# Dashiell
# 2022

**Keith Hill**
**Principal Engineer**
**Doble Engineering Company**

# Doble Power Factor Training Objectives

1. Basic understanding of Doble Power Factor Theory

    1. Current
    2. Watts
    3. Power Factor
    4. Capacitance
    5. Dielectric constant
    6. AC versus DC testing

2. Basic understanding of Doble Power Factor Basics

    1. Construction of high voltage lead
    2. Identify GST Ground connections
    3. Identify GST Guard connections
    4. Identify UST connections

3. Basic understanding of bushing construction

4. The student will be able to perform Power Factor testing on:

    a. Bushings

        1. Overall
        2. C1
        3. C2
        4. Inverted UST /C1
        5. C1 + C2
        6. Hot Collar

    b. Transformers

        1. Two Winding Transformers
        2. Shielded transformer
        3. Wye-Wye with H0 and X0 internally connected
        4. Three Winding Transformers
        5. Auto-transformers with tertiary
        6. Auto-transformers without tertiary

    c. Breakers

        1. Oil Circuit Breakers
        2. Gas Circuit Breakers
        3. Vacuum Circuit Breakers
        4. Air Magnetic Breakers
        5. Live tank breakers

# Doble Power Factor Training Objectives

d. Miscellaneous equipment

1. Arresters
2. PTs
3. CTs
4. CCVTs
5. Oil
6. Wood members
7. Oil test cell

5. The student will be able to safely make all connections on Doble Power Factor Test Set.

6. The student will be able to perform diagnostic tests on M4000 equipment

7. The student will have a basic understanding of DTA Field software.

8. Interpretation of case studies.

# REVIEW OF SAFE TEST PRACTICES

| SECTION: | PAGE: |
|---|---|

1-9-2020

# Power Factor Training

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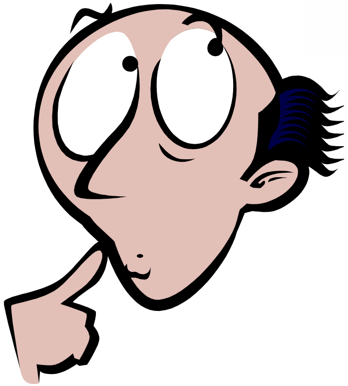
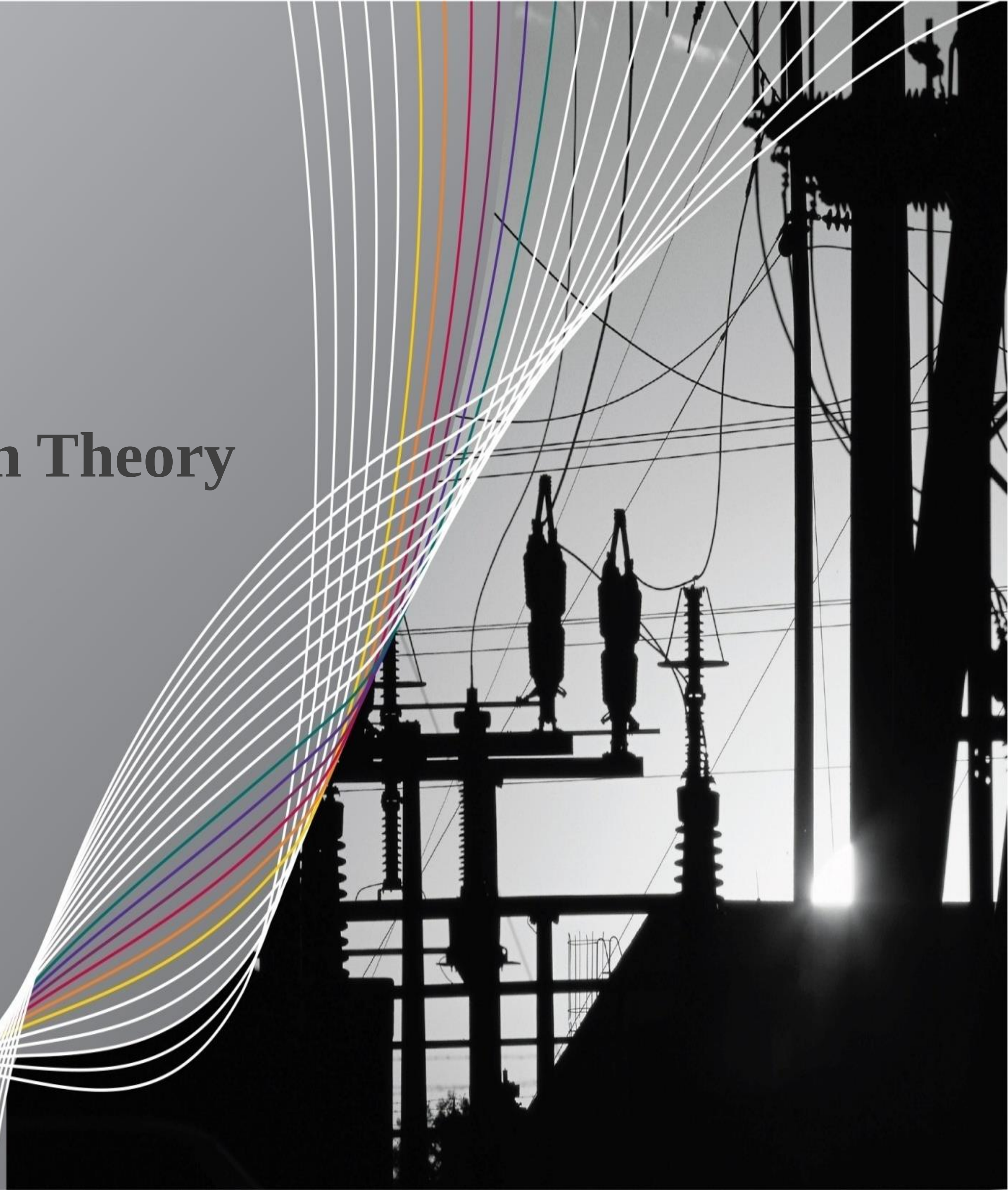
# Confidential Notice

# We Learn



- **10% of what we read**
- **20 % of what we hear**
- **30% of what we see**
- **50% of what we both see and hear**
- **70% of what is discussed with others**
- **80% of what we personally experience**
- **95% of what we TEACH to someone else**

# Basic Insulation Theory



# Basic Insulation & Power Factor Theory

## Topical Guide Objectives

- Review the Basic Insulation Models

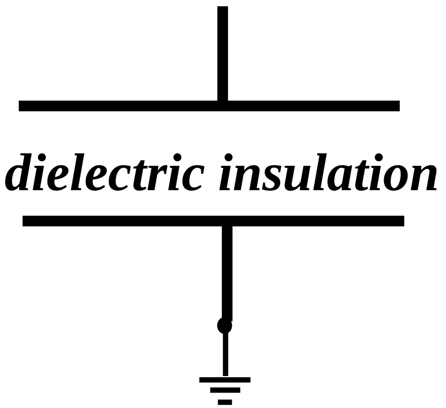
- Review Capacitance and it's Properties

- Review A-C dielectric Loss

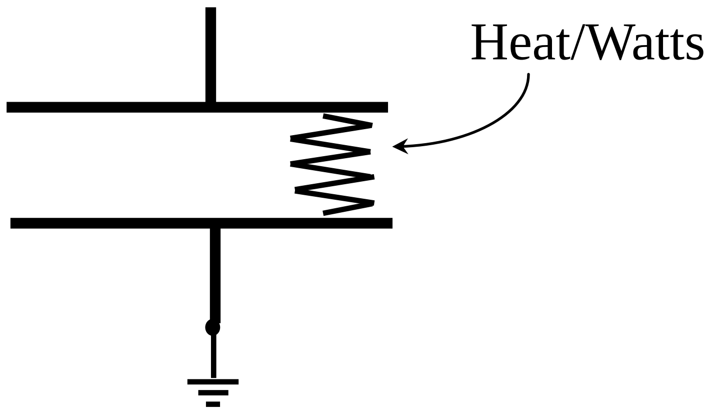
- Define Power Factor

# Insulation

Insulation is basically two plates separated by one or more dielectrics. One plate is at a high potential and the other at a lower or ground potential.



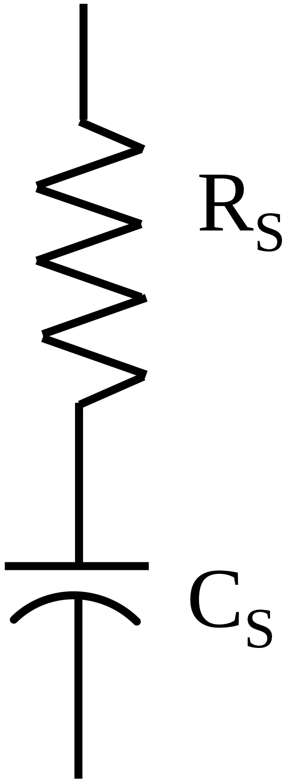

Current generated by polar contaminants in the dielectric shows up as Watts.



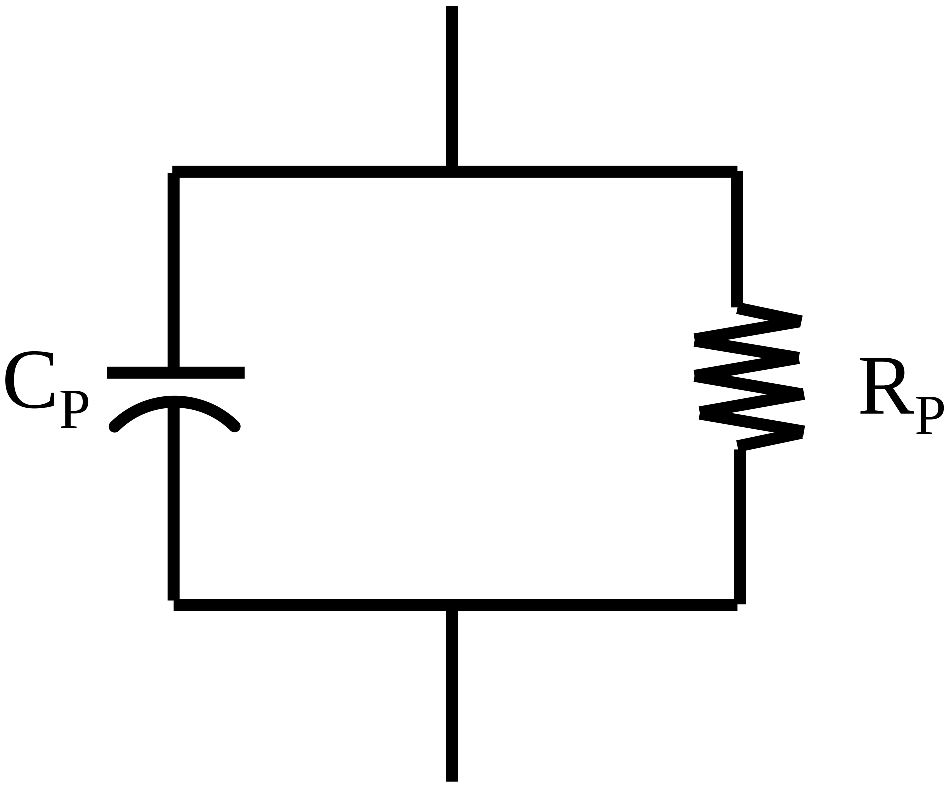
# Examples of Material With Insulating Properties

| Gaseous | Liquid | Solid |
|---|---|---|
| High Vacuum | Hydrocarbon-Based Oil | Cellulose |
| Air | Silicone Oil | Porcelain |
| Sulfur Hexafluoride ($SF_6$) | Distilled Water | Phenolics |

# Simplified Equivalent Circuits of an Insulation Specimen

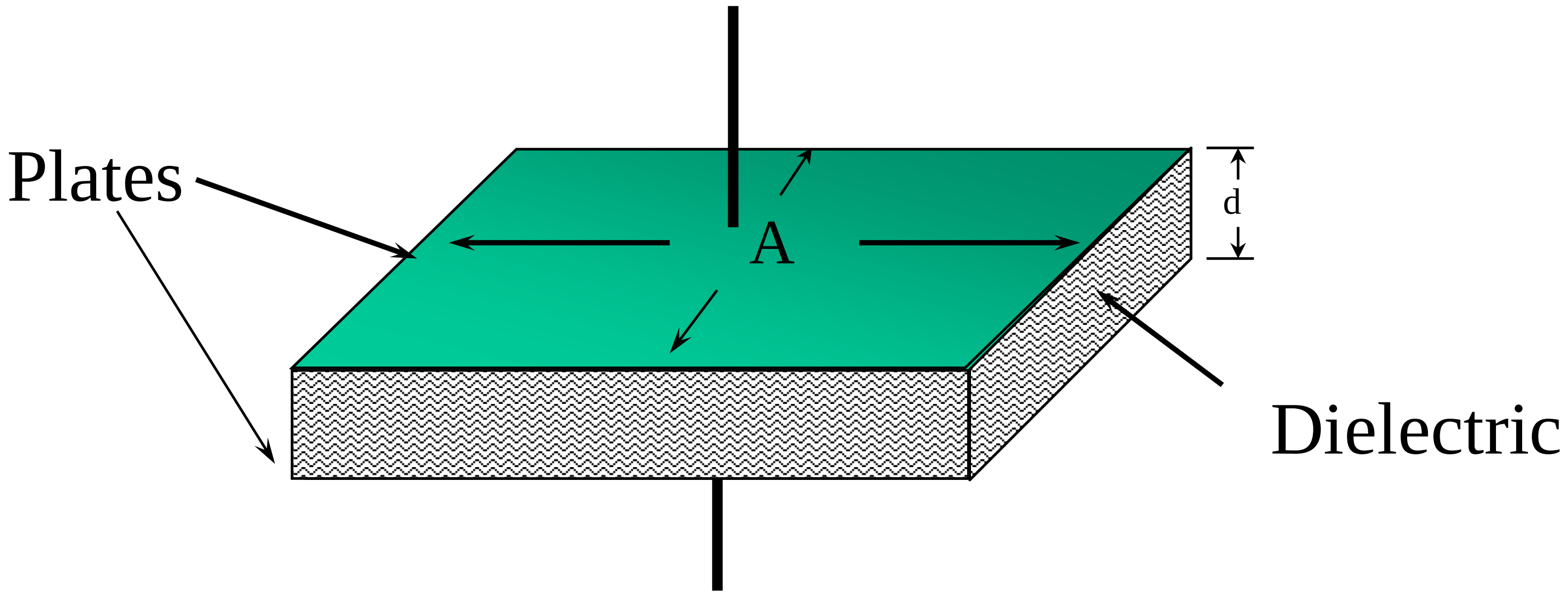



Series Circuit (a)




Parallel Circuit (b)

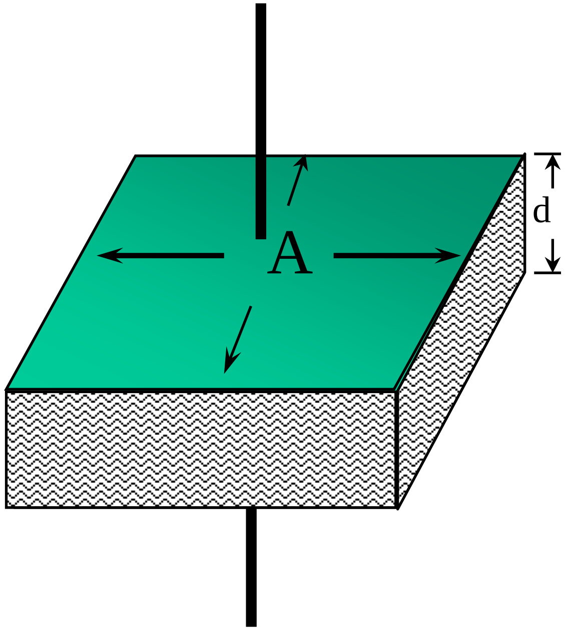
# The Capacitor




Two conducting plates with area “A” separated by a dielectric with a thickness of “d” and dielectric constant ε

# Capacitance

$$C = \frac{A\varepsilon}{d}$$




C = Capacitance

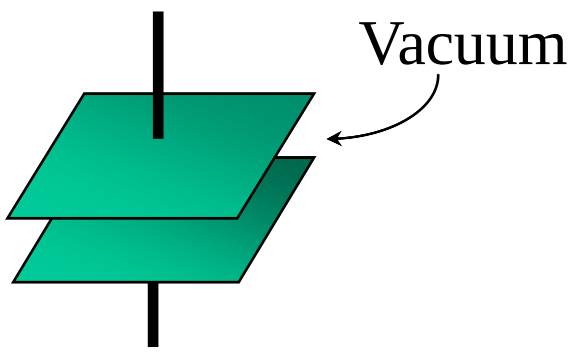
ε = dielectric constant

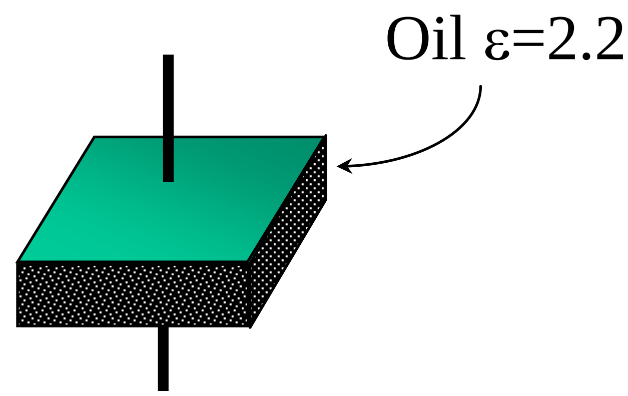
d = Distance between plates

All the variables are Physical parameters

# Dielectric Constant

- In 1836, Michael Faraday (the father of the Capacitance -- Just look at his name) discovered that when the plates between a capacitor were filled with another insulating material, the capacitance would change.
- This factor is the dielectric constant ε
- By definition the dielectric constant of a Vacuum is 1.0. All other dielectric constants are referenced to this standard.




$C_{vacuum}$=10 pF

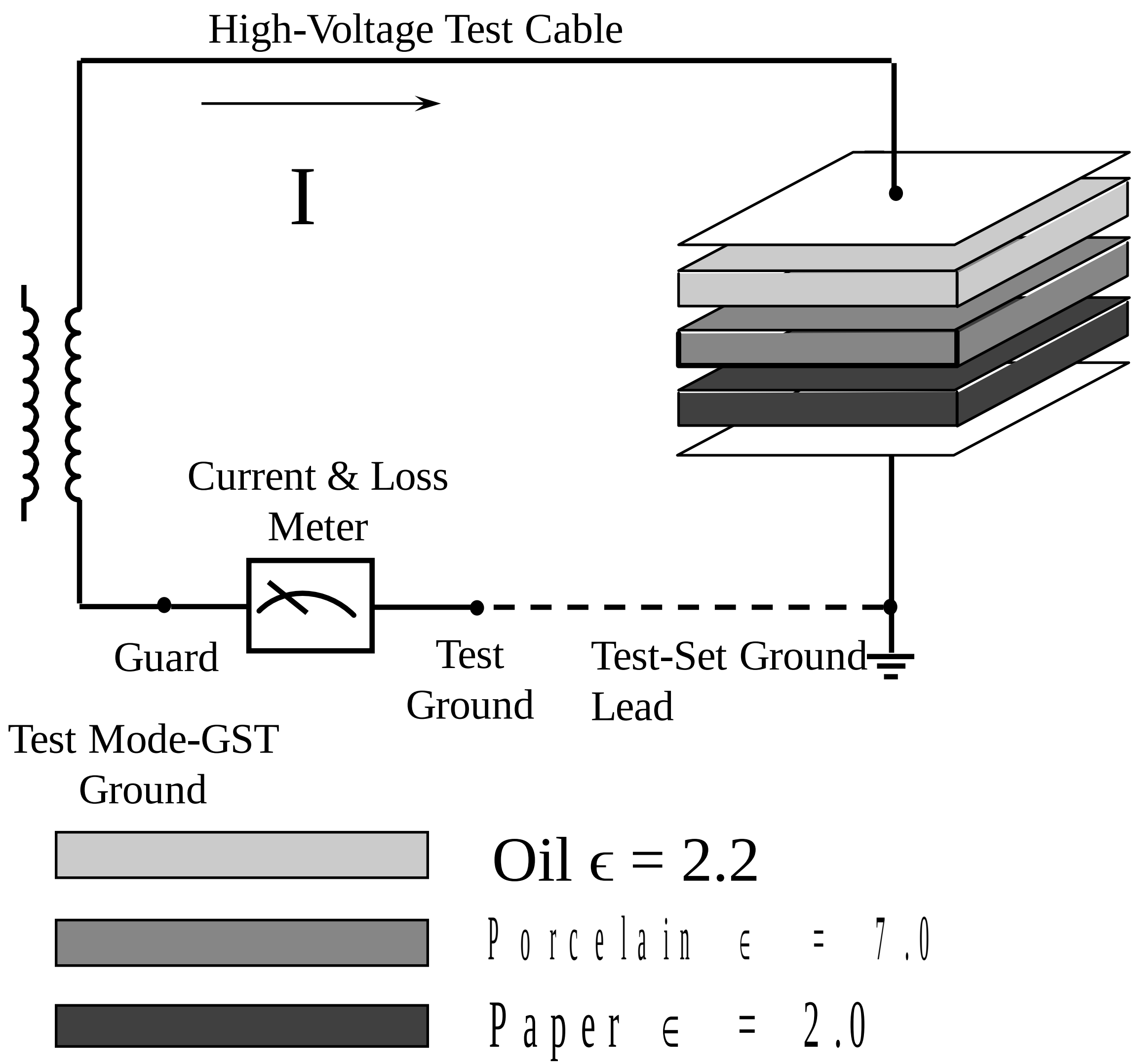
$C_{oil} = \varepsilon \; x \; C_{Vacuum}$ = <u>22 pF</u>

# Dielectric Constants

| Material | Constant |
|---|---|
| Vacuum | 1.0 |
| Air | 1.000549 |
| Mica | 5.4 |
| Paper | 2 |
| Porcelain | 7 |
| Oil | 2.2 |
| Silicone Fluid | 2.75 |
| Water (20$^{o}$ C) | 80 |

*SF6 is not listed as the dielectric is dependent on temperature and pressure*

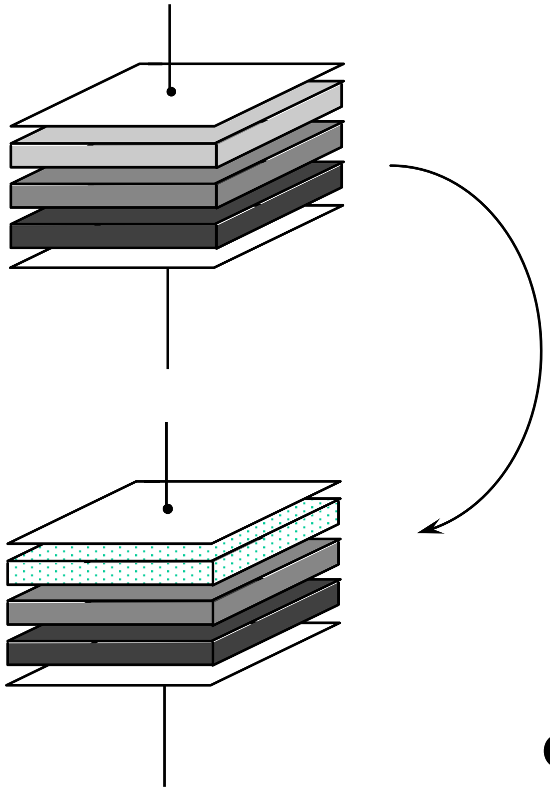
# Typical Insulation System



# Example: Oil leaking from an Insulation System

Oil = 2.2
Porcelain = 7.0
Paper = 2.0
Air = 1.0

Given three dielectrics in series the dielectric constant ε is:



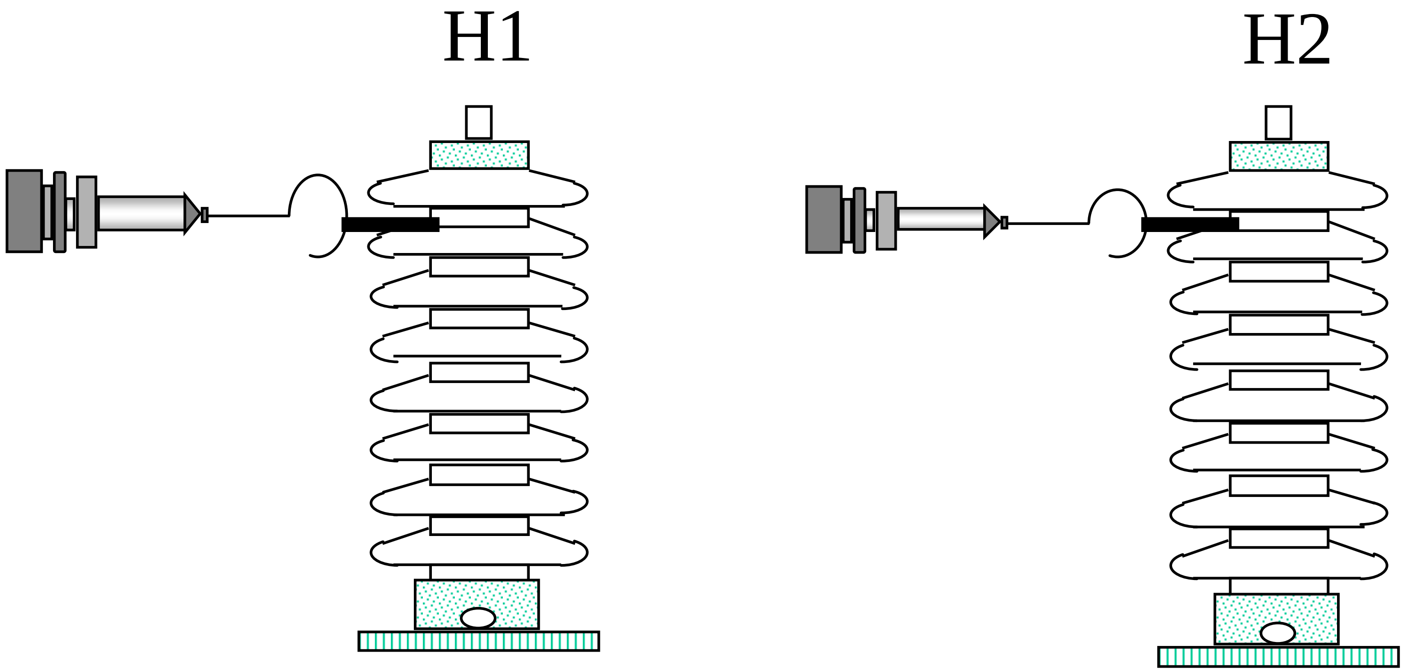
$\varepsilon_{before}$ = 1/2.2+1/7.0+1/2.0 = 1/T= 1.097

If the Oil leaks out and is replaced by air...

$\varepsilon_{after}$ = 1/1+1/7+1/2.0= 1/T= 0.608

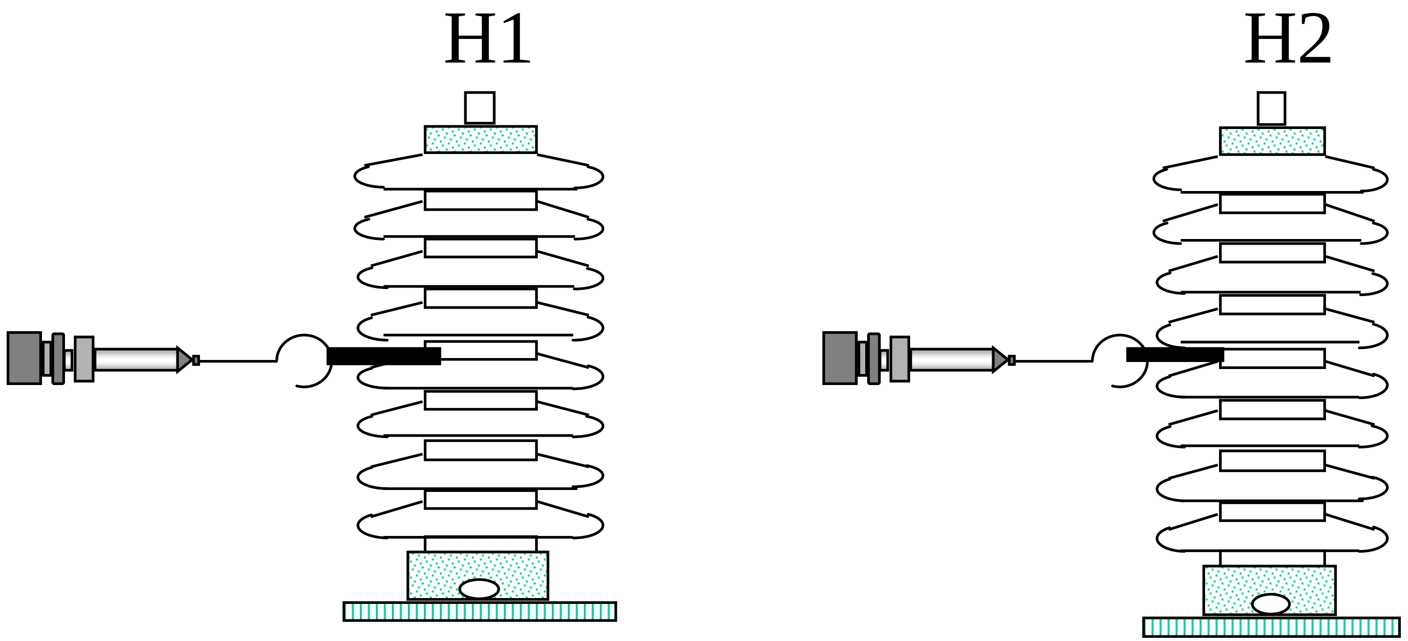
$\therefore \quad C \downarrow \quad \Rightarrow \quad I_t \downarrow$

# Example: Oil leaking from an Insulation System



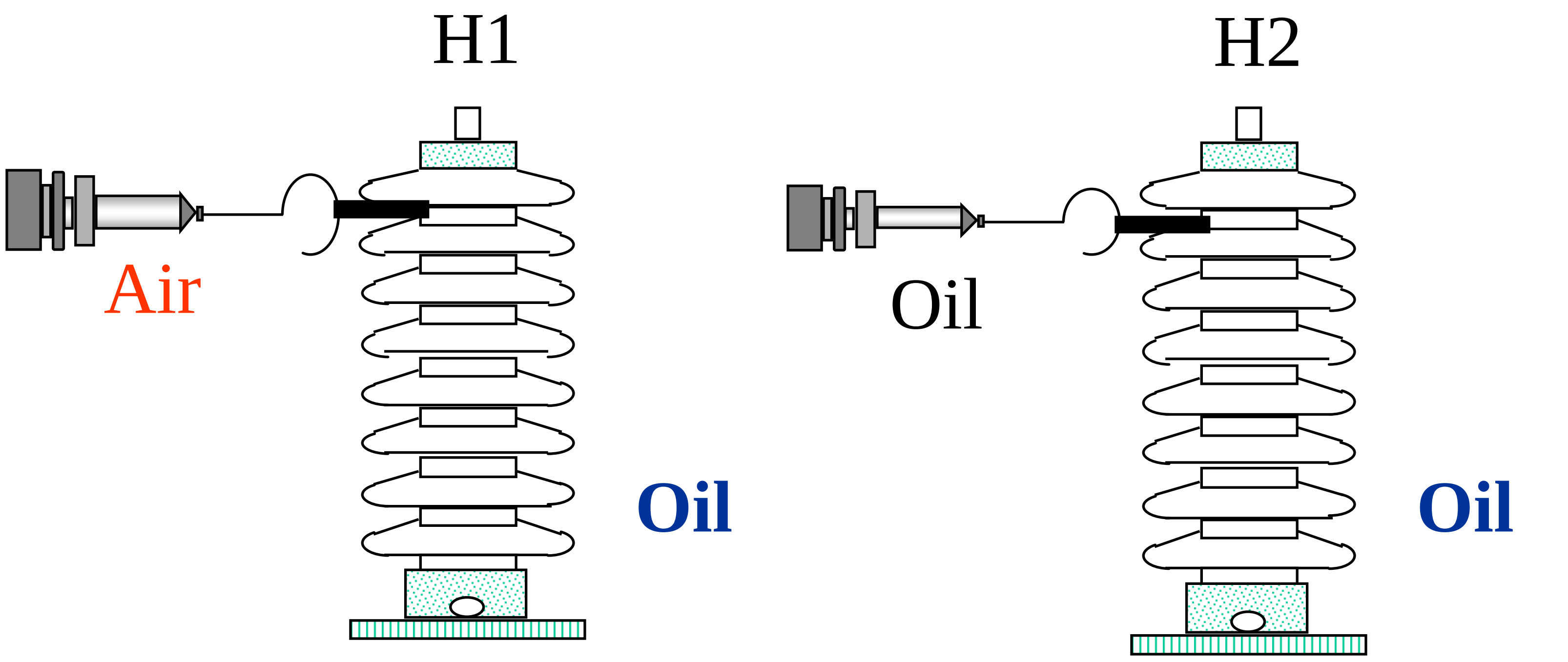

**H1 mA < H2 mA**

# Example: Oil leaking from an Insulation System




**H1 mA = H2 mA**

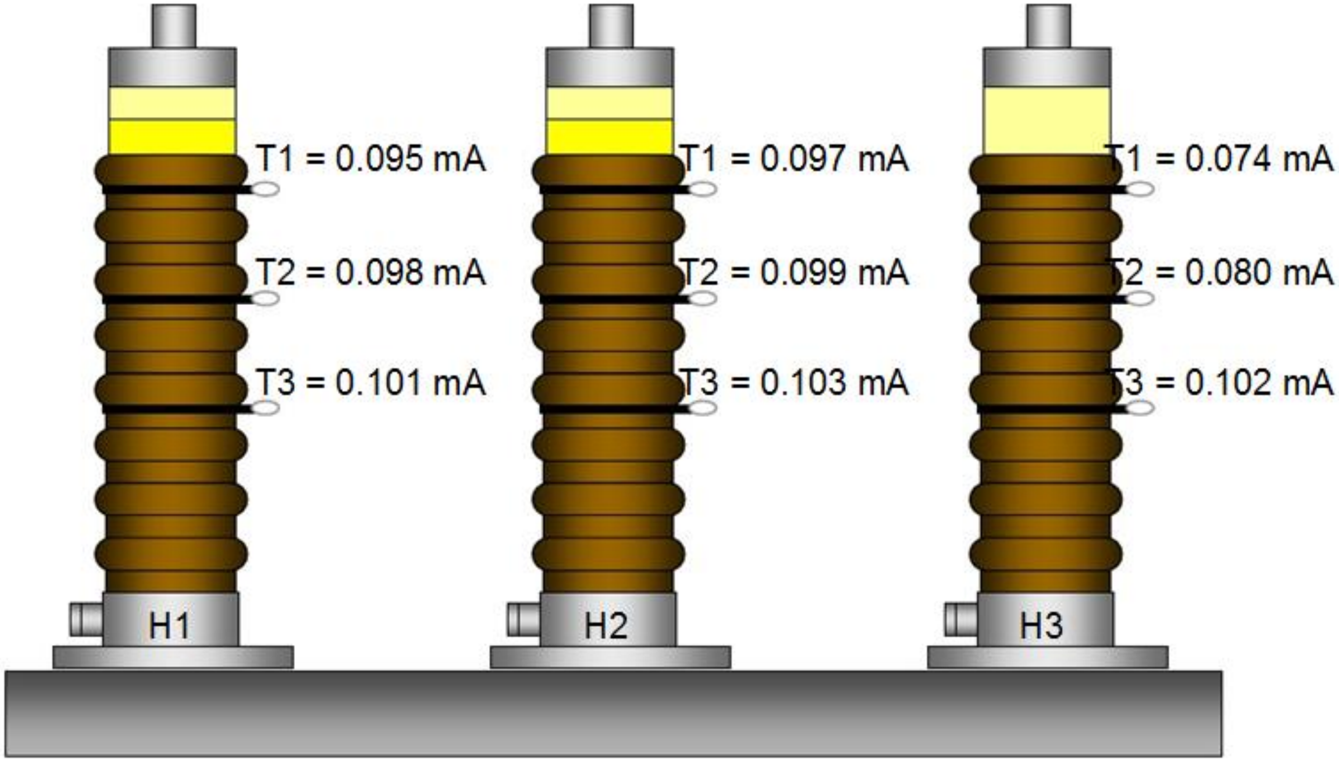
# Example: Oil leaking from an Insulation System




**H1 mA < H2 mA**

**Dielectric Constant of Air is Less than Oil**

# Hot Collar Test – Comparing Currents




Conclusion: The oil level in the H3 bushing is somewhere between the locations used for tests hot-collar tests 2 and 3.

# Dielectric Loss

Dielectric Loss is the time rate at which electric energy is transformed into heat in a dielectric when it is subjected to an electric field. The heat generated is given in terms of Watts.

$$i_R \approx Watts \qquad \text{(from vector diagram)}$$

$$Watts = E\, I_R \qquad \text{(from dielectric model circuit, parallel R/C network)}$$

$$Watts = Normal\ losses + Contamination + Deterioration$$

$$Contamination = Water + Carbon + Dirt$$

$$Deterioration = Carbon + Corona$$

# Watts

- Is the current created by polar contaminants in a dielectric that are influenced by electrical stress.
- Is the energy expended on these contaminants in the of form of HEAT
- Is a function of Volume. The more insulation the more area there is to dissipate watts (from contamination, deterioration, and normal losses).
- To analyze Watts-Loss your need to be able to compare the dimension of the insulation tested -- difficult.
- If you had perfect insulation the testing current would be purely capacitive

# The Term *Power Factor*

Describes:

- The phase angle relationship between the applied voltage across and the current through a specimen

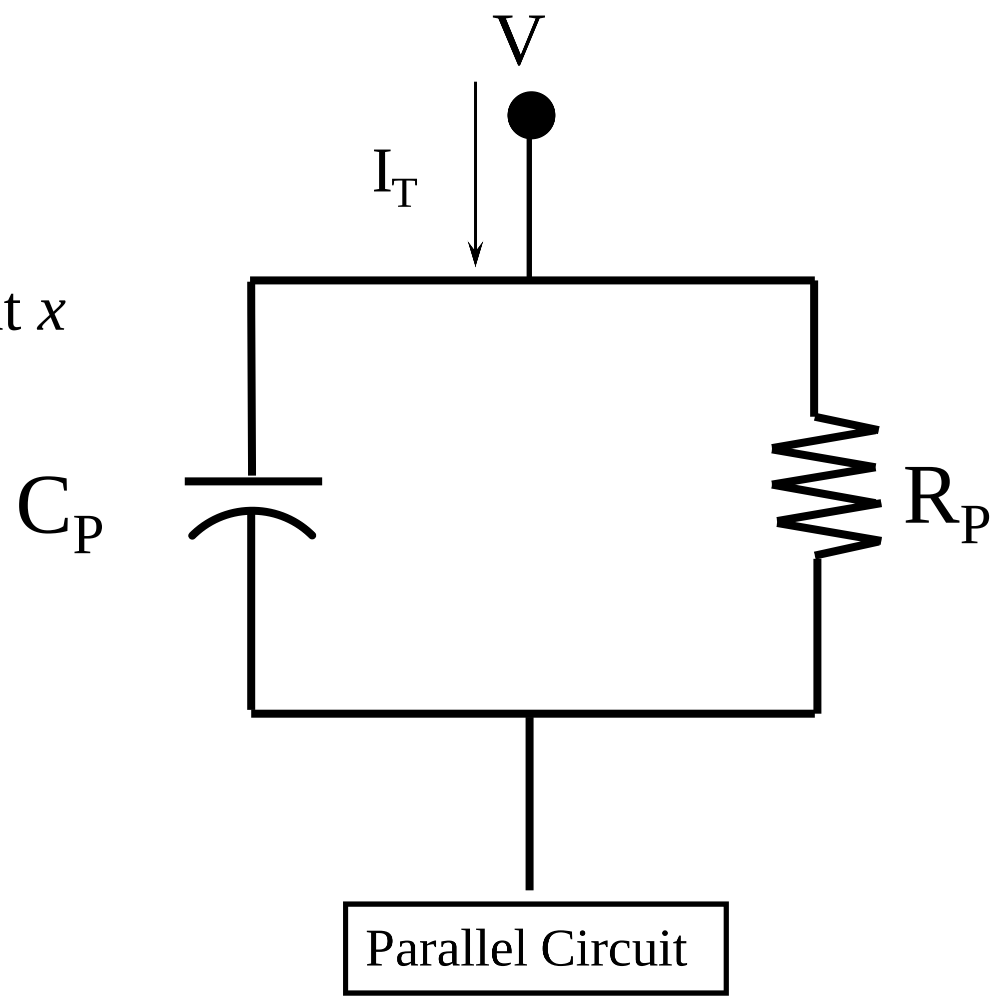
- The ratio of the real or average power to the apparent power

- The efficiency of a power system in terms of real and reactive power flows

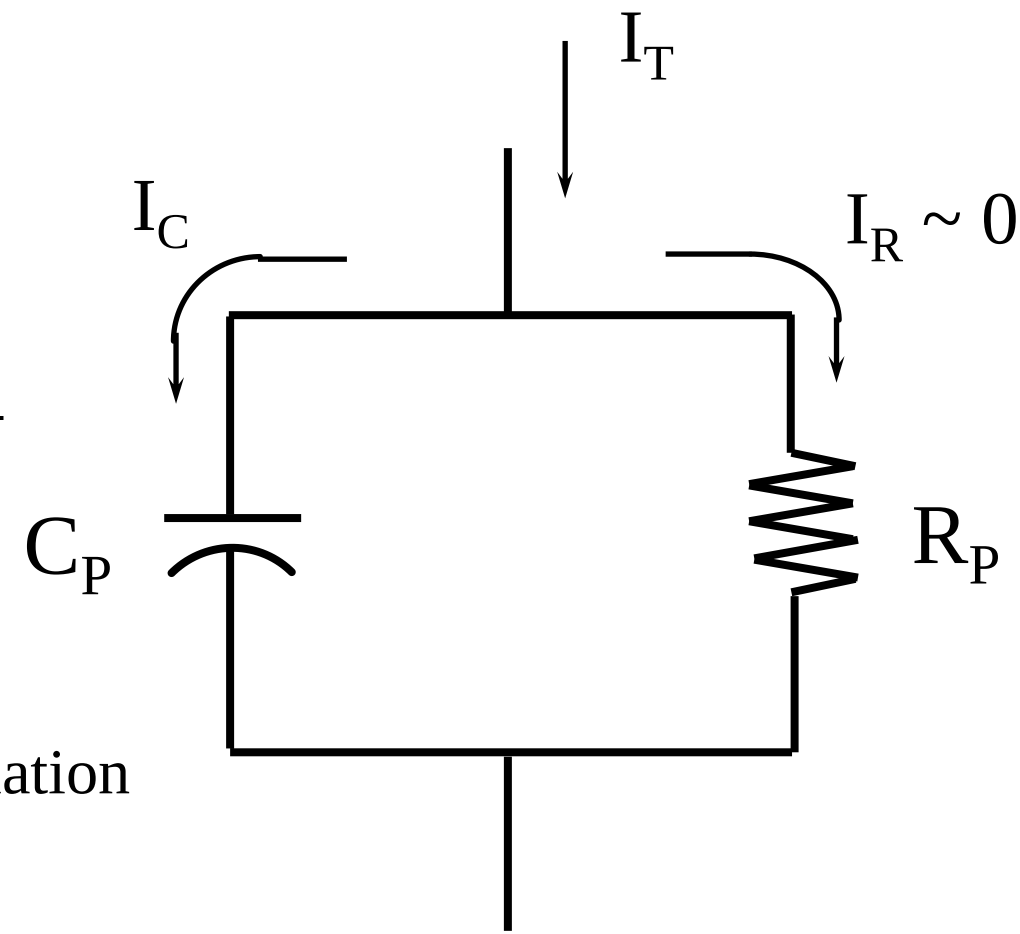
# Basic Equation

Power = Voltage *x* Current *x* Cosine(θ)

**P= VI Cos(θ)**



# Typical Insulation System




**Good Insulation: Has a very low power factor**

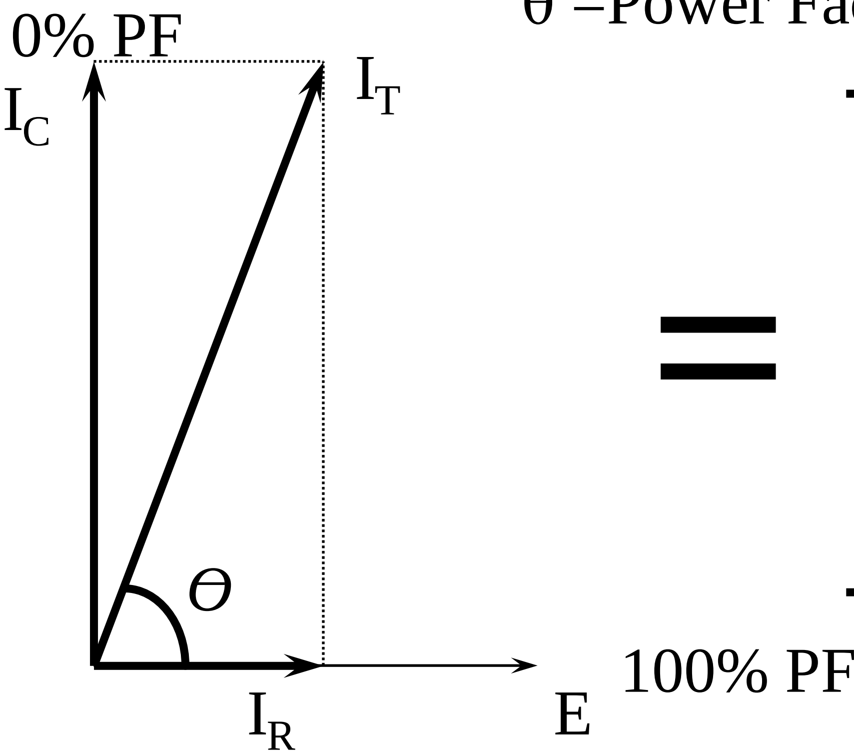
- $I_R << I_C$ for most insulation systems, $I_C \sim I_T$

# Basic Power Factor

$I_T$=Total Current  $I_C$=Capacitive Current

$I_R$=Resistive Current  E=Applied Voltage

$\theta$ =Power Factor Angle

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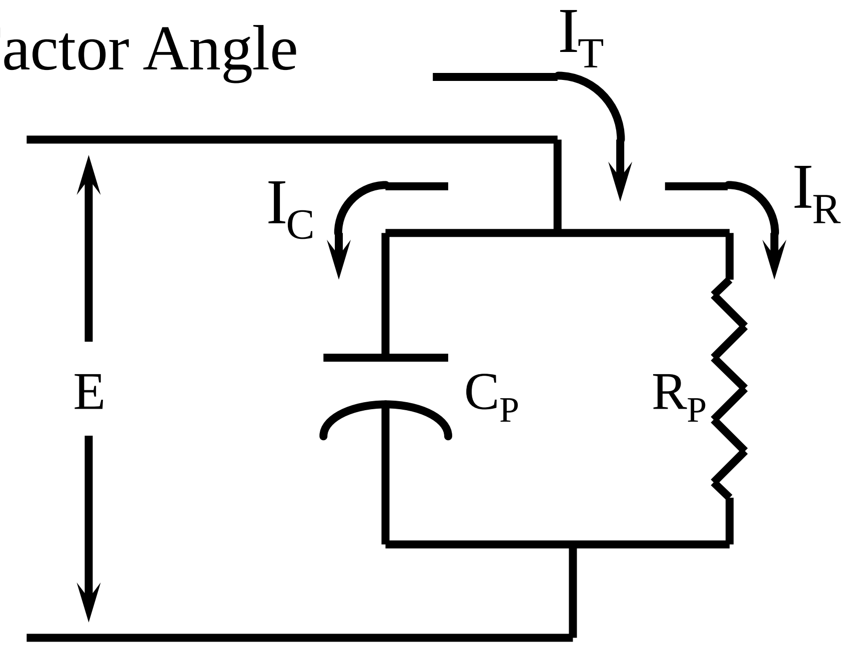


# Power Factor Is:

$$\text{Watts} = E \times I_R$$

$$\text{Watts} = E \times I \times \text{Cosine } \Theta$$

$$PF = \text{Cosine } \Theta = \frac{\text{Watts}}{E \text{ x } I_T} =$$

$$\frac{E \times I_R}{E \times I_T} = \frac{I_R}{I_T}$$

# What Is Power Factor (PF)?

$$Power\ Factor = \frac{W}{I_T * E} = \frac{\text{Real Power}}{\text{Apparent Power}}$$

To express power factor in percent (% PF), multiply by 100:

$$\%PF = \frac{W}{mA \text{ X} 10^{-3} * 10 \text{ X} 10^{3}} \text{X} 100$$

$$= \frac{W \text{ X} 10}{mA}$$

10 kV equivalent values

# Power Factor Is:

- Independent of specimen size

  Useful for tabulations and comparisons

- Temperature sensitive

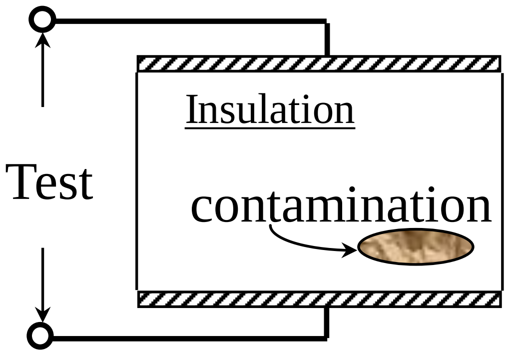
  Needs to be corrected for liquid-filled apparatus

- Performed at or near apparatus frequency

  Similar to normal operation

# Basic Principals of Testing:

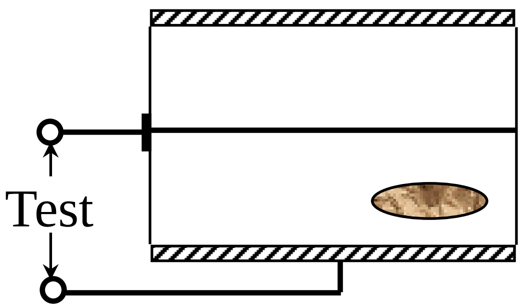
## *Always test the smallest piece possible*




- Power factor testing measure the average condition of an insulation system

- Contamination would affect the total insulation system, but not to a large degree

## Always break an insulation system into the Smallest possible part in order to detect insulation faults.




The contamination becomes a "bigger piece" of the insulation and is easier to see

# Dielectric Loss and Power Factor:

## *What are they good for...*

The Dielectric Loss and Power Factor are sensitive to soluble polar, ionic or colloidal materials:

Moisture (free, in cellulose, with particles in oil)

Products of Oxidation or mineral oil

Carbon  (with moisture)

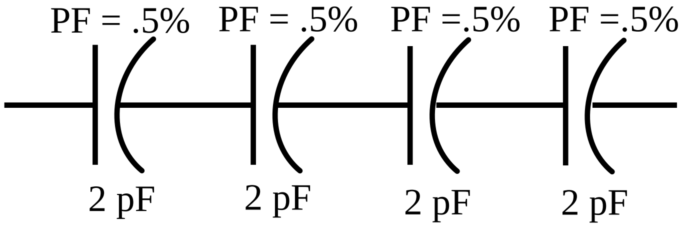
Metal Soaps

At Higher voltage:

Ionization in solid insulation

# Is the Doble Test Effective for Detecting Defective Insulation?

1)

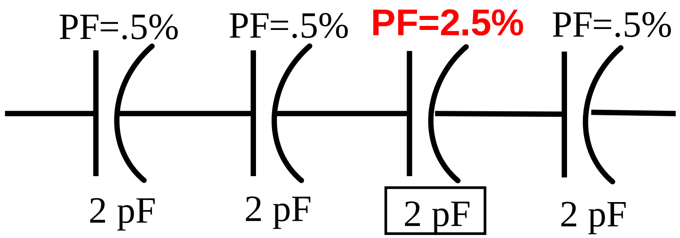



$$PF_{\Sigma} = \frac{.5 + .5 + .5 + .5}{4} = .5\%$$

$$\frac{1}{c} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} = 2 \qquad c = \frac{1}{2}\,pF$$

# Is the Doble Test Effective for Detecting Defective Insulation?

2)

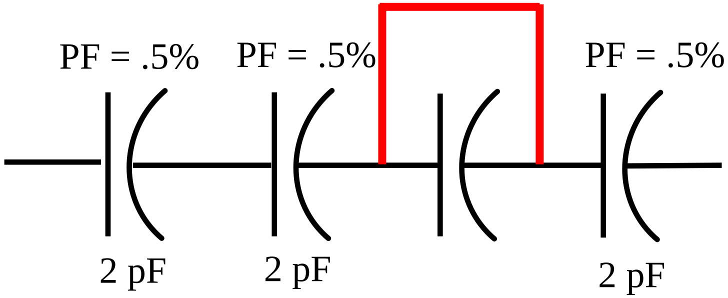



$$PF_{\Sigma} = \frac{.5x3 + 2.5}{4} = 1.0 \qquad c = \frac{1}{2}pF$$

Power Factor increases from 0.5% to 1.0%
no change in capacitance

# Is the Doble Test Effective for Detecting Defective Insulation?

3)



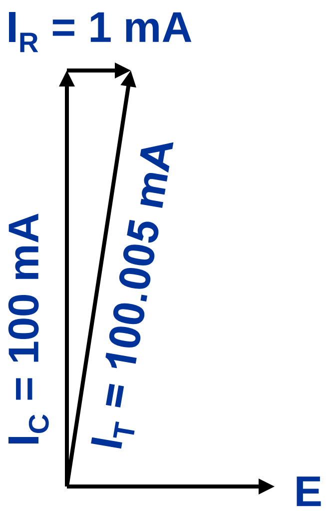

$$PF = \frac{.5 + .5 + .5}{3} = .5\%$$

$$\frac{1}{c} = \frac{1}{2} + \frac{1}{2} + \cancel{\frac{1}{2}} + \frac{1}{2} \qquad c = .667\ pF$$

Power Factor remains 0.5% with a 33% change in current

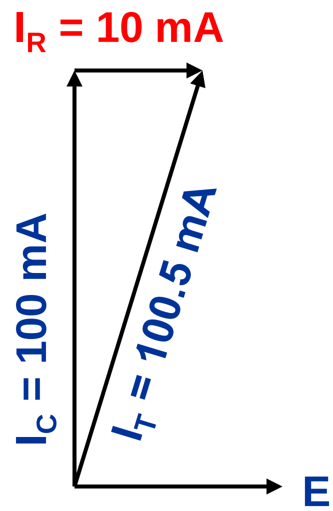
# Changes in Power Factor

**Case 1**
Starting Condition



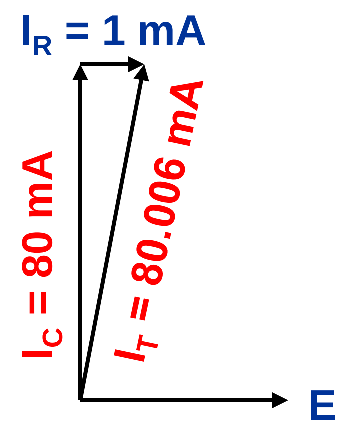

$W_{LOSS}$ = 10
C = 26,500 pF
PF = 1.00%
$I_T \cong I_C$

**Case 2**
Contamination




$W_{LOSS}$ = 100
C = 26,500 pF
PF = 9.95%
$I_T \cong I_C$

**Case 3**
Change in A, d, or ε



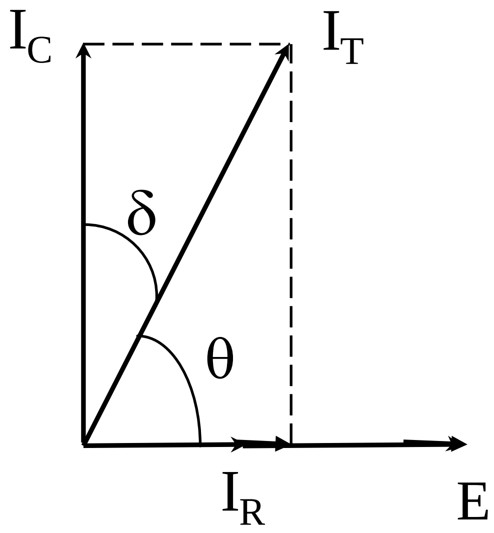

$W_{LOSS}$ = 10
C = 21,200 pF
PF = 1.25%
$I_T \cong I_C$

Except for extreme cases, contamination has only a small effect on the measured current $I_T$.

A significant change in $I_T$ is usually related to a change in capacitance; $I_T \cong I_C = E\omega C$.

Power Factor is affected by both contamination (watts) and capacitance (mA).

# Power Factor Vs. Dissipation Factor




$$\text{Power Factor} = \cos\theta = \frac{I_R}{I_T}$$

$$\text{Dissipation Factor} = \tan\delta = \frac{I_R}{I_C}$$

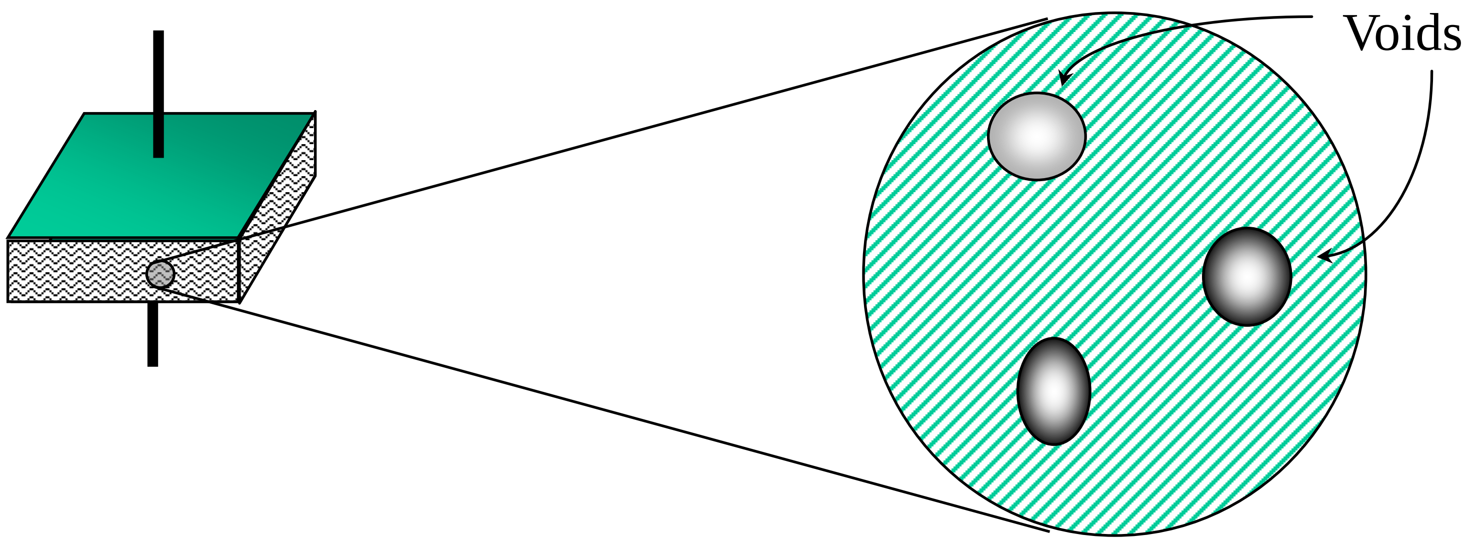
| θ ° | % PF (%COS θ ) | δ° | % DF (% TAN Δ) |
|---|---|---|---|
| 90 | 0 | 0 | 0 |
| 89.71 | .500 | .29 | .500 |
| 84.26 | 10.00 | 5.74 | 10.05 |
| 0 | 100.00 | 90 | INFINITY |

# Comparison of Percent Power Factor With Percent Dissipation Factor for Various Phase Angles of Q and d

| $\theta$ | % PF (% cos) | $\delta$ | % DF (% tan) |
|---|---|---|---|
| 90 | 0 | 0 | 0 |
| 89.71 | .50 | .29 | .50 |
| 87.13 | 5.00 | 2.87 | 5.00 |
| 84.26 | 10.00 | 5.74 | 10.05 |
| 81.37 | 15.00 | 8.63 | 15.18 |
| 53.13 | 60.00 | 36.87 | 75.00 |
| 45.00 | 70.71 | 45.00 | 100.00 |
| 0 | 100 | 90 | infinity |

# Voids and the Power Factor Tip-Up Test

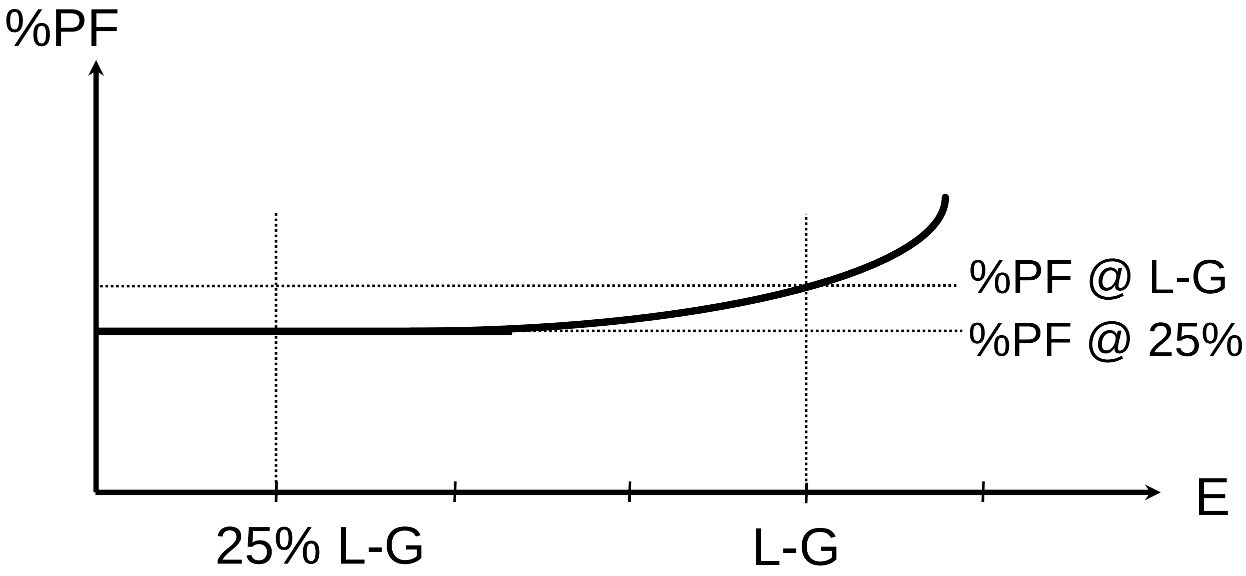
When we closely examine insulation, very small gaps or "voids" exist. These voids develop an electrostatic potential on their surfaces. These small gaps become ionized: Partial Discharge/Corona.



# Power Factor Vs. Test Voltage

Tip-Up = Power Factor at Line-to-ground voltage -
Power Factor at 25% Line-to-ground voltage

As test voltage is increased, the power factor will increase depending on the void density.




Tip-up occurs in dry-type insulation specimens such as Dry Type Transformer, rotating machinery, and cables.

# Calculation of Results

**For 10 kV sets:**

***Calculation of Percent (%) Power Factor***

% Power Factor = Watts x 10/Milliamperes

***Calculation of Capacitance***

Capacitance (pf) = 265 x Milliamperes (60 Hz)

Capacitance (pf) = 318 x Milliamperes (50 Hz)

***Calculation of Parallel AC Resistance***

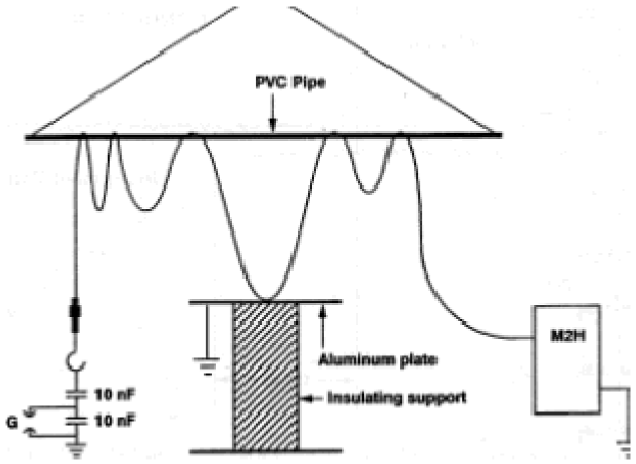
$R_{P\ (Megaohms)}$ = 100/Watts

(Equivalent 10kV values)

# Safety

# Safety Issues

- ***Do Not Hold the High Voltage Cable While Test Voltage is Applied***
  - Reference: 1995 Doble Conference Paper, Page 1-2.1




***Voltage is only on the ground shield when there is an abnormal condition.***

# Safety Issues

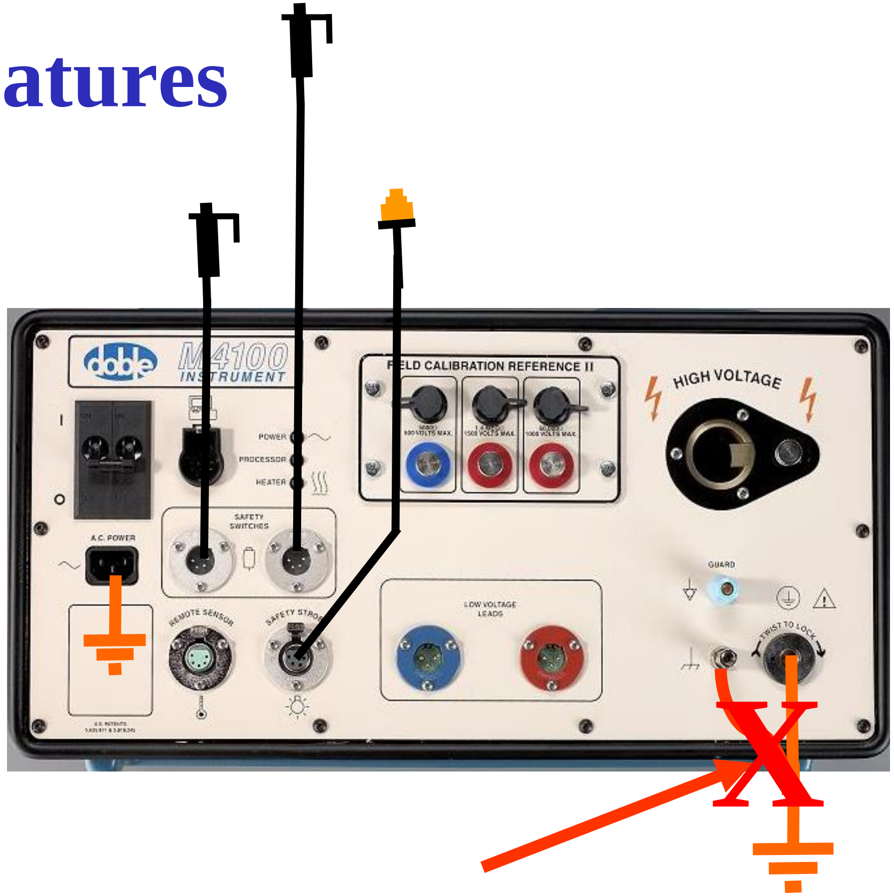
- One safety switch is for use by the test set operator; but since he cannot watch the apparatus while operating the test set, the other safety switch should be used by a designated safety observer
- Be aware that induced voltages or trapped charges may be present on the equipment to be tested, and be sure to drain these charges by applying grounds prior to making test connections
- ***Do not stand on equipment while testing is being performed.***

# Safety Issues

- Be familiar with the M4000 manual’s safety section in chapter one.  Note, however, that your company rules and government regulations take precedence over Doble recommendations

# Safety Features

- ✓ **<u>Ground Relay</u>**: two grounds connected to the M4000, assure continuity between them.
- ✓ **<u>Safety Switches</u>** : In good condition and both in use.
- ✓ **<u>Safety Strobe</u>** : Visible in the working area.
- ✓ **<u>Safety Beeper</u>**




**NEVER place a jumper from the ground to the “chassis” ground on the test set**

# Safety

## Prepare the Specimen for Testing

**Safety meetings, de-energize, ground, isolate, safeguard, etc., observe your company's safety policy and in compliance with applicable safety regulations (OSHA, NFPA, etc).**

## Grounding the Test Equipment

**The ground lead should always be the first test lead connected and the last test lead removed. This ensures that the test set chassis is safely grounded, and it removes touch potential hazards.**

# Safety

## Static and Induced Voltages

**To avoid exposure to static or induced voltages:**

- **Ground before making test lead connections**
- **Connect test leads to M4100 first and then to specimen**
- **Ground before removing test lead from specimen**
- **Remove test leads from specimen first and then from M4100**

*** Note: Proper protective equipment and live line tools must be utilized while applying and removing grounds.**

# Safety

## During Tests

**Good Communication to avoid confusion, example of communication:**

1. **Operator - “Ready?”**
2. **Safety Lookout – Responds “Ready” if the connections are made and the work area is safe, or “No” if not ready and safe.**
3. **Operator – “Going hot.”**
4. **Safety Lookout – Echoes “Going hot” to acknowledge the operator.**
5. **Test is initiated … completes.**
6. **Operator – “All Clear.” Operator extends the operators safety switch at arms length with the button released for all to see.**

# Safety

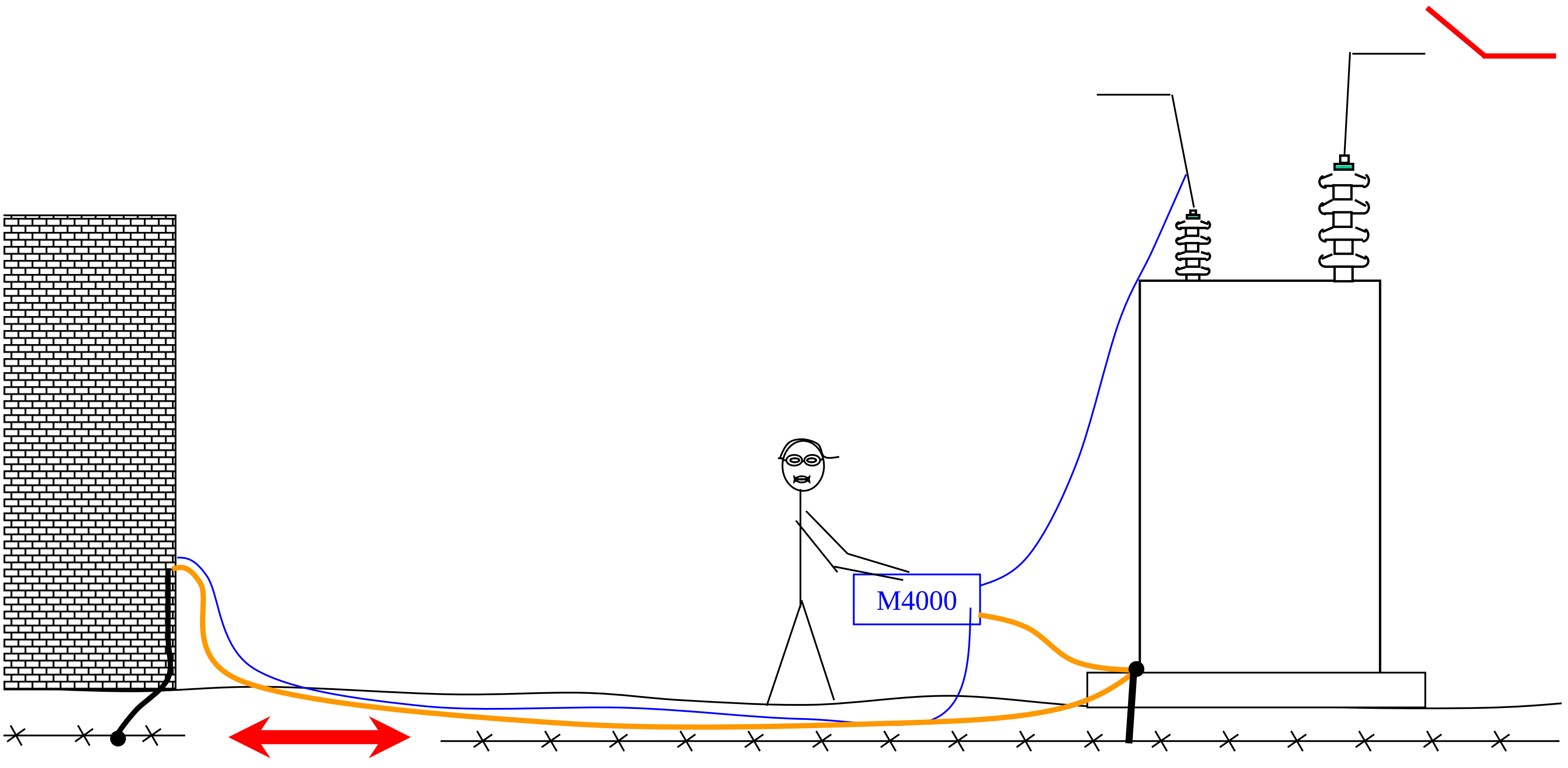
## During Tests (continued)

**Safety Lookout. The Safety Lookout should position himself in an area where he can observe all terminals and access points to the apparatus under test.**

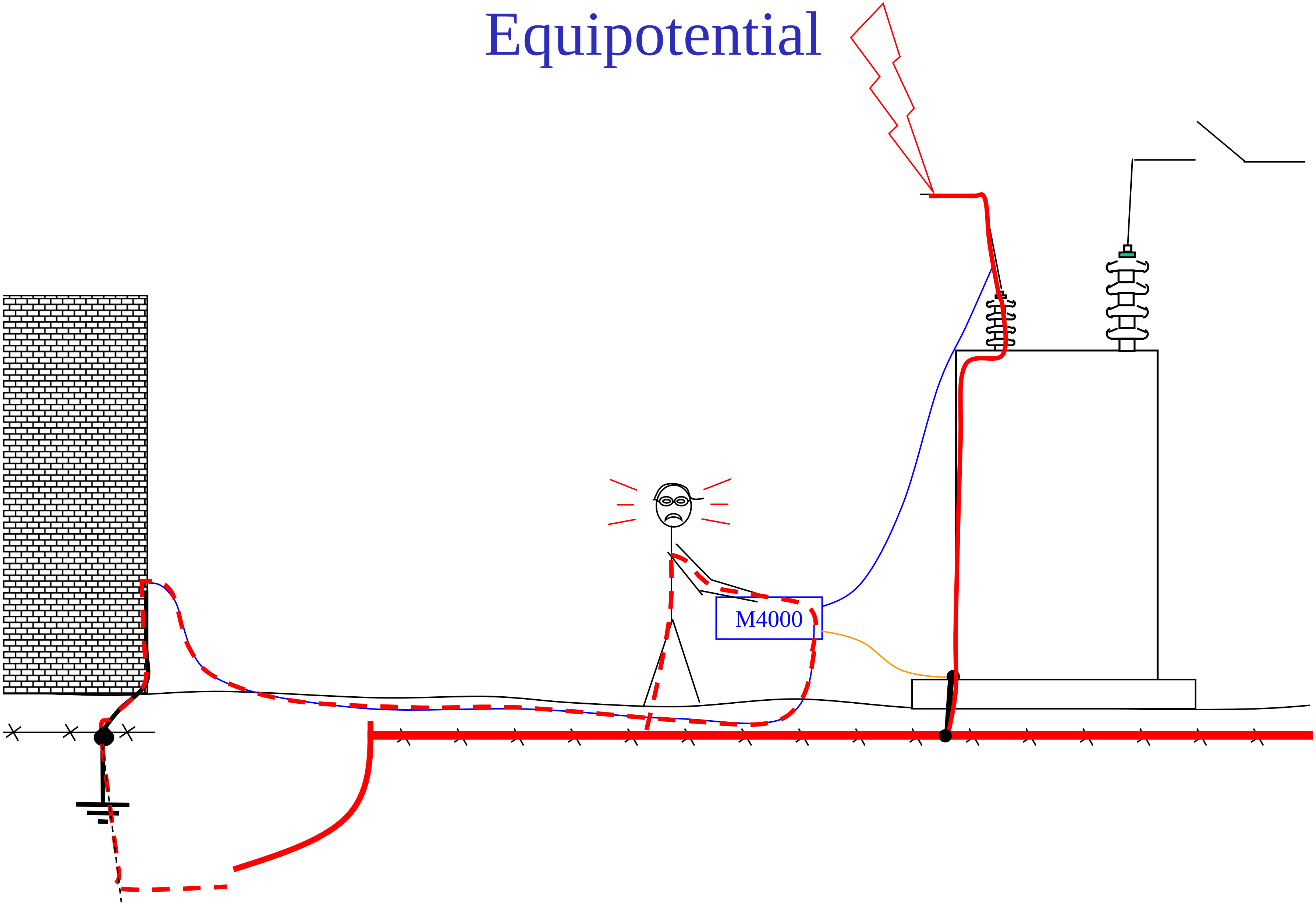
**Safety Switches. The Safety Switches can be released at any time to terminate a test. This may be necessary if unauthorized personnel enter the area or if some other undesirable situation develops.**

**Testing with Personnel on the Specimen. Testing with personnel on the specimen is strongly discouraged.**

# Equipotential



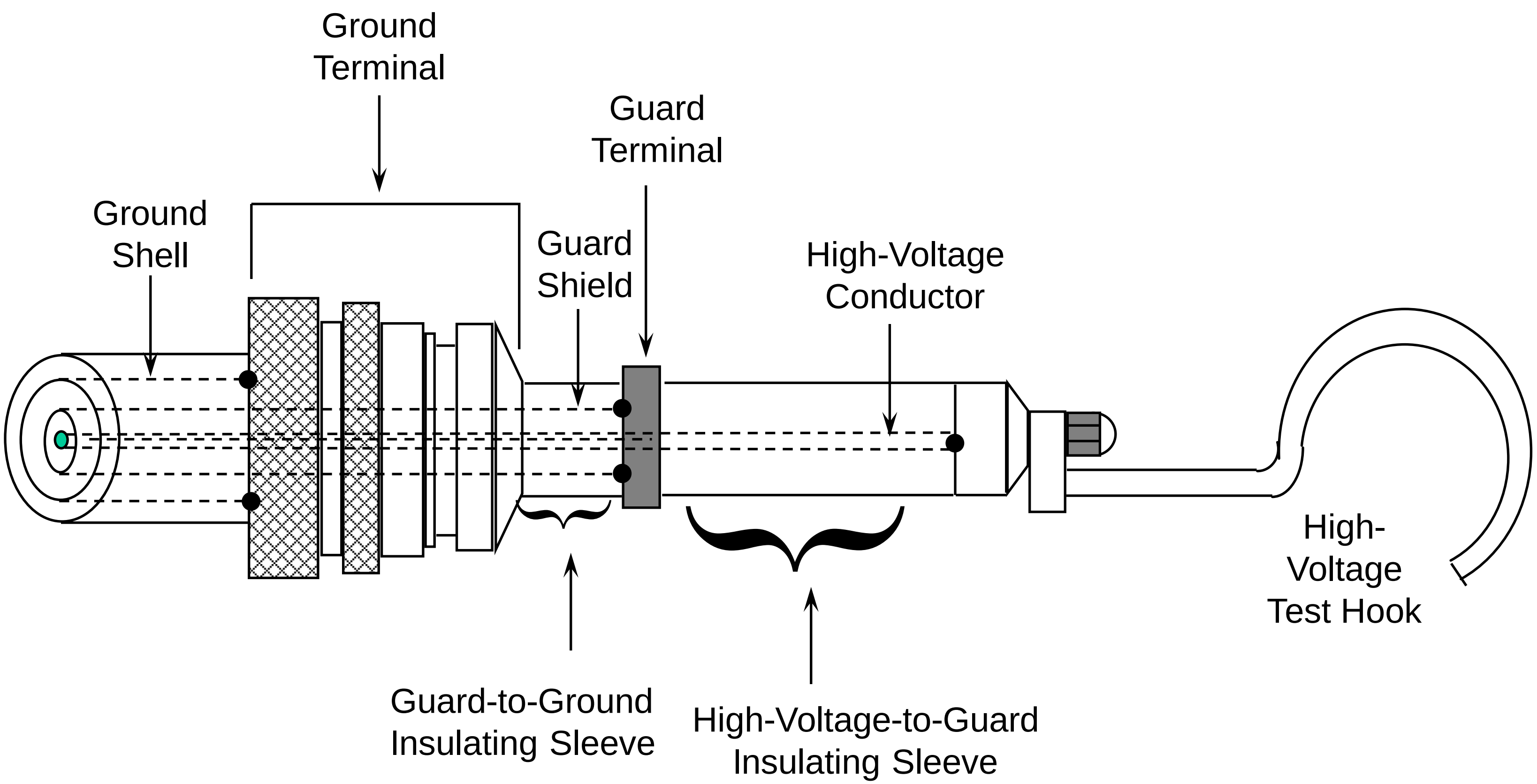
# Equipotential



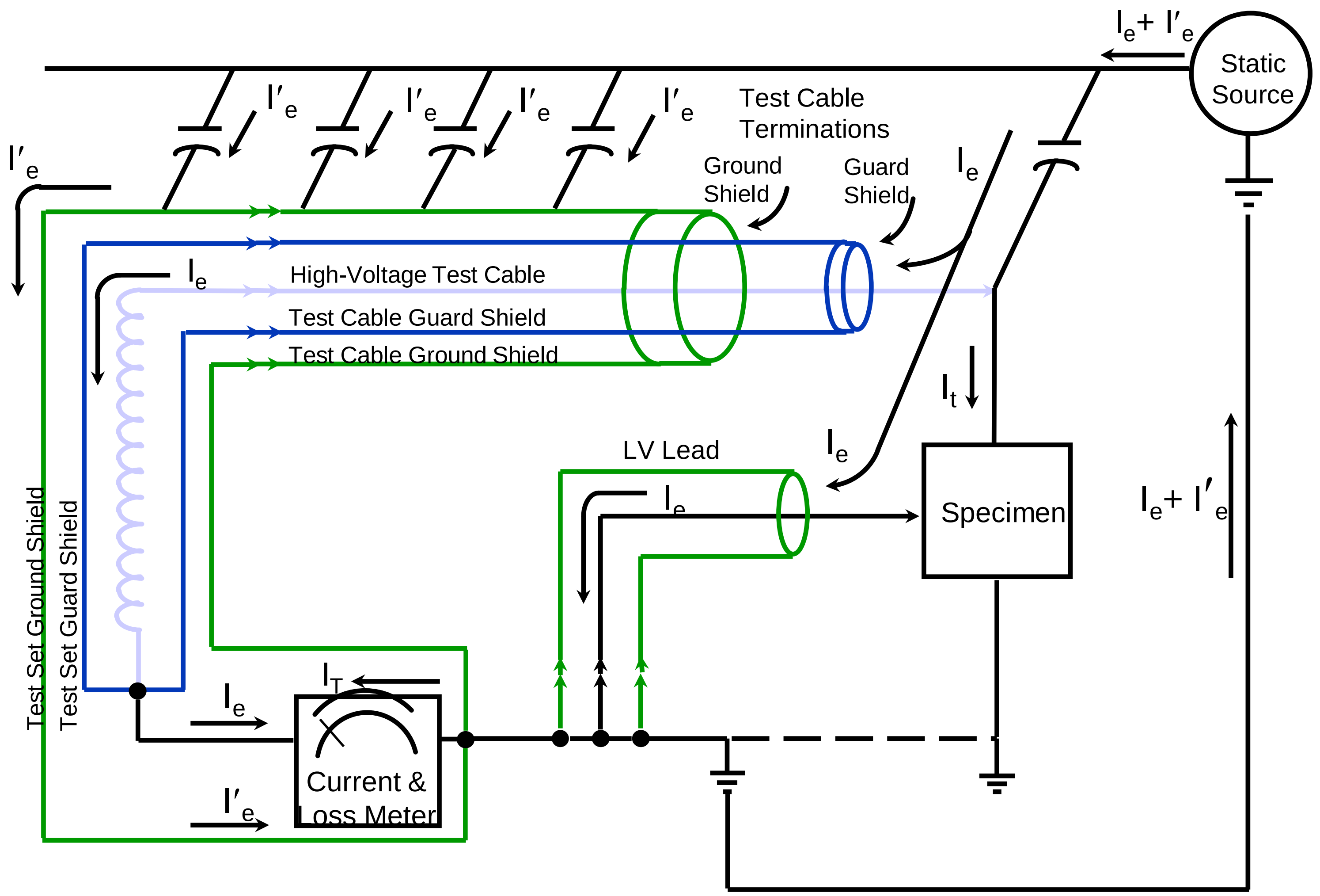
# Test Modes

# Doble High-Voltage Test Cable

## Outboard Pothead



# Test Set Shielding System, GST Mode



# Five Pieces of Information

1) Current

2) Watts Loss

3) Power Factor

4) Capacitance

5) Power Factor Vs. Voltage Characteristic

# Basic Laws of Electricity

- A Difference in Potential Must Exist Between Two Points in order for current to flow
- Current Always Returns to It's Source!
- Current Always Takes the Path of Least Resistance (but current is on each path)

# Components of Simplified Test Circuits

- Power Source
- Current & Loss Meter
- High-Voltage Test Cable
- Low-Voltage Test Cable
- Insulation Specimen
- Test Ground

- Test Set Operation is Based on the Relative Positions of the Power Source, Current & Loss Meter, and the Insulation Specimen With Respect to the Various Test Leads.

