacitance acts as almost open circuit).

2) At low frequencies winding inductance is determined by the magnetic circuit of the transformer core.

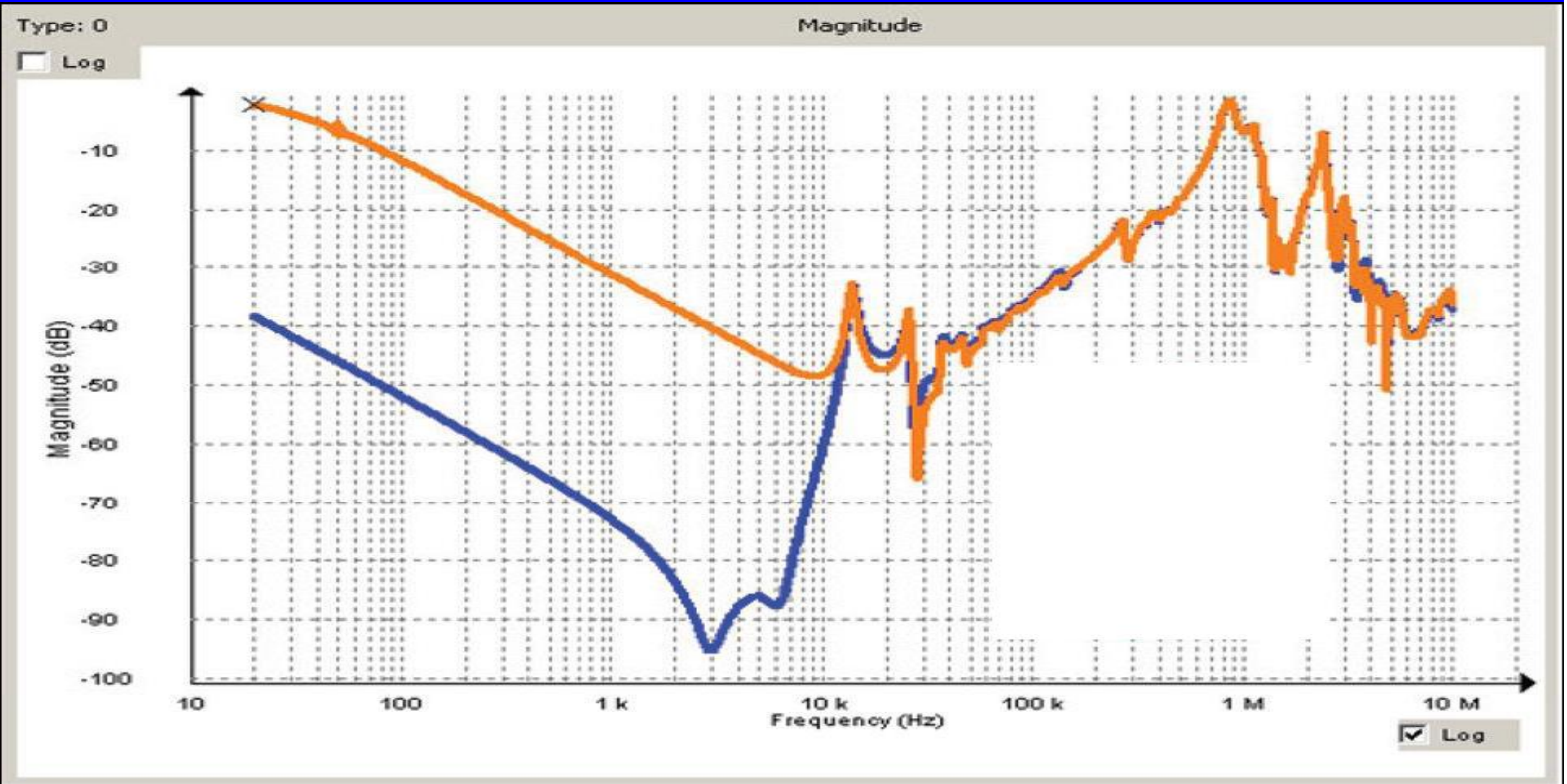
- **High frequency response:**

1) At high frequencies winding behaves as RLC circuits

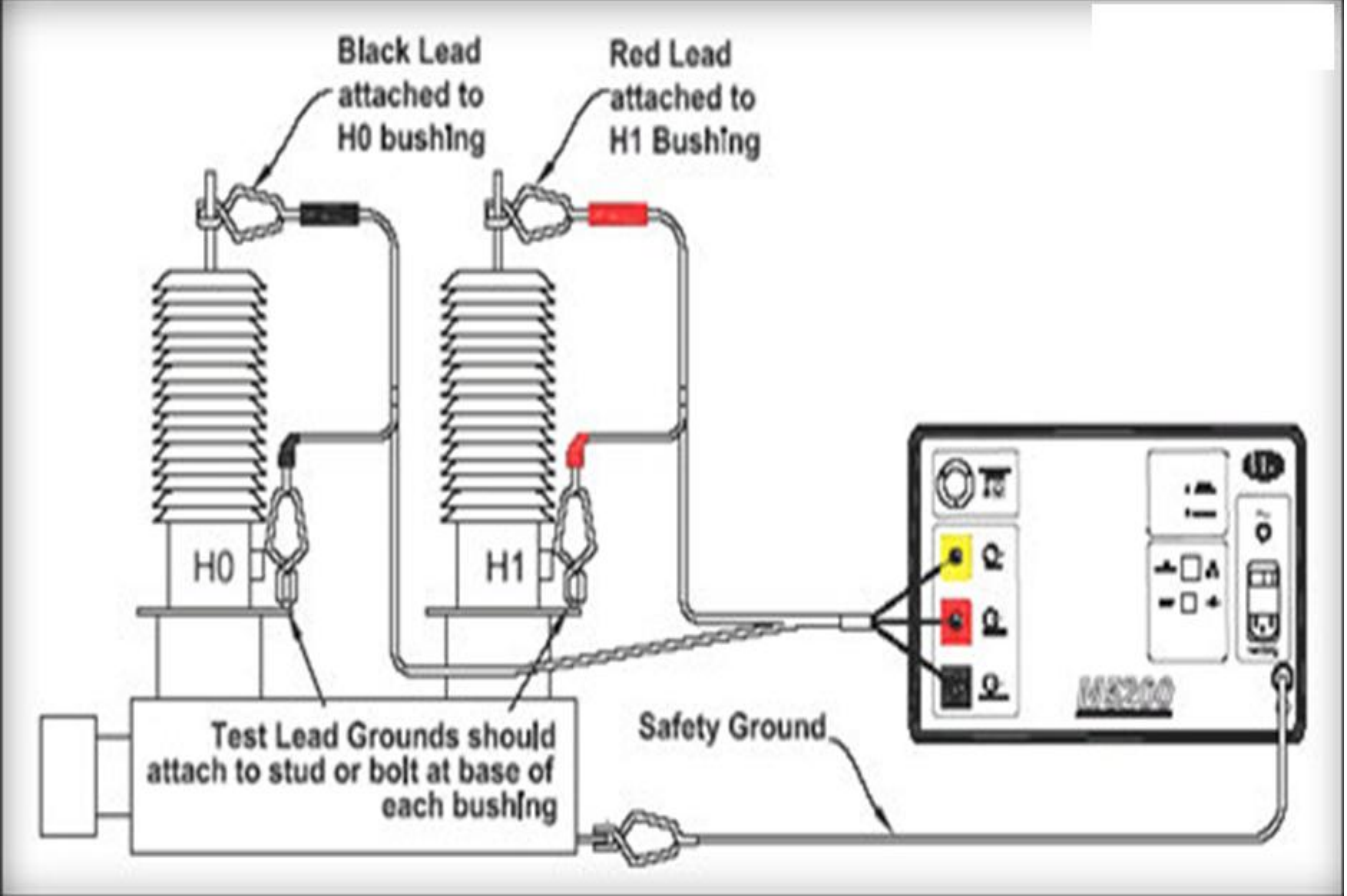
2) Winding exhibits many resonant points

3) Frequency response is more sensitive to winding movement.

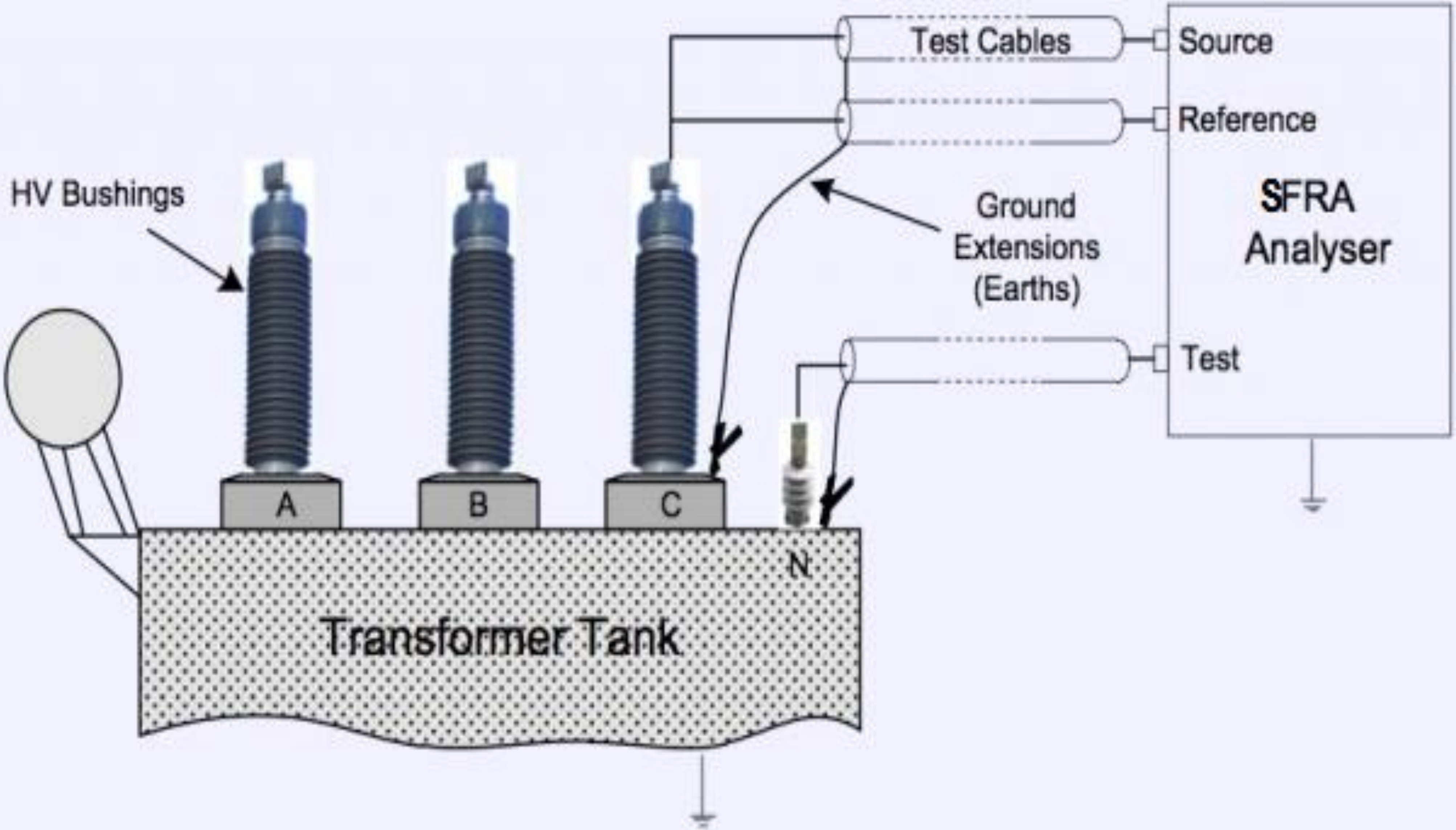
- Any form of physical damage to the transformer results in the changes of this RLC Network.
- Any geometrical deformation changes the RLC network, which in turn changes frequency response.



