Welcome to Presentation on

“ Best Practices in Maintenance of Transmission systems”

Presented by:

Mohammed Faizul Kabir

Chief Engineer, Power Grid Bangladesh PLC

Date: 10/02/2026

MAINTENANCE STRATEGIES

- Preventive Maintenance
- Corrective Maintenance
- Predictive Maintenance
- Condition Based Maintenance

WHY DO WE NEED MAINTENANCE

- System Reliability
- Safety
- Elimination Of Accidents
- Extend The Life Span Of The Asset
- Environmental Issues

  - Oil Spills, Sf6 Gas Etc.

FACTORS INFLUENCING MAINTENANCE DECISIONS

- **Redundancy Of Equipment/Systems**
- **Availability Of Spare Parts/Equipment**
- **Training Of Personnel**
- **Life Of Equipment**
- **Budgets**

EQUIPMENT RECORDS AND INVENTORIES

- **Know what equipment we have and where it is?**
- **Keep accurate drawings-most recent revisions only.**
- **OEM manuals-recommendations for maintenance.**
- **Standards**

EQUIPMENT RECORDS AND INVENTORIES(contd.)

- **Maintenance record-keeping for trending.**
- **Keep records in centralized archives.**
- **Implementation of Computerized Maintenance Management Systems (CMMS).**
- **Don’t rely on individual’s knowledge and memory.**

MAINTENANCE PRACTICES

- **Develop a program of inspections and tests and stick to it .**
- **Written procedures and checklists.**
- **Should be performed by trained, knowledgeable personnel .**
- **Safety of personnel must be considered .**

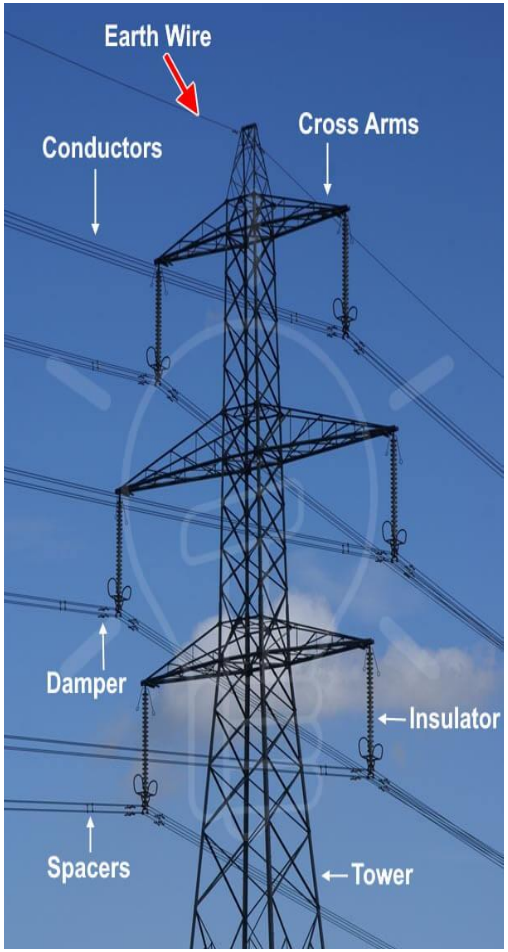
Transmission Line Maintenance

Transmission Line:

A Closed system in which power is transmitted from a source to a destination.

Main Accessories of Transmission Line

- Tower
- Conductor/UG Cable
- Earth wire/OPGW
- Hardware Fittings

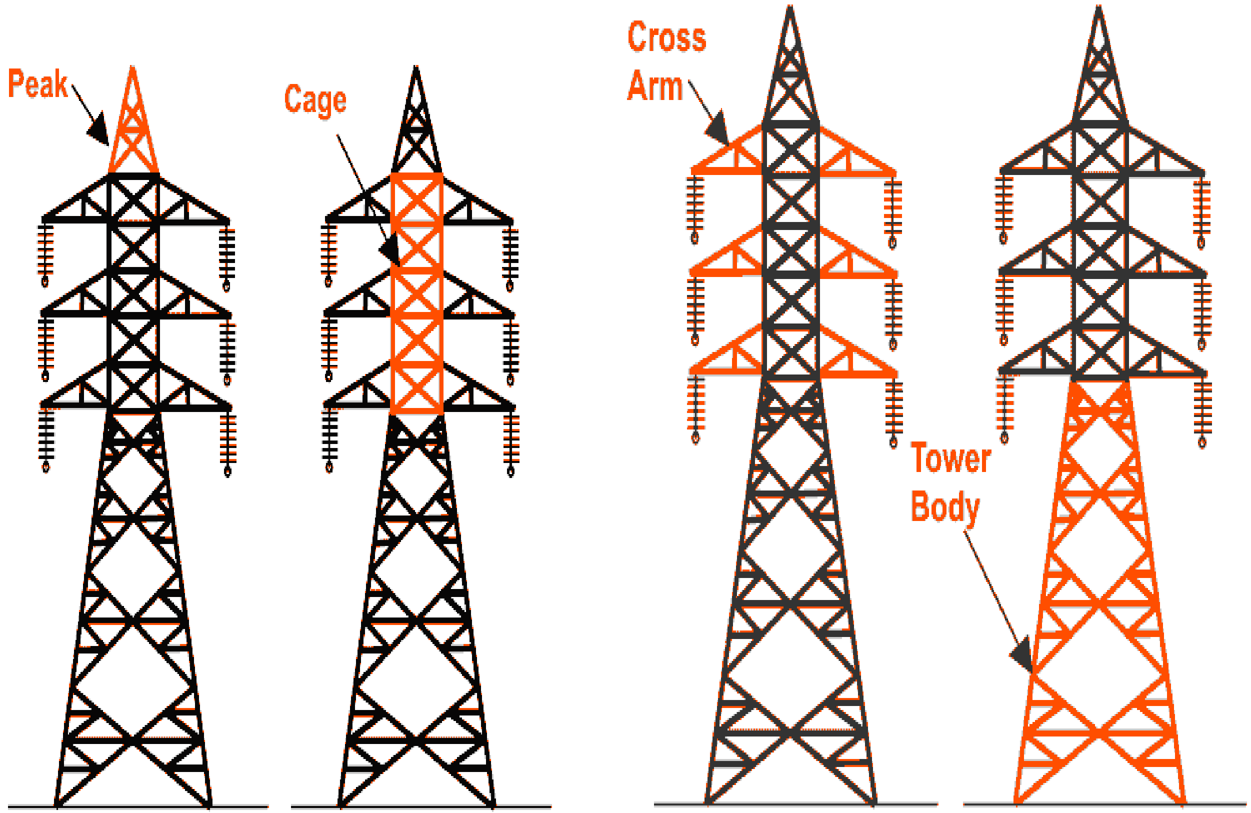


Transmission Tower

- The main supporting unit of overhead transmission line.
- Carry transmission conductor with sufficient clearance.
- Sustain all kinds of natural calamities.

Main Parts of Transmission Tower

- Peak
- Cage
- Cross Arm
- Tower Body
- Stub

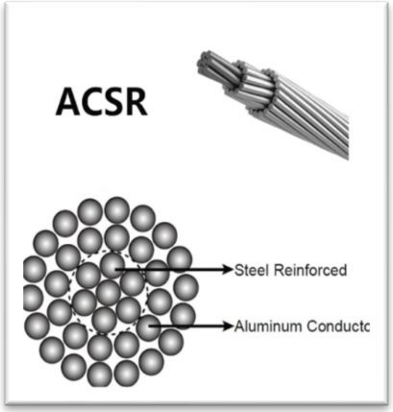


Main Accessories of Transmission Line

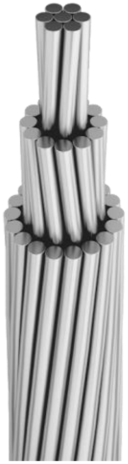
Conductors:

Made of cooper, aluminum or any other composition depending upon the current to be carried and the span of the line. Most used conductor types are:

- ACSR
- TACSR
- ACCC



ACSR



TACSR

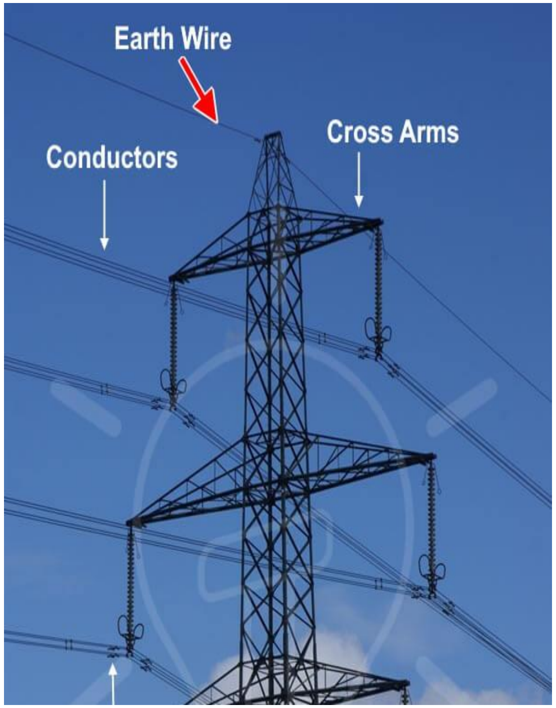
ACCC

Main Accessories of Transmission Line

Earth wire :

Is run on the top of the towers to protect the line against lightning discharges.

An optical ground wire (OPGW) can serve dual purpose of grounding and communication.



Main Accessories of Transmission Line

Anti Climbing Device:

This prevents climbing by unauthorized persons.

Insulators:

Used for supporting the conductors.

Justification of maintenance work in brief

- To Avoid Unwanted Interruption of Transmission System.
- To increase System Reliability.
- To Avoid Accident (Man & Materials)
- To Avoid Grid Fail.
- To Ensure Quality Electricity.

Maintenance of Transmission Line

Type of Maintenance:

i) Preventive Maintenance (Dead line & Live Line) :

a) Tree Trimming

b) Missing Tower member Replacement

c) Tower Leg protection Work

d) Conductor Repair, Hardware change etc.

ii) Emergency Maintenance:

After Any Breakdown or any unwanted situation Emergency work has to be done.

iii) Schedule Maintenance:

After dead line checking & find out the problems of lines maintenance work has to be done. In this respect all electrical connection are tighten.

Why Maintenance Work Required?

In one word maintenance is required to avoid any types of unwanted incidences or faults.

There are some common types of faults in transmission line. Such as –

1) **Insulator Disc Braking**
2) **Conductor Snapping**
3) **Tower Overturning**

Insulator Disc Braking

- **Cause:**

- **Pollution:** Electrical flash over occurs due to different type of pollution such as environmental pollution, emission from brick field, salinity in coastal area resulting deterioration of insulation of disc material.

- **Aging:** Live line disc is always under high voltage. For long term effect of high voltage quality of insulators deteriorates.

Conductor Snapping

Snapping occurs due to –

- **Mid Span Joint Failure**

  Cause: Joint failure may resulted from improper/ inadequate joining.

  Remedial action: Line route and conductor inspection, if possible collect thermal image of mid span joint in regular interval.

- **Dead end clamp failure**

  Cause: Dead end clamp failure may resulted from improper/ inadequate joining.

  Remedial action: Line route and conductor inspection, if possible collect thermal image of dead end in regular interval.

- **Previous Injury In Conductor**

  Injury may come from thawing of aluminum due to flash over when tree branches comes in contact with conductor due to wind where ROW clearance is not properly maintained.

Tower Overturning

Overturning of tower may occur for several reason. Such as-

- **Foundation failure**: It happens generally in hilly areas or adjacent to river.
- **Failure due to tornado**: In this case one tower may fall and it may cause cascade failing of adjacent towers.
- **Failure due to corrosion:** Corrosion in stub or main leg when they are exposed to polluted stagnant water. This polluted water generally comes from agricultural field where chemical fertilizer is used.
- **Nut bolt missing:** Nut bolts may be missed after tower erection because of stealing.
- **Bracing missing:** Bracing may be missed after erection due to stealing.

Concerned officer is supposed to make maintenance plan according to line check report considering all the above issues.

High Voltage Transmission Line Inspection Using Drone

Traditional Transmission Line Inspection Methods

Challenges of Traditional Methods

- ➢Manual inspection using binoculars and cameras.
- ➢Time-consuming and labor-intensive.
- ➢Risky for personnel.
- ➢Limited accuracy and coverage.

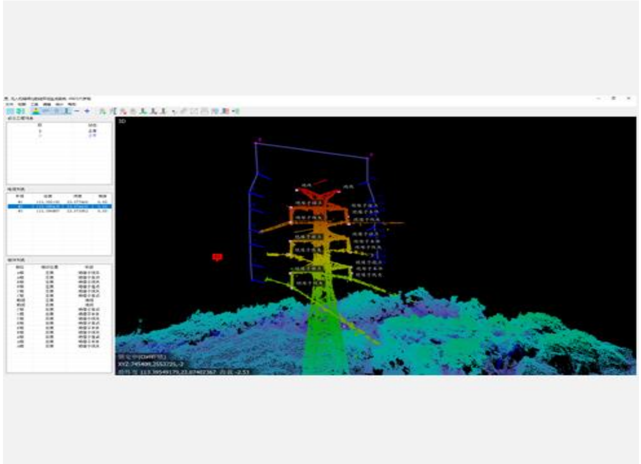
Data Analysis Software Overview of Power Grid Bangladesh PLC

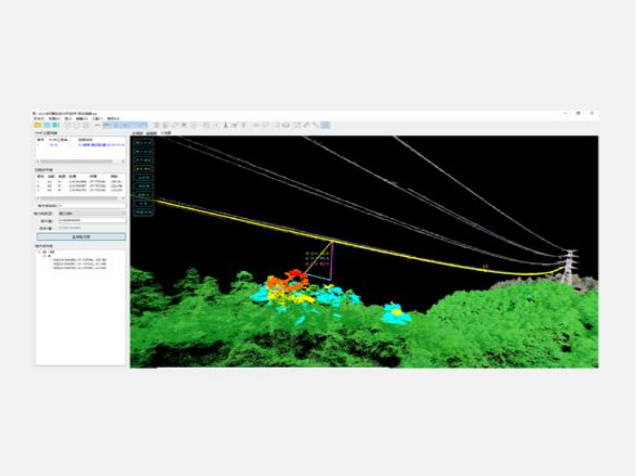
Software Capabilities:

- Developed by UFLY company in China.
- Advanced data analysis and reporting tools.