# Basic Test Circuits

- GST - Grounded-Specimen Test
  - The Grounded Specimen Tests Measures Current Flowing to Ground
- UST - Ungrounded Specimen Test
  - The Ungrounded Specimen Test Measures Current Flowing to an Ungrounded (Floating) Meter Circuit

- **GST** – The Low Voltage Lead can be Grounded or Guarded
- **UST** – The Low Voltage lead can be Measured or Grounded

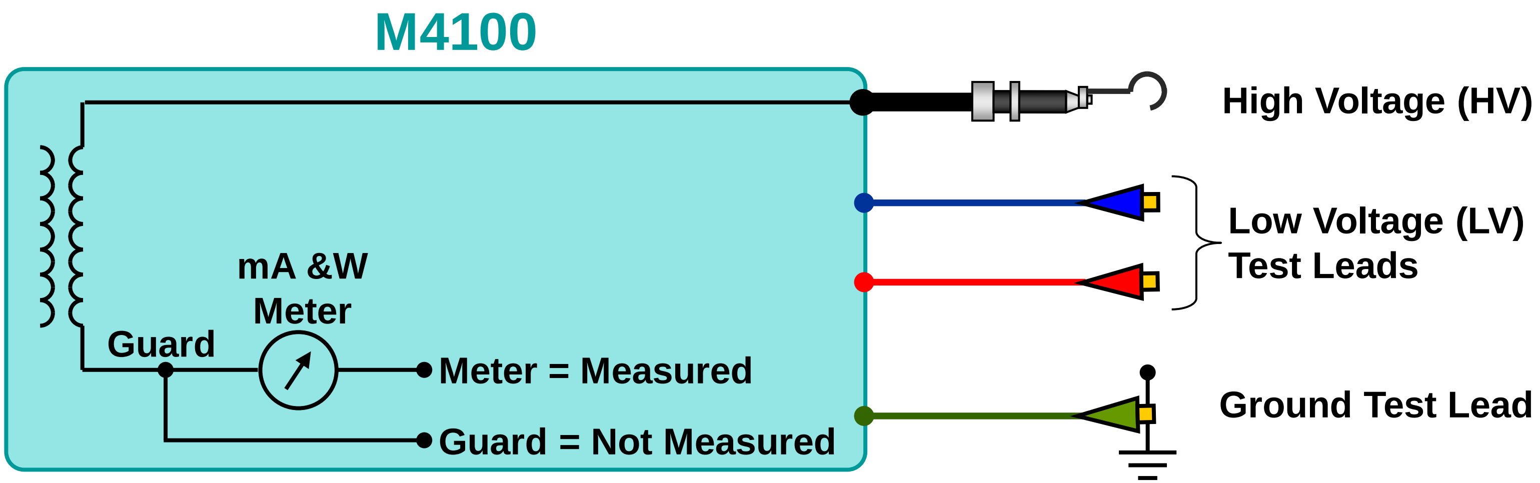
# Basic Test Circuits

**GST - Grounded-Specimen Test**

- In the GST, All Current Going to Ground is Measured

- **UST - Ungrounded Specimen Test**
  - In the UST, No Ground Current is Being Measured

# Test Modes



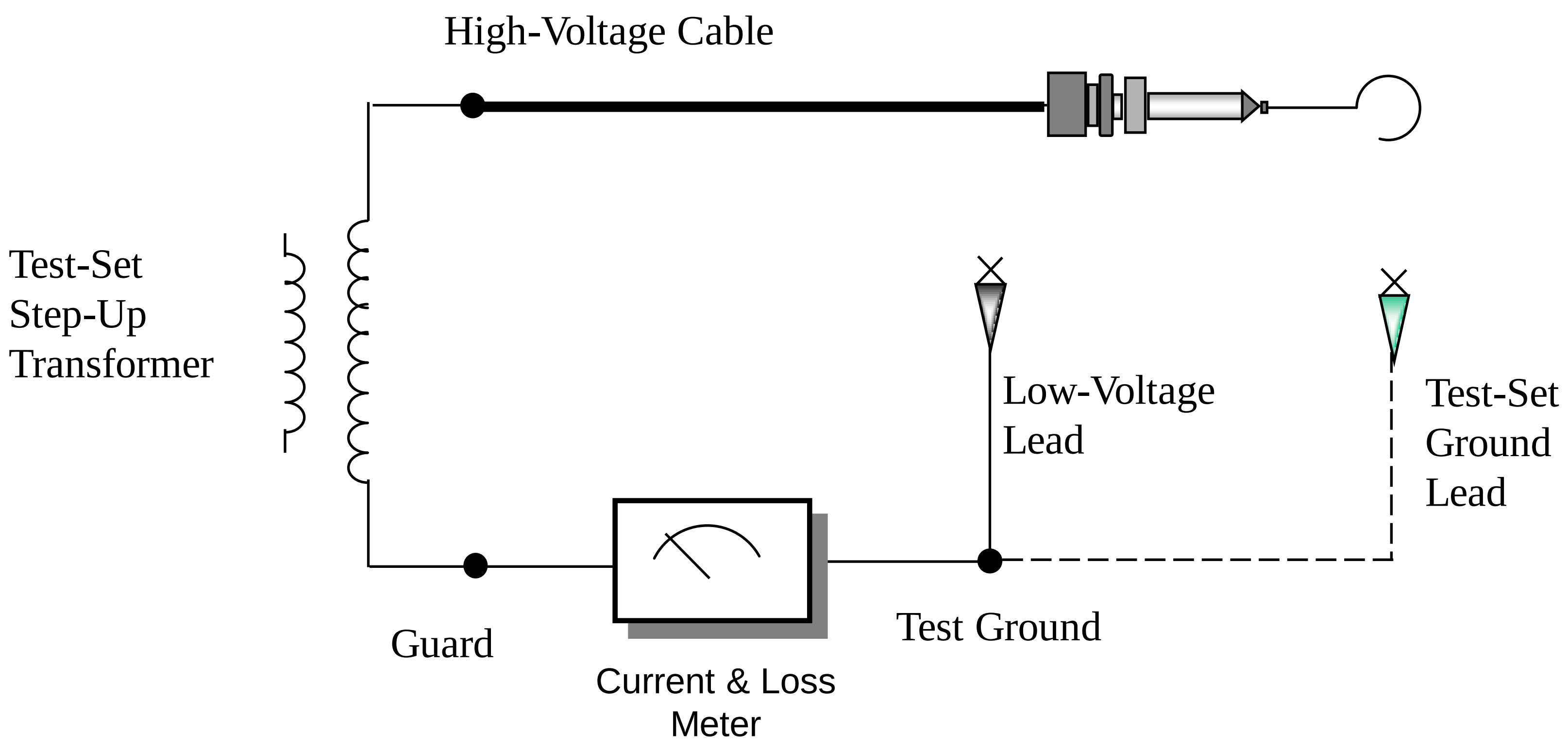

**Kirchoff's Current Law – All current leaving must return. Therefore, by KCL all current leaving the test set through the HV Cable must return to it … either through the LV Test Leads (red or blue) or the Ground Lead.**

**Internal to the M4100, test leads that are connected to the METER will be measured, and test leads that are connected to GUARD will not be measured.**

**We can choose to measure the RED LEAD, the BLUE LEAD, the GROUND LEAD, or ANY COMBINATION (any two, or all three) by specifying the correct TEST MODE.**

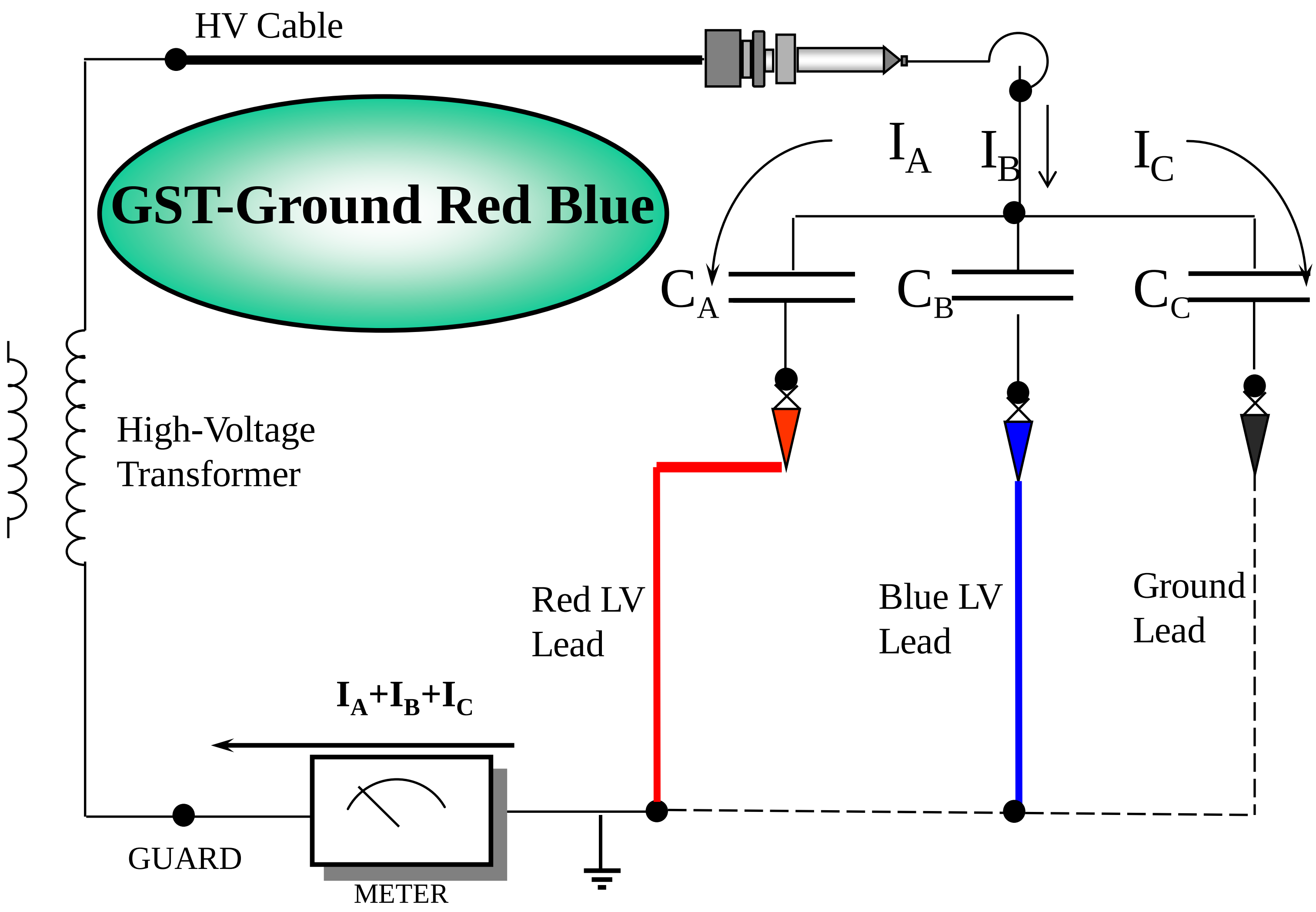
**The TEST MODE is specified in the DTAF software. It is an instruction that tells the M4100 which test leads to connect to the meter and which leads to connect to guard circuit.**

# Simplified Doble Test Circuit

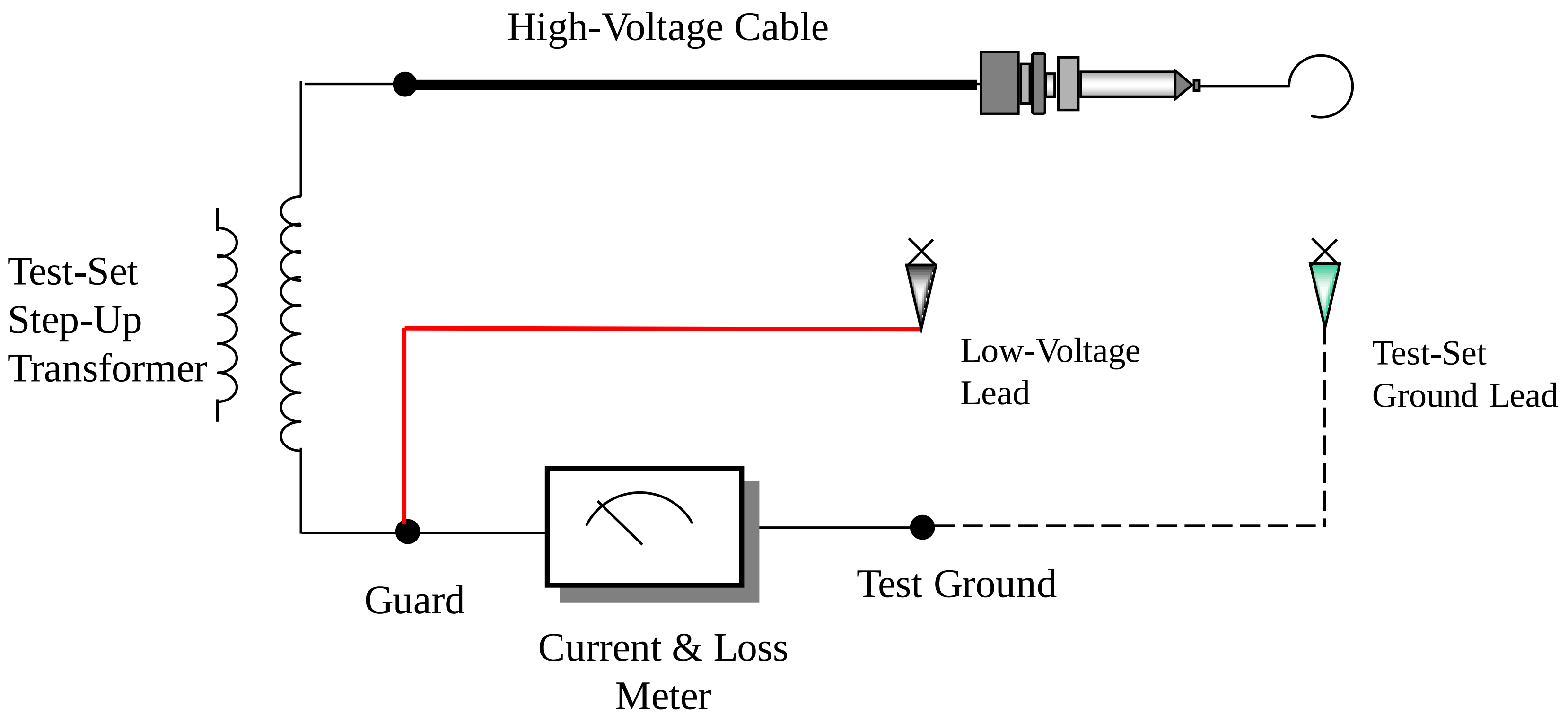



Grounded-Specimen Test Mode (GST-Ground)

# Doble Test Circuit

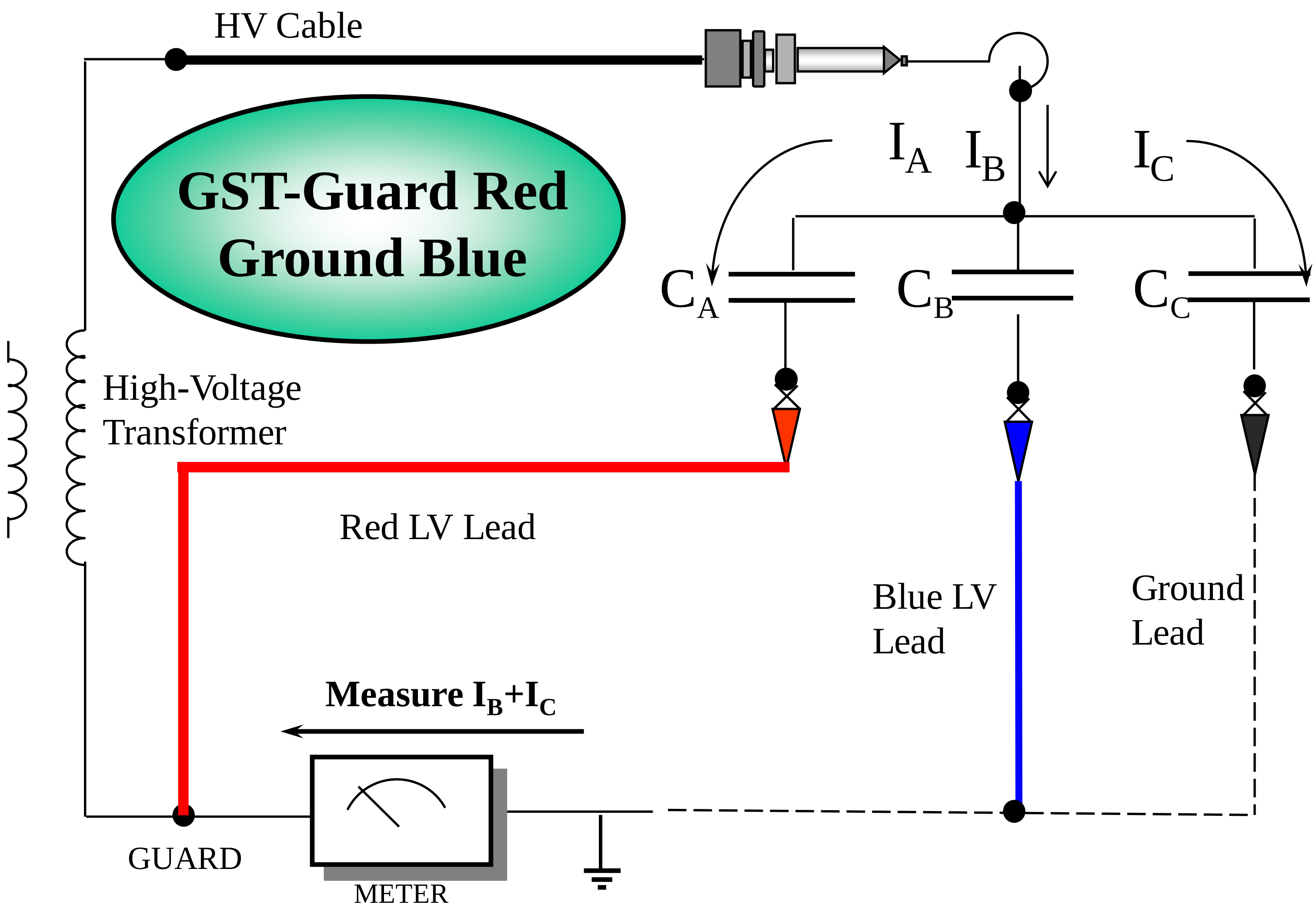


# Simplified Doble Test Circuit

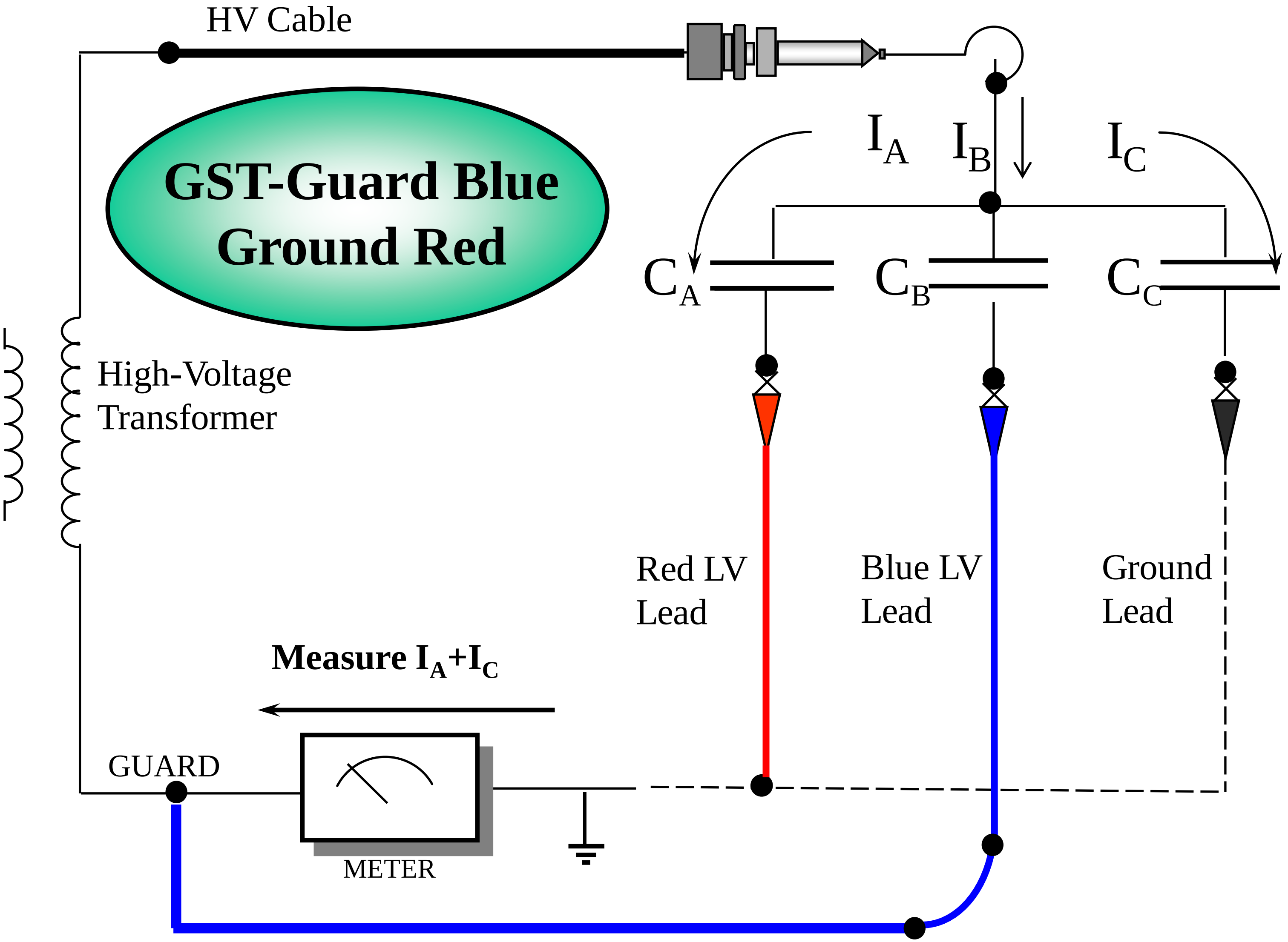



## Grounded-Specimen Test Mode (GST-Guard)

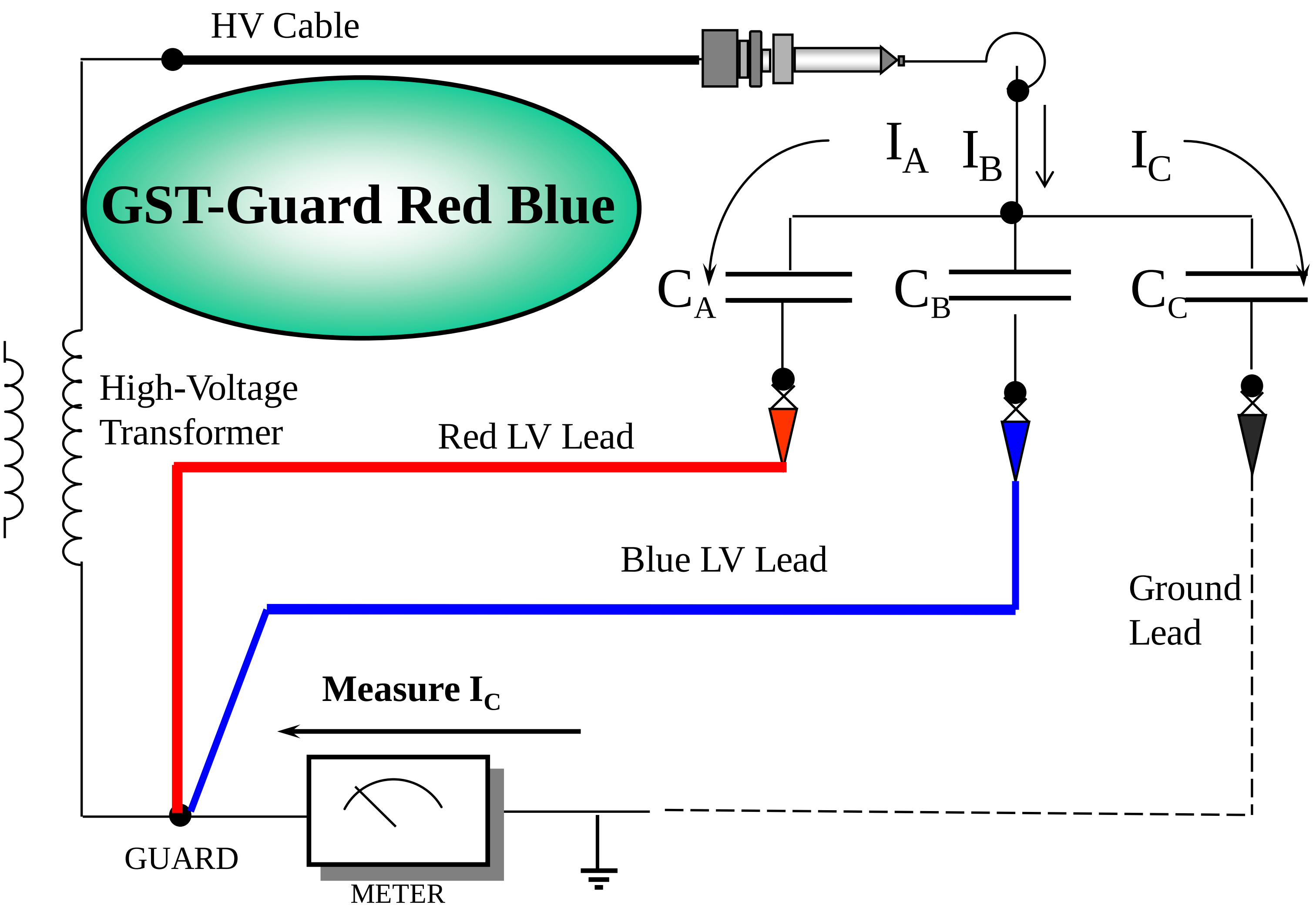
# Doble Test Circuit



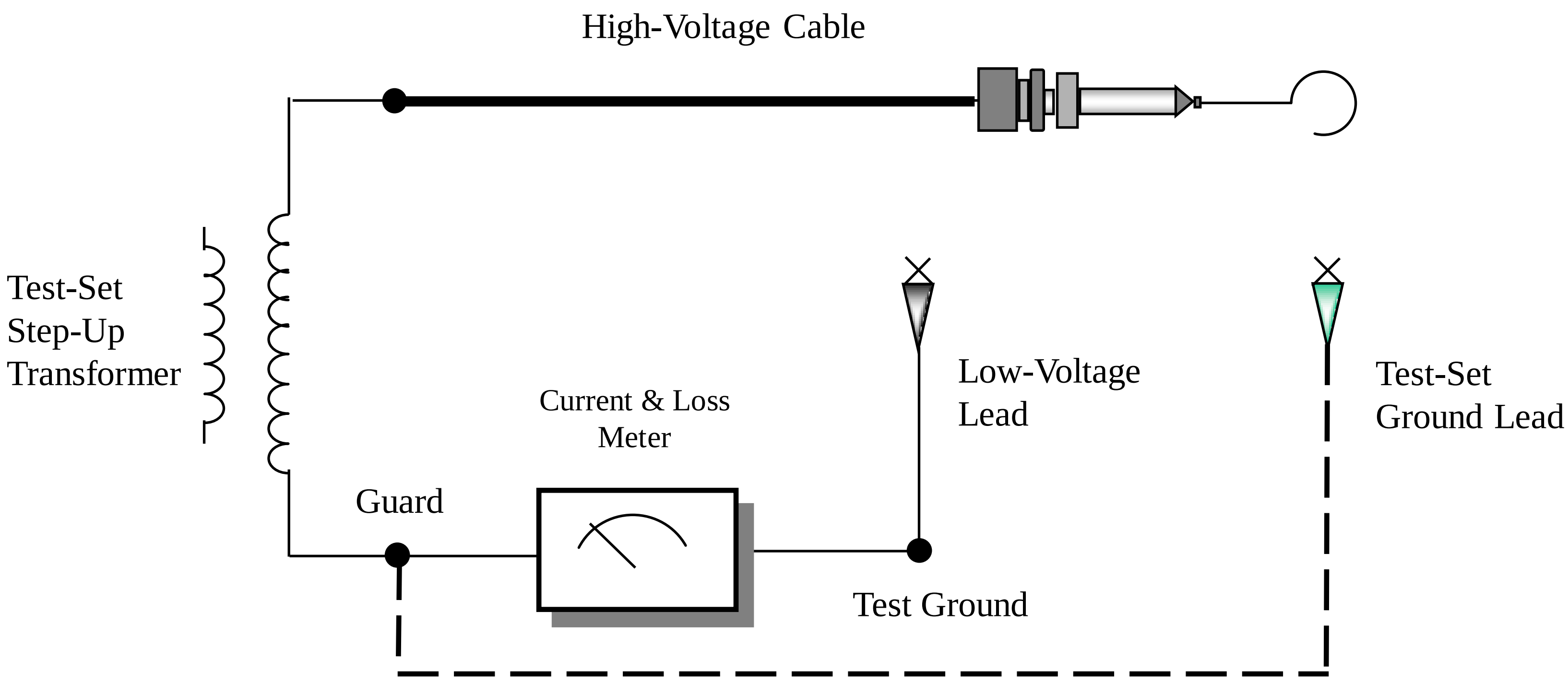
# Doble Test Circuit



# Doble Test Circuit

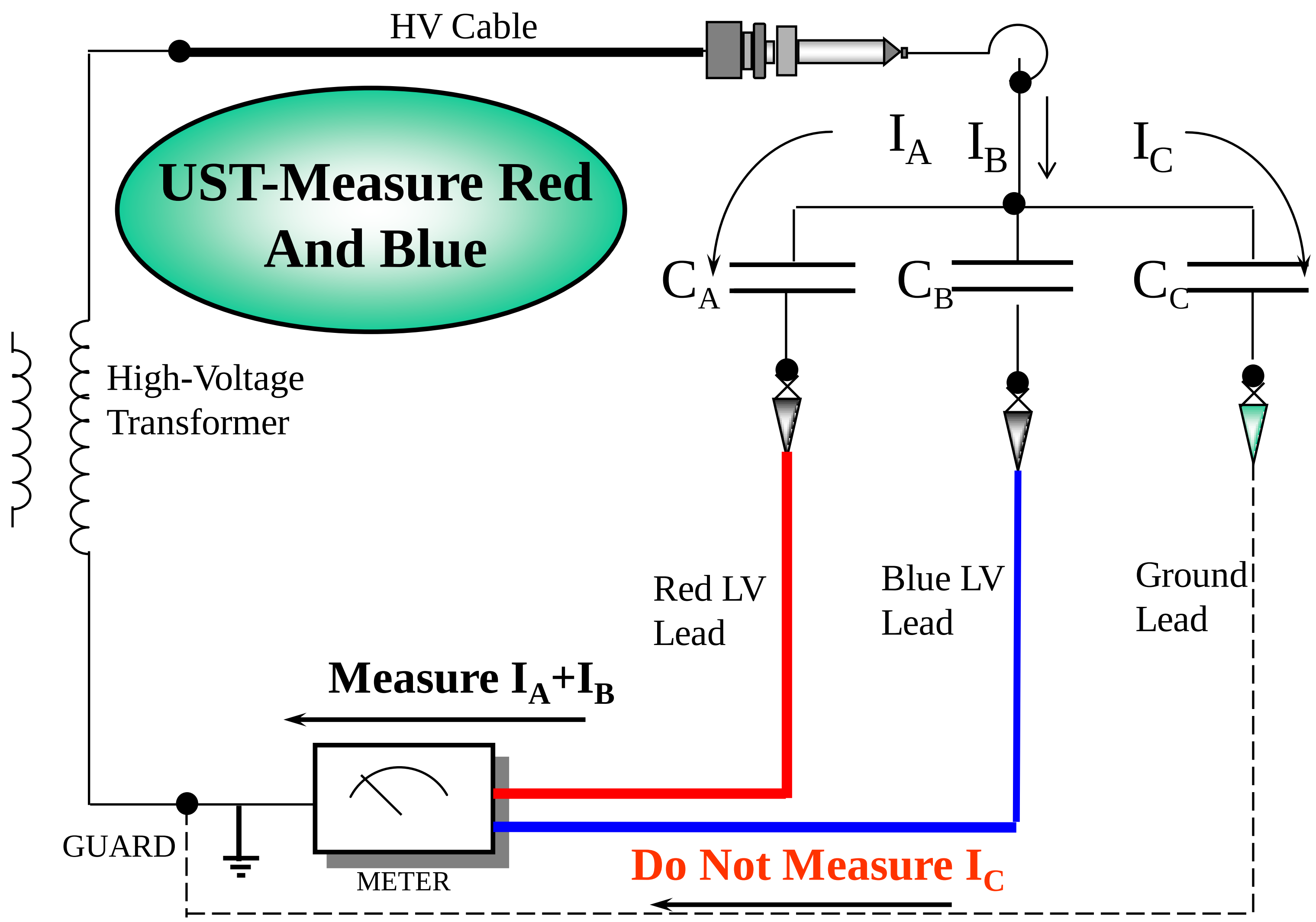


# Simplified Doble Test Circuit

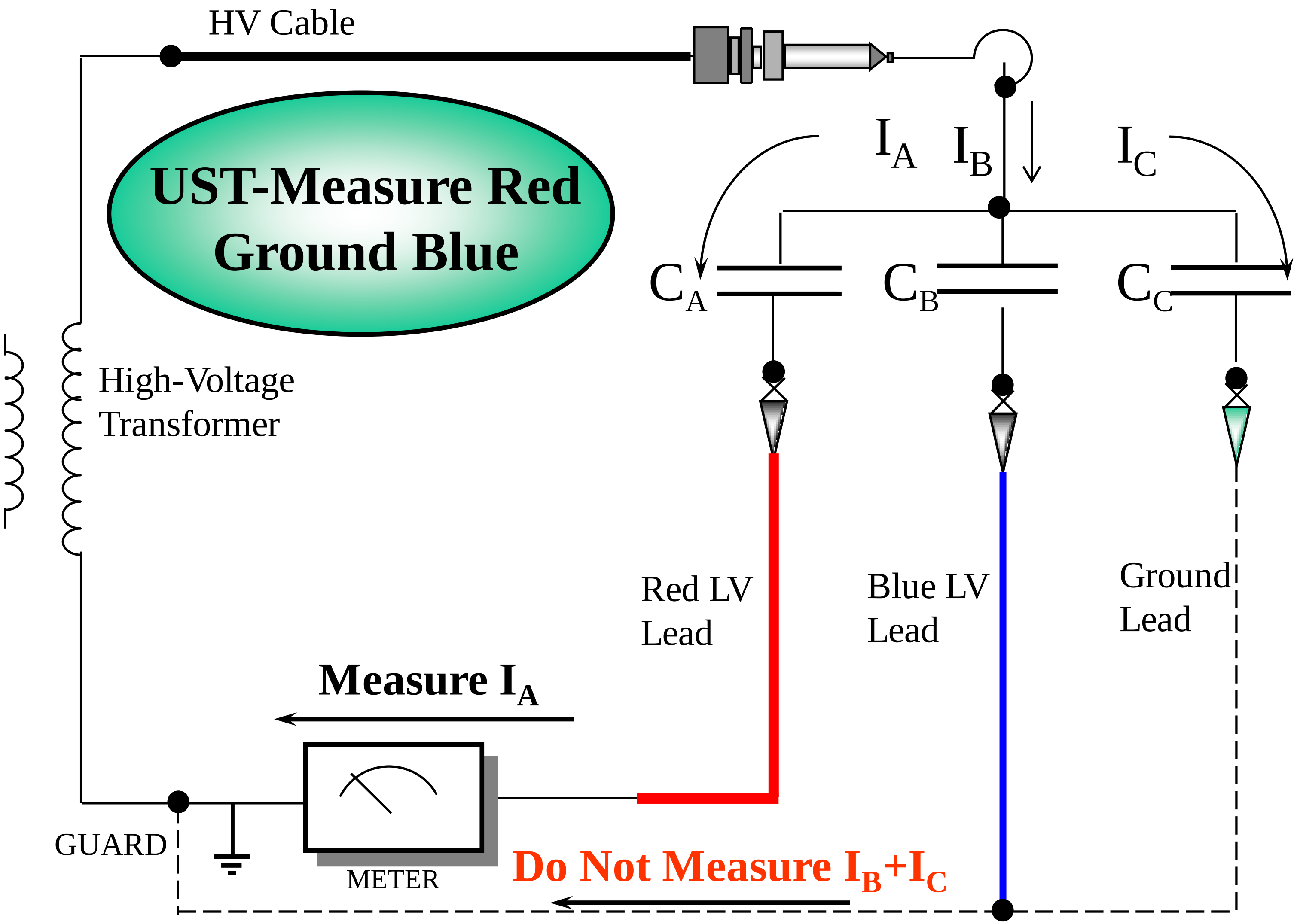



Ungrounded-Specimen Test Mode (UST)

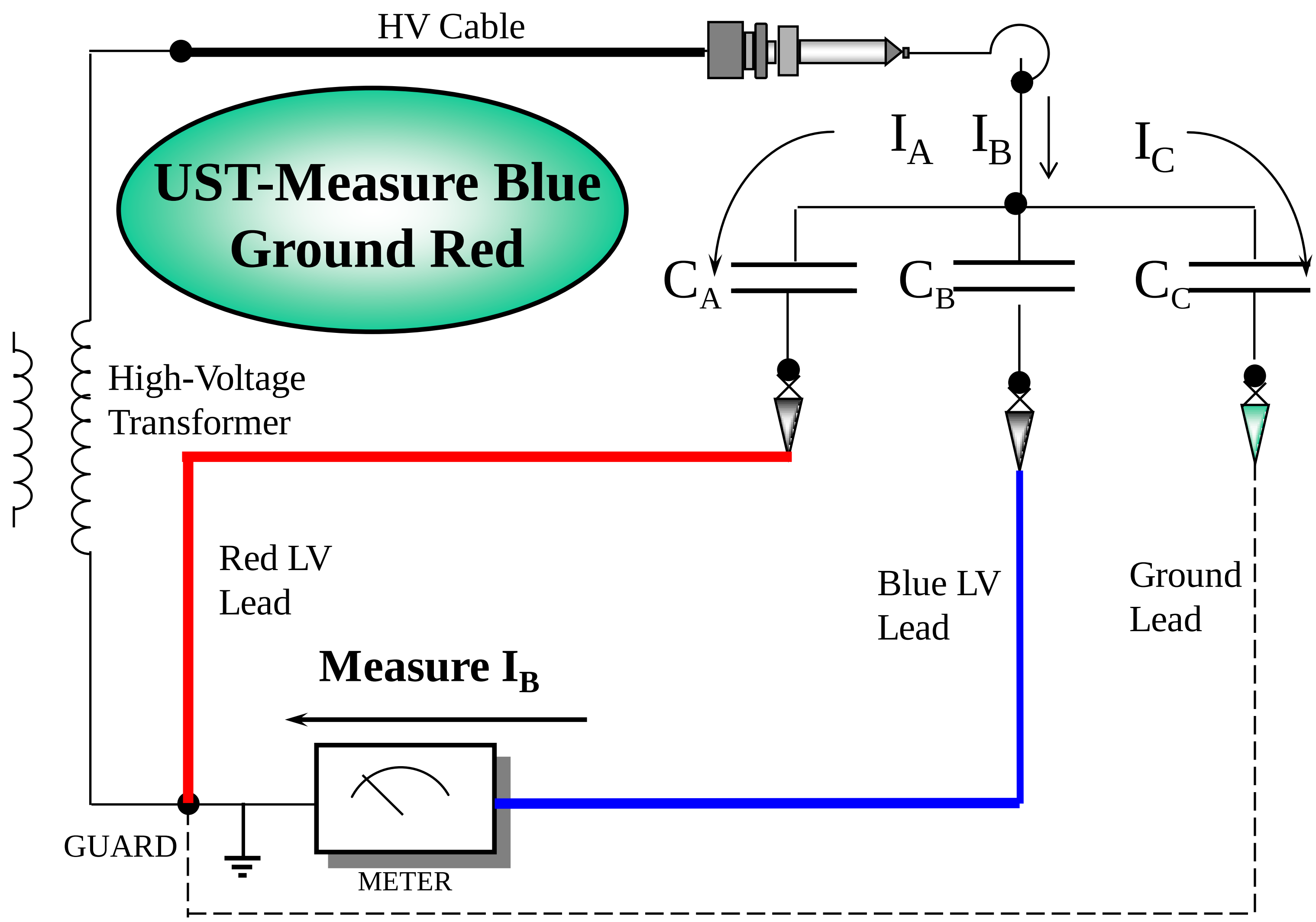
# Doble Test Circuit



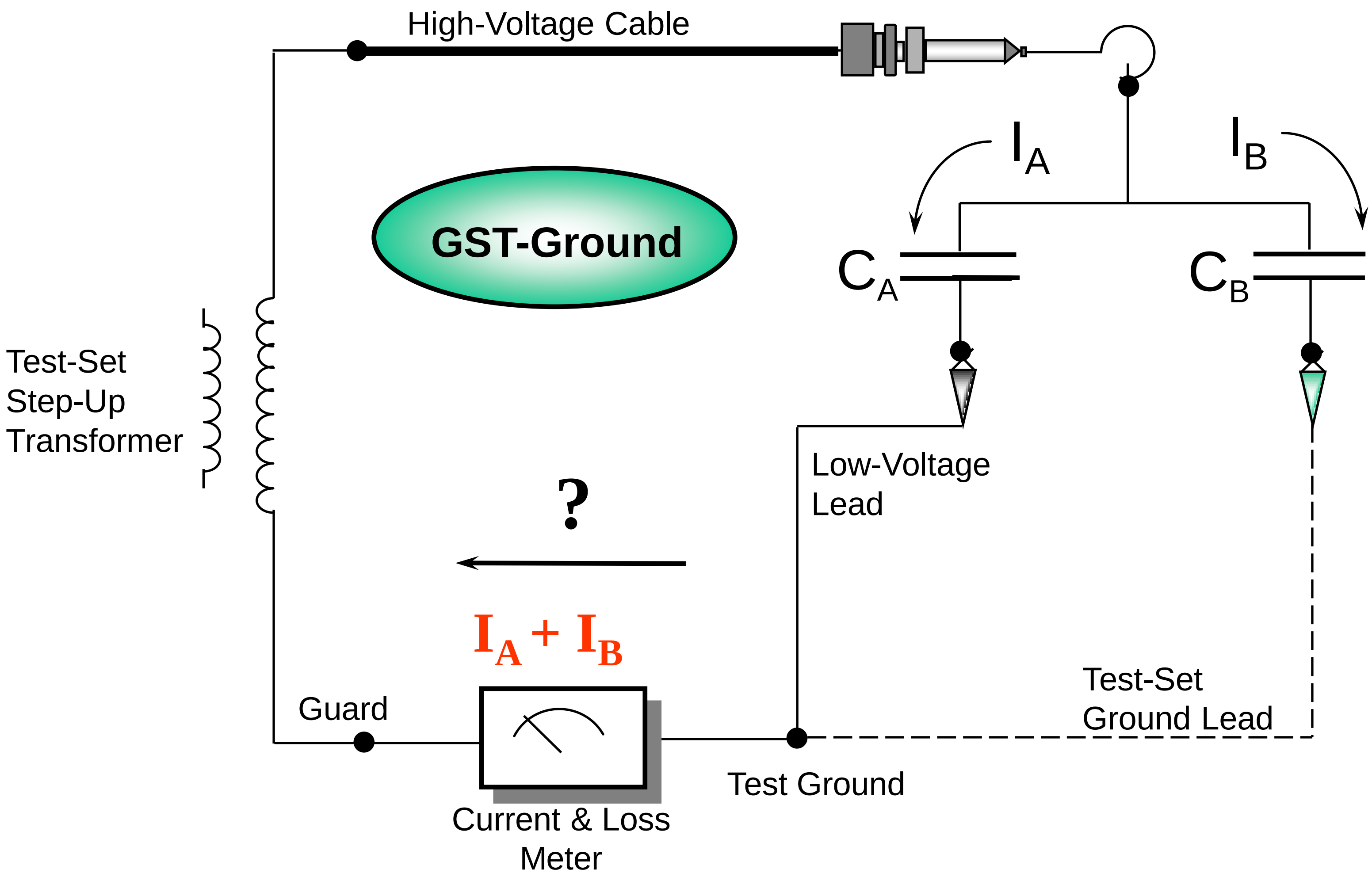
# Doble Test Circuit



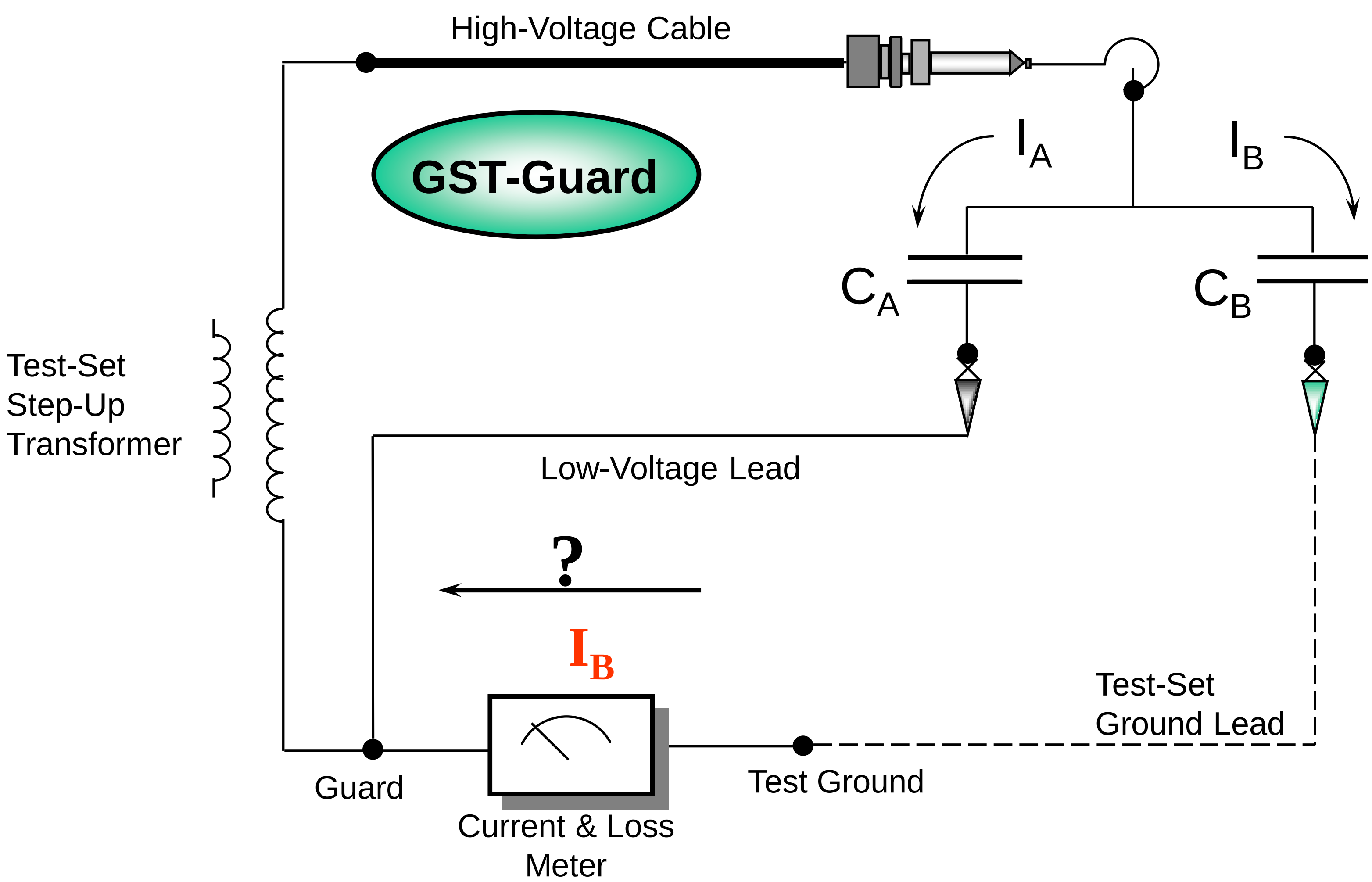
# Doble Test Circuit



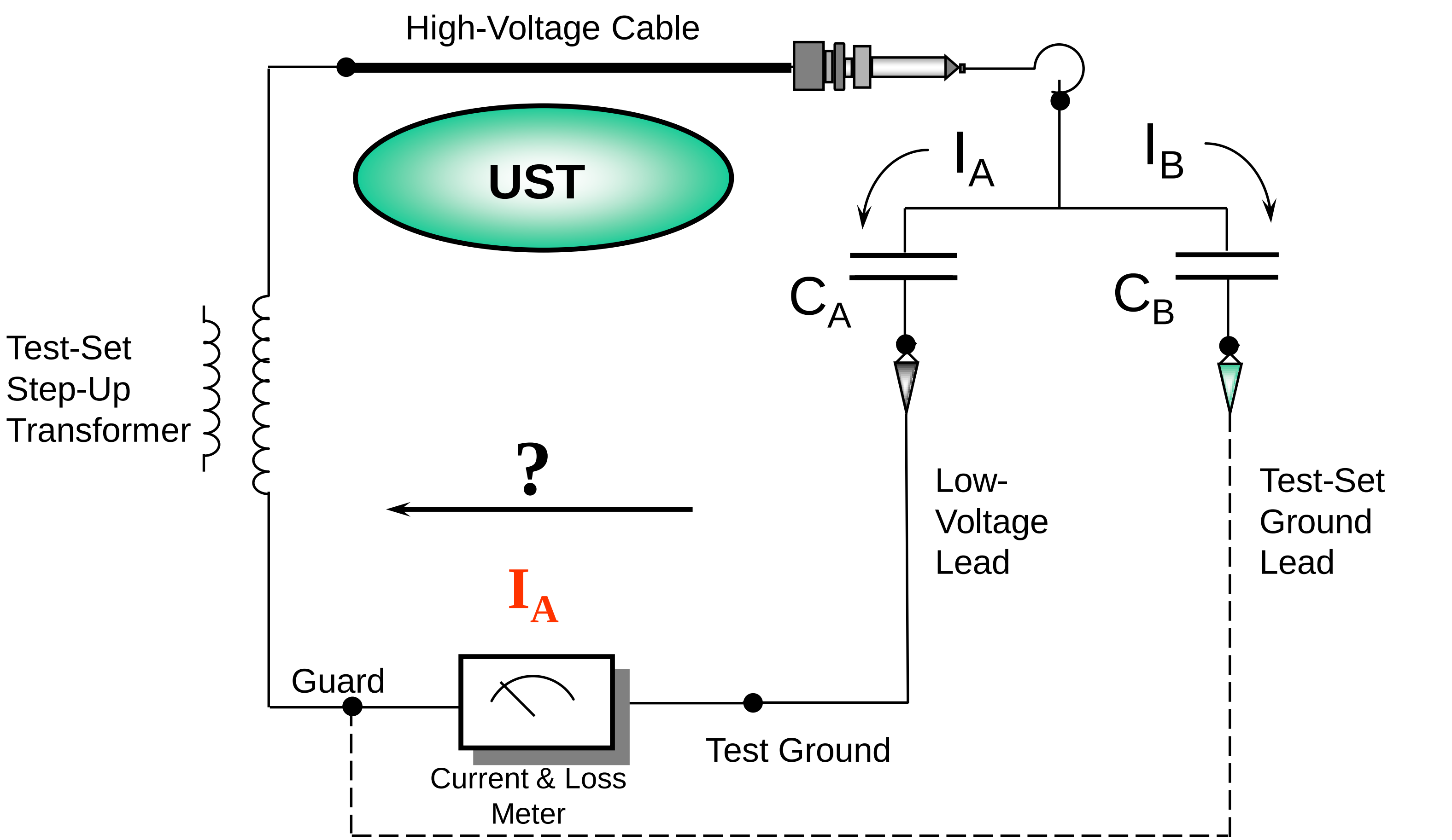
# Doble Test Circuit



# Doble Test Circuit



# Doble Test Circuit



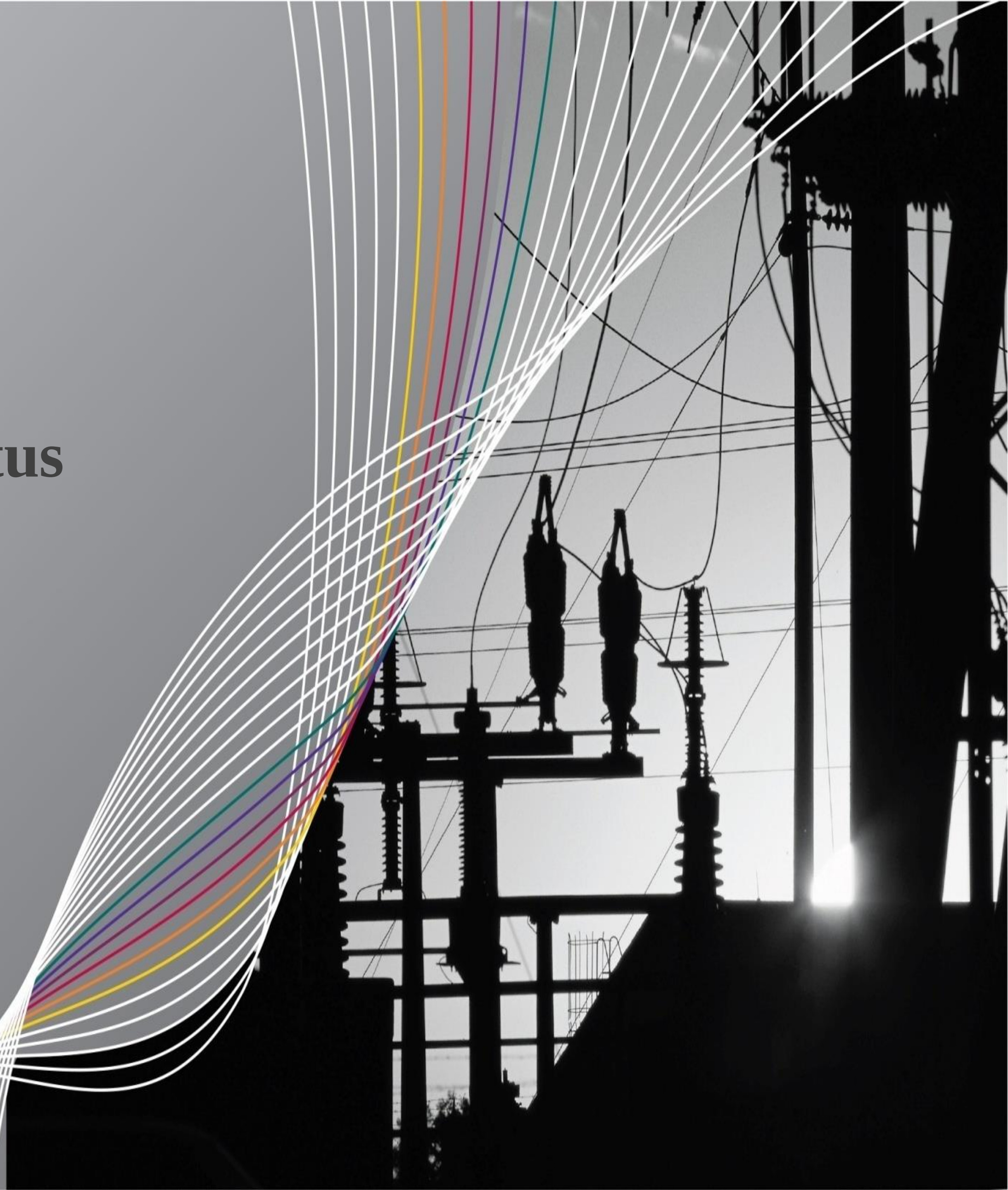
# Analysis Of Data (General)

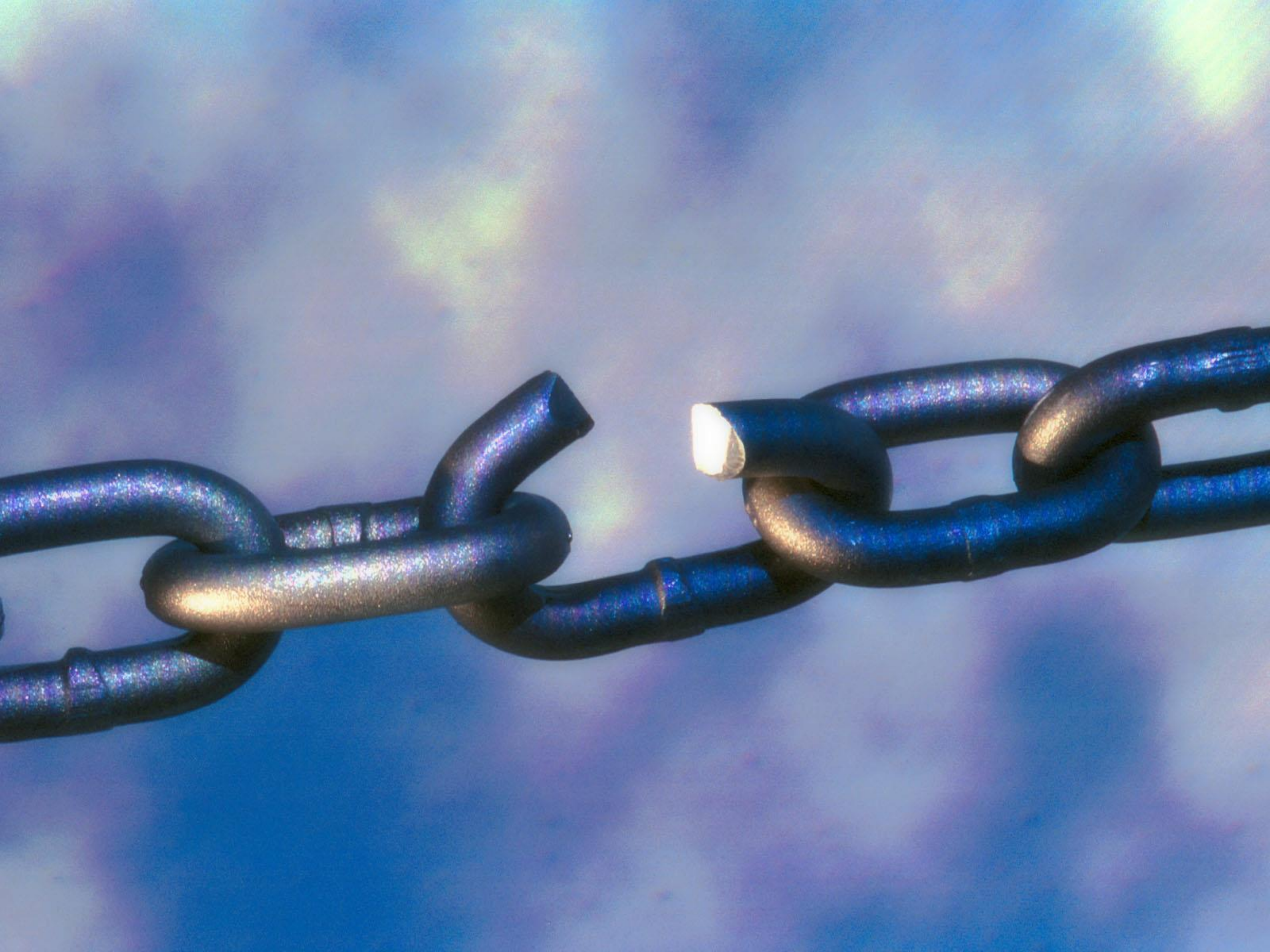
- Compare to nameplate data
- Compare to previous tests
- Compare to tests on identical apparatus type
- Review not only percent power factor, but current, watts, and capacitance as well
- Percent power factor that is much lower than expected is just as unacceptable as that which is much higher.
- A change in current or capacitance of 5% or more is cause for concern.
- If current is less than about 300 μ amps, do not calculate percent power factor; use watts instead. This applies at least to arresters, live tank breaker support columns, some breakers without grading capacitors, and the UST test across the contacts on vacuum and SF6 breakers.

# Troubleshooting When Data Is Unacceptable

- Check all connections, including the ground lead.  Make sure there is solid metal-to-metal contact
- Clean and dry porcelain surfaces and retest
- Check leads (using ohmmeter, expect less than one ohm conductor resistance; on LV Leads, measure between clip and pin 3)
- Check test set using self-diagnostic program
- Check test procedure and repeat test
- See M4000 manual for further tests

# Power Apparatus Bushings



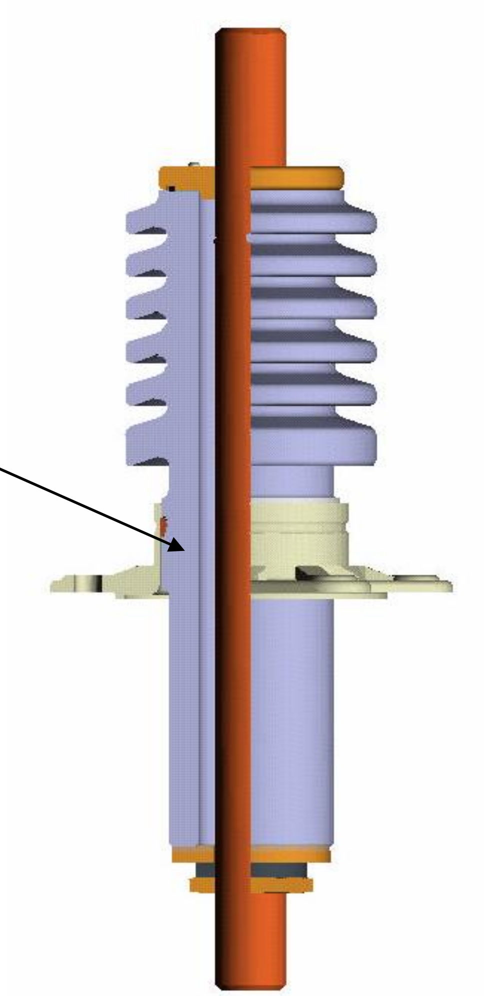


# Major Bushing Types

- Bulk Bushings
  - A single bulk material provides the insulation
  - Bulk material may be porcelain, epoxy, polymer concrete, etc.
- Gas Insulated
  - Insulation provided by compressed gas (usually SF6), and electrodes shaped for field control
  - Special type - usually a part of a circuit breaker, etc.
- Condenser Bushings
  - Insulation comprised of a condenser to control field distribution
  - These are the main topic of this presentation

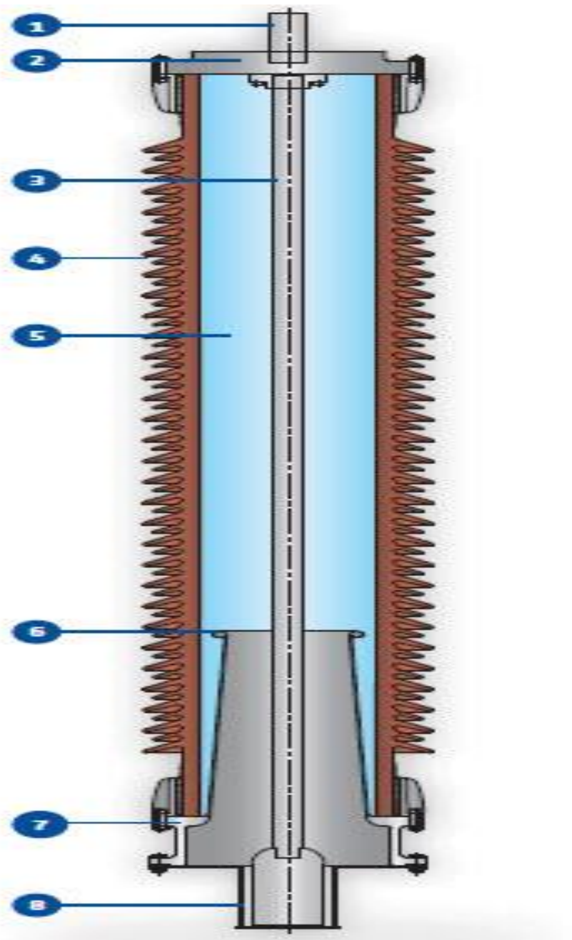
# A Typical Bulk Bushing

- Bulk Material Provides Insulation



# Gas Insulated Bushing

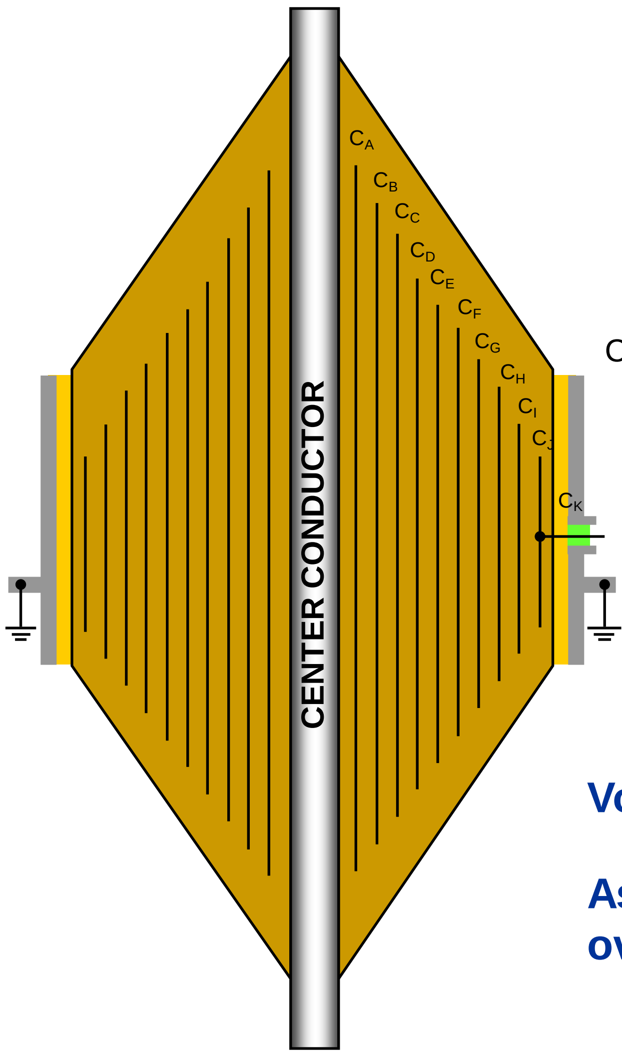
1. HV Terminal
2. Top closing plate
3. Inner conductor
4. Insulator
5. SF6 gas zone
6. Internal shield
7. Flange
8. Transport cover

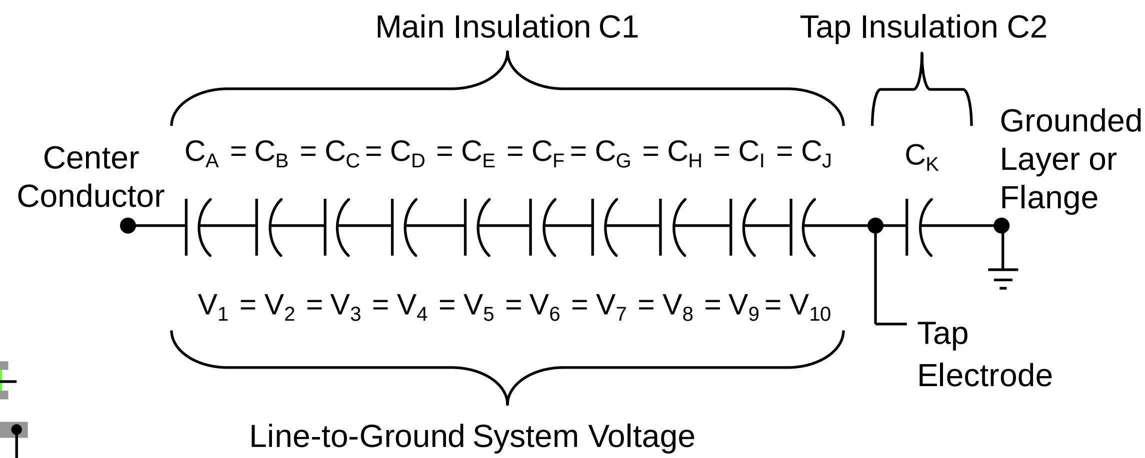


# Why Use a Condenser Bushing?

- In a bulk type bushing, the electrical field is not evenly distributed (very non-linear).
- On the outside of the bushing, the voltage stress will be more concentrated near the flange.
- Inside the bushing, the voltage stress will be more concentrated near the conductor, or in an oil gap.
- The condenser provides control over the distribution of the electric field, and therefore the electric stress levels.