SFRA Test circuit:



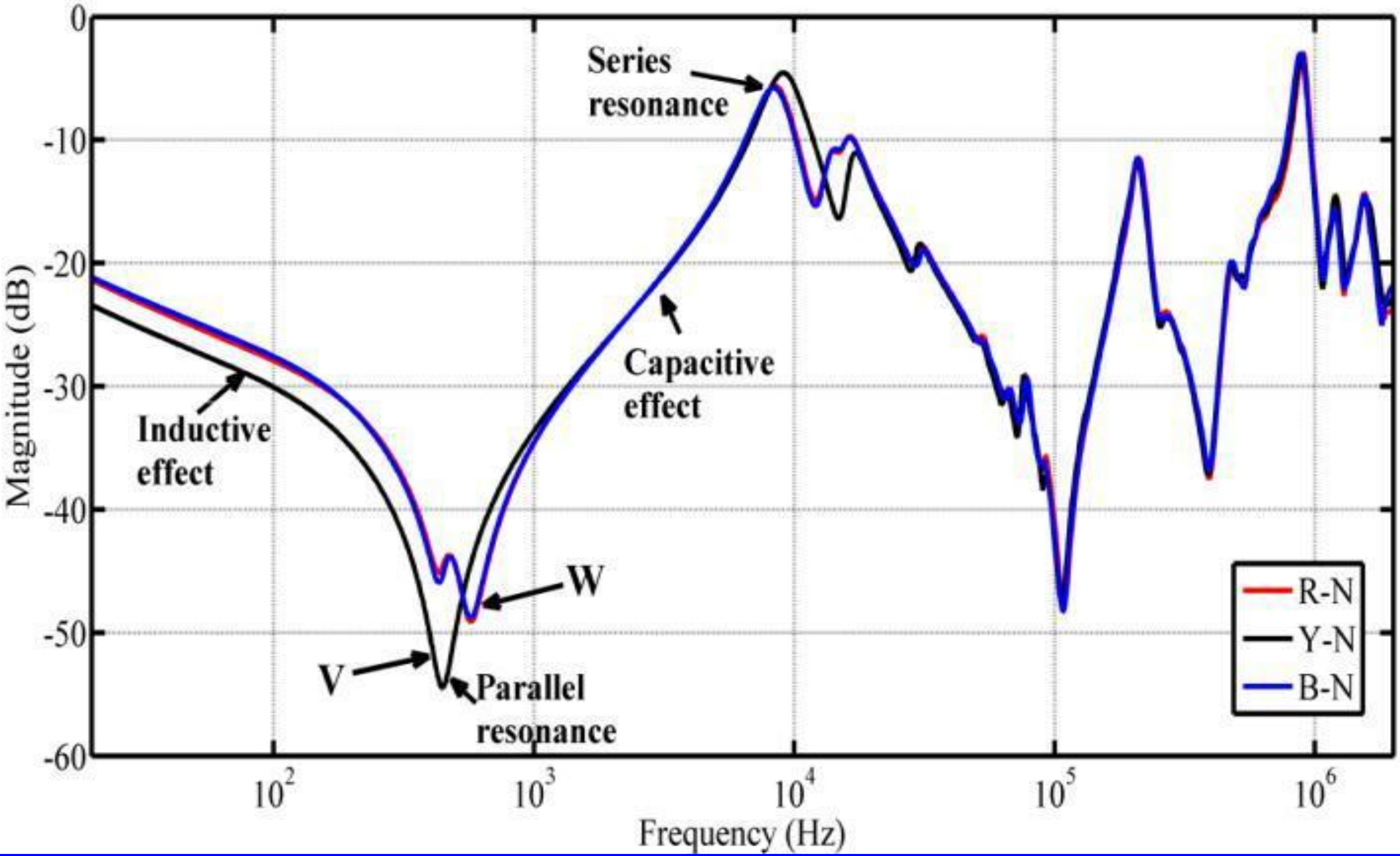
SFRA Test circuit:



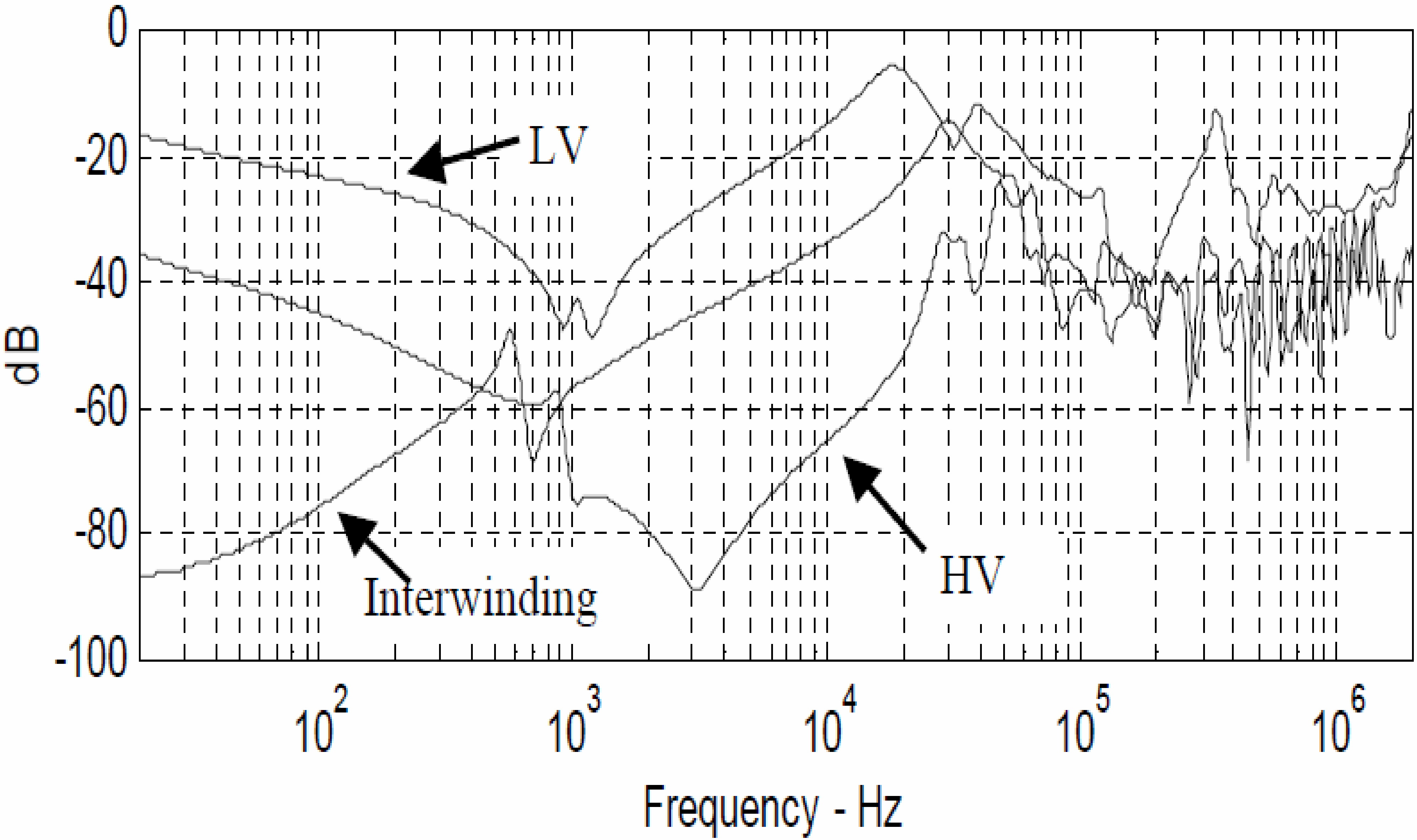
Different Connection During SFRA

S No.	Signal applied across transformer terminals	Conditions
1.	HV Red phase to Neutral	LV Red Yellow Blue phases are open
2.	HV Yellow phase to Neutral	LV Red Yellow Blue phases are open
3.	HV Blue phase to Neutral	LV Red Yellow Blue phases are open
4.	HV Red phase to Neutral	LV Red Yellow Blue phases are shorted
5.	HV Yellow phase to Neutral	LV Red Yellow Blue phases are shorted
6.	HV Blue phase to Neutral	LV Red Yellow Blue phases are shorted
7.	LV Red to Yellow phase	HV Red Yellow Blue phases and LV Blue phase are open
8.	LV Yellow to Blue phase	HV Red Yellow Blue phases and LV Red phase are open
9.	LV Blue to Red phase	HV Red Yellow Blue phases and LV Yellow phase are open