Key Functional Modules:

- Real-time data processing
- Automated defect detection
- 3D modeling and mapping
- Predictive maintenance analytics





Inspection Process Workflow

1. Pre-flight Planning
   - Route planning - Weather assessment

2. Flight Operation
   - Drone deployment - Data capture

3. Data Processing
   - Upload data to UFLY software - Analysis and defect detection

4. Reporting
   - Generate inspection reports - Review and action plan

Benefits of Power Grid by Drone Surveillance

•**Enhanced Safety for Inspection Crews**: Reduces the need for personnel to work in high-risk areas.

•**Improved Accuracy and Reliability of Inspections**: Provides high-resolution imagery and detailed data analysis.

•**Cost Savings**: Reduces manual labor and operational costs, leading to faster and more efficient inspections.

•**Access to Hard-to-Reach Areas**: Drones can easily access and inspect areas that are difficult or dangerous for humans to reach.

•**Real-time Data Collection**: Enables immediate analysis and quicker decision-making.

•**Better Asset Management and Maintenance Planning**: Facilitates predictive maintenance and improved planning, reducing downtime and enhancing system reliability.

•**Compliance and Reporting**: Enhanced documentation and reporting capabilities for regulatory compliance and audit purposes.

Challenges and Limitations

- **Weather Conditions:**
Use of weather-resistant drones and planning.

- **Data Management:**
Implementation of robust data processing and storage systems.

- **Regulatory Compliance:**
Adherence to aviation regulations and standards.

Primary Equipment of Substation & their Periodic Maintenance

What is a Substation

- A substation is a part of an electrical generation, transmission, and distribution system. Substations transform voltage from high to low, or the reverse, or perform any of several other important functions.

Pictorial view of a substation

Primary equipment of a substation

- Power transformer
- Circuit breaker (CB)
- Instruments transformer (CT/PT)
- Lightning arrestor (LA)
- Disconnection switch (DS)
- Wave Trap
- Reactor

Power transformer

- A power transformer is an electrical device that varies the amounts of current and voltages flowing through power lines. This means that, a transformer steps up the current while reducing the voltage and vice versa. Both side MVA is same .

Internal view of a power transformer

Daily inspection of a transformer

- Main terminal and ground connections
- Temperature & load (hourly)
- Oil level indicator
- Silica gel breathers
- Ac/Dc Power supply & wiring
- Cooling fans
- Fuel pump of radiator system (if any)

MAINTENANCE OF TRANSFORMER

- Transformer is the heart of any power system. Hence preventive maintenance is always cost effective and time saving. Any failure to the transformer can extremely affect the whole functioning of the organization.

MAINTENANCE PROCEDURE

❖ OIL :

1. Oil level checking. Leakages to be attended.
2. Oil BDV : Spherical electrodes with gap of 2.5 mm
3. Oil BDV : Recommended Value: 60 kV
4. Acidity checking at regular intervals. BDV, Color and smell of oil are indicative.
5. Dissolve Gas Analysis of Transformer Oil

MAINTENANCE PROCEDURE

6. Sludge, dust, dirt ,moisture can be removed by filtration.

7. Oil when topped up shall be of the same make. Otherwise it may lead to sludge formation and acidic contents.

MAINTENANCE PROCEDURE

❖ INSULATION

1. Insulation resistance of the transformer should be checked Periodically.
2. Insulation values along with oil values indicate the condition of transformer.
3. Insulation value may required to be 1 M.Ohm. Per kV at 75 degree celcius.
4. Tan-delta and Capacitance measurement as per manufacturer’s instruction.

MAINTENANCE PROCEDURE

❖ BUSHINGS:

- Bushings should be cleaned and inspected for any cracks.
- Dust & dirt deposition, salt or chemical deposition, cement or acid fumes depositions should be carefully noted and rectified.
- Tan-delta test as per manufacturer's instruction.

MAINTENANCE PROCEDURE

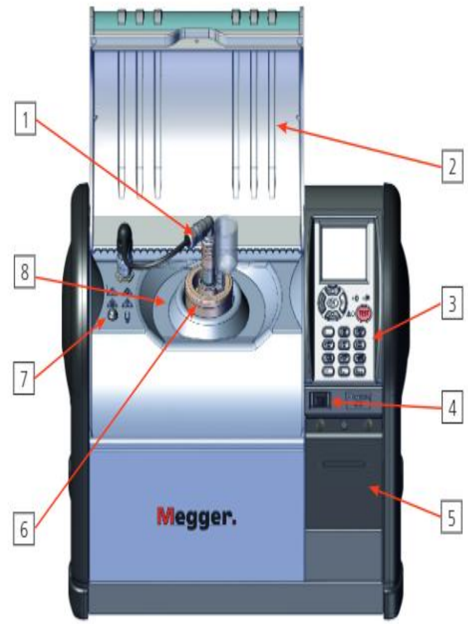
- Periodic checking of any loose connections of the terminations of HV & LV side.
- Breather examination. Dehydration of Silica gel if necessary.
- Explosion vent diaphragm examination.
- Conservator to be cleaned from inside after every three years.
- Cleanliness in the transformer yards with all nests, shrubs removed.
- Thermal Imaging

Tests Performed in Power Grid Bangladesh PLC

Name of the Test	Instrument Used
Oil Dissipation Factor	OTD by Megger
Water Content (ppm)	KF875 by Megger
Acidity or Neutralization Number	848 Titrino Plus
Dissolved Gas Analysis (DGA)	Kelman Transport X
Interfacial Tension (IFT)	Support Energy, Germany

Oil Dissipation Factor (Tan-delta)

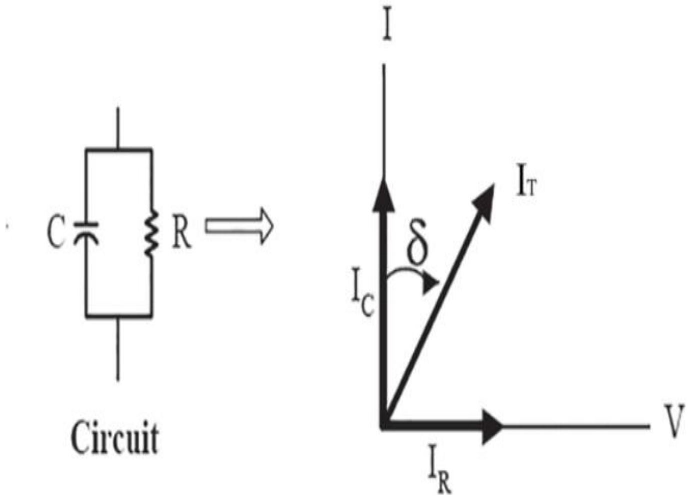
- Tan δ, or Tan Delta, is an electrical dielectric test for insulating oil quality assessment.
- Also known as Loss Angle, Dielectric Dissipation Factor (DDF), or Power Factor (PF) testing.
- Conducted at two temperatures for comprehensive analysis.
- Results aid in determining transformer suitability for continued service.
- Crucial for identifying when replacement or regeneration of transformer oil is necessary.



Item	Description	Item	Description
1	Probe (temperature sensor and inner electrode low voltage)	5	Printer
2	Test Chamber Lid	6	Test Cell
3	Control Panel	7	Manual Oil Drain Button
4	On / Off Switch	8	Test Chamber

How does it work?

•Tan Delta test involves applying AC voltage to a test cell with known gap.
•Measures total current flow through the oil and separates reactive and resistance components.
•Ideal scenario mimics properties of a perfect parallel plate capacitor.
•Presence of impurities in oil reduces insulation resistance, leading to increased resistive current.
•Loss Angle (δ) represents angle between capacitive and total current.
•Tangent of δ indicates level of insulation contamination.
•Increasing Tan Delta percentage signifies oil deterioration or contamination.



Test Standards

•IEC and IEEE provide test standards, that are applicable to specific groups of transformer oil, namely New Oil, Oil in service and Reclaimed oil.

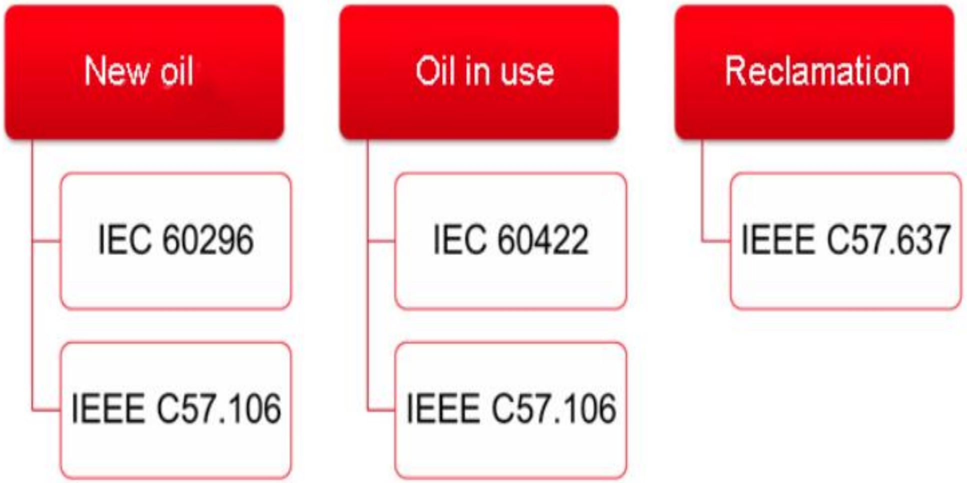


Fig: Different IEEE and IEC Standard for Insulation Oil Tan-delta Measurement.

Neutralization Number (Acidity)

•The Insulation Oil Neutralization Number Test measures the acidity level of insulating oil, revealing the presence of acidic compounds such as organic acids.

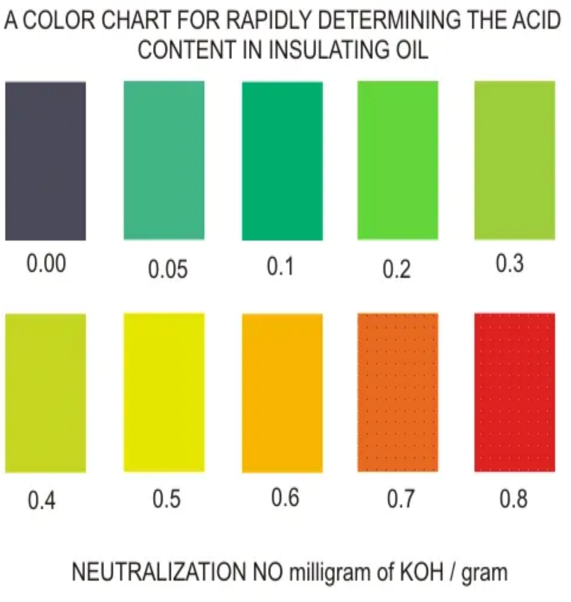
•It assesses the oil's capability to neutralize acids generated during operation, crucial for preventing equipment failure.

•Early detection of oil degradation is facilitated, aiding in proactive maintenance planning.

•The test assists in deciding whether oil replacement or regeneration is necessary to uphold optimal performance and prolong equipment lifespan.

How Acid Forms and Why It's Harmful

- **Oxidation**: Reaction between oil and oxygen.
- **Hydrolysis**: Breakdown of oil with water.
- **Corrosive Sulfur**: Degradation of insulating materials.
- **Contaminants**: Dust and impurities.



Test Procedure and Interpretation

- A sample of insulating oil undergoes titration with a standardized solution of potassium hydroxide (KOH).
- KOH neutralizes acidic compounds present in the oil, leading to a color change in the indicator.
- The amount of KOH required to neutralize the acidity is measured to determine the neutralization number.
- A lower neutralization number indicates higher acidity and greater oil degradation.
- Comparison with standard values or historical data helps in assessing the oil's condition and planning maintenance activities accordingly.

How to Improve or Remove Acidity Levels from Transformer Oil

- **Routine Monitoring**: Regular testing of oil acidity.
- **Preventative Maintenance**: Identifying and addressing factors causing acid formation.
- **Oil Purification**: Removing acids through filtration or chemical treatments.
- **Oil Replacement**: Using fresh oil when acidity levels are too high.
- **Regeneration**: Continuous or intermittent treatment to remove acids and restore oil properties.

Benefits of Acidity Test

- Enhances equipment reliability by ensuring the oil's acidity remains within acceptable limits.

- Facilitates predictive maintenance strategies by monitoring oil condition over time.

- Cost-effective method for assessing oil health and optimizing maintenance schedules.

- Contributes to environmental sustainability by promoting efficient use of resources and minimizing oil waste.

Dissolved Gas Analysis (DGA)

What is DGA (Dissolved Gas Analysis)

•**Definition**: DGA is the study of dissolved gases in transformer oil to assess the condition of the transformer.
•**Purpose**: Identifies electrical faults and their severity by analyzing gas types and generation rates.
•**Process**: Oil samples are analyzed in a laboratory or on-site using mobile units.
•**Significance**: It is a comprehensive tool for asset condition assessment and management, offering advanced detection of potential fault conditions.

Purpose of DGA

- To provide a non-intrusive means to determine if a transformer incipient fault condition exists or not .
- To have a high probability that when entering a transformer a problem is apparent.
- To prevent an unexpected outage.
- To reduce risk to the unit, to the system it connected, to the company and most of all to the personnel monitoring that transformer.