# Graded Bushing – Electrical Characteristics

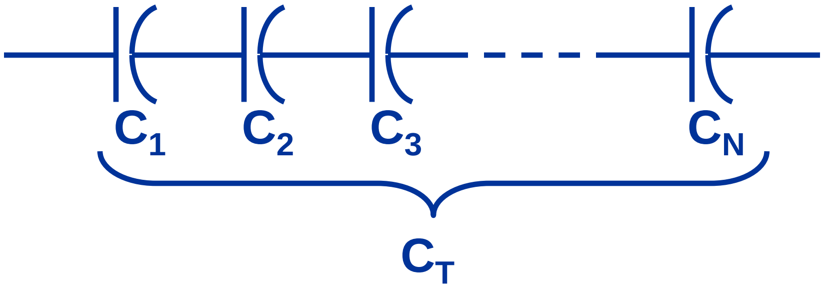



**Voltage stress is evenly distributed across the insulation.**

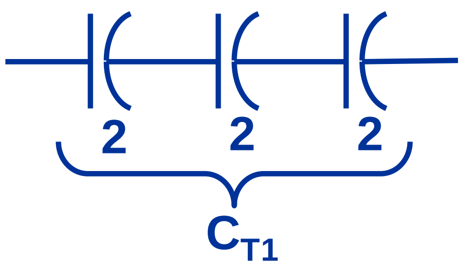
**As capacitive layers (i.e.. $C_A$, $C_B$, etc.) are shorted out the overall capacitance, $C_1$, <u>increases</u>.**

# Adding Capacitors in Series




$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots + \frac{1}{C_N}$$

**Case 1: 3 Capacitors in Series**



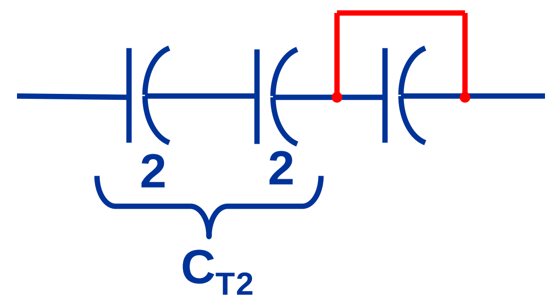

$$\frac{1}{C_{T1}} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} = \frac{3}{2}$$

$$C_{T1} = \frac{2}{3} \quad .667\text{pF}$$

$C_{T2} > C_{T1}$

**Shorting out a capacitor results in an increase in capacitance.**

**Case 2: Shorted Capacitor**




$$\frac{1}{C_{T2}} = \frac{1}{2} + \frac{1}{2} = \frac{2}{2}$$

$$C_{T2} = 1$$

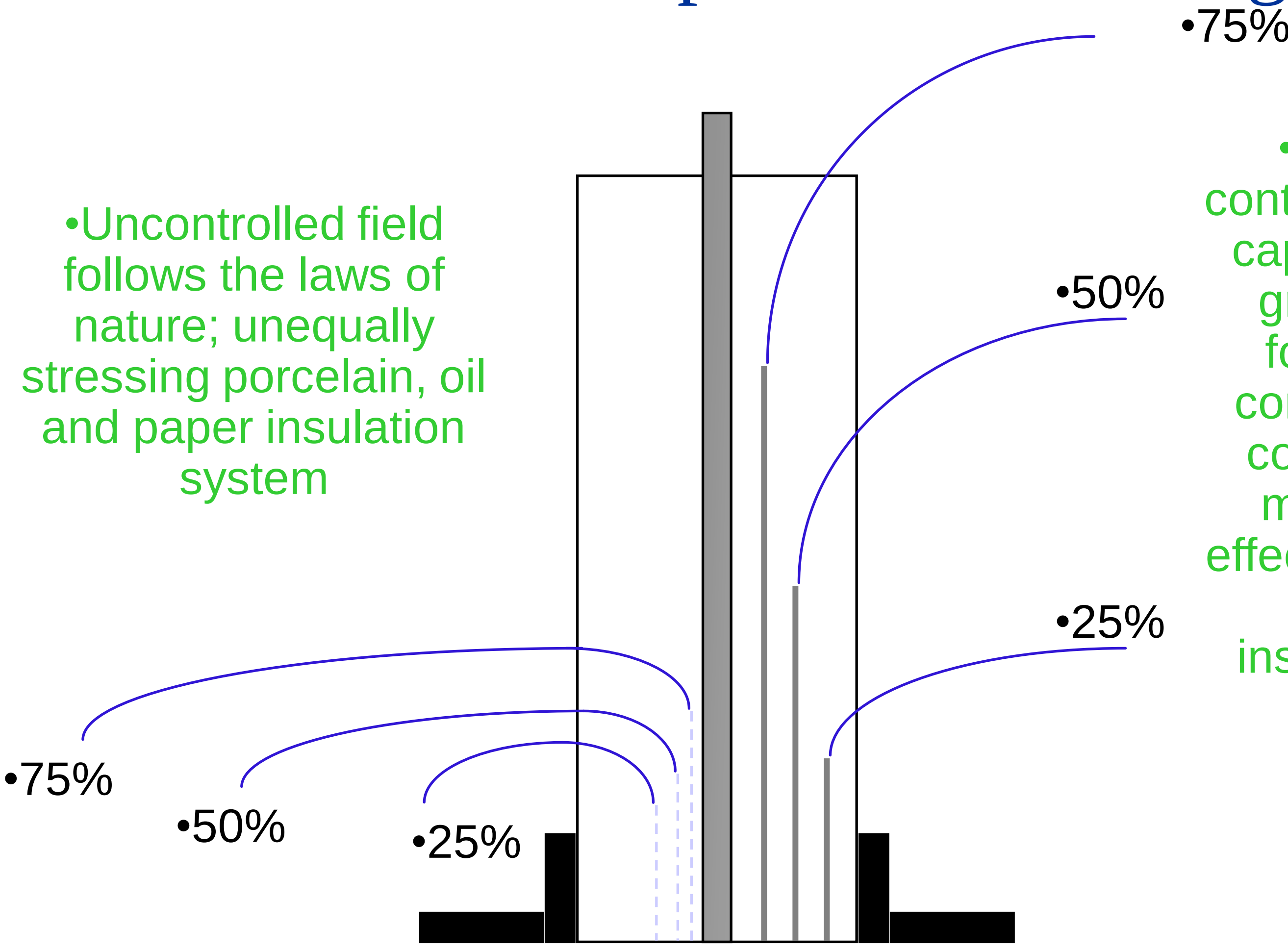
# How the Condenser Works

- AC voltage fields essentially distribute according to the capacitances of the surroundings
- DC voltage fields distribute according to resistivities
- Discussion here is limited to AC voltages
- Condenser is an old term for a capacitor and it "condenses" the bushing
- Any two conductors, separated by an insulator, form a capacitor
- Each section in the condenser forms a capacitor
- These capacitances are much more significant than the stray capacitances of the surroundings
- The entire condenser then is comprised of several cylindrical capacitors in series

# Voltage Distribution

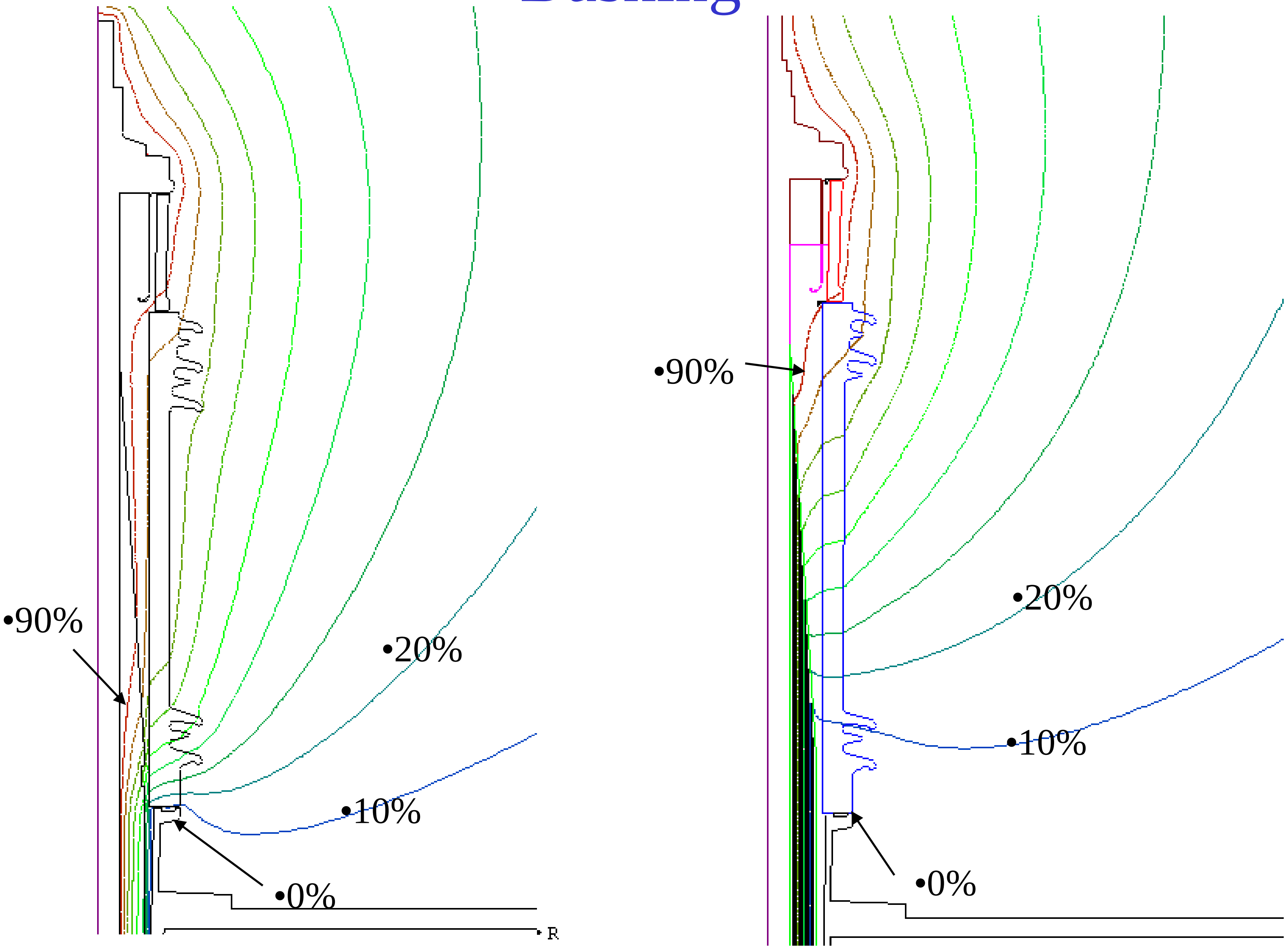
- With and Without Capacitance Grading

•Uncontrolled field follows the laws of nature; unequally stressing porcelain, oil and paper insulation system

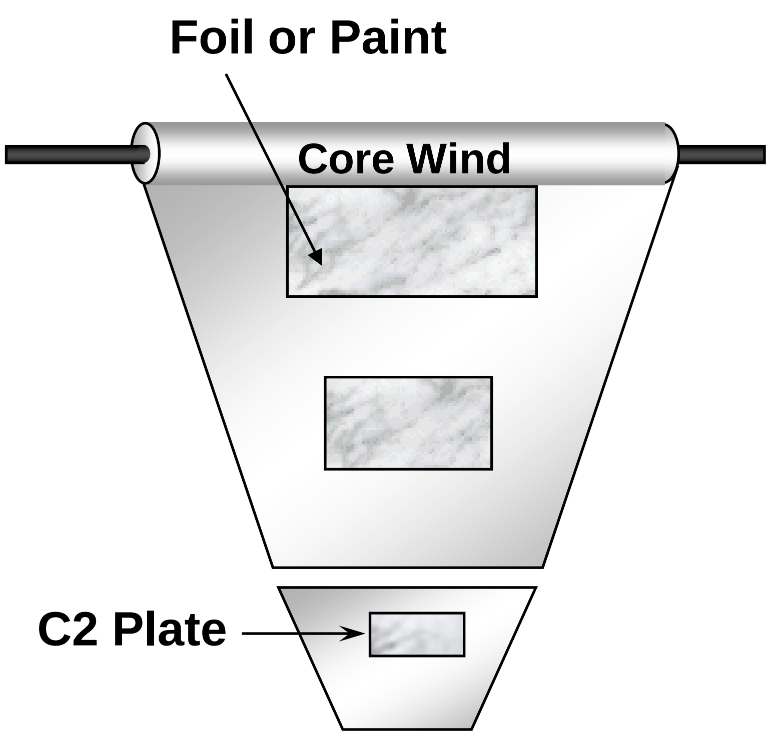



•Field controlled by capacitive grading follows controlled contours making effective use of all insulation

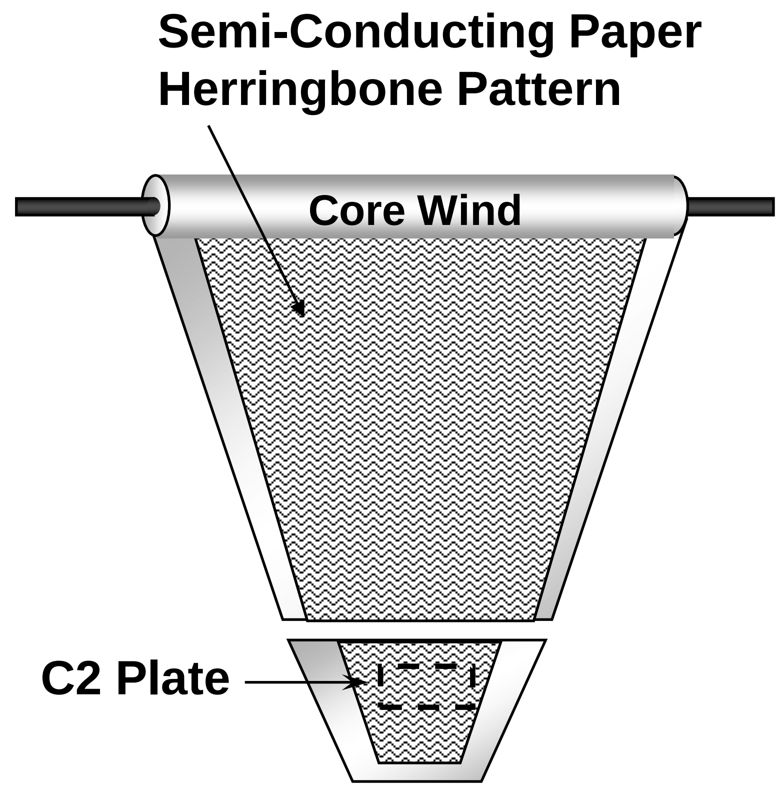
# Electric Field: Non-condenser & Condenser Bushing



# Graded Bushing - Core Construction




**Common Construction**

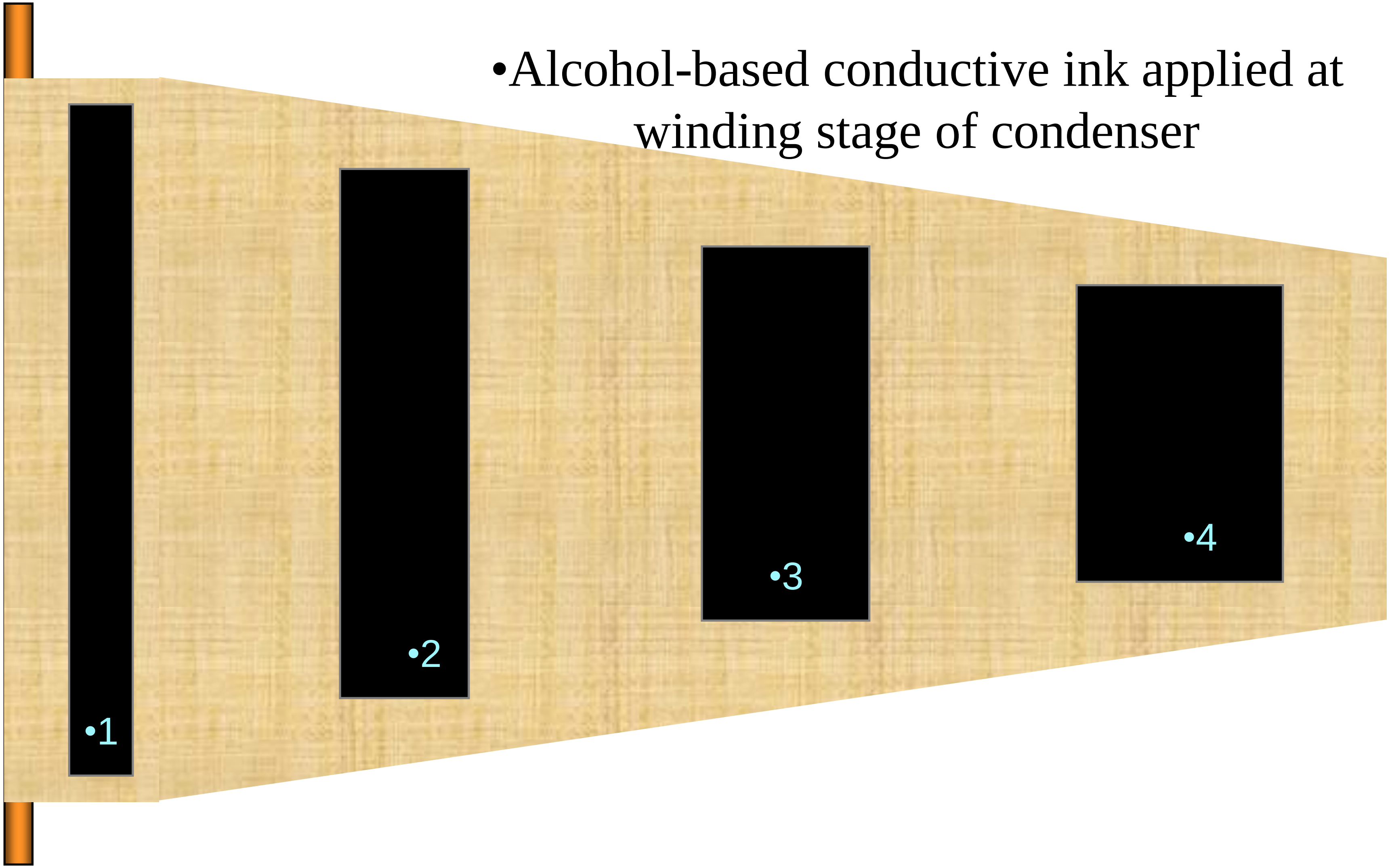



**Distributed Capacitance**

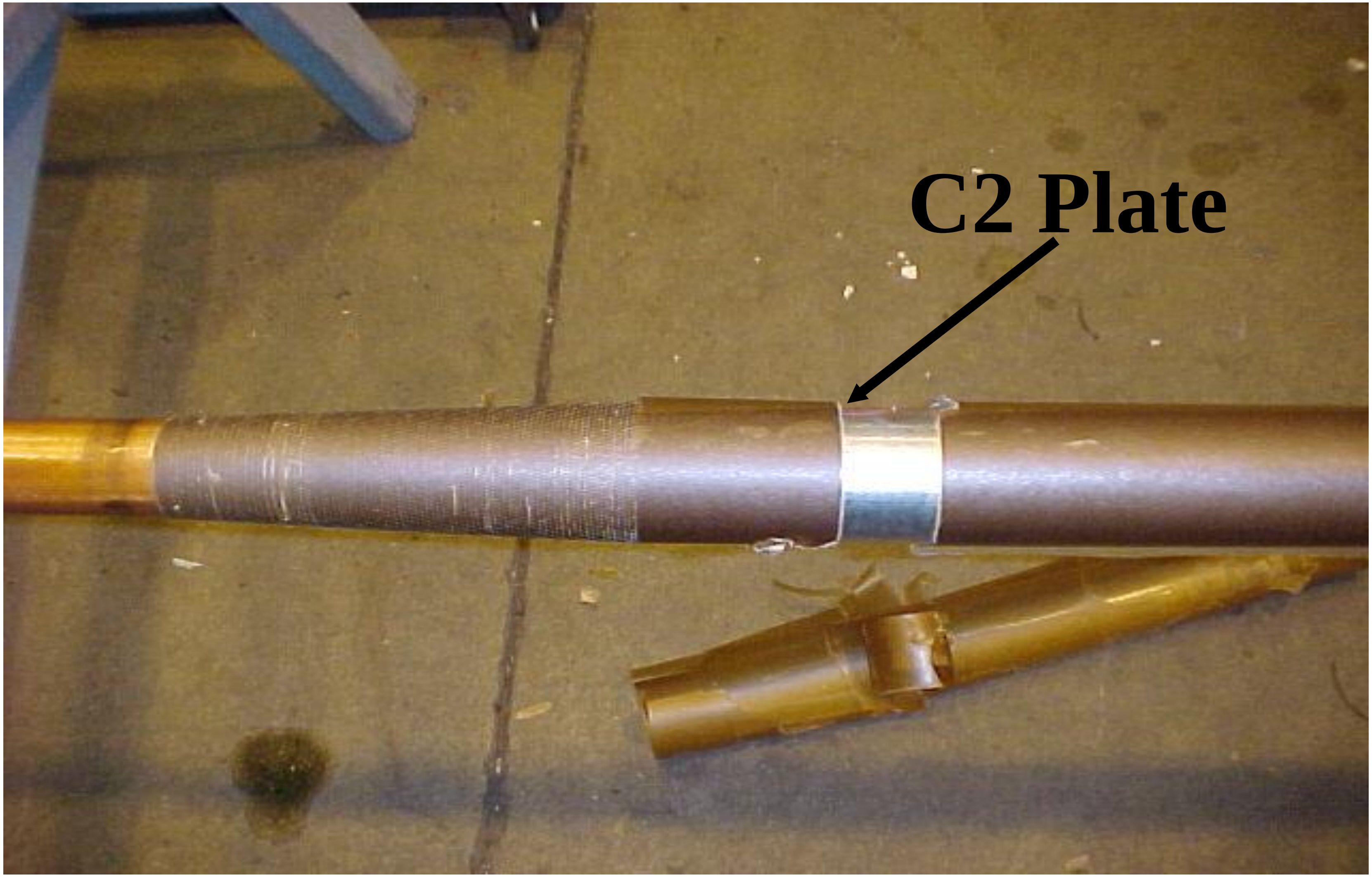
**GE Type U**

# Graded Bushing - Core Construction

- Alcohol-based conductive ink applied at winding stage of condenser

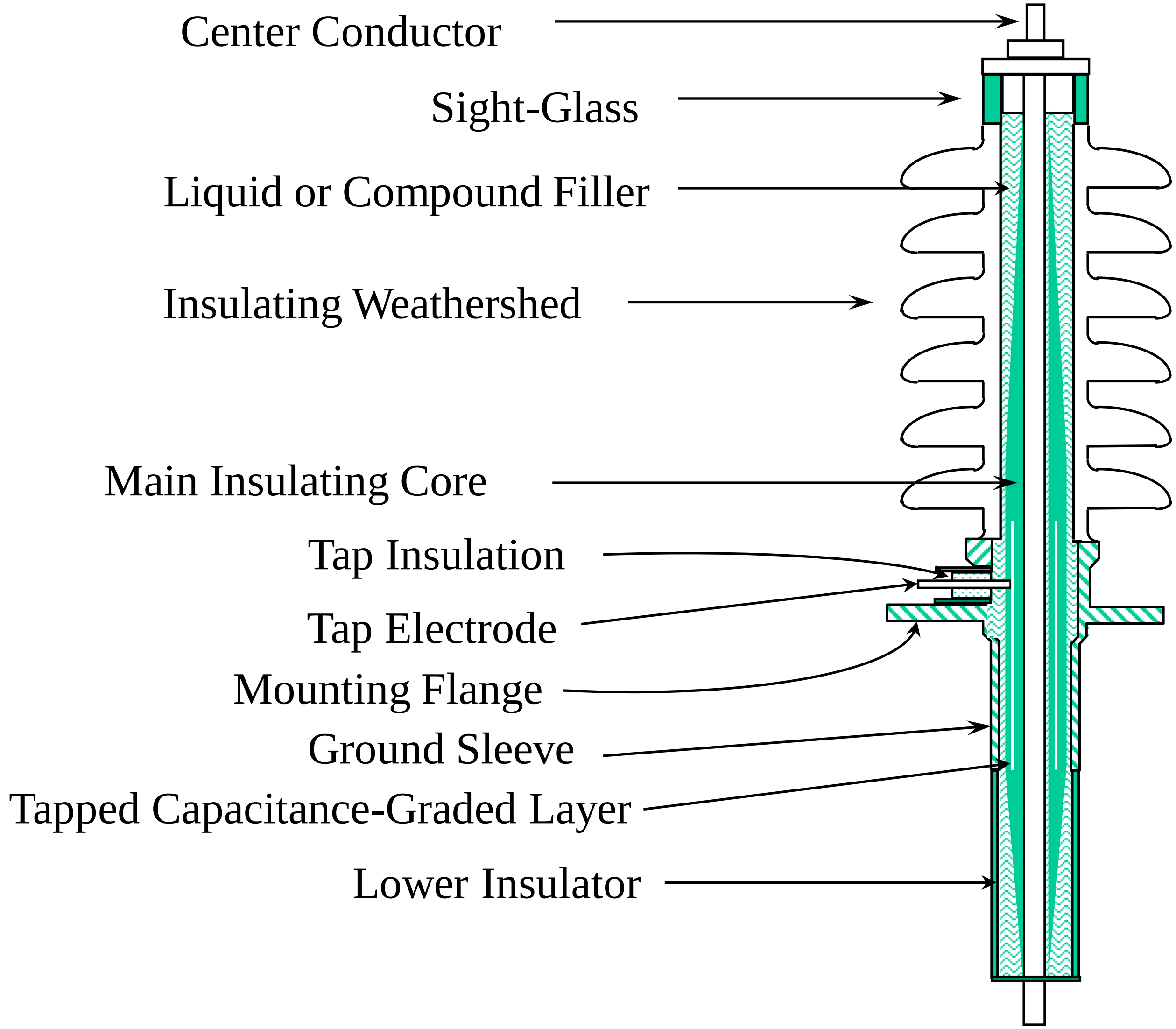


# ABB O + C Construction

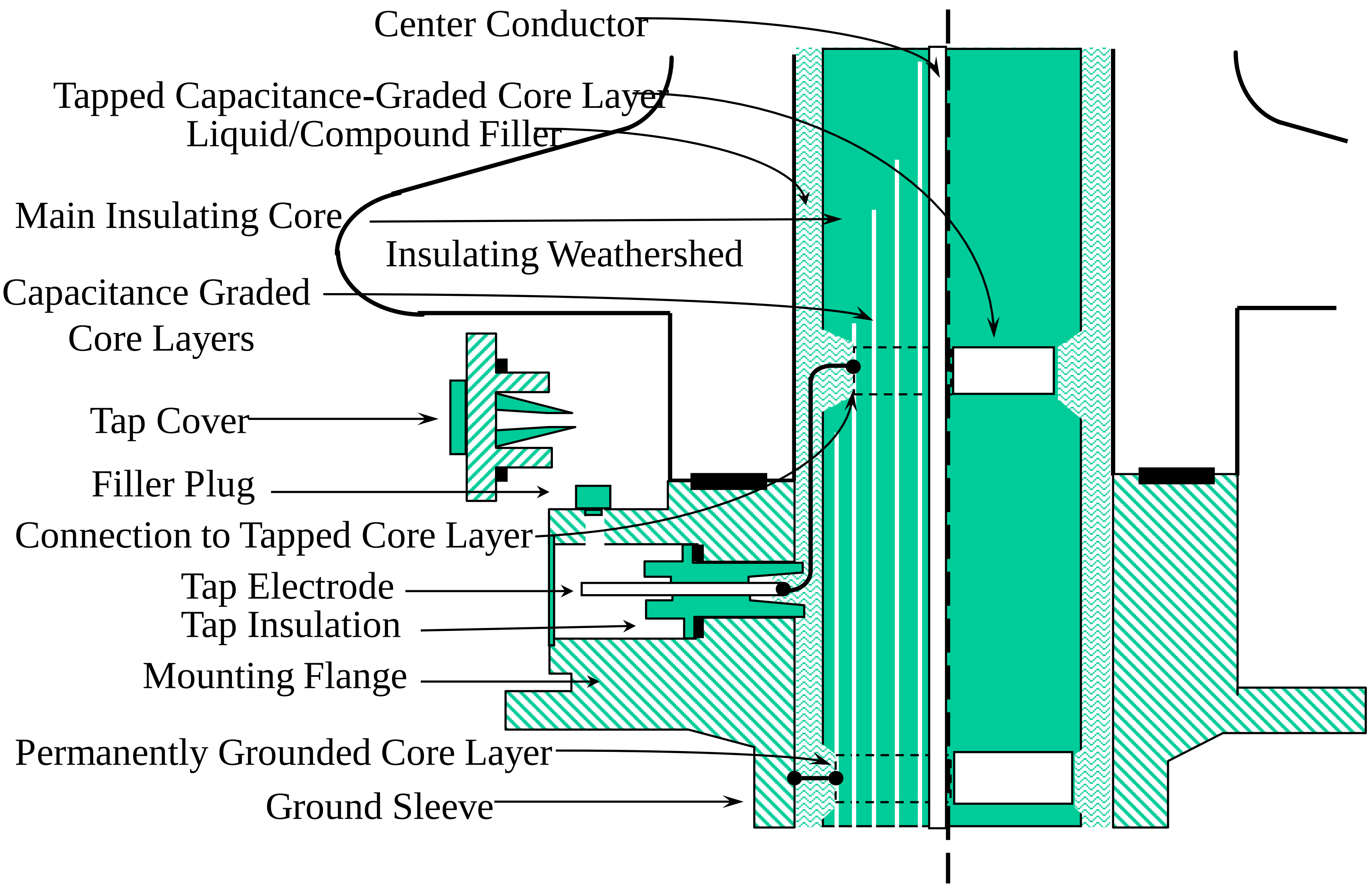


# ABB O + C, 27 kV

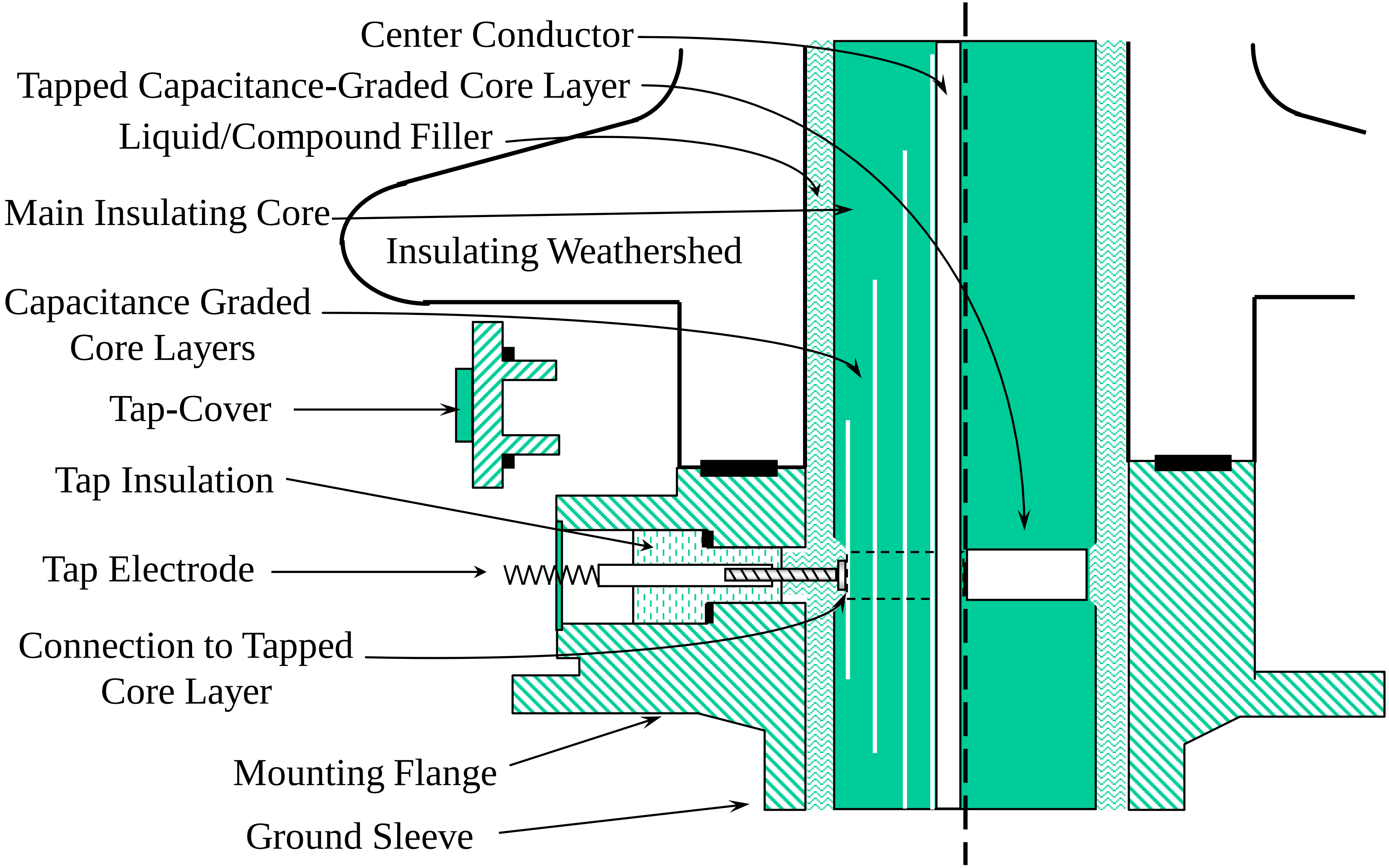
# Components of a Typical Oil-Impregnated Capacitance-Graded Bushing



# Typical Bushing Potential Tap Construction



# Typical Bushing Test Tap Construction



# Difference Between Power Factor Test and Potential Taps

Power Factor Test Tap

- Bushing Rated to <= 69 kV
- C2 (PF) ~ C1(PF)
  Except Lapp PRC >00-189100
- Doble Test Voltage: 500 V
  Except Ohio Brass Class G and L Bushing Taps, to which no more than 250 Volts should be applied
- Tap cover 1 1/2 “ or smaller
- Grounded in Service

Potential Tap

- Bushing Rated > 69 kV
- C2 (pF) ~ C1 x 10 (pF)
  or C2>>C1
- Doble Test Voltage: 2 kV
- Tap cover 2 1/2 “ or larger
- In Service: Floating Supply Voltage or Grounded

# LAPP PRC BUSHING

# NEW DESIGN

# Lapp PRC Bushing New Design

- Design Introduced February 2000

- Design Modification
  - Extra Grounded Layer
    - Shorts Out Epoxy Potting Compound

- Bushings With Serial Numbers 00-189100 And Higher

# Lapp Type PRC Bushing Design Change

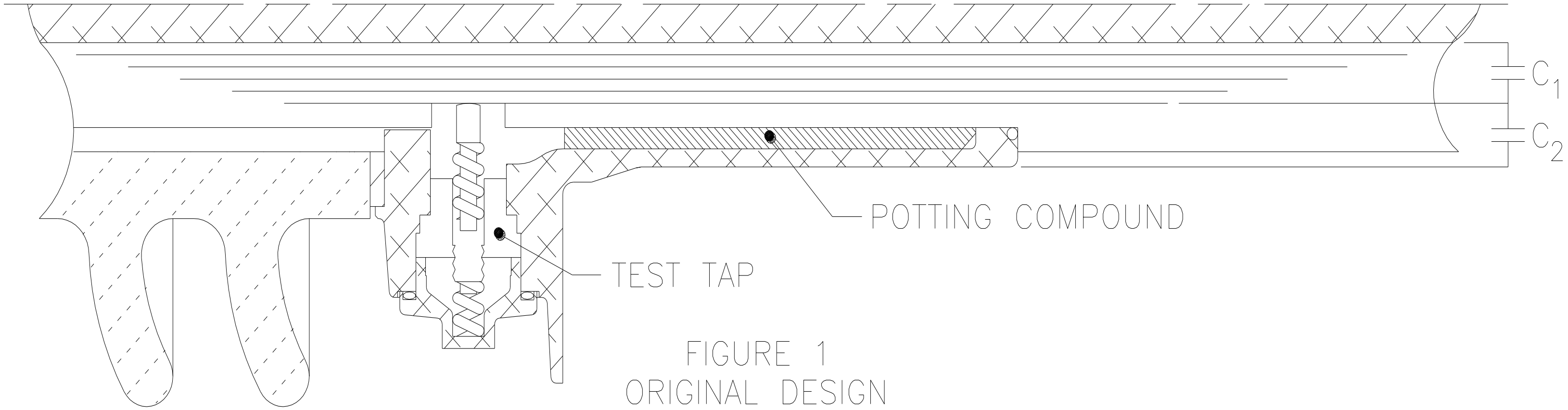



FIGURE 1
ORIGINAL DESIGN

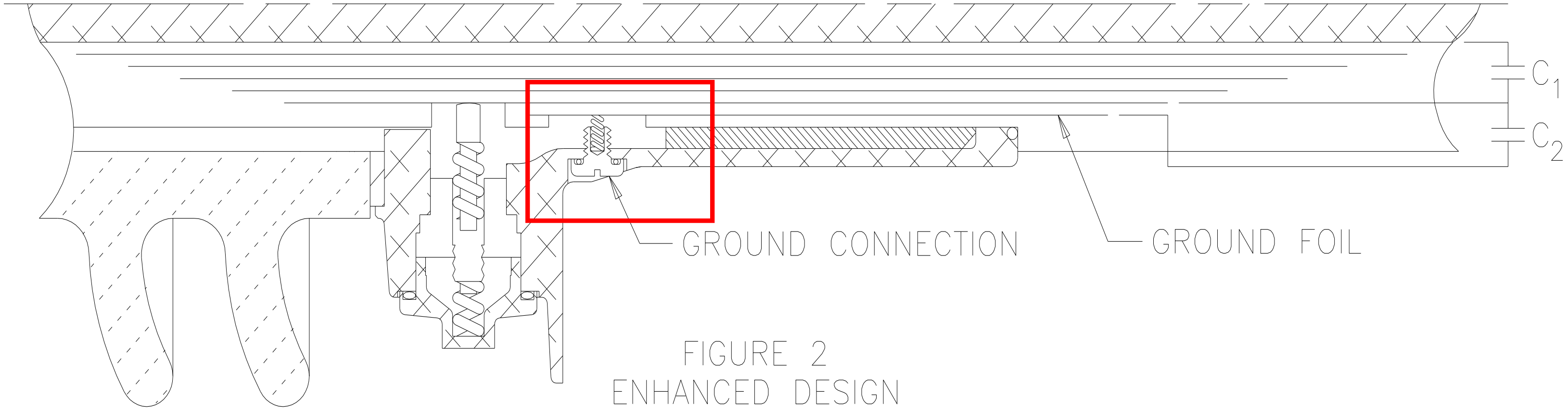



FIGURE 2
ENHANCED DESIGN

# Bushing Tests

- Ungrounded-Specimen Test
  - Center Conductor to Tap, $C_1$
- Tap Insulation Test
  - Tap to Flange, $C_2$
- Hot Collar Test
  - Externally Applied Collar to Center Conductor
- Overall
  - Center Conductor to Flange

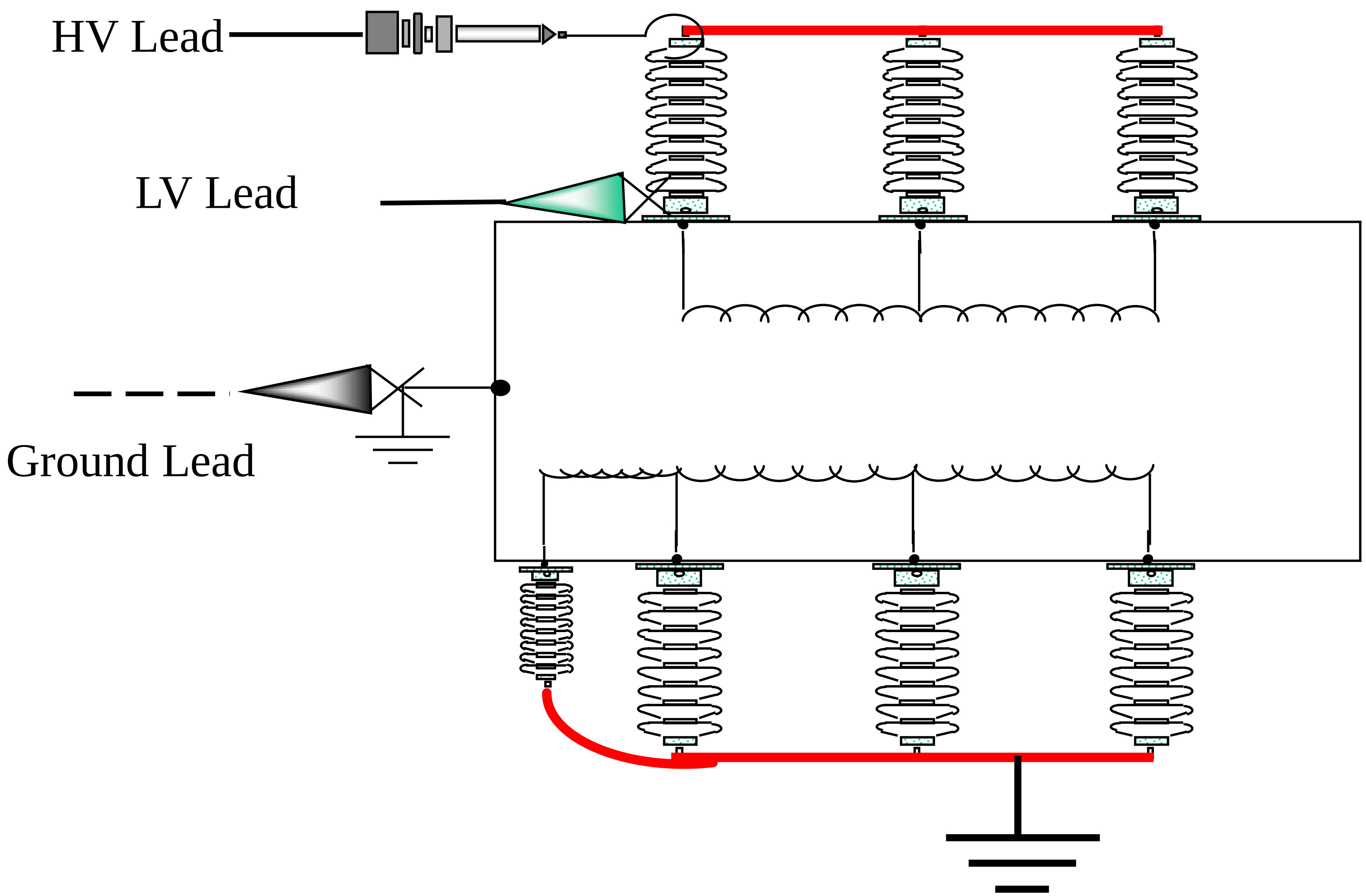
# Investigative Bushing Tests

- Inverse Ungrounded-Specimen Test
  - Tap to Center Conductor, C1
  - Do Not Exceed Tap Voltage Rating
- Tip-up Test
  - Repeat C1 Test at 2 and 10 kV or 2 and L-G kV if Less Than 10kV
- Alternate C2 Test
  - GST Ground Test
    - Tap to Center Conductor (C1 + C2)
- Supplemental Hot Collar Tests

# Bushing Test Set-Up

- Short-Circuit All Windings
- Clean Bushings to Minimize Surface Leakage
- Ground Opposite Winding
- Remove Test Tap Cover From Bushing Under Test Only
- Performed C1, Main Core Insulation Test in UST Mode
- Perform C2, Tap Test in GST-Guard Mode
- Replace Test Tap Cover

# Test Connections for Bushing C1 Test

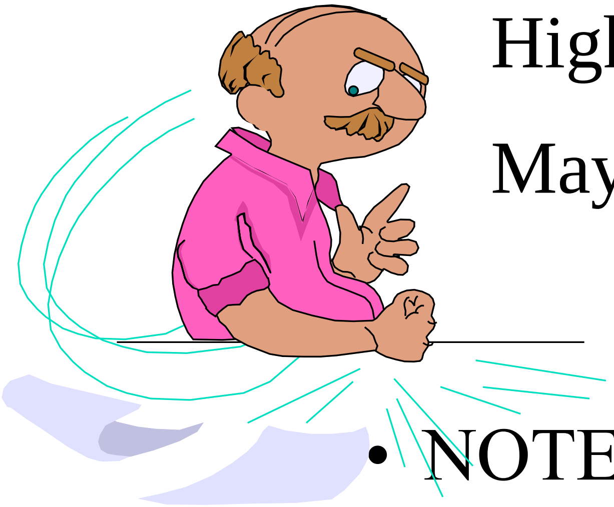


# Transformer Bushings

- Prior to Bushing Tests, Ensure
  - High Side Winding Shorted
  - Low Side Winding Shorted Including Neutral
- WHY???

  Higher Than Normal Power Factor Values

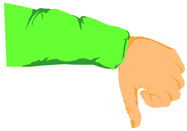
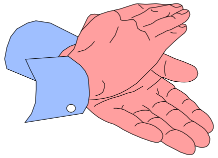
  May Be Obtained



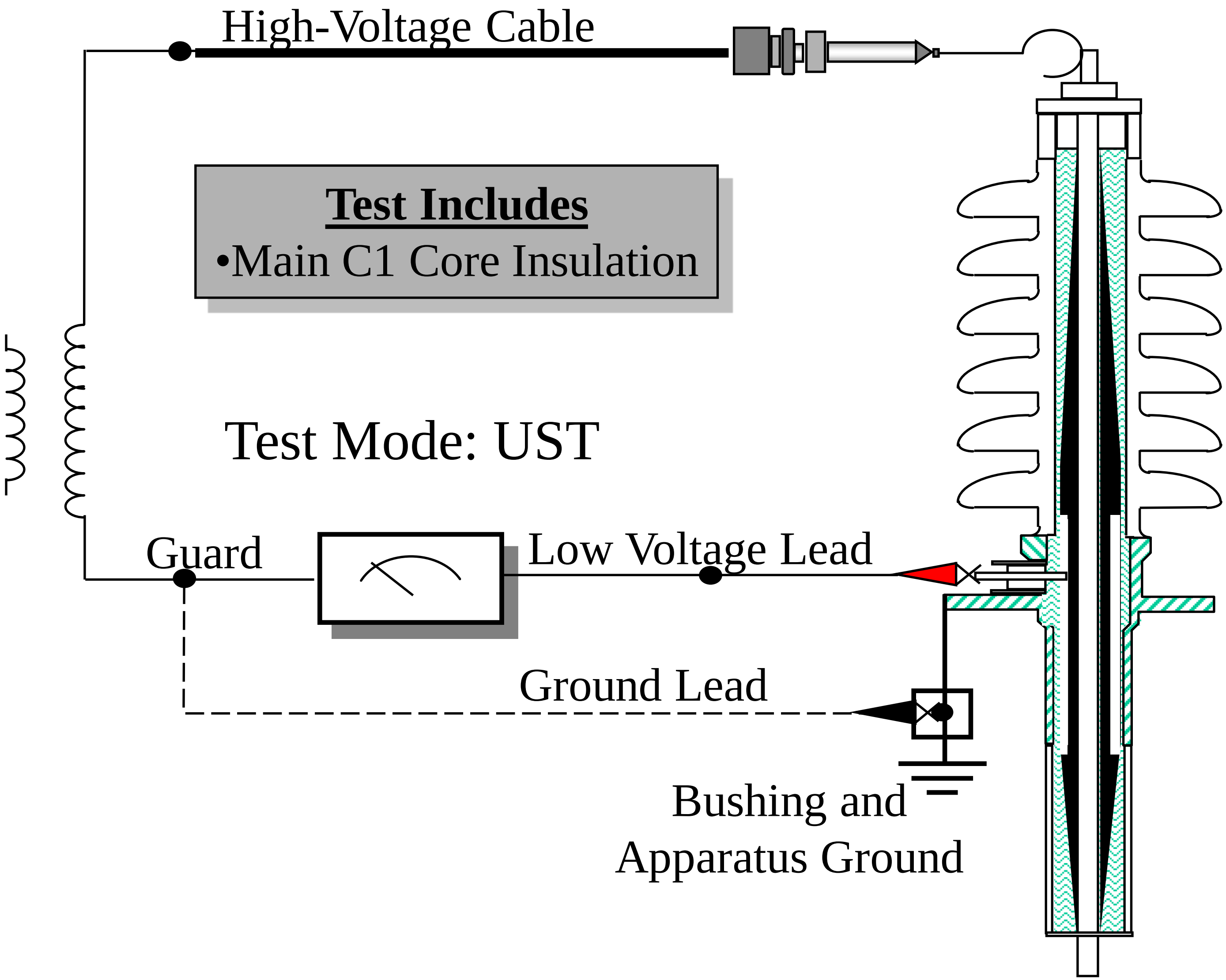
- NOTE Remove Only One Tap Cover at a time….

# Bushing Test Set-Up

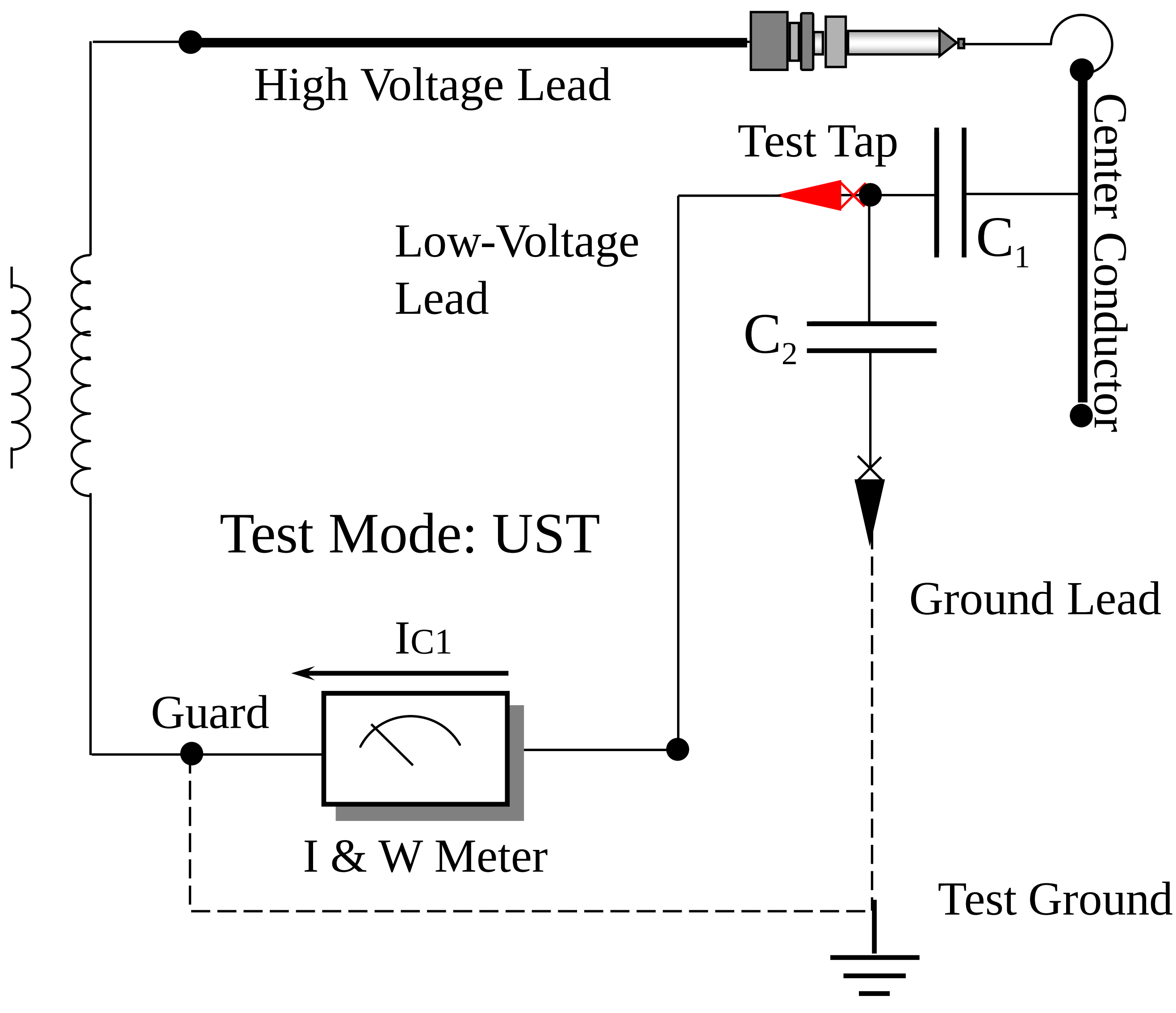
Test Setup: Which Bushing Under Test is Connected With the Winding Short-Circuited?

| | Power Factor | |
|---|---|---|
| Procedure: | Incorrect | Correct |
| |  |  |
| Phase A | 0.60% | 0.39% |
| Phase B | 0.65% | 0.40% |
| Phase C | 0.56% | 0.39% |

# Main-Insulation/C1 Test Standard Method



# Dielectric Circuit - Main Insulation C1 Test



# Typical C1 Test Data

| Description | Current (mA) | Watts | %PF |
|---|---|---|---|
| Typical Good Bushing | 1.08 | 0.03 | .28 |
| Same Bushing, Contaminated | 1.09 | 0.06 | .55 |
| Same Bushing, Shorted Condenser layers | 1.19 | 0.04 | .34 |

# C1 Test Result Analysis

Power Factor

- Modern Condenser Type Bushings
  - Generally of the Order of **0.5%**
  - Temperature Correction to 20 Degrees C
- Deteriorated Bushings
  - Generally Between **0.5% to 1.0%**
- Investigate Bushings
  - Above **1.0%**

**EXCEPTIONS…**

# C1 Test Result Analysis

**Current/Capacitance**

- Suggested Limits
  - ± 5% - Investigate
  - ± 10% - Investigate/Remove From Service

# General Electric Company

| Type | Description | Typical PF | Questionable PF |
|---|---|---|---|
| *A | Through Porcelain | 3.0% | 5.0% |
| **A | High Current | 1.0% | 2.0% |
| *B | Flexible Cable, Compound Filled | 5.0% | 12.0% |
| D | Oil Filled Upper Portion, Sealed | 1.0% | 2.0% |
| F | Oil Filled, Sealed | 0.7% | 1.5% |
| L | Oil Filled Upper Portion, Sealed | 1.5% | 3.0% |
| LC | Oil Filled Upper Portion, Sealed | 0.8% | 2.0% |
| OF | Oil Filled Expansion Chamber | 0.8% | 2.0% |
| *S | Force C & CG, Rigid Core, Compound Filled | 1.5% | 6.0% |

* Type S, Form F, DF & EF (flexible cable) redesigned as Types B, BD, and BE, respectively. Type S, no Form letter (through porcelain) redesigned as Type A

# LAPP Insulator Division

| | Typical C1 PF | Questionable C1 PF |
|---|---|---|
| Type ERC (Epoxy-Resin-Core, Plastic or Oil Filled) | 0.8% | 1.5% |
| Type PRC and PRC-A (Paper-Resin-Condenser Core) | 0.8% | 1.5% |

*Typical C2 power factors for older PRC design range from 4-15% due to injected compound used during manufacturing.*

# Ohio Brass Company

| | Typical %PF | Questionable %PF |
|---|---|---|
| Class LK-Type A, 23 to 69 kV | 0.4 | 1.0 |
| ODOF, Class G, and Class L Oil-Filled: | | |
| Prior to 1926 and after 1938 | 1.0-5.0 | Change of 22% from initial |
| Between 1926 and 1938 | 2.0-4.0 | Change of 16% from initial |
| Type S, OS, and FS | 0.8 | 2.0 |
| On OCB and Inst. Trans. 69 kV and below (except Types S, OS, and FS) | 1.5 | 3.0 |

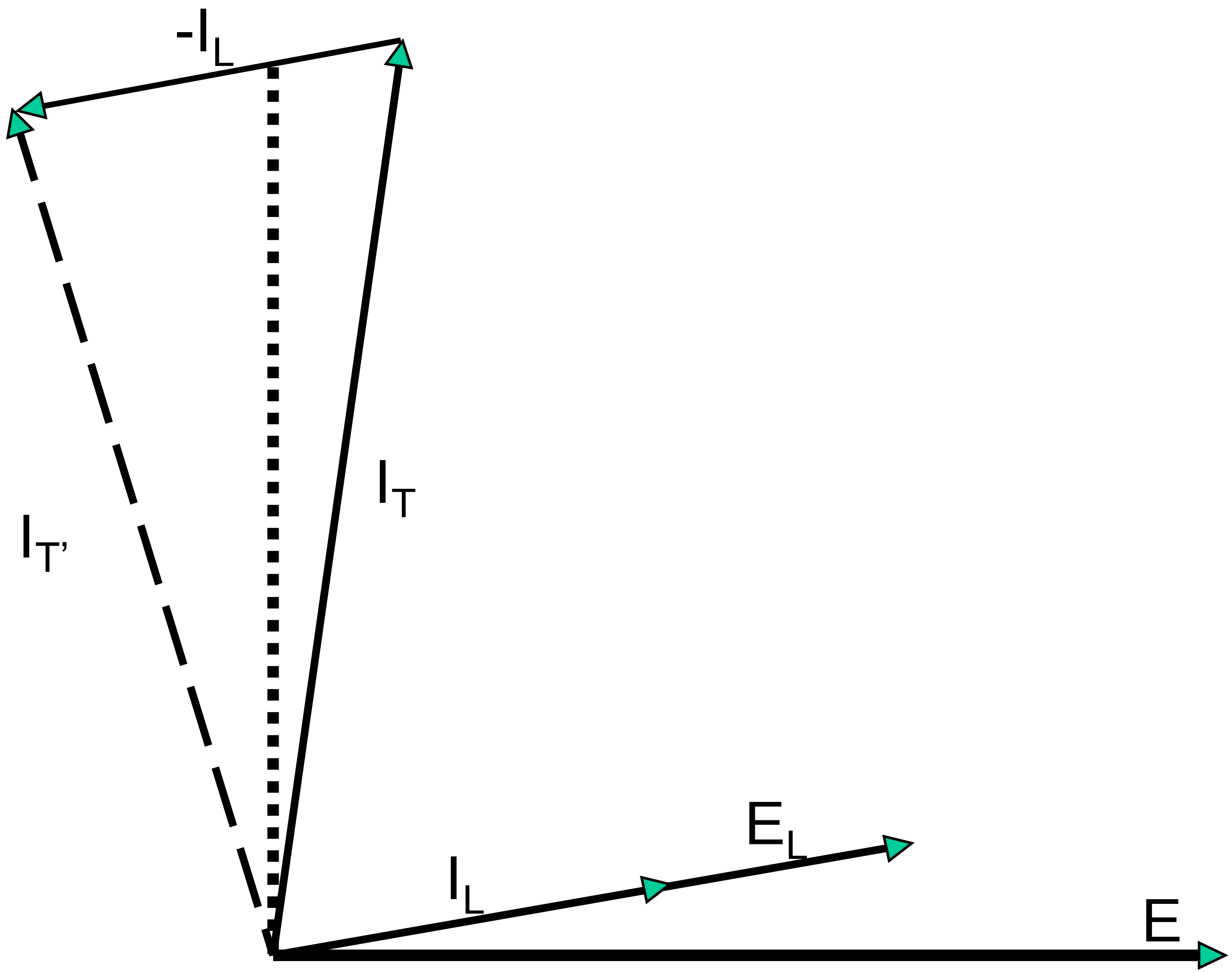
# Westinghouse

| | Typical %PF | Questionable %PF |
|---|---|---|
| On OCB and Inst. Trans. 92 kV to 139 kV (except Types O, O-A1, OC and O Plus) | 1.5 | 3.0 |
| On Power and Dist Trans of all rating, and OCB & Inst. Trans. 161 kV to 288 kV (except Types O, O-A1, OC, and O Plus) | 1.0 | 2.0 |
| All Type D Transformer Bushings ( Semi-Condenser) | 1.5 | 3.0 |
| Type RJ (Solid Porcelain) | 1.0 | 2.0 |

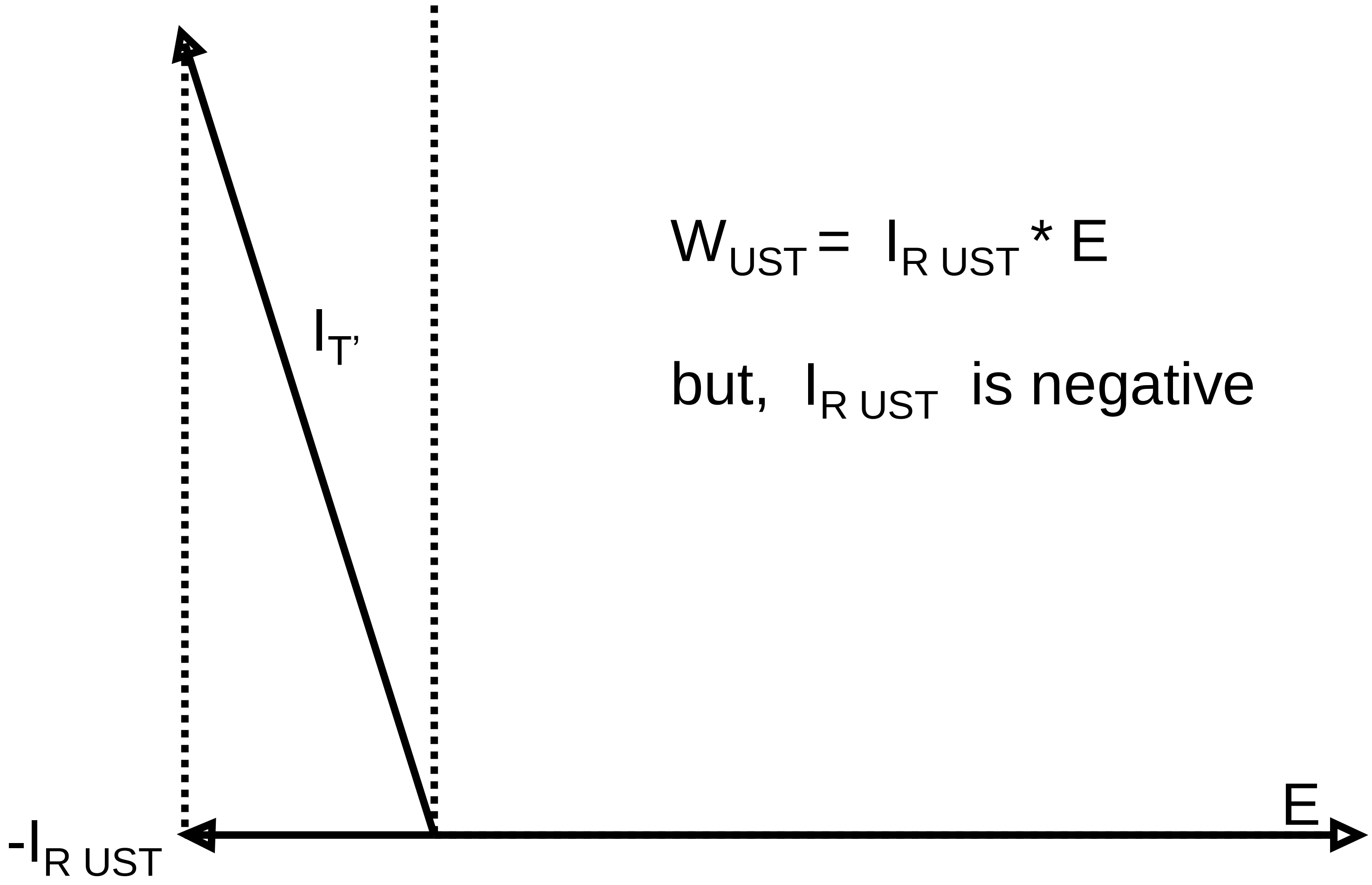
# Negative Power Factor Value

- Typically Created Due to a High Resistance Leakage Path to Ground
- Conditions:
  - Extensive Surface Contamination
    - Lower Porcelain
    - Upper Porcelain
  - Poor Grounding of Bushing Flange
  - Tracking Over the Internal Insulation to the Bushing

# $I_{T'} = I_T - I_L$



# $I_{R\ UST}$ = Real Component of $I_{T'}$

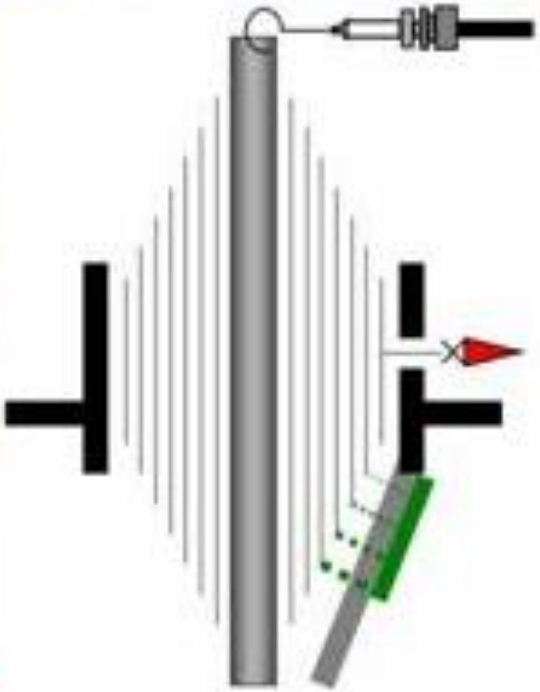


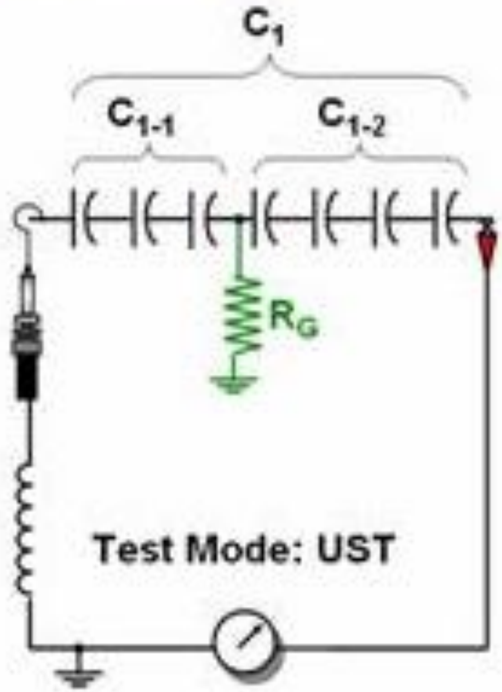

$W_{UST} = I_{R\ UST} * E$

but, $I_{R\ UST}$ is negative

# Resistive Path-to-Ground Negative Power Factor

## ABB Type O+C Bushing, Surface Contamination





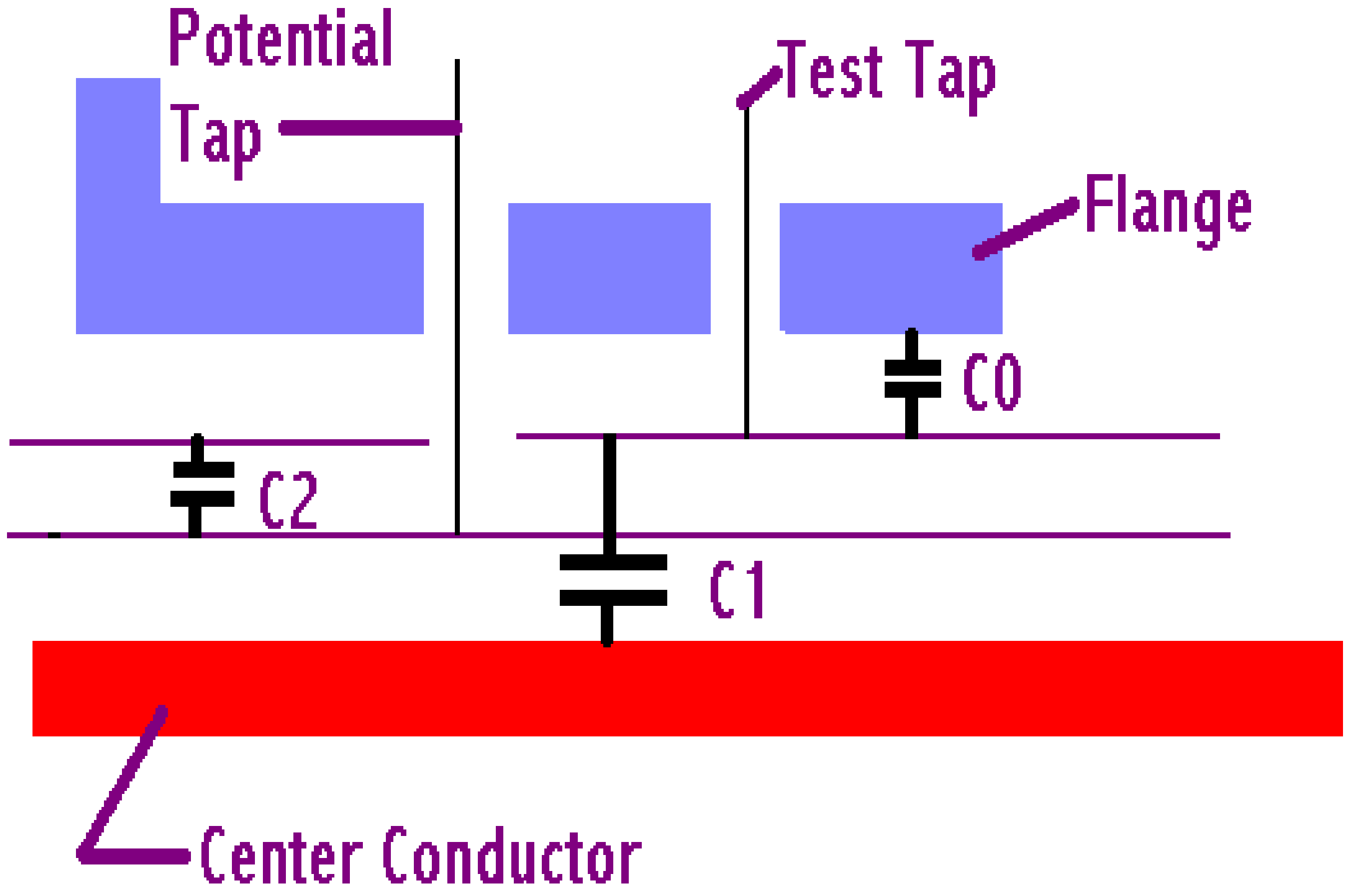

| Test / Mode | Test KV | mA | W | %PF |
|---|---|---|---|---|
| C1 / UST | 10 | 1.313 | -0.007 | -0.053 |

# Haefely Tap Used During Factory Tests

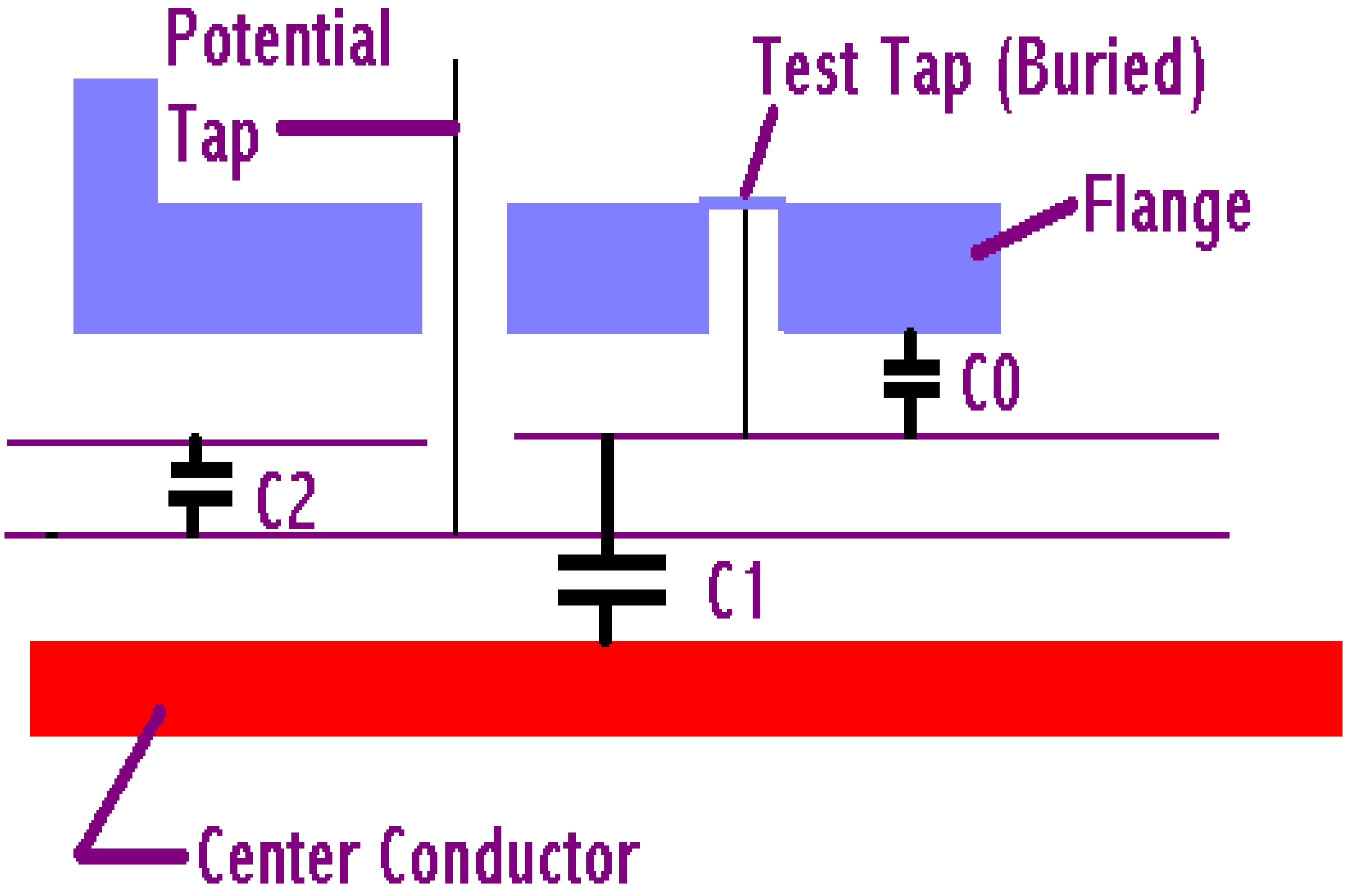
- Some Haefely Bushings, 115kV and Above
  - Factory Measures C1 Capacitance With a Special Tap Only Available at Factory
  - Variance in Test Procedure Results in Field Test Results Being 5% or Higher Than Nameplate Values
  - The C1 Capacitance in the Field Must be Modified by Using the Equation Below:

$$C1(\text{Doble Test}) = \frac{C1(\text{Haefely}) * C2(\text{Haefely})}{C2(\text{Haefely}) - C1(\text{Haefely})}$$

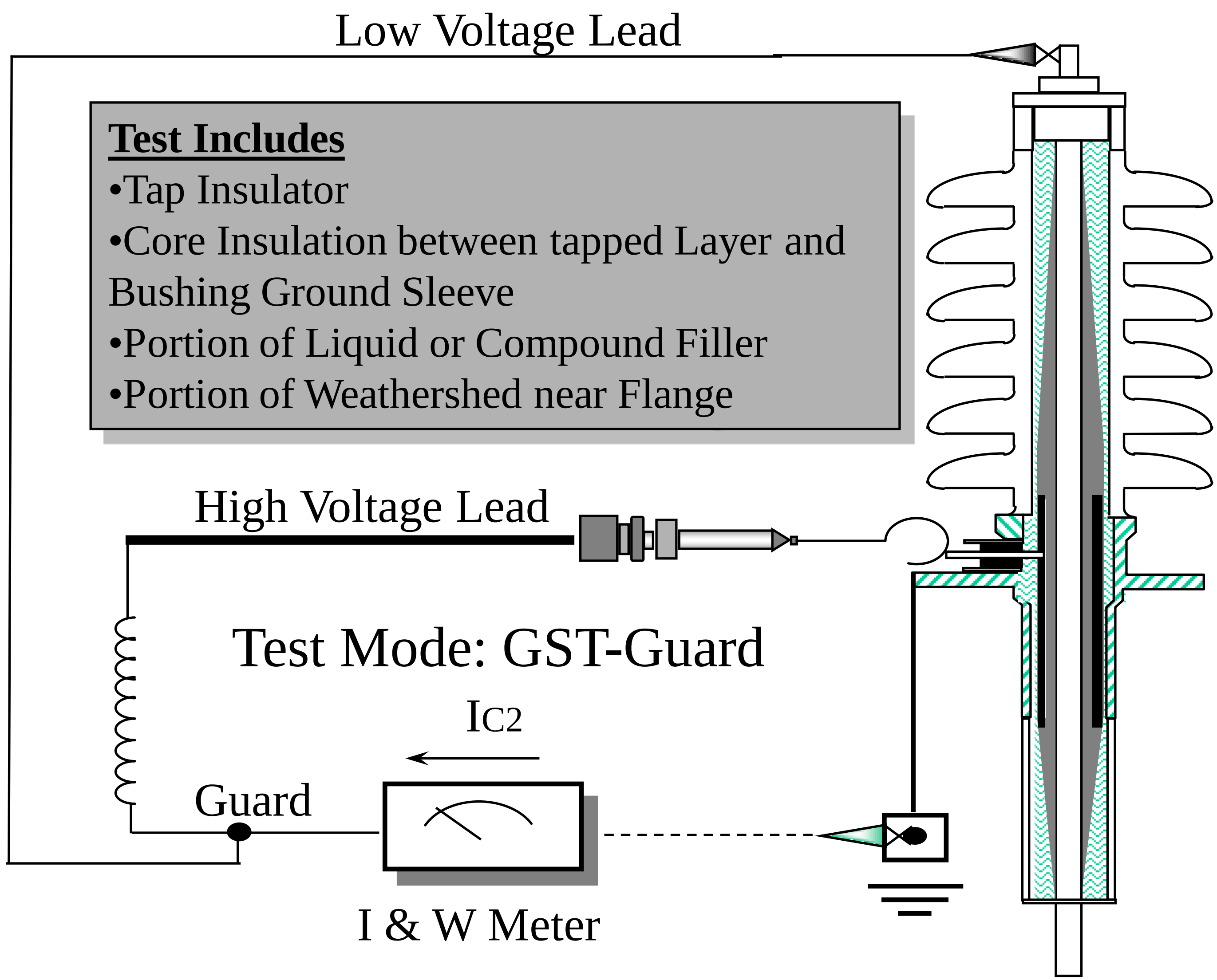
# Haefely Tap Used During Factory Tests



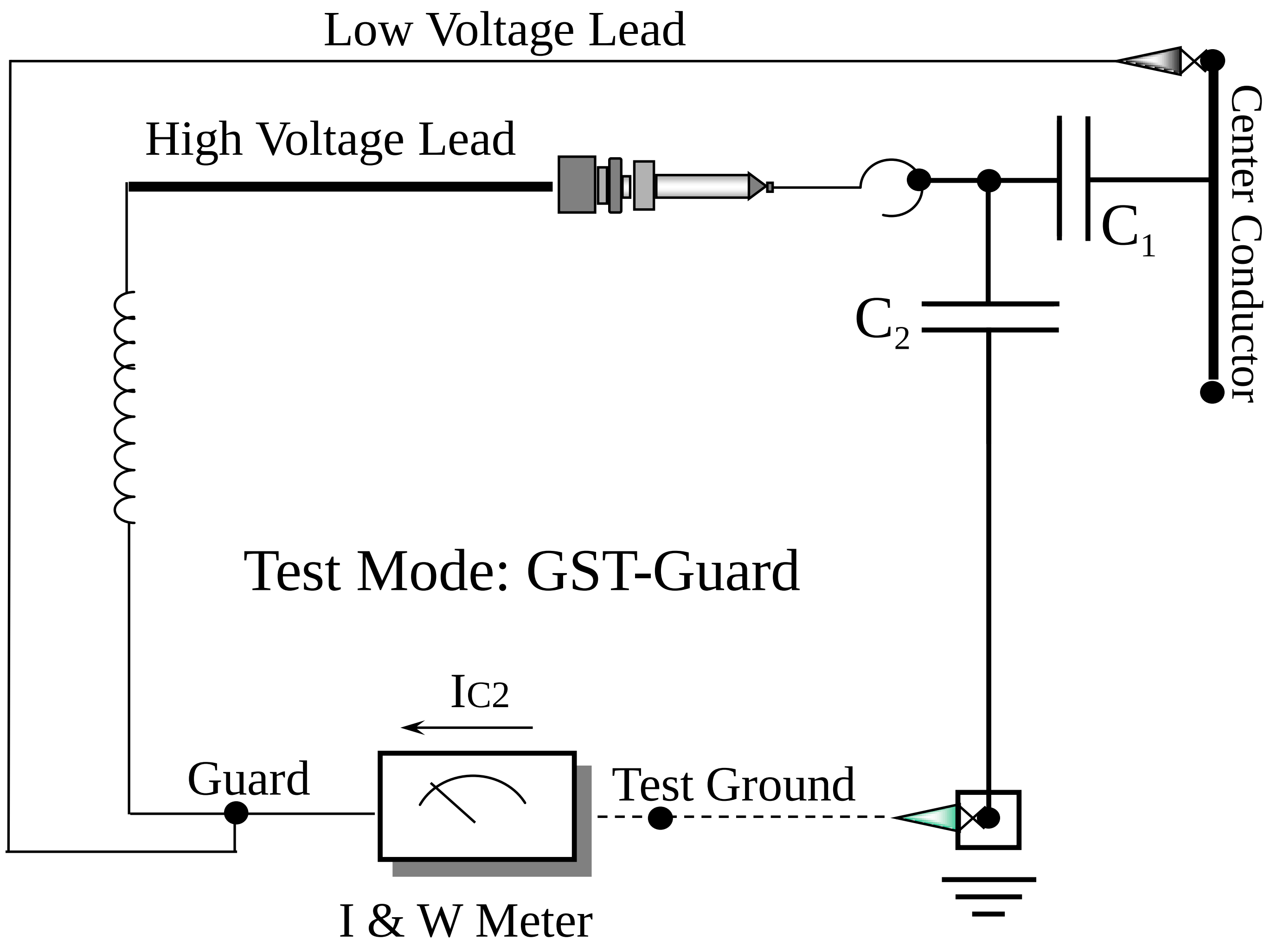
# Haefely Tap Used During Factory Tests



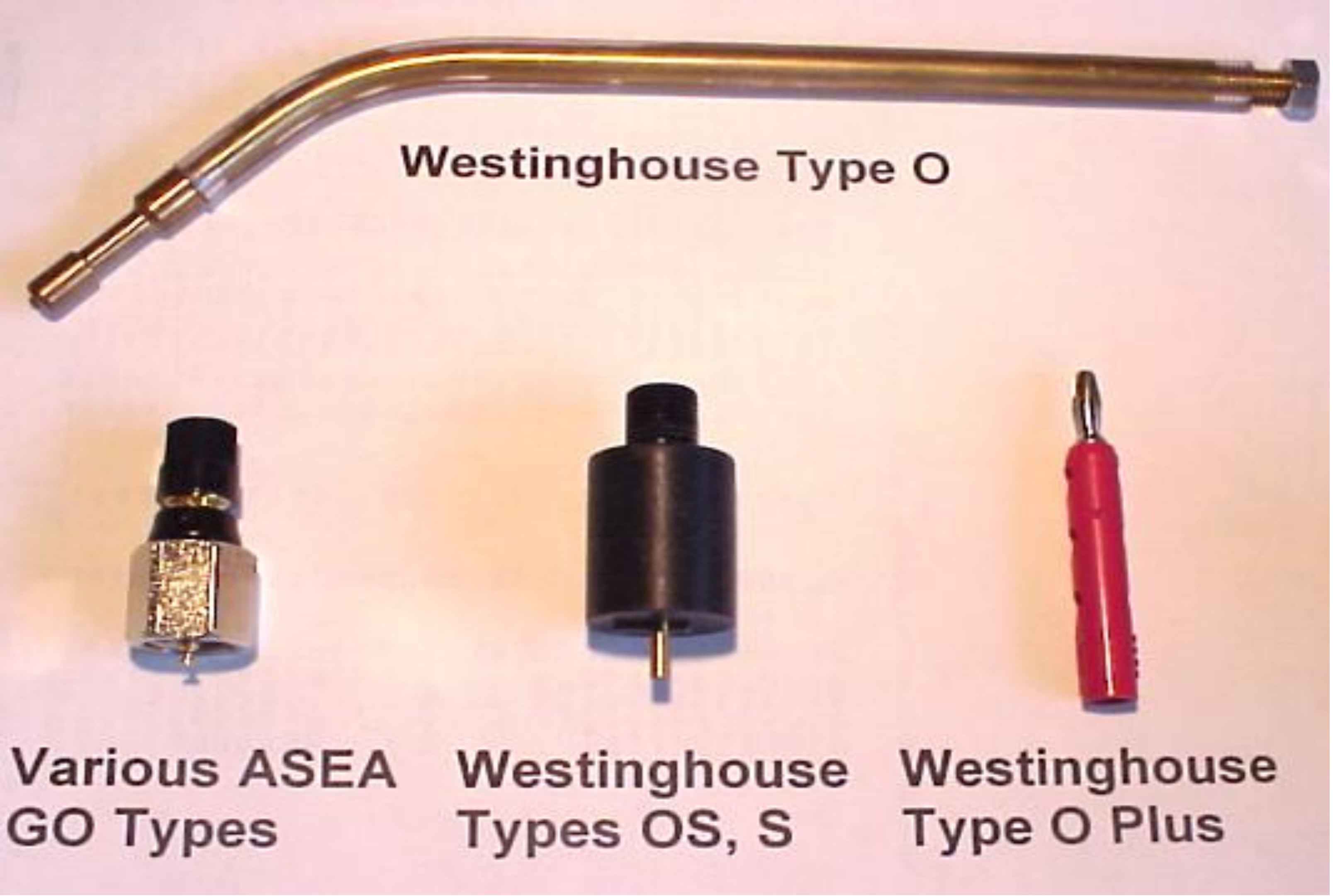
# Tap-Insulation - C2 Test - Standard Method