End-to-end open circuit frequency response for a 10 MVA transformer

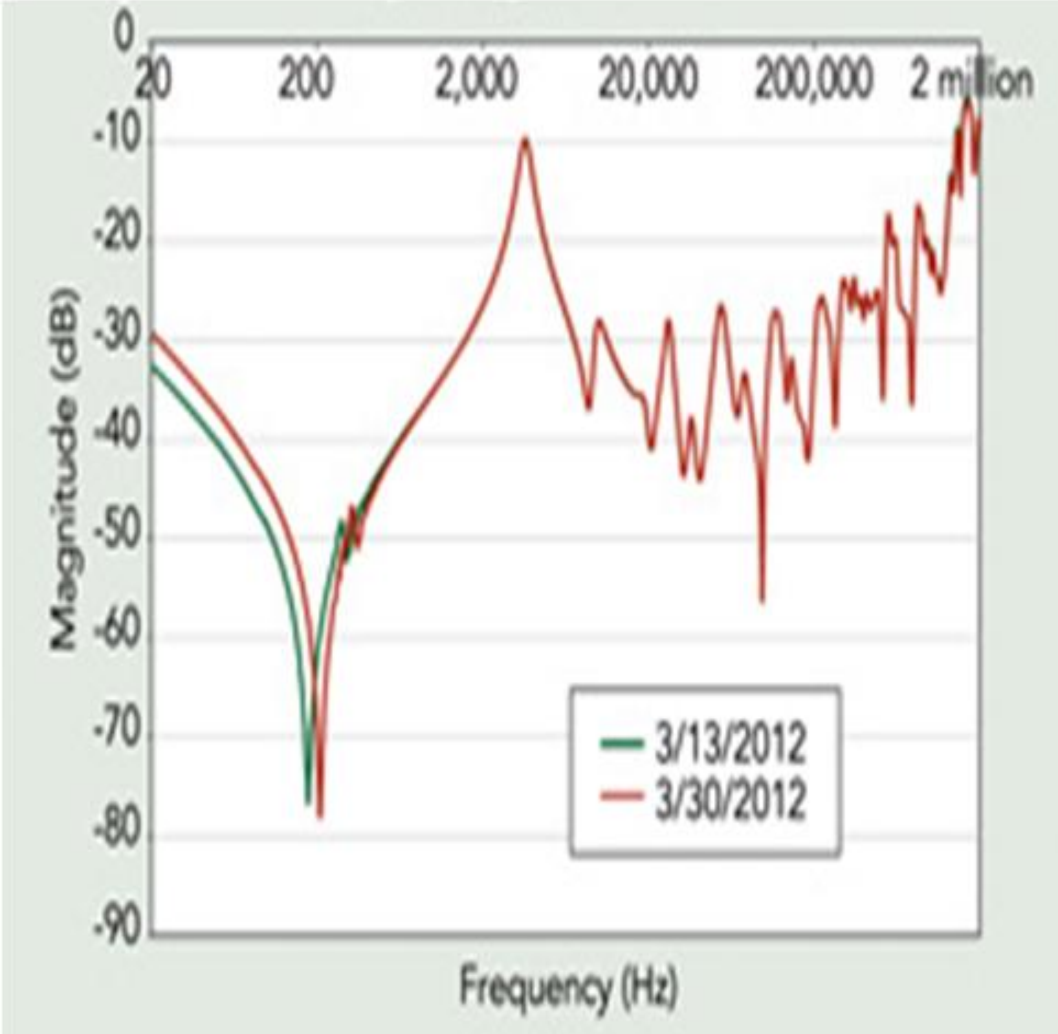


Example: SFRA of a 10 MVA transformer

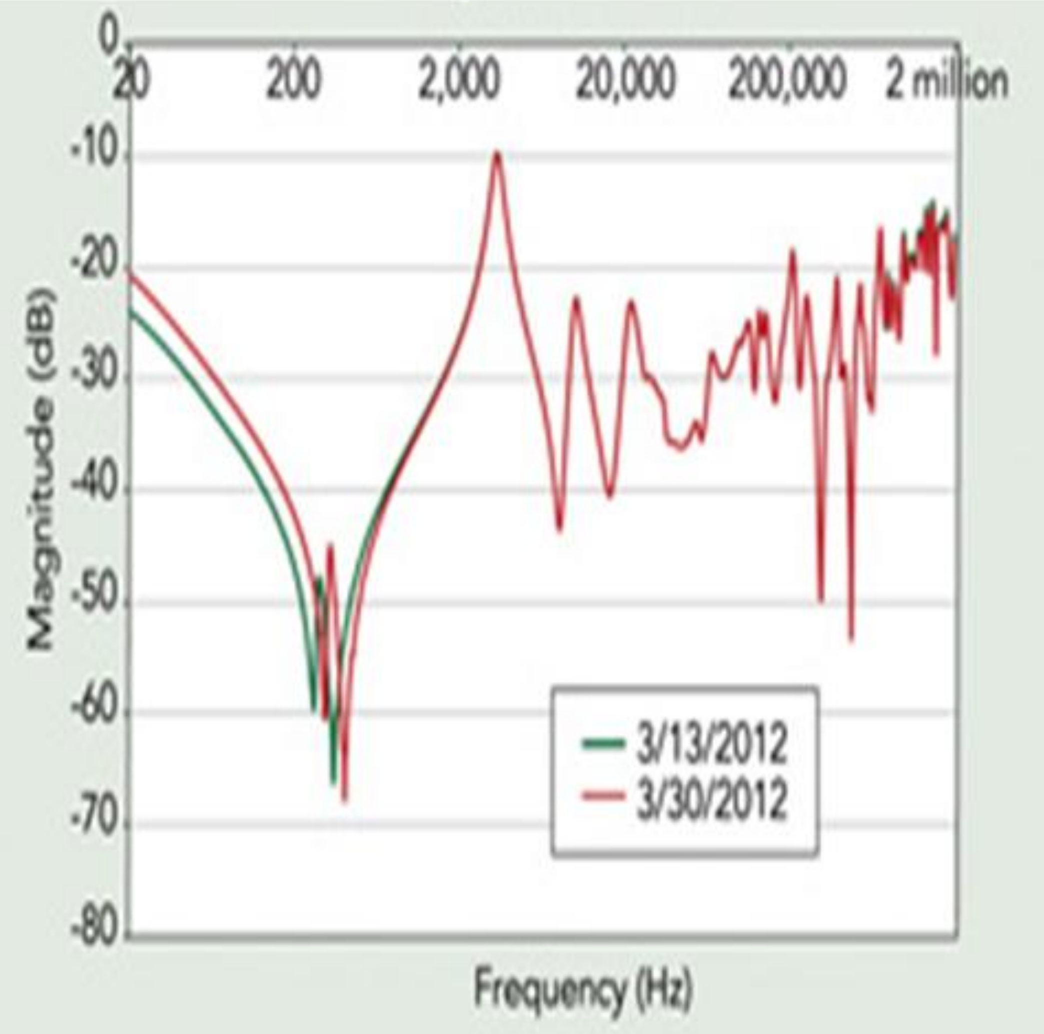


Example of SFRA

High Voltage



Low Voltage



2. Thermal Analysis

- Thermal analysis of the transformers can provide useful information about its condition and indicate any incipient inside it.
- Many of the incipient faults cause change in thermal behavior of the transformer.
- It is usually accepted that transformer life can be affected very much for a continuous maximum hotspot temperature.
- Between 80°C to 140°C, the rate of ageing of Insulation doubles for every increase of 6°C increase in hot-spot temperature.

3. Vibration Analysis

- The usage of the vibration analysis was used to assess the health of the transformer or some important parts of it such as OLTC (On Load Tap Changer).
- According to the tank vibration consists of two types; (i) core and (ii) winding vibrations.
- These generated vibrations propagate through the transformer oil until reaching the transformer walls, at which the vibration signature of the transformer can be collected via vibration sensors.
- The collected vibration signal was analyzed using Fourier transform to show that the transient vibration signals are concentrated in the range from 10 to 2000 Hz.

- Any OLTC (On Load Tap Changer) has its own vibration signature regarding the number of the rising edges of the vibration busts and the duration between each successive two rising edges.

4. Partial Discharge Analysis

- Partial discharge is a kind of discharge that only partially bridges the insulation gap between conductors/electrodes.
- The discharge may happen totally inside the transformer insulation or adjacent to the conductors.
- The partial discharge around an electrode in gases is called corona, while the others such as the one which occurs in a transformer liquid is commonly named as streamer.
- Partial discharges (PDs) occur in a transformer when the electric field strength exceeds the dielectric breakdown strength of a certain localized area.

- The dielectric properties of the insulation may be severely affected if subjected to consistent partial discharges activity over long periods of time.
- Partial discharges can be detected and measured using piezo-electric sensors.