Formation of Gases in Transformer Oil

S/N	Name of Gas	Formula	Temp. at which significant amount of gas forms (0C)	Reason of gas forming
1	Hydrogen	H2	<1500C for “cold plasma” ionization, (corona in oil) >250 0C for thermal & electrical faults	Partial discharge, thermal faults, power discharges, rust, galvanized parts, stainless steel, sunlight
2	Methane	CH4	<150 -3000C	Corona partial discharge, low & medium temperature thermal faults
3	Ethane	C2H6	200 -4000C	low & medium temperature thermal faults
4	Ethylene	C2H4	300 -7000C	High temperature thermal faults
5	Acetylene	C2H2	>7000C	Very hot spot; low-energy discharge (spitting from floating part); high energy discharge (arc)
6	Carbon Monoxide	CO	105 -3000C (complete decomposition & carbonization occurs >3000C	Thermal fault involving cellulose (paper, pressboard, wood blocks); slowly from oil oxidation
7	Carbon Dioxide	CO2	105 -3000C	Normal aging (accelerated by amount of O2-in-oil & H2O-in-paper); thermal fault involving cellulose (paper, pressboard, wood blocks); accumulation from oil oxidation.
8	Oxygen	O2	Vacuum	Exposure to atmosphere (air), leaky gasket (under vacuum), air breathing conservator, leaky bladder.

Faults Detectable by DGA

Symbol	Fault	Examples
PD	Partial Discharges	Discharges of the cold plasma (corona) type in gas bubbles or voids, with the possible formation of X-wax in paper
D1	Discharges of Low Energy	Partial discharges of the sparking type, inducing pinholes, carbonized punctures in paper. Low energy arcing inducing carbonized perforation or surface tracking of paper, or the formation of carbon particles in oil.
D2	Discharge of High Energy	Discharge in paper or oil, with power follow-through, resulting in extensive damage to paper or large formation of carbon particles in oil, metal fusion, tripping of the equipment and gas alarms.
T1	Thermal Fault, T<300 oC	Evidenced by paper turning brownish (>200 oC) or carbonized (>300 oC)
T2	Thermal Fault, 300 <T<700 oC	Carbonization of paper, formation of carbon particles in oil.
T3	Thermal Fault, T>700 oC	Extensive formation of carbon particles in oil, metal coloration (800 oC) or metal fusion (>1000 oC).

INDIVIDUAL GAS AND TDCG METHOD (IEEE C57.104-2008)

CONDITION 1: ***TDCG below this level indicates the transformer is operating satisfactorily. Any individual combustible gas exceeding specified levels should prompt additional investigation.***

Status	Dissolved key gas concentration limits in parts per million (ppm)							
	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon Monoxide (CO)	Carbon Dioxide (CO_2)	TDCG
Condition 1	100	120	2	50	65	350	2500	720

Action based on Dissolved Combustible Gas

Status	TDCG levels (ppm)	TDCG rate (ppm/day)	Sampling intervals and operating procedures for gas generation rates	
			Sampling interval	Operating procedures
Condition 1	≤720	>30	Monthly	Exercise caution Analyze for individual gases Determine load dependence
		10 to 30	Quarterly	Continue normal operation
		<10	Annual	

CONDITION 2: ***TDCG within this range indicates greater than normal combustible gas level. Any individual combustible gas exceeding specified levels should prompt additional investigation. Action should be taken to established trend. Faults(s) may be present.***

Status	Dissolved key gas concentration limits in parts per million (ppm)							
	Hydrogen (H2)	Methane (CH4)	Acetylene (C2H2)	Ethylene (C2H4)	Ethane (C2H6)	Carbon Monoxide (CO)	Carbon Dioxide (CO2)	TDCG
Condition 2	101-700	121-400	2-9	51-100	66-100	351-570	2500-4000	721-1920

Action based on Total Dissolved Combustible Gas

Status	TDCG levels (ppm)	TDCG rate (ppm/day)	Sampling intervals and operating procedures for gas generation rates	
			Sampling interval	Operating procedures
Condition 2	721 to 1920	>30	Monthly	Exercise caution
		10 to 30	Monthly	Analyze for individual gases
		<10	Quarterly	Determine load dependence

Condition 3: TDCG within this range indicates a high level of decomposition. Any individual combustible gas exceeding specified levels should prompt additional investigation. Immediate action should be taken to establish trend. Fault(s) are probably present.

Status	Dissolved key gas concentration limits in parts per million (ppm)							
	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon Monoxide (CO)	Carbon Dioxide (CO_2)	TDCG
Condition 3	701-1800	401-1000	10-35	101-200	101-150	571-1400	4001-10 000	1921-4630

Action based on Total Dissolved Combustible Gas

<table>
<tr><th rowspan="2">Status</th><th rowspan="2">TDCG levels (ppm)</th><th rowspan="2">TDCG rate (ppm/day)</th><th colspan="2">Sampling intervals and operating procedures for gas generation rates</th></tr>
<tr><th>Sampling interval</th><th>Operating procedures</th></tr>
<tr><td rowspan="3">Condition 3</td><td rowspan="3">1921 to 4630</td><td>>30</td><td>Weekly</td><td rowspan="3">Exercise extreme caution
Analyze for individual gases
Plan Outage
Advise manufacturer</td></tr>
<tr><td>10 to 30</td><td>Weekly</td></tr>
<tr><td><10</td><td>Monthly</td></tr>
</table>

Condition 4: TDCG within this range indicates excessive decomposition of cellulose insulation and/or oil. Continued operation could result in failure of the transformer. Need to retest.

- **There some transformer operating safely under this condition, however gases are stable.**
- **If TDCG and individual gases are increasing significantly (>30ppm/day), the fault is active, transformer should be de-energized.**

Status	Dissolved key gas concentration limits in parts per million (ppm)							
	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon Monoxide (CO)	Carbon Dioxide (CO_2)	TDCG
Condition 4	>1800	>1000	>35	>200	>150	>1400	>10 000	>4630

Action based on TDCG

Status	TDCG levels (ppm)	TDCG rate (ppm/day)	Sampling intervals and operating procedures for gas generation rates	
			Sampling interval	Operating procedures
Condition 4	>4630	>30	Daily	Consider removal from service
		10 to 30	Daily	Advise manufacturer
		<10	Weekly	Exercise extreme caution Analyze for individual gases Plan Outage Advise manufacturer

Evaluation of possible fault type by Rogers Ratio Method (IEEE C57.104.2008)

Case	**R1** **CH_4/H_2**	**R2** **C_2H_2/C_2H_4**	**R3** **C_2H_4/C_2H_6**	**Suggested fault diagnosis**
0	>0.1 to <1.0	<0.1	<1.0	Unit normal
1	<0.1	<0.1	<1.0	Low-energy density arcing-PD
2	0.1 to 1.0	0.1 to 3.0	>3.0	Arcing-High energy discharge
3	>0.1 to <1.0	<0.1	1.0 to 3.0	Low temperature thermal
4	>1.0	<0.1	1.0 to 3.0	Thermal $<700_{o}C$
5	>1.0	<0.1	>3.0	Thermal $>700_{o}C$

IEC 60599-2007-05

Name	**Ratio**	**Value Significant**	**Indication**
CO_2 VS. CO Ratio	CO_2 / CO	<3 Excessive	Thermal Cellulosic Degradation

NOTE: Ratio valid when levels exceed minimums:
CO > 500 ppm, CO_2 > 5000 ppm

Duval Triangle

Proposed by Michel Duval.
- **Developed empirically in the early 1970's.**
- **Adopted in IEC 60599**
- **Uses three characteristics gases – CH4, C2H4, and C2H2 corresponding to the energy levels of gas formation.**

The faults which are detected by Duval triangle are expressed as follows;

Partial Discharge (PD)
Discharges of Low energy (D1)
Discharges of High energy (D2)
Thermal fault, (T1)
Thermal fault, (T2)
Thermal fault, (T3)
Thermal & Electrical fault (DT)

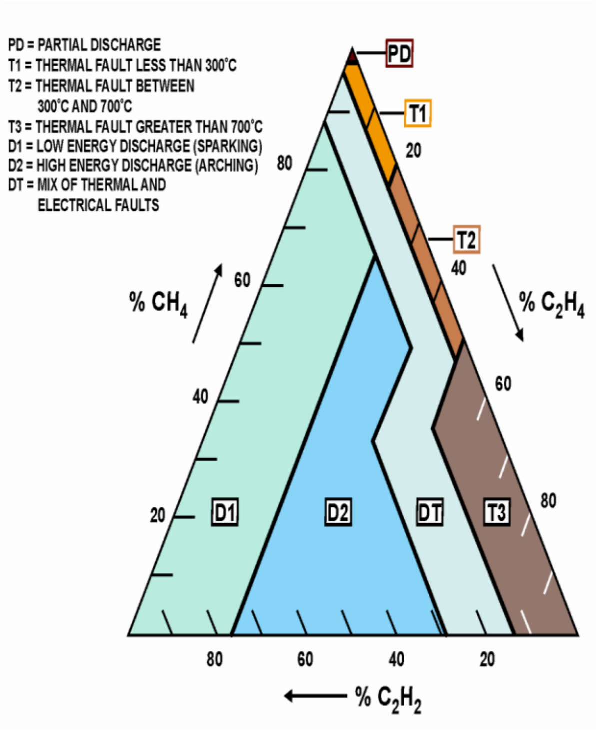


Fig: The Duval Triangle

How to Use the Duval Triangle

1. First determine whether a problem exists by using the IEEE® method above, and/or table 13 below. At least one of the hydrocarbon gases or hydrogen must be in IEEE® Condition 3 and increasing at a generation rate (G2), from table 13, before a problem is confirmed. To use table 13 without the IEEE® method, at least one of the individual gases must be at L1 level or above and the gas generation rate must be at least at G2. The L1 limits and gas generation rates from table 13 are more reliable than the IEEE® method; however, one should use both methods to confirm that a problem exists.

Gas	L1 limits	G1 limits (ppm per month)	G2 limits (ppm per month)
H_2	100	10	50
CH_4	75	8	38
C_2H_2	3	3	3
C_2H_4	75	8	38
C_2H_6	75	8	38
CO	700	70	350
CO_2	7000	700	3500

How to Use the Duval Triangle

2. Once a problem has been determined to exist, use the total accumulated amount of the three Duval Triangle gases and plot the percentages of the total on the triangle to arrive at a diagnosis. An example is shown below. Also, calculate the amount of the three gases used in the Duval Triangle, generated since the sudden increase in gas began. Subtracting out the amount of gas generated prior to the sudden increase will give the amount of gases generated since the fault began.

3. Add the three numbers (differences) obtained by the process of step 2 above. This gives 100 % of the three key gases, generated since the fault, used in the Duval Triangle.

4. Divide each individual gas difference by the total difference of gas obtained in step 3 above. This gives the percentage of increase of each gas of the total increase.

5. Plot the percentage of each gas on the Duval Triangle, beginning on the side indicated for that particular gas. Draw lines across the triangle for each gas, parallel to the hash marks shown on each side of the triangle.

Duval Triangle Example

For example the following table shows the gas contents derived from a transformer.

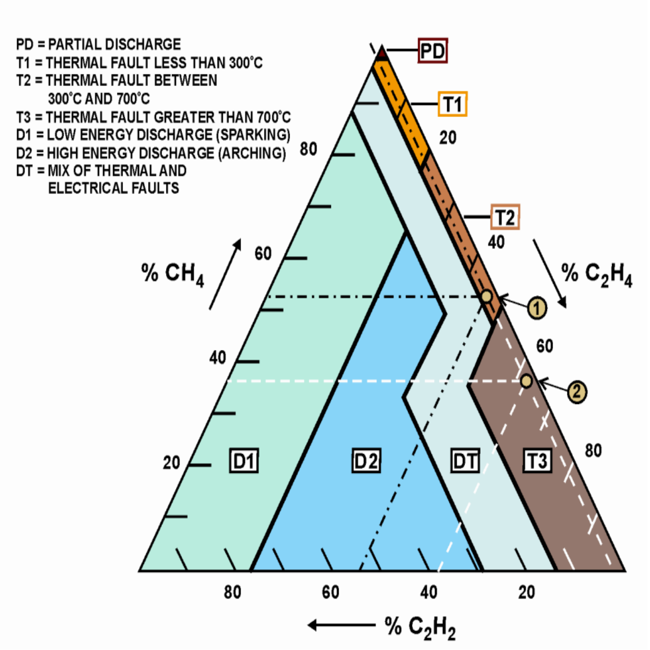
	DGA No. 1	DGA No. 2	Increase		DGA No. 1	DGA No. 2	Increase
CH_4	142	192	50	CO	176	199	23
C_2H_4	84	170	86	CO_2	1,009	2,326	1,317
C_2H_2	4	7	3				
Total	230	369	139				

Steps to Obtain the First Diagnosis (Point 1) on the Duval Triangle

1. Use the **total accumulated** gas from DGA 2 = 369
2. Divide each gas by the total to find the percentage of each gas of the total.

% CH4 = 192/369 = 52%,
% C2H4 = 170/369 = 46%,
% C2H2 = 7/369 = 2%

Point 1 is obtained where the lines intersect within the T2 diagnostic area of the triangle, which indicates a thermal fault between 300 and 700 °C.



Figure– Duval Triangle Diagnostic Example of a Reclamation Transformer.

Different Oil Testing Standard According to IEEE and IEC

Guidelines of IEC for Interpreting moisture content in insulation oil.

Percent saturation water in oil, adjusted to 20 °C	Condition of cellulosic insulation
0 – 5 %	Dry insulation
6 – 20 %	Moderate wet, low numbers indicate fairly dry to moderate levels of water in the insulation. Values toward the upper limit indicate moderately wet insulation
21 – 30 %	Wet insulation
> 30 %	Extremely wet insulation

Acidity or Neutralization Number of Insulation Oil.