# Dielectric Circuit - Tap Insulation C2 Test

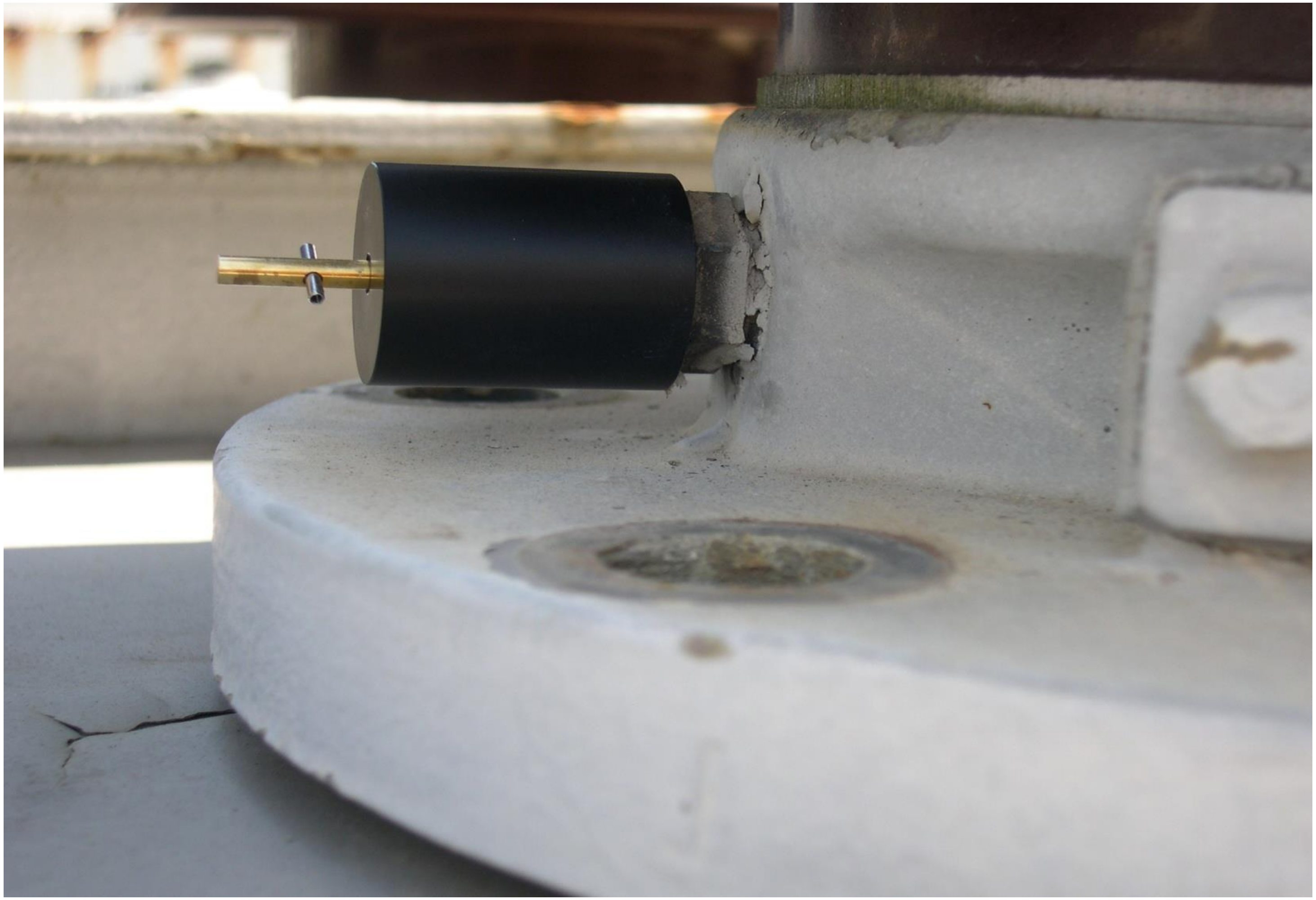


# C2 Tap Adapters

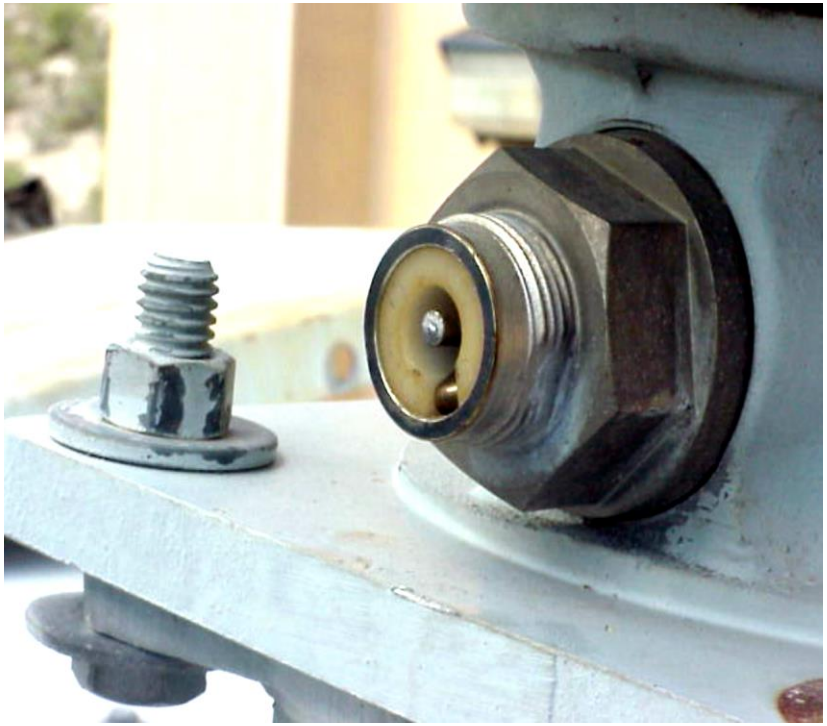


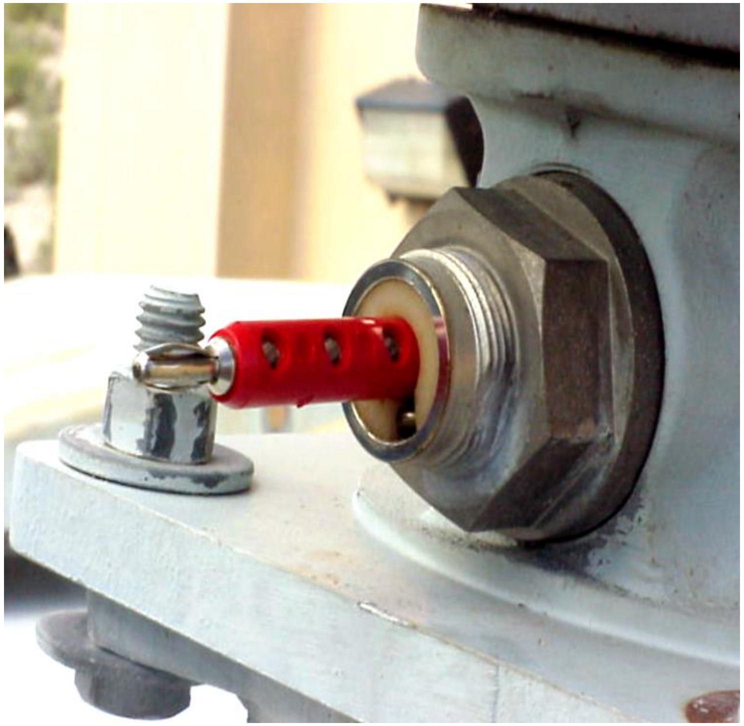
# Westinghouse Type 0, C2 Tap Adapter

# Westinghouse Type 0S and S, C2 Tap Adapter



# Westinghouse Type 0 +, C2 Tap Adapter





# ASEA Type GO

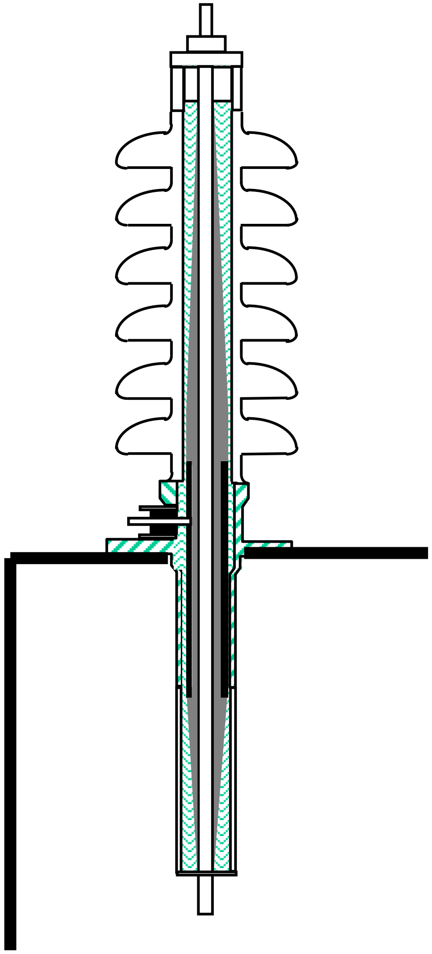
# Environment: Factors Affecting Capacitance Tests

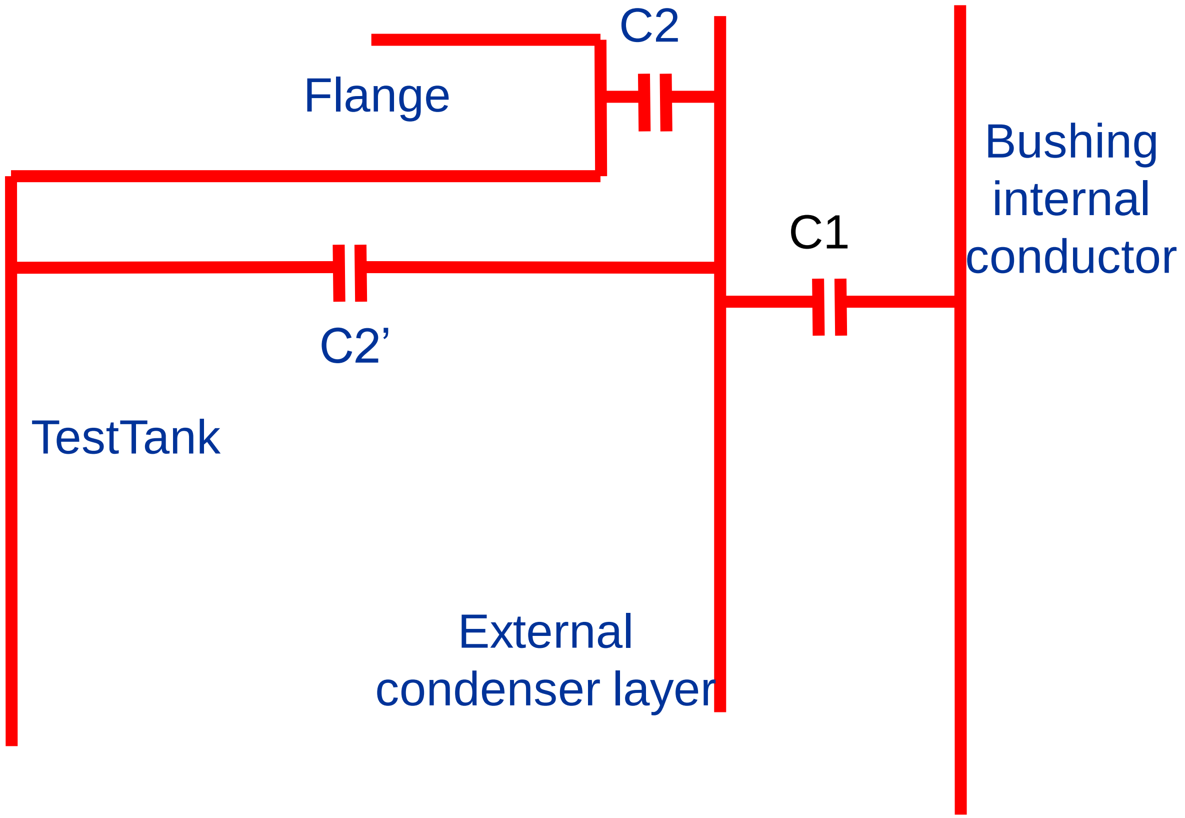
- Length of Outer Grounded Condenser Layer
- Physical Movement of Paper Core
- Condition of Tap Connection
- Distance From Bushing to Grounded Tank Wall

# Bushing With Test Tap In Testing Tank versus In Transformer Tank

Capacitance C2 varies depending on the length of the grounded outer condenser layer, and is made up of C2, C2', etc

**C2 = C2 + C2'**





# C2 TESTS

- **Why Perform C2 Tests ?????**

# C2 TESTS

- Internal Flashover Around the Main Core is a Real and Serious Threat to all Sealed Capacitance Graded Bushings

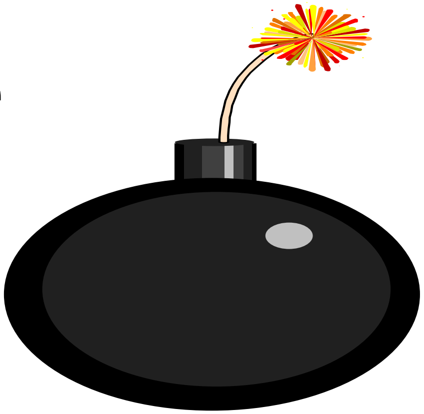
- The C2 Power Factor Test has Been Shown, in Some Cases, to be a More Apparent Indicator of Internal Fluid Contamination Than the C1 Test

# C2 TESTS

## GE Type U 230kV Bushing:

| | C1 | | C2 | |
|---|---|---|---|---|
| Date | %PF | Cap | %PF | Cap |
| 1/6/82 | .31 | 508.8 | .28 | 4134 |
| 5/1/96 | .58 | 510.2 | 2.26 | 4138 |

1/30/97 Failed in service



# C2 TESTS

## Example:

McGraw-Edison Type PA 23kV Bushings

| Bushing # | C1(%PF) | C2(%PF) |
|---|---|---|
| X1 | 0.46 | 0.50 |
| X2 | 0.60 | 2.78 |
| X3 | 0.45 | 0.50 |

- X2 was removed from service and found to have highly contaminated fluid with low dielectric-breakdown strength

# Spare Bushings

- Do Not Test Bushings in Wooden Crate or Stand
- Support Bushing on a Metal Stand if Possible
- Web Slings May be Used for Tests
  - Cleanliness of Sling May Affect Test Results
  - Sling Should be Kept Clear of Energized Points

# Spare Bushings

- Connect Ground Lead Directly to Bushing Flange
- Ground Both Test Set and Specimen to Substation Ground
- Clean Upper and Lower Surfaces BeforeTesting

# DTA Spare Bushing Test Screen

**Overall Test Setup**

| Connections | | | | | | Inputs | | | Test Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | Test | HV Lead | Ground | Red Measure Lead | Test Mode | Skirt # | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) |
| 1 | C1 | Conductor | Flange | Tap | UST RB | | 10.000 | 1.06 | 1.489 | 0.038 | 0.255 | 0.271 | 394.9 |
| 2 | C2 | Tap | Flange | Conductor | GAR RB | | 1.999 | 1.00 | 15.786 | 0.435 | 0.276 | 0.276 | 4187.2 |
| 3 | Overall | Conductor | Flange | Unused | GND RB | | 10.000 | 1.06 | 1.501 | 0.041 | 0.273 | 0.290 | 398.1 |
| 4 | C1+C2 | Tap | Flange | Conductor | GND RB | | 2.000 | 1.00 | 17.276 | 0.444 | 0.257 | 0.257 | 4582.5 |
| 5 | Inverted-UST | Tap | Flange | Conductor | UST RB | | 1.999 | 1.00 | 1.489 | 0.042 | 0.282 | 0.282 | 395.0 |
| **Hot Collar Tests** | | | | | | | | | | | | | |
| 6 | Hot Collar | Collar | Flange | Conductor | GND RB | | 10.000 | 1.00 | 0.111 | 0.030 | 2.703 | 2.703 | 29.5 |
| **Miscellaneous Tests** | | | | | | | | | | | | | |

Note that Tests 1 & 2 add up to match Test 4

17.275 mA 0.473 watts

Note that Tests 1 & 5 are "equal"

# DTA Spare Bushing Test Screen

**Overall Test Setup**

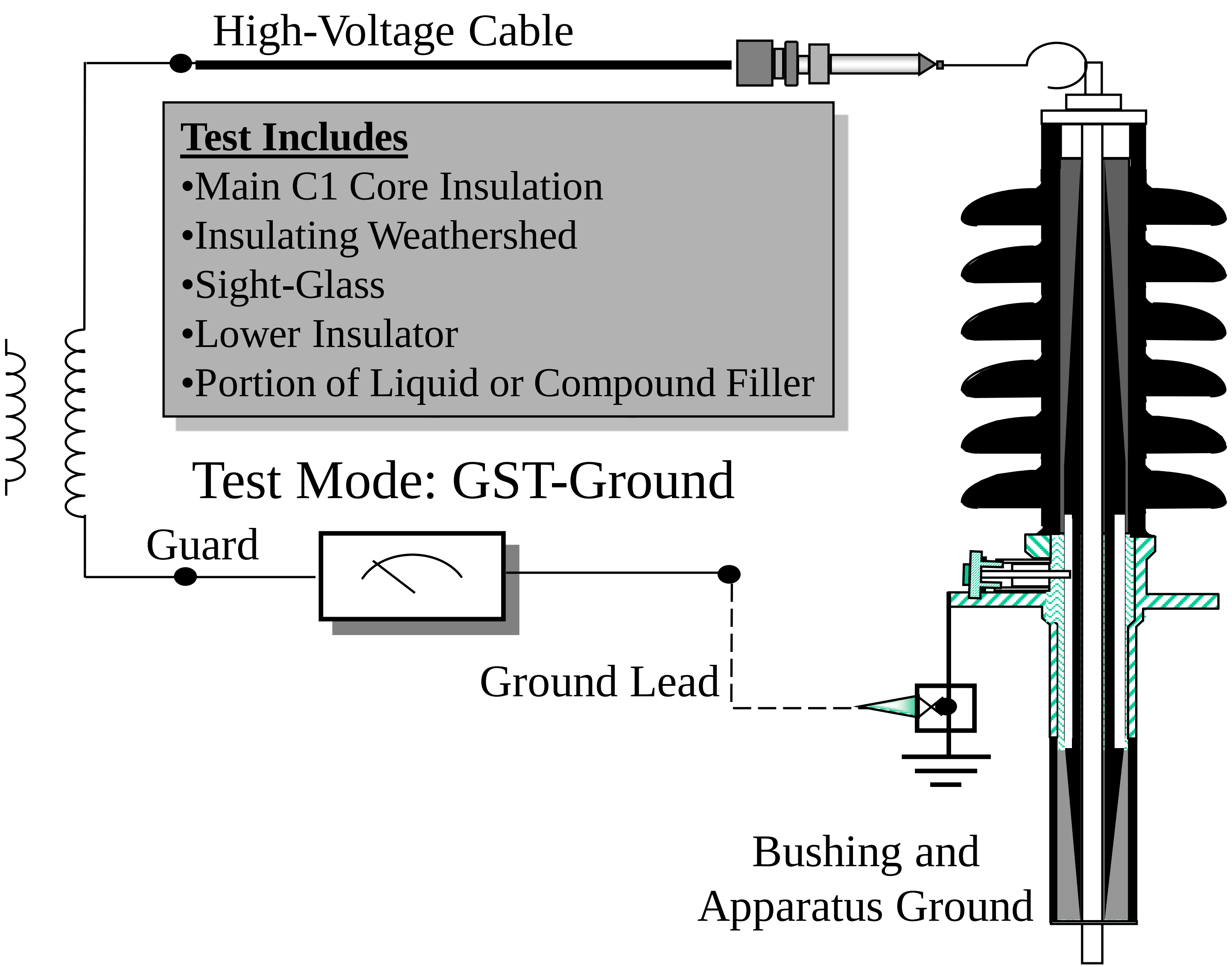
| Connections | | | | | | Inputs | | | Test Results | | | | | Ratings | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | Test | HV Lead | Ground | Red Measure Lead | Test Mode | Skirt # | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | Ask FRANK™ | Manual |
| 1 | C1 | Conductor | Flange | Tap | UST RB | | 10.000 | 1.06 | 1.489 | 0.038 | 0.255 | 0.271 | 394.9 | Good | Unrated |
| 2 | C2 | Tap | Flange | Conductor | GAR RB | | 1.999 | 1.00 | 15.786 | 0.435 | 0.276 | 0.276 | 4187.2 | Good | Unrated |
| 3 | Overall | Conductor | Flange | Unused | GND RB | | 10.000 | 1.06 | 1.501 | 0.041 | 0.273 | 0.290 | 398.1 | Good | Unrated |
| 4 | C1+C2 | Tap | Flange | Conductor | GND RB | | 2.000 | 1.00 | 17.276 | 0.444 | 0.257 | 0.257 | 4582.5 | Good | Unrated |
| 5 | Inverted-UST | Tap | Flange | Conductor | UST RB | | 1.999 | 1.00 | 1.489 | 0.042 | 0.282 | 0.282 | 395.0 | Good | Unrated |
| **Hot Collar Tests** | | | | | | | | | | | | | | | |
| 6 | Hot Collar | Collar | Flange | Conductor | GND RB | | 10.000 | 1.00 | 0.111 | 0.030 | 2.703 | 2.703 | 29.5 | Good | Unrated |
| **Miscellaneous Tests** | | | | | | | | | | | | | | | |

FRANK Provides Ratings!

# Bushing Overall Test

**Test Includes**
- Main C1 Core Insulation
- Insulating Weathershed
- Sight-Glass
- Lower Insulator
- Portion of Liquid or Compound Filler

Test Mode: GST-Ground



# Bushing Hot-Collar Test – When To Perform

1. Compound-Filled Bushings

2. Solid Porcelain Bushings

3. Gas-Filled Bushings

4. Oil Filled Bushings Not Equipped With Taps and Overall Test Cannot be Performed:

   a) Single Hot-Collar Test on Small Bushings 15 kV and Below

   b) Several Single Hot-Collar Tests for Bushings Rated Above 15 kV

# Bushing Hot-Collar Test
# When To Perform

5. Check Oil Level on all Liquid-Filled Bushings Without Liquid-Level Gauges or Sight Glass

6. Check Bushing With Liquid-Level Gauges Whenever the Gauge is Suspect

7. As Supplementary Test When Overall, UST, Tap Tests Indicate Possible Problem

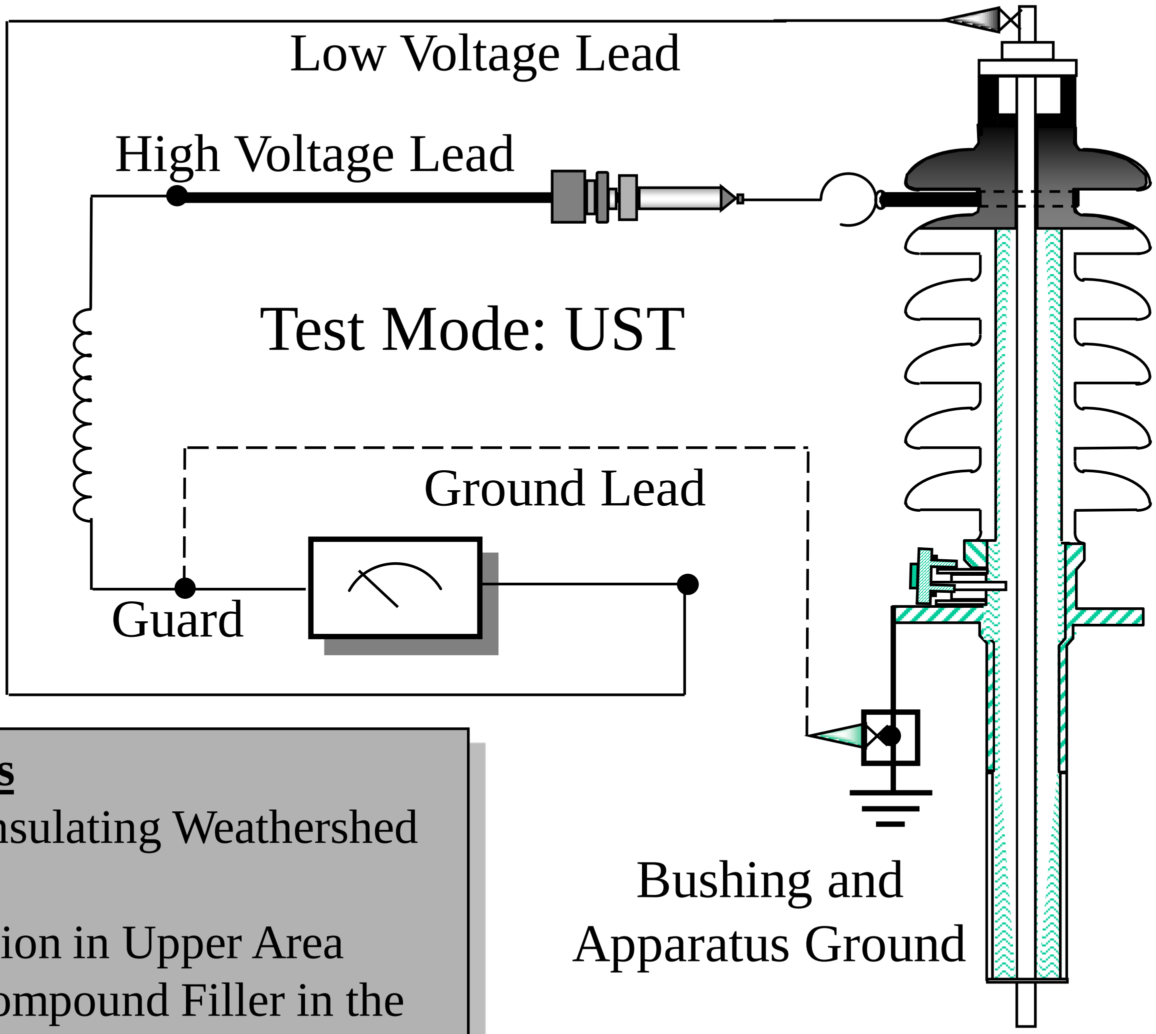
# Doble Hot Collar Test

**Test Voltage:** 10 kV

**Recommended Acceptable Limits:**

| **Watts** | **Current** |
|---|---|
| <= 0.1 Watts | Similar for Same Type Bushings |

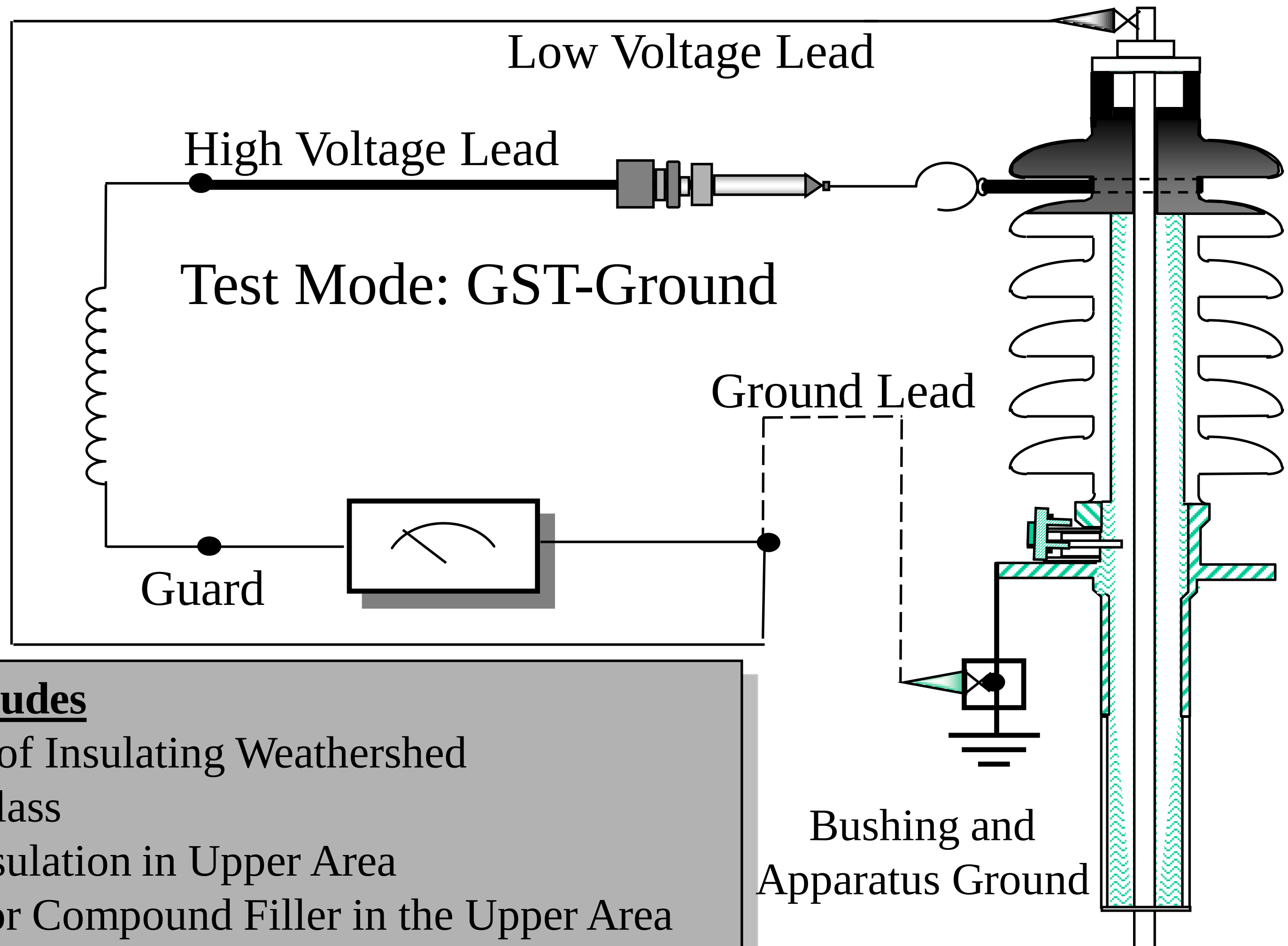
# Single Hot Collar Test - UST Mode




**Test Includes**

- Portion of Insulating Weathershed
- Sight-Glass
- Core Insulation in Upper Area
- Liquid or Compound Filler in the Upper Area

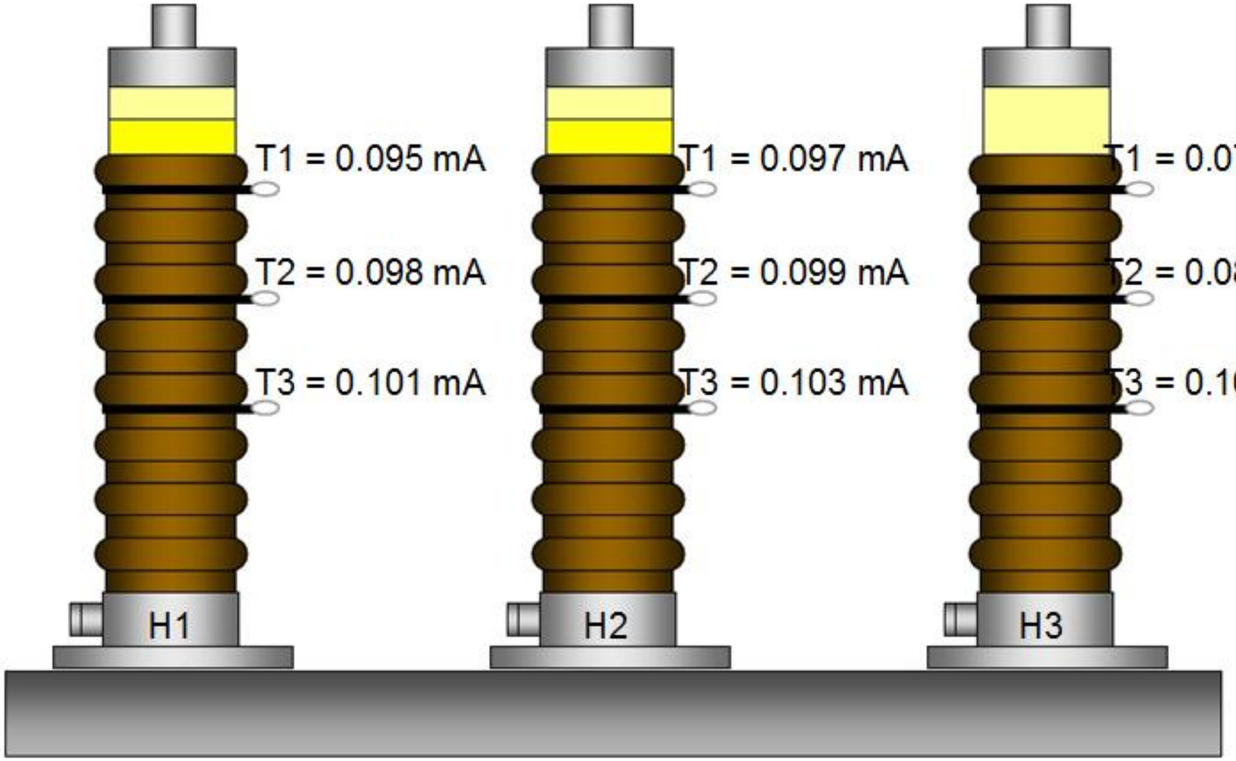
# Single Hot Collar Test - GST-Ground Mode




**Test Includes**

- Portion of Insulating Weathershed
- Sight-Glass
- Core Insulation in Upper Area
- Liquid or Compound Filler in the Upper Area
- Surface leakage from Collar to LV lead & to bushing flange

# Hot Collar Test – Comparing Currents




<u>Conclusion:</u> The oil level in the H3 bushing is somewhere between the locations used for tests hot-collar tests 2 and 3.

# Hot Collar Test Result Analysis

**<u>Hot Collar Test Results</u>**

- Increased Watt-Losses
  - Contamination of the Insulation
  - Maximum Acceptable Limit, 0.1 W

- Decreased Current (Amperes)
  - Voids
  - Low Liquid or Compound Level

# Typical Hot-Collar Test Data

| Description | Current (mA) | Watts |
| --- | --- | --- |
| Typical Good Bushing | .090 | 0.02 |
| Same Bushings, Contaminated | .095 | 0.31 |
| Same Bushing, Low Liquid Level | .070 | 0.02 |

# Hot Collar Test Results
# Westinghouse, Type “S”

Good Condition

| Bushing | Current | Watts |
|---|---|---|
| X1 | 110 μA | 0.06 |
| X2 | 110 μA | 0.04 |
| X3 | 110 μA | 0.05 |

General Contamination

| Bushing | Current | Watts |
|---|---|---|
| X1 | 110 μA | 0.16 |
| X2 | 110 μA | 0.18 |
| X3 | 110 μA | 0.17 |

Physical Changes (X2)

| Bushing | Current | Watts |
|---|---|---|
| X1 | 110 μA | 0.06 |
| X2 | 80 μA | 0.05 |
| X3 | 110 μA | 0.05 |

Defective Bushing (X3)

| Bushing | Current | Watts |
|---|---|---|
| X1 | 110 μA | 0.06 |
| X2 | 110 μA | 0.05 |
| X3 | 120 μA | 0.20 |

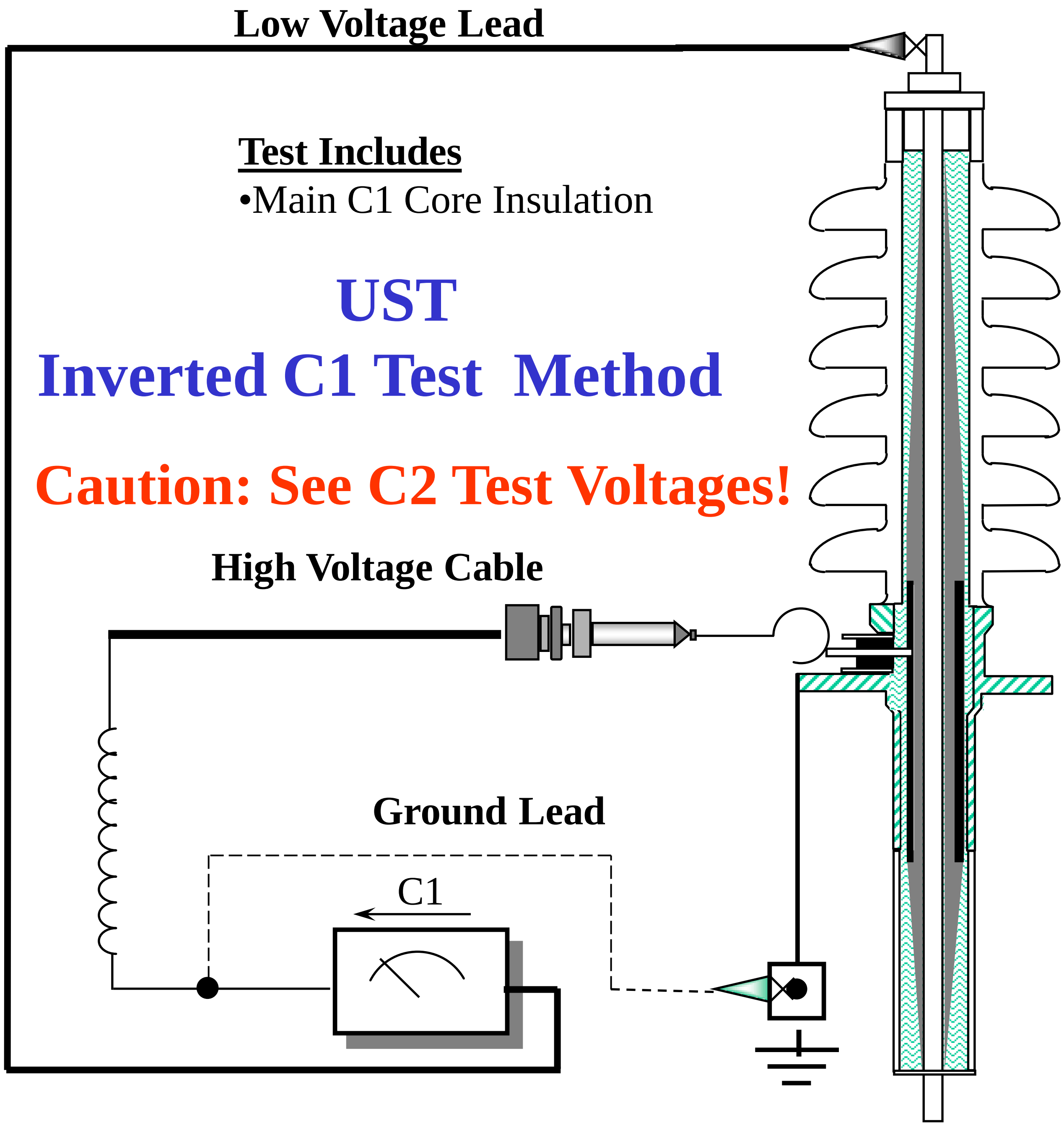
# Bushing
# Diagnostic Tests

<u>**Test Includes**</u>

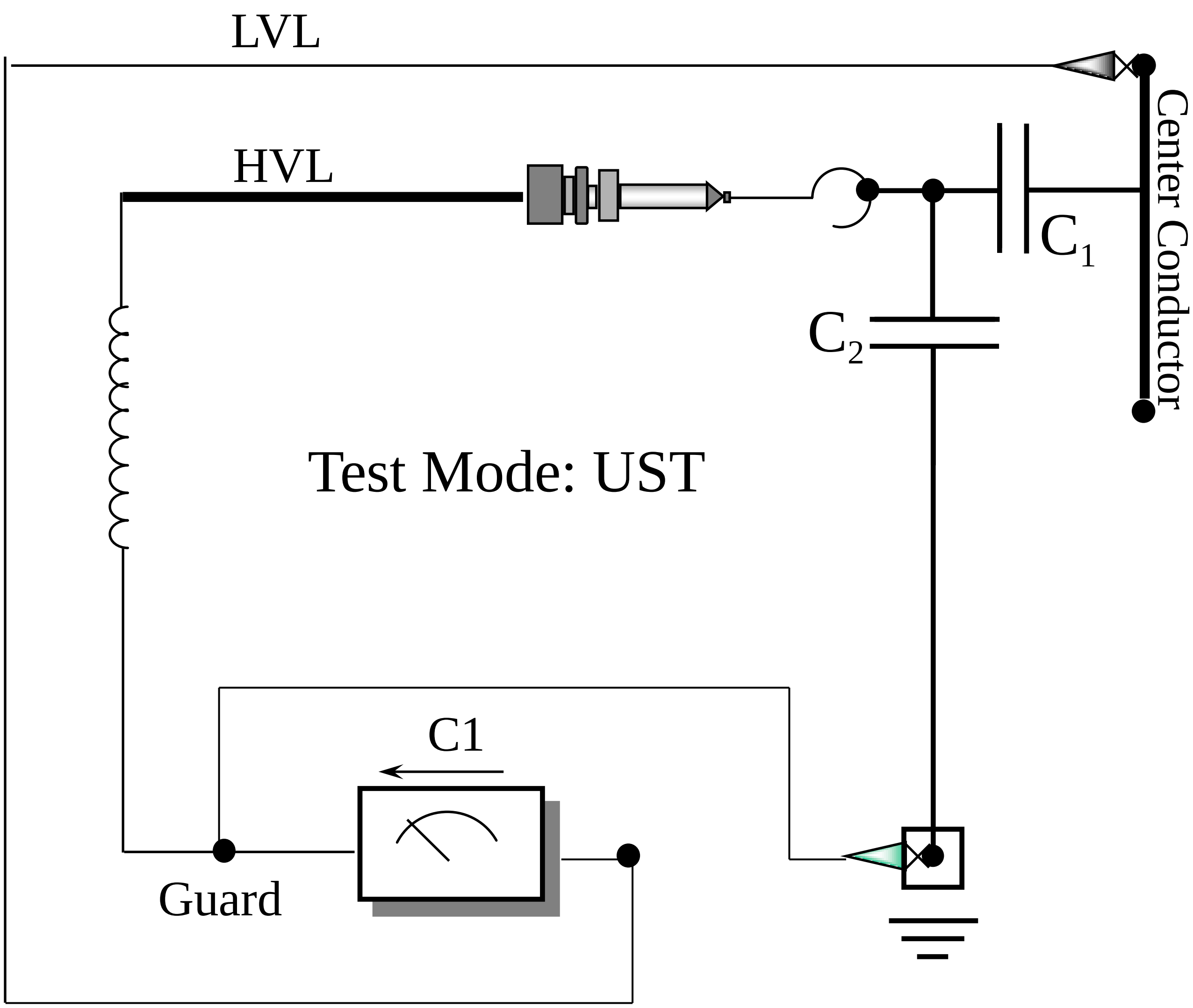
•Main C1 Core Insulation

# UST
# Inverted C1 Test Method

**Caution: See C2 Test Voltages!**



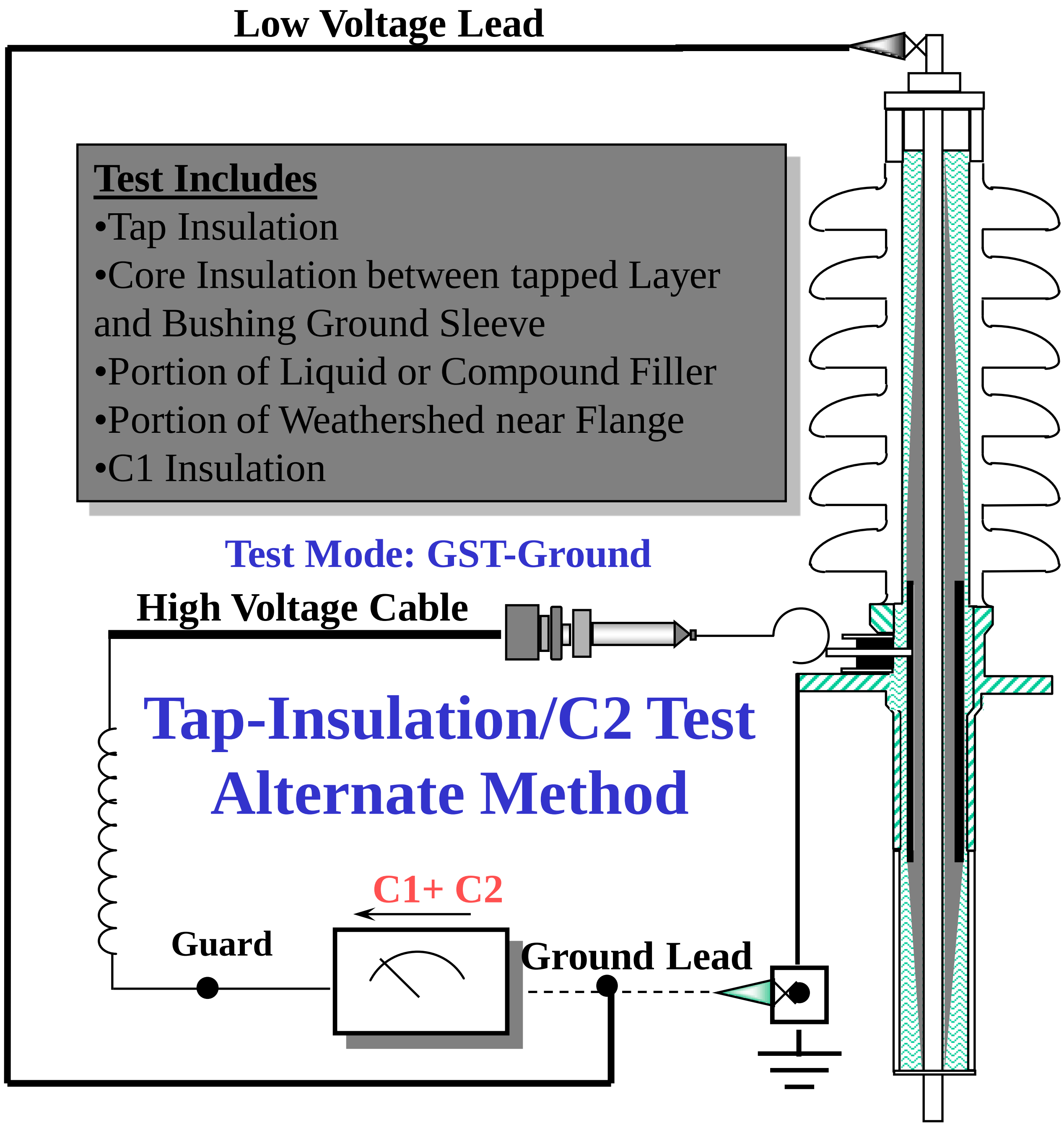
# Inverted C1 Test



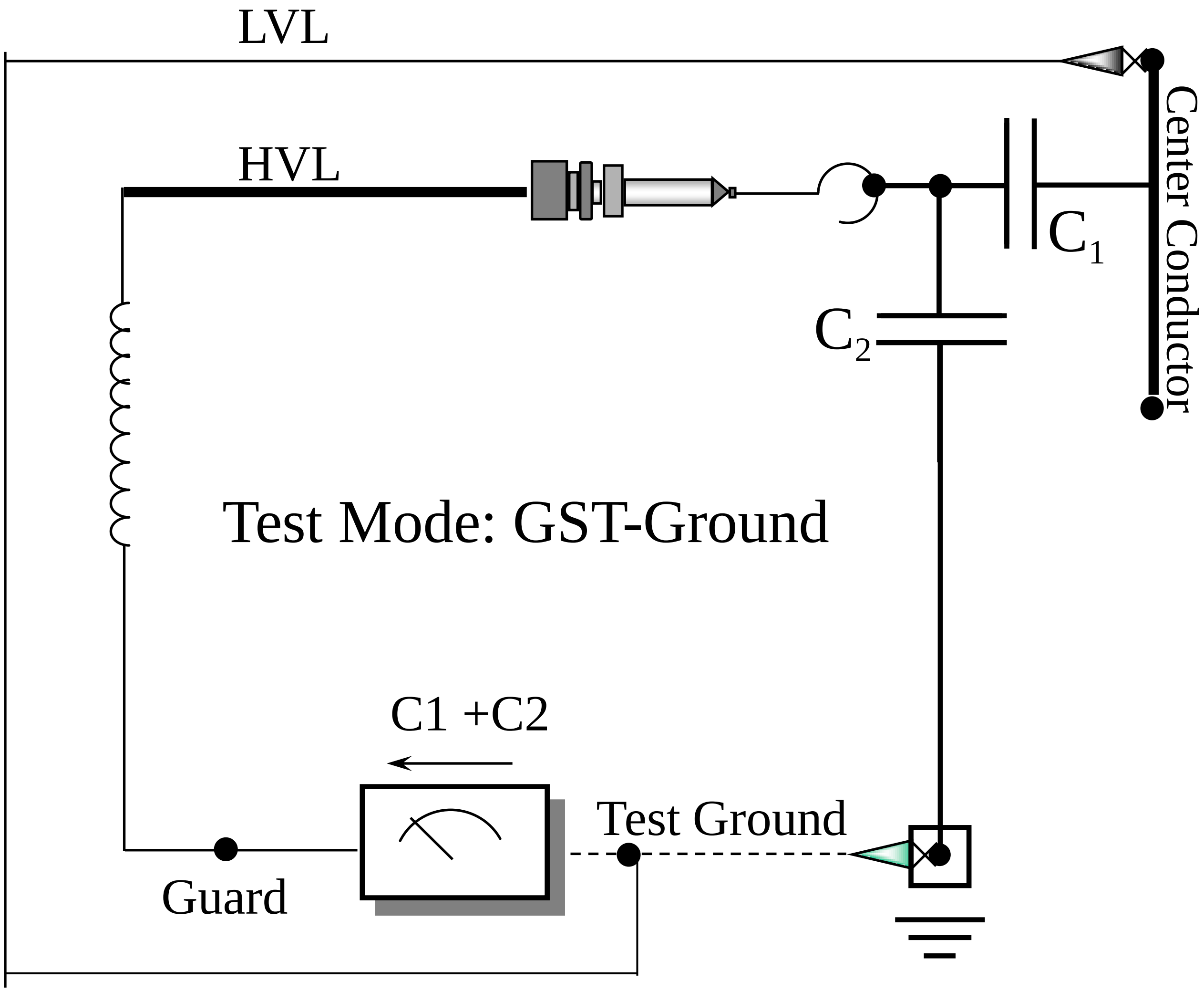
# Tap-Insulation/C2 Test Alternate Method

**Test Mode: GST-Ground**

**<u>Test Includes</u>**
- Tap Insulation
- Core Insulation between tapped Layer and Bushing Ground Sleeve
- Portion of Liquid or Compound Filler
- Portion of Weathershed near Flange
- C1 Insulation



# C1 + C2 Test



LVL
HVL
Center Conductor
C1
C2
Test Mode: GST-Ground
C1 +C2
Test Ground
Guard

# Power Factor Tip Up Tests

- Perform C1 Test at 2 kV
- Perform C1 Test at 10 kV
- Compare Power Factor Values at 2kV and 10kV

# Factory VS Field Test Results

**REMEMBER:**

- The Test Circuits Used are Generally the Same, BUT NOT ALWAYS
- The Environment is More Controlled in the Factory Setting
- Bushing Placement May Different
- Grounding May be Different

# Client Recommended Bushing Cleaners

- **Client Recommendations:**
  - Dry Clean Cloth
  - Water & Soap
  - Collonite™
  - PF Solvent (LPS)
  - Windex™ with Ammonia
  - Apply Heat to Fully Dry all Surfaces

**Do Not Use Evaporative Materials**

# Field Technique Problems

- **Drying Tap Area With Heat**
  - May Result in Power Factor Values Affected by Temperature

- **Cleaning Porcelain Surface With Alcohol-Based or Evaporative Cleaner**
  - May Cool Surface When Cleaner Evaporates, Resulting in Further Condensation

- **Leads Used to Short-Circuit Bushings**
  - To Avoid Stray Capacitive Currents to Ground, Leads Should Not Sag Near Tank Surface

# When Bushing Tests Are Doubtful

- Re-Check All Connections, Including Ground Lead and Bushing Flange Ground
- Check Test Circuit Used
- Check Test Set and Test Set Leads
- Visually Inspect Bushing Sheds and Oil
- Clean and Dry All Surfaces

# When Bushing Tests Are Doubtful

- Compare and Analyze Results of Identical Bushings
- Research Bushing History of Flashovers or Line Surges
- Verify Temperature Correction Factor Was Used for C1 and Overall Tests *
- Verify the Necessary Fields in the Nameplate Were Used in Order for DTA to Identify the Correct Limit File.

* Note C2 Power Factors Are Not Temperature Corrected

# Bushing Temperature Correction

TABLE OF MULTIPLIERS FOR USE IN CONVERTING POWER FACTORS AT TEST TEMPERATURES TO POWER FACTORS AT 20°C

| BUSHINGS | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ABB | | ASEA | BROWN BOVERI | | | | GENERAL ELECTRIC | | | | | | | HAEFELY |
| Type T | Type O + C | All GO Types 25-765 kV | Types CTF, CTKF 20-60 kV | Types CTF, CTKF 85-330 kV | TEST TEMPERATURES °C | °F | Type B | Type F | Types L, LC, LI, LM | Types OF, OFI, OFM | Types S, SI, SIM (Cpd.-Filled) | Types TandU | Types COT, COS, SOT |
| 1.02 | .87 | .79 | 1.24 | 1.00 | 0 | 32.0 | 1.09 | .93 | 1.00 | 1.18 | 1.26 | 1.02 | – |
| 1.02 | .89 | .81 | 1.22 | ↑ | 2 | 35.6 | 1.09 | .95 | 1.00 | 1.16 | 1.24 | 1.02 | – |
| 1.02 | .91 | .83 | 1.20 | | 4 | 39.2 | 1.09 | .97 | 1.00 | 1.15 | 1.21 | 1.02 | – |
| 1.01 | .92 | .85 | 1.17 | | 6 | 42.8 | 1.08 | .98 | 1.00 | 1.13 | 1.19 | 1.01 | – |
| 1.01 | .93 | .87 | 1.15 | | 8 | 46.4 | 1.08 | .99 | 1.00 | 1.11 | 1.16 | 1.01 | – |
| 1.01 | .94 | .89 | 1.12 | | 10 | 50.0 | 1.07 | .99 | 1.00 | 1.10 | 1.14 | 1.01 | 0.88 |
| 1.01 | .95 | .92 | 1.10 | | 12 | 53.6 | 1.06 | .99 | 1.00 | 1.08 | 1.11 | 1.01 | 0.90 |
| 1.01 | .96 | .94 | 1.06 | | 14 | 57.2 | 1.05 | 1.00 | 1.00 | 1.06 | 1.08 | 1.01 | 0.93 |
| 1.00 | .98 | .95 | 1.05 | | 16 | 60.8 | 1.04 | 1.00 | 1.00 | 1.04 | 1.06 | 1.00 | 0.95 |
| 1.00 | .99 | .98 | 1.03 | | 18 | 64.4 | 1.02 | 1.00 | 1.00 | 1.02 | 1.03 | 1.00 | 0.98 |
| 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 20 | 68.0 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1.00 | 1.01 | 1.03 | .98 | | 22 | 71.6 | .97 | .99 | .99 | .97 | .97 | 1.00 | 1.02 |
| 1.00 | 1.02 | 1.05 | .96 | | 24 | 75.2 | .93 | .97 | .99 | .94 | .93 | 1.00 | 1.04 |
| .99 | 1.03 | 1.07 | .94 | | 26 | 78.8 | .90 | .96 | .98 | .91 | .90 | .99 | 1.07 |
| .99 | 1.04 | 1.09 | .91 | | 28 | 82.4 | .85 | .94 | .97 | .88 | .87 | .99 | 1.09 |
| .98 | 1.05 | 1.12 | .88 | | 30 | 86.0 | .81 | .92 | .96 | .86 | .84 | .98 | 1.11 |
| .97 | 1.06 | 1.14 | .86 | | 32 | 89.6 | .77 | .89 | .95 | .83 | .81 | .97 | 1.13 |
| .97 | 1.07 | 1.17 | .84 | | 34 | 93.2 | .73 | .87 | .94 | .80 | .77 | .97 | 1.15 |
| .96 | 1.07 | 1.19 | .82 | | 36 | 96.8 | .69 | .84 | .93 | .77 | .74 | .96 | 1.17 |
| .95 | 1.08 | 1.21 | .80 | | 38 | 100.4 | .65 | .81 | .91 | .74 | .70 | .95 | 1.19 |
| .94 | 1.08 | 1.23 | .78 | | 40 | 104.0 | .61 | .78 | .89 | .70 | .67 | .94 | 1.21 |
| .93 | 1.09 | 1.26 | .76 | | 42 | 107.6 | – | .74 | .87 | .67 | .63 | .93 | 1.22 |
| .91 | 1.10 | 1.28 | .74 | | 44 | 111.2 | – | .70 | .85 | .63 | .60 | .91 | 1.24 |
| .89 | 1.10 | 1.30 | .72 | | 46 | 114.8 | – | .64 | .83 | .61 | .56 | .89 | 1.25 |
| .87 | 1.11 | 1.31 | .70 | | 48 | 118.4 | – | .58 | .82 | .58 | .53 | .87 | 1.26 |
| .86 | 1.11 | 1.33 | .68 | | 50 | 122.0 | – | .52 | .80 | .56 | .50 | .86 | 1.27 |
| .84 | 1.11 | 1.34 | .66 | | 52 | 125.6 | – | – | .79 | .53 | .47 | .84 | 1.28 |
| .82 | 1.11 | 1.36 | .64 | | 54 | 129.2 | – | – | .78 | .51 | .44 | .82 | 1.29 |
| .79 | 1.11 | 1.37 | .62 | | 56 | 132.8 | – | – | .77 | .49 | .41 | .79 | 1.30 |
| .77 | 1.12 | 1.37 | .60 | ↓ | 58 | 136.4 | – | – | .76 | .46 | .38 | .77 | 1.29 |
| .75 | 1.12 | 1.38 | .58 | 1.00 | 60 | 140.0 | – | – | .74 | .44 | .36 | .75 | 1.27 |

TMCF-4950

# DTA - Fields Required To Activate Temperature Correction Factor

- Manufacturer
- Type
- Ambient Temperature (Probe)
- Apparatus Temperature
    - Transformer - Oil Temperature
    - Oil Circuit Breaker - Ambient Temperature

# DTA - Fields Required To Identify Correct Limit File

- Manufacturer
- Type
- KV

# Resistive Coatings on Bushings

- **Semi-Conductive Glaze Coating**
- **Reason:**
  - To Control Voltage Distribution
  - To Reduce Flashover Problems Under Contaminated Conditions

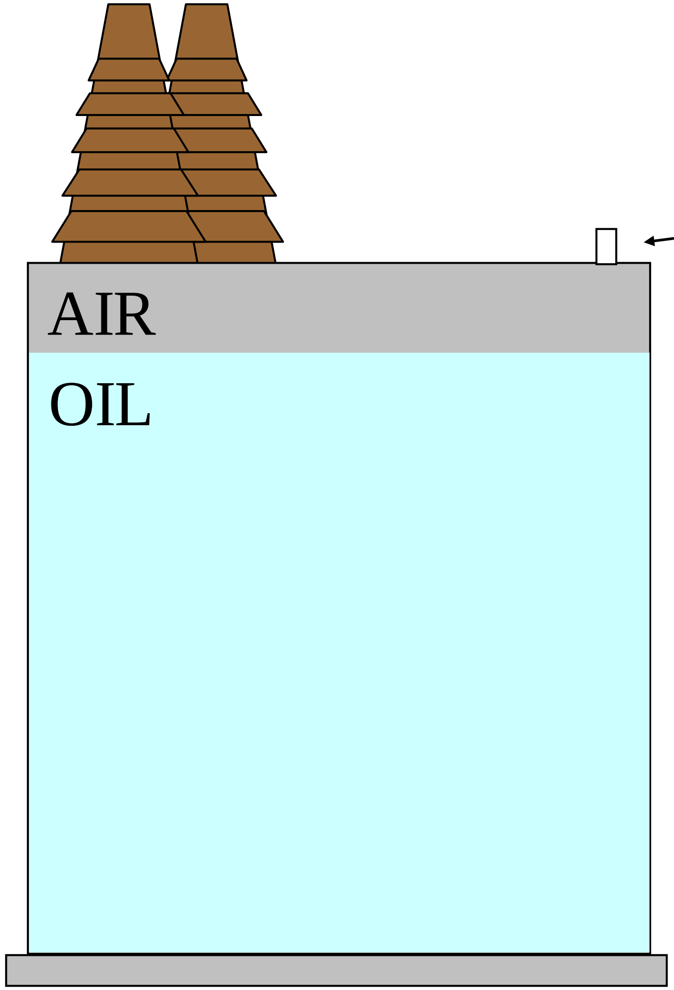
- **Power Factor Tests Affected by Highly Resistive Surface Leakage**
  - Refer to the 1974 Doble Client Conference paper “Doble Tests on Bushings Equipped with Resistance-Graded Porcelains. (Section 4-101)

# Transformers

# Transformer Outline

- Introduction
- Safety
- Test Procedures

# Free Breather Tank Transformer




Breather, often has desiccant material to dry the air.

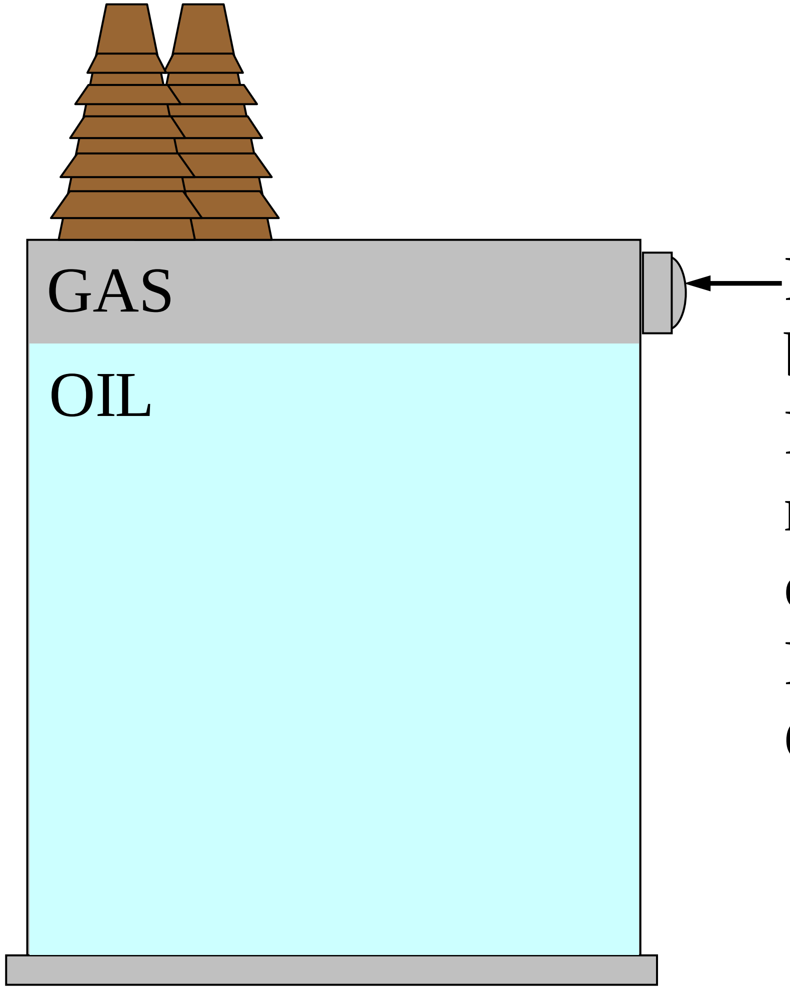
# Sealed Tank Transformer

A volume of gas is above the oil and is sealed from the atmosphere.

Reference:

GEI-28013D

GEI-70369




Pressure-vacuum bleeder.

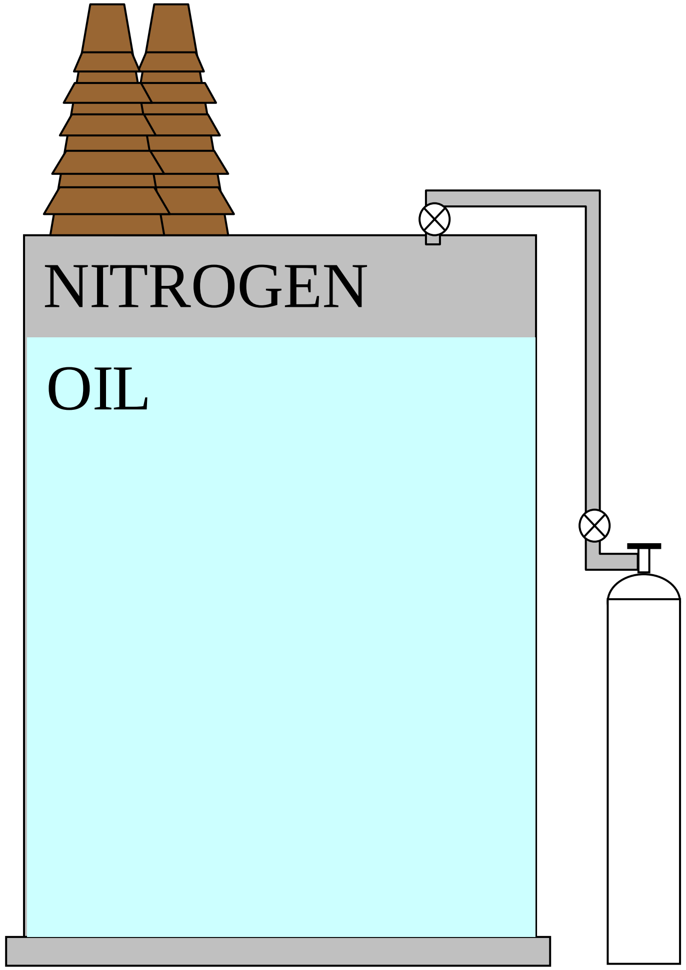
For safety, normally does not operate.

Reference:

GEI-54928D

# Gas (Nitrogen) Blanketed Tank Transformer Automatic Gas Seal System

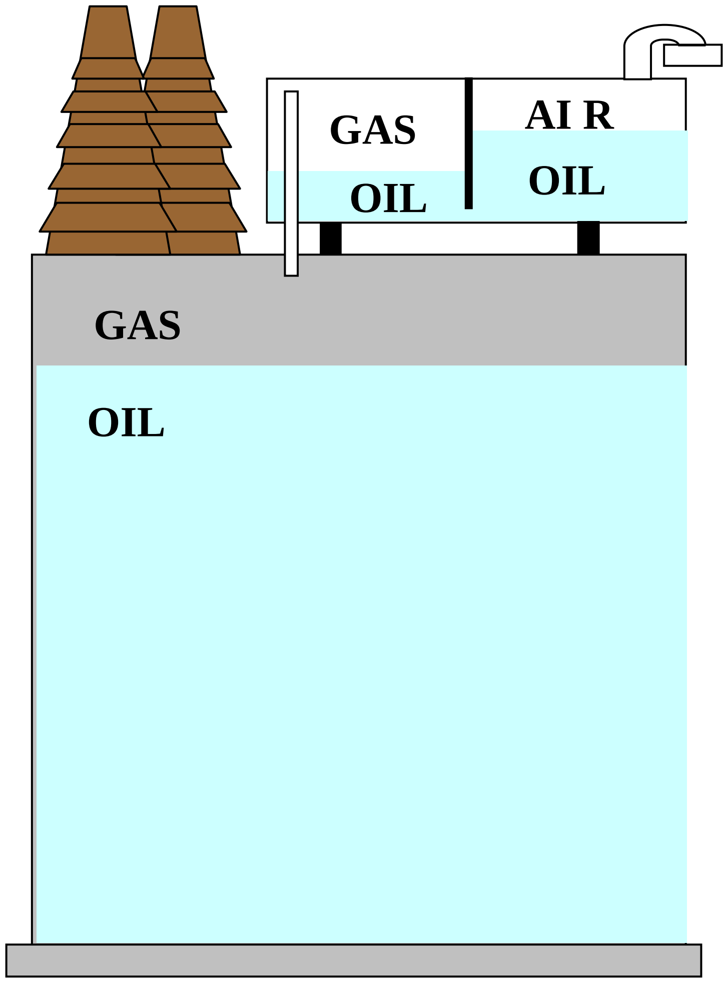
A volume of dry nitrogen is maintained above the oil and is sealed from the atmosphere. Reference: GEI-70366 GEK-19695B




High nitrogen pressure may operate a relief valve during times of high oil expansion due to heating. Nitrogen enters as the oil cools and reduces in volume. There is a low pressure alarm.

# Gas-Oil Sealed Tank Transformer

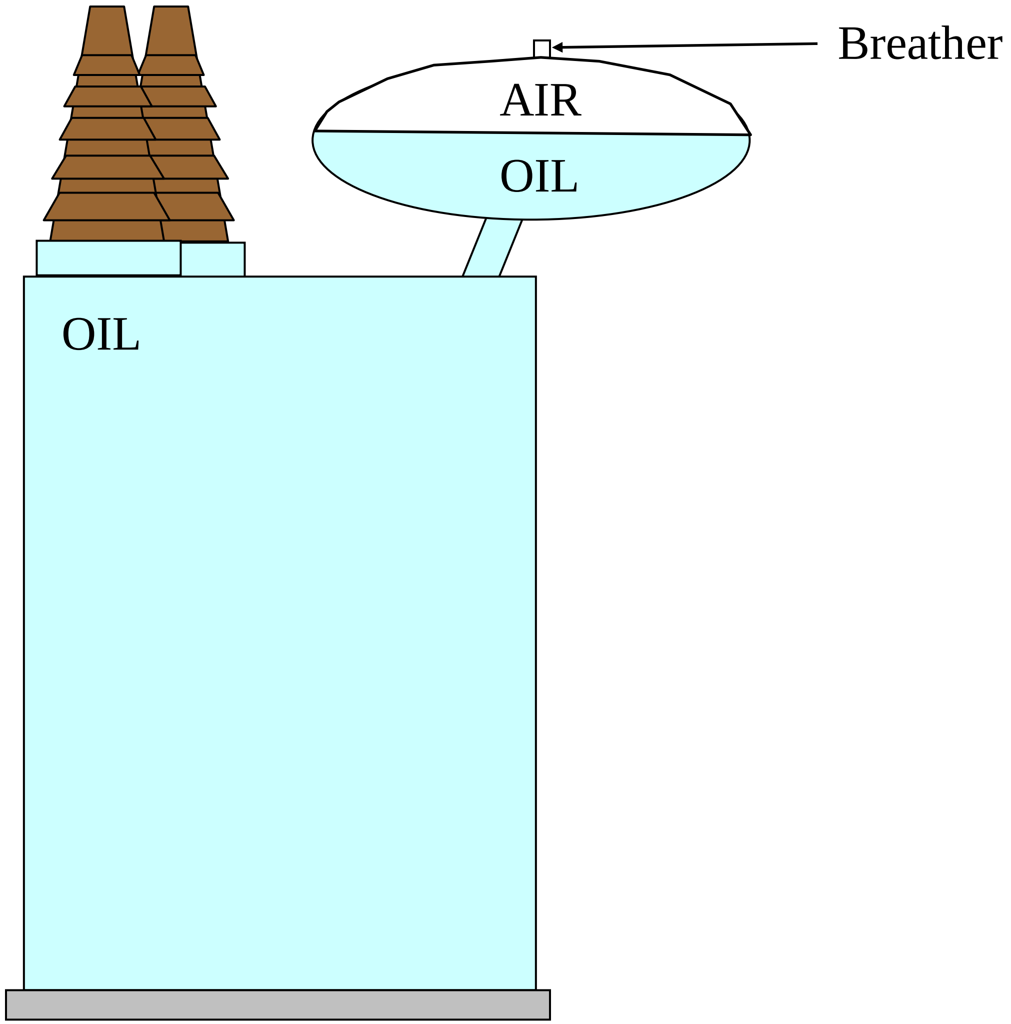
A volume of gas is above the oil in the main tank which can move in and out of an expansion tank. The oil in the expansion tank isolates the gas above the oil from the atmosphere. Reference: GEI-28012A



# Open Conservator Tank Transformer
# Conservator Oil-Preservation System, COPS

The atmosphere is in contact with a small portion of oil in the conservator tank.

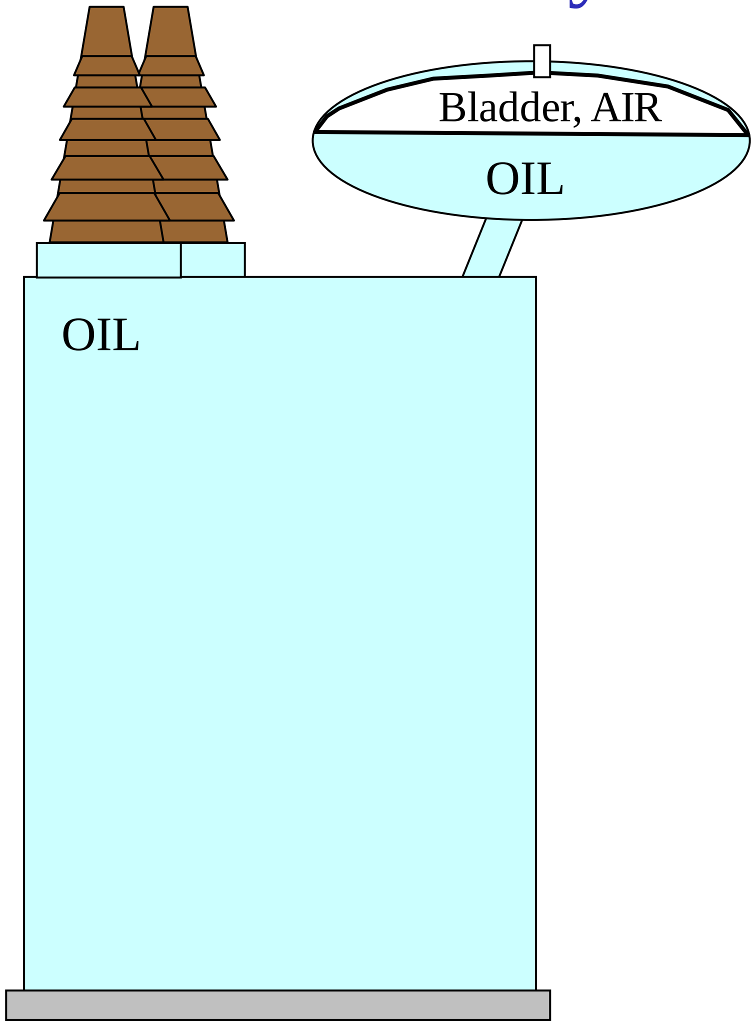
Reference GEI-70368C



# Modern Sealed Conservator Tank
# Transformer Atmoseal Oil Preservation System

The atmosphere is separated from the oil by an expandable bladder. A breather is provided directly into the bladder to allow for the expansion.