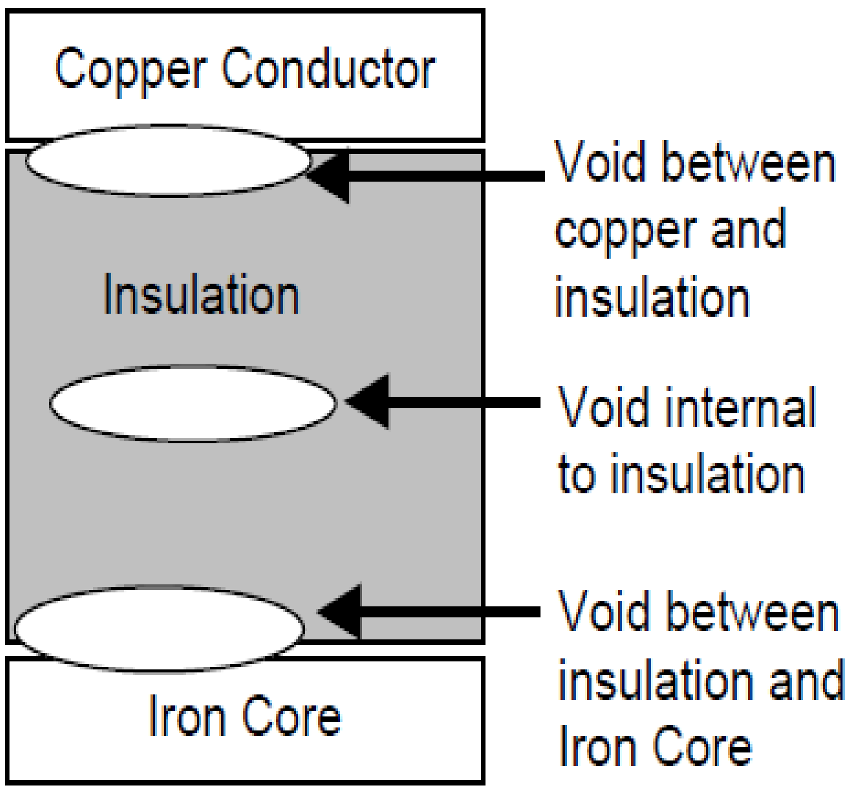


Figure 1 – PD within Insulation System

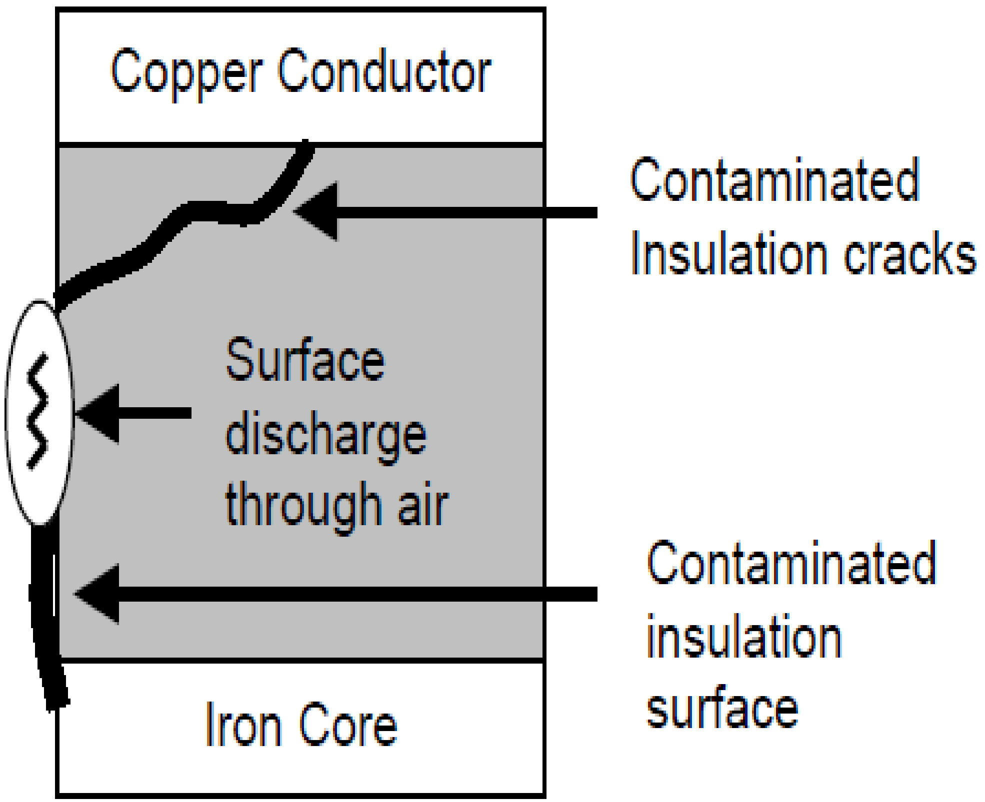


Figure 2 – Surface Partial Discharges

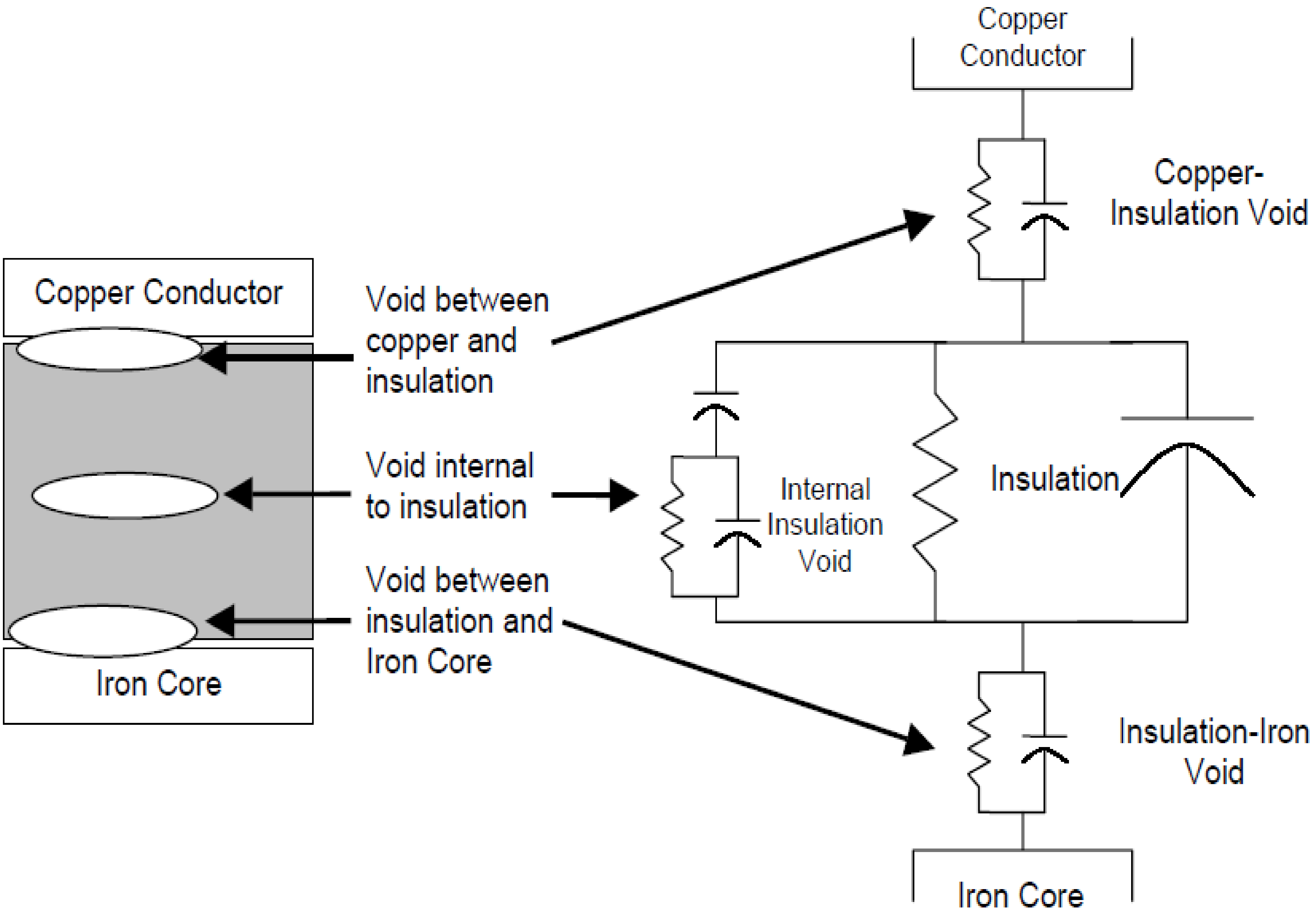


Figure 3 – Insulation System Partial Discharge Model

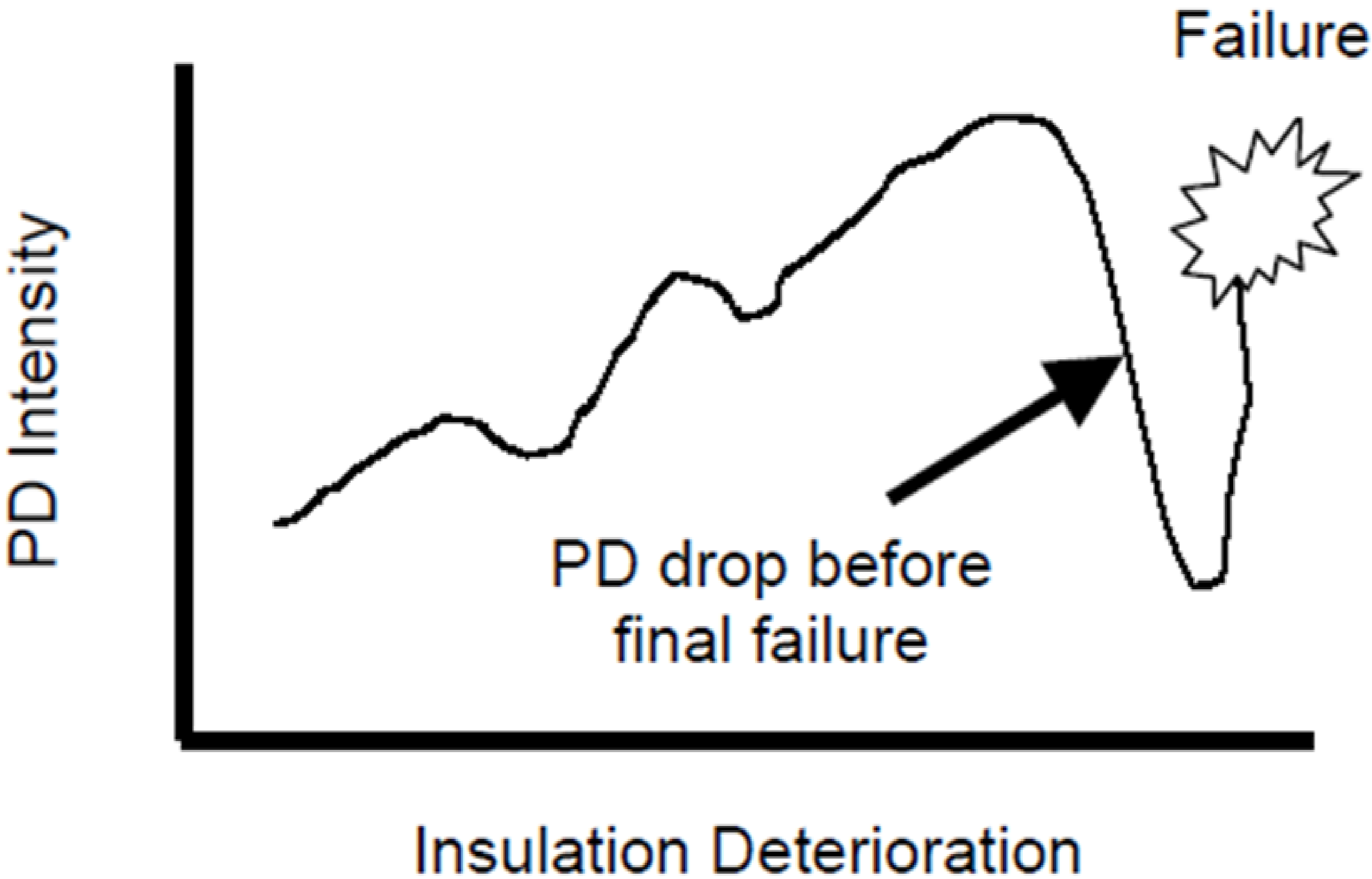


Figure 4 – PD versus Insulation Failure Mode

4. Dissolved Gas Analysis (DGA)

4. Dissolved Gas Analysis (DGA)

- In assessing the condition monitoring of the transformer, DGA is the first indicator of a problem and can identify deteriorating insulation and oil, overheating, hot spots, partial discharge, and arcing.
- Insulation ageing in transformers is most commonly associated with long-term effects of the operating temperature, moisture and air.
- The thermal degradation of oil results in the production of faults gases such as hydrogen, methane, ethane, ethylene, acetylene, CO, CO2 and other products of oil breakdown include alcohols, organic acids, aldehydes, peroxides, etc.

- For any given oil sample, the absolute and relative concentrations of fault gases can be used to indicate the type, intensity and location of the fault.

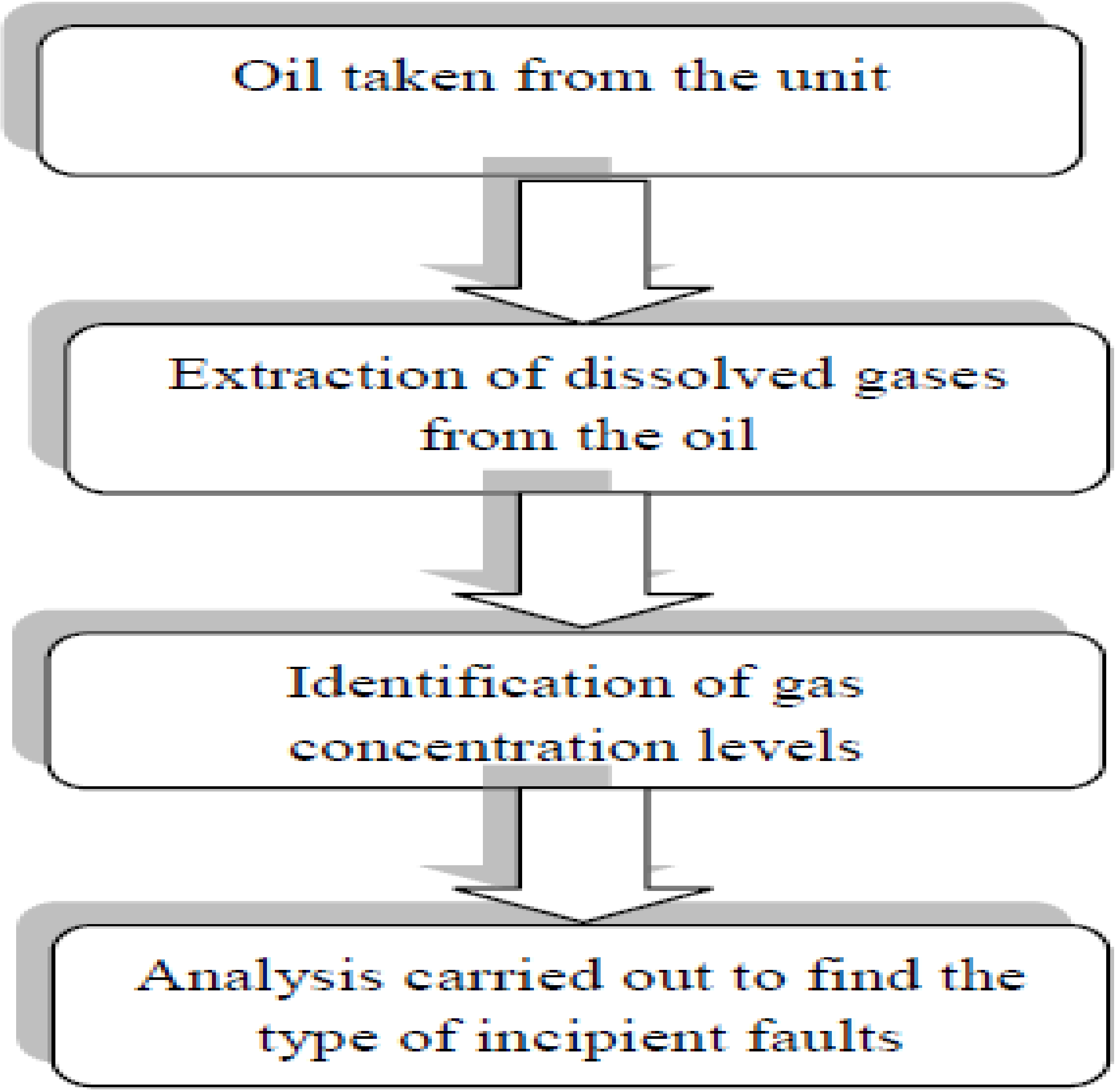
➢ **CAUTION:**

- DGA is unreliable if the transformer is de-energized and has cooled, if the transformer is new, or if it has had less than 1 to 2 weeks of continuous service after oil processing.

➢ **DGA involves following steps:**

- 1. Sample of the oil taken from the unit and extract the dissolved gases from oil.
- 2. Detect the gas concentrations and analyze by diagnostic methods (Key Gas and Ratio analysis methods) to find faults.

Flow Chart of DGA



Flow Chart of DGA

Advantages of DGA:

1. Advance warning of developing of faults.
2. Status check on new and aged mineral oil.
3. Convenient online scheduling of repairs.
4. Identifies degradation level before it leads to failure.
5. Monitoring of units under overload case.
6. Checking the improper use of units.

The main advantage of DGA method is

"IT GIVES EARLY IDENTIFICATION OF INCIPIENT FAULTS"

Key Gas Method of DGA:

- The key gas method is mainly depends on the quantity of fault gases release in mineral oil when fault occur.
- Generally the thermal decomposition of oil produced more than 60% of ethylene.
- (C2H2) and thermal decomposition of cellulose produce key gas carbon monoxide (CO) is 90%.
- In case of corona in oil mainly produce large amount principal gas hydrogen nearly 80%.
- Due to arcing key gas acetylene produced 30% with trace quantity of hydrogen.

Figure 1 to Figure 4 indicates the key gases and their relative proportions for different fault types.

i. During Thermal Faults in Transformer oil

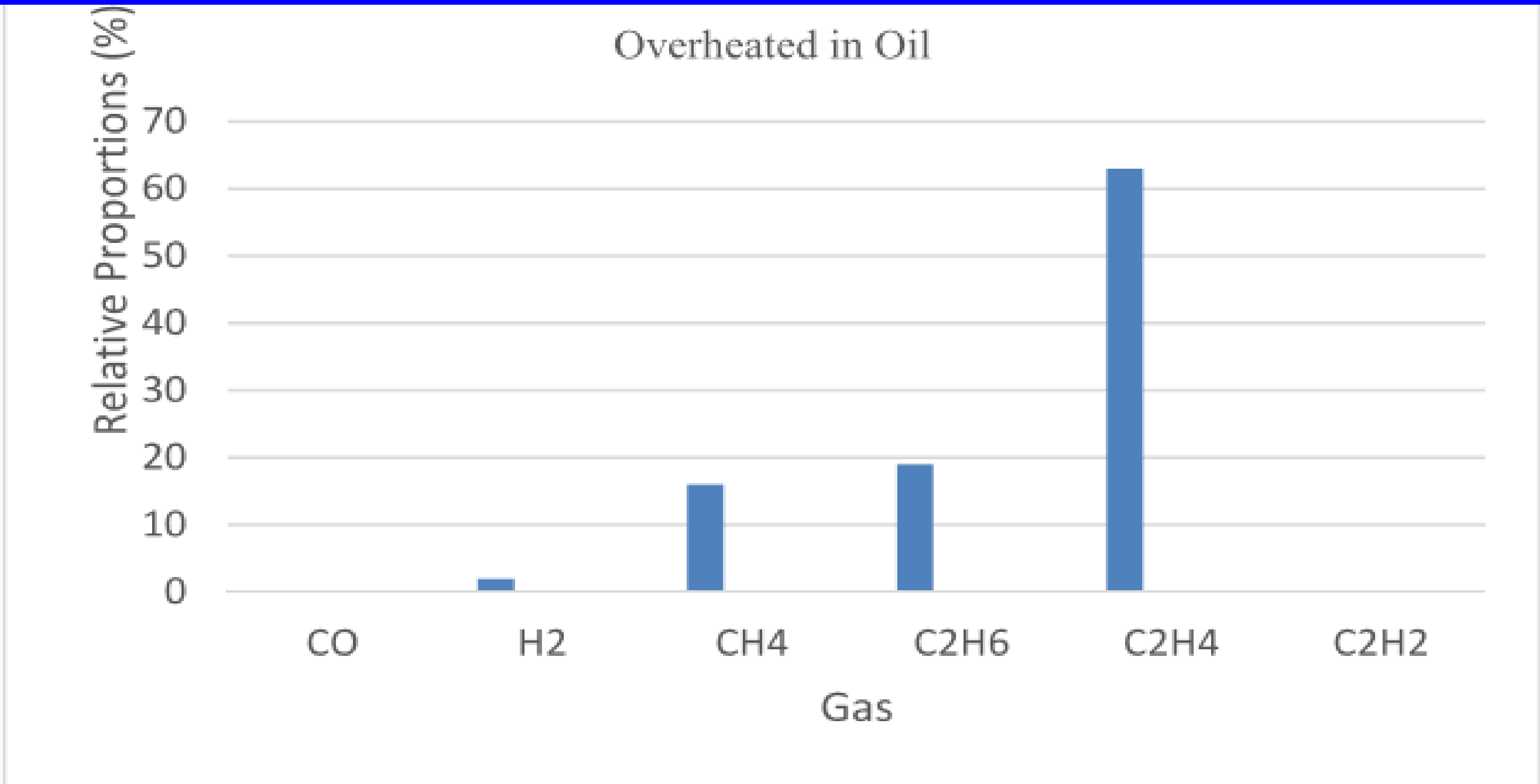


Figure 1 Approximate percentage (%) of gases found during thermal faults in oil inside the Transformer

ii. During Thermal Fault In Transformer Paper Insulation:

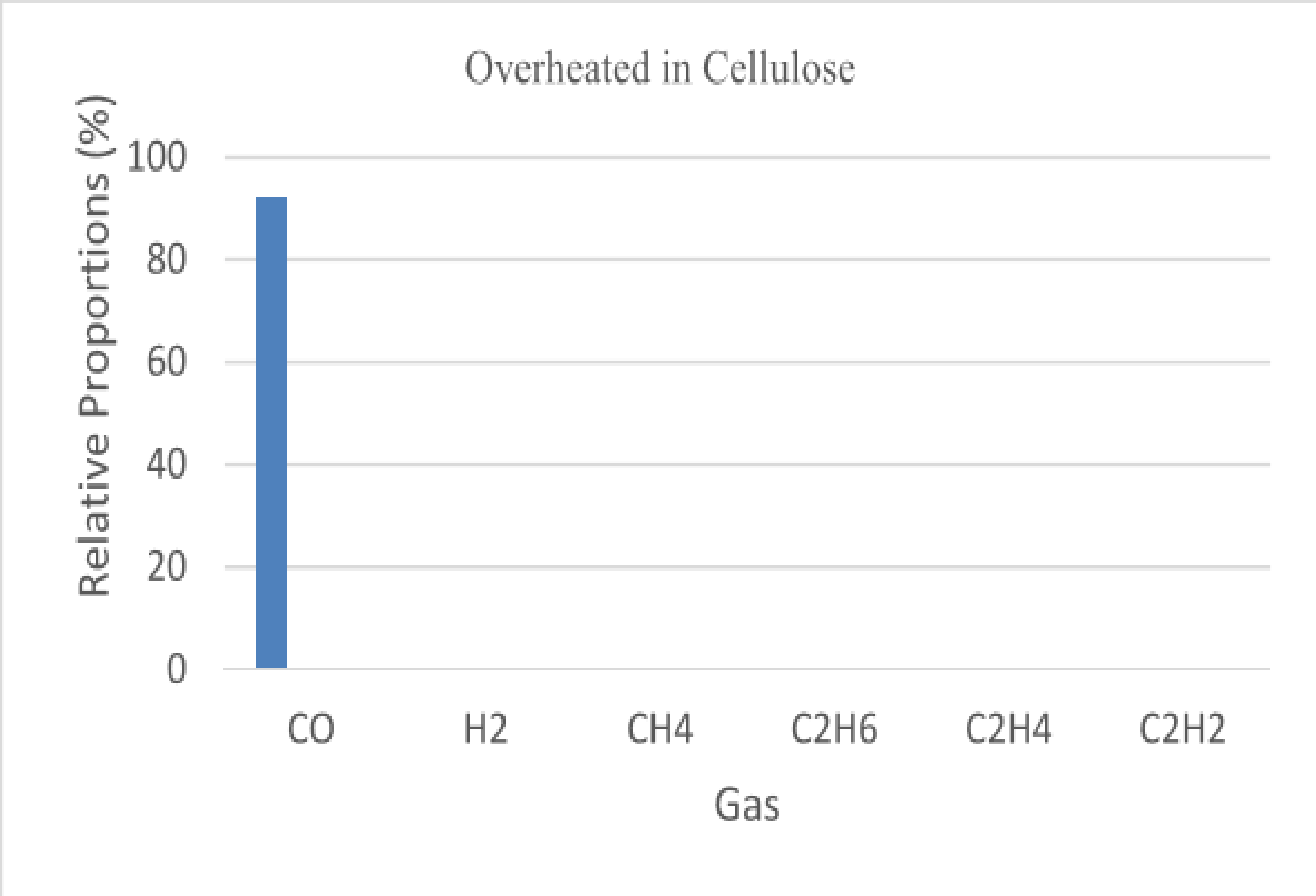


Figure 2 : Approximate percentage (%) of gases found during thermal faults in Cellulose inside the Transformer

iii. During Corona (Electrical Fault) in Transformer oil

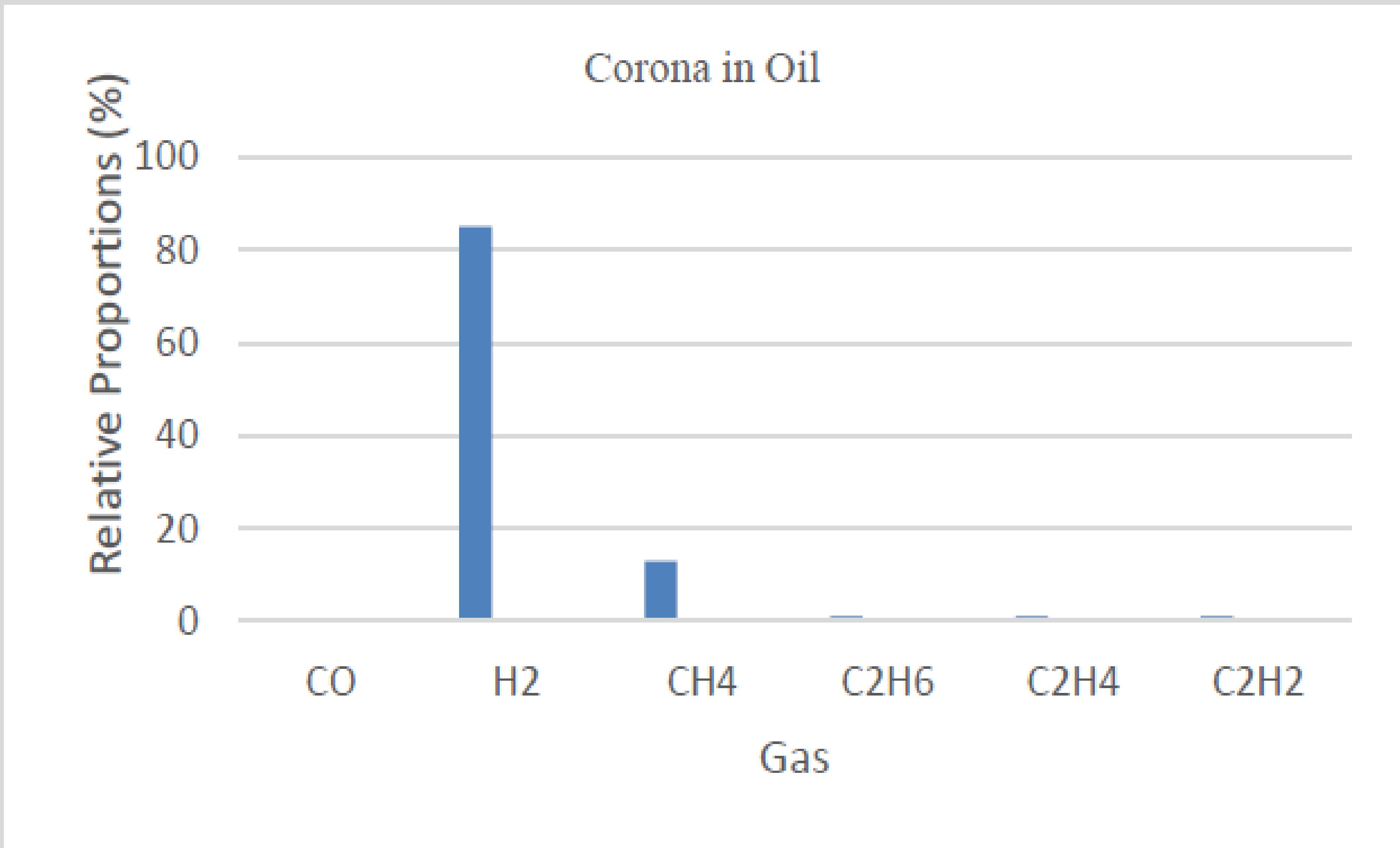


Figure 3 : Approximate percentage (%) of gases found during Corona in oil inside the Transformer

iv. During Arcing (Electrical Fault) in Transformer oil)

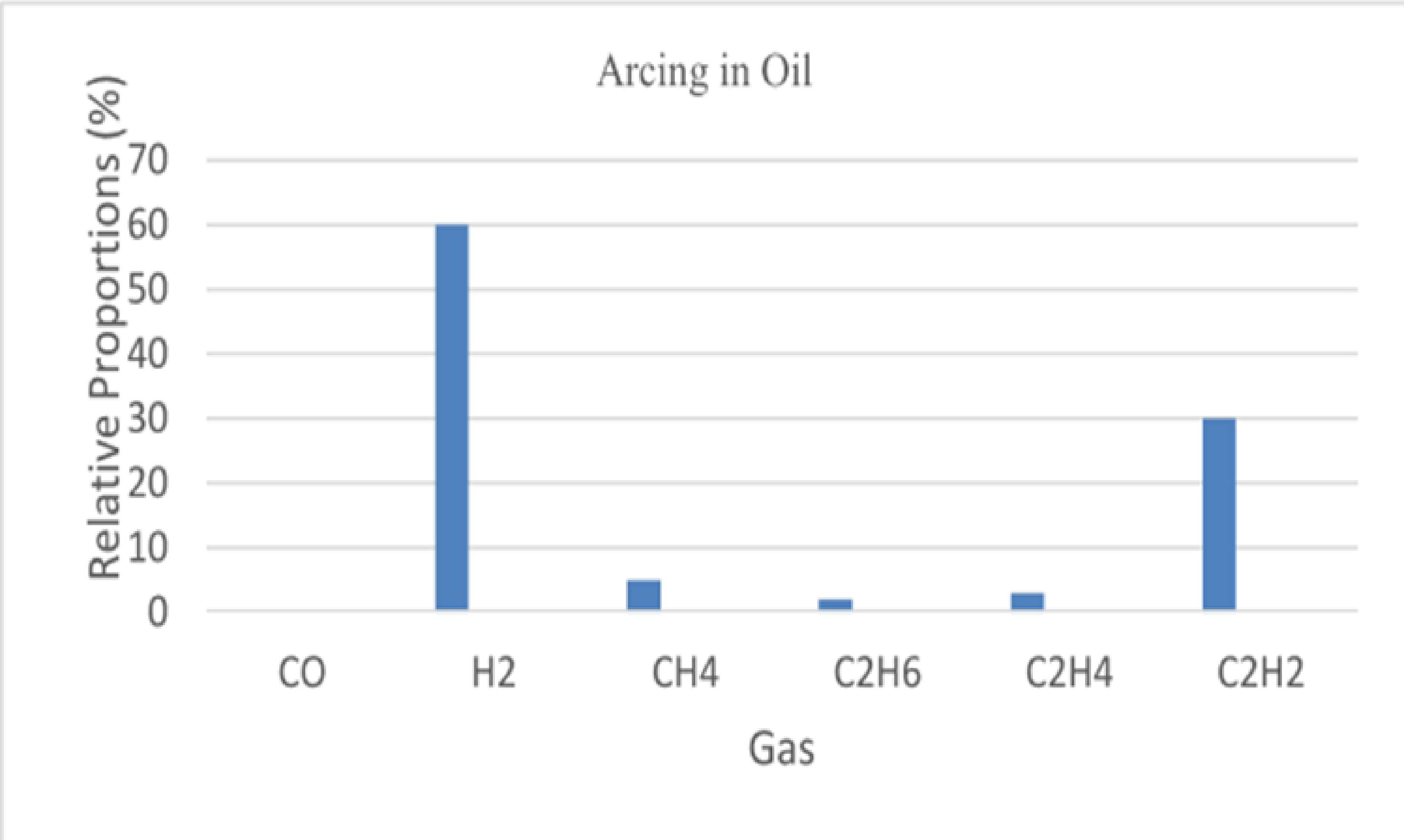


Figure 4 : Approximate percentage (%) of gases found during Arcing in oil inside the Transformer