Property	**Category**	**Recommended Action Limits**		
		Good	Fair	Poor
Acidity (mgKOH/g)	>72.5KV	<0.1	0.1-0.2	>0.2
	<72.5KV	<0.15	0.15-0.3	>0.3

Dielectric Dissipation Factor of Oil According to IEEE C57.106 °C

Oil Condition	Satisfactory Limit at 25°C
For New Oil	<0.05
For Service Aged Oil	<0.5

Oil Breakdown Voltage Limit According to IEC

Property	Category	Recommended Action Limit		
		Good	Fair	Poor
Breakdown Voltage (KV)	>170 KV	>60	60-50	<50
	170-72.5 KV	>50	50-40	<40
	<72.5 KV	>40	40-30	<30

Dissolved Gas Analysis Test According to IEEE

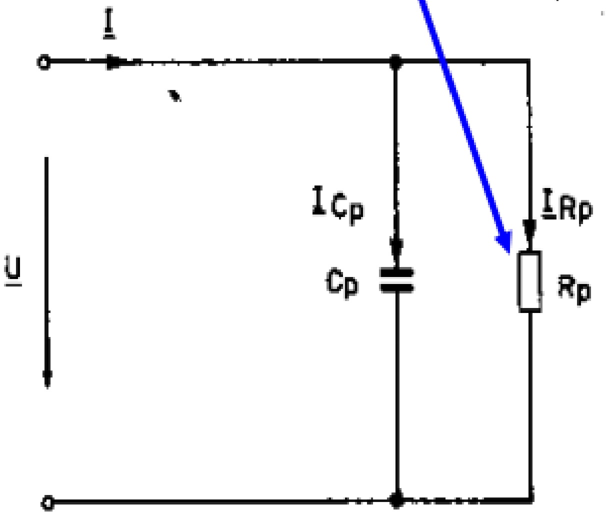
Status	Dissolved key gas concentration limits [µL/L (ppm)]							
	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon monoxide (CO)	Carbon dioxide (CO_2)	TDCGb
Condition 1	100	120	1	50	65	350	2500	720
Condition 2	101–700	121–400	2–9	51–100	66–100	351–570	2500–4 000	721–1920
Condition 3	701–1800	401–1000	10–35	101–200	101–150	571–1400	4001–10 000	1921–4630
Condition 4	>1800	>1000	>35	>200	>150	>1400	>10000	>4630

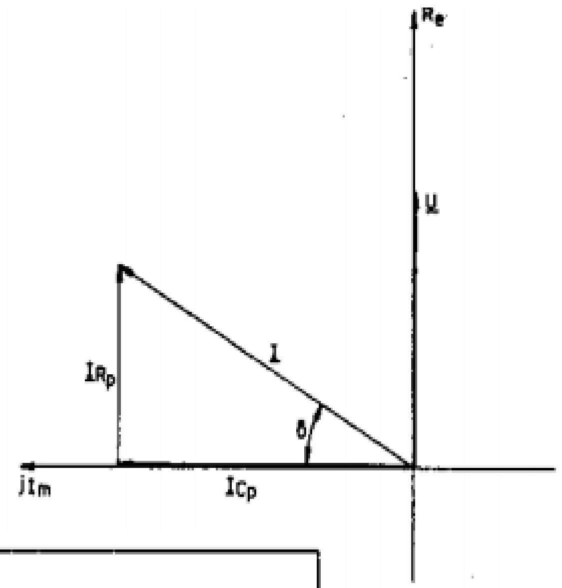
Capacitance and Tan-Delta Test of Power Transformer and HV Bushing

Definition of Tan Delta

Equivalent Parallel Circuit Diagram and Vector Diagram

Mainly conductive losses



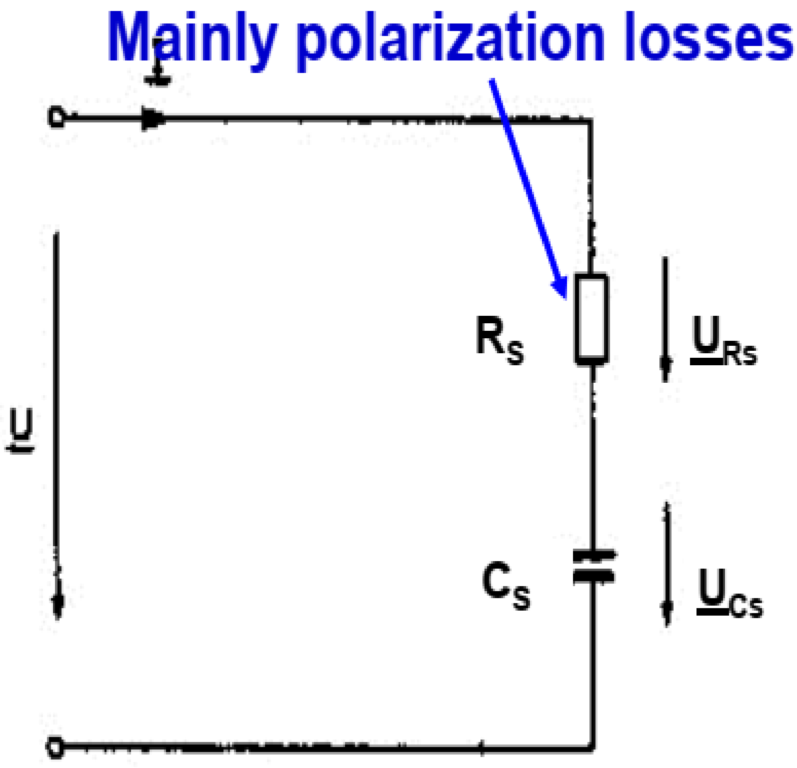


$$\tan\delta = \frac{|I_{Rp}|}{|I_{Cp}|} = \frac{1}{R_p \cdot \omega C_p}$$

with $\omega = 2 \cdot \pi \cdot f$

and f = Frequency

Equivalent Serial Circuit Diagram



$$\tan\delta = \frac{U_R}{U_C} = R_S \omega C_S$$

Transformer Winding Insulation

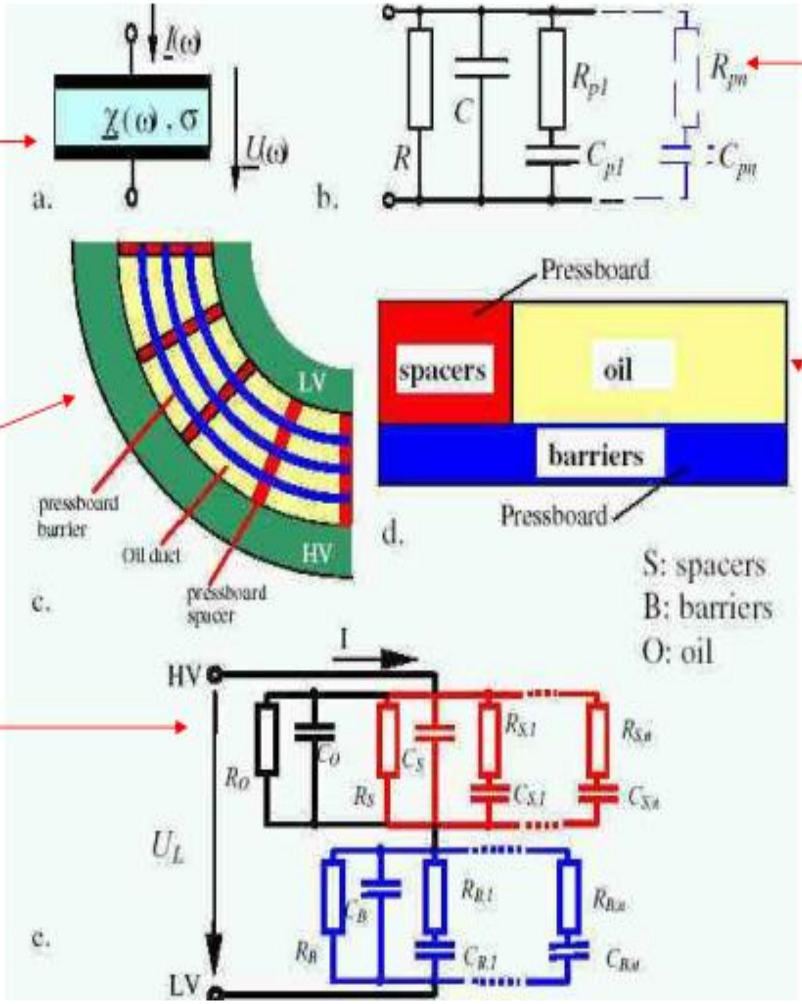
a. Plate condenser as a model for dielectric insulation

b. Model for the behaviour of a dielectric with polarisation characteristic and conductivity

c. Part of the cross section of a power transformer main insulation system between HV and LV windings

d. Simplified geometry model for the main components oil, barriers and spacers

e: Dielectric model for the insulation system of power transformers



Losses in Dielectric Material

- Transport of electrons and ions
- Losses through polarisation effects

- Losses in dielectrics are dependent of
  - Ageing
  - Water content
  - Conductive losses by particles
  - Partial discharges

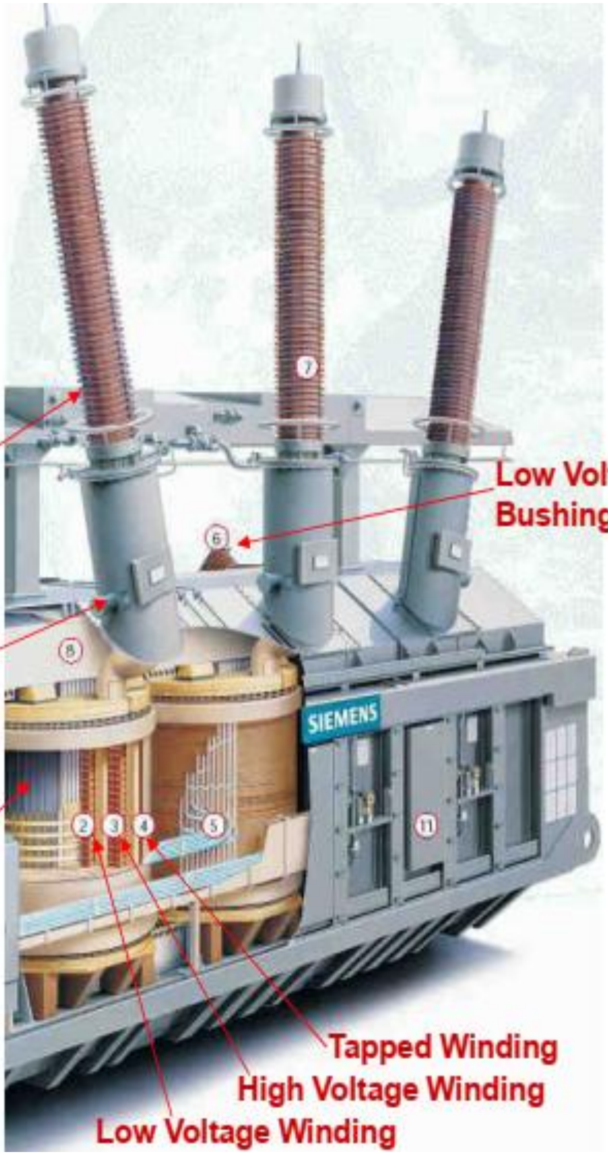
What can C-Tan Delta tell us?

- Capacity:
  - Bushings:
    - Partial breakdowns between layers
    - Incoming oil into cracks of solid insulation (RBP hard paper)
  - Transformer windings:
    - Change of the geometry between windings (deformation and displacement of windings due to big fault currents trough the transformer)

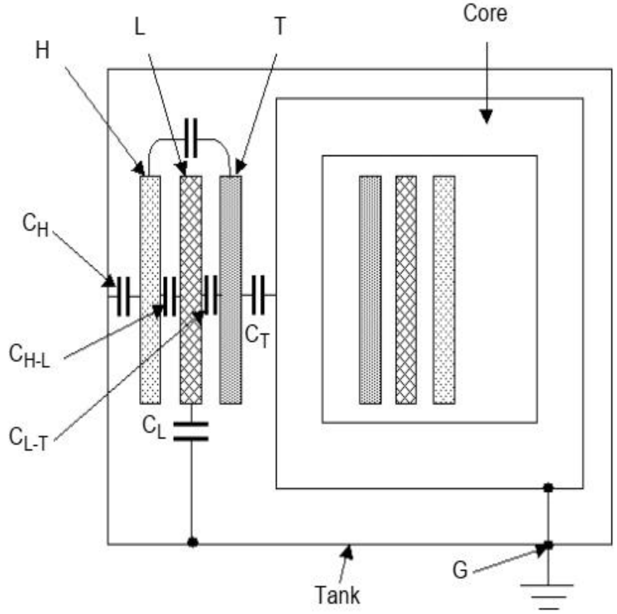
What can C-Tan Delta tell us?

- Dissipation factor:
  - Bushings:
    - Aging and decomposition of insulation
    - Water content
    - Bad contacted electrodes or capacitive layers
    - Cracks in the insulation
    - Partial discharges
  - Transformers:
    - Aging
    - Water content in the oil and in the paper
    - Contamination by particles

C-Tan-Delta Measurement on Power Transformers



Three Phase Transformer With Winding Capacitance.