Reference
GEI-70367
GEK-29290



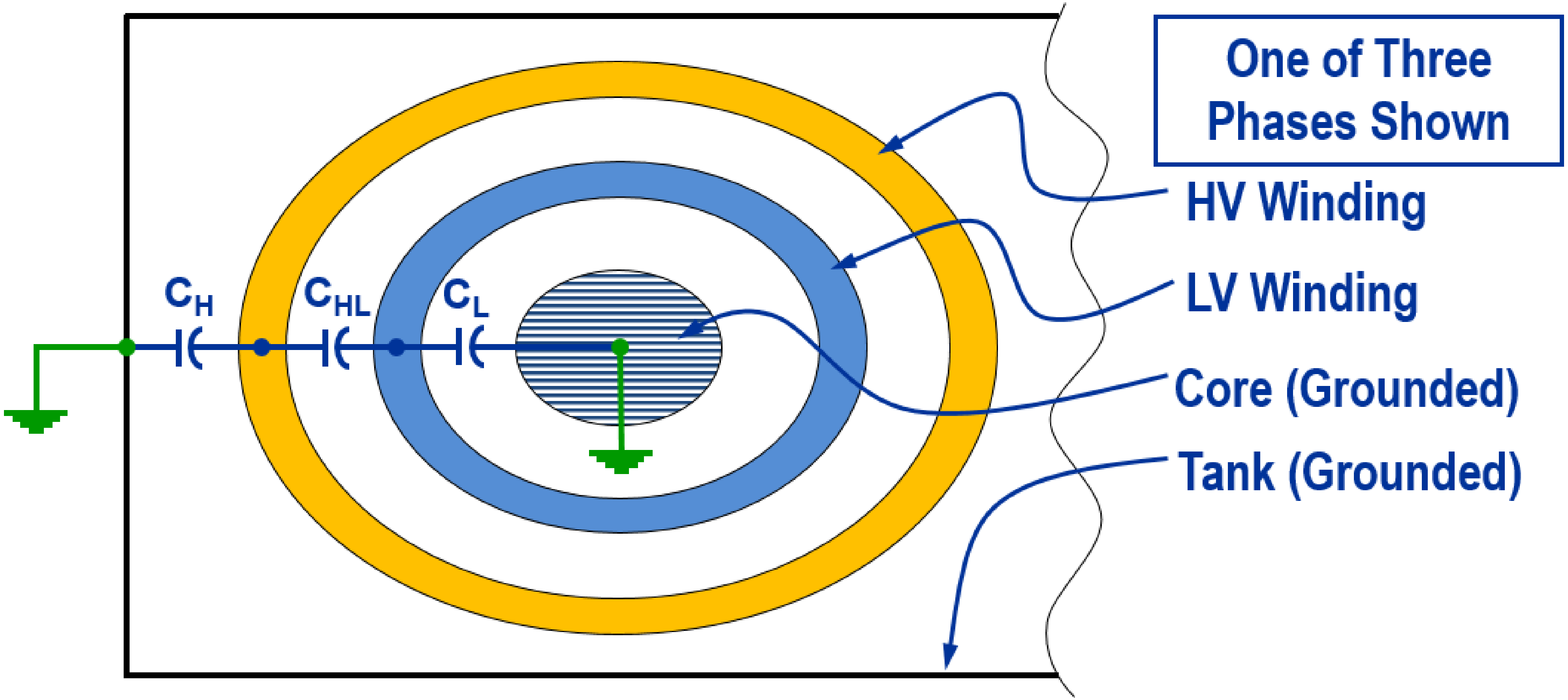
# Apparatus and Personal Safety

- Connect the Doble Test Set Safety Ground Cable First
  Connect the Safety Ground Cable to the Apparatus Ground Point, Then Connect to the Doble Test Instrument

- The Order of Connection of the Remaining Test Set Cables is Not Critical; However, All Cables Should be Connected to the Test Instrument Before Connecting to the Apparatus Under Test

# Two Winding Transformers

# Physical Representation of a Three-Phase Two-Winding Transformer



# Dielectric Circuit: Two Winding Transformer

$C_H$ - Insulation between the High-Voltage Winding Conductors and the Grounded Tank & Core

- High Voltage Bushings
- Winding Insulation
- Structural Insulating Members
- DETC Insulation
- Insulating Fluid

# Dielectric Circuit: Two Winding Transformer

**$C_L$** - Insulation Between the Low-Voltage Winding Conductors and Grounded Tank & Core

- Low Voltage Bushings
- Winding Insulation
- Structural Insulating Members
- LTC
- Insulating Fluid

# Dielectric Circuit: Two Winding Transformer

.$C_{HL}$ - Insulation between the High and Low-Voltage Windings

- Winding Insulation Barriers
- Insulating Fluid

# Review of Test Sheet

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Overall Test Setup** | | | | | | | | | | | | | |
| **Connections** | | | | | **Inputs** | | **Test Results** | | | | | | **Ra** |
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | Ask FRANK™ | |
| 1 | HV Winding | LV Winding | Unused | CH+CHL | 10.001 | 0.93 | 28.817 | 0.682 | 0.237 | 0.221 | 7644.0 | | |
| 2 | | | | CH | 10.001 | 0.93 | 9.371 | 0.167 | 0.179 | 0.167 | 2485.6 | G Good | |
| 3 | | | | CHL(UST) | 10.001 | 0.93 | 19.448 | 0.513 | 0.264 | 0.247 | 5158.7 | G Good | |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 0.93 | 19.447 | 0.515 | 0.265 | 0.247 | 5158.4 | | |
| 5 | LV Winding | HV Winding | Unused | CL+CHL | 10.002 | 0.93 | 62.826 | 2.948 | 0.469 | 0.439 | 16664.9 | | |
| 6 | | | | CL | 10.002 | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | D Deteriora... | |
| 7 | | | | CHL(UST) | 10.002 | 0.93 | 19.449 | 0.515 | 0.265 | 0.247 | 5159.0 | | |
| 8 | Test 5 - Test 6 (calculated) | | | CHL | | 0.93 | 19.451 | 0.525 | 0.270 | 0.252 | 5159.5 | G Good | |
| **Winding without Attached Bushing Calculation** | | | | | | | | | | | | | |
| | CH-C1 | | | CH' | | 0.93 | 5.319 | 0.085 | 0.160 | 0.150 | 1410.8 | | |
| | CL-C1 | | | CL' | | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | | |

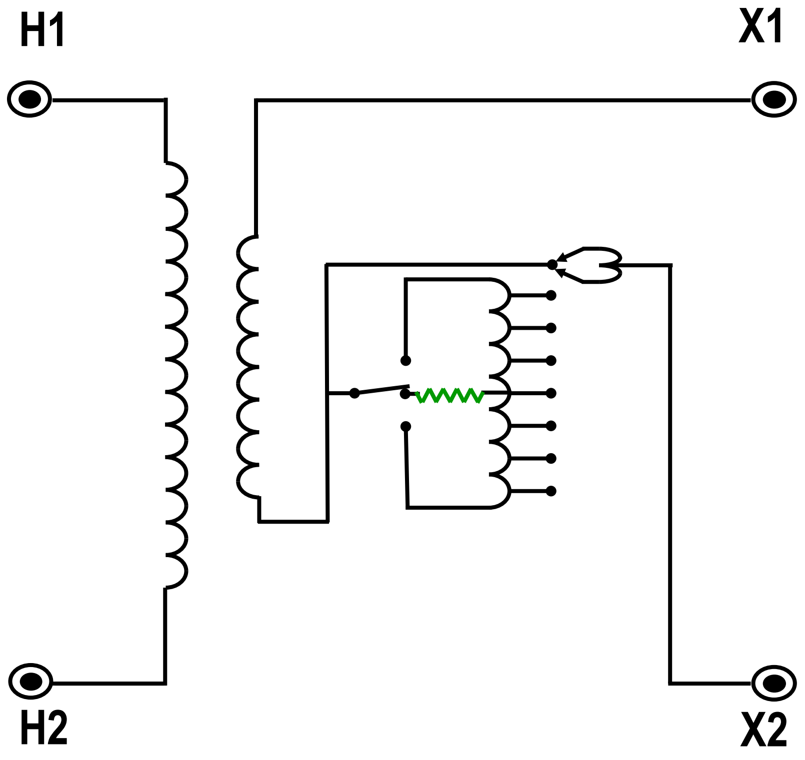
# Transformer Overall Tests

# Important – LTC Must Be Off Neutral

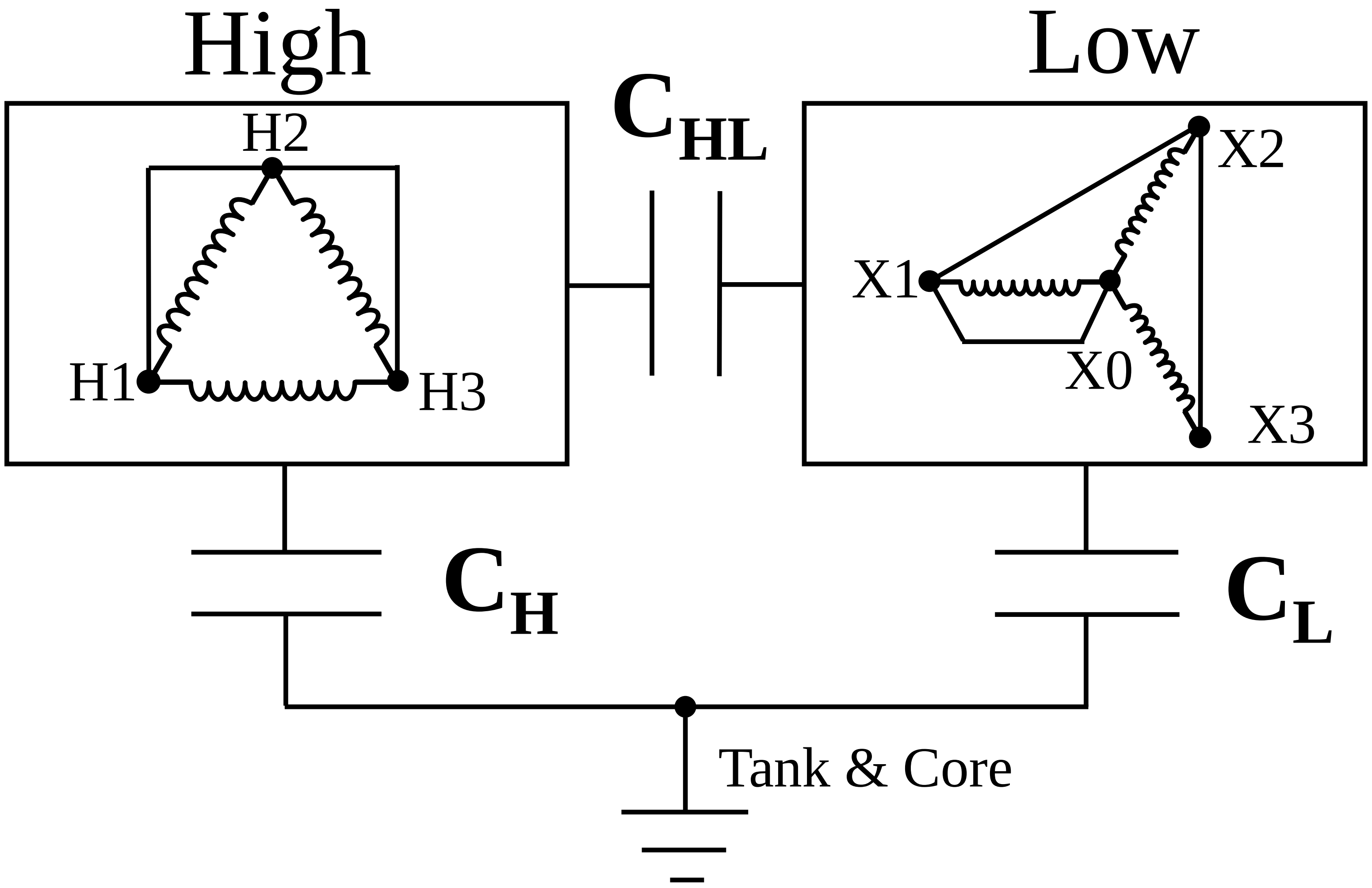
Load Tap Changers

If the transformer contains a LTC, then it should be ***moved to any non-neutral tap position*** for/during overall power factor testing.

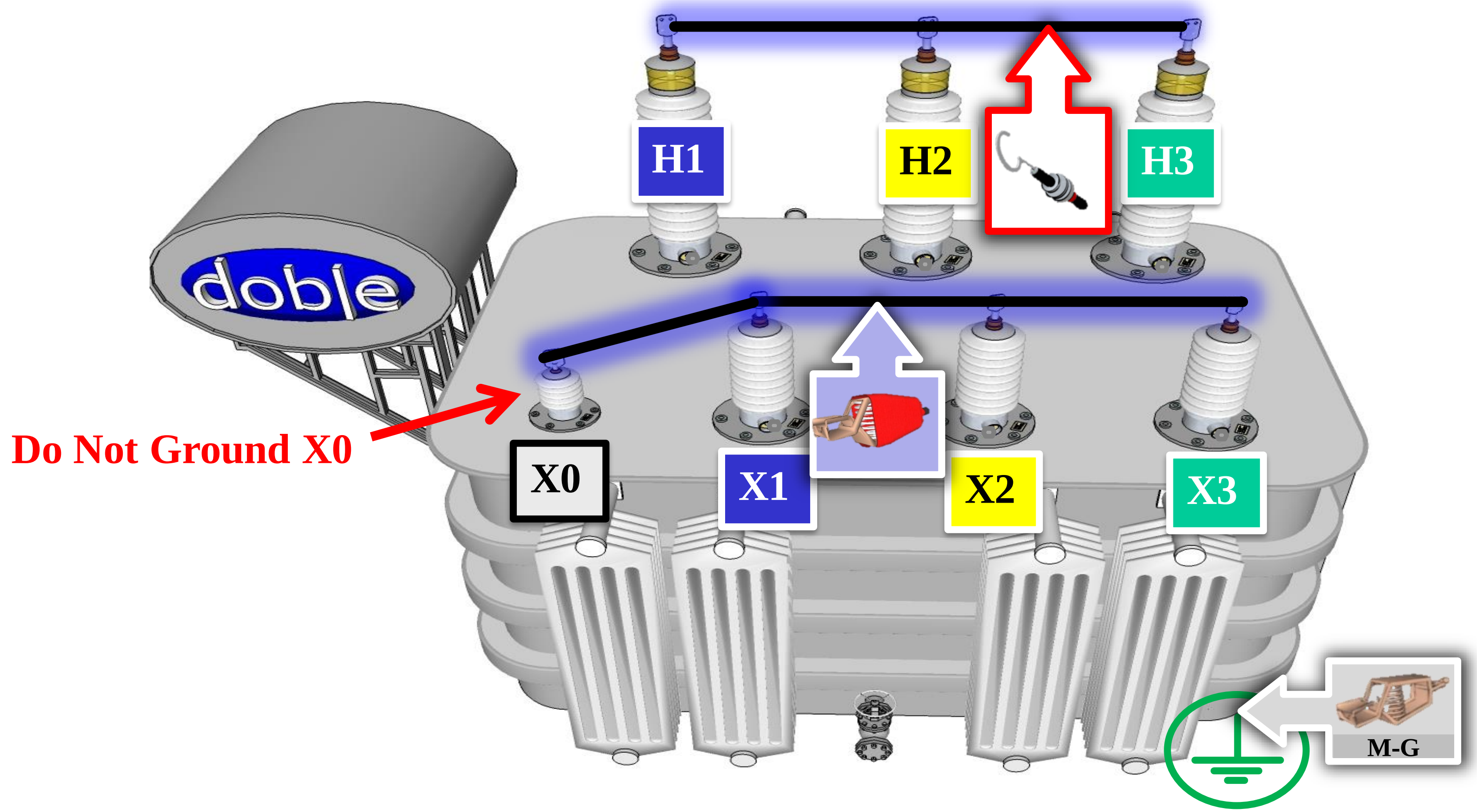
Certain LTC schemes contain ***non-linear resistor elements*** (surge protection) that may cause abnormal test results (high or negative power factors) if tested in the neutral tap position.



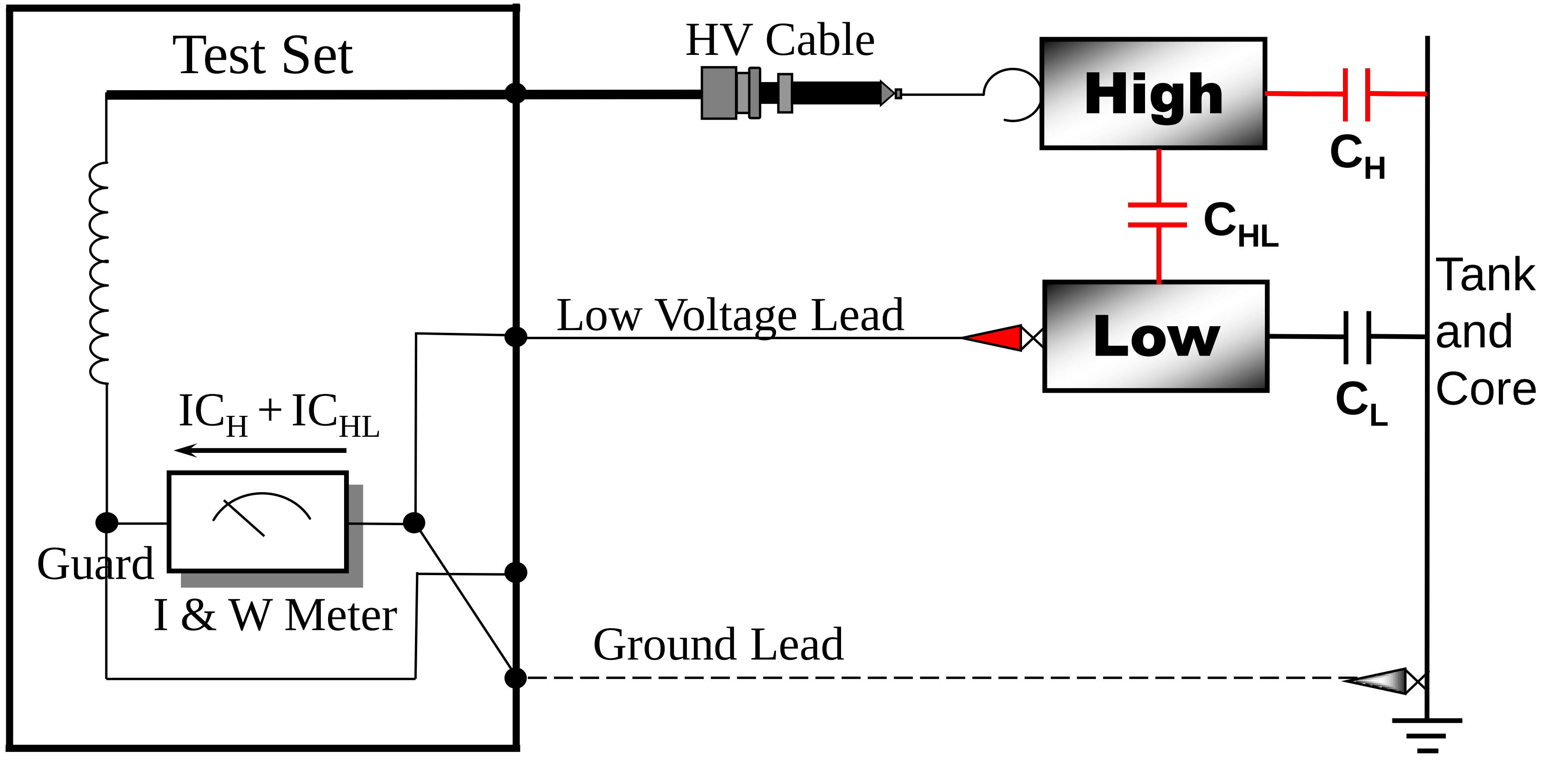
# Transformer Overall Tests



# Test Connections - Primary

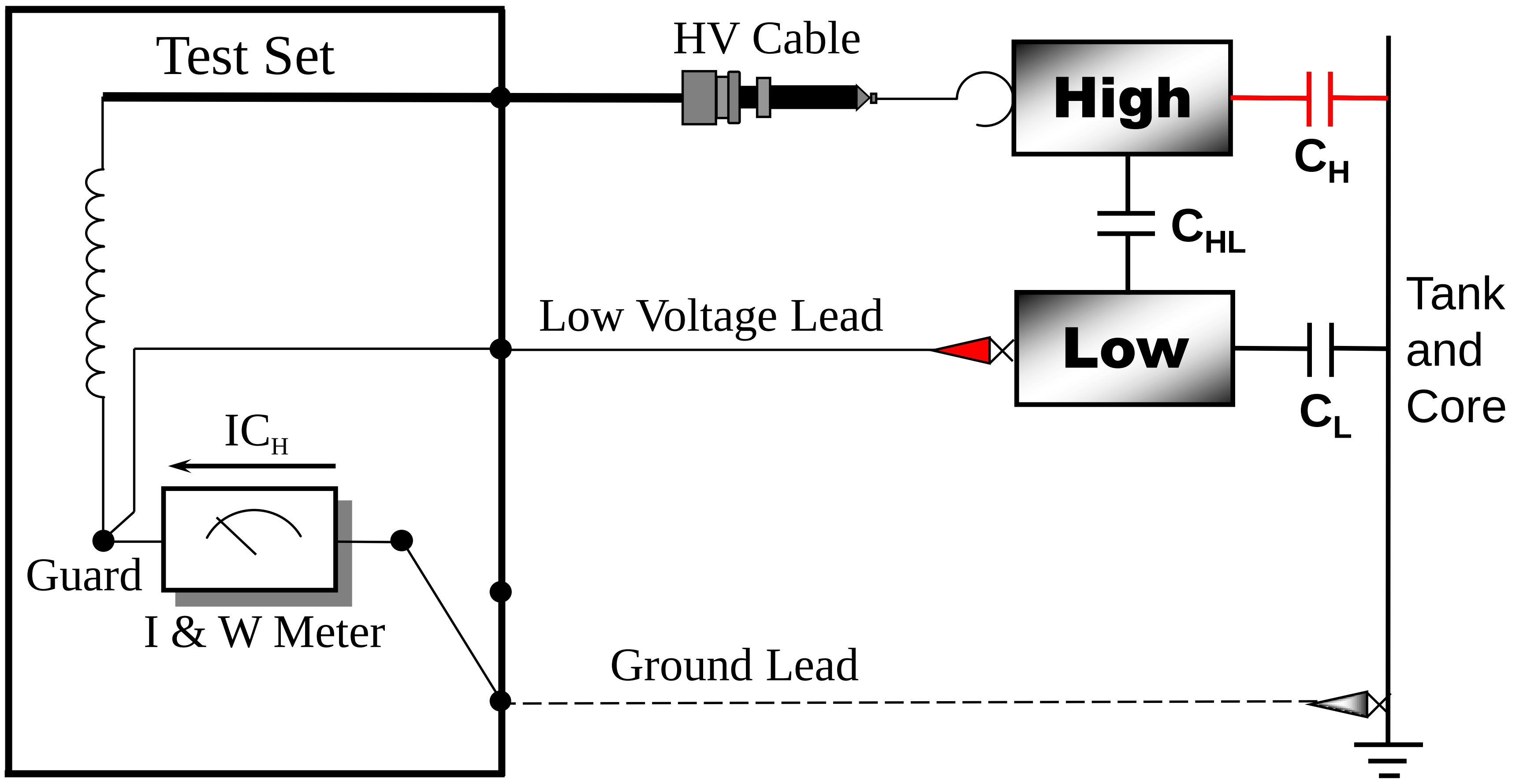


# Test Procedure -Test #1: Measure $C_H$+$C_{HL}$



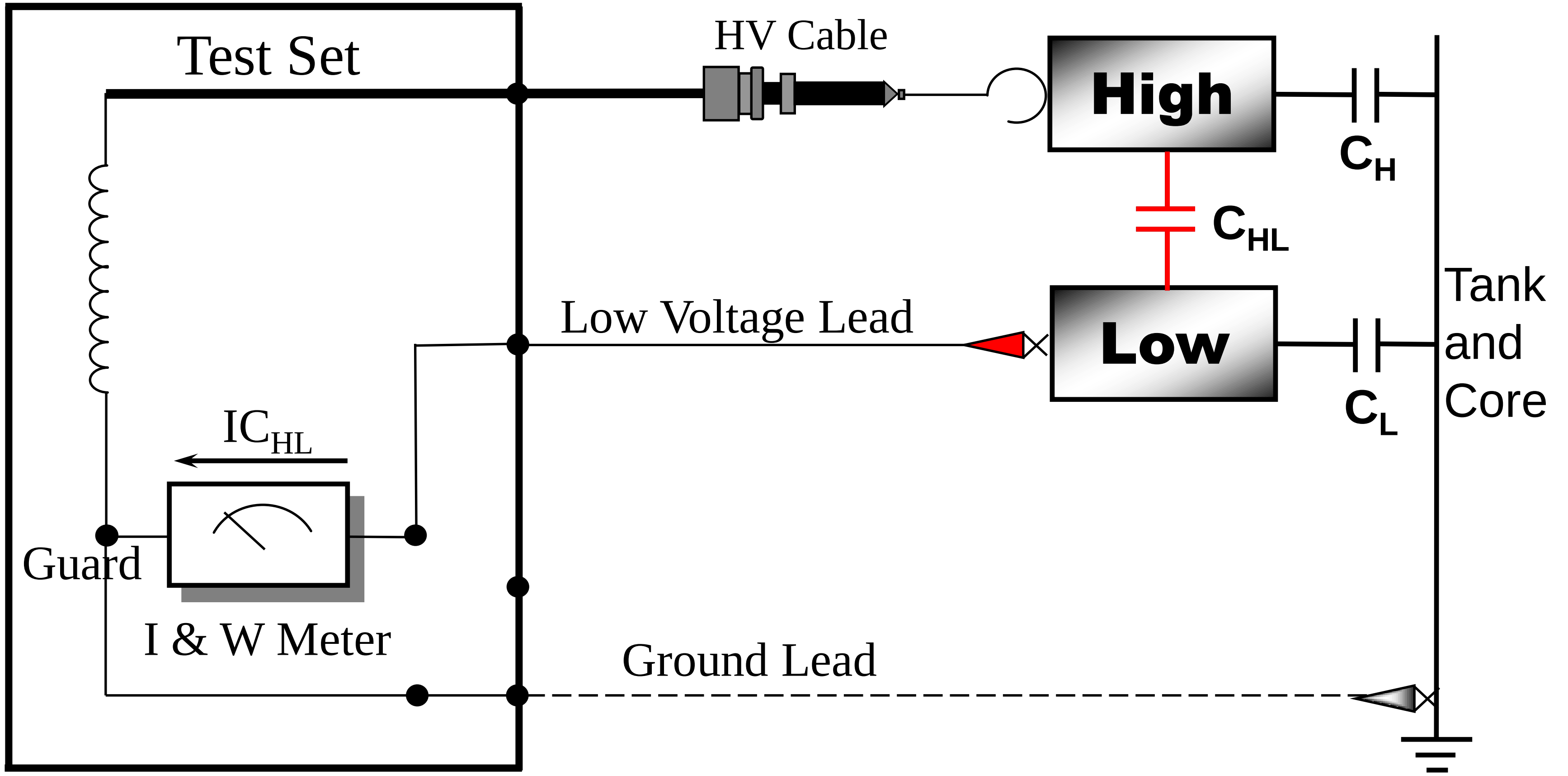

**GST – GROUND RED/BLUE**

# Test Procedure -Test #2: Measure $C_H$




**GST – GUARD RED/BLUE**

# Test Procedure -Test #3: Measure $C_{HL}$




**UST – MEASURE RED/BLUE**

# Verify that the Primary tests were performed correctly

| Overall Test Setup | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Connections | | | | | Inputs | | Test Results | | | | | Ra | |
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | Ask FRANK™ | |
| 1 | HV Winding | LV Winding | Unused | CH+CHL | 10.001 | 0.93 | 28.817 | 0.682 | 0.237 | 0.221 | 7644.0 | | |
| 2 | | | | CH | 10.001 | 0.93 | 9.371 | 0.167 | 0.179 | 0.167 | 2485.6 | Good | |
| 3 | | | | CHL(UST) | 10.001 | 0.93 | 19.448 | 0.513 | 0.264 | 0.247 | 5158.7 | Good | |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 0.93 | 19.447 | 0.515 | 0.265 | 0.247 | 5158.4 | | |
| 5 | LV Winding | HV Winding | Unused | CL+CHL | 10.002 | 0.93 | 62.826 | 2.948 | 0.469 | 0.439 | 16664.9 | | |
| 6 | | | | CL | 10.002 | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | Deteriora... | |
| 7 | | | | CHL(UST) | 10.002 | 0.93 | 19.449 | 0.515 | 0.265 | 0.247 | 5159.0 | | |
| 8 | Test 5 - Test 6 (calculated) | | | CHL | | 0.93 | 19.451 | 0.525 | 0.270 | 0.252 | 5159.5 | Good | |
| **Winding without Attached Bushing Calculation** | | | | | | | | | | | | | |
| | CH-C1 | | | CH' | | 0.93 | 5.319 | 0.085 | 0.160 | 0.150 | 1410.8 | | |
| | CL-C1 | | | CL' | | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | | |

Test 2 mA + test 3 mA = Test 1 mA

(CH) + (CHL) = (CH + CHL)

Same for the Watts

# Verify that the Primary tests were performed correctly

**Overall Test Setup**

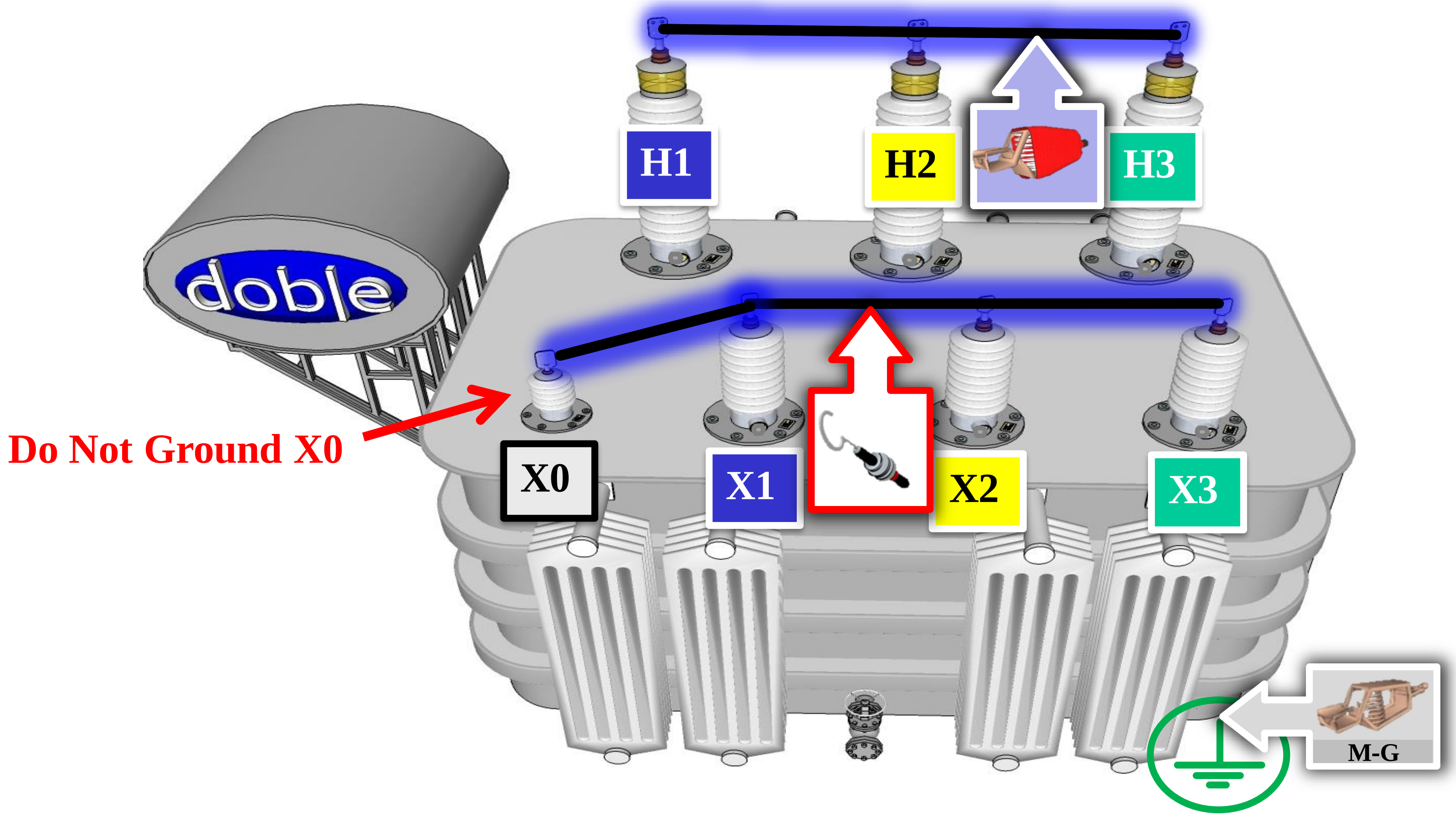
| Connections | | | | | Inputs | | Test Results | | | | | Ra |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | Ask FRANK™ |
| 1 | HV Winding | LV Winding | Unused | CH+CHL | 10.001 | 0.93 | 28.817 | 0.682 | 0.237 | 0.221 | 7644.0 | |
| 2 | | | | CH | 10.001 | 0.93 | 9.371 | 0.167 | 0.179 | 0.167 | 2485.6 | Good |
| 3 | | | | CHL(UST) | 10.001 | 0.93 | 19.448 | 0.513 | 0.264 | 0.247 | 5158.7 | Good |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 0.93 | 19.447 | 0.515 | 0.265 | 0.247 | 5158.4 | |
| 5 | LV Winding | HV Winding | Unused | CL+CHL | 10.002 | 0.93 | 62.826 | 2.948 | 0.469 | 0.439 | 16664.9 | |
| 6 | | | | CL | 10.002 | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | Deteriora... |
| 7 | | | | CHL(UST) | 10.002 | 0.93 | 19.449 | 0.515 | 0.265 | 0.247 | 5159.0 | |
| 8 | Test 5 - Test 6 (calculated) | | | CHL | | 0.93 | 19.451 | 0.525 | 0.270 | 0.252 | 5159.5 | Good |
| **Winding without Attached Bushing Calculation** | | | | | | | | | | | | |
| | CH-C1 | | | CH' | | 0.93 | 5.319 | 0.085 | 0.160 | 0.150 | 1410.8 | |
| | CL-C1 | | | CL' | | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | |

Test1 – Test 2 = Calculated UST (Test 4)

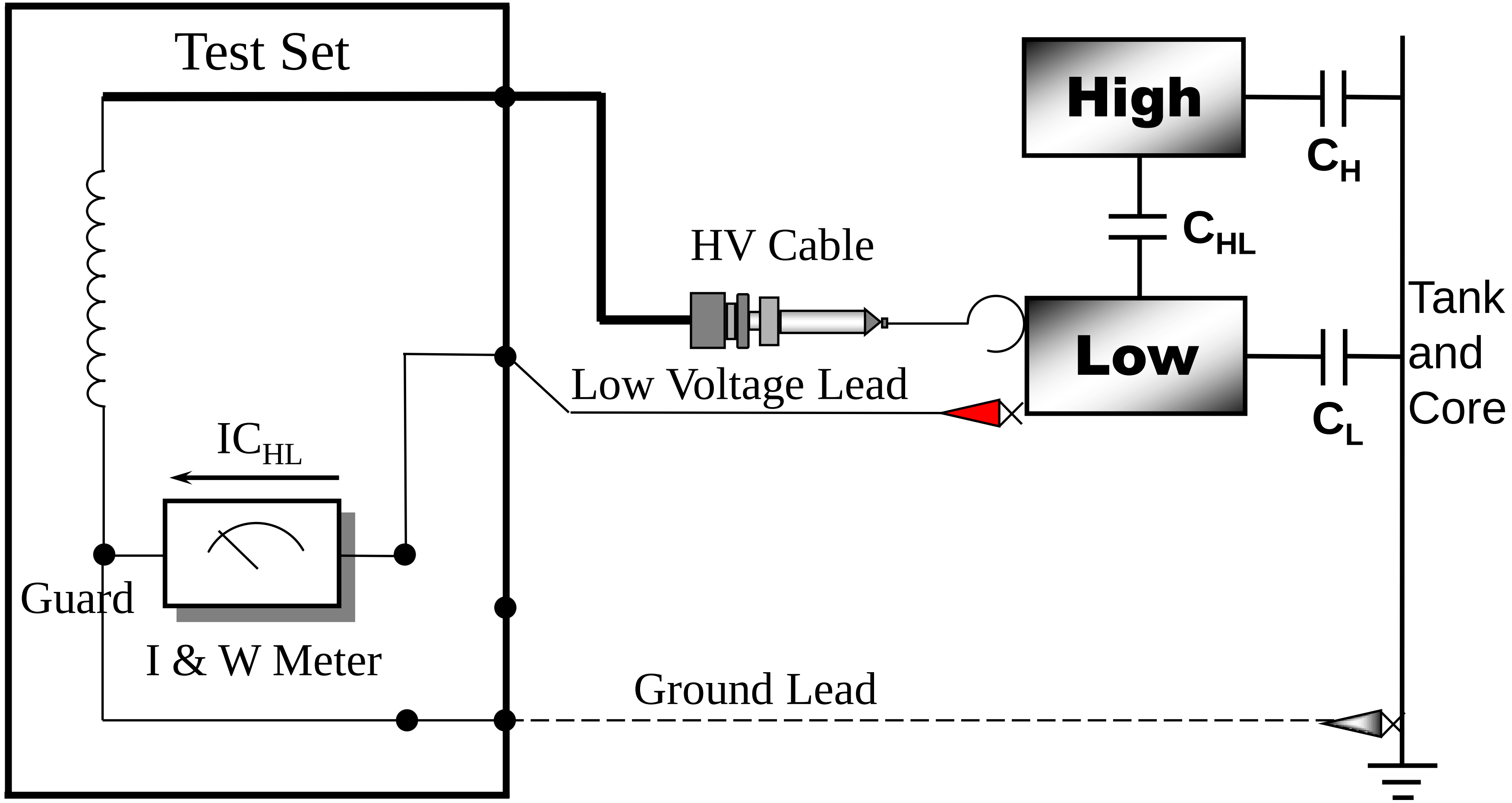
Test 3 and Test 4 should be equal

Same for the Watts

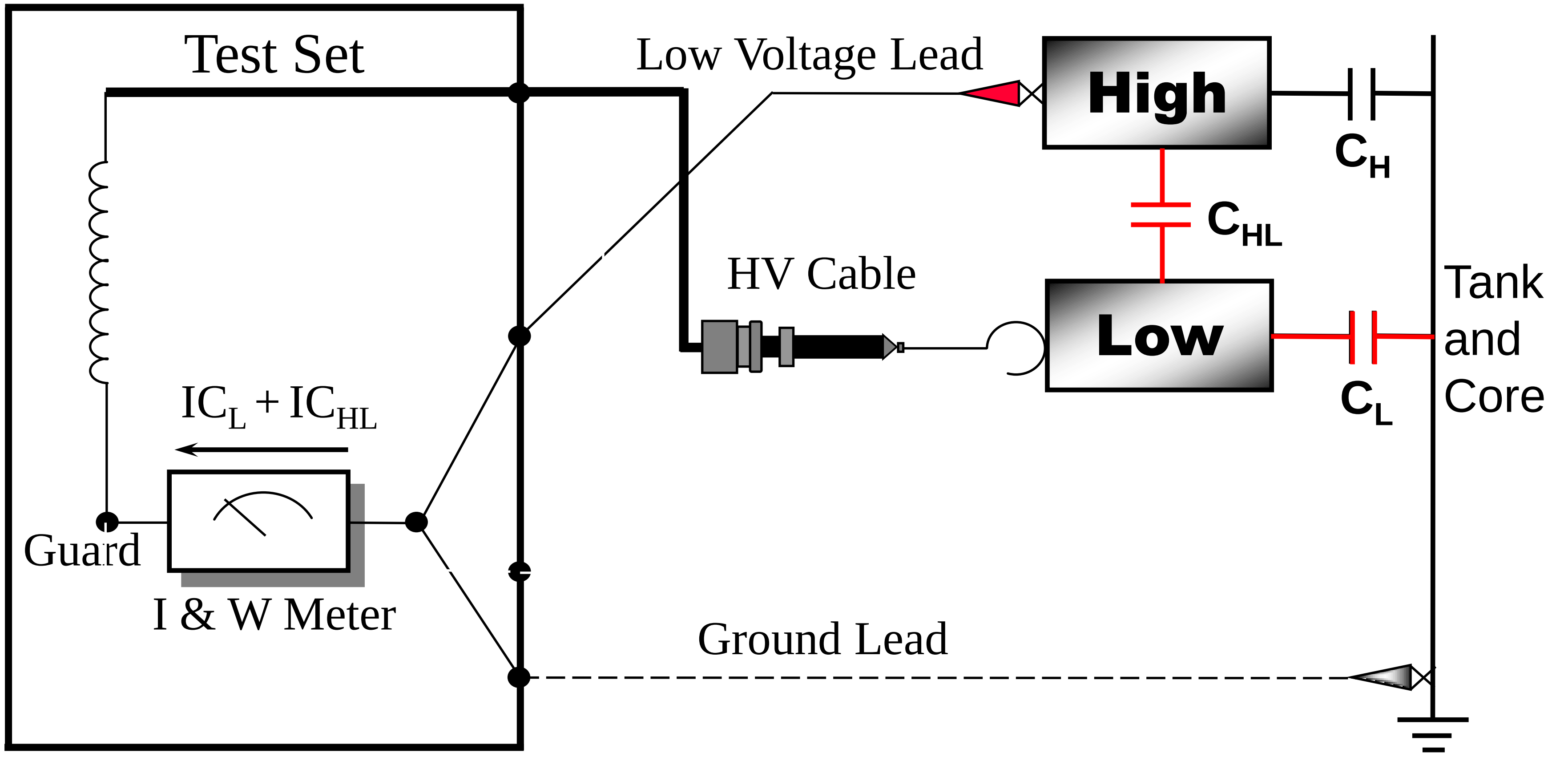
# Test Connections - Secondary



# Test Procedure-Rotate Test Leads

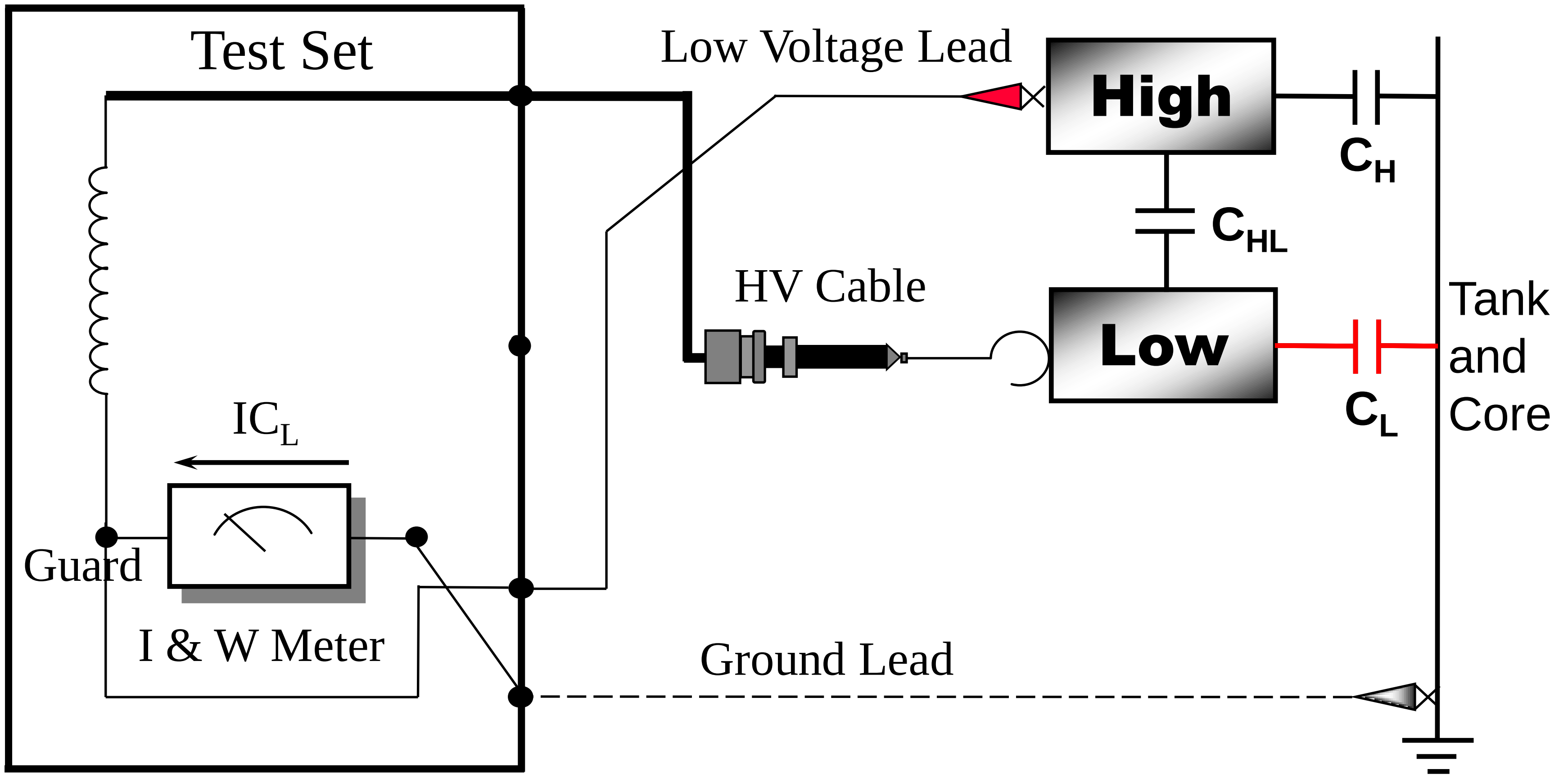


# Test Procedure-Test #5: Measure $C_L+C_{HL}$



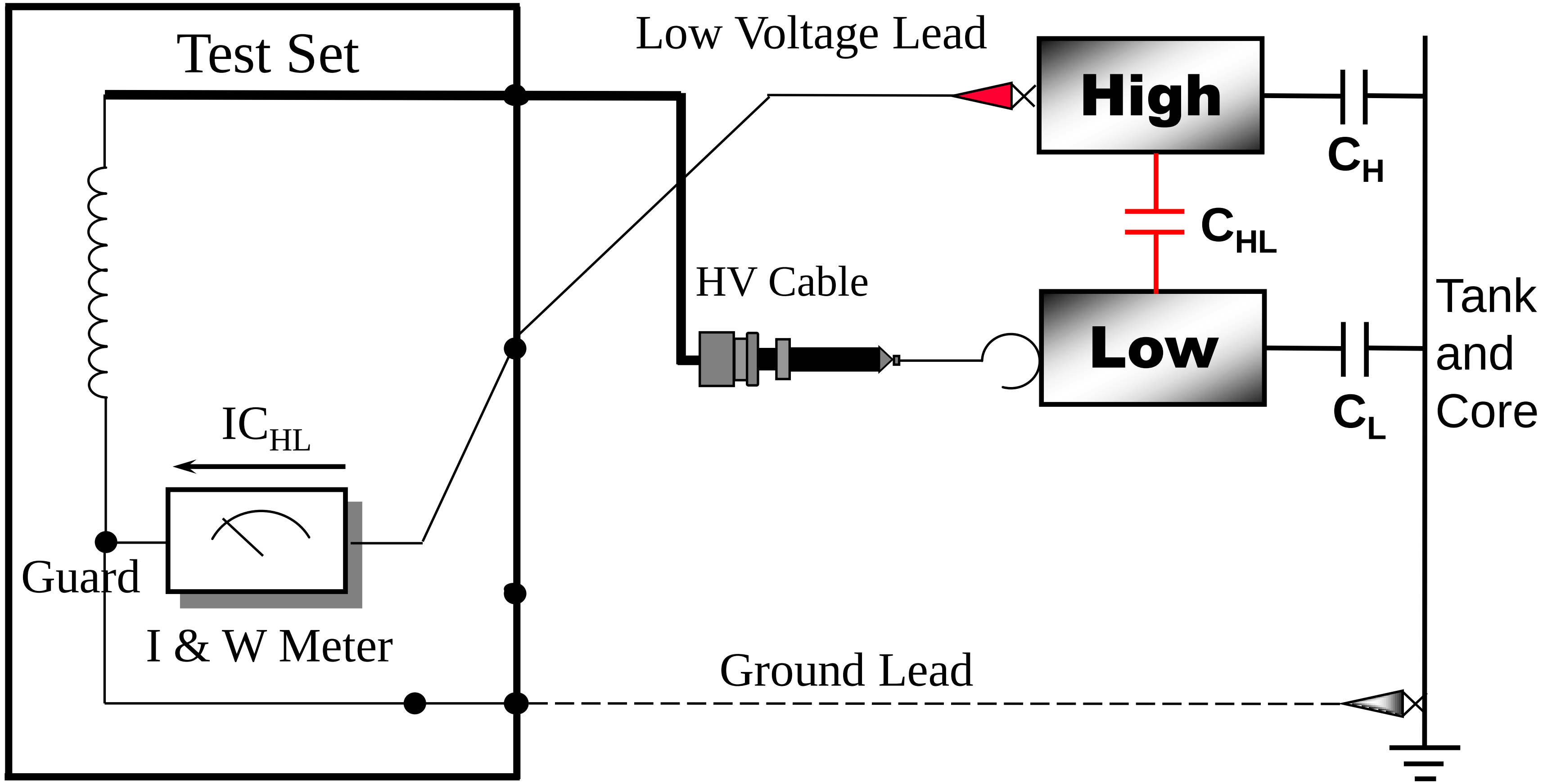

**GST – GROUND RED/BLUE**

# Test Procedure-Test #6: Measure $C_L$




**GST - GUARD RED/BLUE**

# Test Procedure-Test #7: Measure $C_{HL}$




**UST – MEASURE RED/BLUE**

# Verify that Secondary tests were performed correctly

| Overall Test Setup | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Connections | | | | | Inputs | | Test Results | | | | | Ra |
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | Ask FRANK™ |
| 1 | HV Winding | LV Winding | Unused | CH+CHL | 10.001 | 0.93 | 28.817 | 0.682 | 0.237 | 0.221 | 7644.0 | |
| 2 | | | | CH | 10.001 | 0.93 | 9.371 | 0.167 | 0.179 | 0.167 | 2485.6 | Good |
| 3 | | | | CHL(UST) | 10.001 | 0.93 | 19.448 | 0.513 | 0.264 | 0.247 | 5158.7 | Good |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 0.93 | 19.447 | 0.515 | 0.265 | 0.247 | 5158.4 | |
| 5 | LV Winding | HV Winding | Unused | CL+CHL | 10.002 | 0.93 | 62.826 | 2.948 | 0.469 | 0.439 | 16664.9 | |
| 6 | | | | CL | 10.002 | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | Deteriora... |
| 7 | | | | CHL(UST) | 10.002 | 0.93 | 19.449 | 0.515 | 0.265 | 0.247 | 5159.0 | |
| 8 | Test 5 - Test 6 (calculated) | | | CHL | | 0.93 | 19.451 | 0.525 | 0.270 | 0.252 | 5159.5 | Good |
| | **Winding without Attached Bushing Calculation** | | | | | | | | | | | |
| | CH-C1 | | | CH' | | 0.93 | 5.319 | 0.085 | 0.160 | 0.150 | 1410.8 | |
| | CL-C1 | | | CL' | | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | |

Test 6 ma + Test 7 ma = Test 5 mA

(CL) + (CHL) = (CL + CHL)

Same for the Watts

# Verify that Secondary tests were performed correctly

| Overall Test Setup | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Connections | | | | | Inputs | | Test Results | | | | | Ra |
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | Ask FRANK™ |
| 1 | HV Winding | LV Winding | Unused | CH+CHL | 10.001 | 0.93 | 28.817 | 0.682 | 0.237 | 0.221 | 7644.0 | |
| 2 | | | | CH | 10.001 | 0.93 | 9.371 | 0.167 | 0.179 | 0.167 | 2485.6 | Good |
| 3 | | | | CHL(UST) | 10.001 | 0.93 | 19.448 | 0.513 | 0.264 | 0.247 | 5158.7 | Good |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 0.93 | 19.447 | 0.515 | 0.265 | 0.247 | 5158.4 | |
| 5 | LV Winding | HV Winding | Unused | CL+CHL | 10.002 | 0.93 | 62.826 | 2.948 | 0.469 | 0.439 | 16664.9 | |
| 6 | | | | CL | 10.002 | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | Deteriora... |
| 7 | | | | CHL(UST) | 10.002 | 0.93 | 19.449 | 0.515 | 0.265 | 0.247 | 5159.0 | |
| 8 | Test 5 - Test 6 (calculated) | | | CHL | | 0.93 | 19.451 | 0.525 | 0.270 | 0.252 | 5159.5 | Good |
| | Winding without Attached Bushing Calculation | | | | | | | | | | | |
| | CH-C1 | | | CH' | | 0.93 | 5.319 | 0.085 | 0.160 | 0.150 | 1410.8 | |
| | CL-C1 | | | CL' | | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | |

Test 5 – Test 6 = Calculated UST (Test 8)

Test 7 and Test 8 should be equal

Same for the watts

# Verify that Secondary tests were performed correctly

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Overall Test Setup** | | | | | | | | | | | | | |
| Connections | | | | | Inputs | | Test Results | | | | | | Ra |
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | Ask FRANK™ | |
| 1 | HV Winding | LV Winding | Unused | CH+CHL | 10.001 | 0.93 | 28.817 | 0.682 | 0.237 | 0.221 | 7644.0 | | |
| 2 | | | | CH | 10.001 | 0.93 | 9.371 | 0.167 | 0.179 | 0.167 | 2485.6 | Good | |
| 3 | | | | CHL(UST) | 10.001 | 0.93 | 19.448 | 0.513 | 0.264 | 0.247 | 5158.7 | Good | |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 0.93 | 19.447 | 0.515 | 0.265 | 0.247 | 5158.4 | | |
| 5 | LV Winding | HV Winding | Unused | CL+CHL | 10.002 | 0.93 | 62.826 | 2.948 | 0.469 | 0.439 | 16664.9 | | |
| 6 | | | | CL | 10.002 | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | Deteriora... | |
| 7 | | | | CHL(UST) | 10.002 | 0.93 | 19.449 | 0.515 | 0.265 | 0.247 | 5159.0 | | |
| 8 | Test 5 - Test 6 (calculated) | | | CHL | | 0.93 | 19.451 | 0.525 | 0.270 | 0.252 | 5159.5 | Good | |
| **Winding without Attached Bushing Calculation** | | | | | | | | | | | | | |
| | CH-C1 | | | CH' | | 0.93 | 5.319 | 0.085 | 0.160 | 0.150 | 1410.8 | | |
| | CL-C1 | | | CL' | | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | | |

**Tests (lines) 3, 4 , 7 and 8 should be equal as all are the CHL insulation**

# Two-Winding Transformer Overall Test Sheet

| Overall Test Setup | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Connections | | | | | Inputs | | Test Results | | | | | Ra |
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | Ask FRANK™ |
| 1 | HV Winding | LV Winding | Unused | CH+CHL | 10.001 | 0.93 | 28.817 | 0.682 | 0.237 | 0.221 | 7644.0 | |
| 2 | | | | CH | 10.001 | 0.93 | 9.371 | 0.167 | 0.179 | 0.167 | 2485.6 | G Good |
| 3 | | | | CHL(UST) | 10.001 | 0.93 | 19.448 | 0.513 | 0.264 | 0.247 | 5158.7 | G Good |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 0.93 | 19.447 | 0.515 | 0.265 | 0.247 | 5158.4 | |
| 5 | LV Winding | HV Winding | Unused | CL+CHL | 10.002 | 0.93 | 62.826 | 2.948 | 0.469 | 0.439 | 16664.9 | |
| 6 | | | | CL | 10.002 | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | D Deteriora... |
| 7 | | | | CHL(UST) | 10.002 | 0.93 | 19.449 | 0.515 | 0.265 | 0.247 | 5159.0 | |
| 8 | Test 5 - Test 6 (calculated) | | | CHL | | 0.93 | 19.451 | 0.525 | 0.270 | 0.252 | 5159.5 | G Good |
| Winding without Attached Bushing Calculation | | | | | | | | | | | | |
| | CH-C1 | | | CH' | | 0.93 | 5.319 | 0.085 | 0.160 | 0.150 | 1410.8 | |
| | CL-C1 | | | CL' | | 0.93 | 43.375 | 2.424 | 0.559 | 0.522 | 11505.4 | |

# CH' and CL' on OVERALL

After bushing tests, CH' and CL' can be calculated.

# CH’ Calculations

| | N | ENG | GND | GAR | UST | Test kV | mA | Watts | % PF Meas. | % PF Corr. | Corr. Factor | Cap. (pF) | Meas | Rtg | Rtg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ☐ | H | L | | | 10 | 30.980 | 0.829 | 0.27 | 0.22 | 0.81 | 8219 | CH + CHL | | |
| 2 | ☐ | H | | L | | 10 | 11 | 0.248 | 0.23 | 0.19 | 0.81 | 2918 | CH | G | G |
| 3 | ☐ | H | | | L | 10 | 19.970 | 0.578 | 0.29 | 0.23 | 0.81 | 5299 | CHL(UST) | G | G |
| 4 | ☐ | (1-2) | | | | | 19.980 | 0.581 | 0.29 | 0.23 | 0.81 | 5301.0 | CHL | G | G |
| 5 | ☐ | L | H | | | 10 | 65.410 | 1.907 | 0.29 | 0.23 | 0.81 | 17351 | CL + CHL | | |
| 6 | ☐ | L | | H | | 10 | 45.430 | 1.328 | 0.29 | 0.23 | 0.81 | 12051 | CL | G | G |
| 7 | ☐ | L | | | H | 10 | 19.970 | 0.576 | 0.29 | 0.23 | 0.81 | 5299 | CHL(UST) | G | G |
| 8 | ☐ | (5-6) | | | | | 19.980 | 0.579 | 0.29 | 0.23 | 0.81 | 5300.0 | CHL | G | G |
| 9 | ☐ | CH-C1 | | | | | 5.677 | 0.128 | 0.23 | 0.19 | 0.81 | 1506.4 | CH' | G | G |
| 10 | ☐ | CL-C1 | | | | | 36.843 | 1.111 | 0.30 | 0.24 | 0.81 | 9773.5 | CL' | G | G |

Line 9 is the CH without the bushings

C1 | C2

| N | BH | Serial Number | NP %PF | NP Cap. | Test kV | mA | Watts | % PF Meas. | % PF Corr. | Corr. Factor | Cap. (pF) | Rtg | Rtg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ☐ | H1 | 1766473 | .23 | 360 | 10 | 1.333 | 0.030 | 0.23 | 0.23 | 1.00 | 353.40 | G | G |
| ☐ | H2 | 1766470 | .23 | 359 | 10 | 1.333 | 0.030 | 0.23 | 0.23 | 1.00 | 353.60 | G | G |
| ☐ | H3 | 1766471 | .23 | 357 | 10 | 1.323 | 0.030 | 0.23 | 0.23 | 1.00 | 350.80 | G | G |
| ☐ | H0 | 1766472 | .23 | 359 | 10 | 1.334 | 0.030 | 0.22 | 0.22 | 1.00 | 353.80 | G | G |
| ☐ | X1 | 2093510 | .27 | 564 | 10 | 2.114 | 0.054 | 0.26 | 0.26 | 1.00 | 560.80 | G | G |
| ☐ | X2 | 2093509 | .26 | 571 | 10 | 2.129 | 0.053 | 0.25 | 0.25 | 1.00 | 567 | G | G |

# CH' Calculations

C1 C2

| N | BH | Serial Number | NP %PF | NP Cap. | Test kV | mA | Watts | % PF Meas. | % PF Corr. | Corr. Factor | Cap. (pF) | Rtg | Rtg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H1 | 1766473 | .23 | 360 | 10 | 1.333 | 0.030 | 0.23 | 0.23 | 1.00 | 353.40 | G | G |
| | H2 | 1766470 | .23 | 359 | 10 | 1.333 | 0.030 | 0.23 | 0.23 | 1.00 | 353.60 | G | G |
| | H3 | 1766471 | .23 | 357 | 10 | 1.323 | 0.030 | 0.23 | 0.23 | 1.00 | 350.80 | G | G |
| | H0 | 1766472 | .23 | 359 | 10 | 1.334 | 0.030 | 0.22 | 0.22 | 1.00 | 353.80 | G | G |
| | X1 | 2093510 | .27 | 564 | 10 | 2.114 | 0.054 | 0.26 | 0.26 | 1.00 | 560.80 | G | G |
| | X2 | 2093509 | .26 | 571 | 10 | 2.128 | 0.053 | 0.25 | 0.25 | 1.00 | 567 | G | G |

Sum of the H bushings C1 tests currents

1.333 + 1.333 + 1.323 + 1.334 = 5.323 mA

# CH' Calculations

| | N | ENG | GND | GAR | UST | Test kV | mA | Watts | % PF Meas. | % PF Corr. | Corr. Factor | Cap. (pF) | Meas | Rtg | Rtg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | H | L | | | 10 | 30.980 | 0.829 | 0.27 | 0.22 | 0.81 | 8219 | CH + CHL | | |
| 2 | | H | | L | | 10 | 11 | 0.248 | 0.23 | 0.19 | 0.81 | 2918 | CH | G | G |
| 3 | | H | | | L | 10 | 19.970 | 0.578 | 0.29 | 0.23 | 0.81 | 5299 | CHL(UST) | G | G |
| 4 | | (1-2) | | | | | 19.980 | 0.581 | 0.29 | 0.23 | 0.81 | 5301.0 | CHL | G | G |
| 5 | | L | H | | | 10 | 65.410 | 1.907 | 0.29 | 0.23 | 0.81 | 17351 | CL + CHL | | |
| 6 | | L | | H | | 10 | 45.430 | 1.328 | 0.29 | 0.23 | 0.81 | 12051 | CL | G | G |
| 7 | | L | | | H | 10 | 19.970 | 0.576 | 0.29 | 0.23 | 0.81 | 5299 | CHL(UST) | G | G |
| 8 | | (5-6) | | | | | 19.980 | 0.579 | 0.29 | 0.23 | 0.81 | 5300.0 | CHL | G | G |
| 9 | | CH-C1 | | | | | 5.677 | 0.128 | 0.23 | 0.19 | 0.81 | 1506.4 | CH' | G | G |
| 10 | | CL-C1 | | | | | 36.843 | 1.111 | 0.30 | 0.24 | 0.81 | 9773.5 | CL' | G | G |

Line 9 is the CH without the Primary Bushings

Sum of the Primary Bushings C1 tests currents
1.333 + 1.333 + 1.323 + 1.334 = 5.323 mA

Line 2 mA – Sum of C1 mA = Line 9 mA
11mA – 5.323 mA = 5.677 mA

# CL’ Calculations

| | N | ENG | GND | GAR | UST | Test kV | mA | Watts | % PF Meas. | % PF Corr. | Corr. Factor | Cap. (pF) | Meas | Rtg | Rtg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | H | L | | | 10 | 30.980 | 0.829 | 0.27 | 0.22 | 0.81 | 8219 | CH + CHL | | |
| 2 | | H | | L | | 10 | 11 | 0.248 | 0.23 | 0.19 | 0.81 | 2918 | CH | G | G |
| 3 | | H | | | L | 10 | 19.970 | 0.578 | 0.29 | 0.23 | 0.81 | 5299 | CHL(UST) | G | G |
| 4 | | (1-2) | | | | | 19.980 | 0.581 | 0.29 | 0.23 | 0.81 | 5301.0 | CHL | G | G |
| 5 | | L | H | | | 10 | 65.410 | 1.907 | 0.29 | 0.23 | 0.81 | 17351 | CL + CHL | | |
| 6 | | L | | H | | 10 | 45.430 | 1.328 | 0.29 | 0.23 | 0.81 | 12051 | CL | G | G |
| 7 | | L | | | H | 10 | 19.970 | 0.576 | 0.29 | 0.23 | 0.81 | 5299 | CHL(UST) | G | G |
| 8 | | (5-6) | | | | | 19.980 | 0.579 | 0.29 | 0.23 | 0.81 | 5300.0 | CHL | G | G |
| 9 | | CH-C1 | | | | | 5.677 | 0.128 | 0.23 | 0.19 | 0.81 | 1506.4 | CH' | G | G |
| 10 | | CL-C1 | | | | | 36.843 | 1.111 | 0.30 | 0.24 | 0.81 | 9773.5 | CL' | G | G |

Line 10 is the CL without the bushings

C1 | C2

| N | BH | Serial Number | NP %PF | NP Cap. | Test kV | mA | Watts | % PF Meas. | % PF Corr. | Corr. Factor | Cap. (pF) | Rtg | Rtg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | X1 | 2093510 | .27 | 564 | 10 | 2.114 | 0.054 | 0.26 | 0.26 | 1.00 | 560.80 | G | G |
| | X2 | 2093509 | .26 | 571 | 10 | 2.138 | 0.053 | 0.25 | 0.25 | 1.00 | 567 | G | G |
| | X3 | 2093508 | .27 | 584 | 10 | 2.189 | 0.054 | 0.25 | 0.25 | 1.00 | 580.50 | G | G |
| | X0 | 2093505 | .26 | 574 | 10 | 2.146 | 0.056 | 0.26 | 0.26 | 1.00 | 569.20 | G | G |

# CL' Calculations

C1 | C2

| N | BH | Serial Number | NP %PF | NP Cap. | Test kV | mA | Watts | % PF Meas. | % PF Corr. | Corr. Factor | Cap. (pF) | Rtg | Rtg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | X1 | 2093510 | .27 | 564 | 10 | 2.114 | 0.054 | 0.26 | 0.26 | 1.00 | 560.80 | G | G |
| | X2 | 2093509 | .26 | 571 | 10 | 2.138 | 0.053 | 0.25 | 0.25 | 1.00 | 567 | G | G |
| | X3 | 2093508 | .27 | 584 | 10 | 2.189 | 0.054 | 0.25 | 0.25 | 1.00 | 580.50 | G | G |
| | X0 | 2093505 | .26 | 574 | 10 | 2.146 | 0.056 | 0.26 | 0.26 | 1.00 | 569.20 | G | G |

Sum of the Secondary Bushings C1 tests currents

2.114 + 2.138 + 2.189 + 2.146 = 8.587 mA

# CL' Calculations

| | N | ENG | GND | GAR | UST | Test kV | mA | Watts | % PF Meas. | % PF Corr. | Corr. Factor | Cap. (pF) | Meas | Rtg | Rtg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | H | L | | | 10 | 30.980 | 0.829 | 0.27 | 0.22 | 0.81 | 8219 | CH + CHL | | |
| 2 | | H | | L | | 10 | 11 | 0.248 | 0.23 | 0.19 | 0.81 | 2918 | CH | G | G |
| 3 | | H | | | L | 10 | 19.970 | 0.578 | 0.29 | 0.23 | 0.81 | 5299 | CHL(UST) | G | G |
| 4 | | (1-2) | | | | | 19.980 | 0.581 | 0.29 | 0.23 | 0.81 | 5301.0 | CHL | G | G |
| 5 | | L | H | | | 10 | 65.410 | 1.907 | 0.29 | 0.23 | 0.81 | 17351 | CL + CHL | | |
| 6 | | L | | H | | 10 | 45.430 | 1.328 | 0.29 | 0.23 | 0.81 | 12051 | CL | G | G |
| 7 | | L | | | H | 10 | 19.970 | 0.576 | 0.29 | 0.23 | 0.81 | 5299 | CHL(UST) | G | G |
| 8 | | (5-6) | | | | | 19.980 | 0.579 | 0.29 | 0.23 | 0.81 | 5300.0 | CHL | G | G |
| 9 | | CH-C1 | | | | | 5.677 | 0.128 | 0.23 | 0.19 | 0.81 | 1506.4 | CH' | G | G |
| 10 | | CL-C1 | | | | | 36.843 | 1.111 | 0.30 | 0.24 | 0.81 | 9773.5 | CL' | G | G |

Line 10 is the CL without the Secondary Bushings

Sum of the Secondary Bushings C1 tests currents

2.114 + 2.138 + 2.189 + 2.146 = 8.587 mA

Line 6 mA – Sum of C1 mA = Line 10 mA

45.430mA – 8.587 mA = 36.843 mA

# Overall Test Temperature Correction

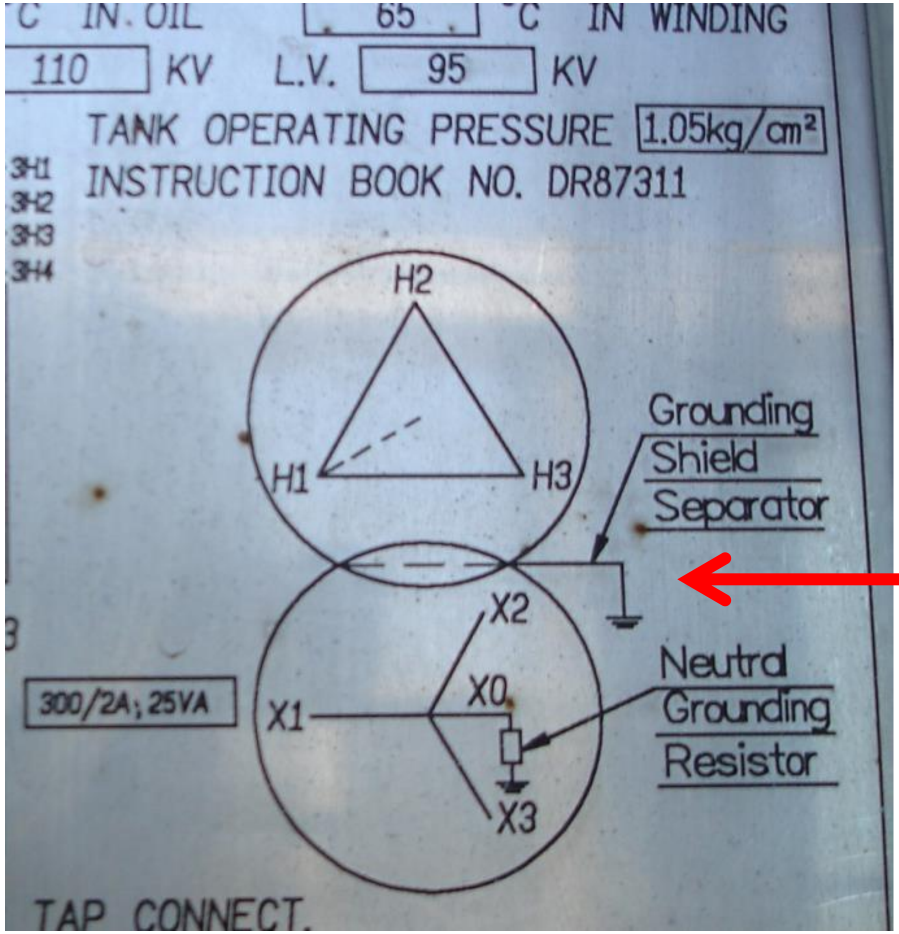
| LIQUID-FILLED TRANSFORMERS, SHUNT REACTORS, AND VOLTAGE REGULATORS | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| POWER TRANSFORMERS (Above 500 kVA) | | | | | DISTRIBUTION TRANSFORMERS (500 kVA and Below) | | | | | | | | PTs/VT |
| | Oil-Filled Transformers | | | | | Oil-Filled | | | TEST TEMPERATURES | | | | |
| Askarel-Filled Trans. | Free Breathing and Older Conservator Types | Sealed, Gas-blanketed and Modern Conservator Types ≤161 kV | Sealed, Gas-blanketed and Modern Conservator Types >161 kV | Silicone | Askarel | Prior to 1950 | Modern | Silicone | °C | °F | HV/EHV Shunt Reactors (Oil-Filled) | Voltage Regulators (Oil-Filled) | Askarel |
| – | 1.56 | 1.57 | .95 | – | – | 1.56 | 1.57 | – | 0 | 32.0 | .95 | 1.56 | – |
| – | 1.52 | 1.50 | .96 | – | – | 1.52 | 1.50 | – | 2 | 35.6 | .96 | 1.52 | – |
| – | 1.48 | 1.44 | .98 | – | – | 1.48 | 1.44 | – | 4 | 39.2 | .98 | 1.48 | – |
| – | 1.45 | 1.37 | .98 | – | – | 1.45 | 1.37 | – | 6 | 42.8 | .98 | 1.45 | – |
| – | 1.43 | 1.31 | .99 | – | – | 1.43 | 1.31 | – | 8 | 46.4 | .99 | 1.43 | – |
| – | 1.38 | 1.25 | .99 | – | – | 1.38 | 1.25 | – | 10 | 50.0 | .99 | 1.38 | – |
| – | 1.31 | 1.19 | 1.00 | – | – | 1.31 | 1.19 | – | 12 | 53.6 | 1.00 | 1.31 | – |
| – | 1.24 | 1.14 | 1.01 | – | – | 1.24 | 1.14 | – | 14 | 57.2 | 1.01 | 1.24 | – |
| – | 1.16 | 1.09 | 1.01 | – | – | 1.16 | 1.09 | – | 16 | 60.8 | 1.01 | 1.16 | – |
| – | 1.08 | 1.05 | 1.00 | – | – | 1.08 | 1.05 | – | 18 | 64.4 | 1.00 | 1.08 | – |
| 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 20 | 68.0 | 1.00 | 1.00 | 1.00 |
| .90 | .91 | .96 | .99 | .96 | .90 | .91 | .96 | .96 | 22 | 71.6 | .99 | .91 | .90 |
| .81 | .83 | .92 | .98 | .92 | .81 | .83 | .92 | .92 | 24 | 75.2 | .98 | .83 | .81 |
| .72 | .76 | .88 | .97 | .88 | .72 | .76 | .88 | .88 | 26 | 78.8 | .97 | .76 | .72 |
| .64 | .70 | .84 | .96 | .84 | .64 | .70 | .84 | .84 | 28 | 82.4 | .96 | .70 | .64 |
| .56 | .63 | .80 | .95 | .80 | .56 | .63 | .80 | .80 | 30 | 86.0 | .95 | .63 | .56 |
| .51 | .58 | .76 | .94 | .76 | .51 | .58 | .76 | .76 | 32 | 89.6 | .94 | .58 | .51 |
| .46 | .53 | .73 | .93 | .73 | .46 | .53 | .73 | .73 | 34 | 93.2 | .93 | .53 | .46 |
| .42 | .49 | .70 | .91 | .70 | .42 | .49 | .70 | .70 | 36 | 96.8 | .91 | .49 | .42 |
| .39 | .45 | .67 | .90 | .67 | .39 | .45 | .67 | .67 | 38 | 100.4 | .90 | .45 | .39 |
| .35 | .42 | .65 | .89 | .65 | .35 | .42 | .65 | .65 | 40 | 104.0 | .89 | .42 | .35 |
| .33 | .38 | .62 | .87 | .62 | .33 | .38 | .62 | .62 | 42 | 107.6 | .87 | .38 | .33 |
| .30 | .36 | .59 | .86 | .59 | .30 | .36 | .59 | .59 | 44 | 111.2 | .86 | .36 | .30 |
| .28 | .33 | .56 | .84 | .56 | .28 | .33 | .56 | .56 | 46 | 114.8 | .84 | .33 | .28 |
| .26 | .30 | .54 | .83 | .54 | .26 | .30 | .54 | .54 | 48 | 118.4 | .83 | .30 | .26 |
| .24 | .28 | .51 | .81 | .51 | .24 | .28 | .51 | .51 | 50 | 122.0 | .81 | .28 | .24 |
| .22 | .26 | .49 | .79 | .49 | .22 | .26 | .49 | .49 | 52 | 125.6 | .79 | .26 | .22 |
| .21 | .23 | .47 | .77 | .47 | .21 | .23 | .47 | .47 | 54 | 129.2 | .77 | .23 | .21 |
| .19 | .21 | .45 | .75 | .45 | .19 | .21 | .45 | .45 | 56 | 132.8 | .75 | .21 | .19 |
| .18 | .19 | .43 | .72 | .43 | .18 | .19 | .43 | .43 | 58 | 136.4 | .72 | .19 | .18 |

# Other types of 2 winding Transformers

Shielded Transformers

Wye-Wye Internally Tied Together

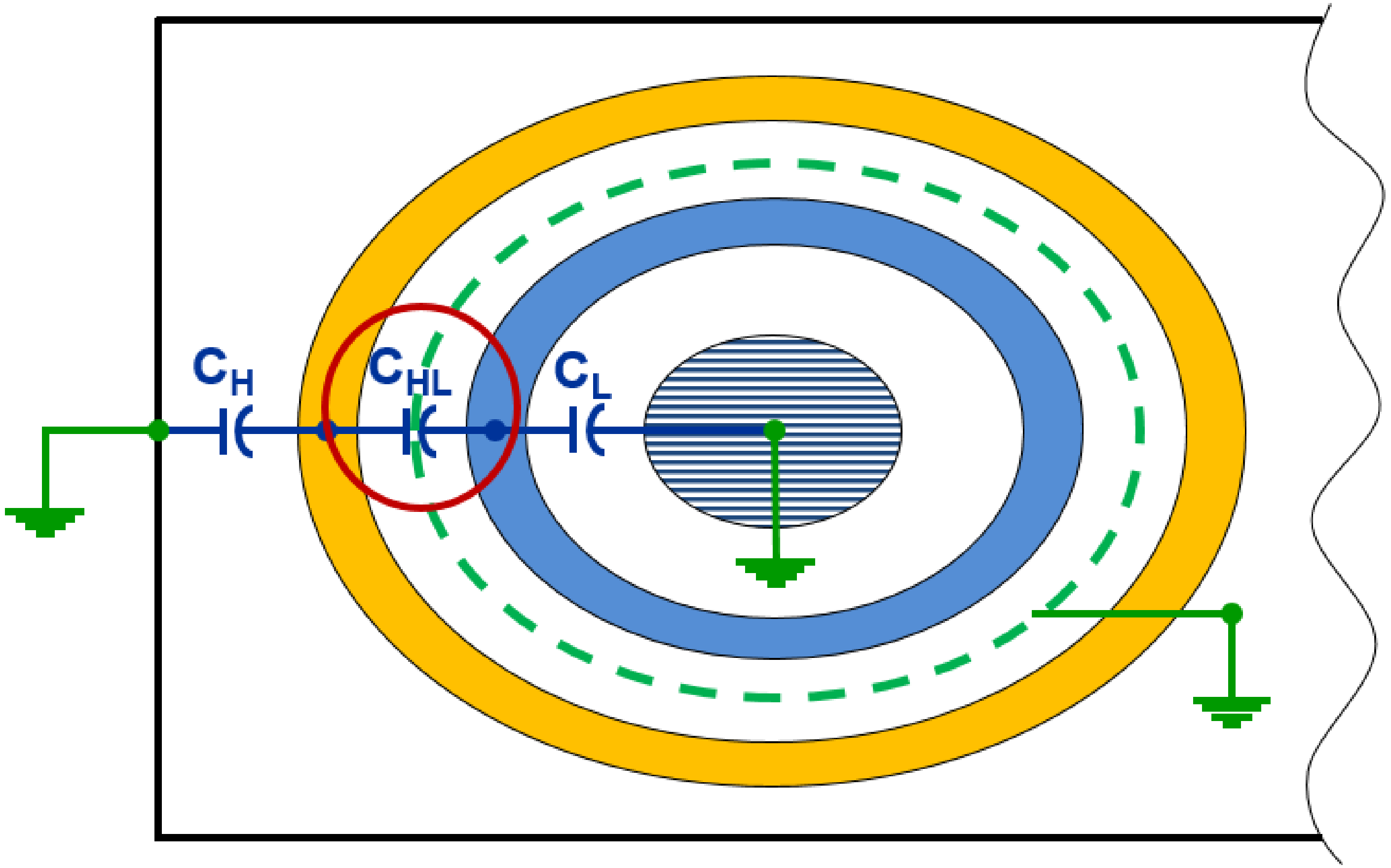
# Testing Transformers with Inter-Winding Shield




Inter-Winding Shield

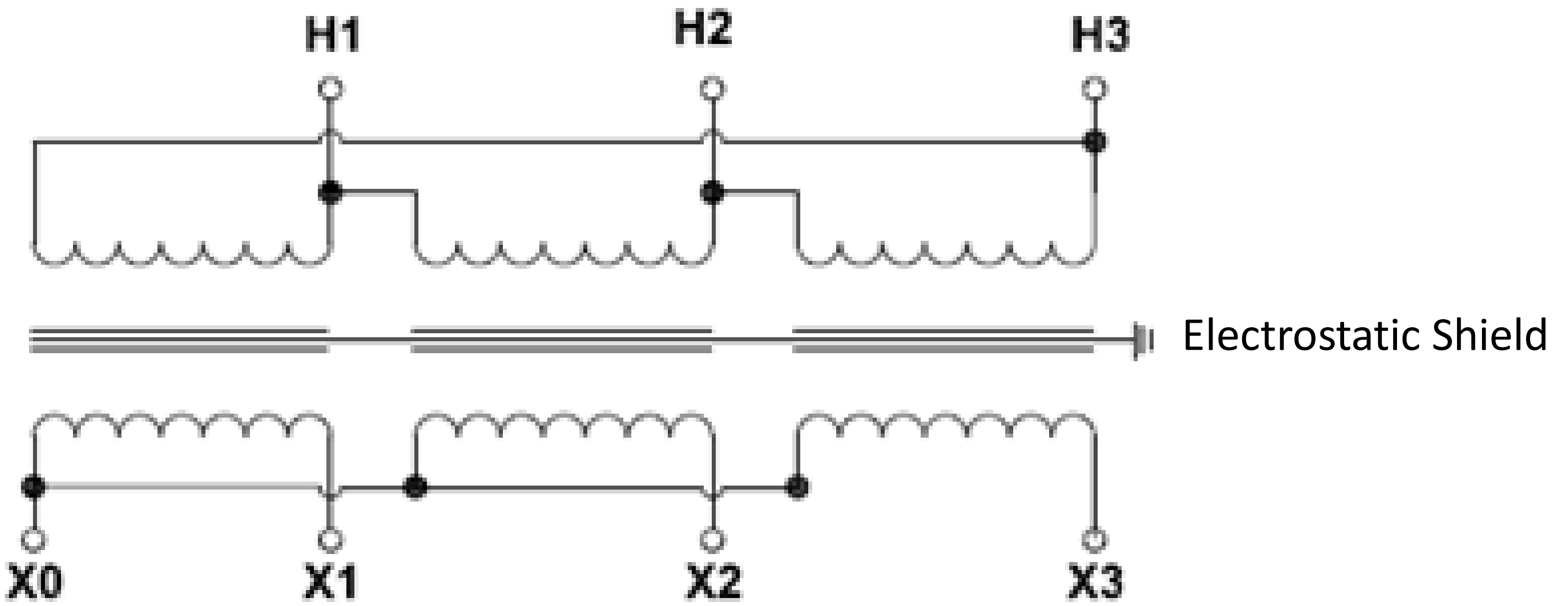
(not always shown on nameplate)