मनुष्य के रुप में परमात्मा सदा हमारे सामने है, उसकी सेवा करो।

रेल अग्रदूत Transforming Railways

EXCELLENCE IN MAINTENANCE

Indian Railways

Centre for Advanced Maintenance Technology

CONDITION MONITORING

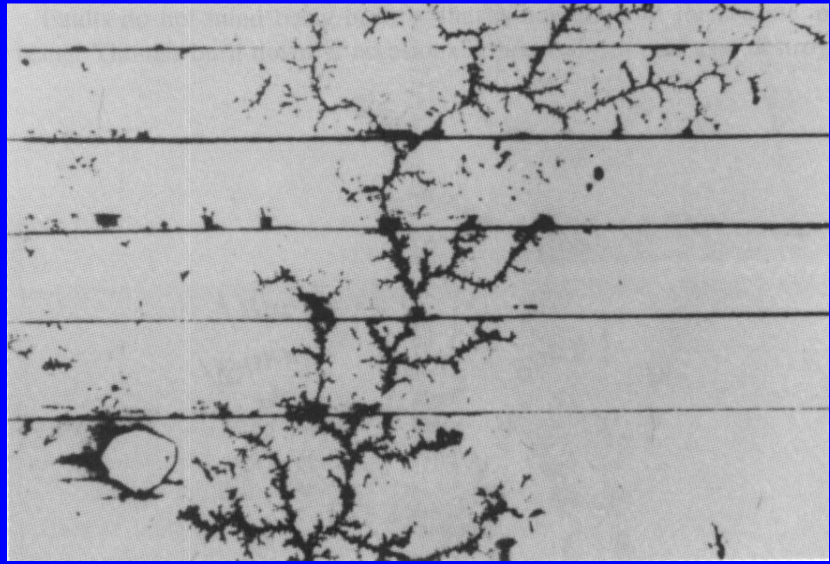
OF

POWER CABLES

Phase I : Module No. FC-02

What is a cable fault?

The most common electrical cable fault occurs as a breakdown between one of the system phases and the ground. Typically this breakdown results from a process known as 'treeing.'



Types of Fault:

- **Open conductor fault**
- **Shorted fault**
- **High impedance fault**

Measurement of IR (Insulation Resistance) of Cable

- IR is the most commonly measured parameter to check the health of Electrical Insulation.
- In case of cables, IR differs from cable to cable depending upon the length of cable, insulation thickness and type of cable.

(a) Megger Voltage & Sample length for IR Measurement

- For XLPE cable, Elastomeric Cable, PVC insulated cable, or even HV cables - the test method for IR is as per IS 10810-Pt.43, the voltage should be 300 ± 30 or 500 ± 50 volt DC . Since 300V is non-standard, only 500 V Megger is used.
- The voltage rating of cable has no relation to the test-voltage to be applied for the measurement of IR.
- The sample length as per relevant IS i.e. IS 10810 Part 43 should be full drum length or not less than 3 meters.
- Pre-conditioning of multi-core cable is done by immersing it in water at 27 deg C, before applying IR test.

(b) Limiting Value

- Limiting values of IR is not given directly in IS specifications.
- However, the limiting values for "IR-Constant" and "Volume Resistivity" are given.
- These parameters take into account the factors like, the size of the cable and the length of cable.

➢ IR Constant and Volume Resistivity-

$$\underset{(\text{M ohm km})}{\text{IR Constant}} = \frac{L \times R}{1000 \times \log_{10}(D/d)}$$

$$\underset{(\text{ohm cm})}{\text{Volume Resistivity}} = \frac{2\pi \times L \times R \times 10^{8}}{\log_{e}(D/d)}$$

Where :-

R =Measured Resistance (MΩ), L= Length of Cable (m)

D = Diameter over the insulation excluding screen if any (mm)

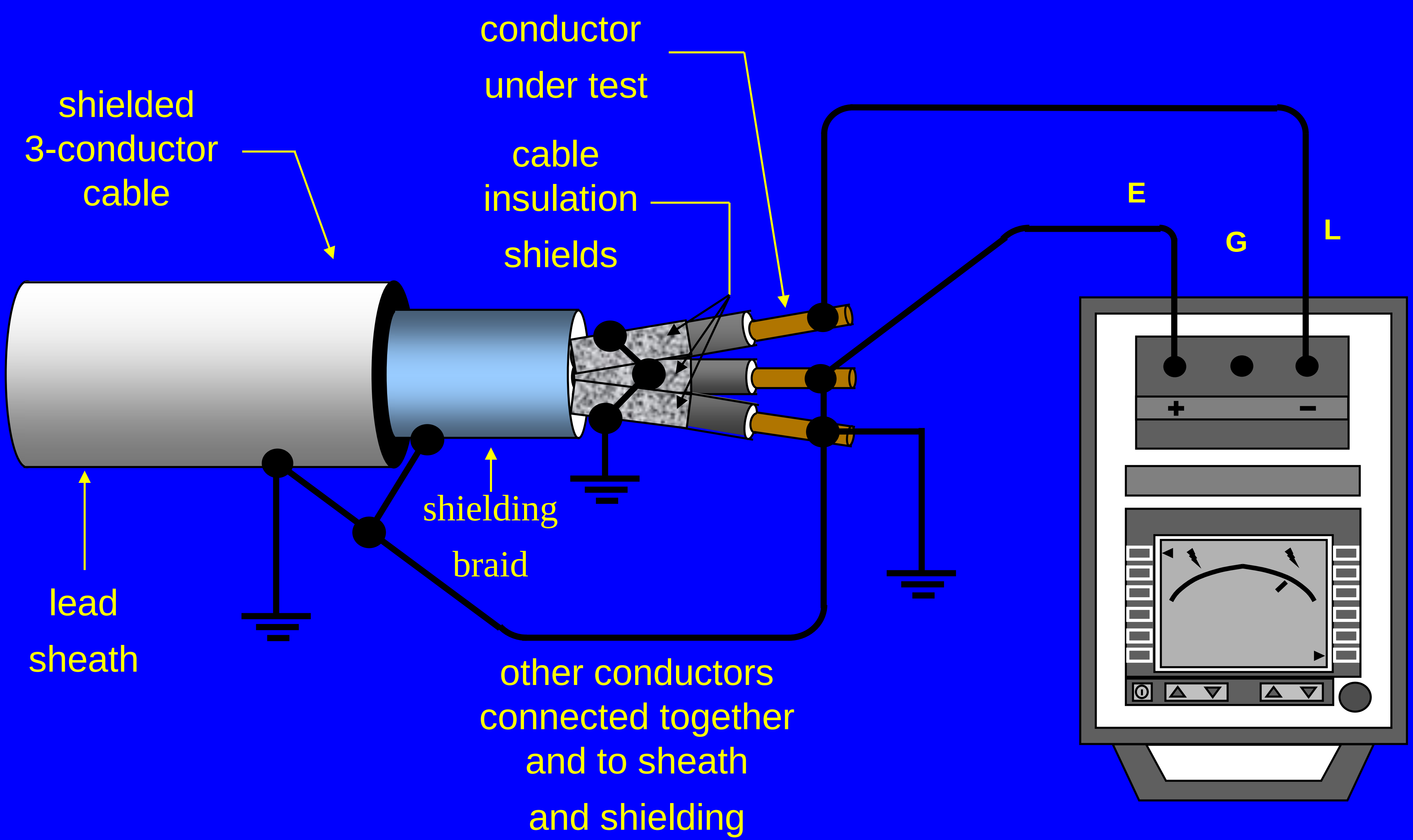
d = Diameter over the conductor including screen if any (mm)

IR Constant

- Requirements given in IS 5831
- For cables of rated voltage up to and including 1100V
  - At 27 ^{o}C temperature, IR constant >= 36.7 M ohm km
  - At 90+/-3 ^{o}C temperature, IR constant >= 0.037 M ohm km.

- Requirements given in ELRS/SPEC/ELC/0019 (Rev 2)
- For cables of rated voltage up to and including 750V
  - At 27 ^{o}C temperature, IR constant >= 45 M ohm km
  - At 90+/-3 ^{o}C temperature, IR constant >= 6.6 M ohm km.

IR Test Connection to Shielded Power Cable



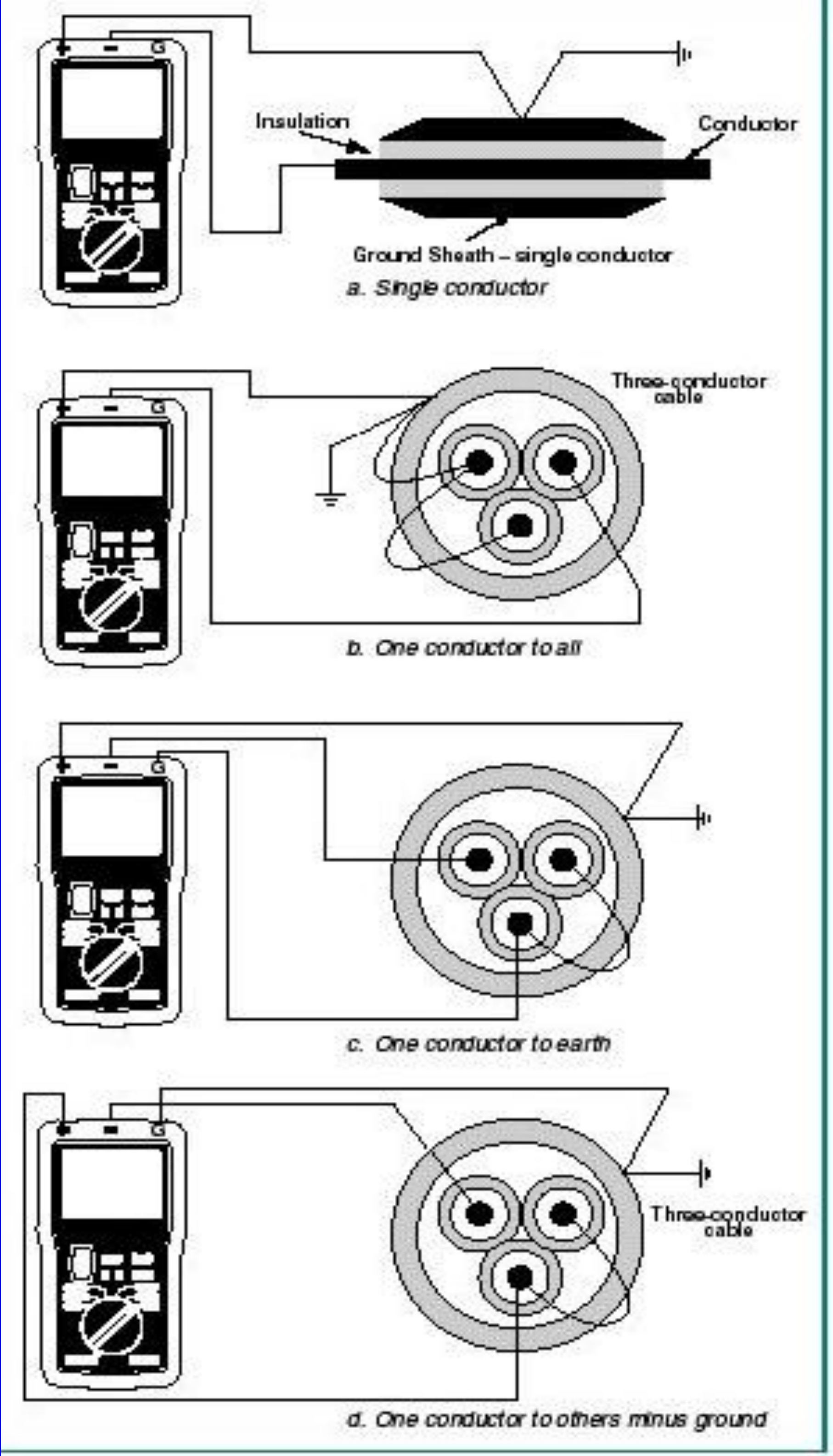
IR Test On Cable

1. 1-Core Cable - Conductor to ground.

2. 3-Core Cable - One conductor to other conductors and sheath to ground.