H	High-Voltage winding	C H	Cap. H to Ground	C H-L	Cap. H to L
L	Low-Voltage winding	C L	Cap. L to Ground	C L-T	Cap. L to T
T	Tertiary winding	C T	Cap. T to Ground	C H-T	Cap. H to T

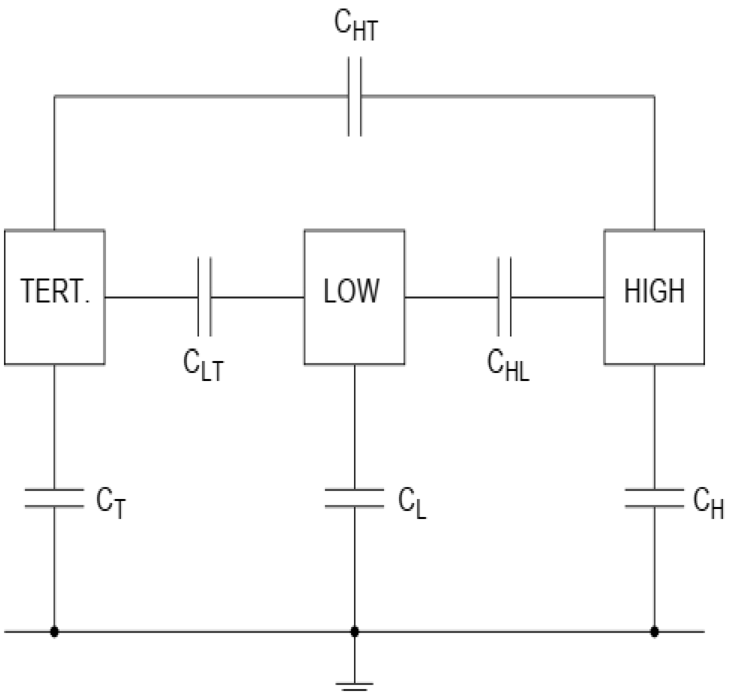
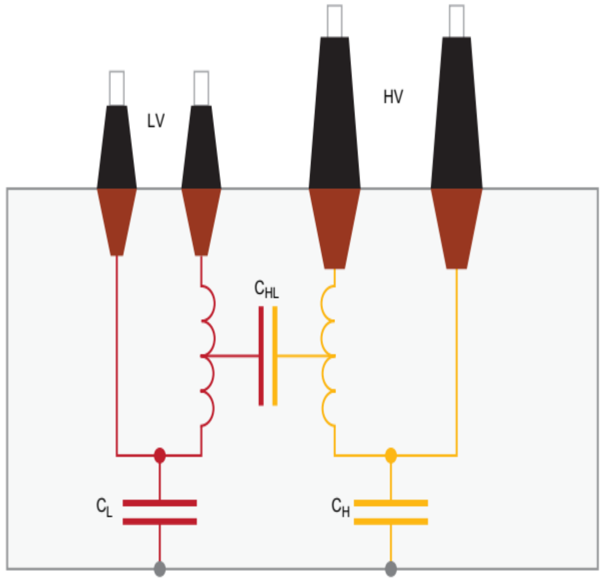


Fig: 3 Winding transformer test according to IEEE 62-1995

Measurements on two winding transformers



Fig; Insulation of two winding transformer

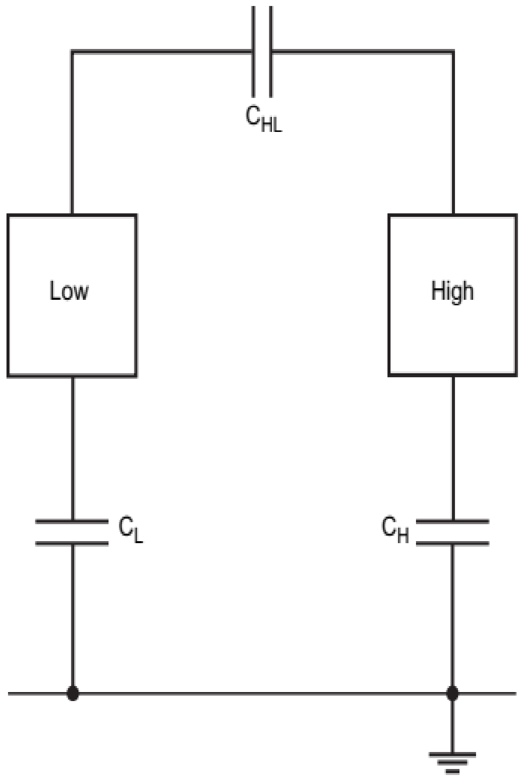


Fig: Two winding transformer test according to *IEEE C57.152-2013*

Measurements on two winding transformers

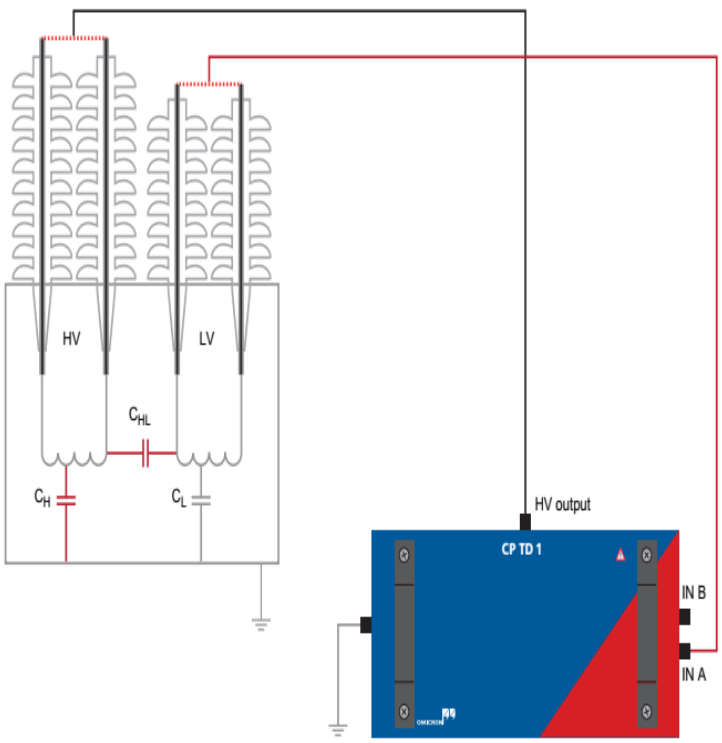


Fig: Measurement of C_{HL} and C_H

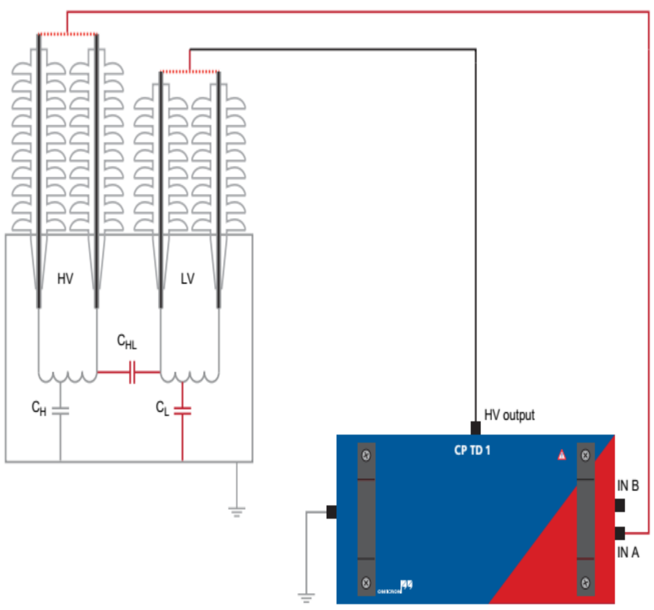
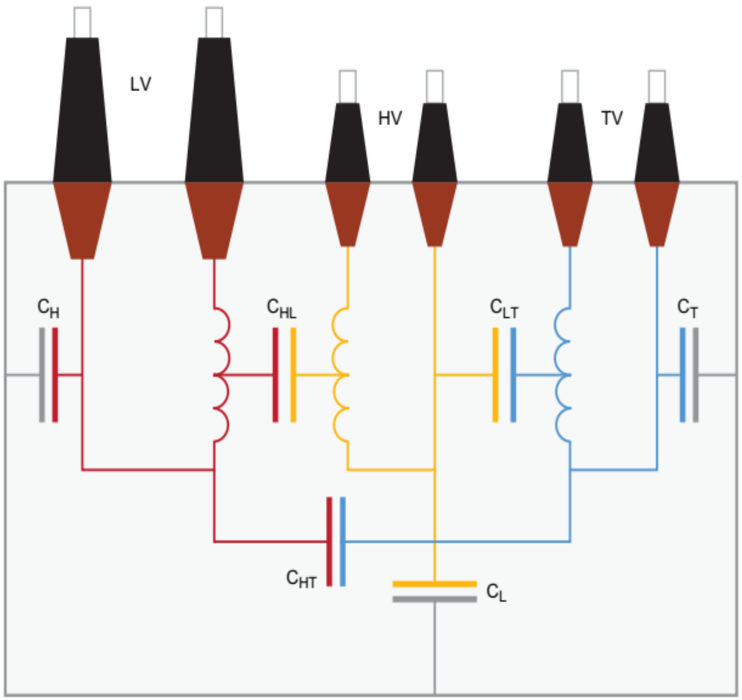


Fig: Measurement of C_{HL} and C_L

Measurements on three winding transformers



Fig; Insulation of three winding transformer

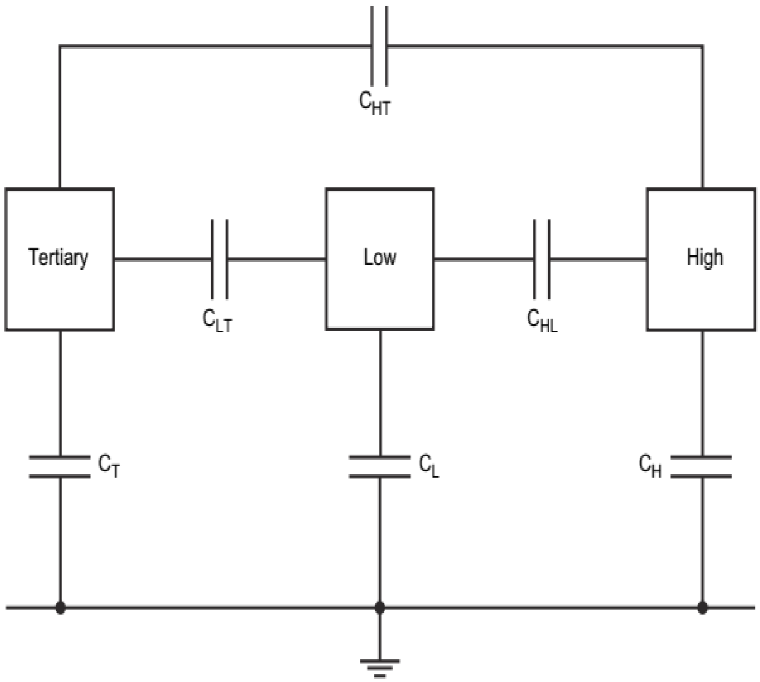
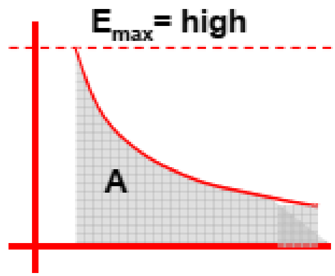


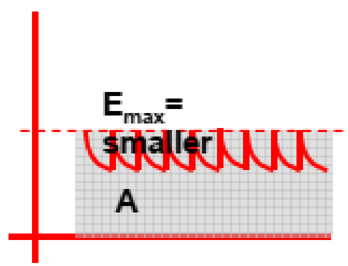
Fig: Two winding transformer test according to *IEEE C57.152-2013*

HV Bushings

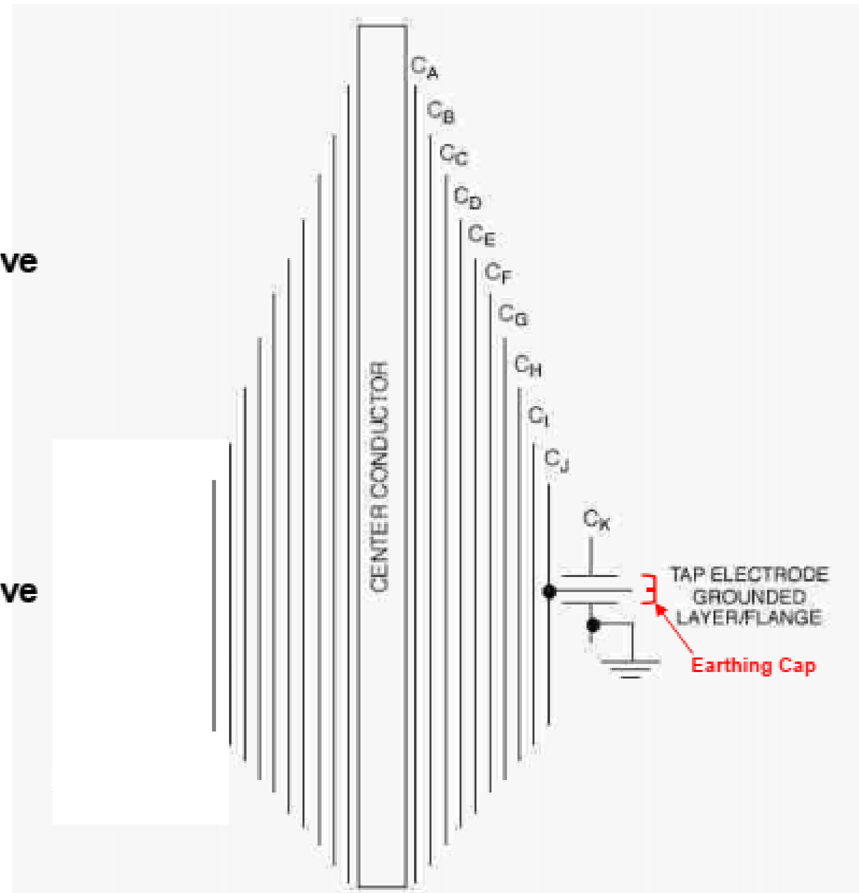
Capacitive Bushings (1)