## Physical Representation of a Three-Phase Two-Winding Transformer

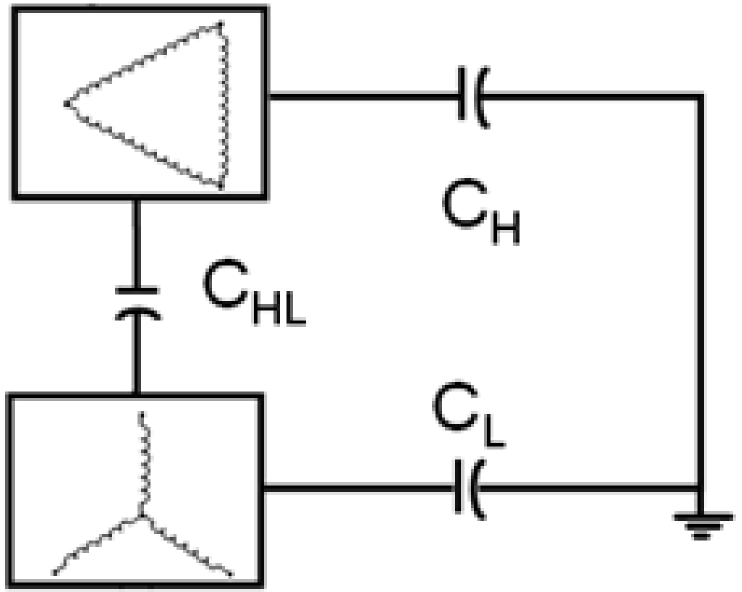



**One of Three Phases Shown**

# Inter-Winding Shield

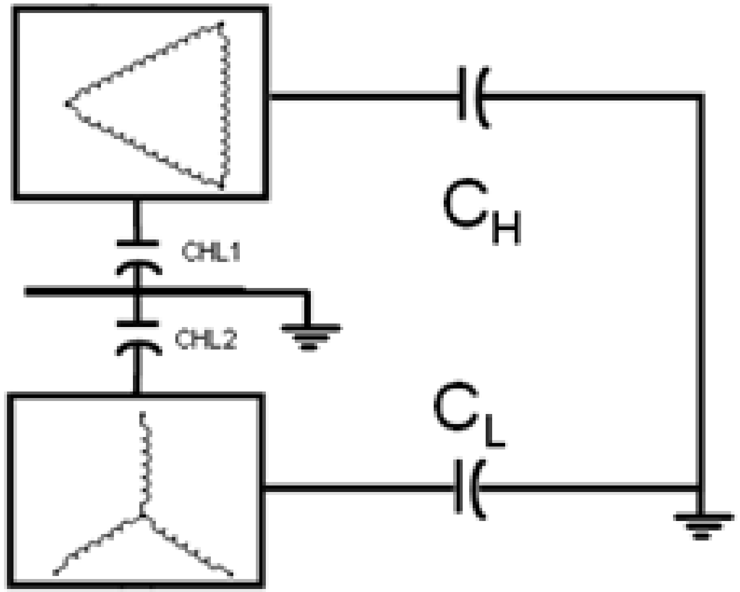


A

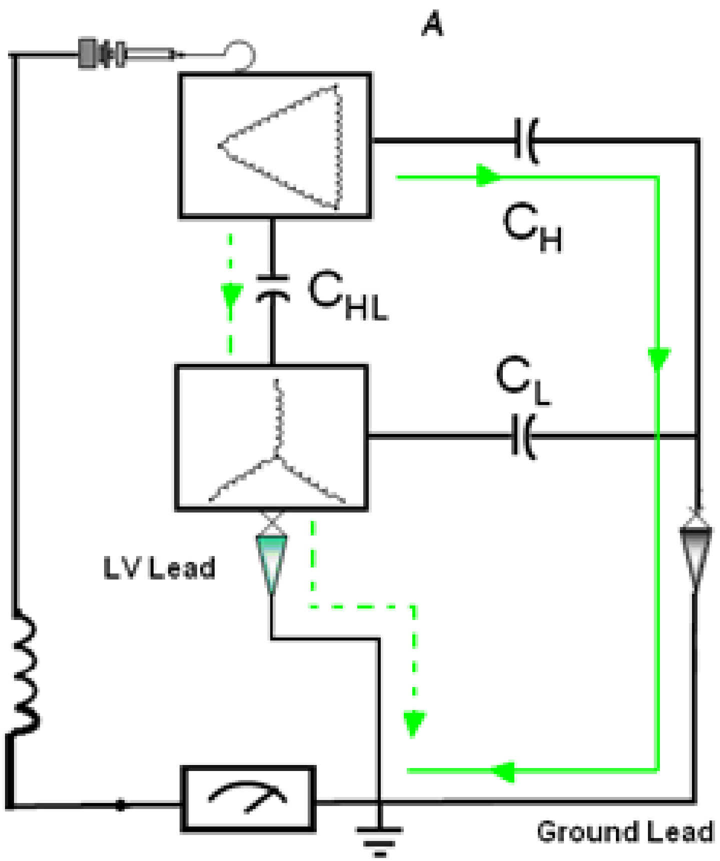



2 winding transformer

B

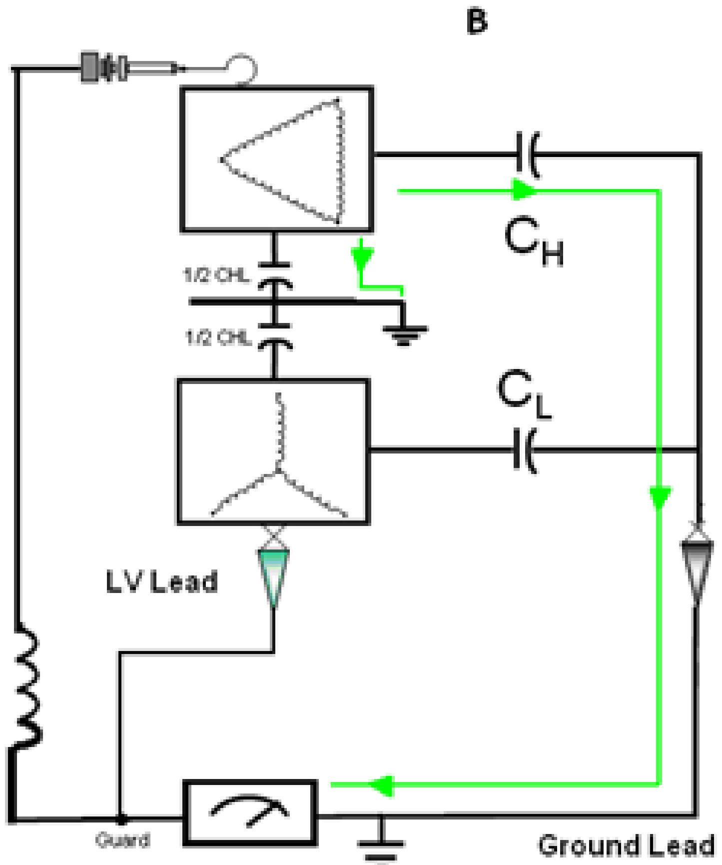



2 winding transformer with grounded electrostatic shield



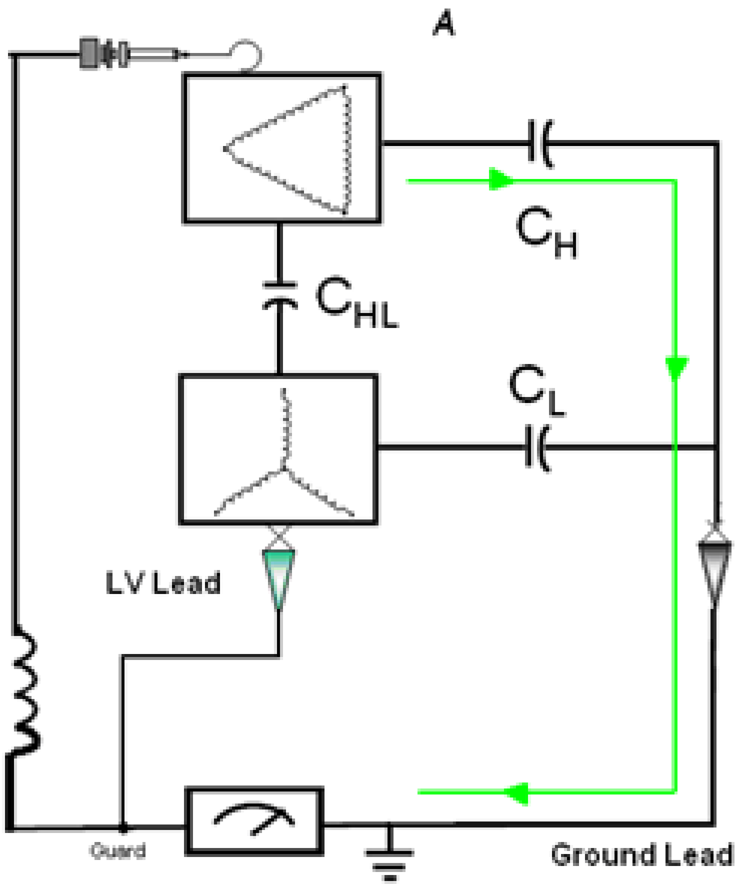

Test 1: Ground

Measures CH + CHL



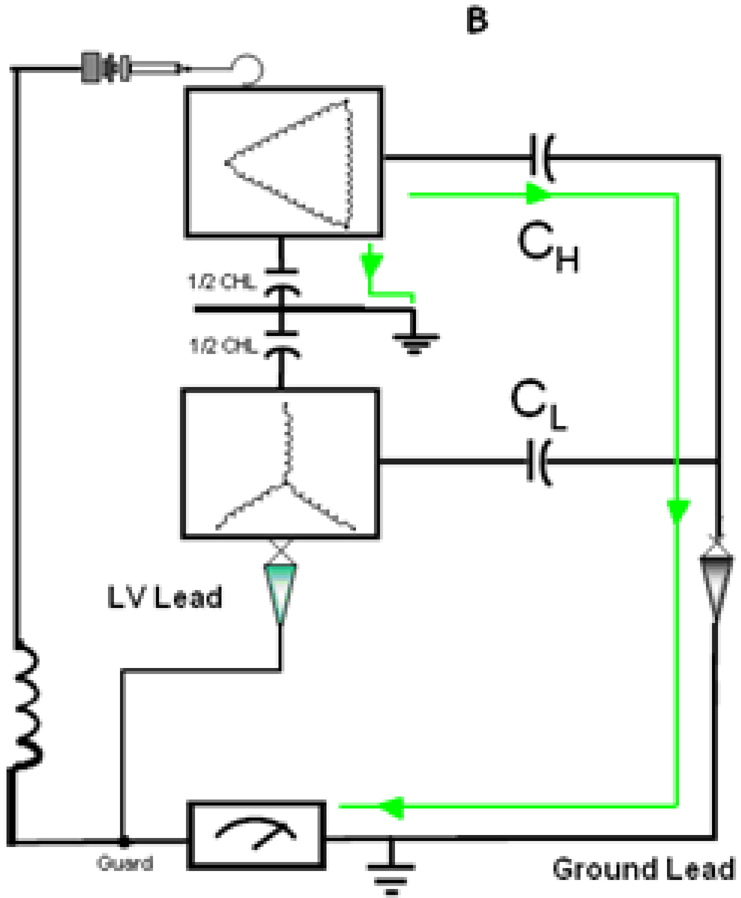

Test 1: Ground

Measures CH + 1/2 CHL



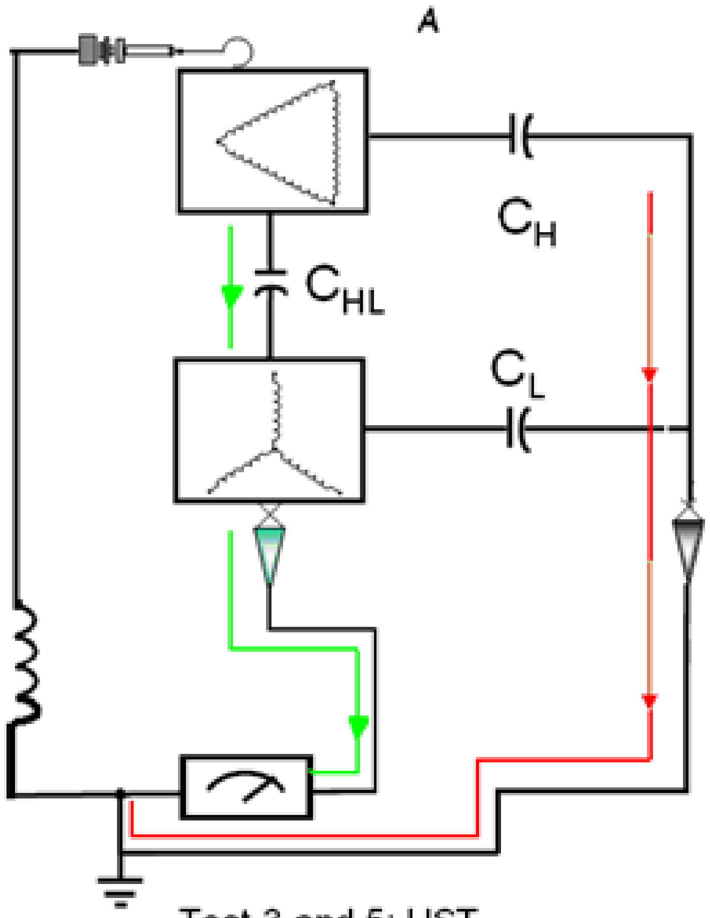

Test 2: Guard

Measures CH



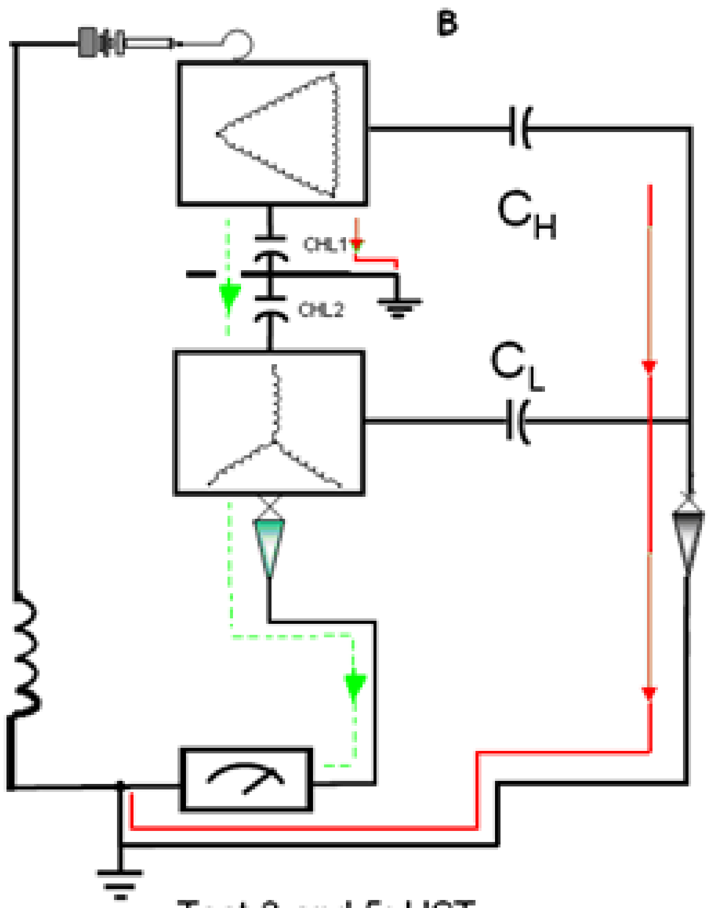

Test 2: Guard

Measures CH + 1/2 CHL




Test 3 and 5: UST

Measures CHL




Test 3 and 5: UST

Current takes the path of least resistance therefore most of the current flows to ground. There is, however, a small amount of current that is measured for the UST test. Lines 3,4,7 and 8 of the overall test will be similar.

# Inter-Winding Shield

**Overall Test Setup**

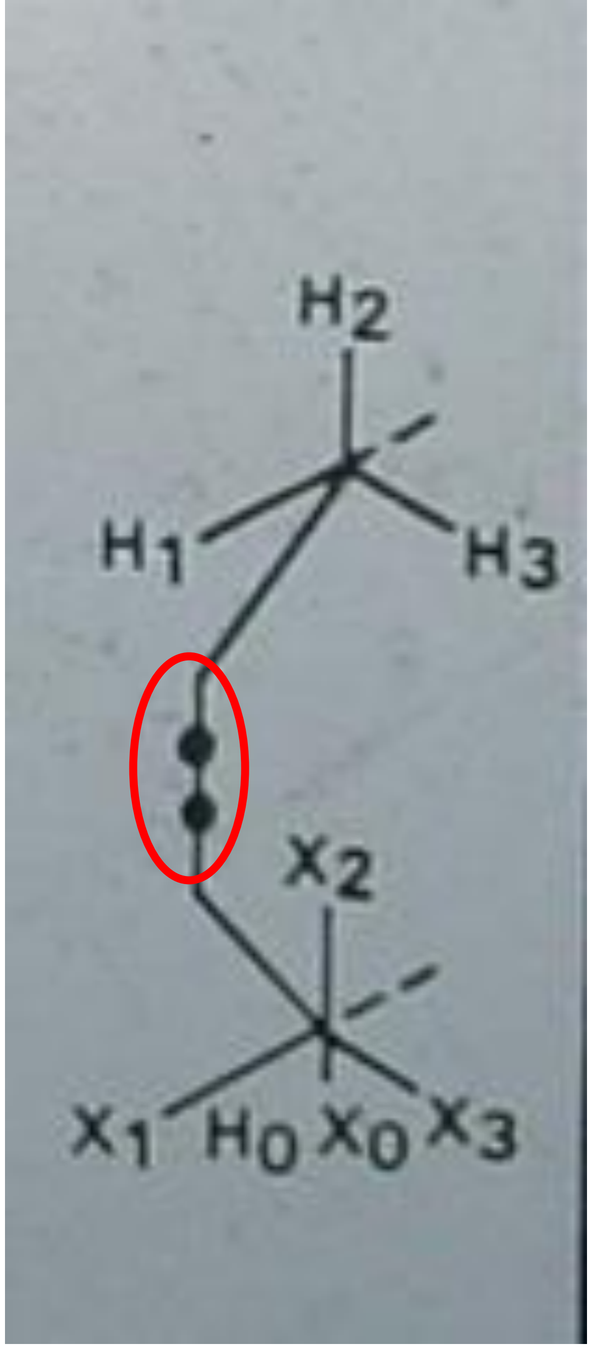
| Connections | | | | | Inputs | | Test Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) |
| 1 | HV Winding | LV Winding | Unused | CH+CHL | 2.000 | 1.00 | 42.053 | 2.619 | 0.623 | 0.624 | 11154.6 |
| 2 | | | | CH | 2.000 | 1.00 | 42.051 | 2.631 | 0.626 | 0.627 | 11154.1 |
| 3 | | | | CHL(UST) | 2.000 | * | 0.000 | 0.000 | * | * | 0.0 |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 1.00 | 0.002 | -0.012 | -60.000 | -60.149 | 0.5 |
| 5 | LV Winding | HV Winding | Unused | CL+CHL | 2.000 | 1.00 | 154.020 | 4.796 | 0.311 | 0.312 | 40854.6 |
| 6 | | | | CL | 2.001 | 1.00 | 153.470 | 4.796 | 0.313 | 0.313 | 40708.9 |
| 7 | | | | CHL(UST) | 2.000 | * | 0.552 | 0.000 | 0.000 | 0.000 | 146.4 |
| 8 | Test 5 - Test 6 (calculated) | | | CHL | | 1.00 | 0.550 | 0.000 | 0.000 | 0.000 | 145.7 |

# Wye-Wye Transformers Internally Connected

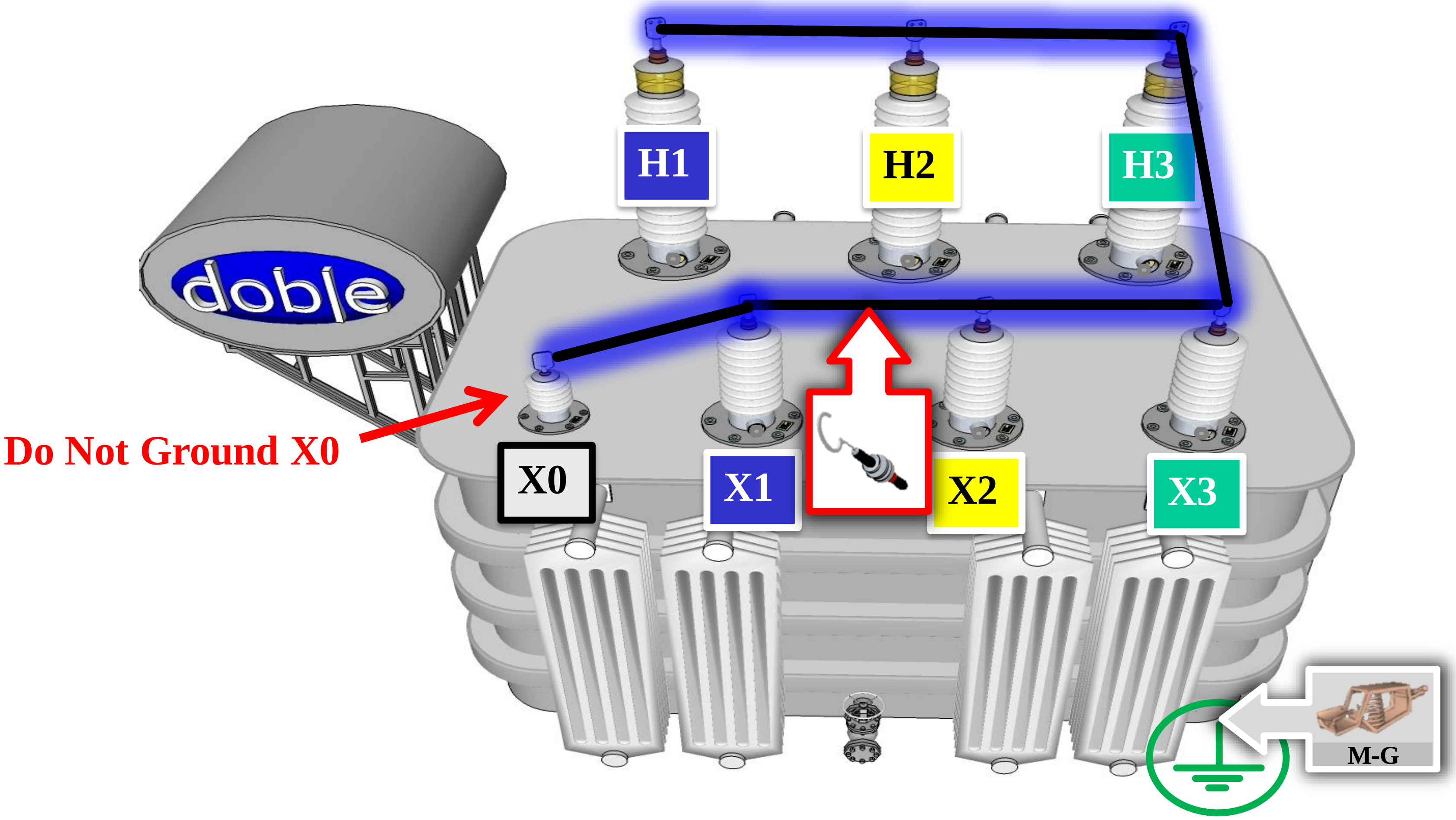
**Wye – Wye**
**Internally**
**Grounded**

**How Many**
**Windings?**

**1**

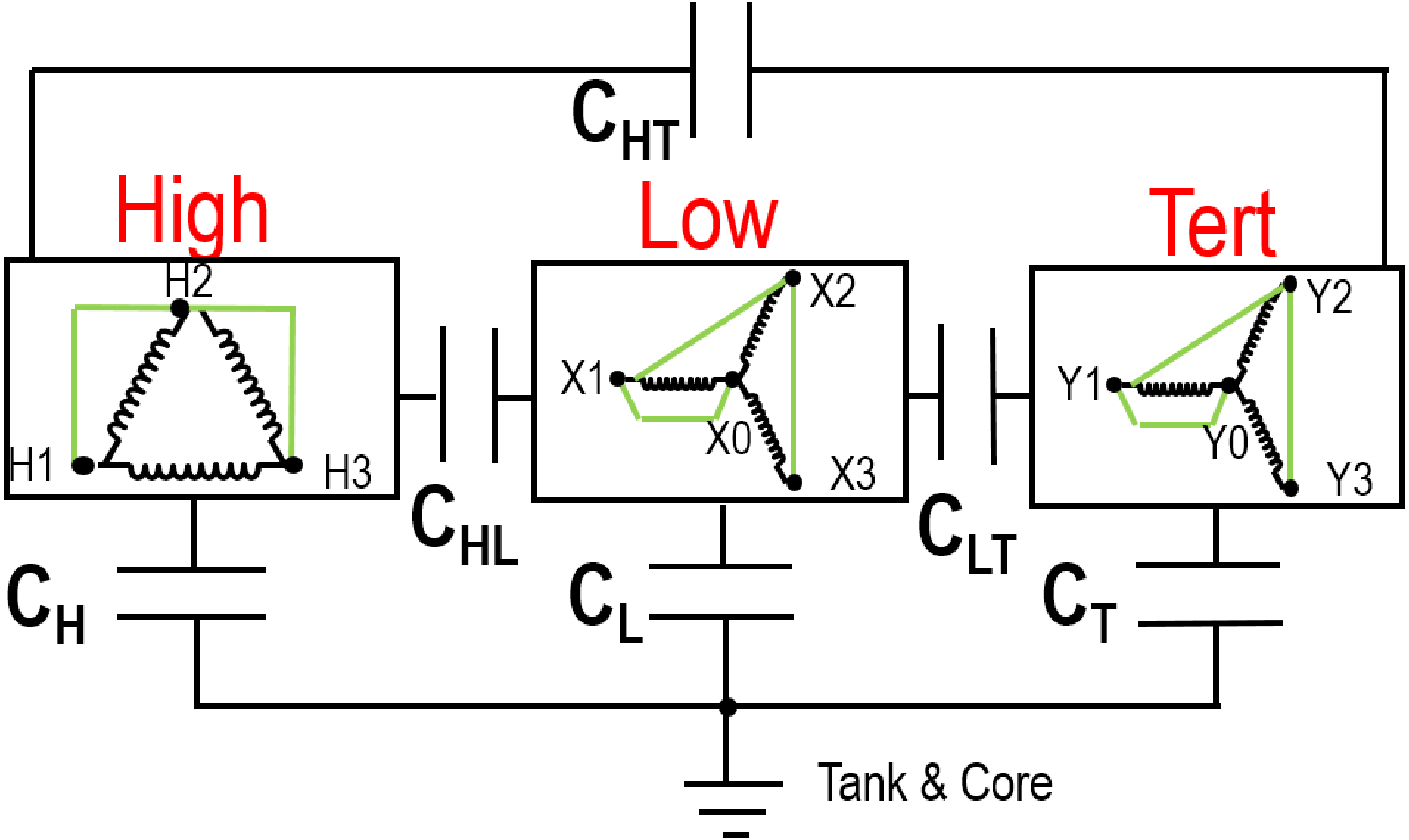


# Test Connections – Wye – Wye Internally Connected

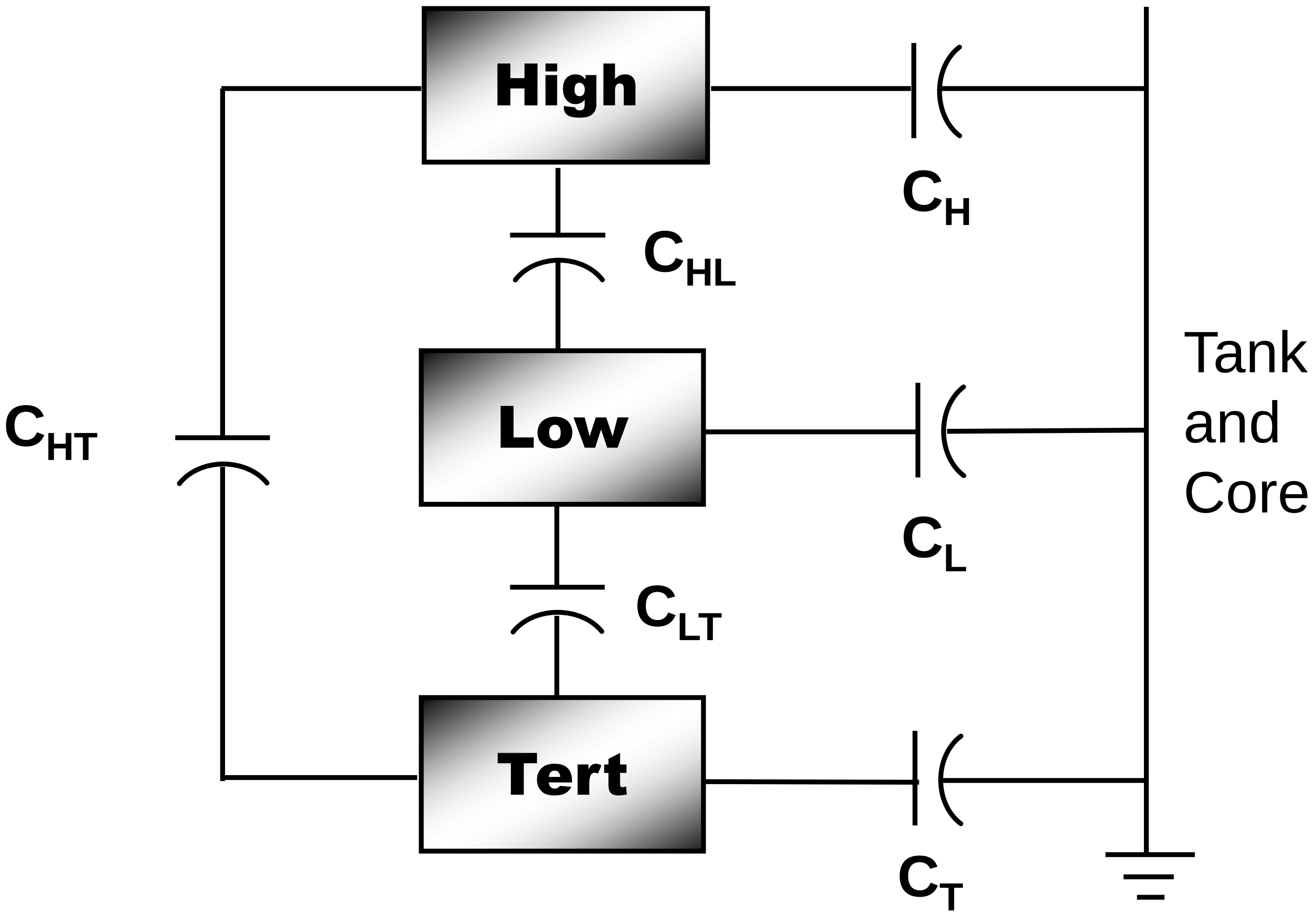


# Three Winding Transformers

# Dielectric Circuit
# Three-Winding Transformers



# Dielectric Circuit
# Three-Winding Transformers



# Dielectric Circuits of Transformers

**$C_H$ : $C_L$ : $C_T$**

Insulation between the Winding Conductors and the Grounded Tank & Core

- Winding Insulation
- High, Low, Tertiary Voltage Bushings
- Structural Insulating Members
- DETC Insulation
- LTC
- Insulating Fluid

# Dielectric Circuits of Transformers

**$C_{HL}$ : $C_{HT}$ : $C_{LT}$**

Insulation Between Two Windings; Inter-winding Insulation

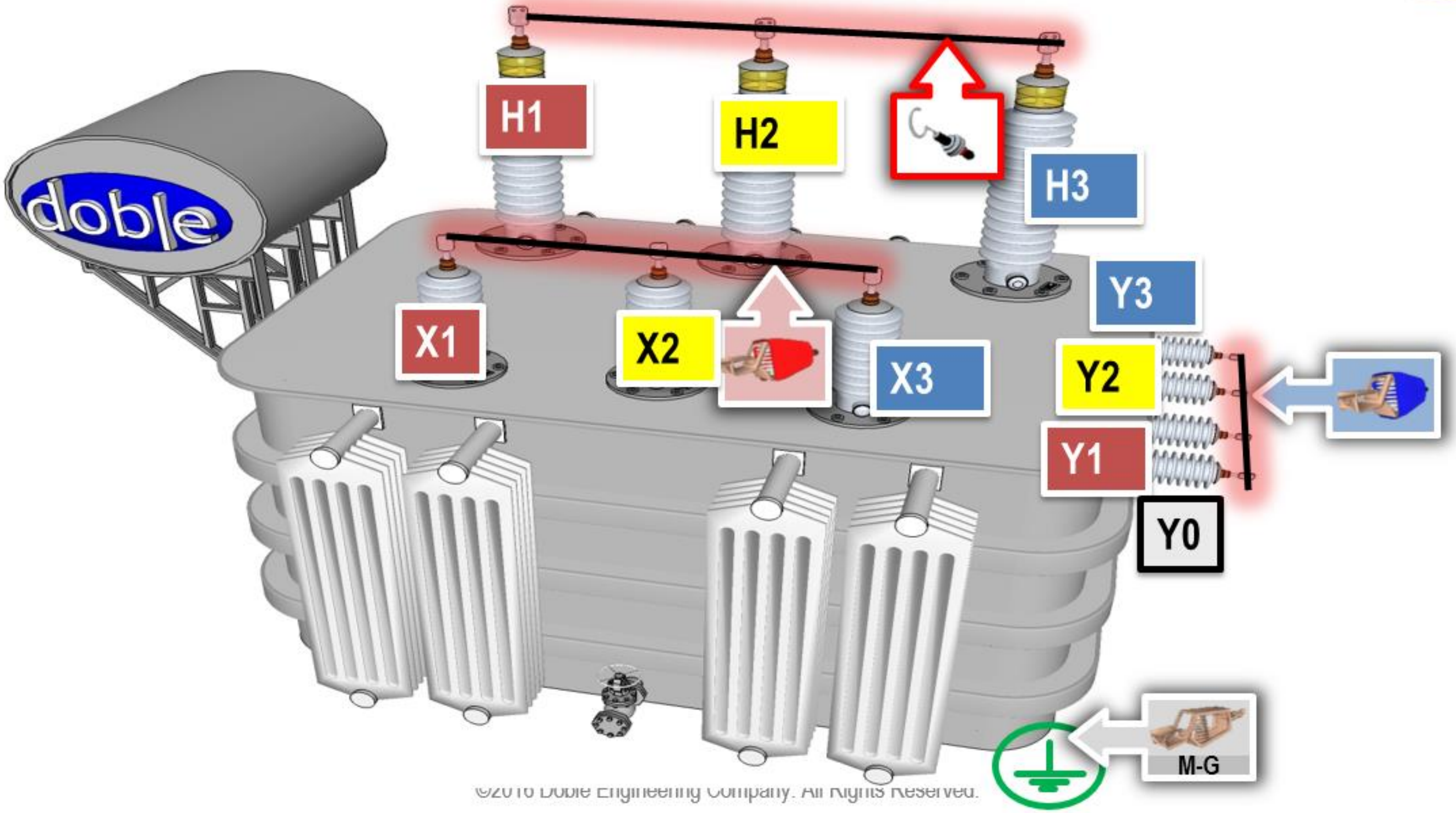
- Winding Insulation Barriers
- Insulating Liquid

# Three Winding Transformer
# Overall Tests

**Overall Test Setup**

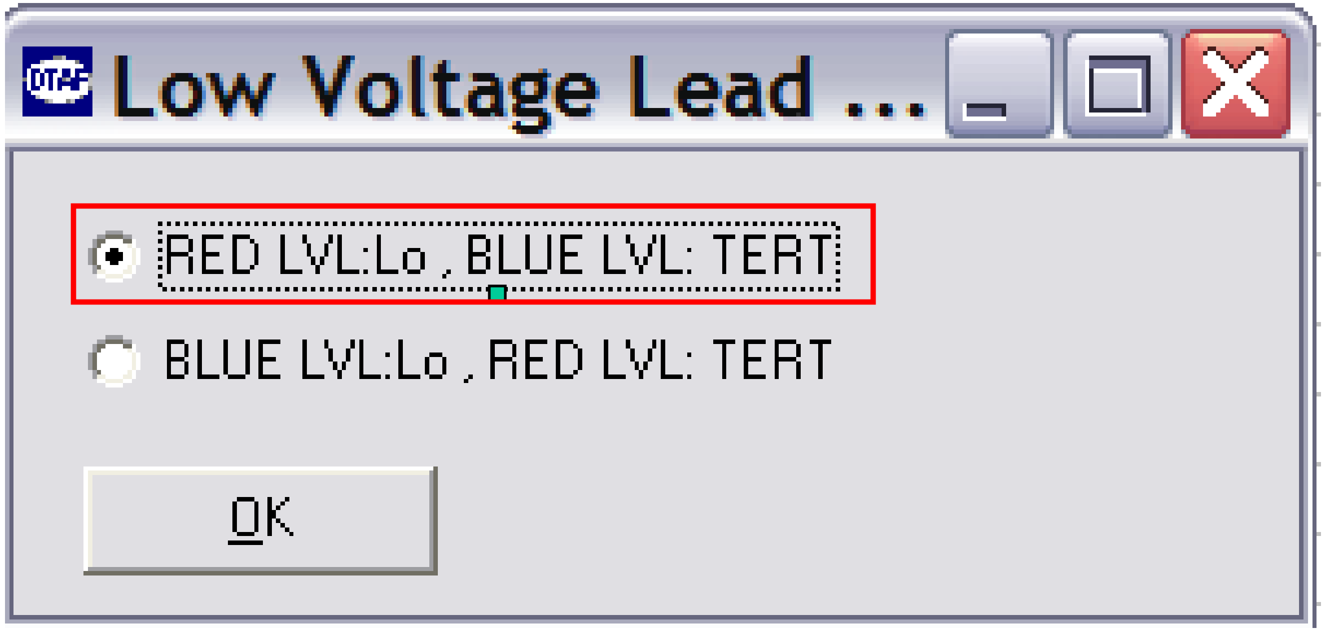
| Connections | | | | | Inputs | | Test Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) |
| 1 | HV Winding | LV Winding | TV Winding | CH+CHL | 10.007 | 1.00 | 43.800 | 1.796 | 0.410 | 0.409 | 11618.1 |
| 2 | | | | CH | 10.006 | 1.00 | 17.452 | 0.616 | 0.353 | 0.352 | 4629.1 |
| 3 | | | | CHL(UST) | 10.006 | 1.00 | 26.356 | 1.156 | 0.439 | 0.438 | 6991.2 |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 1.00 | 26.348 | 1.180 | 0.448 | 0.447 | 6989.0 |
| 5 | LV Winding | TV Winding | HV Winding | CL+CLT | 10.004 | 1.00 | 51.199 | 1.886 | 0.368 | 0.368 | 13580.9 |
| 6 | | | | CL | 10.003 | 1.00 | 22.519 | 0.819 | 0.364 | 0.363 | 5973.3 |
| 7 | | | | CLT(UST) | 10.003 | 1.00 | 28.689 | 1.036 | 0.361 | 0.361 | 7610.0 |
| 8 | Test 5 - Test 6 (calculated) | | | CLT | | 1.00 | 28.680 | 1.067 | 0.372 | 0.371 | 7607.6 |
| 9 | TV Winding | HV Winding | LV Winding | CT+CHT | 7.503 | 1.00 | 51.188 | 2.259 | 0.441 | 0.441 | 13577.9 |
| 10 | | | | CT | 7.503 | 1.00 | 50.320 | 2.258 | 0.449 | 0.448 | 13347.7 |
| 11 | | | | CHT(UST) | 7.503 | 1.00 | 0.867 | 0.010 | 0.115 | 0.115 | 229.9 |
| 12 | Test 9 - Test 10 (calculated) | | | CHT | | 1.00 | 0.868 | 0.001 | 0.012 | 0.012 | 230.2 |
| 13 | All | | | CH+CL+CT | 10.006 | 1.00 | 90.272 | 3.735 | 0.414 | 0.413 | 23945.2 |

# Three Winding Transformer – Tests #1, 2 & 3 Setup

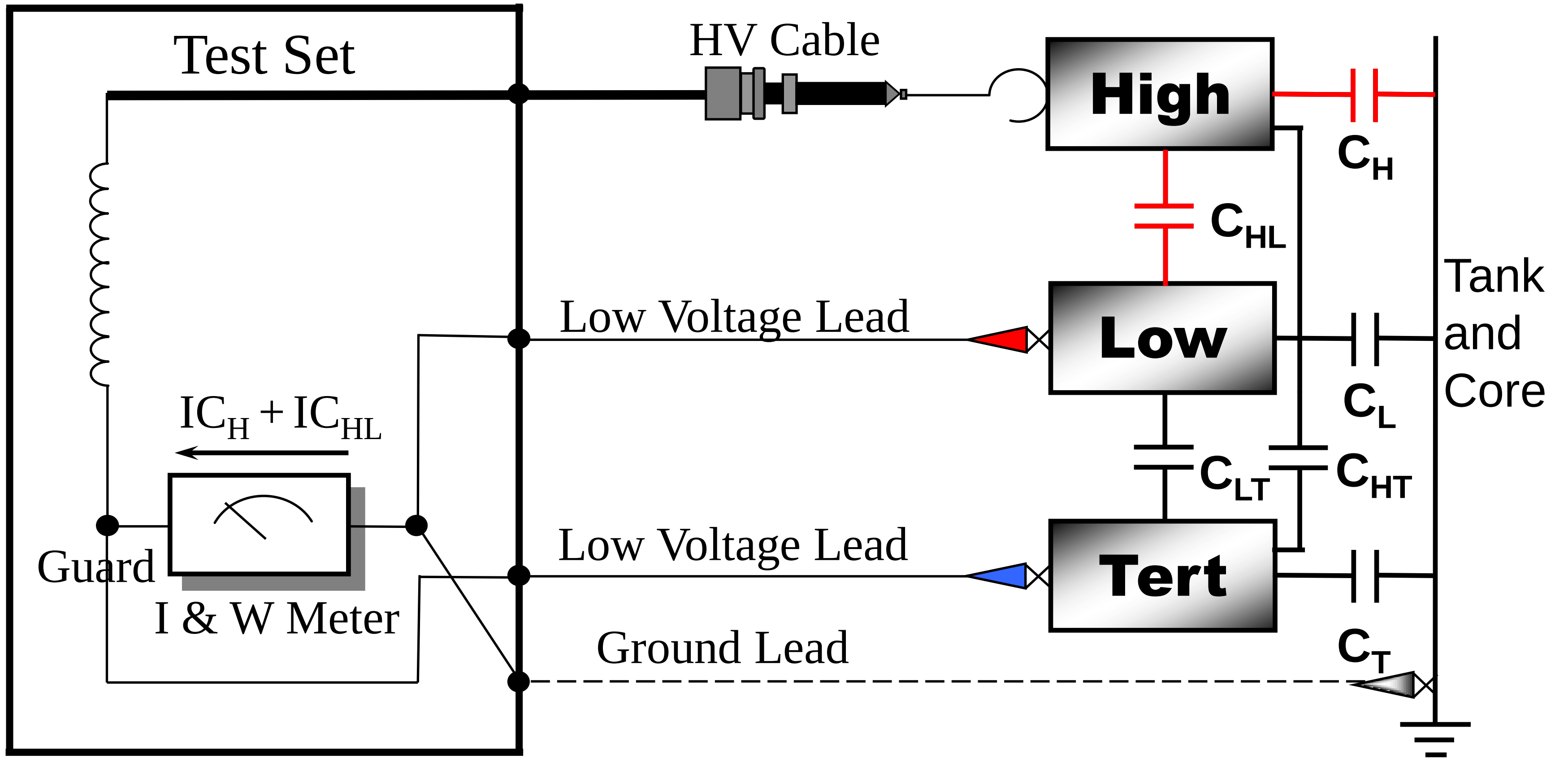


# Lead Selection Screen

Select if Red LV is on Low and Blue LV is on Tertiary
Or if Blue LV is on Low and Red LV is on Tertiary

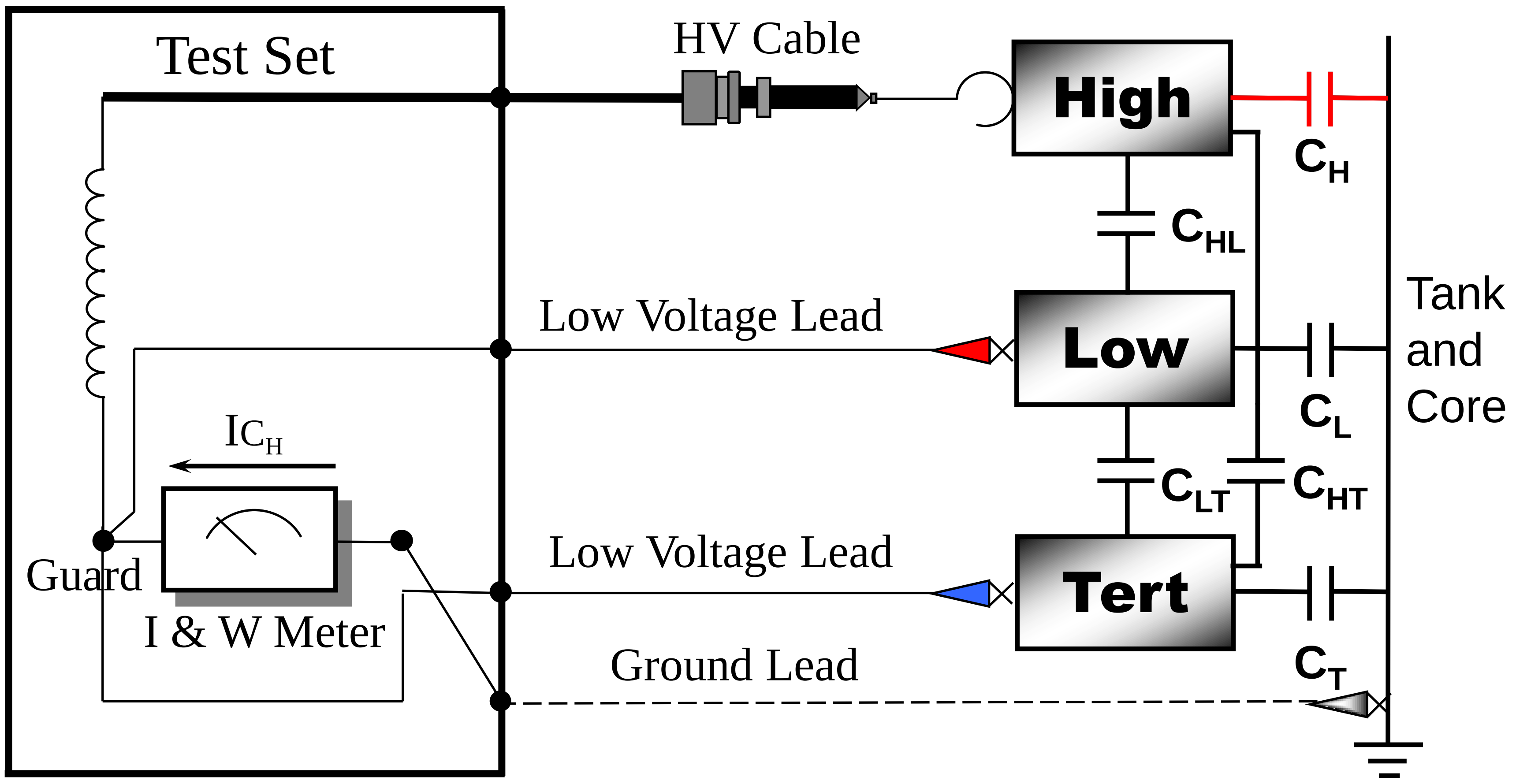


# Test Procedure -Test #1: Measure $C_H+C_{HL}$



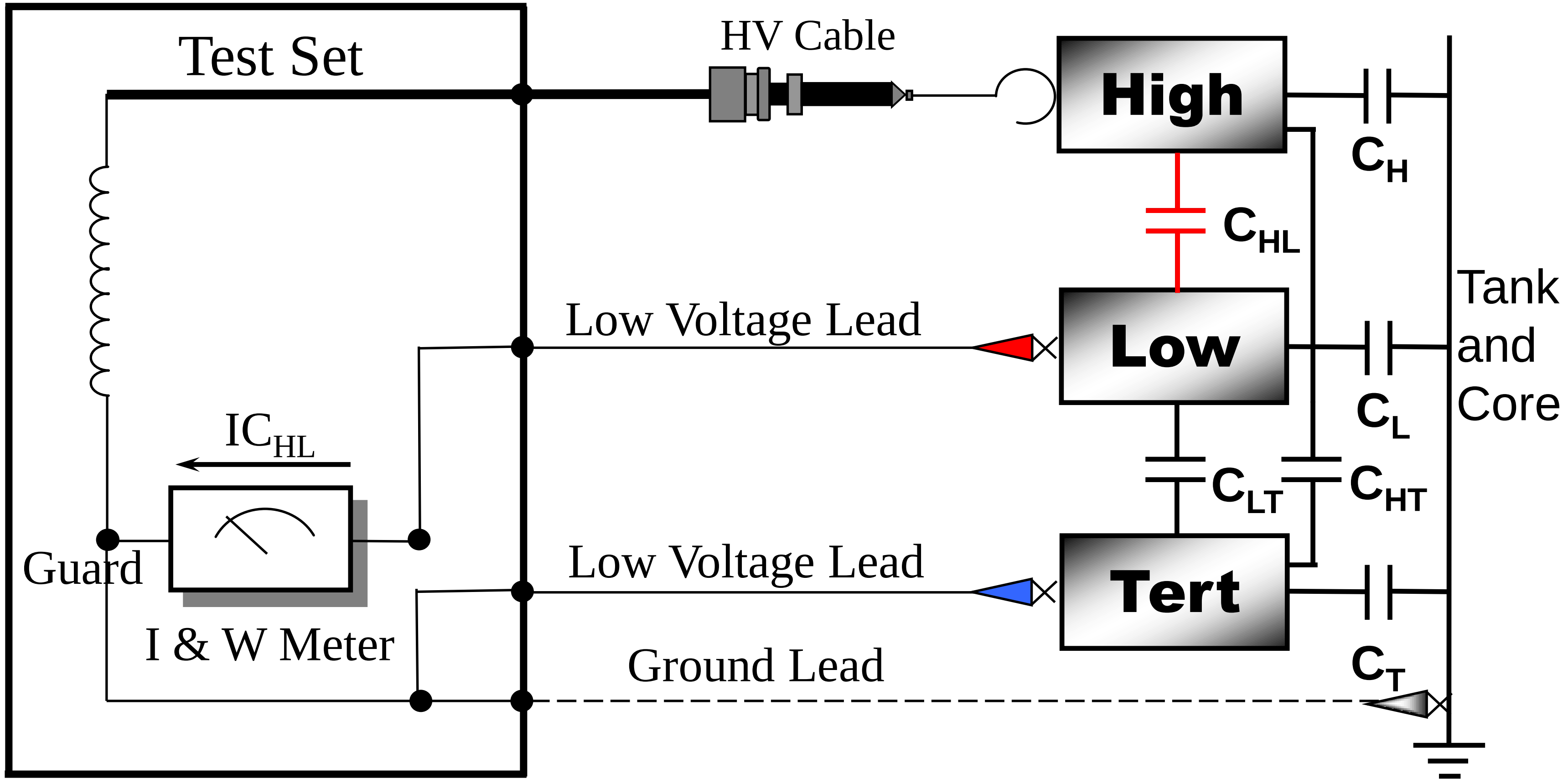

**GST – GROUND RED - GUARD BLUE**

# Test Procedure -Test #2: Measure $C_H$




**GST – GUARD RED & BLUE**

# Test Procedure -Test #3: Measure $C_{HL}$

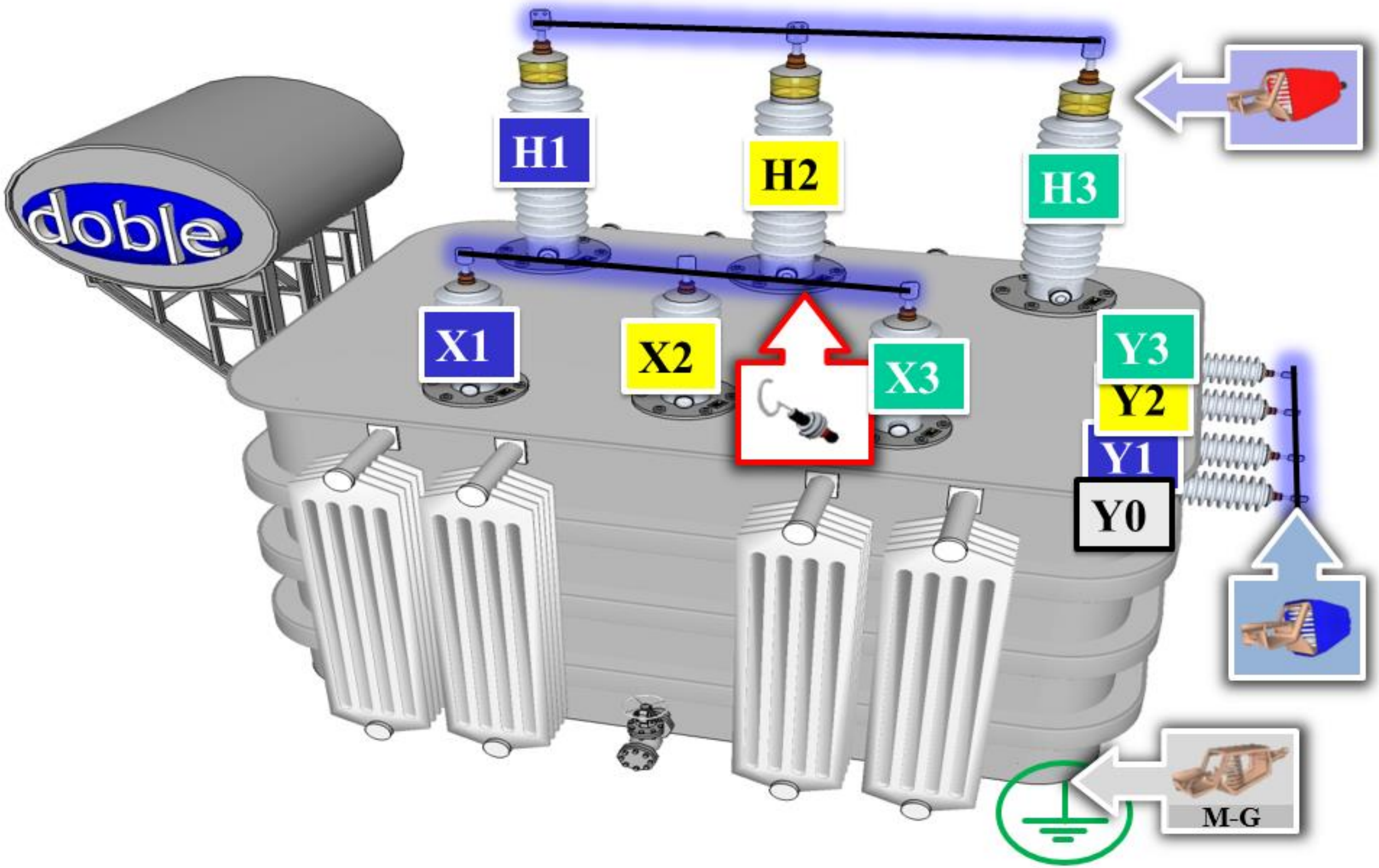



**UST – MEASURE RED – GROUND BLUE**

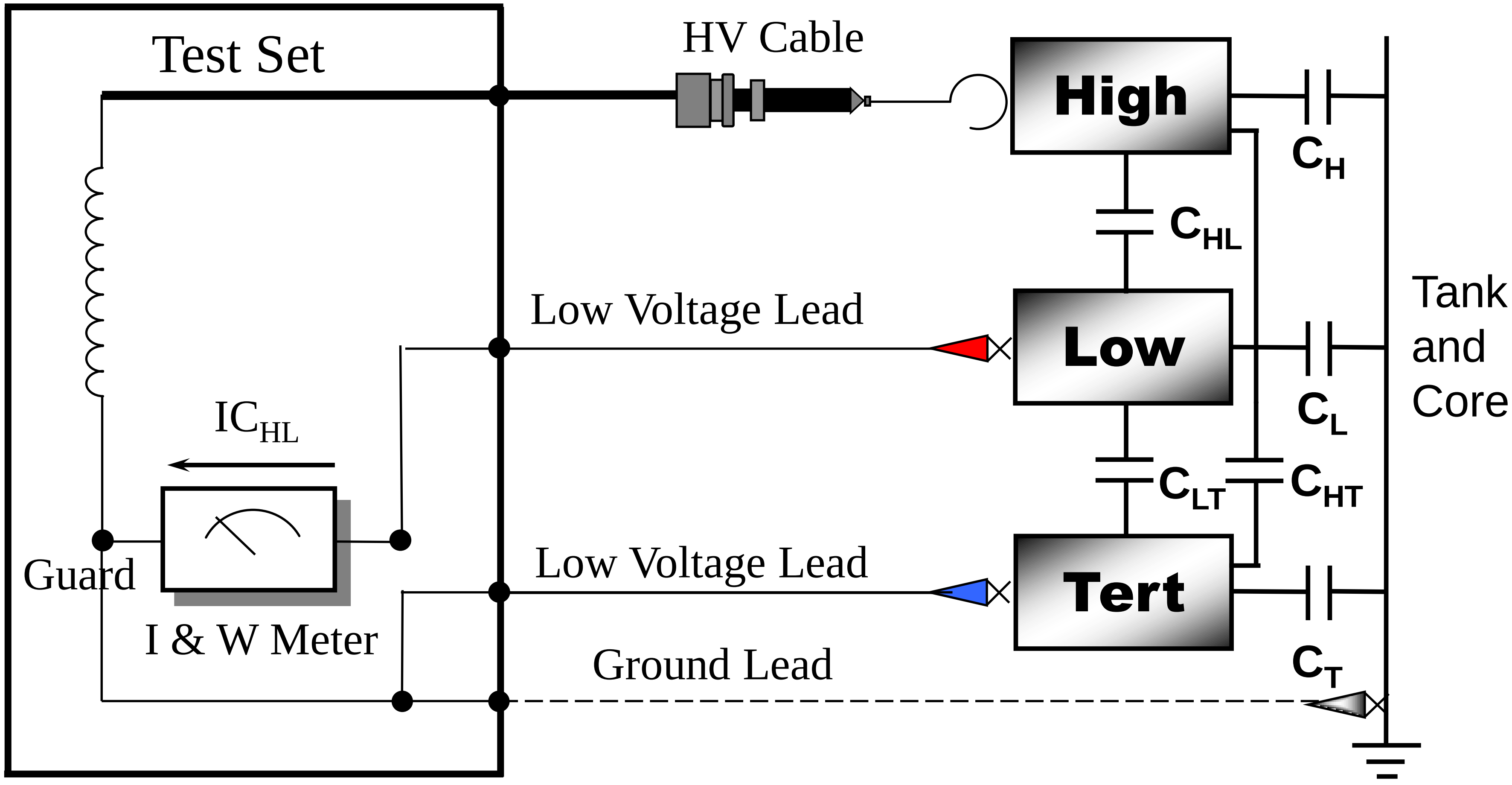
# Three Winding Transformer Overall Tests

| Overall Test Setup | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Connections | | | | | Inputs | | Test Results | | | | |
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) |
| 1 | HV Winding | LV Winding | TV Winding | CH+CHL | 10.007 | 1.00 | 43.800 | 1.796 | 0.410 | 0.409 | 11618.1 |
| 2 | | | | CH | 10.006 | 1.00 | 17.452 | 0.616 | 0.353 | 0.352 | 4629.1 |
| 3 | | | | CHL(UST) | 10.006 | 1.00 | 26.356 | 1.156 | 0.439 | 0.438 | 6991.2 |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 1.00 | 26.348 | 1.180 | 0.448 | 0.447 | 6989.0 |
| 5 | LV Winding | TV Winding | HV Winding | CL+CLT | 10.004 | 1.00 | 51.199 | 1.886 | 0.368 | 0.368 | 13580.9 |
| 6 | | | | CL | 10.003 | 1.00 | 22.519 | 0.819 | 0.364 | 0.363 | 5973.3 |
| 7 | | | | CLT(UST) | 10.003 | 1.00 | 28.689 | 1.036 | 0.361 | 0.361 | 7610.0 |
| 8 | Test 5 - Test 6 (calculated) | | | CLT | | 1.00 | 28.680 | 1.067 | 0.372 | 0.371 | 7607.6 |
| 9 | TV Winding | HV Winding | LV Winding | CT+CHT | 7.503 | 1.00 | 51.188 | 2.259 | 0.441 | 0.441 | 13577.9 |
| 10 | | | | CT | 7.503 | 1.00 | 50.320 | 2.258 | 0.449 | 0.448 | 13347.7 |
| 11 | | | | CHT(UST) | 7.503 | 1.00 | 0.867 | 0.010 | 0.115 | 0.115 | 229.9 |
| 12 | Test 9 - Test 10 (calculated) | | | CHT | | 1.00 | 0.868 | 0.001 | 0.012 | 0.012 | 230.2 |
| 13 | All | | | CH+CL+CT | 10.006 | 1.00 | 90.272 | 3.735 | 0.414 | 0.413 | 23945.2 |

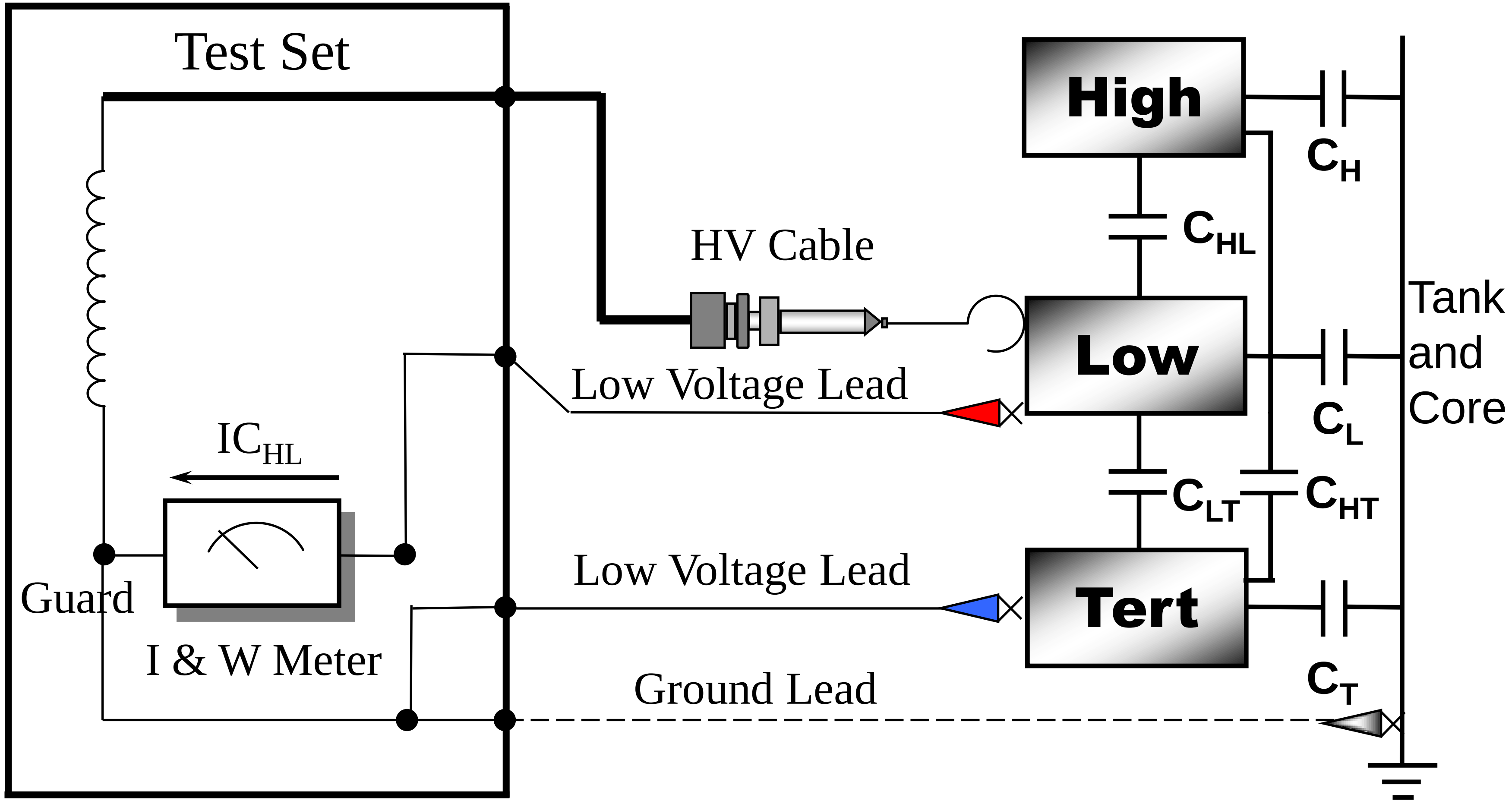
# Three Winding Transformer – Tests #5, 6 & 7 Setup



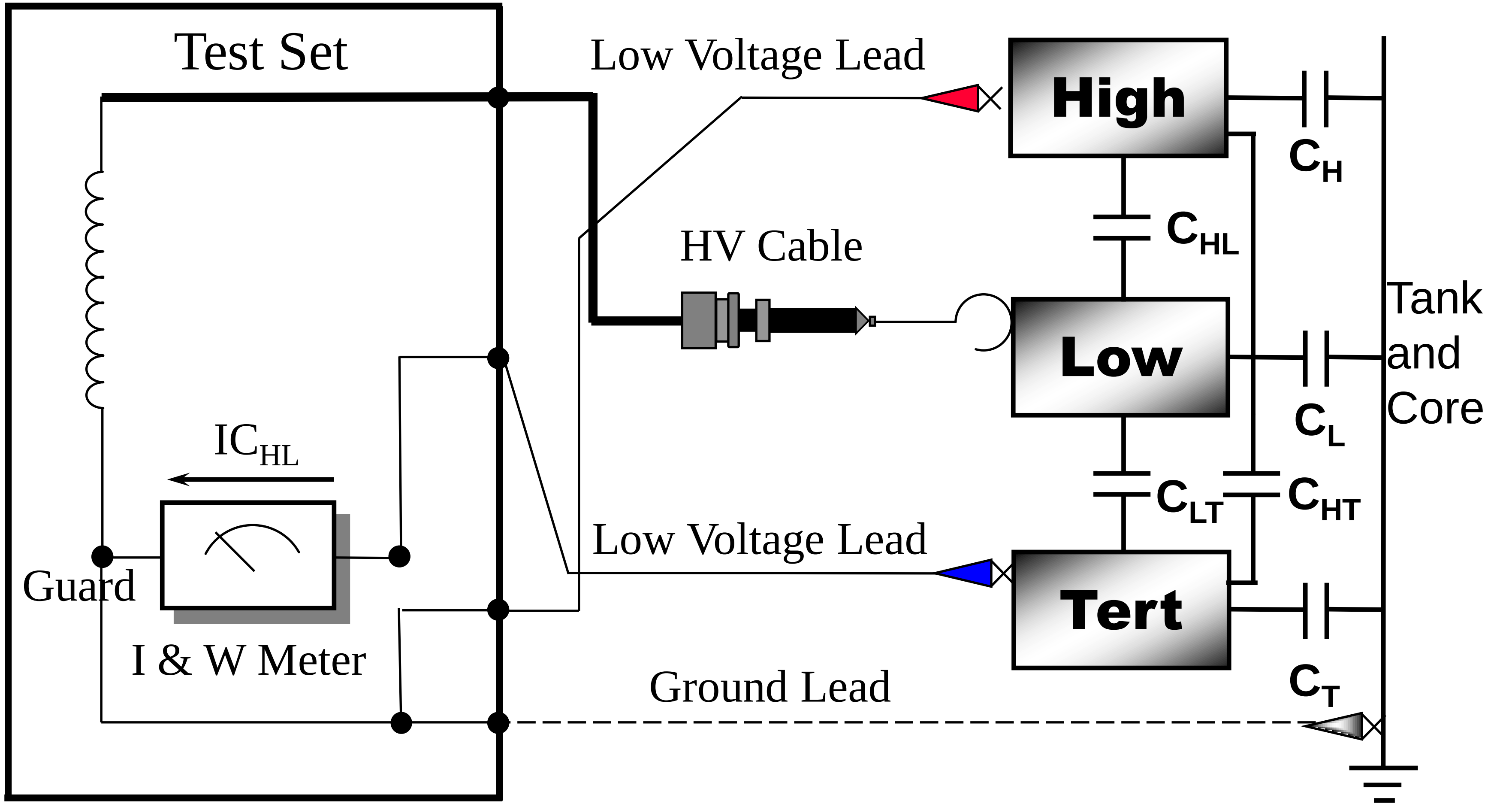
# Test Procedure-Rotate Test Leads



# Test Procedure-Rotate Test Leads

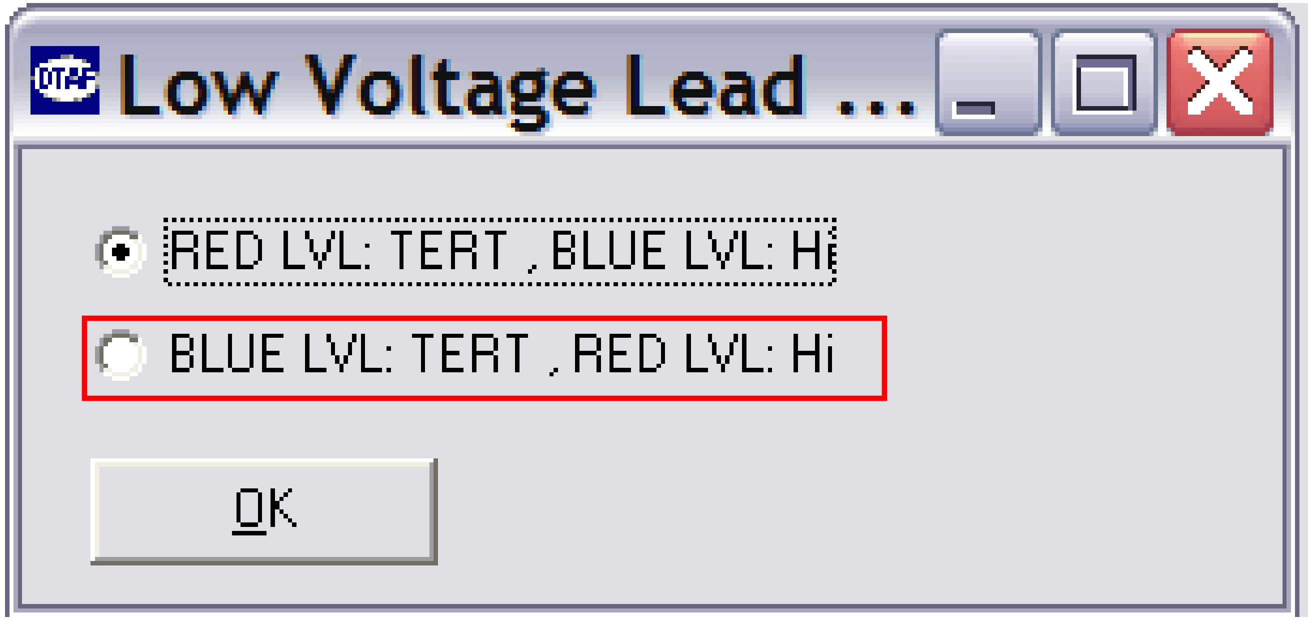


# Test Procedure-Rotate Test Leads

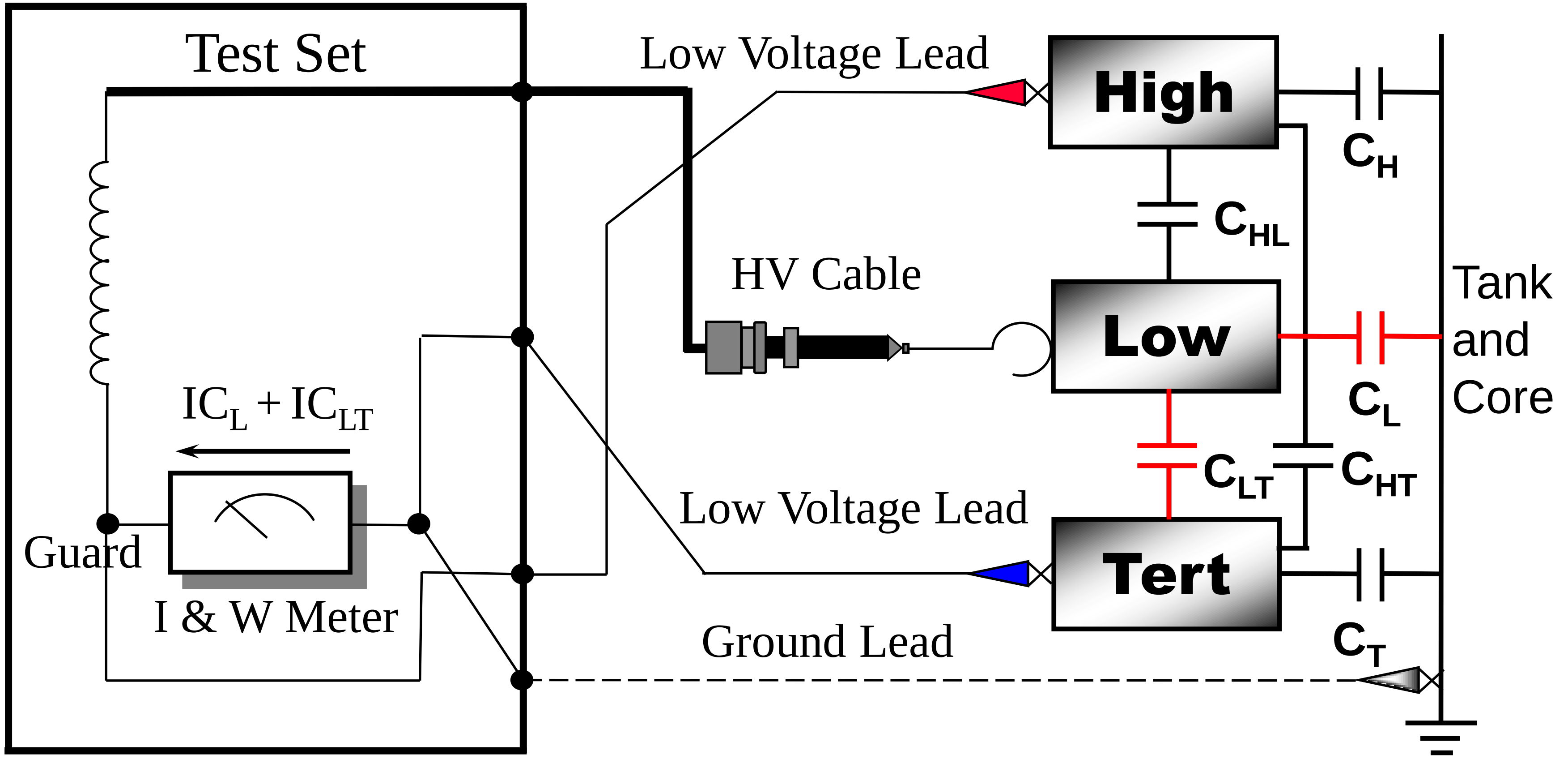


# Lead Selection Screen

Select if Red HV is on Tert and Blue LV is on High
Or if Blue LV is on Tert and Red LV is on High