3. One conductor to sheath & to ground, with other conductors Guarded.

4. One conductor to all other conductors, without leakage to ground.



Standard Values of PD and tanδ for Cable

<table>
<tr><th colspan="3">PARTIAL DISCHARGE</th><th colspan="2">TAN Delta</th></tr>
<tr><td rowspan="9">Elastomeric cables from 3.3 KV to 11 KV</td><td rowspan="9">At 1.25 Uo</td><td rowspan="9">20 PC Max. (Butyl)

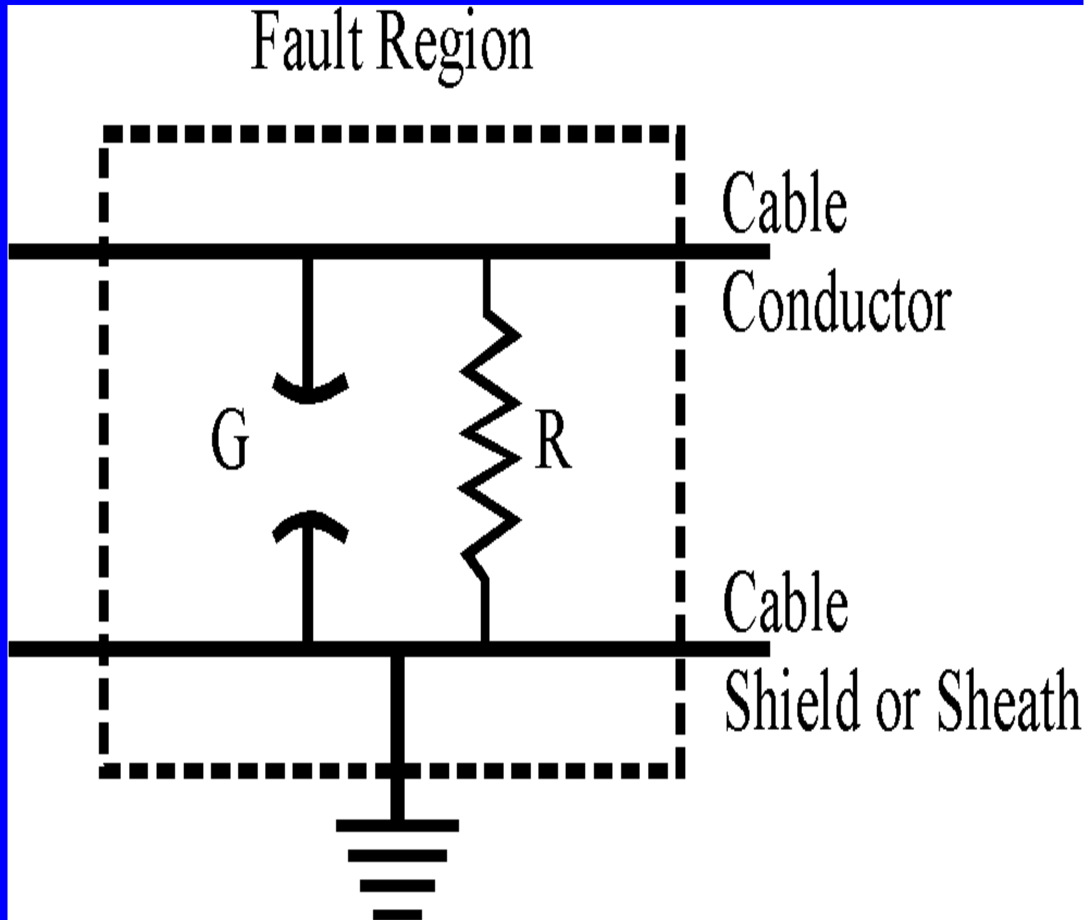
20 PC Max. (EPR)</td><td colspan="2"><u>Function of Voltage</u></td></tr>
<tr><td rowspan="2">At U_o</td><td>0.03 (Butyl)</td></tr>
<tr><td>0.02 (EPR)</td></tr>
<tr><td rowspan="2">Max. increment of Tan Delta between $0.5\ U_o$ to $2\ U_o$</td><td>0.0055 (Butyl)</td></tr>
<tr><td>0.0025 (EPR)</td></tr>
<tr><td colspan="2"><u>Function of Temperature</u></td></tr>
<tr><td rowspan="2">Max. Tan Delta at ambient temperature</td><td>0.03 (Butyl)</td></tr>
<tr><td>0.02 (EPR)</td></tr>
<tr><td>Max. Tan Delta at rated temperature</td><td>0.05 (Butyl)
0.004 (EPR)</td></tr>
</table>

Detection of Cable Fault & Fault Location

(Theory Behind the Techniques)

Simplified Diagram of a Cable Fault

Regardless of whether the fault begins as a 'water tree' or 'carbon tree', a simplified diagram of this failure can be represented by resistance R in parallel with a spark gap G.



Types of Cable Fault

- The faults in the cables can be classified into four main categories-

- Open circuit fault
- Short circuit fault (conductor to earth or another conductor)
- High Impedance fault or High resistance to earth.

- **High Impedance Fault:**

- A high impedance fault contains a resistive path to ground (shunted fault).

Electrical circuit represantation of cable faults

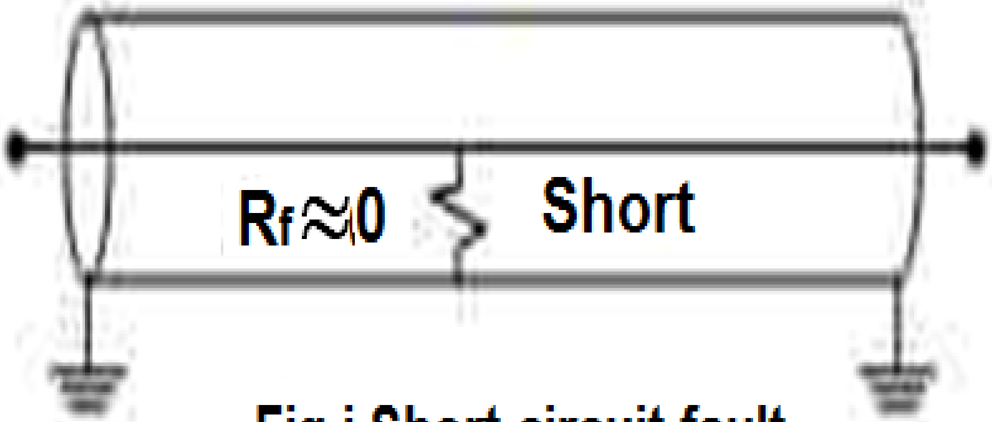


Fig.i Short circuit fault

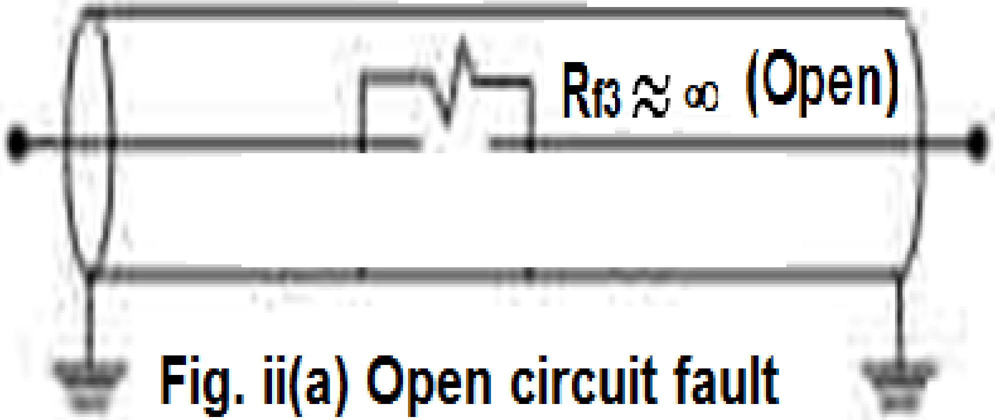


Fig. ii(a) Open circuit fault

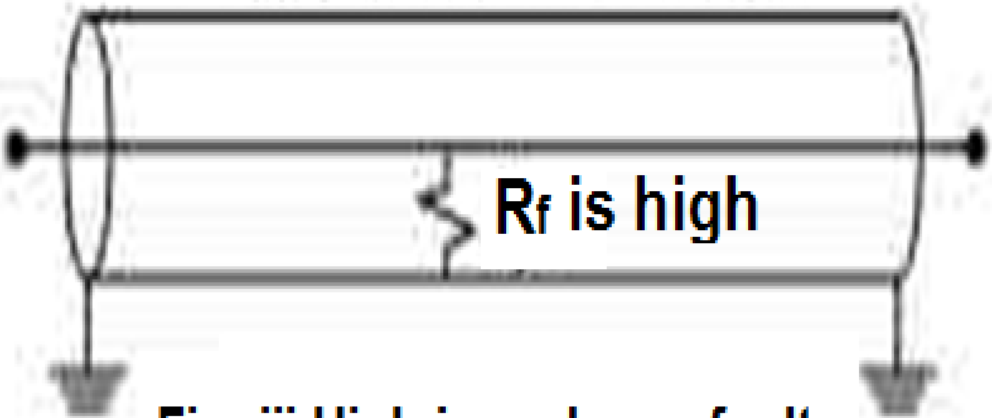


Fig. iii High impedance fault

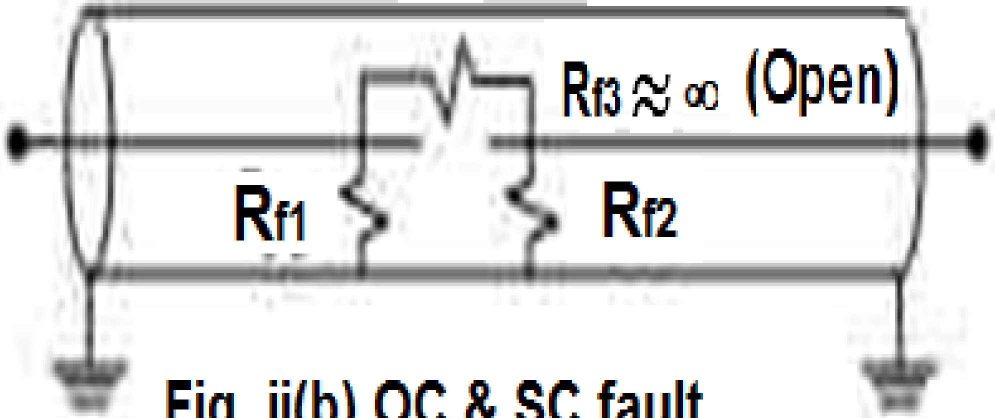


Fig. ii(b) OC & SC fault

Note:- Either Rf1, Rf2 or both fault resistances can be low enough to constitute a short circuit.

TYPES OF CABLE FAULTS

Open Circuit Fault

- When there is a break in the conductor of a cable, it is called open circuit fault.
- **Procedure Of Testing Open Circuit Fault**

I. The open circuit fault can be checked by megger. For this purpose, the three conductors of the 3-core cable at the far end are shorted and earthed.

II. The resistance between each conductor and earth is measured by a megger and it will indicate zero resistance in the circuit of the conductor that is not broken.

III. However, if the conductor is broken, the megger will indicate infinite resistance in its circuit

Short Circuit Fault

- When two conductors of a multi-core cable come in electrical contact with each other due to insulation failure, it is called a short circuit fault.
- **Procedure For Testing Short Circuit Fault**

I. For this purpose the two terminals of the megger are connected to any two conductors.

II. If the megger gives zero reading, it indicates short circuit fault between these conductors.

III. The same steps is repeated for other conductors taking two a time.

Earth Fault

- When the conductor of a cable comes in contact with earth, it is called earth fault or ground fault.
- **Procedure Of Finding An Earth Fault**

I. To identify this fault, one terminal of the megger is connected to the conductor and the other terminal connected to earth.

II. If the megger indicates zero reading, it means the conductor is earthed. The same procedure is repeated for other conductors of the cable.

➢ *__Note:__ Megger method is useful only for finding the fault type, not for locating the fault location in cable.*

मनुष्य का अपना अनुभव उसके रास्ते का प्रकाश होता है।

अअमा तं RDSO
रेल अग्रदूत Transforming Railways

An ISO 9001-2008 Certified Organisation
EXCELLENCE IN MAINTENANCE

Indian Railways
Centre for Advanced Maintenance Technology

NON DESTRUCTIVE TESTING OF MATERIALS

PHASE I – MODULE NO. FC-02

DEFINITION

The use of noninvasive techniques to determine the integrity of a material, component or structure

or

Quantitatively measure some characteristic of an object.