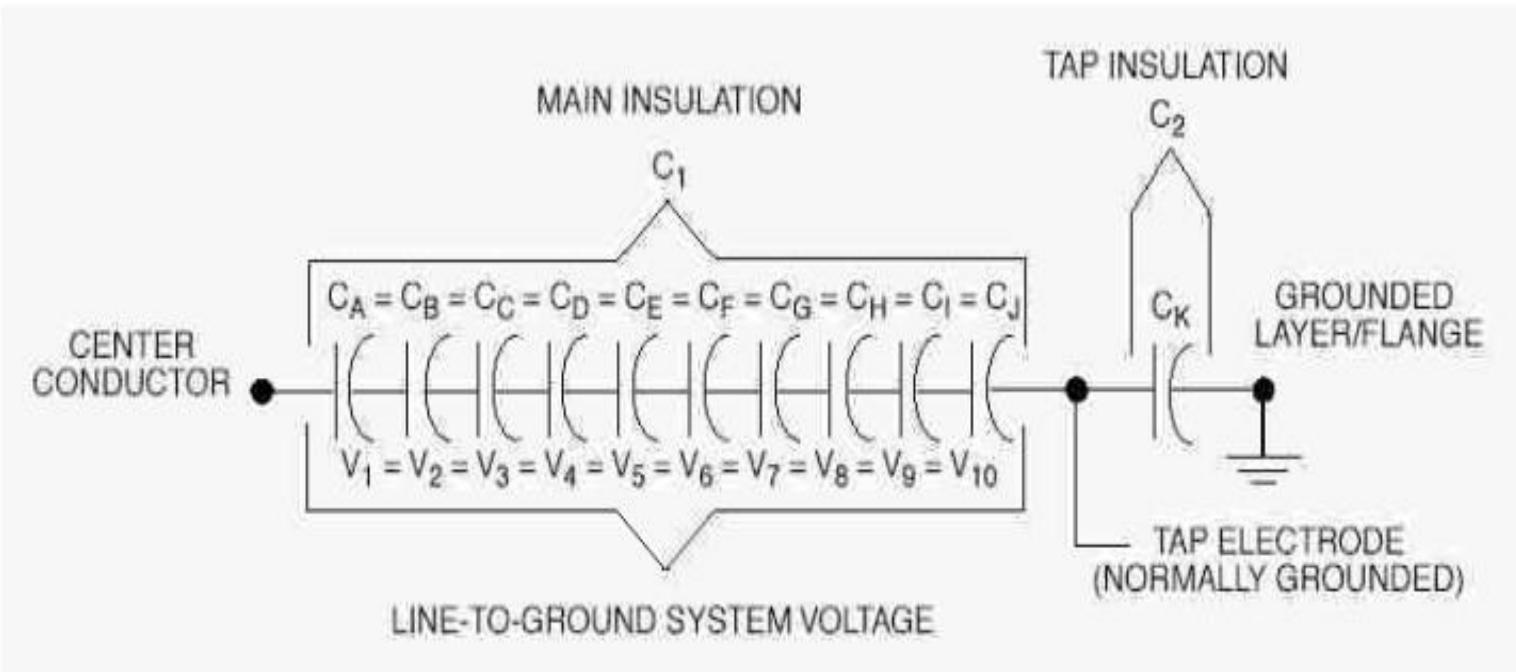
without capacitive layers



with capacitive layers

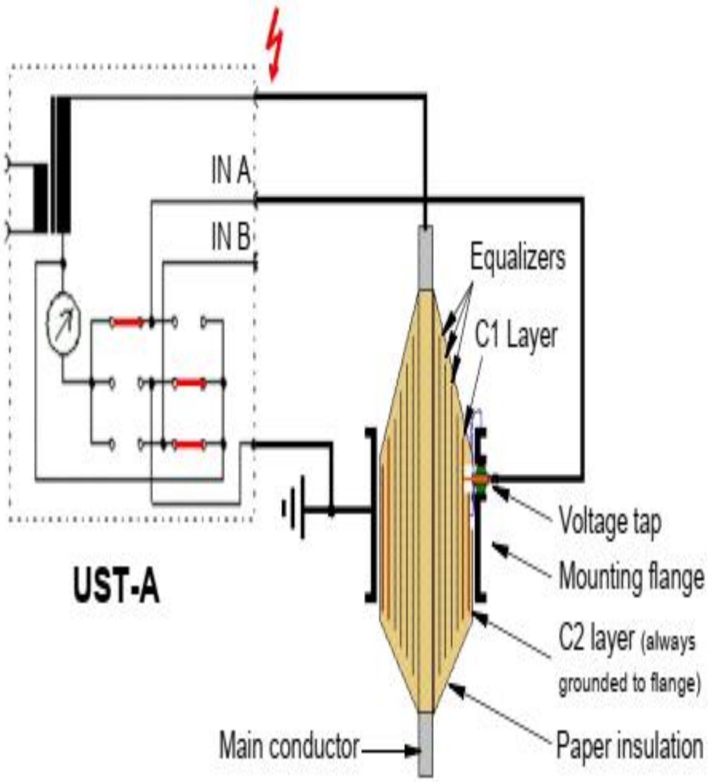


Capacitive Bushings (2)



Bushing Measuring Tap

Bushing Tan-Delta Test Mode & Format

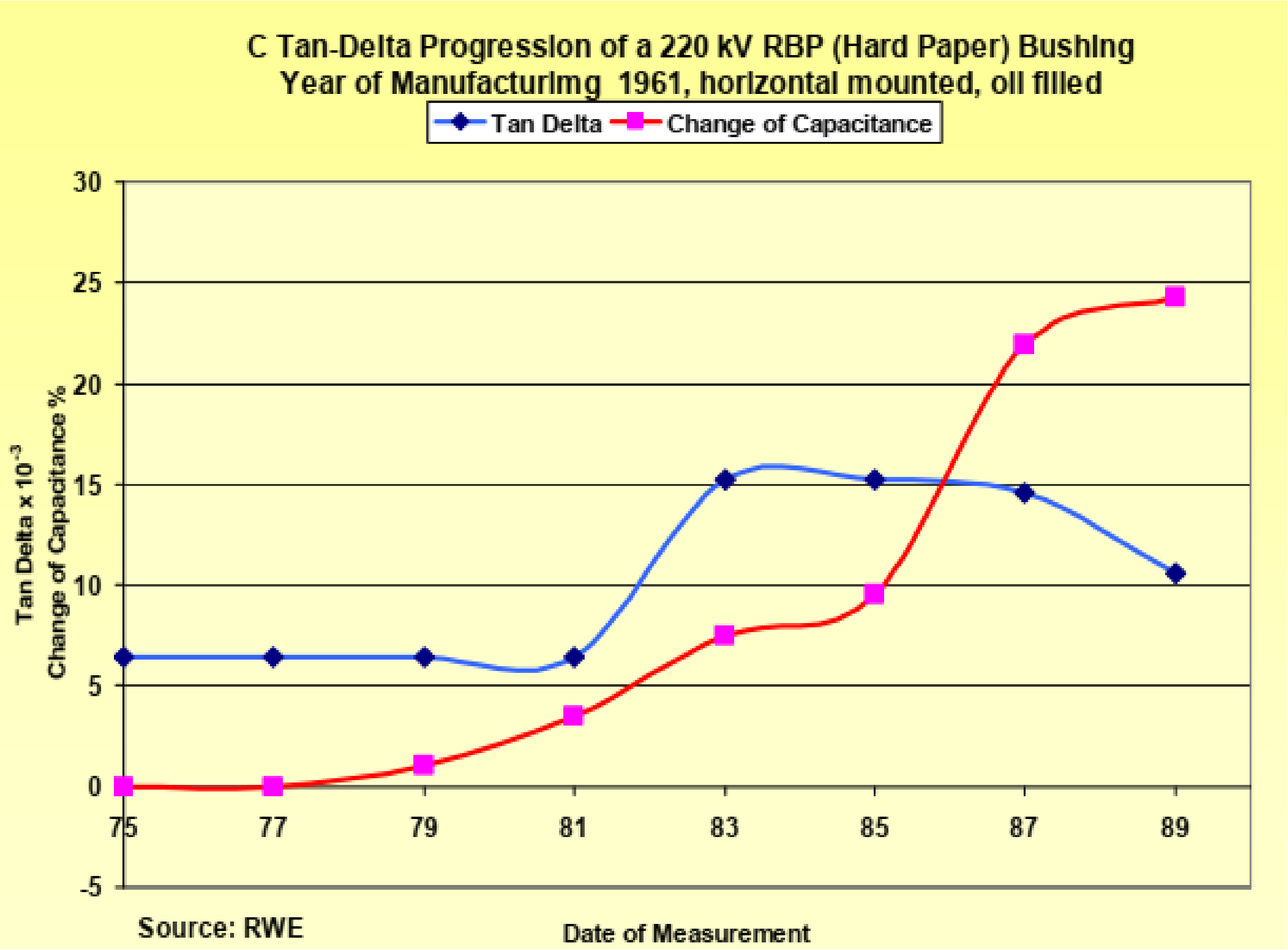


Phase Name	Mode	Voltage Level	Applied Voltage	Capacitance(pF)	Tanδ (%)	Remarks
R	UST-A		5 KV			
			10KV			
Y	UST-A		5 KV			
			10KV			
B	UST-A		5 KV			
			10KV			

Fig: Bushing Tan-Delta test format

NB - ***According to IEEE C57.152-2013, the Tanδ limit is 0.4%(max.) for new Bushing and .5% (max.) for service aged transformer.***

C-Tan Delta Progression of a Bushing



Circuit Breaker (CB)

A **circuit breaker** is an conditionally auto operated electrical switch designed to separate and protect an electrical system from impact caused by overload or short circuit .

- In a simple sense, the main function of the circuit breaker is to break and make the electrical circuit in both live and dead condition.

- In fault condition, Its basic function is to immediately interrupt continuity of current flow.

Functions of Circuit Breaker

Providing maintenance facilities:

- Emergency/ routine maintenance of transmission lines;
- Emergency/ routine maintenance of switchgear equipment;

Over current or Overload protection:

-to follow the command from relay and to save the line conductors, connectors & other series equipment like Transformers, CT's, DS etc. from continuous overloading .

Short circuit protection :

- to follow the command from relay and to save the substation equipment from any unwanted impulse like thundering, transient faults in line or any equipment etc.

Types of Circuit Breaker

According to their arc quenching media the circuit breaker can be divided as-

- Oil circuit breaker
- Air circuit breaker. (Majority < 110 kV)
- SF_6 circuit breaker.(mostly used for high voltage)
- Vacuum circuit breaker.(22 kV to 66 kV)

According to their services the circuit breaker can be divided as-

- Outdoor circuit breaker
- Indoor breaker.

According to the operating mechanism of circuit breaker they can be divided as-

- Spring operated circuit breaker.
- Pneumatic circuit breaker.
- Hydraulic circuit breaker.

Types of Circuit Breaker…

According to the voltage level of installation types of circuit breaker are referred as-

- High voltage circuit breaker.(>72 kV)
- Medium voltage circuit breaker.(1-72 kV)
- Low voltage circuit breaker.(<1 kV)

According to their arc quenching interrupting chamber position it can be divided as-

- Live Tank Circuit breaker
- Dead Tank Circuit breaker

Circuit Breaker

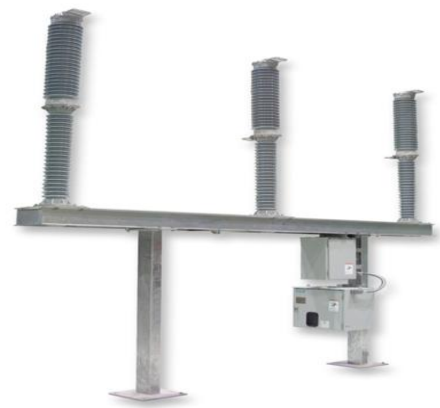


Fig 1 Representation of Live Tank Circuit Break.

Fig 1 Representation of Dead Tank Circuit Break.

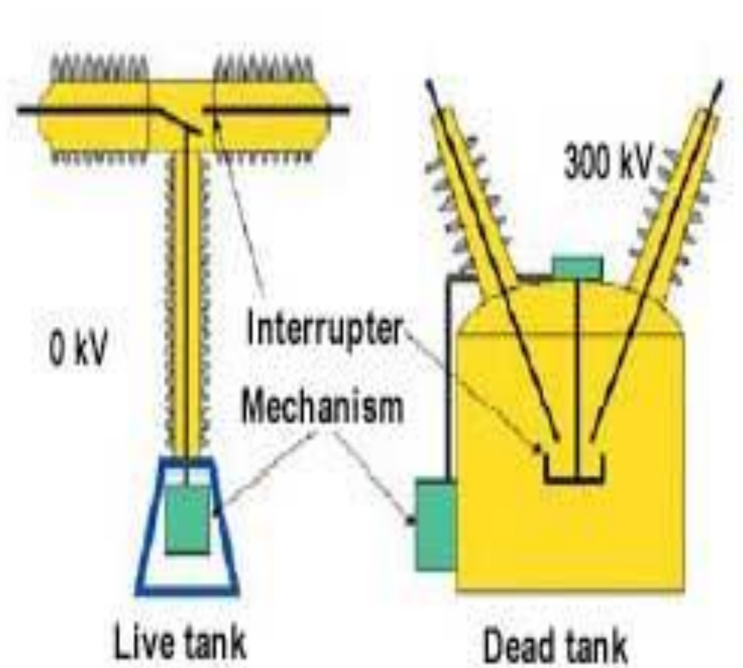
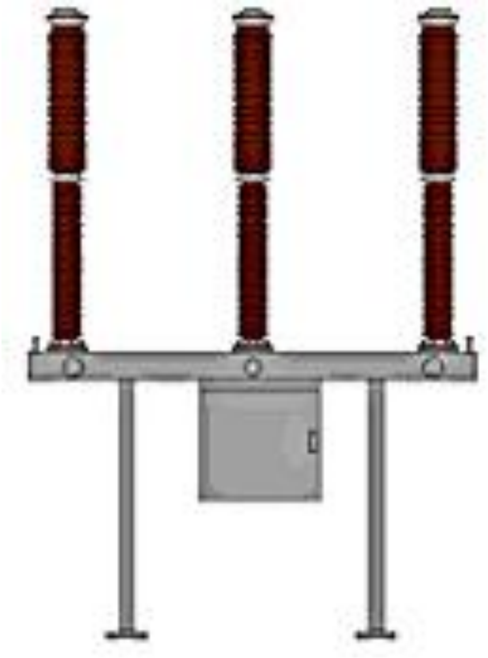


Fig 2 Representation of Live Tank and dead tank Circuit Breaker

Live Tank Circuit Breakers

Live Tank circuit breakers are circuit breakers in which the interrupting chamber is at the line potential. The interrupting chamber should therefore be provided with insulated supports.