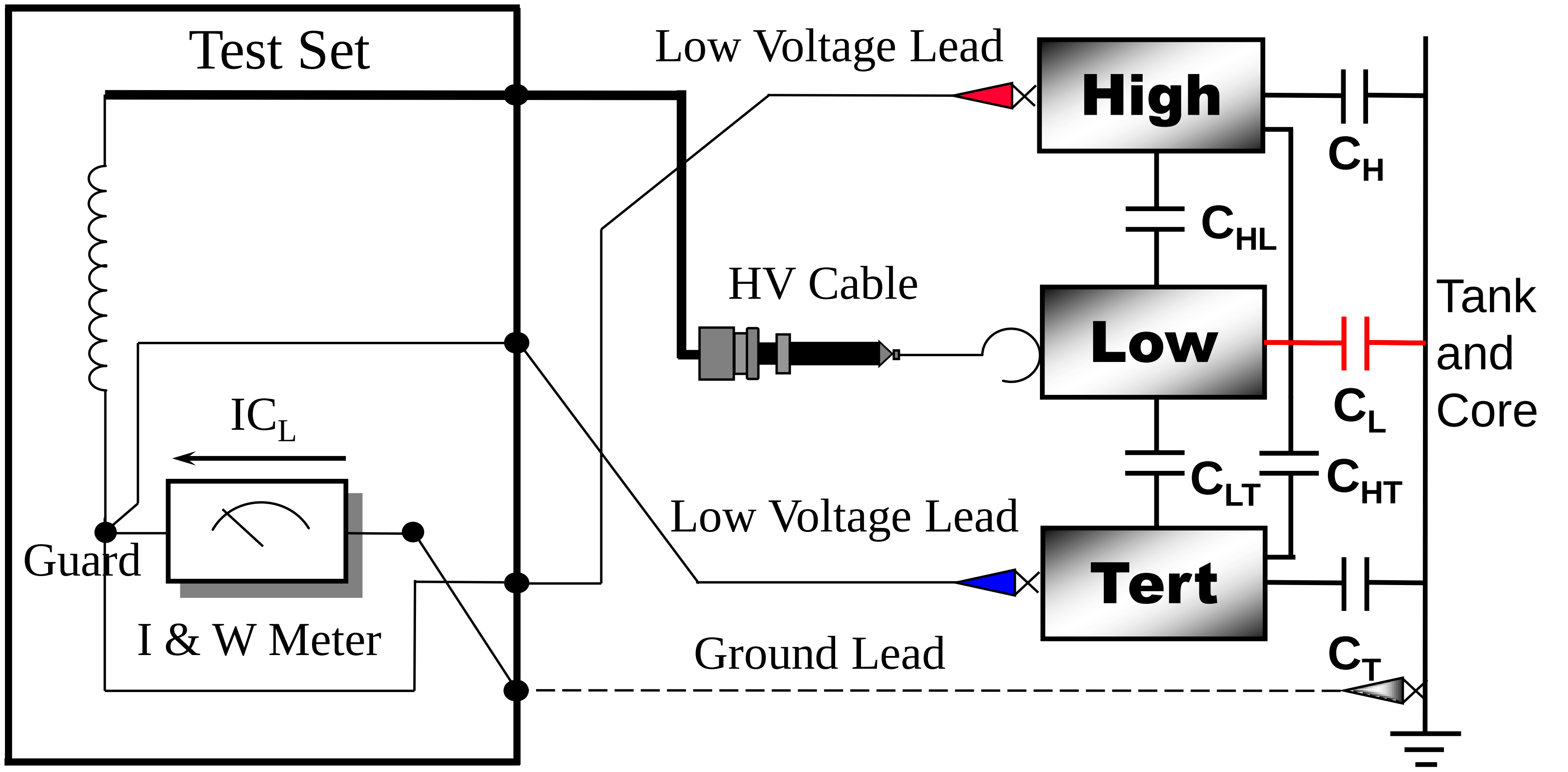


# Test Procedure-Test #5: Measure $C_L + C_{LT}$



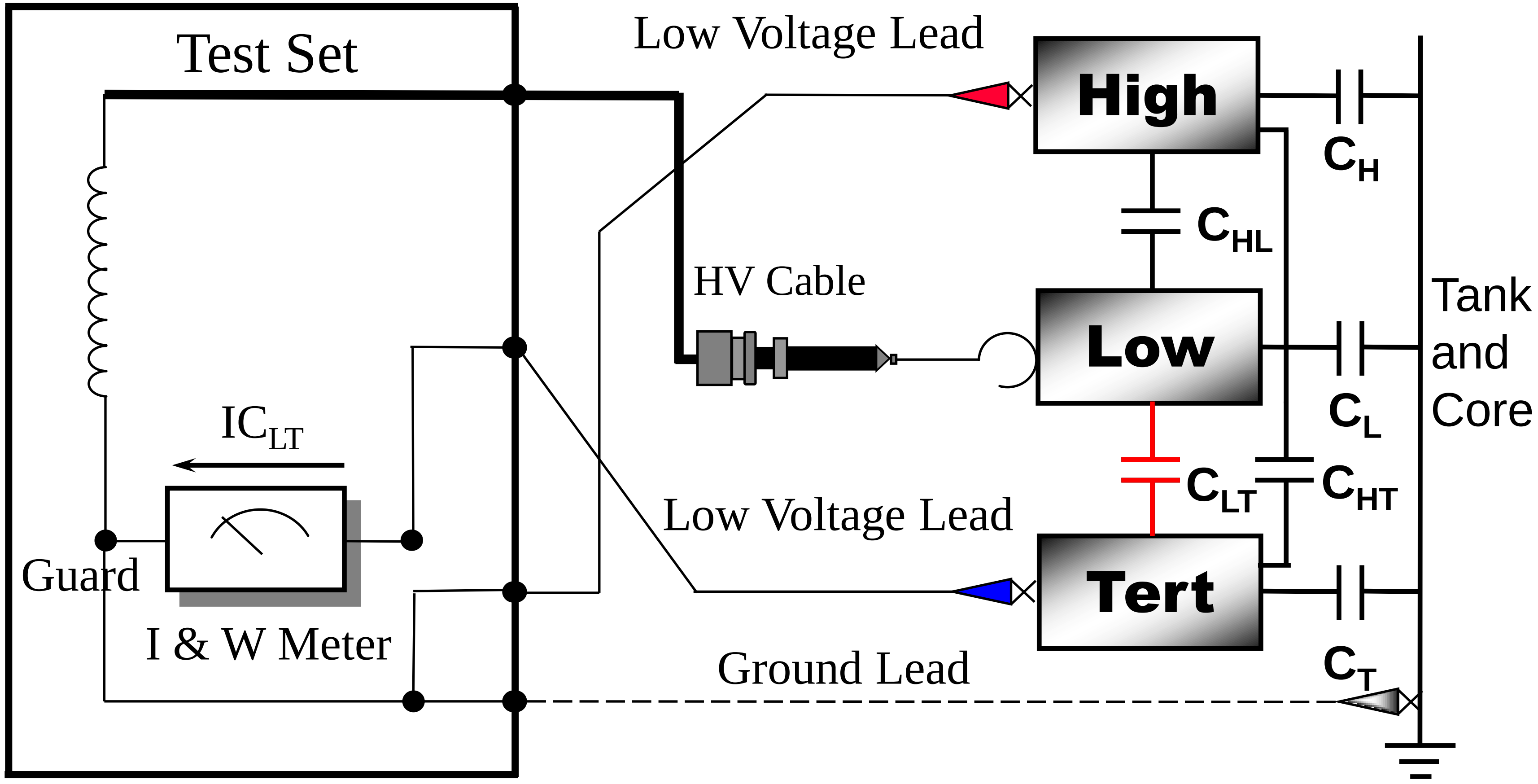

**GST – GUARD RED – GROUND BLUE**

# Test Procedure-Test #6: Measure $C_L$




**GST - GUARD RED & BLUE**

# Test Procedure-Test #7: Measure $C_{LT}$

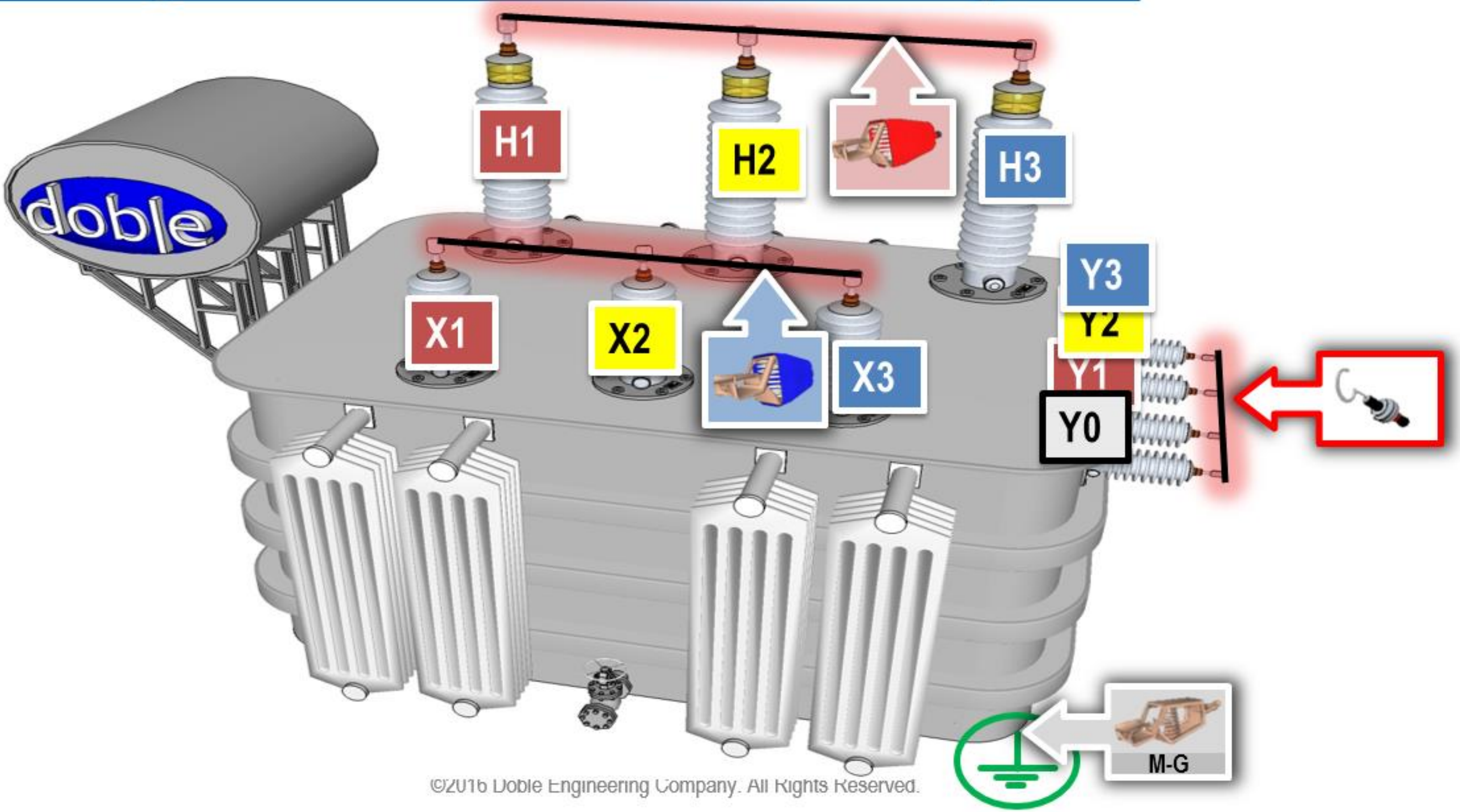



**UST – MEASURE BLUE - GROUND RED**

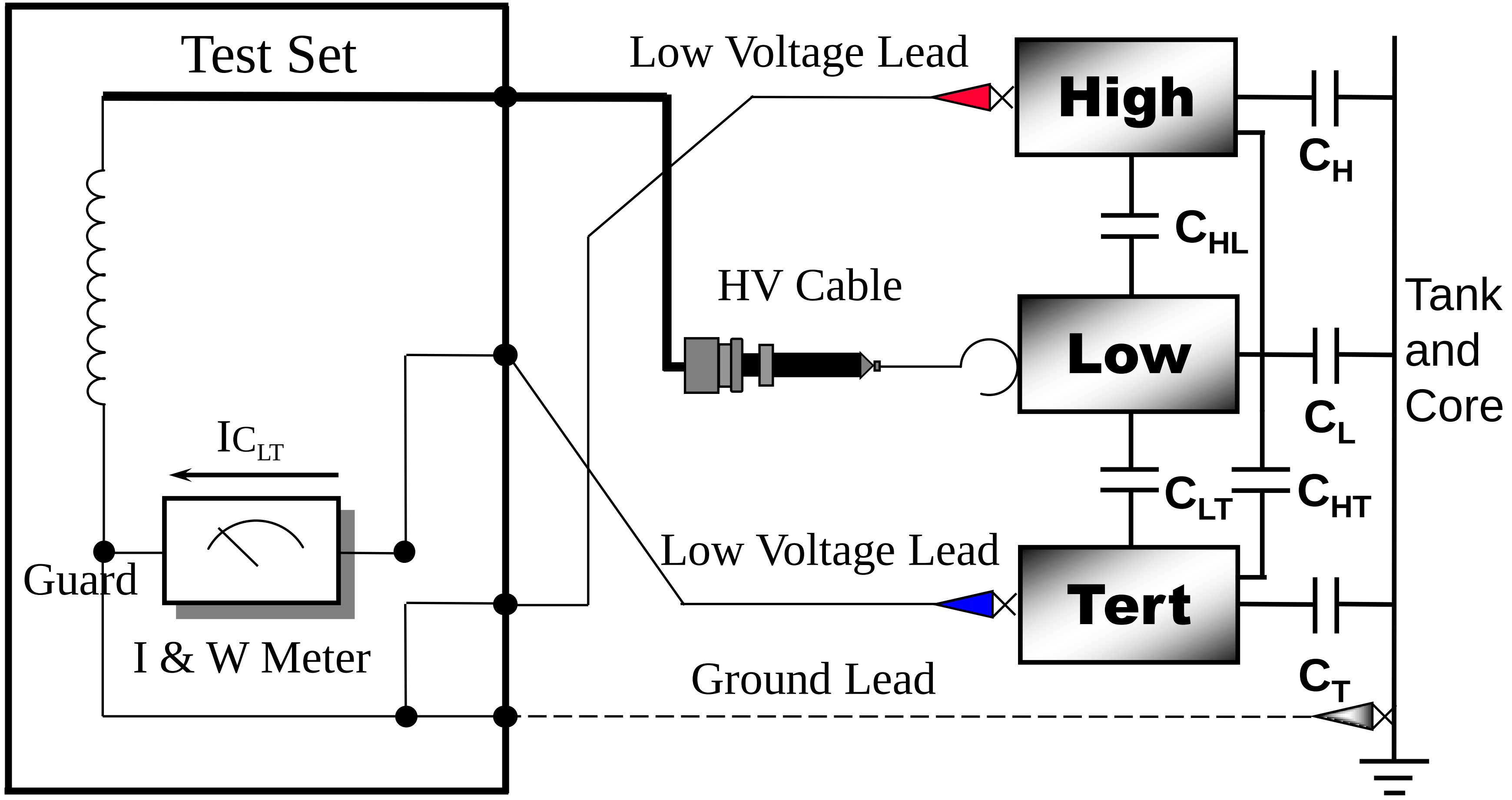
# Three Winding Transformer Overall Tests

| Overall Test Setup | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Connections | | | | | Inputs | | Test Results | | | | | |
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) |
| 1 | HV Winding | LV Winding | TV Winding | CH+CHL | 10.007 | 1.00 | 43.800 | 1.796 | 0.410 | 0.409 | 11618.1 |
| 2 | | | | CH | 10.006 | 1.00 | 17.452 | 0.616 | 0.353 | 0.352 | 4629.1 |
| 3 | | | | CHL(UST) | 10.006 | 1.00 | 26.356 | 1.156 | 0.439 | 0.438 | 6991.2 |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 1.00 | 26.348 | 1.180 | 0.448 | 0.447 | 6989.0 |
| 5 | LV Winding | TV Winding | HV Winding | CL+CLT | 10.004 | 1.00 | 51.199 | 1.886 | 0.368 | 0.368 | 13580.9 |
| 6 | | | | CL | 10.003 | 1.00 | 22.519 | 0.819 | 0.364 | 0.363 | 5973.3 |
| 7 | | | | CLT(UST) | 10.003 | 1.00 | 28.689 | 1.036 | 0.361 | 0.361 | 7610.0 |
| 8 | Test 5 - Test 6 (calculated) | | | CLT | | 1.00 | 28.680 | 1.067 | 0.372 | 0.371 | 7607.6 |
| 9 | TV Winding | HV Winding | LV Winding | CT+CHT | 7.503 | 1.00 | 51.188 | 2.259 | 0.441 | 0.441 | 13577.9 |
| 10 | | | | CT | 7.503 | 1.00 | 50.320 | 2.258 | 0.449 | 0.448 | 13347.7 |
| 11 | | | | CHT(UST) | 7.503 | 1.00 | 0.867 | 0.010 | 0.115 | 0.115 | 229.9 |
| 12 | Test 9 - Test 10 (calculated) | | | CHT | | 1.00 | 0.868 | 0.001 | 0.012 | 0.012 | 230.2 |
| 13 | All | | | CH+CL+CT | 10.006 | 1.00 | 90.272 | 3.735 | 0.414 | 0.413 | 23945.2 |

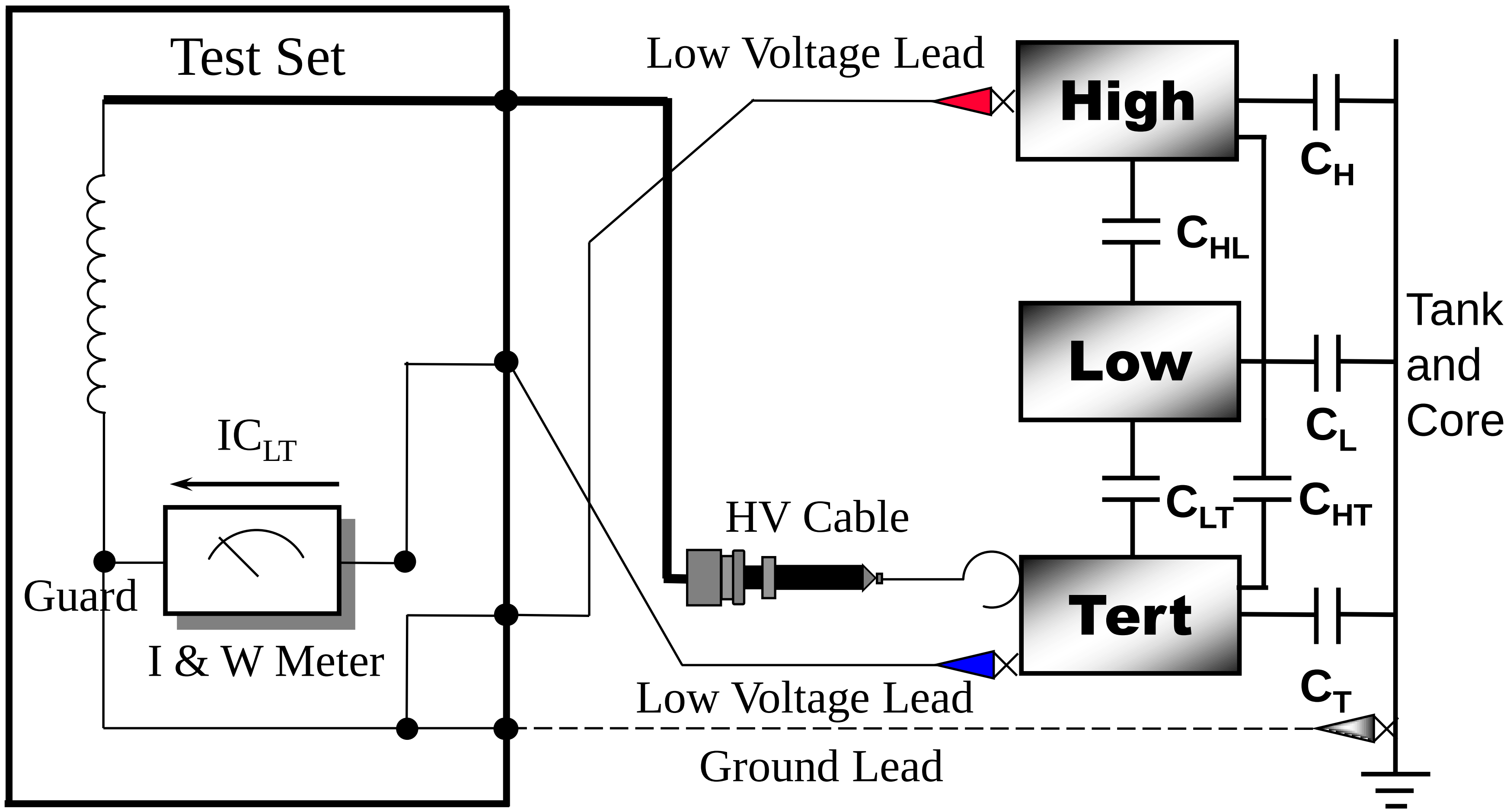
# Three Winding Transformer – Tests #9, 10 & 11 Setup



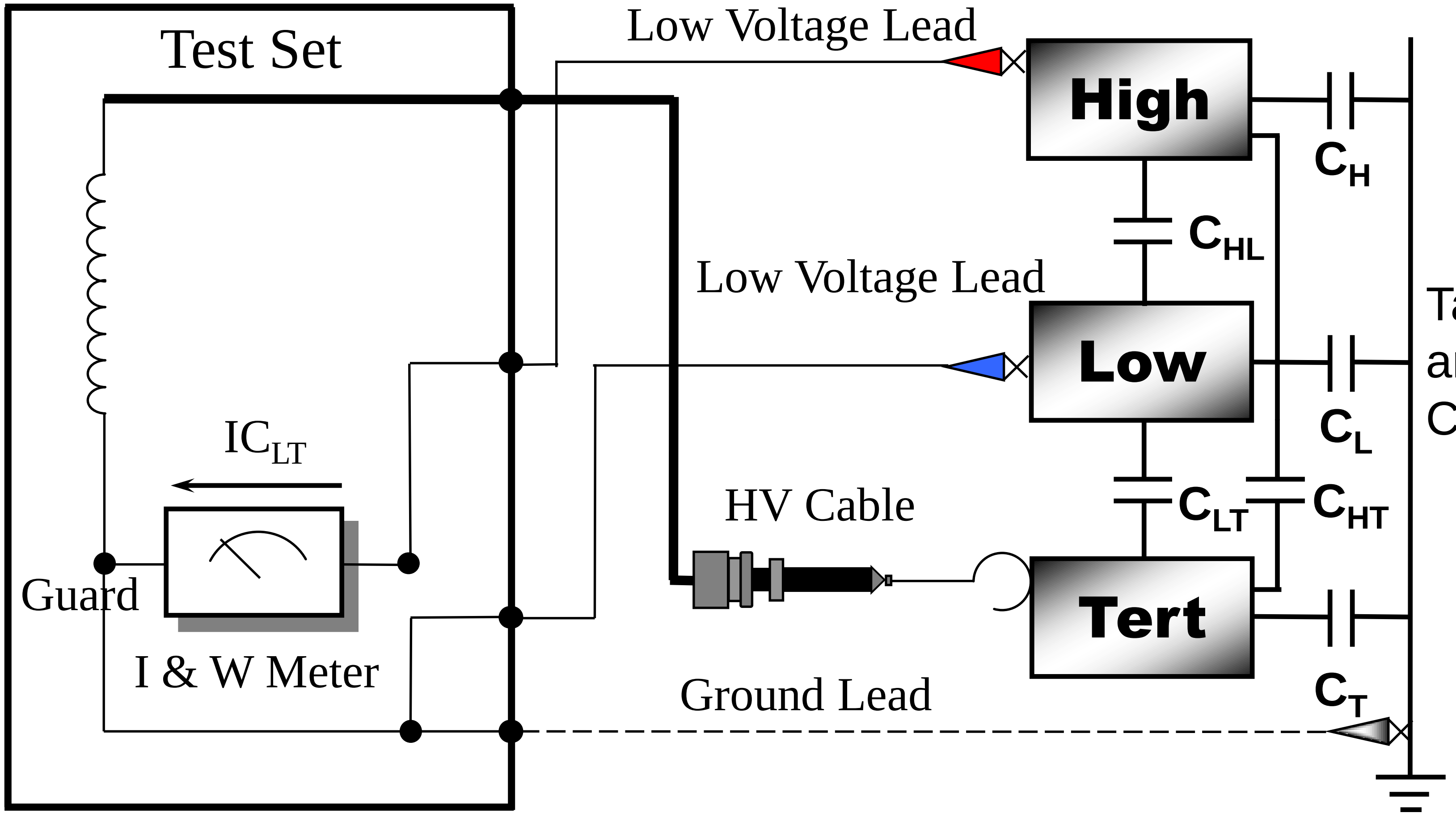
# Test Procedure-Rotate Test Leads



# Test Procedure-Rotate Test Leads

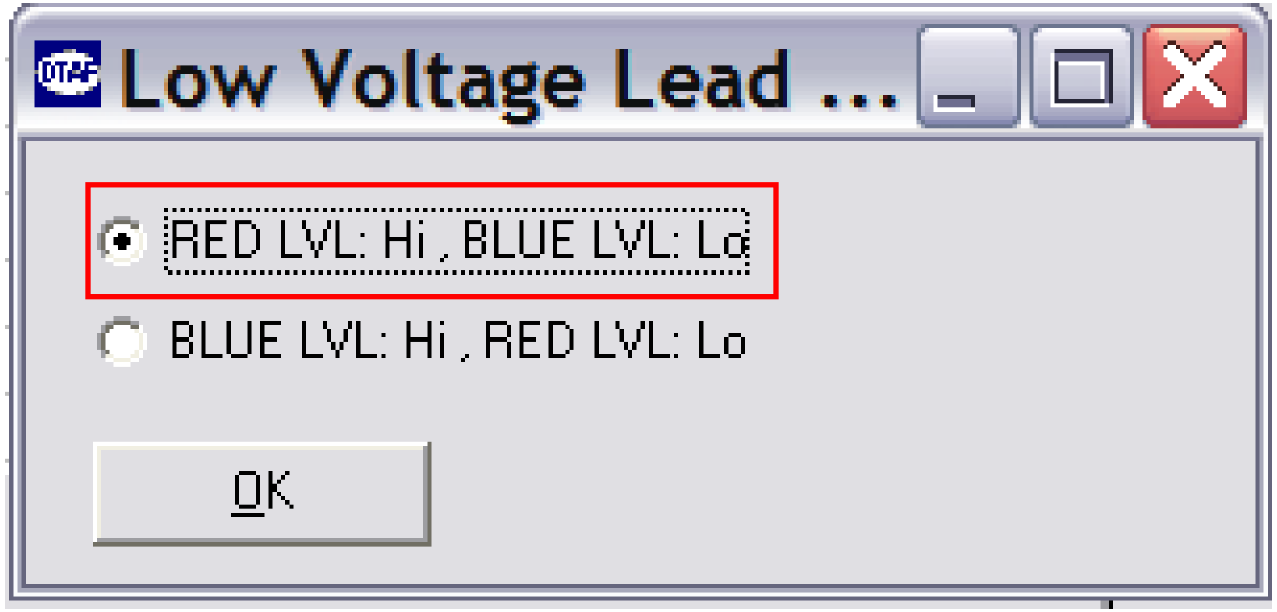


# Test Procedure-Rotate Test Leads

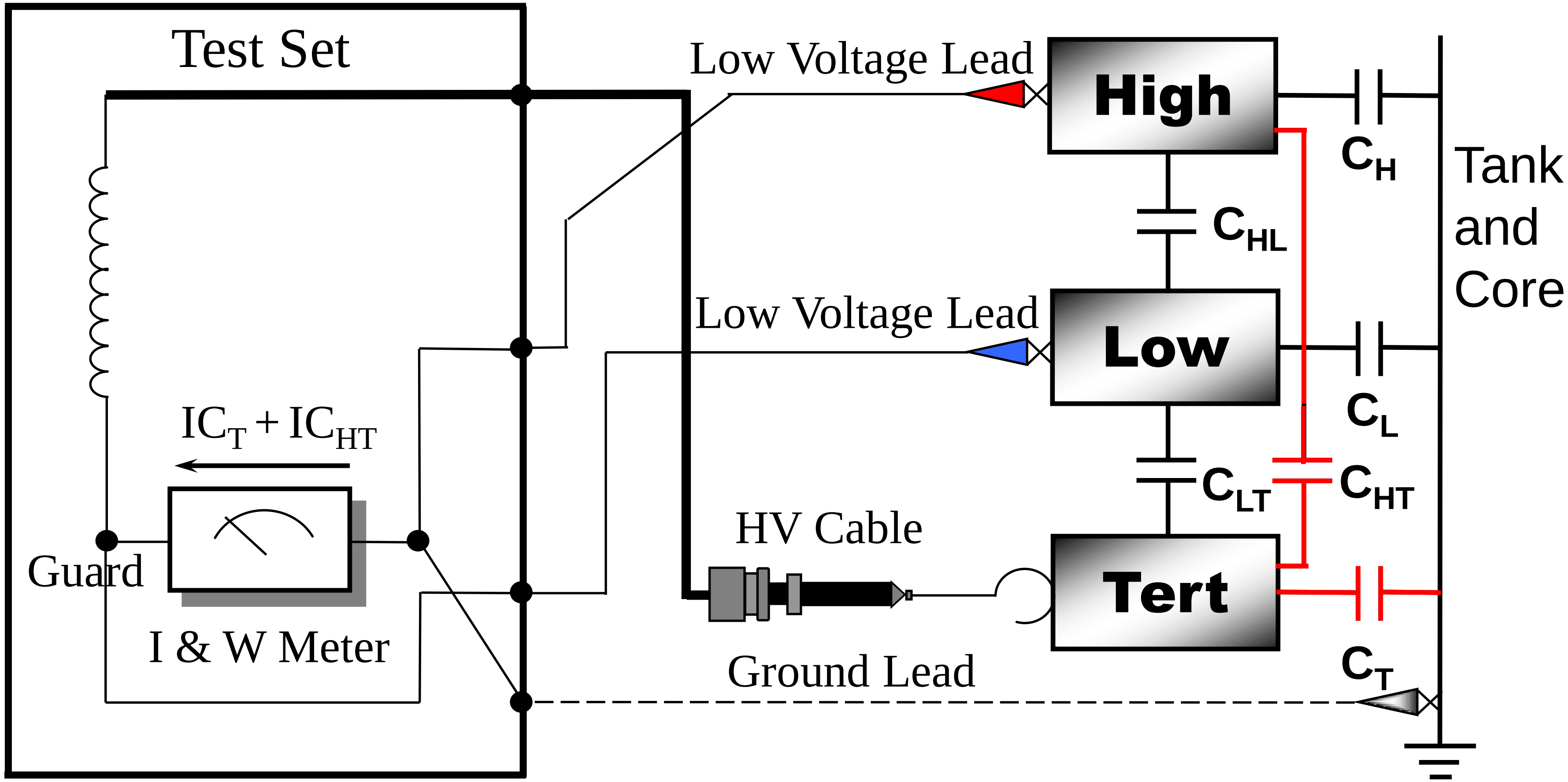


# Lead Selection Screen

Select if Red HV is on High and Blue LV is on Low
Or if Blue LV is on High and Red LV is on Low

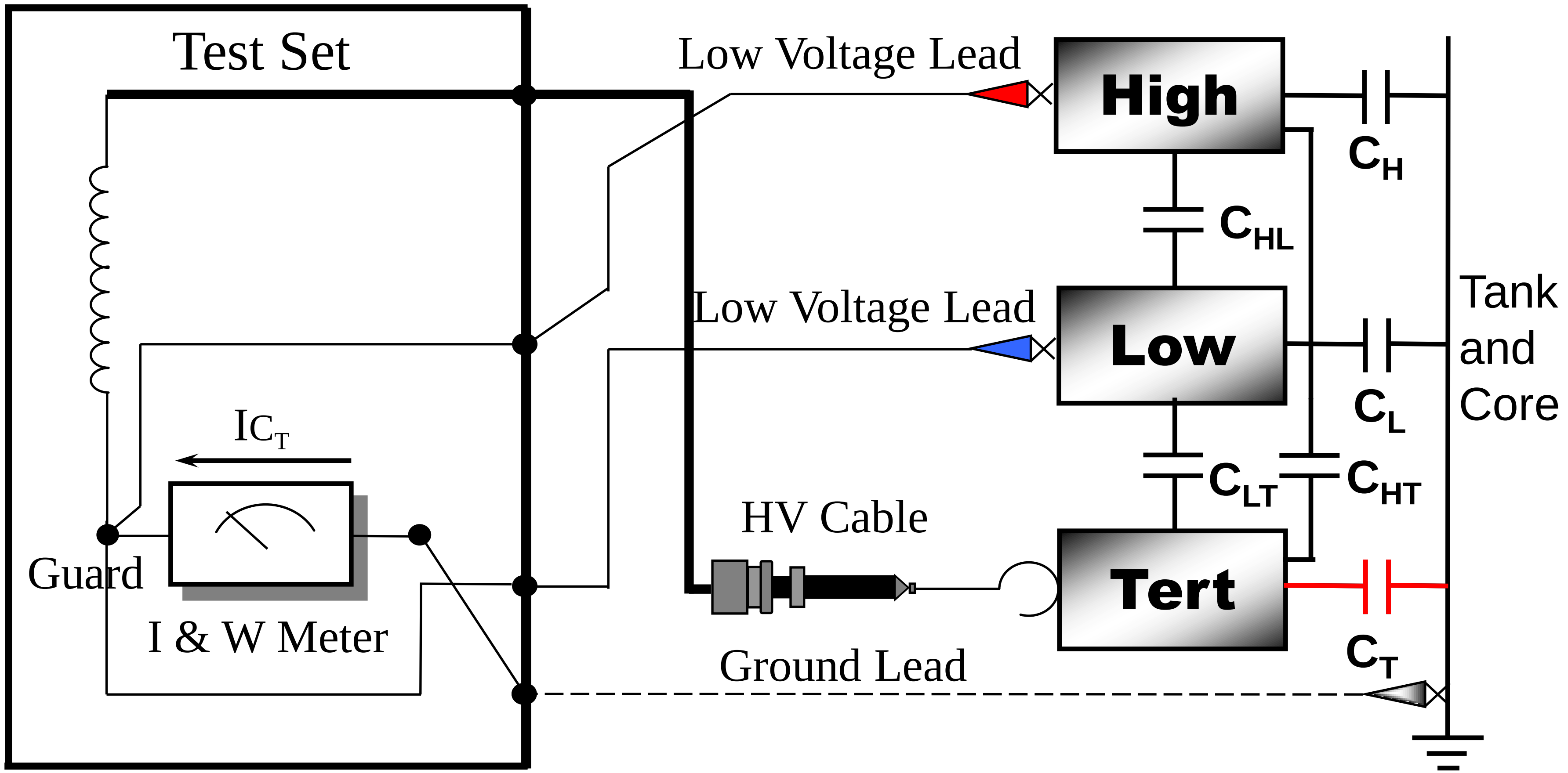


# Test Procedure-Test #9: Measure $C_T+C_{HT}$



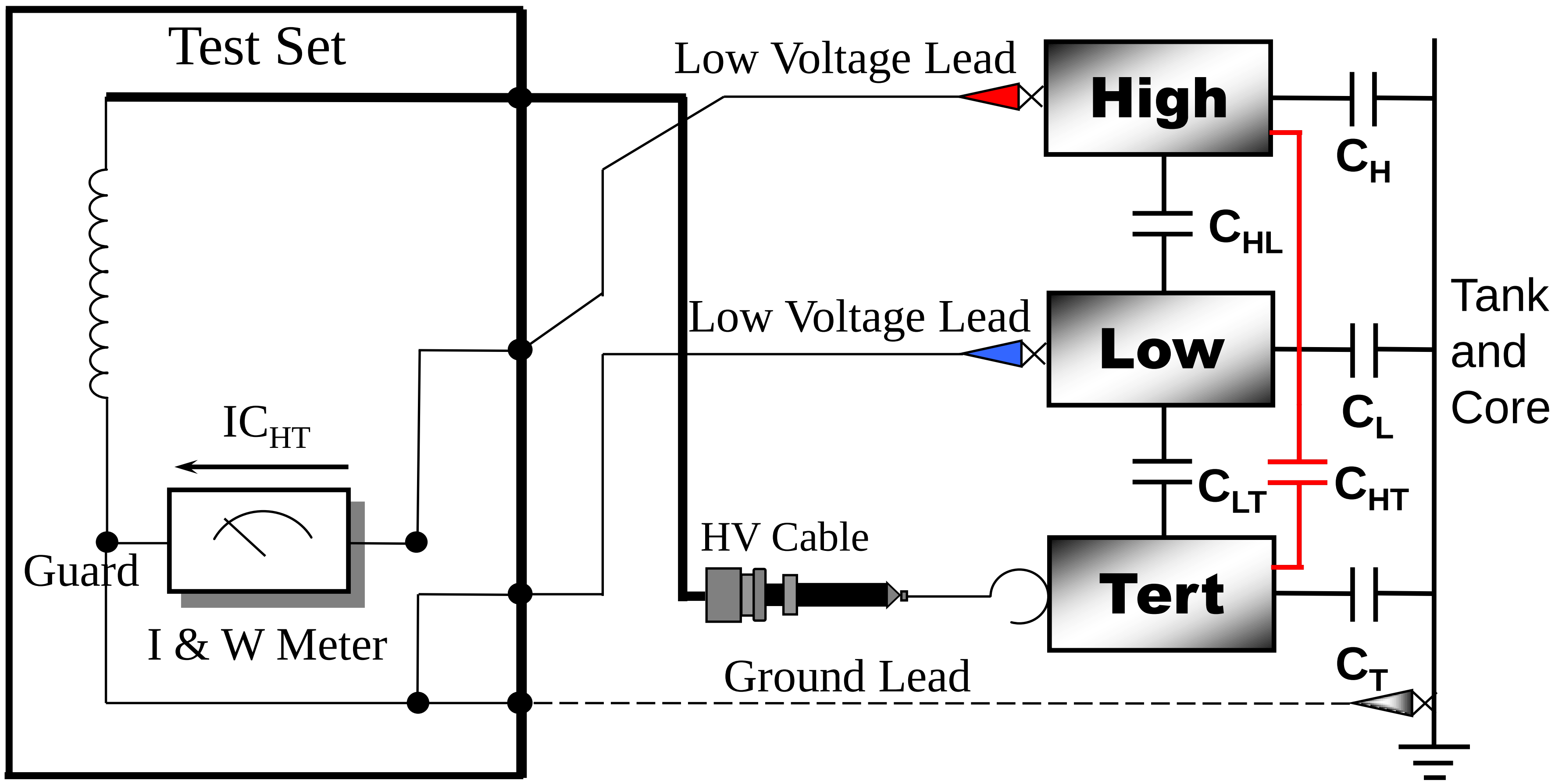

**GST – GROUND RED – GUARD BLUE**

# Test Procedure-Test #10: Measure $C_T$




**GST - GUARD RED & BLUE**

# Test Procedure-Test #11: Measure $C_{HT}$




**UST – MEASURE RED – GROUND BLUE**

# Three Winding Transformer Overall Tests

| Overall Test Setup | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Connections | | | | | Inputs | | Test Results | | | | | |
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) |
| 1 | HV Winding | LV Winding | TV Winding | CH+CHL | 10.007 | 1.00 | 43.800 | 1.796 | 0.410 | 0.409 | 11618.1 |
| 2 | | | | CH | 10.006 | 1.00 | 17.452 | 0.616 | 0.353 | 0.352 | 4629.1 |
| 3 | | | | CHL(UST) | 10.006 | 1.00 | 26.356 | 1.156 | 0.439 | 0.438 | 6991.2 |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 1.00 | 26.348 | 1.180 | 0.448 | 0.447 | 6989.0 |
| 5 | LV Winding | TV Winding | HV Winding | CL+CLT | 10.004 | 1.00 | 51.199 | 1.886 | 0.368 | 0.368 | 13580.9 |
| 6 | | | | CL | 10.003 | 1.00 | 22.519 | 0.819 | 0.364 | 0.363 | 5973.3 |
| 7 | | | | CLT(UST) | 10.003 | 1.00 | 28.689 | 1.036 | 0.361 | 0.361 | 7610.0 |
| 8 | Test 5 - Test 6 (calculated) | | | CLT | | 1.00 | 28.680 | 1.067 | 0.372 | 0.371 | 7607.6 |
| 9 | TV Winding | HV Winding | LV Winding | CT+CHT | 7.503 | 1.00 | 51.188 | 2.259 | 0.441 | 0.441 | 13577.9 |
| 10 | | | | CT | 7.503 | 1.00 | 50.320 | 2.258 | 0.449 | 0.448 | 13347.7 |
| 11 | | | | CHT(UST) | 7.503 | 1.00 | 0.867 | 0.010 | 0.115 | 0.115 | 229.9 |
| 12 | Test 9 - Test 10 (calculated) | | | CHT | | 1.00 | 0.868 | 0.001 | 0.012 | 0.012 | 230.2 |
| 13 | All | | | CH+CL+CT | 10.006 | 1.00 | 90.272 | 3.735 | 0.414 | 0.413 | 23945.2 |

# Three Winding Transformer Overall Tests

| Overall Test Setup | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Connections | | | | | Inputs | | Test Results | | | | |
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) |
| 1 | HV Winding | LV Winding | TV Winding | CH+CHL | 10.007 | 1.00 | 43.800 | 1.796 | 0.410 | 0.409 | 11618.1 |
| 2 | | | | CH | 10.006 | 1.00 | 17.452 | 0.616 | 0.353 | 0.352 | 4629.1 |
| 3 | | | | CHL(UST) | 10.006 | 1.00 | 26.356 | 1.156 | 0.439 | 0.438 | 6991.2 |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 1.00 | 26.348 | 1.180 | 0.448 | 0.447 | 6989.0 |
| 5 | LV Winding | TV Winding | HV Winding | CL+CLT | 10.004 | 1.00 | 51.199 | 1.886 | 0.368 | 0.368 | 13580.9 |
| 6 | | | | CL | 10.003 | 1.00 | 22.519 | 0.819 | 0.364 | 0.363 | 5973.3 |
| 7 | | | | CLT(UST) | 10.003 | 1.00 | 28.689 | 1.036 | 0.361 | 0.361 | 7610.0 |
| 8 | Test 5 - Test 6 (calculated) | | | CLT | | 1.00 | 28.680 | 1.067 | 0.372 | 0.371 | 7607.6 |
| 9 | TV Winding | HV Winding | LV Winding | CT+CHT | 7.503 | 1.00 | 51.188 | 2.259 | 0.441 | 0.441 | 13577.9 |
| 10 | | | | CT | 7.503 | 1.00 | 50.320 | 2.258 | 0.449 | 0.448 | 13347.7 |
| 11 | | | | CHT(UST) | 7.503 | 1.00 | 0.867 | 0.010 | 0.115 | 0.115 | 229.9 |
| 12 | Test 9 - Test 10 (calculated) | | | CHT | | 1.00 | 0.868 | 0.001 | 0.012 | 0.012 | 230.2 |
| 13 | All | | | CH+CL+CT | 10.006 | 1.00 | 90.272 | 3.735 | 0.414 | 0.413 | 23945.2 |

# Three Winding Transformer Overall Tests

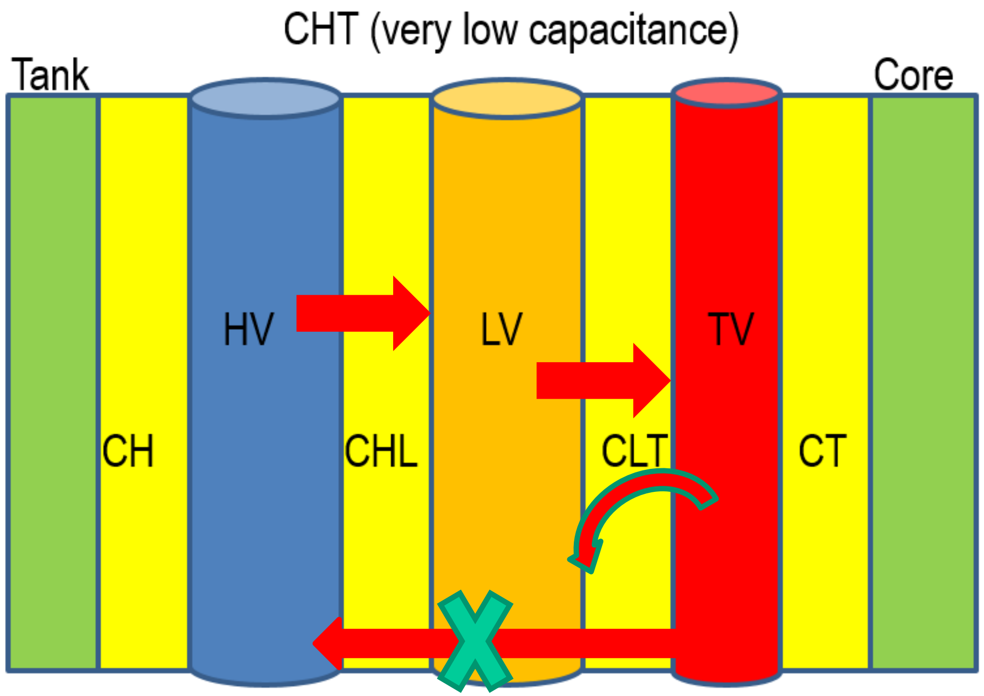
## Where Did We See This Type of Results?

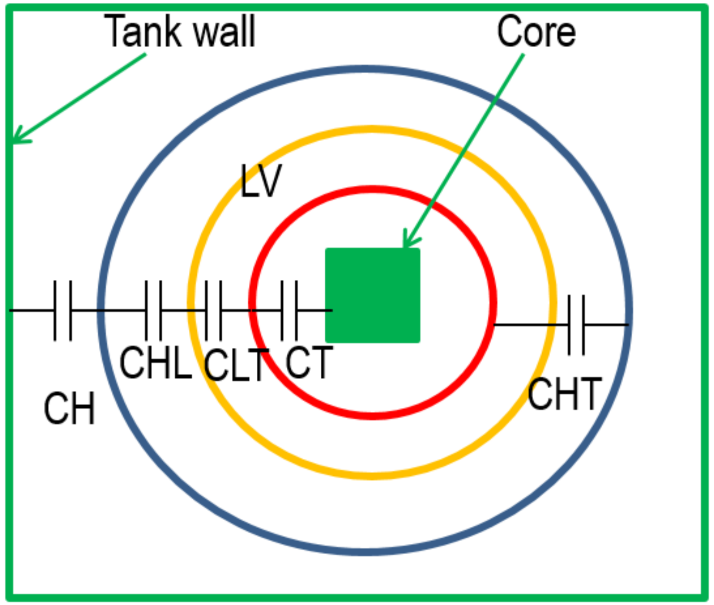
# Shielded Transformer

# But Is It Really Shielded?

# Dielectric Circuit  Three-Winding Transformers

Transformer tertiary configurations - Tertiary inside the low voltage winding closer to core not on same insulation tube



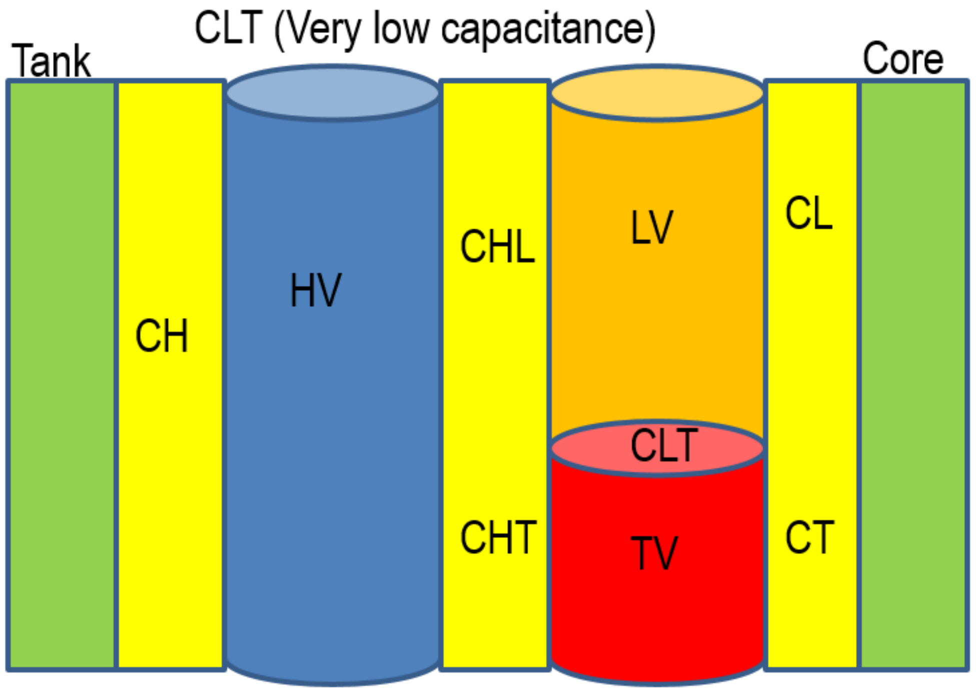



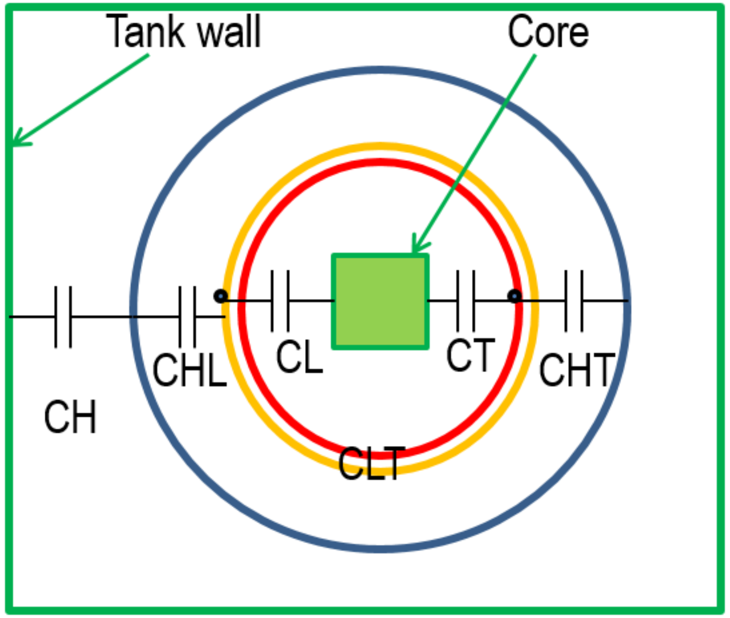
# Three Winding Transformer Overall Tests

| Overall Test Setup | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Connections | | | | | Inputs | | Test Results | | | | | |
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) |
| 1 | HV Winding | LV Winding | TV Winding | CH+CHL | 10.010 | 0.97 | 67.225 | 3.461 | 0.515 | 0.498 | 17831.6 |
| 2 | | | | CH | 10.004 | 0.97 | 41.992 | 2.692 | 0.641 | 0.620 | 11138.4 |
| 3 | | | | CHL(UST) | 10.004 | 0.97 | 25.220 | 0.747 | 0.296 | 0.287 | 6689.8 |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 0.97 | 25.233 | 0.769 | 0.305 | 0.295 | 6693.2 |
| 5 | LV Winding | TV Winding | HV Winding | CL+CLT | 10.003 | 0.97 | 47.884 | 1.864 | 0.389 | 0.376 | 12701.4 |
| 6 | | | | CL | 10.002 | 0.97 | 12.726 | 0.597 | 0.469 | 0.454 | 3375.6 |
| 7 | | | | CLT(UST) | 10.002 | 0.97 | 35.153 | 1.286 | 0.366 | 0.354 | 9324.6 |
| 8 | Test 5 - Test 6 (calculated) | | | CLT | | 0.97 | 35.158 | 1.267 | 0.360 | 0.348 | 9325.8 |
| 9 | TV Winding | HV Winding | LV Winding | CT+CHT | 10.003 | 0.97 | 42.976 | 1.261 | 0.293 | 0.284 | 11399.6 |
| 10 | | | | CT | 10.002 | 0.97 | 12.763 | 0.572 | 0.448 | 0.433 | 3385.4 |
| 11 | | | | CHT(UST) | 10.002 | 0.97 | 30.207 | 0.717 | 0.237 | 0.230 | 8012.7 |
| 12 | Test 9 - Test 10 (calculated) | | | CHT | | 0.97 | 30.213 | 0.689 | 0.228 | 0.221 | 8014.1 |
| 13 | All | | | CH+CL+CT | 10.004 | 0.97 | 68.200 | 7.302 | 1.071 | 1.035 | 18089.5 |

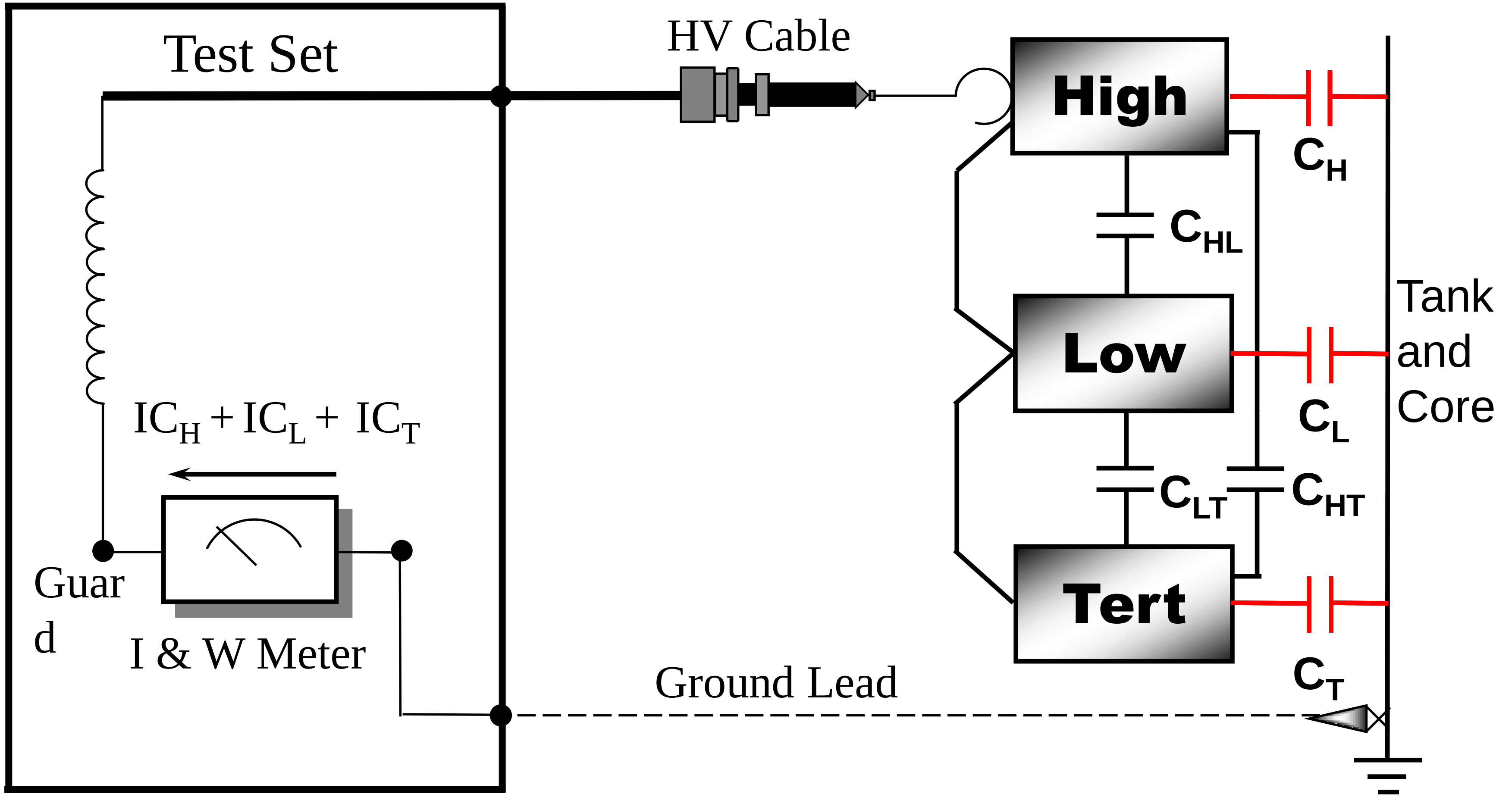
# Dielectric Circuit  Three-Winding Transformers

Transformer tertiary configurations - Tertiary stacked on top of low voltage winding on same insulation tube



# Test Procedure-Test #13: Measure $C_H + C_L + C_T$




**GST - GROUND**

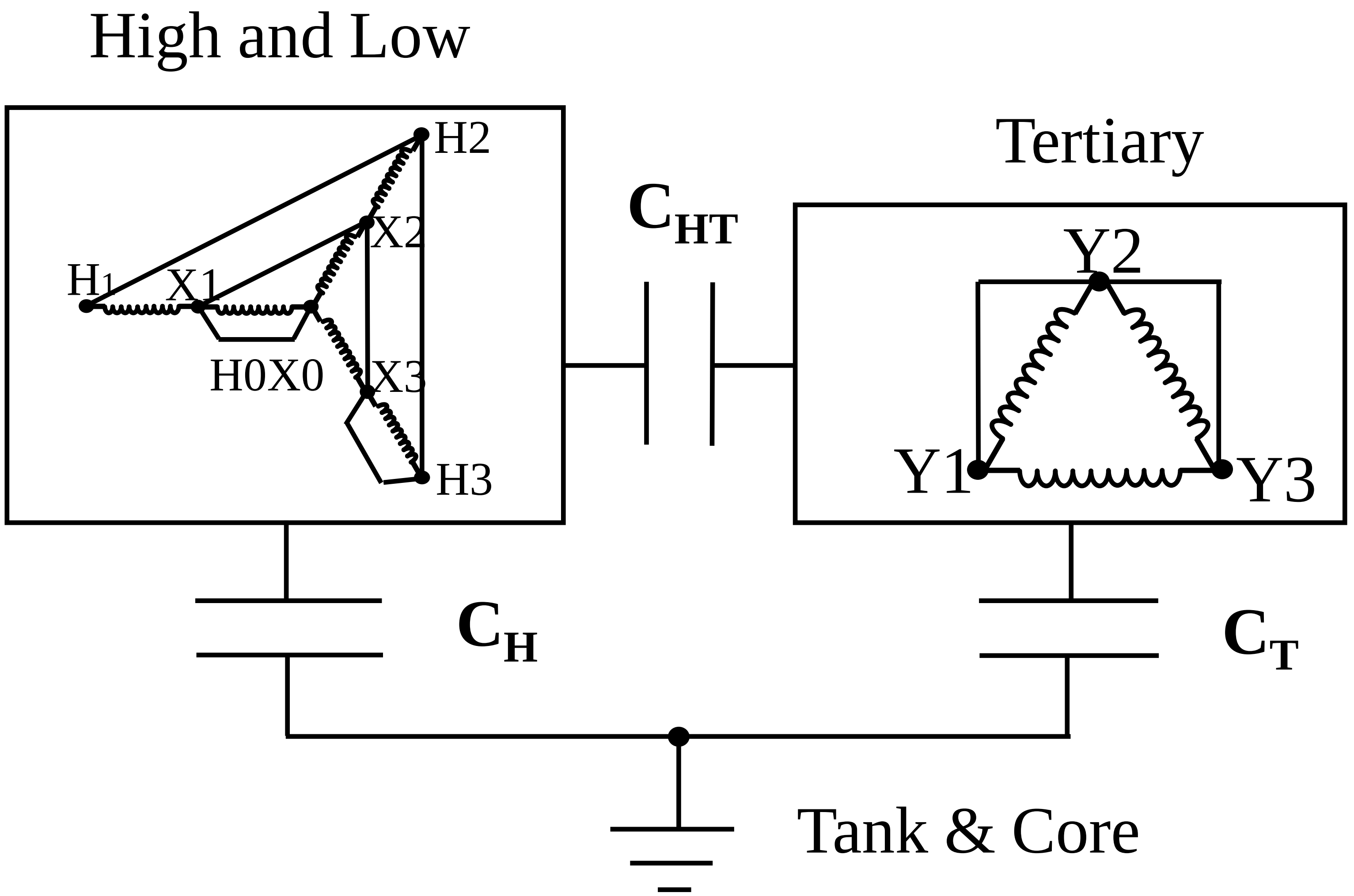
# Three Winding Transformer Overall Tests

**Overall Test Setup**

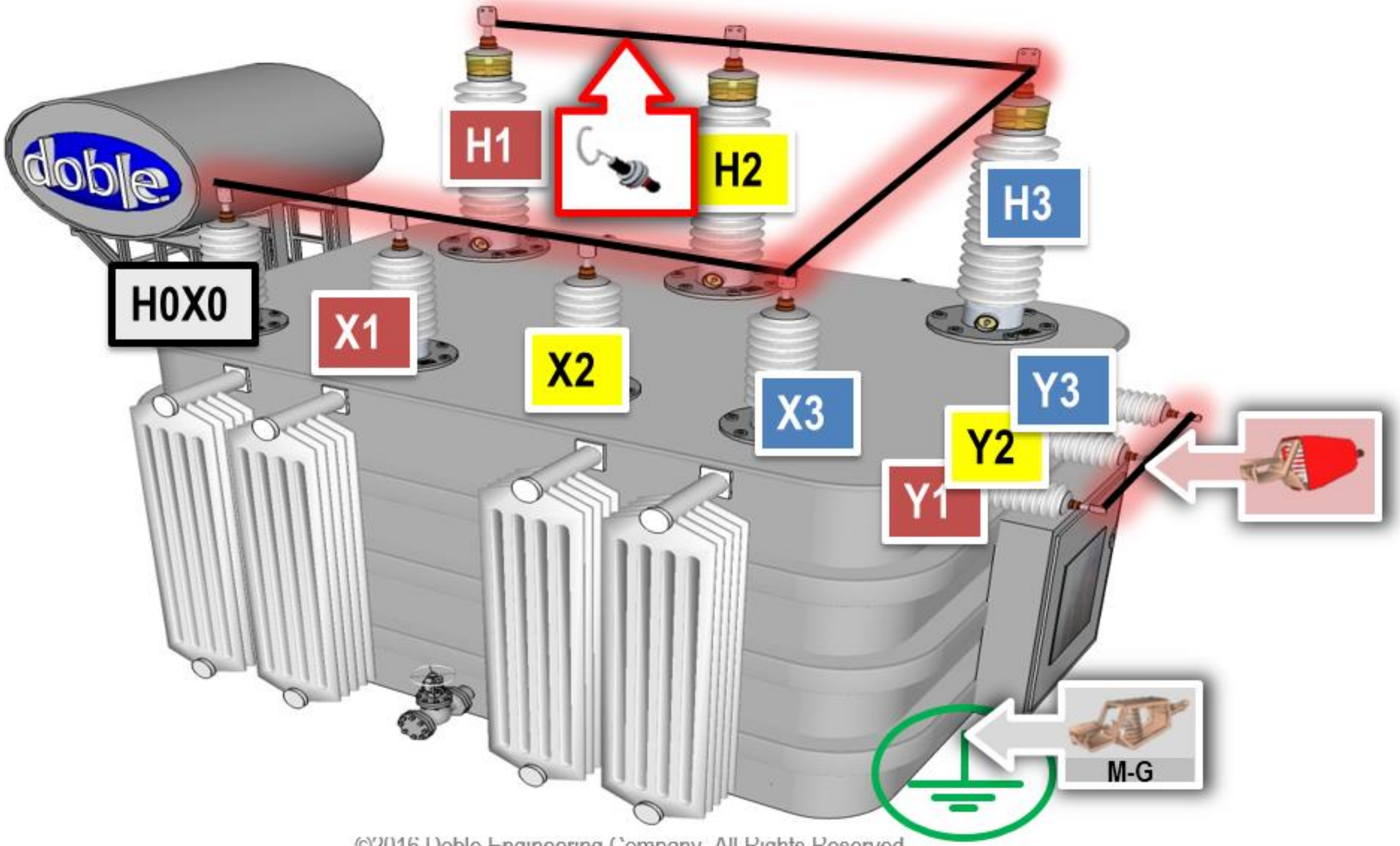
| Connections | | | | | Inputs | | Test Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | |
| 1 | HV Winding | LV Winding | TV Winding | CH+CHL | 10.007 | 1.00 | 43.800 | 1.796 | 0.410 | 0.409 | 11618.1 | |
| 2 | | | | CH | 10.006 | 1.00 | 17.452 | 0.616 | 0.353 | 0.352 | 4629.1 | 17.452 |
| 3 | | | | CHL(UST) | 10.006 | 1.00 | 26.356 | 1.156 | 0.439 | 0.438 | 6991.2 | |
| 4 | Test 1 - Test 2 (calculated) | | | CHL | | 1.00 | 26.348 | 1.180 | 0.448 | 0.447 | 6989.0 | |
| 5 | LV Winding | TV Winding | HV Winding | CL+CLT | 10.004 | 1.00 | 51.199 | 1.886 | 0.368 | 0.368 | 13580.9 | |
| 6 | | | | CL | 10.003 | 1.00 | 22.519 | 0.819 | 0.364 | 0.363 | 5973.3 | 22.519 |
| 7 | | | | CLT(UST) | 10.003 | 1.00 | 28.689 | 1.036 | 0.361 | 0.361 | 7610.0 | |
| 8 | Test 5 - Test 6 (calculated) | | | CLT | | 1.00 | 28.680 | 1.067 | 0.372 | 0.371 | 7607.6 | |
| 9 | TV Winding | HV Winding | LV Winding | CT+CHT | 7.503 | 1.00 | 51.188 | 2.259 | 0.441 | 0.441 | 13577.9 | |
| 10 | | | | CT | 7.503 | 1.00 | 50.320 | 2.258 | 0.449 | 0.448 | 13347.7 | 50.320 |
| 11 | | | | CHT(UST) | 7.503 | 1.00 | 0.867 | 0.010 | 0.115 | 0.115 | 229.9 | |
| 12 | Test 9 - Test 10 (calculated) | | | CHT | | 1.00 | 0.868 | 0.001 | 0.012 | 0.012 | 230.2 | |
| 13 | All | | | CH+CL+CT | 10.006 | 1.00 | 90.272 | 3.735 | 0.414 | 0.413 | 23945.2 | 90.321 |

# Auto Transformers

# Auto-Transformer With Accessible Tertiary Winding



# Auto XFMR With Accessible Tertiary – Test #1, 2, & 3 Setup



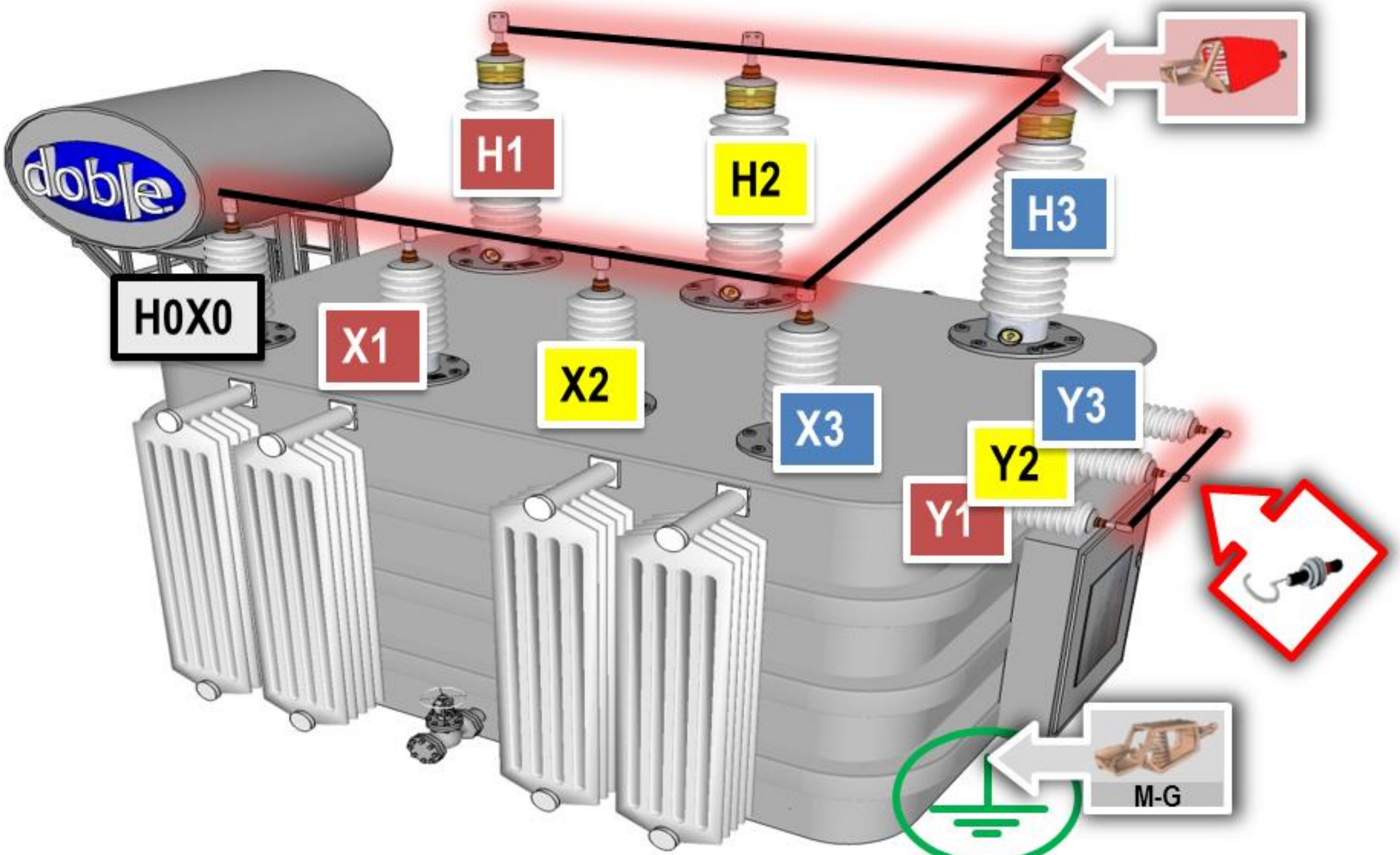
# Auto-Transformer With Accessible Tertiary Winding

**Overall Test Setup**

| Connections | | | | | Inputs | | Test Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) |
| 1 | HV Winding | TV Winding | Unused | CH+CHT | 10.000 | 0.98 | 103.110 | 2.161 | 0.210 | 0.205 | 27349.7 |
| 2 | | | | CH | 10.000 | 0.98 | 49.436 | 0.924 | 0.187 | 0.182 | 13113.0 |
| 3 | | | | CHT(UST) | 10.000 | 0.98 | 53.657 | 1.243 | 0.232 | 0.226 | 14232.7 |
| 4 | Test 1 - Test 2 (calculated) | | | CHT | | 0.98 | 53.674 | 1.237 | 0.230 | 0.225 | 14236.7 |
| 5 | TV Winding | HV Winding | Unused | CT+CHT | 10.000 | 0.98 | 165.700 | 3.567 | 0.215 | 0.210 | 43951.3 |
| 6 | | | | CT | 9.999 | 0.98 | 112.030 | 2.249 | 0.201 | 0.196 | 29717.0 |
| 7 | | | | CHT(UST) | 9.999 | 0.98 | 53.652 | 1.270 | 0.237 | 0.231 | 14231.8 |
| 8 | Test 5 - Test 6 (calculated) | | | CHT | | * | 53.670 | 1.318 | 0.246 | 0.240 | 14234.3 |

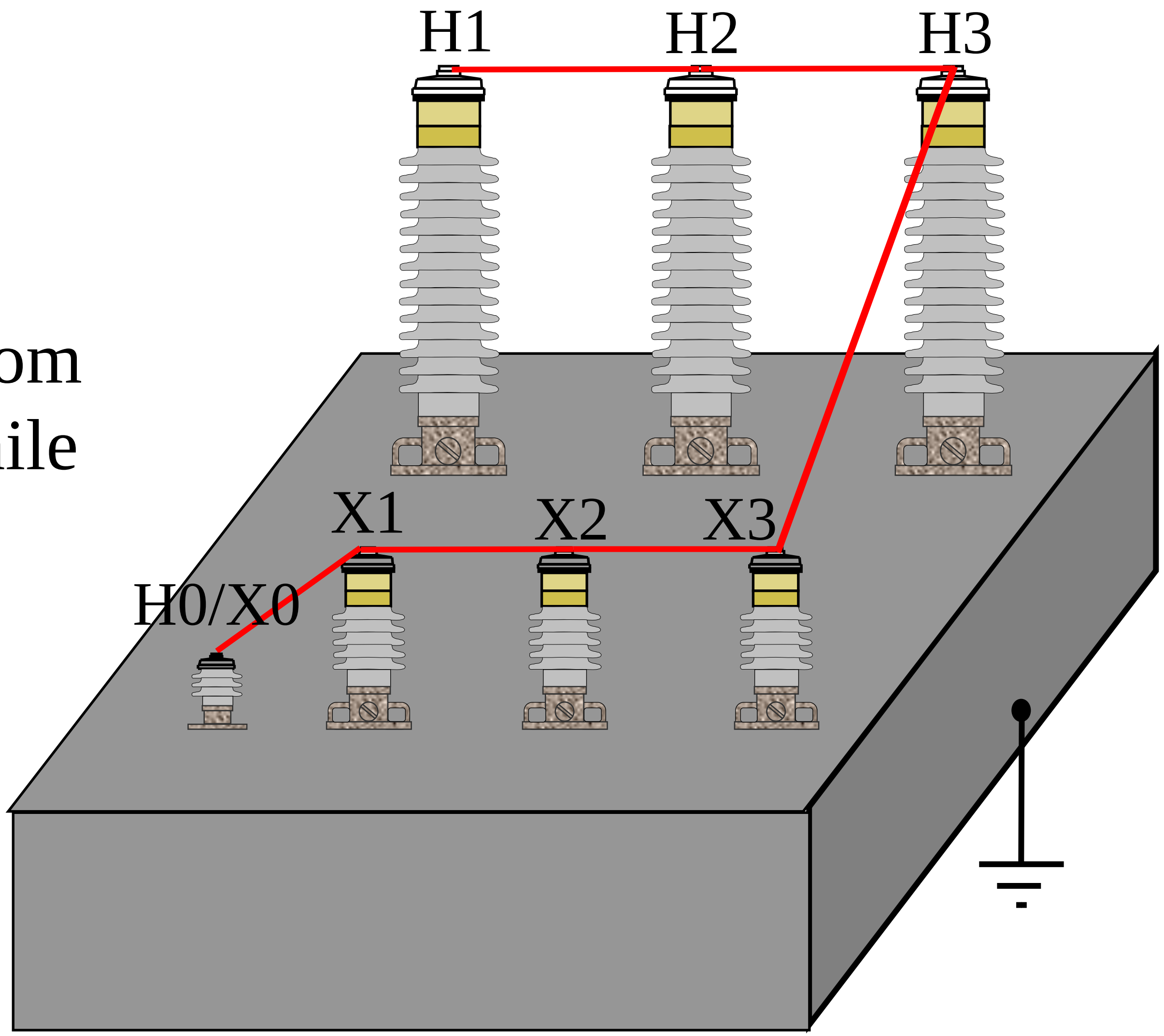
Test as a Two Winding

# Auto-Transformer - With Accessible Tertiary Winding

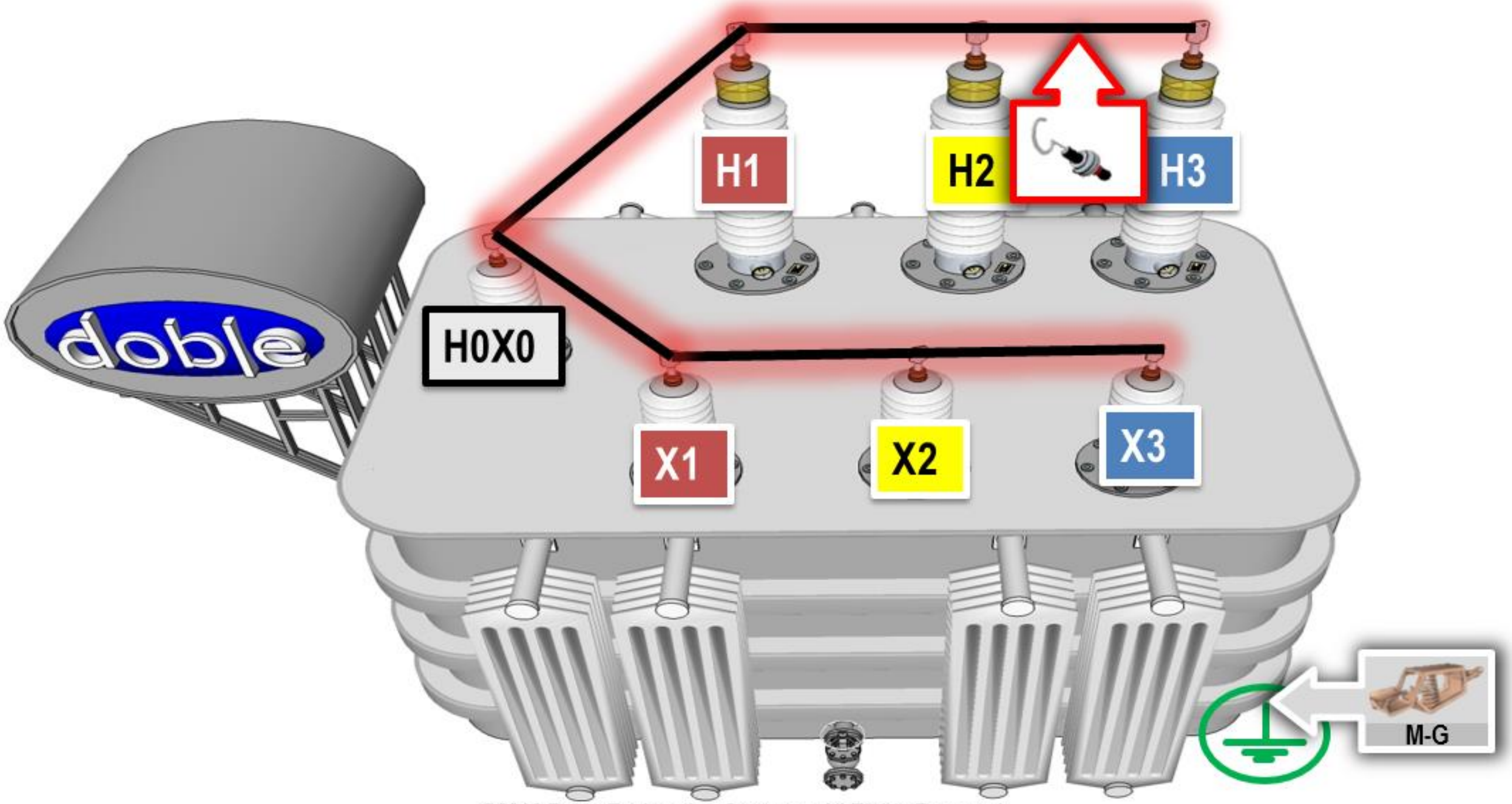


# Auto-Transformer Without Tertiary Winding (Tertiary Winding Not Accessible)

Remove Ground from H0/X0 while Testing



# Auto-Transformer Without Tertiary Winding (Not Accessible)



# Auto-Transformer Without Tertiary Winding (Tertiary Winding Not Accessible)

| Overall Test Setup | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Connections | | | | | Inputs | | Test Results | | | | |
| # | HV Lead | Red Measure Lead | Blue Measure Lead | Insulation | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) |
| 1 | All | Unused | Unused | CH | 10.006 | 0.98 | 164.965 | 3.525 | 0.214 | 0.209 | 43757.6 |

One Test to Ground

(No LV lead is Required)

# Transformer Overall Tests

Updated Recommended Doble Power-Factor Test Voltages for Liquid-Filled Power and Distribution Transformers

| Winding Rating L-L (kV) | Test Voltage (kV) |
|---|---|
| 17.32 kV and Above | 10 kV |
| Below 17.32 kV | Line - Ground |

# Transformer Overall Tests

Examples of common winding voltages and their calculated line to ground voltages. These are general guidelines.

| Winding Rating L-L (kV) | Line to Ground Voltage |
|---|---|
| 17.32 kV | 10,000 |
| 13.8 kV | 7967 |
| 12.47 kV | 7200 |
| 4.16 kV | 2401 |
| 2.4 kV | 1385 |
| .48 kV | 277 |

# Transformer Overall Tests

Recommended Doble Power-Factor Test Voltages for Liquid-Filled Type Power and Distribution Transformers Tested in the Absence Of Insulating Fluid and Under Atmospheric or Greater Absolute Pressure

- **Determine - By Direct Measurement - That the Gas space and fluid contain safe combustible gas levels for testing as prescribed by your company**
- **Purge with dry nitrogen to obtain <2% oxygen**
- **Never apply test voltage to a transformer whose windings are under vacuum or partial vacuum**

# Transformer Overall Tests

Recommended Doble Power-Factor Test Voltages for Liquid-Filled Type Power and Distribution Transformers Tested in the Absence Of Insulating Fluid and Under Atmospheric or Greater Absolute Pressure

- **Low test voltage is sufficient to assess the general level of dryness of a transformer insulation system**

- **Maintain adequate clearance between all energized, floating and grounded conductors when testing with some or all of the transformer leads, core, and coils out of the insulating fluid**

# Transformer Overall Tests

Recommended Doble Power-Factor Test Voltages for Liquid-Filled Type Power and Distribution Transformers Tested in the Absence Of Insulating Fluid and Under Atmospheric or Greater Absolute Pressure

- **Do not apply test voltages that exceed those recommended for transformers with the insulating fluid removed**

# Transformer Overall Tests

Recommended Doble Power-Factor Test Voltages for Liquid-Filled Type Power and Distribution Transformers Tested in the Absence Of Insulating Fluid and Under Atmospheric or Greater Absolute Pressure

| **Transformer Winding Rating L-L (kV)** | **Test Voltage (kV)** |
|---|---|
| ***Delta Windings*** | |
| **161 and Above** | **10** |
| **115 to 138** | **5** |
| **34 to 69** | **2** |
| **12 to 25** | **1** |
| **Below 12** | **0.5** |

# Transformer Overall Tests

## Recommended Doble Power-Factor Test Voltages for Dry-Type Power and Distribution Transformers

| Transformer Winding Rating L-L (kV) | Test Voltages (kV) |
|---|---|
| ***Delta and ungrounded Wye Windings*** | |
| **Above 14.4** | **2 and 10** |
| **12 to 14.4** | **2, L-to-G, 10** |
| **5.04 to 8.72** | **2 and 5** |
| **2.4 to 4.8** | **2** |
| **Below 2.4** | **1** |
| ***Grounded Wye Windings*** | |
| **2.4 and Above** | **2** |
| **Below 2.4** | **1** |

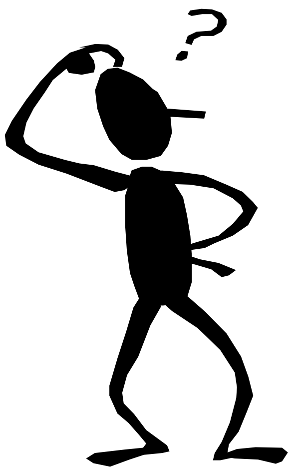
Doble dielectric-loss & power factor testing as applied to transformers is a comprehensive test for insulation assessment, detecting:

- **Moisture**
- **Carbonization**
- **Mechanical Failure**

Test techniques makes it possible to separate the transformer into major components for more effective analysis of test results.