- Testing of materials without destroying them.

- Testing of components without affecting their serviceability.

USES

- Flaw Detection and Evaluation
- Leak Detection
- Location Determination
- Dimensional Measurements
- Structure and Microstructure Characterization
- Estimation of Mechanical and Physical Properties
- Stress (Strain) and Dynamic Response Measurements
- Material Sorting and Chemical Composition Determination

1. Non Destructive Testing (NDT)

   As Manufacturing Control.

2. Non Destructive Testing (NDT)

   As Condition Monitoring/Preventive

   Maintenance.

ADVANTAGES

- To ensure trouble-free transportation, avoid accidents.
- To anticipate the serviceability of the component.
- To predict residual life of a component.
- • To prevent loss of property and human life.
- To obtain maximum economic life of the component.

DIFFERENT NDT METHODS

- There are large number of NDT methods for testing of materials.

- The six ' Big-methods' used all-over Indian Railways are:

1. Visual Inspection
2. Dye penetrant examination (DPE or DPI)
3. Magnetic particle examination (MPE or MPI)
4. Radiography
5. Eddy Current Testing
6. Ultrasonic Testing

VISUAL INSPECTION

- Fastest and cheapest
- Detects surface defects

APPLICABLE TO

- Fastest and cheapest
- Detects surface defects
- Applicable to
- Any metal cast , weld, machined, wrought parts
- Plastic
- Glass
- Ceramics

VISUAL INSPECTION

- Most basic and common inspection method.
- Tools include fiberscopes, bore scopes, magnifying glasses and mirrors

2. DYE PENETRANT EXAMINATION

PRINCIPLE

- This method is used to reveal defects which reach the surface of non-porous materials.
- The penetrating liquid, which is dyed or fluorescent, is applied to the cleaned surface of the component.
- The penetrant is allowed to act for a period of time. Excess penetrant is carefully removed from the surface of the component, after which a developing liquid is applied and dried off.

- The developer acts like a blotter, drawing the penetrant out of the defect. After a short time indications appear in the developer which are wider than the defect and which, therefore, can be seen directly or under ultraviolet light due to the enhancement of the contrast between the penetrant and the developer.

PROCEDURE

1. Pre-clean, remove grease and dry the component.
2. Penetrant is applied to the component and acts for a brief period.
3. Excess penetrant is completely removed from the surface.
4. A developer is applied and dried off.
5. Inspect for indication of defects.

LIMITATIONS

- Components with porous surface can not be tested.

- The crack must be opened to the surface.

COMPONENT TESTED BY LIQUID PENETRANT

- Piston
- Connecting Rod
- Inlet & Exhaust Valves
- Gear
- Locomotive CO-CO BOGIE
- MS X-ings
- Roller Bearings
- Camshaft
- Crankshaft
- Reclaimed Weld Items

3. MAGNETIC PARTICLE EXAMINATION

PRINCIPLE

- This technique is well suited to the detection of surface defects such as cracks, lack of fusion and laminations etc. in ferromagnetic materials.

- A surface defect in a magnetized ferromagnetic item will disturb the magnetic field in the object of the test. The defect will cause some of the lines of magnetic force to depart from the surface and thus to form a magnetic leak field.

- This leak field can be found by placing fine iron particles on the surface. The leakage field will hold the magnetic particles in a ridge on top of the crack.

PROCEDURE

1. Clean the surface.
2. Magnetize the object using either permanent magnet or electromagnet.
3. Spray magnetic liquid over the object.
4. Inspect for indication of defects.
5. Repeat the above test in perpendicular direction.

ADVANTAGES

- The method is most dependable and sensitive for finding surface defects.
- It is fast, simple and inexpensive.
- The indications are directly visible on the surface of the object.
- Simple and durable equipment.

LIMITATIONS

- The method can only be applied to ferromagnetic materials.
- Defects below the surface will not always be indicated.
- The direction of the magnetic field has an important bearing upon the result of the examination.
- Certain objects must be demagnetized before and after the examination.

COMPONENT TESTED

- Springs
- Crank Shaft
- Cam Shaft
- Equalizer Beam
- Bolts
- Roller Bearings
- Piston Rod
- Bars
- Reclaimed Welded Items

PRINCIPLE

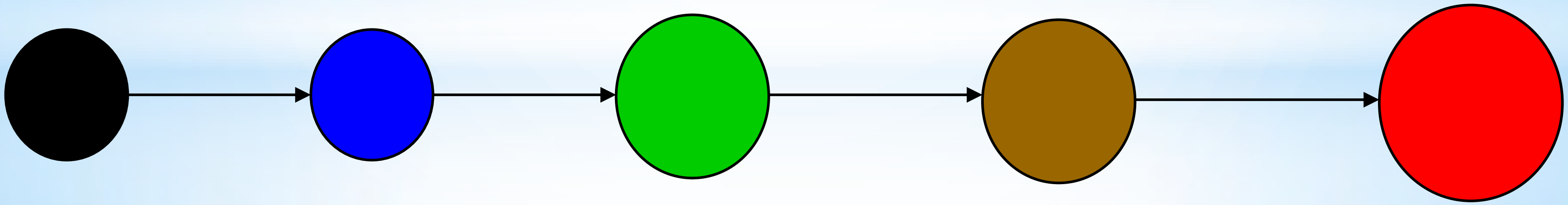
- Based on Differential absorption.

PROCEDURE

- Take the radiograph using penetrometer
- Develop the film.
- Inspect radiograph for indication of defect and compare with standard radiographs (IIW/ASTM).

DEFECT CLASSIFICATION (IIW)

- Least defective to worst
- ASTM E-446
- Level 1 To Level 5 (Least to Worst)



LIMITATIONS

- X-radiation and gamma radiation are health hazards.
- Maximum penetration about 150 mm of steel.

COMPONENT TESTED

- CO-CO Bogie
- Pistons
- Castings
- CMS X-ings
- OHE Castings of Al-bronze
- Bridge Girder Plates Weldment Assessment (Butt Weld)

5. EDDY CURRENT TESTING

PRINCIPLE

- Eddy current testing can be used on all electrically conducting materials. An alternating current is produced in the generator and sent through the test coil.

- When this current passes through the test coil a magnetic field, the primary field, arises surrounding the coil. This magnetic field induces eddy currents in the test object when the test coil in held above it.

- If a galvanometer is attached to the test coil, then it will show a standard reading which is characteristics for the state of the test object.

- If the galvanometer is zeroed it will remain zeroed as the test coil is moved across the object provided that the eddy current can act unhindered in the object .

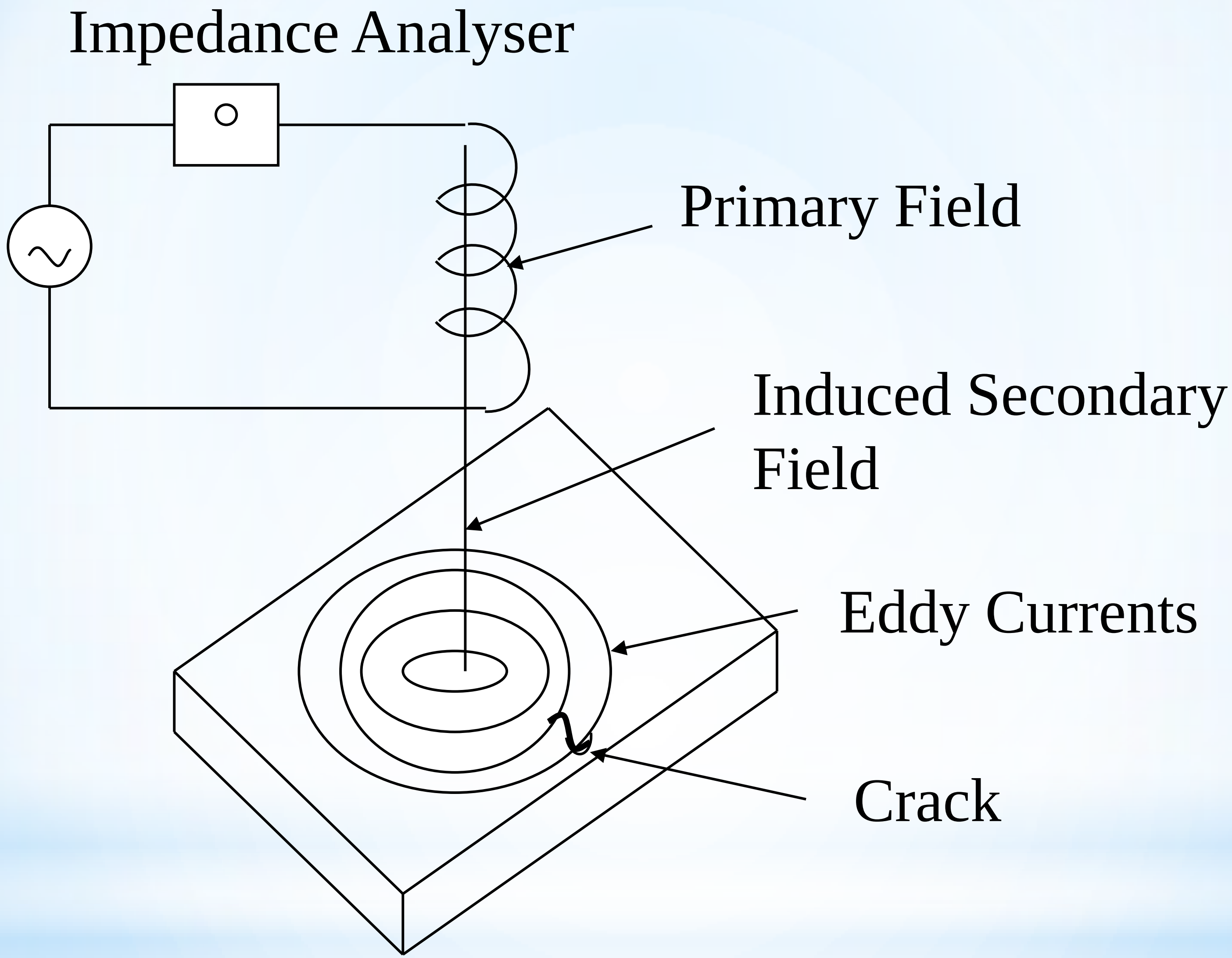
- The value of the eddy current is affected if cracks or cavities in the test objects are present. It is the property which is utilized to perform eddy current measurement.

ADVANTAGES

- The method is quick to use.
- No direct contact is required.
- The method is inexpensive to use.
- Can also be used for sorting of material.

LIMITATIONS

- Used for detecting surface cracks only.
- Used on electrically conducting materials



Eddy current Testing

COMPONENT TESTED EDDY CURRENT

- New Rails
- Helical Springs

6. ULTRASONIC TESTING

PRINCIPLE

1. A series of ultrasonic waves each lasting for a few micro-seconds are introduced in the material under test through a coupling medium.

2. These pulses propagate in the material in a very narrow beam until they strike an interface such as the opposite surface of the test object or an internal defect.

3. The pulses are entirely or partly reflected back to the transmitter, which now functions as a receiver. The receiving probe converts the ultrasonic waves to the electrical energy, which is amplified and displayed on a CRT in such a manner as to indicate the time difference between the transmitted pulses and reflected pulses.

4. The horizontal scale of CRT is calibrated in terms of distance, hence position of flaw peak on horizontal scale speaks about the location of the flaw.

5. The vertical scale of CRT is calibrated with a standard test piece having artificial flaws of known size, hence the height of the flaw peak speaks about the size of the flaw.

PROCEDURE

- Calibrate the horizontal scale of the UFD for required depth range.
- Calibrate the vertical scale using standard block having artificial flaws of known size.
- Scan the component using suitable transducer.
- Compare the trace pattern with the trace pattern from standard block.
- Follow the rejection criteria as specified.

ADVANTAGES

- Most widely used and accepted method for detecting internal flaws.
- Can scan up to 10 m. long steel components.
- Quick results.
- Location as well as size of the defect can be measured.
- IN-SITU Adaptability.

LIMITATIONS

- Not suitable for components having complex geometry.
- Difficult to test coarse-grain material.
- Defects having orientation parallel to the direction of beam propagation are difficult to be detected.

COMPONENT TESTED ULTRASONIC

- Axles
- Armature Shaft
- Suspension Bearings
- Yoke Guide
- Wheels
- Tyres
- Rails
- Rail Welds
- Welded Bridge Girder Plates
- Ohe Insulators

जिसके पास उम्मीद है, वह लाख बार हार कर भी नहीं हारता।

CAMTECH, Gwalior