Dead Tank Circuit Breakers

In dead tank circuit breakers, the interrupting chamber is at **ground potential**. The conductors enter the interrupting chamber through insulated bushings. Maintenance activities are easier to conduct and seismic capability is higher as the interrupting chamber is at ground level.

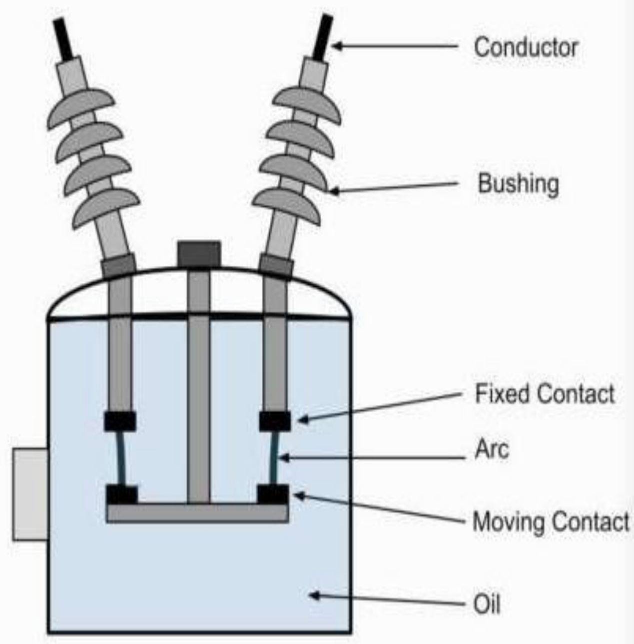


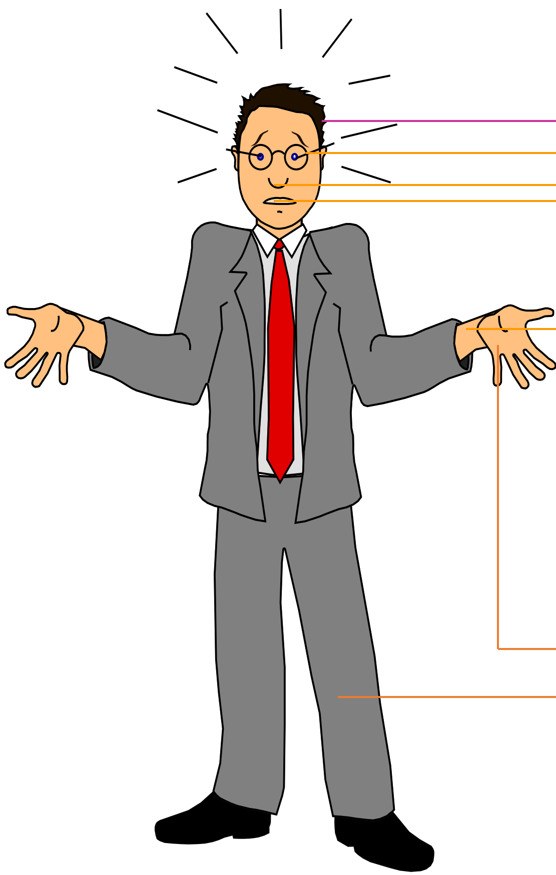
Fig-A: Bulk Oil Circuit Breaker (BOCB)

MAINTENANCE

- Should be cleaned and inspected for any cracks.
- Dust & dirt deposition, salt or chemical deposition, cement or acid fumes depositions should be carefully noted and rectified.
- The Operating Mechanism should be checked.
- Tripping & closing mechanism should be checked.
- Insulation checking.
- Status checking from Local/ Remote position.

Instrument Transformers (CT/ PT)

Protection System Analogy



Brain
Relay

Eyes, Ears, Nose & Skin

Instrument Transformers (CTs, VTs)

Hands & Legs

Circuit Breakers

Classification of Instrument Transformers

- Based on application-
  - Metering
  - Protection
- Based on use-
  - Indoor
  - Outdoor
- Types of Instrument Transformer
  - Current Transformer (CT)
  - Voltage Transformer (VT)
    - Electromagnetic Voltage Transformer (EVT)
    - Capacitive Voltage Transformer (CVT)

What is Current Transformer

- Current Transformer is an instrument transformer which transforms current from one level to another level, such as, 1000A/1A (CT ratio) i.e. transforms current from the level of 1000A into current of 1A level
- Direct measurement of high current (in the tune of 100A or more) is not possible as devices used for measurement of current are not designed to handle such huge amount of current

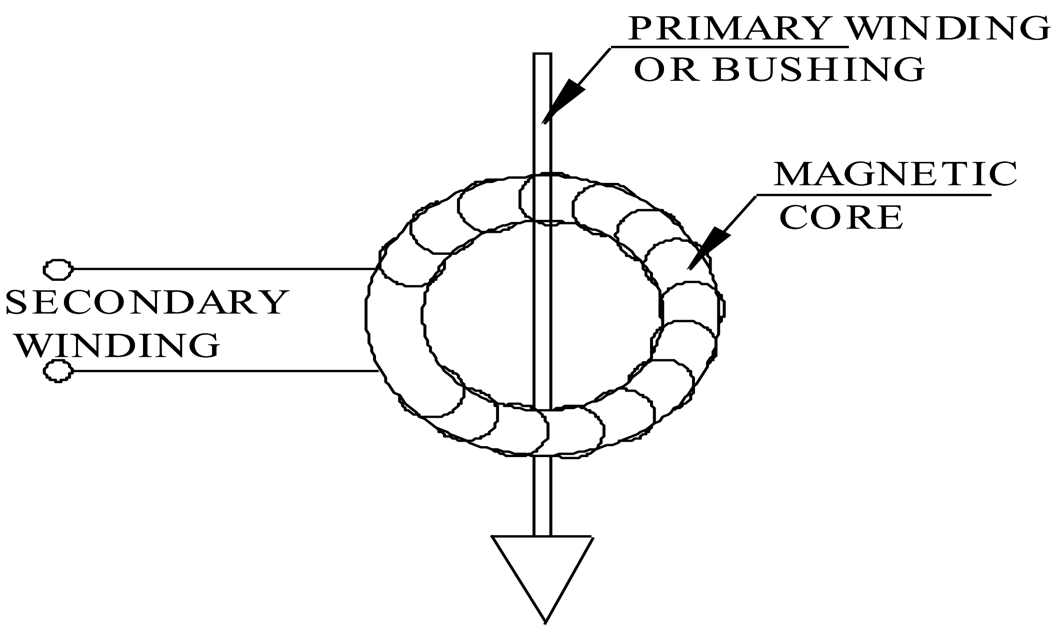
Why Current Transformer is required

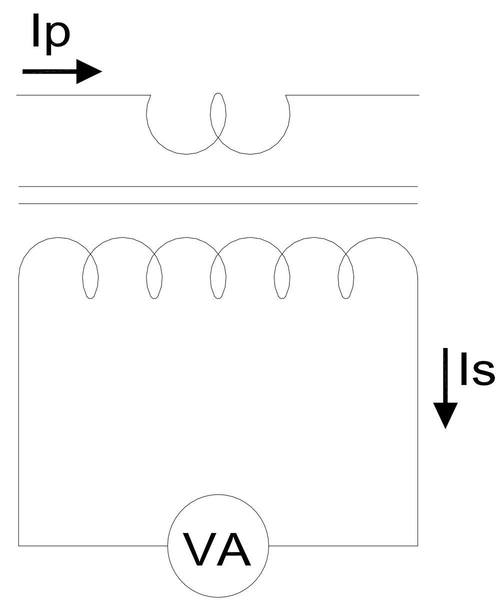
- System has two basic requirements
  - ➢metering of energy sourced or consumed
  - ➢Protection of the electrical system from disturbances

- Types of Current Transformer (CT)
  - Measuring CTs
  - Protection CTs
  - Protection CTs for special applications

How Current Transformer is connected

- It has a primary winding and one or more secondary windings wound on core of magnetic material
- Metering and Protection devices are connected to the secondaries of the CT





Burden of Current Transformer

- Burden

  The external load (e.g. meters, transducers, relays etc) connected to the secondary of a CT is called the burden

  The burden can be expressed in volt-amperes or in ohms

  $VA = I^2 \times Z$

  Z = Total **CT** secondary impedance

  I = Secondary current (Generally 1A or 5A)

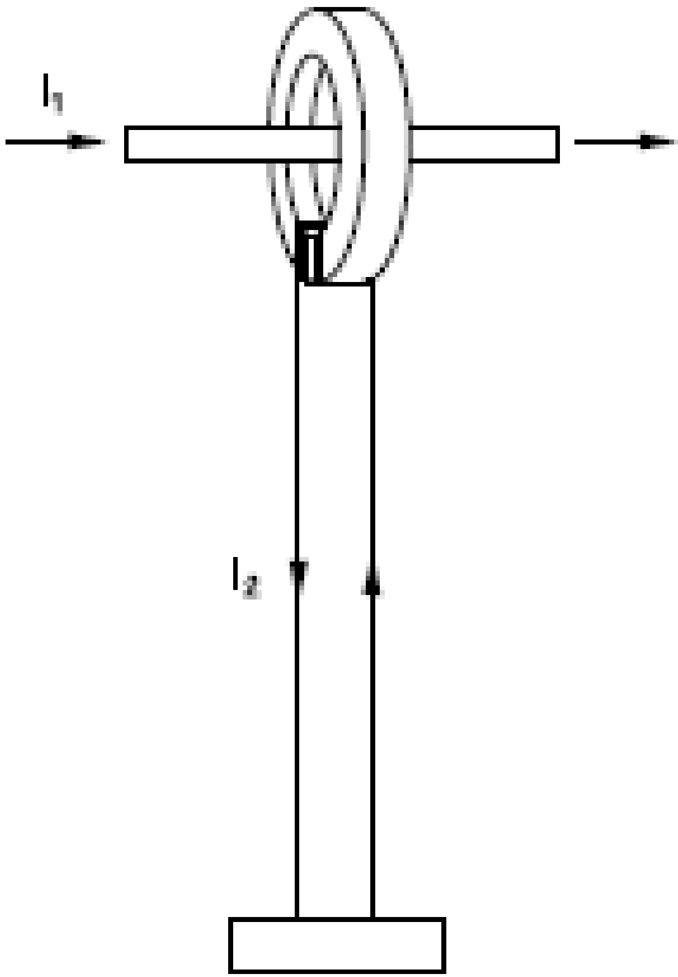
- **Total burden** is the sum of

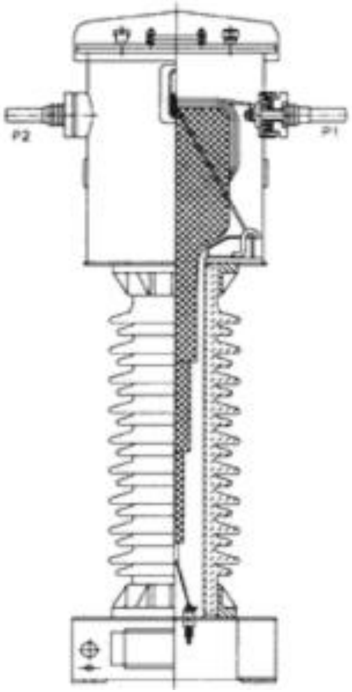
  1. Device (transducer, meter, relay etc) Burden - Furnished by the manufacturer

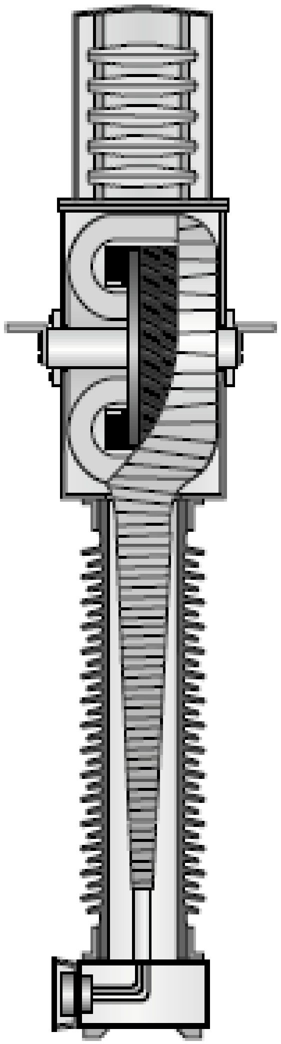
  2. Burden of Interconnecting Leads - can be calculated by using the above formula, use conductor resistance (total to the device and back) for Z

  3. Internal Burden of **CT** Windings - This is so small that it can generally be ignored or specified by manufacturer

Live Tank Current Transformer







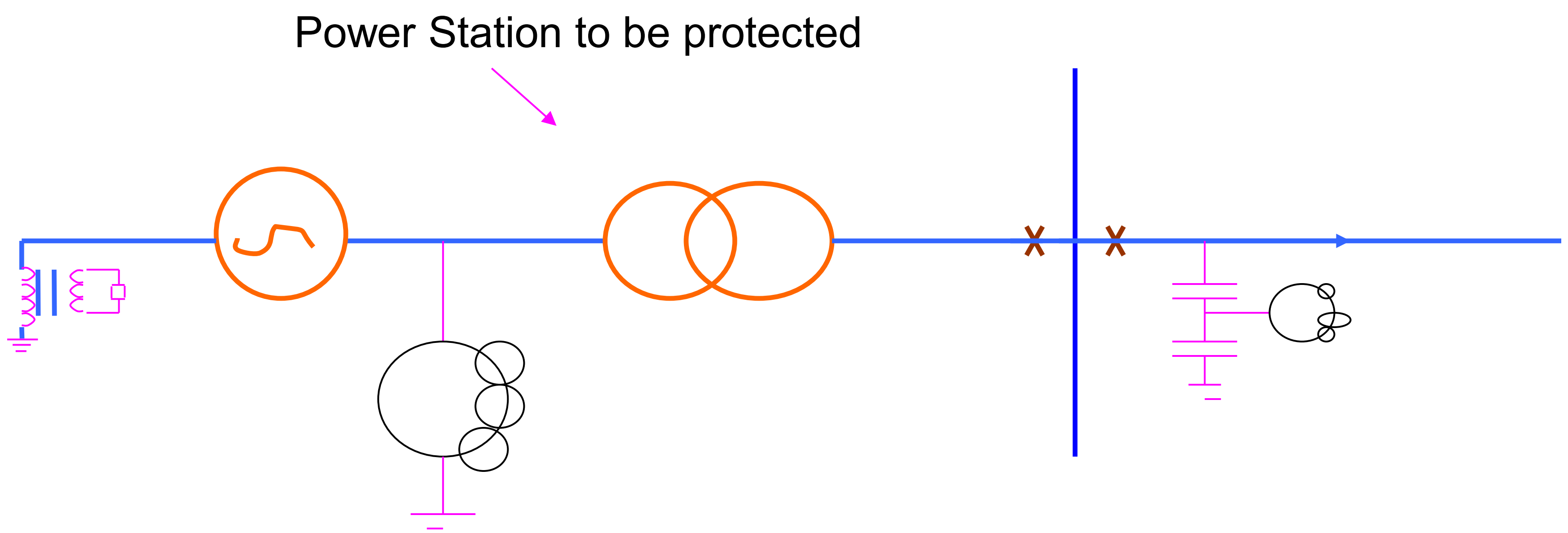
Voltage Transformers / Potential Transformer

What is Voltage Transformer

- Voltage Transformer is an instrument transformer which transforms voltage from one level to another level such as 400KV/√3:110V/√3 (VT ratio) i.e. transforms voltage from the level of 400KV/√3 into voltage of 110V/√3 level
- Direct measurement of high voltage (in the tune of 3.3kV or more) is not possible as devices used for measurement of voltage are not designed to handle such high level of voltage

Where Voltage Transformer is connected

- For metering and protection of a feeder, VT is connected at the beginning of the feeder



MAINTENANCE

- Should be cleaned and inspected for any cracks.
- Dust & dirt deposition, salt or chemical deposition, cement or acid fumes depositions should be carefully noted and rectified.
- Insulation checking.

Disconnecting Switch (DS) or Isolator

- Circuit breaker always trip the circuit but open contacts of breaker cannot be visible physically from outside of the breaker and that is why it is recommended not to touch any electrical circuit just by switching off the circuit breaker.

  Isolator is a manually/automatically operated **mechanical switch** which separates a part of the electrical power system normally at off load condition.

Operation of Electrical Isolator

- As no arc quenching technique is provided in isolator it must be operated when there is no chance current flowing through the circuit.

- No live circuit should be closed or open by isolator operation.

- A complete live closed circuit must not be opened by isolator operation and also a live circuit must not be closed and completed by isolator operation to avoid huge arcing in between isolator contacts.

Operation of Electrical Isolator

- That is why isolators must be open after circuit breaker is open and these must be closed before circuit breaker is closed.

- Isolator can be operated by hand locally as well as by motorized mechanism from remote position.

- Normally for voltages up to 145KV system hand operated isolators are used whereas for higher voltage systems like 245 KV or 420 KV and above motorized isolators are used.

Types of Electrical Isolators

Different types of isolators available depending upon system requirement such as:

1) Double Break Isolator(with & without earth switch)

2) Single Break Isolator (with & without earth switch)

- Centre break
- Side break

3) Vertical break Isolator

4) Knee type Isolator

5) Pantograph Isolator

Types of Electrical Isolators

Depending upon the position in power system, the isolators can be categorized as:

1) **Bus side isolator** – the isolator is directly connected with main bus

2) **Line side isolator** – the isolator is situated at line side of any feeder

3) **Transfer bus side isolator** – the isolator is directly connected with transfer bus.

Single Break Isolator with Earthing Switch

Isolators

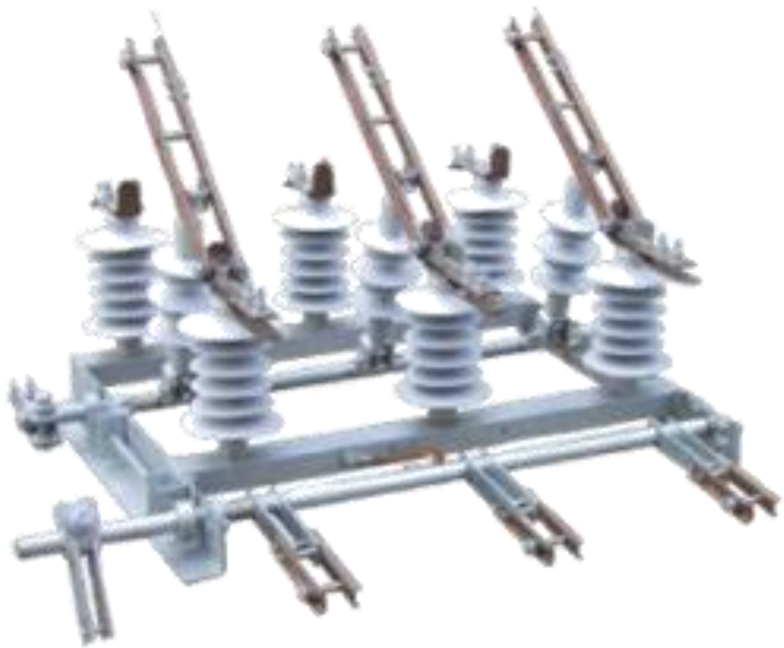
Single Break Isolator

Double Break Isolator

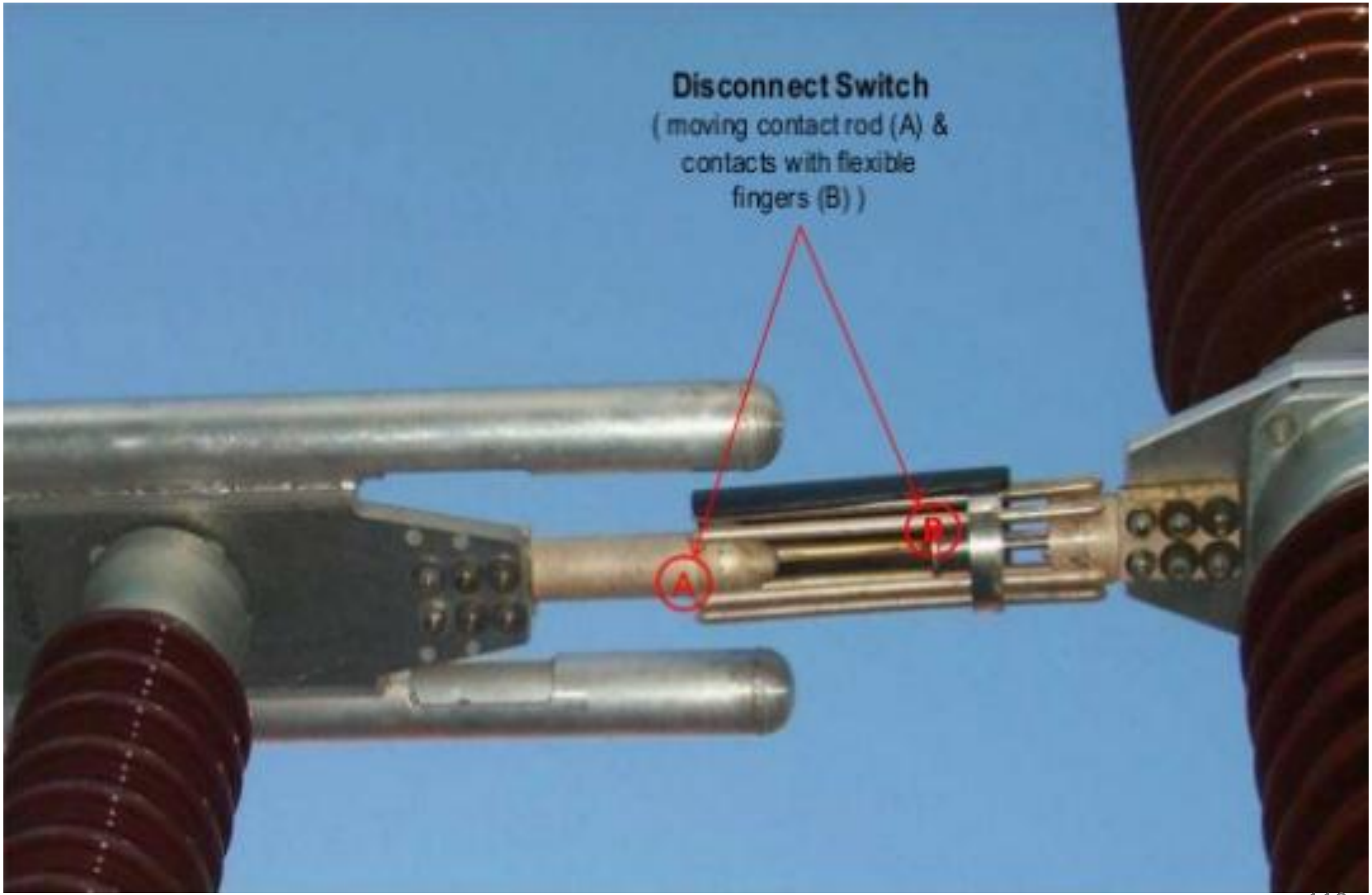
Pantograph Isolator

Knee type Isolator

Vertical break Isolators



Close Up look of Isolator



MAINTENANCE

- Should be cleaned and inspected for any cracks.
- Dust & dirt deposition, salt or chemical deposition, cement or acid fumes depositions should be carefully noted and rectified.
- Operating mechanism should be checked.
- Status checking from Local/ Remote position.
- Conductivity should be checked.
- Insulation checking.

Lightning Arrester or Surge Diverters

- A ***Lightning Arrester*** or a ***Surge diverter*** is a device to protect electrical equipment from over-voltage transients caused by external (lightning) or internal (switching) events.
- Also called a **surge protection device** (SPD) or **transient voltage surge suppressor** (TVSS).

- It conducts the high voltage surges on the power system to the ground.

Metal-oxide surge arrester

An arrester with non-linear (voltage-dependent) metal-oxide resistors , which are connected in series or in parallel without any integrated series or parallel gaps (more precisely: non-gapped meta l-oxide arrester) .

Metal-oxide resistor:

(MO resistor) resistor with an extremely non-linear voltage-cur-rent-characteristic. All resistors currently designated as metal-oxide resistors consist of about 90% zinc-oxide (ZnO); consequently, the metal-oxide arrester is occasionally called a ZnO arrester.

Leakage current

- Current which flows through the arrester at continuously applied power-frequency voltage.
- At alternating voltage it consists of a strongly capacitive and a considerably smaller resistive component , both of which depend on the MO resistors used.
-The capacitive part is heavily affected by stray capacitances and therefore also depends on the actual location of the arrester and on its overall dimensions.

The peak value of the leakage current, is usually within the range of 0.5 mA to 2 mA.

Causes of Over Voltages

Internal causes:

(i) Switching surges
(ii) Insulation failure
(iii) Arcing ground
(iv) Resonance

Resonance in an electrical system occurs when inductive reactance of the circuit becomes equal to the capacitive reactance. Under resonance, the impedance of the circuit is equal to inductance of the circuit and the p.f. is unity. Resonance causes high voltages in the electrical system

External causes:

(i) Lightning

LA Characteristics

An Ideal Lightning Arrester characteristics:

-It should not draw any current at normal operation;

-It should break down very quickly when abnormal transient voltage above it breakdown voltage appears, so that a low impedance path to ground can be provided;

- The discharge current after breakdown should not be so excessive so as to damage the surge arrester itself.

An electric discharge between cloud and earth, between clouds or between the charge canters of the same cloud is known as lightning.

Harmful effect of Lightning :

A direct or indirect lightning stroke on power system produces a step-fronted voltage wave on the system. The voltage of the wave may rise from zero to peak value in about 1μS and decay half of the peak value in about 5 μS. Such voltage initiate travelling waves along the lines.

Protection Against Lightning

- By providing Earthing Screen
- Overhead Ground Wire
- Lightning Arrester or Surge Diverters

Uses of LA in High voltage Transmission System

1) Starting and End of the Transmission lines
   - normally, to protect the transient voltages from lightning

2) Long Transmission lines
   - normally, to protect the transient voltages from lightning

3) HT-LT sides of Transformers
   - normally to protect the switching impulses

Lightning Arrester in Substation

MAINTENANCE

- Leakage current checking.
- Insulation checking.
- Operating counter checking.
- Should be cleaned and inspected for any cracks.
- Dust & dirt deposition, salt or chemical deposition, cement or acid fumes depositions should be carefully noted and rectified.

Wave Trap

- It consists of an inductor coil which is connected in series with the high voltage power system.
- Wave trap is used to trap the carrier wave for communication with high frequency (150kHz to 800kHz).
- It works similar to a filter to separate high frequency wave from power frequency to avoid any damage to power system which are designed to operate at 50 or 60 Hz. Wave traps are also called as line traps.

Pictorial view of Wave Trap

THANKS