# Analysis

Data Interpretation of Modern Oil-Filled Power Transformers (Temperature Corrected)



| | | |
|---|---|---|
| •Less Than 0.5% | -- | GOOD |
| •>0.5% but < 0.7% | -- | DETERIORATED |
| •>0.5% but <1.0% & increasing | -- | INVESTIGATE |
| •Greater than 1.0% | -- | BAD |

GENERAL GUIDELINES!

# Transformer Limit Guidelines

| Rating | Type | New | Used |
|---|---|---|---|
| 0 - 500 KVA | Distribution | 1.0% | 2.0% |
| > 500 KVA | Power | 0.5% | 1.0% |

**THESE ARE GENERAL GUIDELINES!**

| Change in Charging Current | Rating* |
|---|---|
| 0 - 3% | G |
| 3 - 5% | D |
| 5 - 10% | I |
| > 10% | B |

# Analysis of Dry Type Transformers

•Limits Are Determined Based on Manufacturer and Rating

•Based on a Recent Tabulation (1999), the Following General Guidelines Can Be Used:

**Ventilated Transformers**
$C_{HL} \leq 2.0\%$
$C_{H} \leq 3.0\%$
$C_{L} \leq 4.0\%$

**Epoxy-Encapsulated Transformers**
$C_{HL} \leq 1.0\%$
$C_{H} \leq 3.0\%$
$C_{L} \leq 2.0\%$

# Considerations

•NEVER rely only on power factor when reviewing data. Tests can be performed incorrectly and still have an “acceptable” power factor.

•Overall power factor will not reveal shorted turns or an open.

•Always review current, watts, power factor and capacitance.

•Review bushing test data, excitation current, turns ratio and winding resistance.

# Considerations

- Previous Test Results (Rate of Change)
- Test Temperatures
- Reason for Test: Acceptance, Routine or Suspect
- Other Test Results, e.g.
  - High P.F. Readings ⇒ Lab Results (DGA, Moisture in Oil)
  - High P. F. Readings ⇒ P. F. Tip-Up
  - Change in Capacitance ⇒ LRT and/or SFRA

# Exciting Current Tests

# Excitation Current Principles

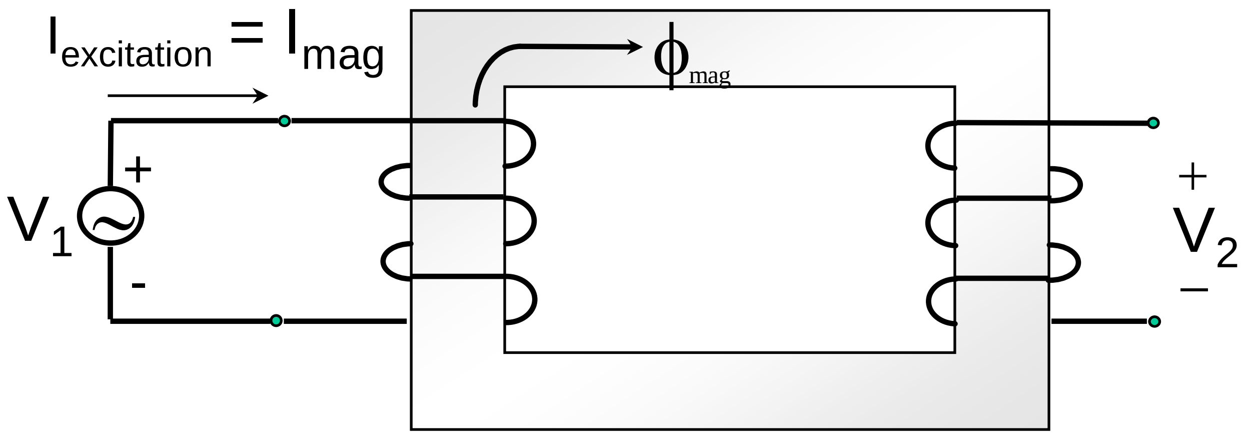
With the LTC On NEUTRAL – We measure the exciting current of the Transformer

With The LTC on an EVEN Tap – The Exciting current may include additional components such as a Series Transformer or Preventative autotransformer.

With the LTC on an ODD tap – The Exciting current in almost all cases includes any Series Transformer or Preventative autotransformer and anything else that will affect it.

# Excitation Current Principles

## No Load



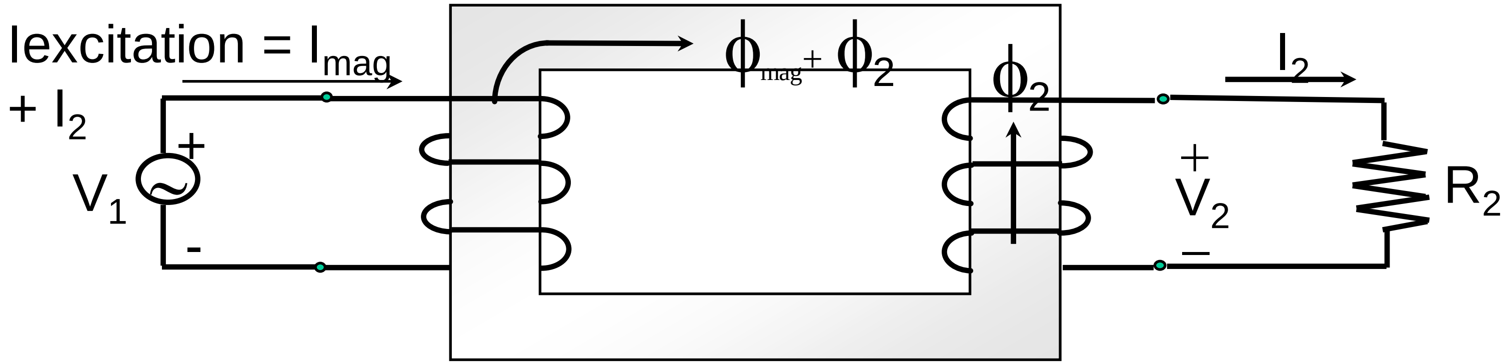

1) When an AC Voltage Source, such as a Doble Test Set, is placed on a transformer, a small current will flow.

2) This small current is the *Magnetizing Current*: the current required to magnetize the Transformer core with the *Magnetic Flux* $\phi_{mag}$. <u>This Magnetizing Current is the Excitation Current we measure and record.</u>

3) This Magnetic Flux will induce a voltage across the secondary windings: $V_2$

# Excitation Current Principles

## Load Added




1) When a Load is placed on the secondary windings a current will flow

**$I_2=V_2/R_2$ [ Ohm's Law ]**

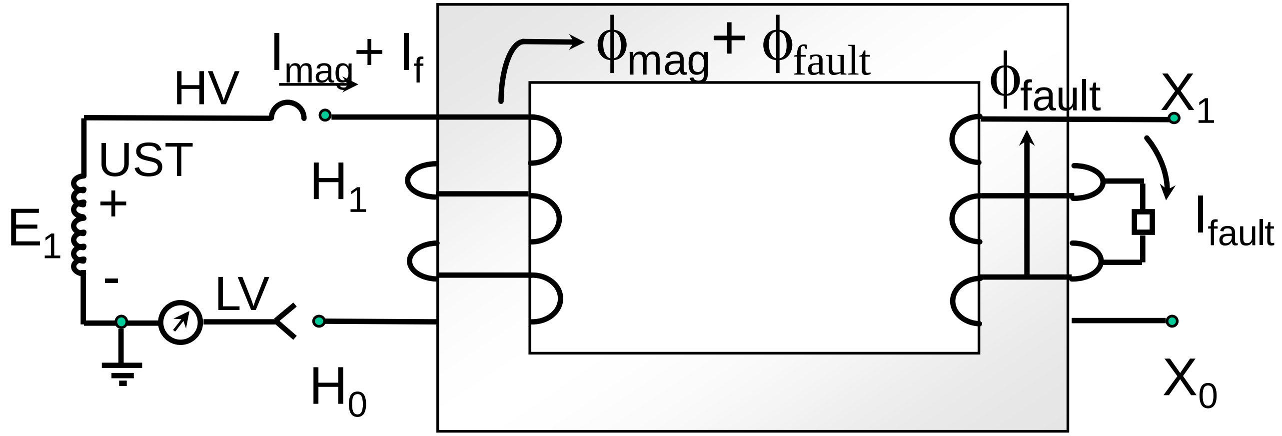
2) The Current $I_2$ will in-turn create an Opposing Magnetic Flux $\phi_{2.}$

3) The Generator, which regulates voltage at a set level, will provide more current to maintain the core magnetized equal to the opposing flux

$$I_{excitation} = I_{mag} + I_2$$

# Excitation Current Principles

## Turn to Turn Fault



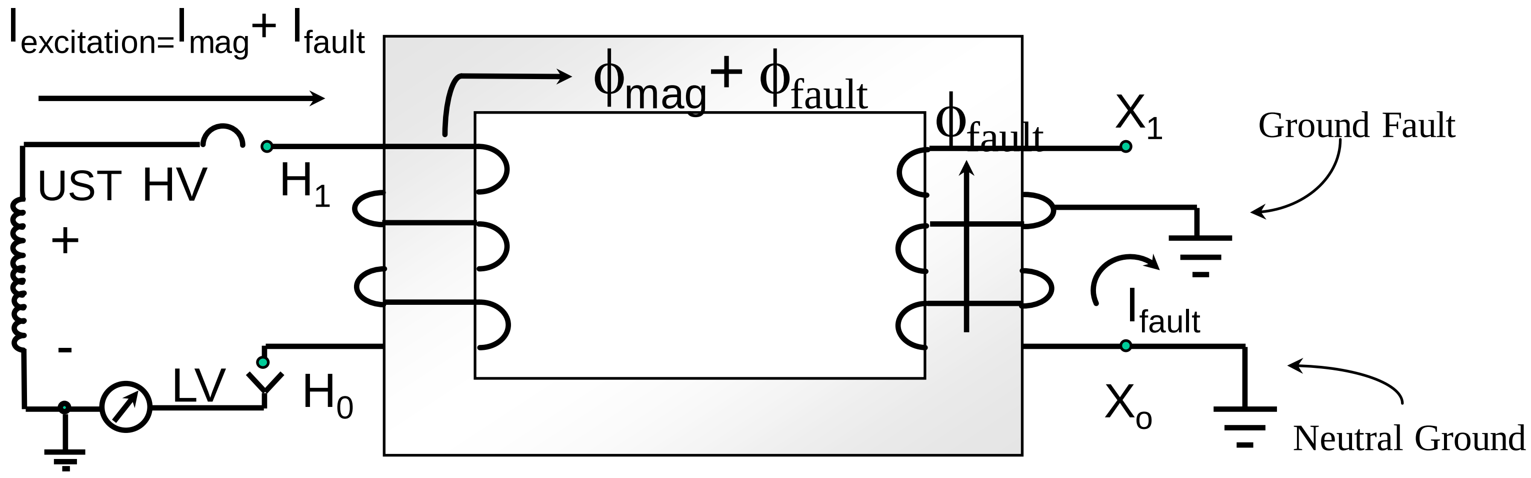

1) If a fault develops in the secondary windings, this fault will act as a load across the faulted windings drawing a current $I_{fault}$.

2) As a result, the Excitation Current will go up due to the opposing flux created by the fault [$\phi_{fault}$].

**Result: A Fault will cause Excitation Current to Increase**

# Excitation Current Principles

## Grounded Winding



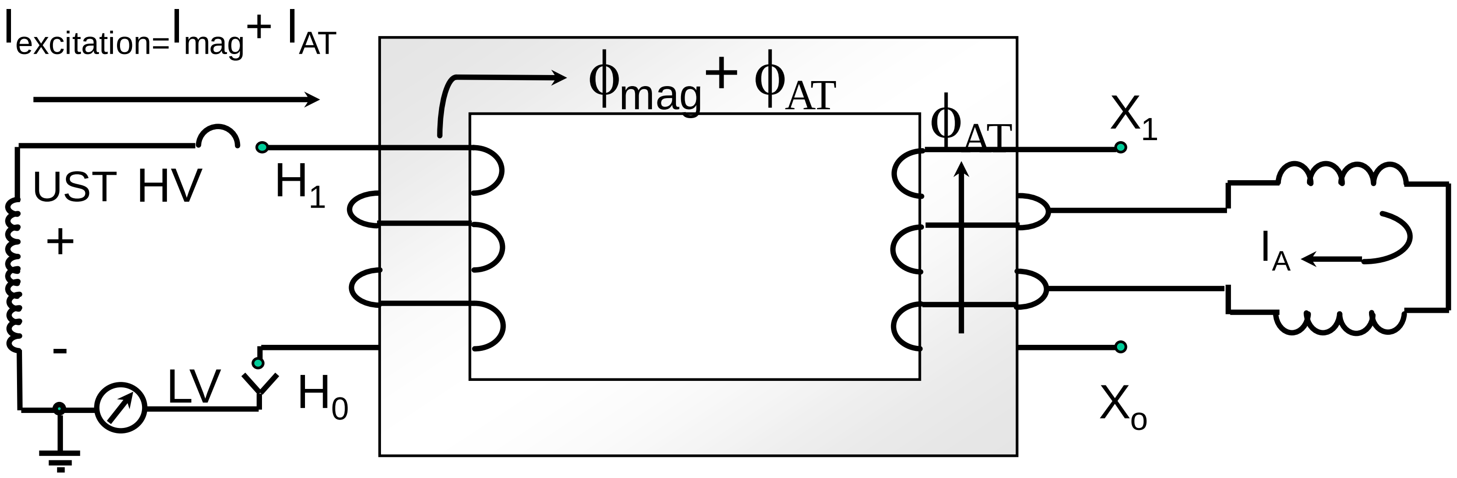

1)If the secondary winding has a grounded neutral and one of the windings develops a fault to ground, grounded windings will draw a fault current.

2) As a result, the Excitation Current will go up due to the opposing flux created by the fault [$\phi_{fault}$].

**Result: A grounded winding on a transformer with a grounded neutral will cause the Excitation Current increase**.

# Excitation Current Principles

## Preventative Autotransformer




When an autotransformer is connected across two taps it acts as a load and the primary current goes up.

**Result: When the Autotransformer is in the bridging position the Excitation Current increase.**

# Transformer Excitation Current Test Procedure - Single Phase

Note :

It is recommended to ground one terminal of each low voltage winding so that excessive voltage in the winding will not be developed from electrostatic coupling.

# Transformer Excitation Current Test

## Test Voltage Guidelines

- Do Not Exceed Test Voltages Recommended For Over-All Winding Test Procedures

- Use the Highest, Whole Number, Voltage in kV, That the Test Set Can Deliver Up To the Maximum Recommended Test Voltage

# Transformer Excitation Current Test

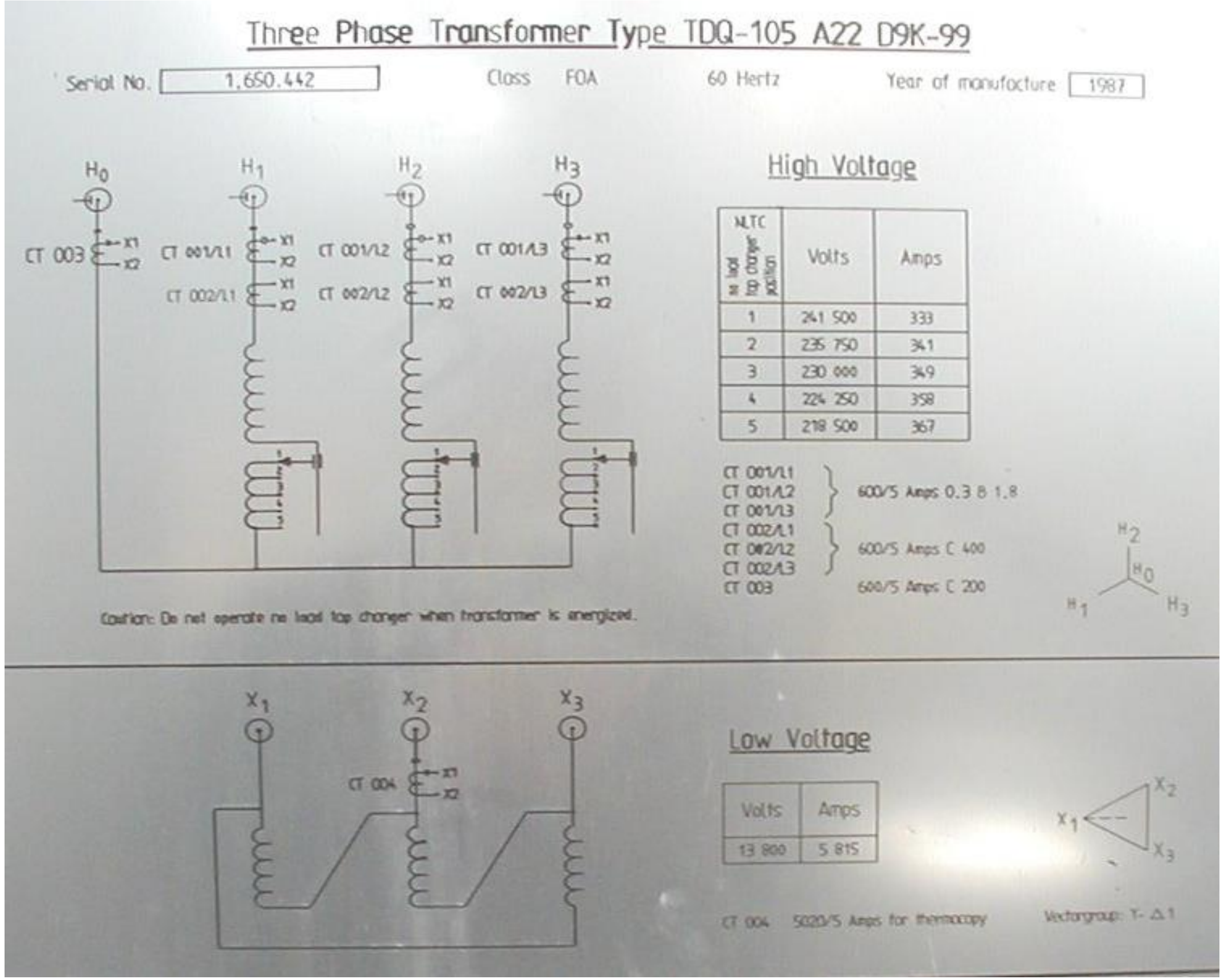
## Test Voltage Guidelines

•The Relationship Between Excitation Current and Applied Test Voltage is Non-Linear

•For Historical Comparisons it is Necessary to Use the Same Test Voltage For Each Test on a Given Transformer

# Wye Winding
# Excitation Current Tests

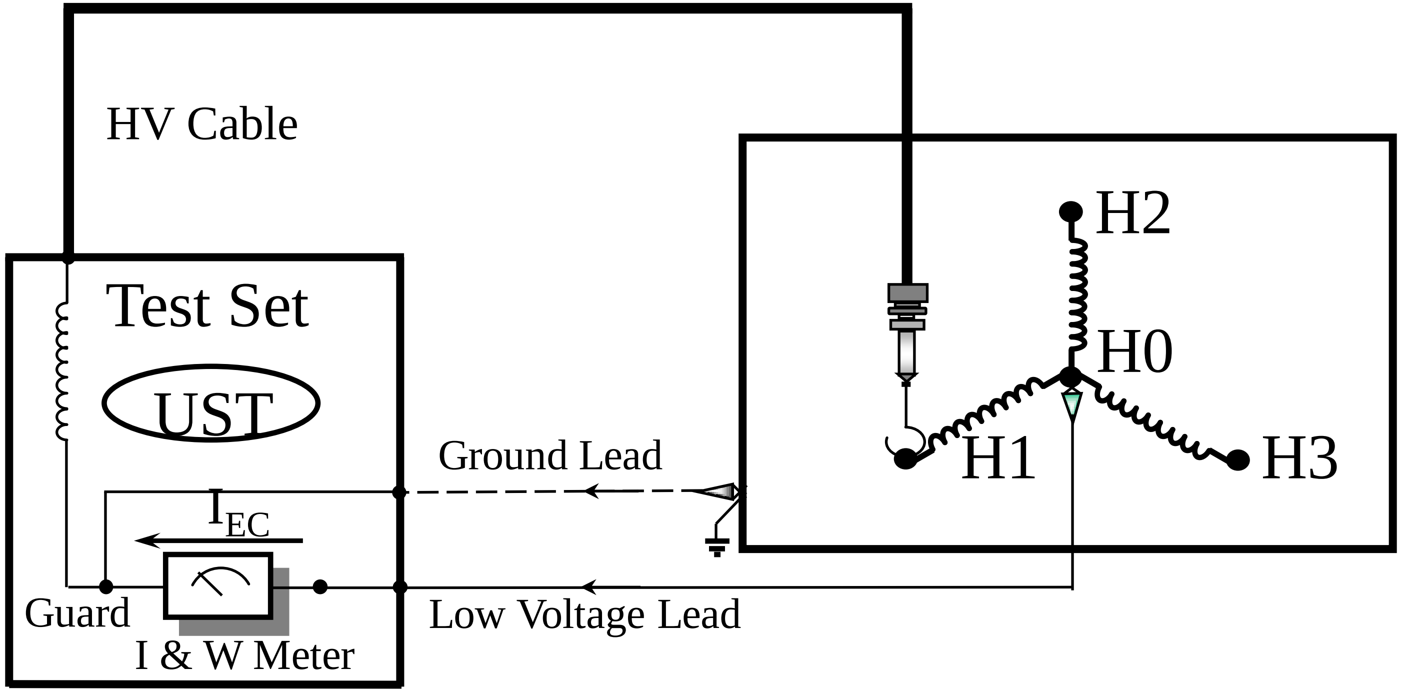
# Transformer Nameplate



# Transformer Excitation Current Test
# Test 1: Measure H1 to H0

Energize: H1, UST: H0,  Float: H2,H3,X1,X2,X3

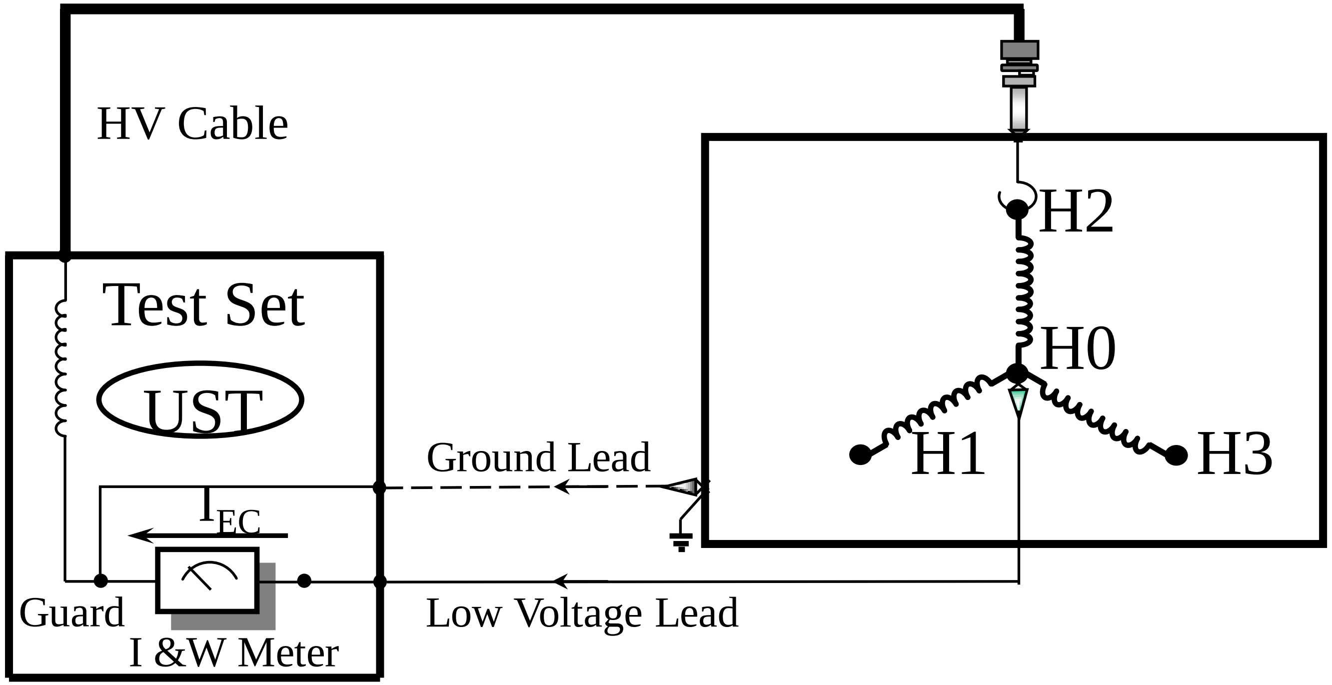
Note: If Low Voltage Winding is Wye-Connected - Ground X0



# Test 2: Measure H2 to H0

Energize:H2, UST: H0, Float: H1,H3,X1,X2,X3

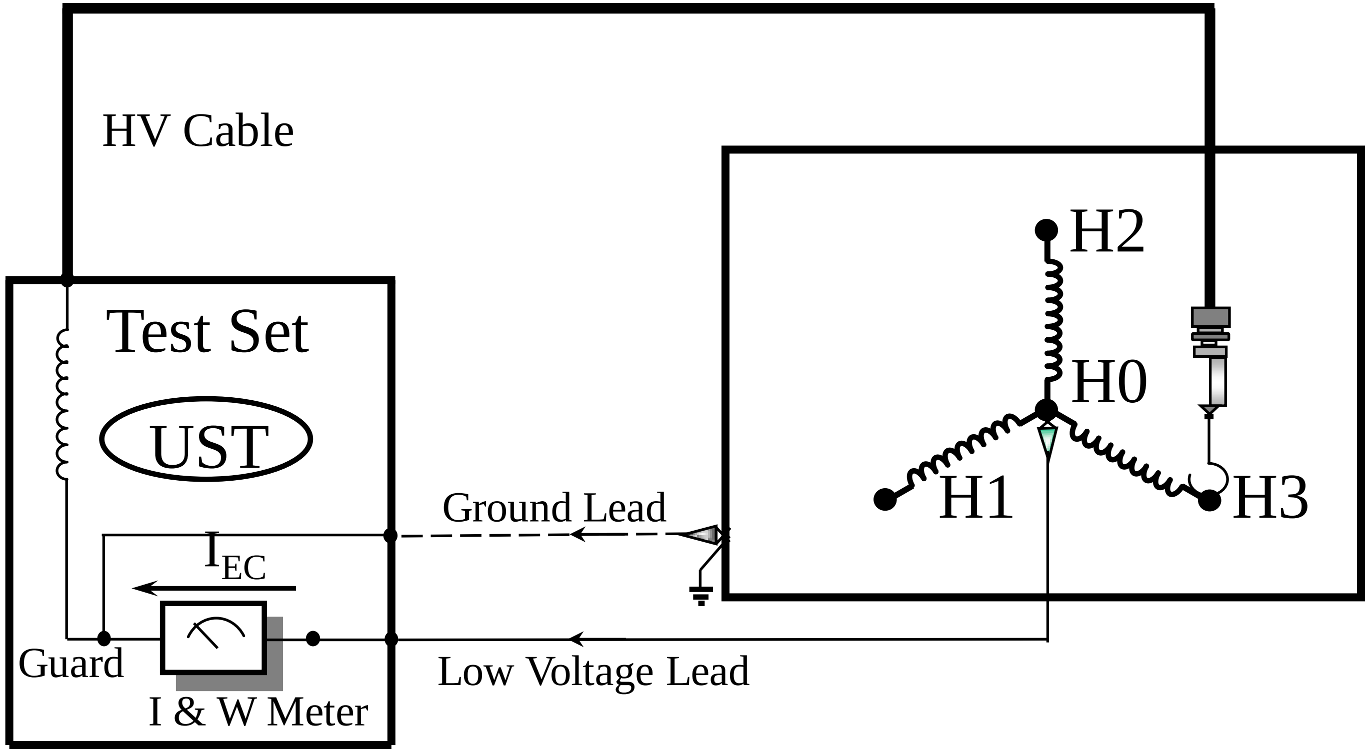
Note: If Low Voltage Winding is Wye-Connected - Ground X0



# Test 3: Measure H3 to H0

Energize: H3, UST: H0, Float: H1,H2,X1,X2,X3

Note: If Low Voltage Winding is Wye-Connected - Ground X0



# Transformer Excitation Current Test

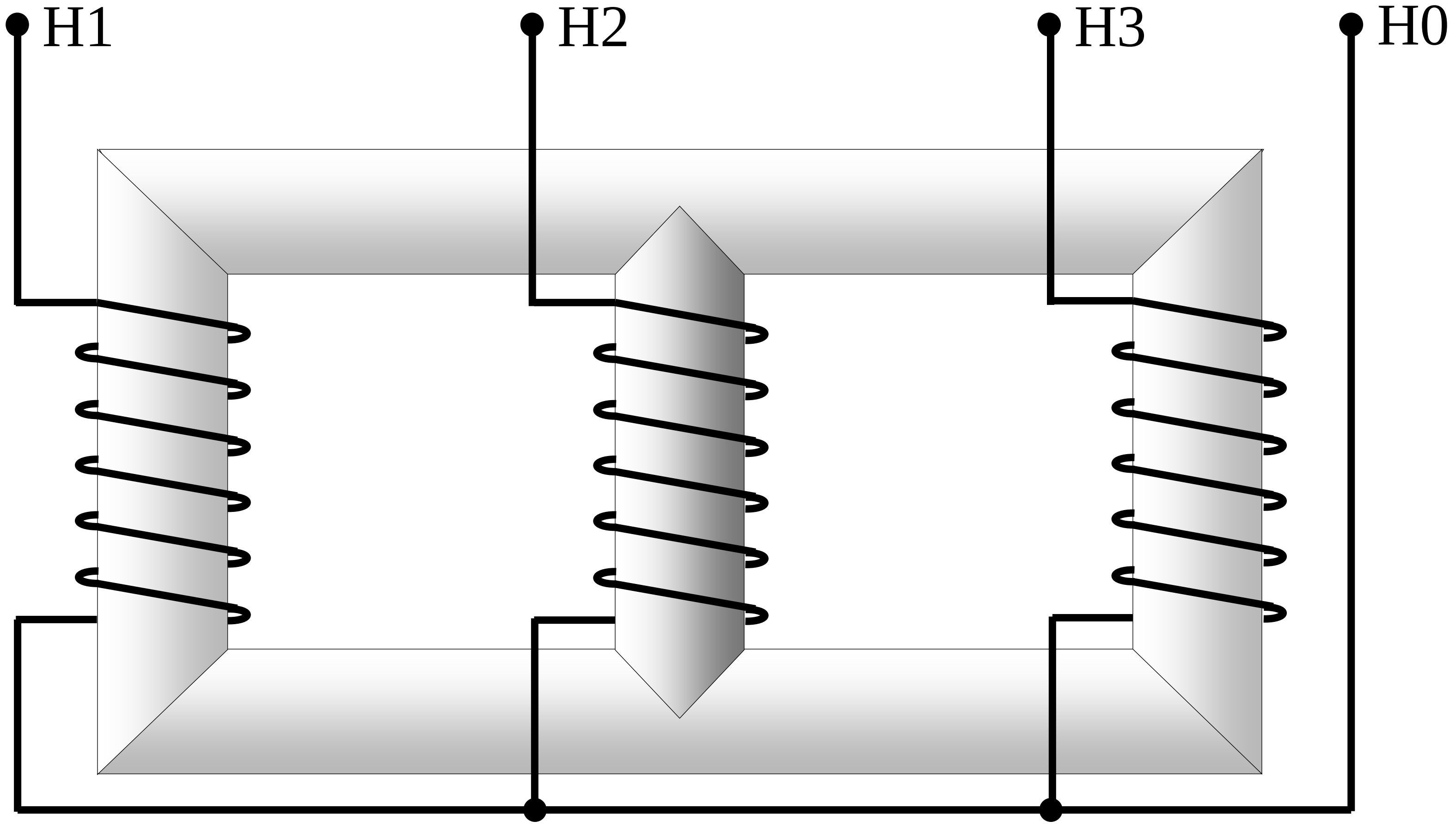
## Summary

| Test No. | Measures | Test Mode | Energize | UST | Ground | Float |
|---|---|---|---|---|---|---|
| 1 | H1-H0 | UST | H1 | H0 | * | H2,H3,X1,X2,X3 |
| 2 | H2-H0 | UST | H2 | H0 | * | H1,H3,X1,X2,X3 |
| 3 | H3-H0 | UST | H3 | H0 | * | H1,H2,X1,X2,X3 |

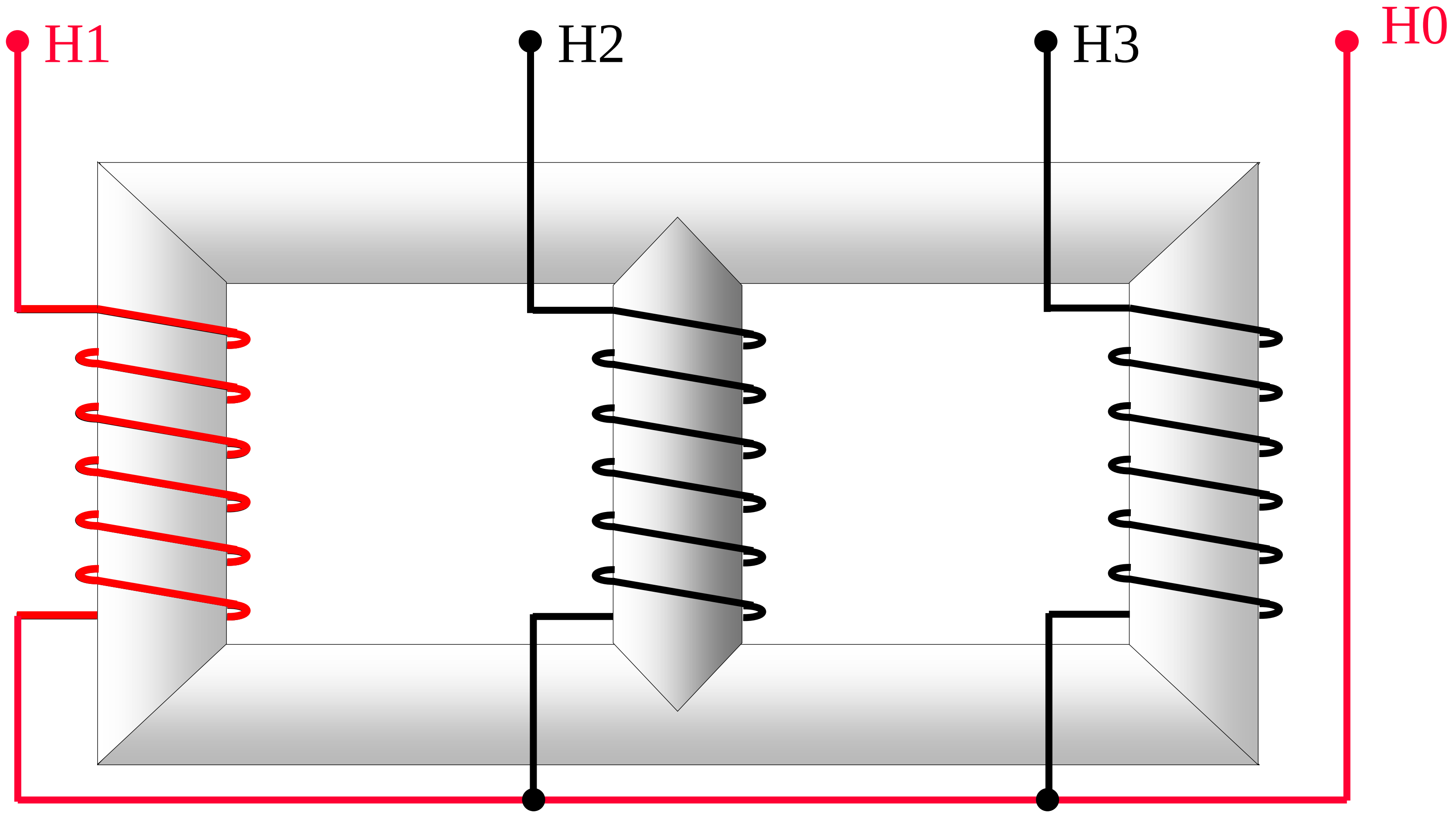
- If Low-Voltage Winding is Wye-Connected, Ground X0

- This Procedure is for Transformers With H2 and H0 Bushings Associated With Center Leg of Core

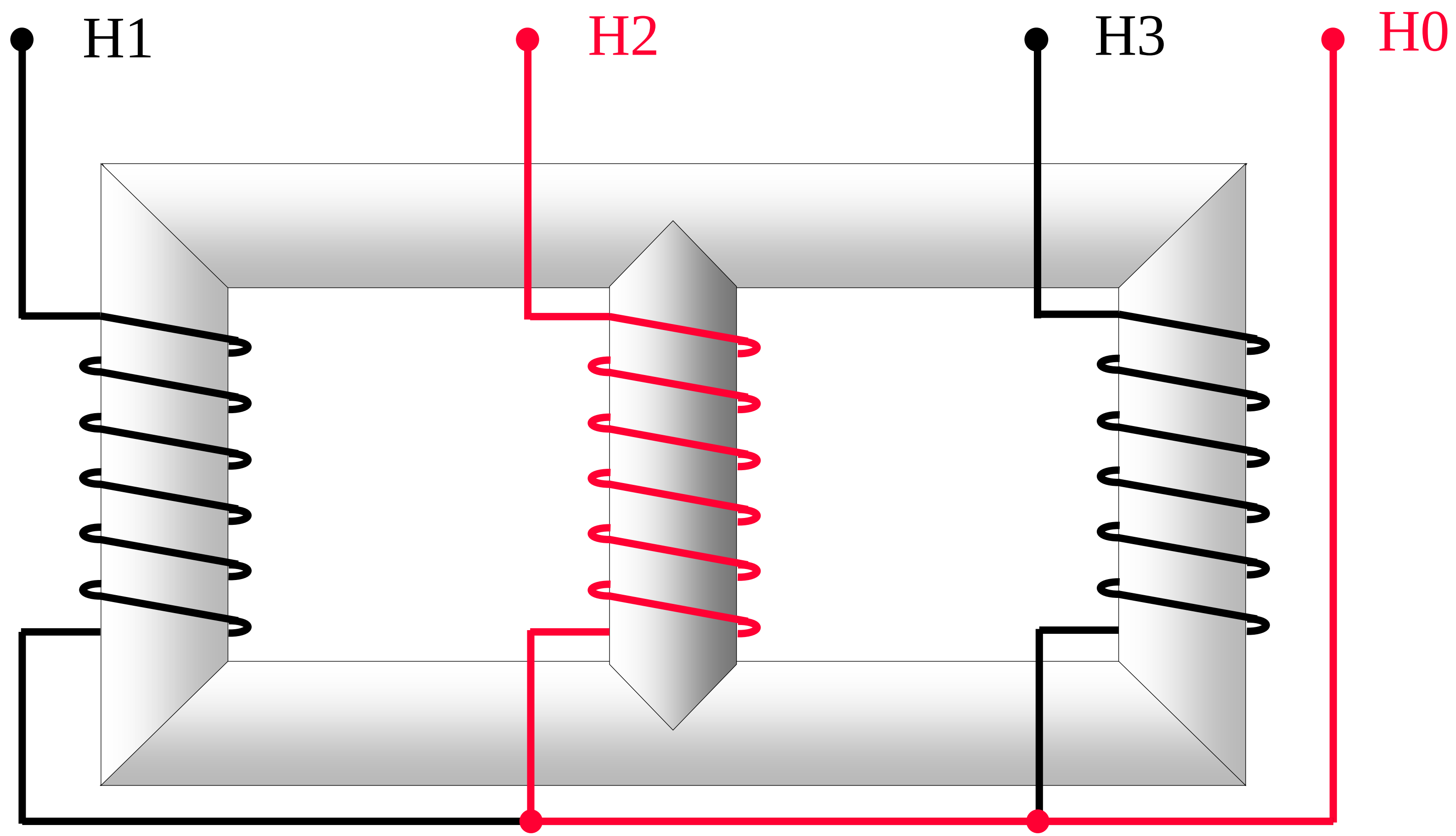
# Transformer Excitation Current Test
## 3-Phase Wye Connected Windings



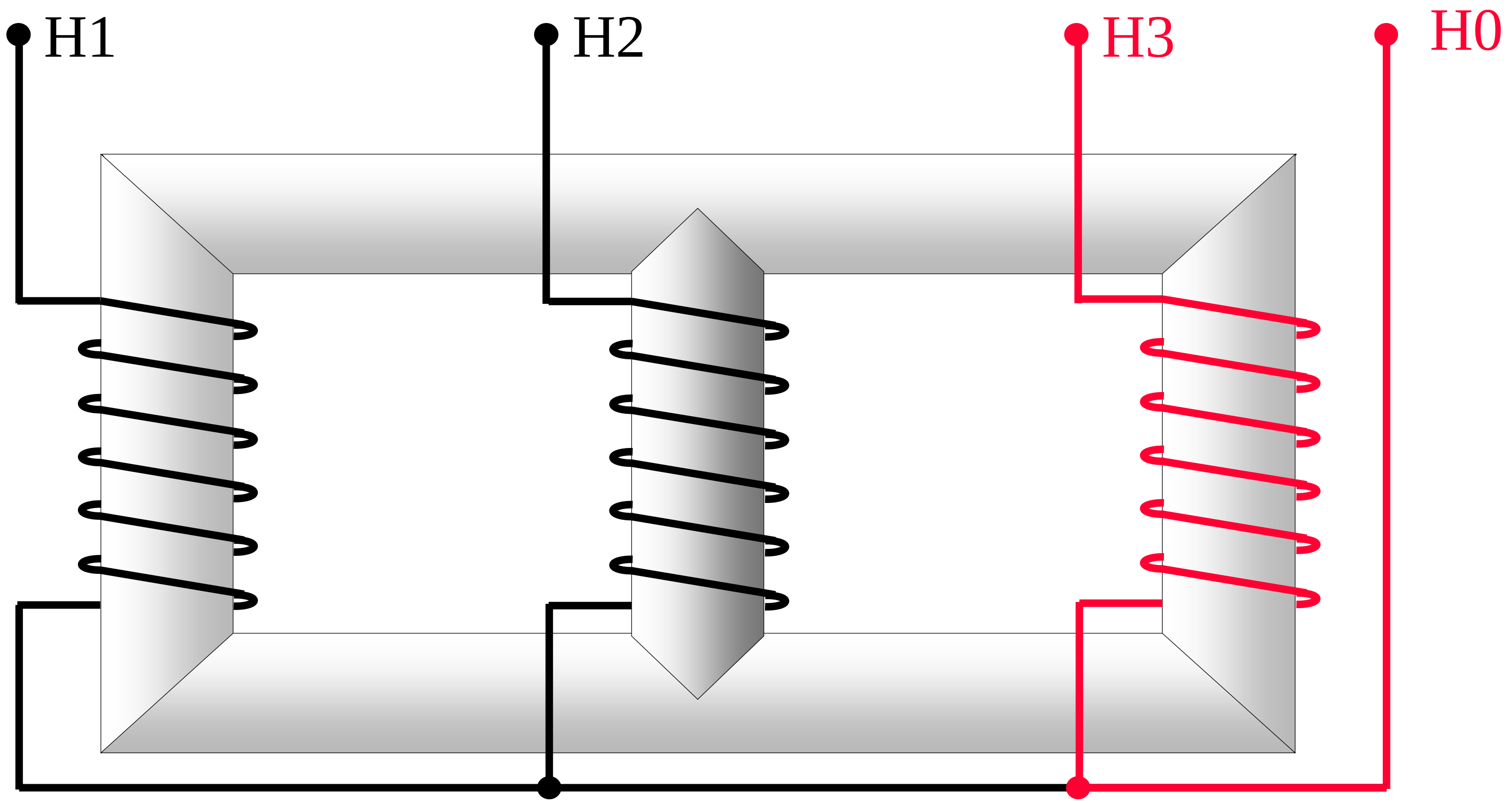
# Transformer Excitation Current Test
# 3-Phase Wye Connected Windings



# Transformer Excitation Current Test
# 3-Phase Wye Connected Windings



# Transformer Excitation Current Test
# 3-Phase Wye Connected Windings



# Current and Watts Pattern - - HLH - Why?

- Test Voltage, E, Applied to Winding - Same For Each Test
- $E = 4.44 f N \Phi$
- f = Alternating Current Frequency (Constant)
- N= Number of Turns of Conductor (Constant)
- The Magnetic Flux $\Phi$ In the Core Within the Conductor Coils - Same for Each Test

# Current and Watts Pattern – HLH - Why?

- Magnetic flux, $\Phi$ - Same for Each Test
- $NI = \Phi\Re$
- N = Number of Turns of Conductor (Constant)
- Current, I, Through the Conductor - Affected Only by $\Re$, Reluctance of the Core
- Larger Reluctance, $\Re$, Larger Current
- Smaller Reluctance, $\Re$, Smaller Current

# Current and Watts Pattern - HLH - Why?

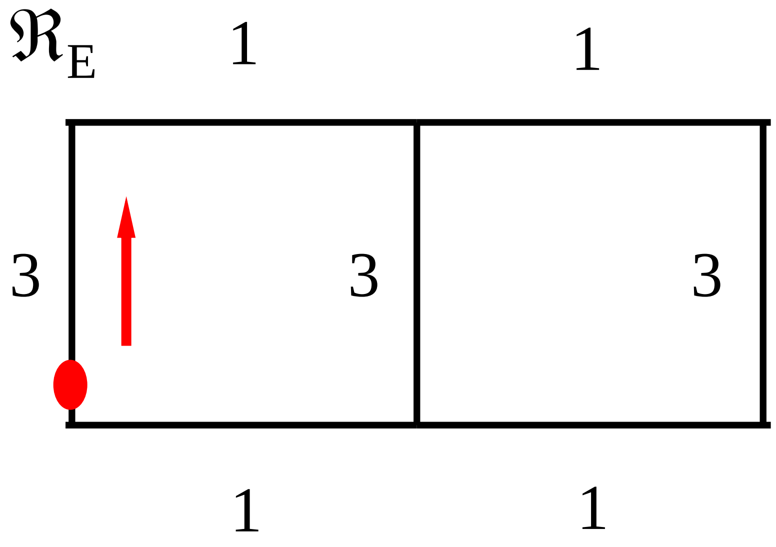
## Summary

- $E = 4.44\ f\ N\ \Phi$
  - Must Keep E Constant to Keep $\Phi$ in the Core Constant
- $NI = \Phi\Re$
  - N and $\Phi$ Are Constant,
  - I (current) Will Vary With $\Re$ (Reluctance)
  - Higher $\Re$ Then Higher I
  - Lower $\Re$ Then Lower I

# Current and Watts Pattern - HLH - Why?

- Larger Reluctance, $\Re$, Larger Current
- Smaller Reluctance, $\Re$, Smaller Current

# Current and Watts Pattern - HLH - Why?

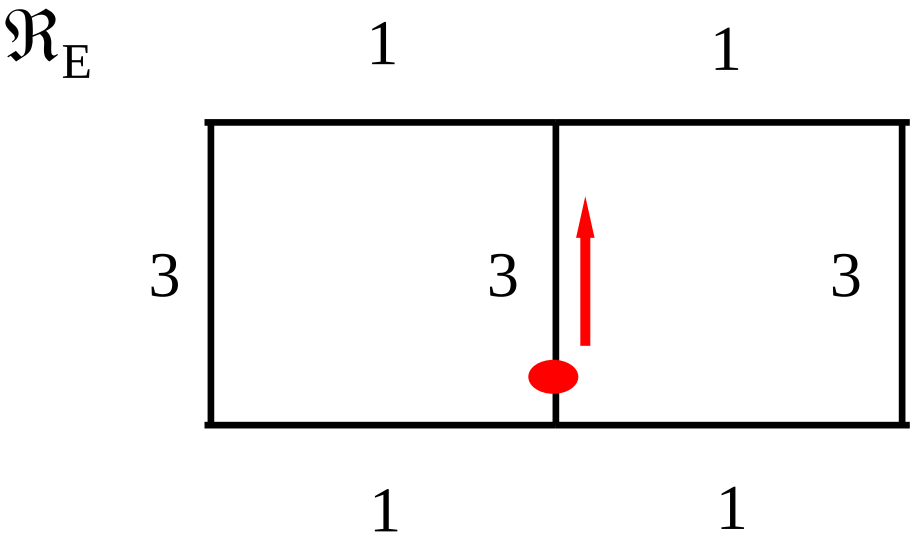



Same for this leg

**Outer Cores**

$$\Re E = (1+3+1) + [3(1+3+1)/(3+1+3+1)] = 6.875$$

# Current and Watts Pattern - HLH - Why?




**Inner Core**

**$\Re E = 3 + (5 \times 5) / 10 = 5.5$**

# Delta Winding
# Excitation Current Tests

# Transformer Excitation Current Test

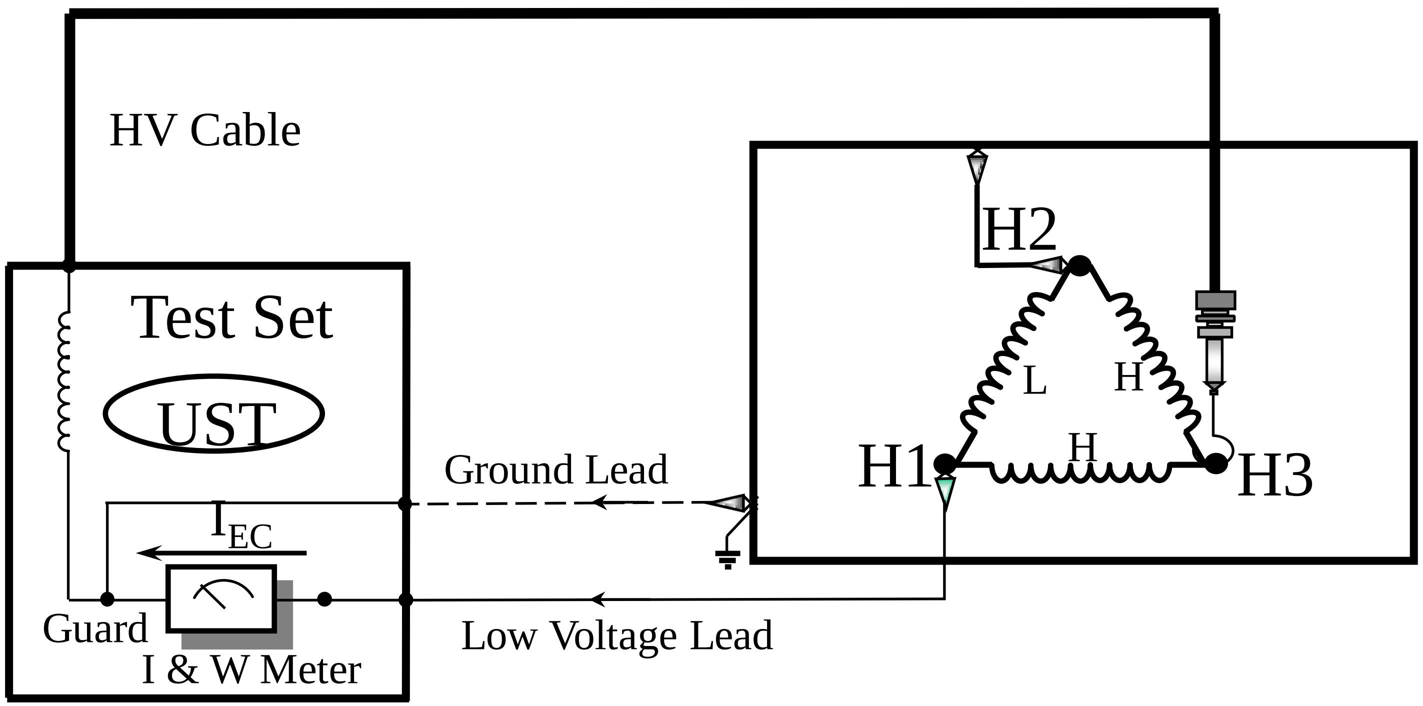
3 Phase, Delta Connected

H1-H2 in Center Phase

# Test 1: Measure H3 to H1

Energize: H3, UST: H1, Ground: H2, Float: X1,X2,X3

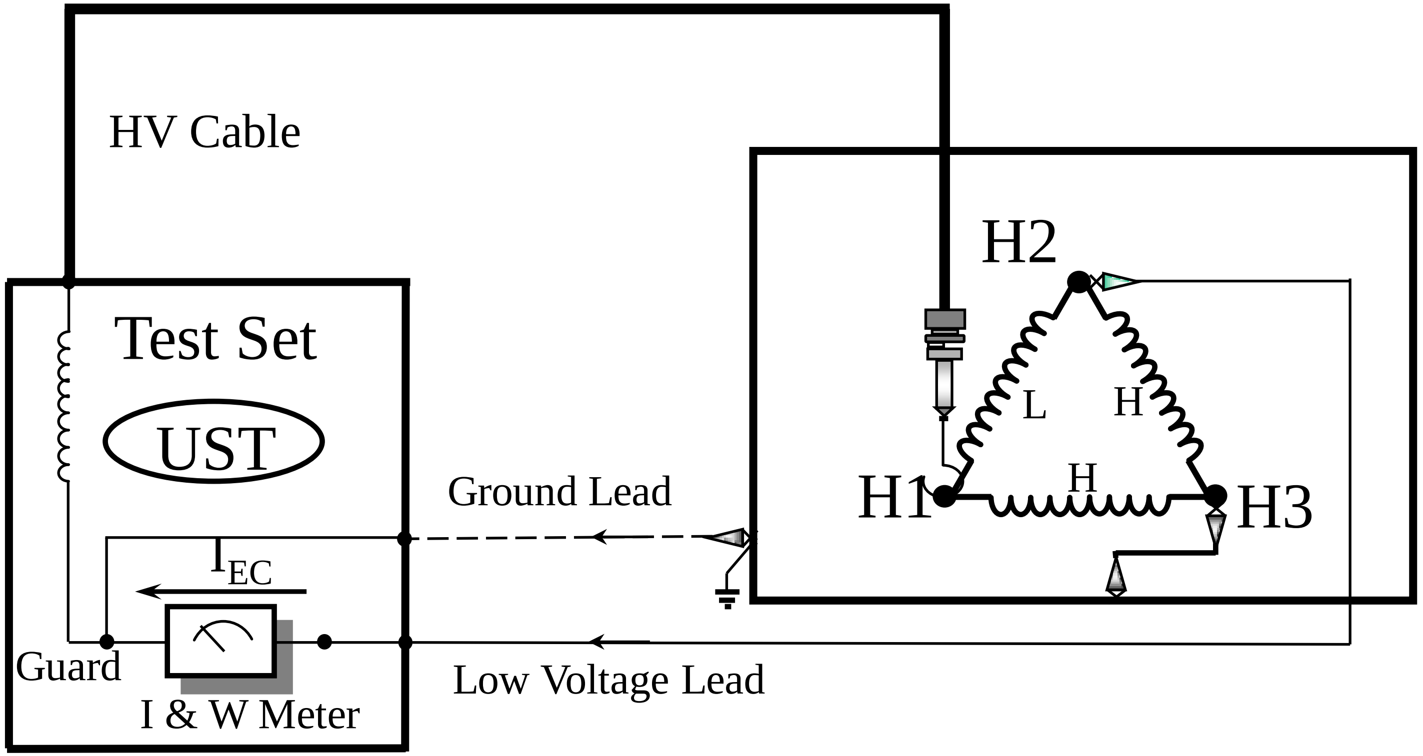
Note: If Low Voltage Winding is Wye-Connected - Ground X0



# Test 2: Measure H1 to H2

Energize: H1, UST: H2, Ground: H3, Float: X1,X2,X3

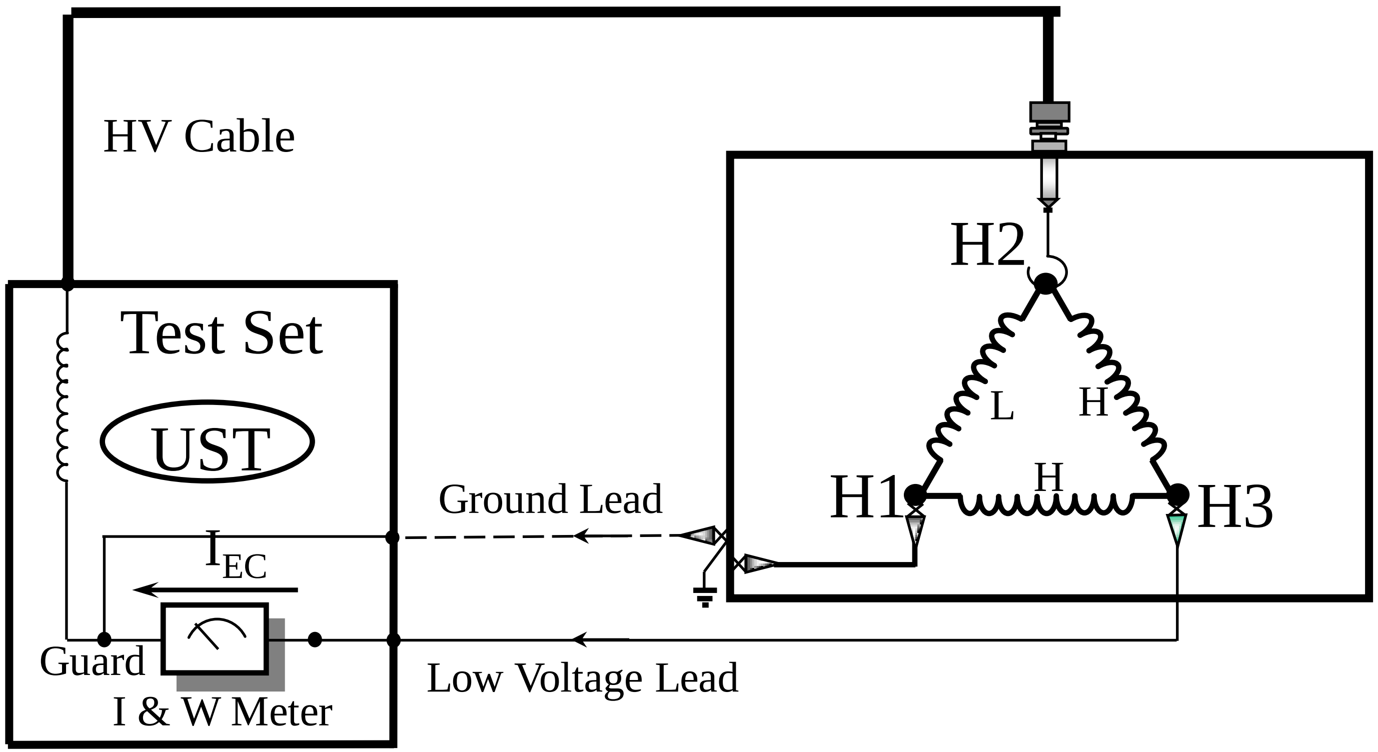
Note: If Low Voltage Winding is Wye-Connected - Ground X0



# Test 3: Measure H2 to H3

Energize: H2, UST: H3, Ground: H1, Float: X1,X2,X3

Note: If Low Voltage Winding is Wye-Connected - Ground X0



# Transformer Excitation Current Test
# 3 Phase, Delta Connected, H1-H2 in Center Phase

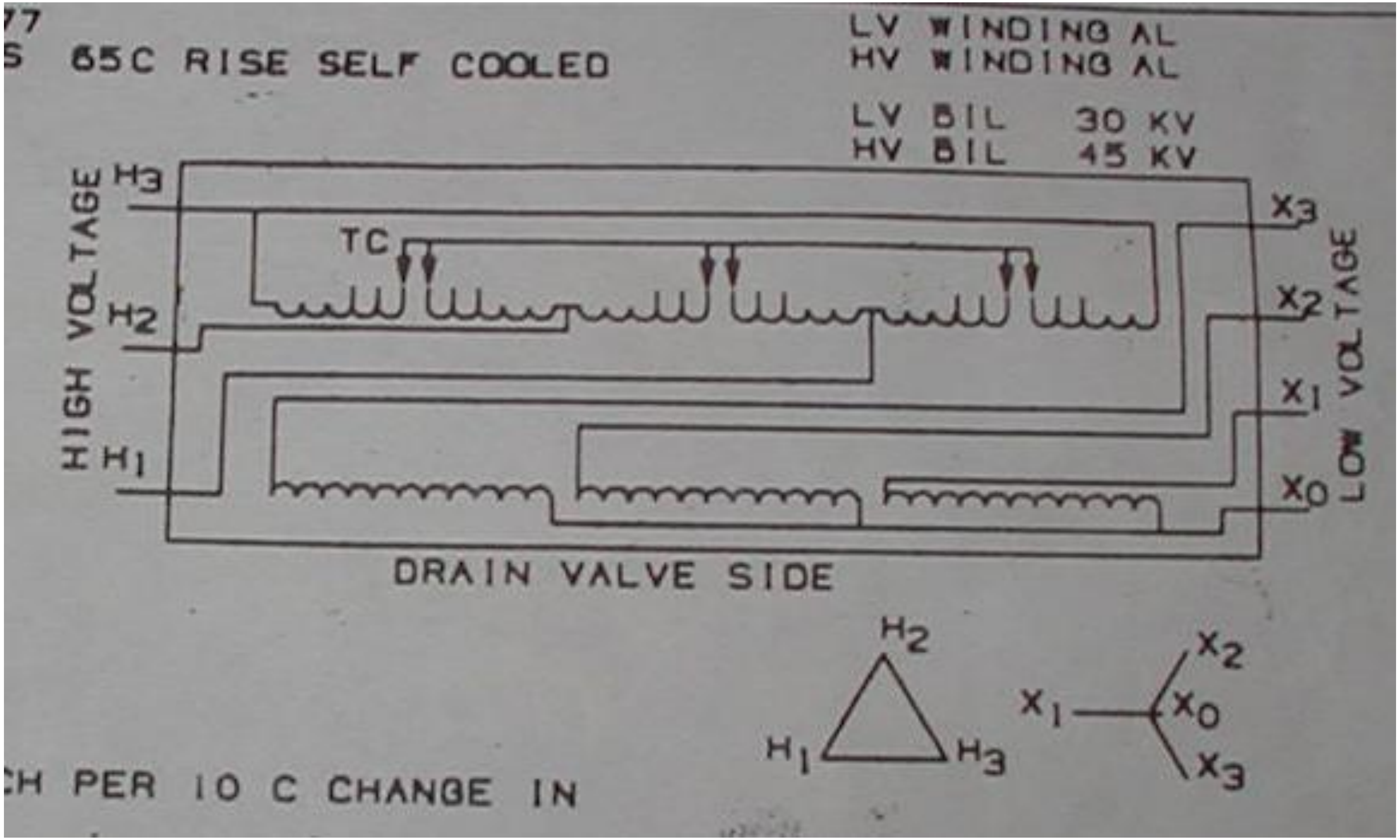
## Summary

| Test No. | Measures | Test Mode | Energize | UST | Ground | Float |
|---|---|---|---|---|---|---|
| 1 | H3-H1 | UST | H3 | H1 | H2 * | X1,X2,X3 |
| 2 | H1-H2 | UST | H1 | H2 | H3 * | X1,X2,X3 |
| 3 | H2-H3 | UST | H2 | H3 | H1 * | X1,X2,X3 |

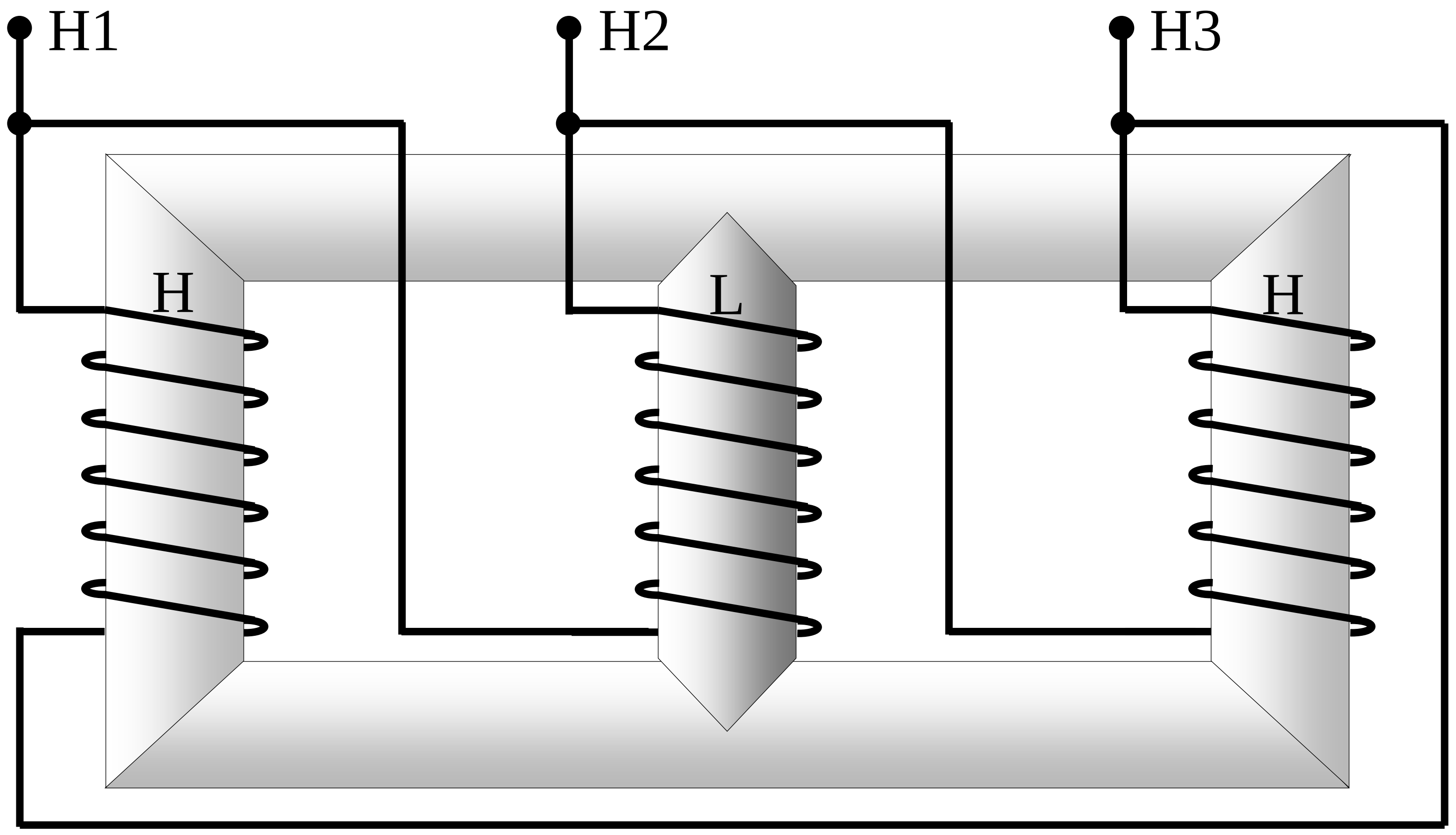
- This Procedure is For Transformers That Have H1 and H2 Bushings Associated With the Center Leg of Core

- Note: If Low Voltage Winding is Wye-Connected - Ground X0

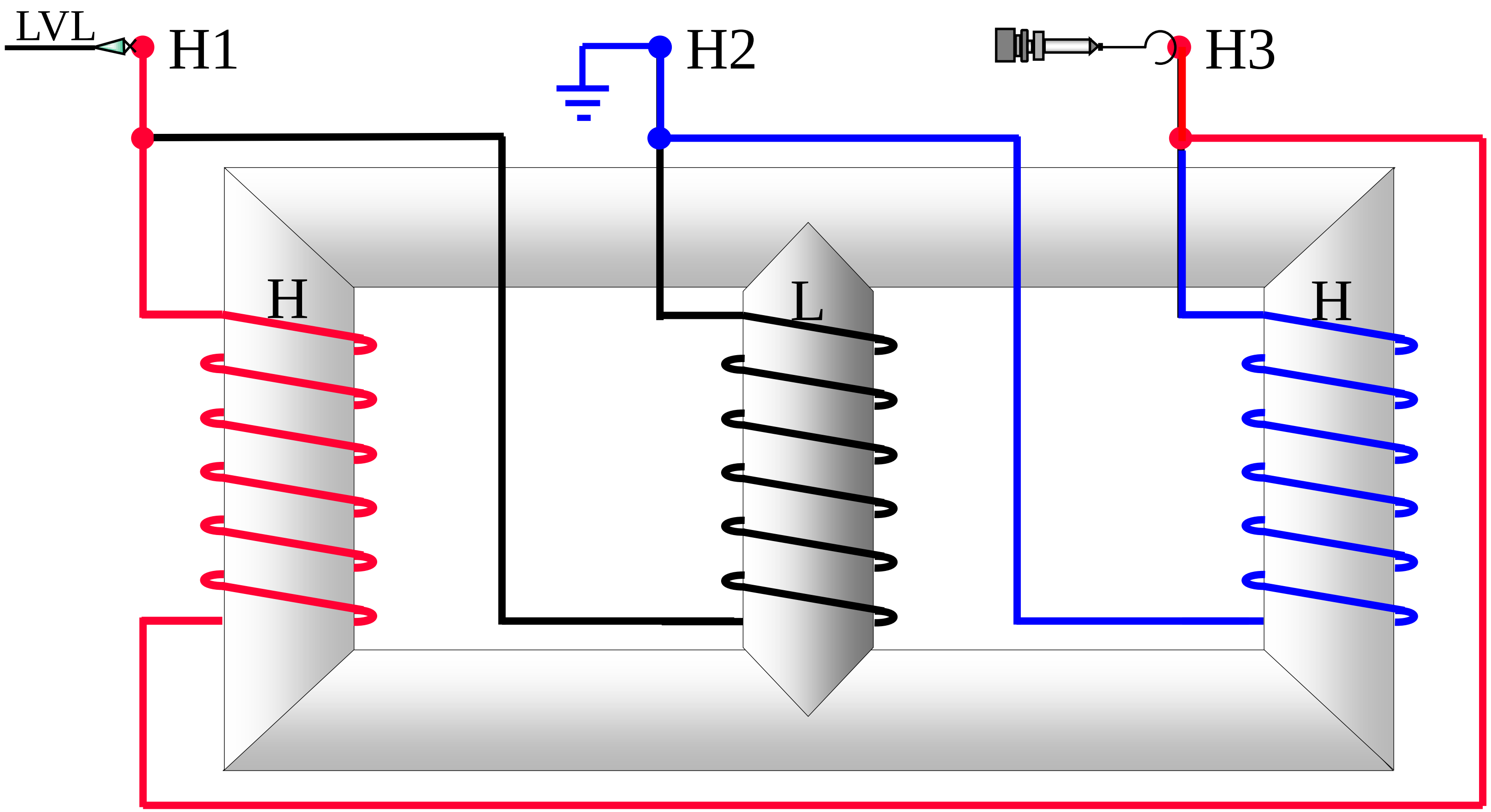
# Transformer Excitation Current Test
# 3 Phase, Delta Connected, H1-H2 in Center Phase



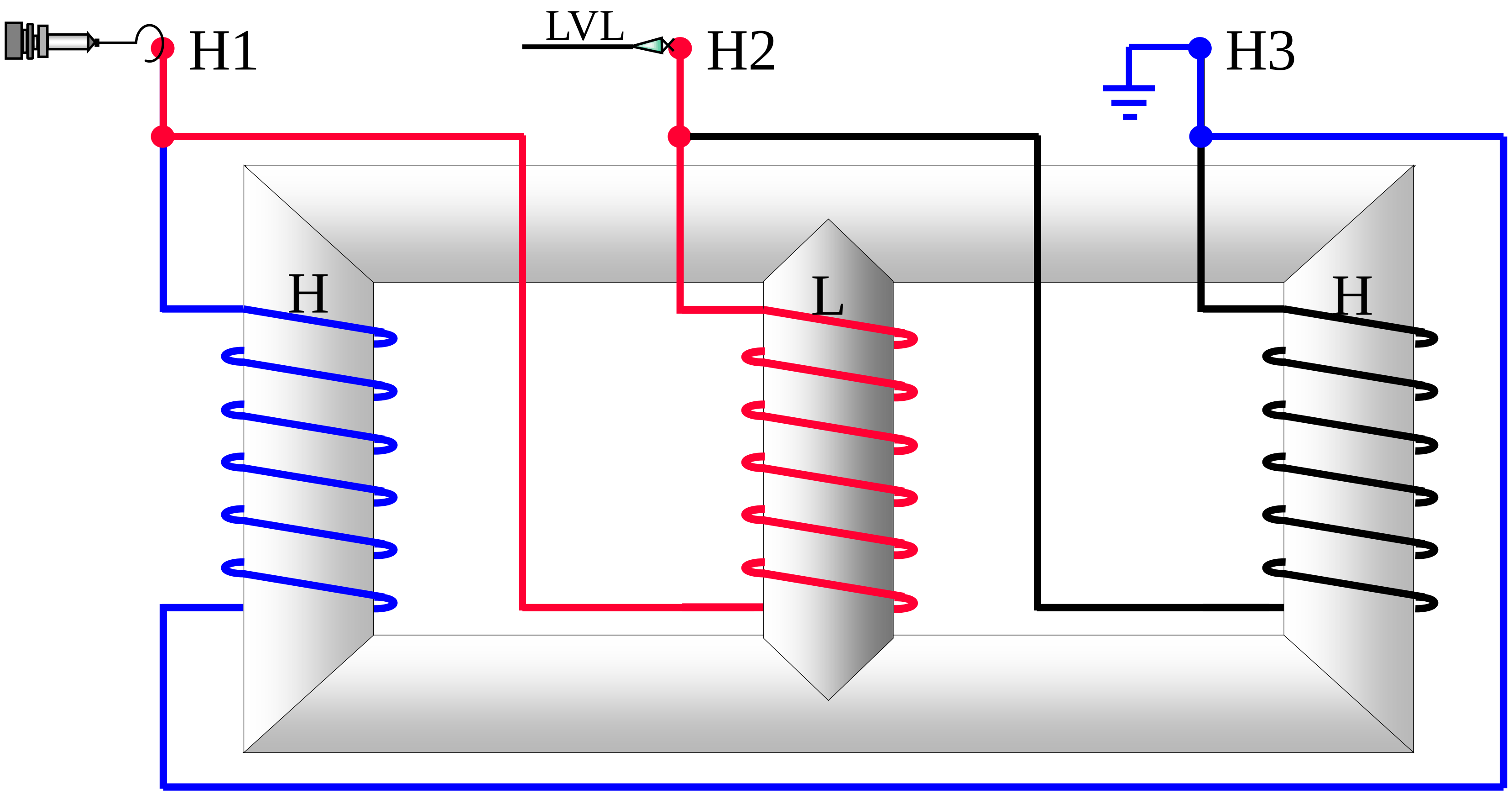
# Transformer Excitation Current Test
## 3 Phase, Delta Connected, H1-H2 in Center Phase



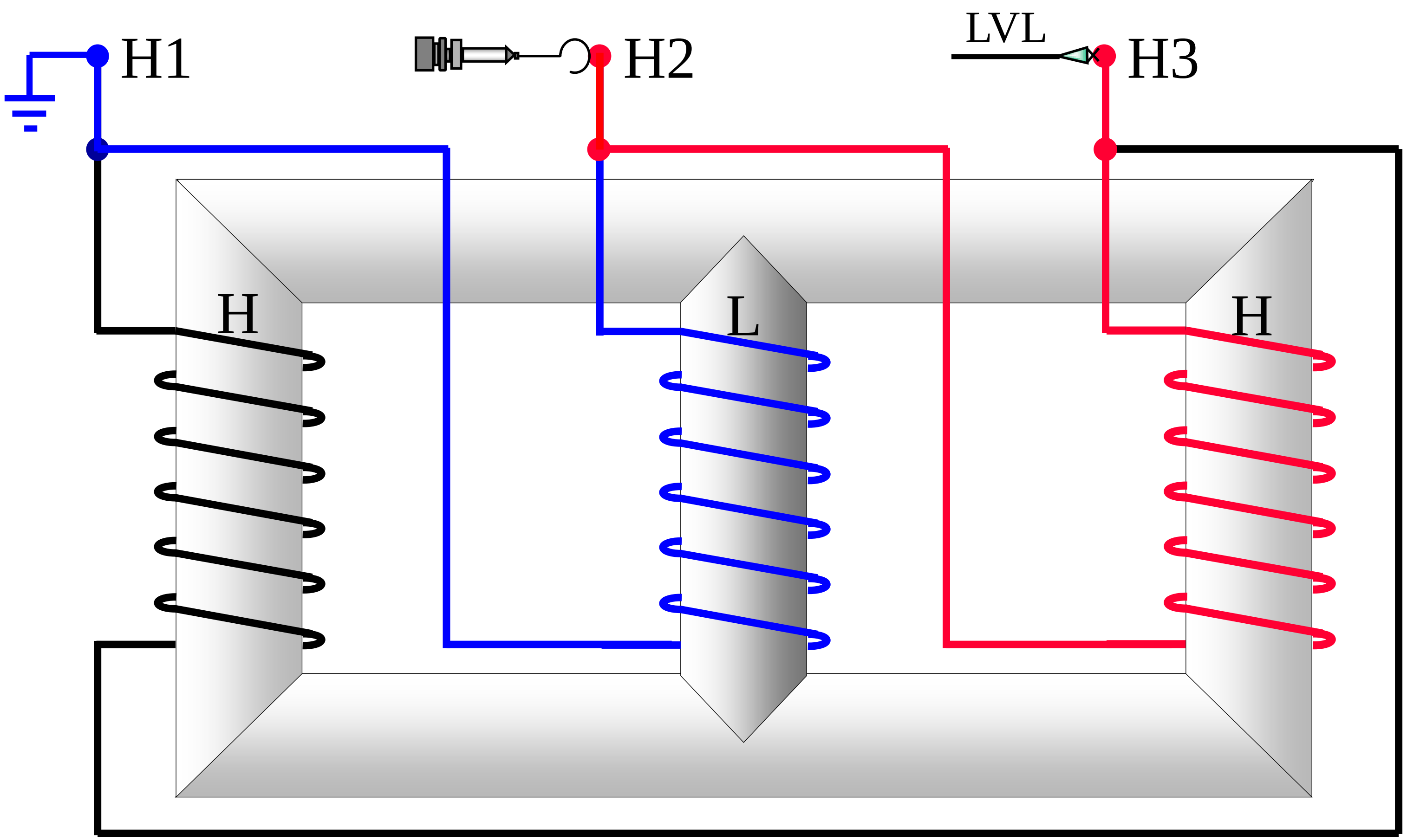
# Transformer Excitation Current Test
## 3 Phase, Delta Connected, H1-H2 in Center Phase



# Transformer Excitation Current Test
## 3 Phase, Delta Connected, H1-H2 in Center Phase



# Transformer Excitation Current Test
# 3 Phase, Delta Connected, H1-H2 in Center Phase



# Application of Excitation Current Test

<u>For New or Questionable Transformers</u>

•Test Positions of the LTC:

All positions
or
1R-16R, N, 1L
or
1L-16L, N, 1R

•Test Each Position of the DETC:

A,B,C,D,E with the LTC in Neutral

# Application of Excitation Current Test

<u>On a Routine Basis</u>

- Test Positions of the LTC

  16R, 1R, N, 1L, 16L

- Leave the DETC in the Nominal Position or the Position to be left on for operation.

# Analysis, Excitation Current and Watts Phase Patterns

**Two Similar (SS)**

Single Phase Transformers

# Analysis, Excitation Current and Watts Phase Patterns

**DTA Field System - [Auxiliary Transformer Tests - Excitation Tests]**

File Edit Operations Test Layout

Location: TCY TRACY 500 YARD
Serial No: 04873T10015-1

Special ID: KT2A1
CCT Desig: KT2A
Date: May 31 2002

**De-Energized Tap Changer**

Mfr: HYUNI Type:
# Steps: 5 Boost: + % Buck: - %
PSN-Fnd: PSN-Left:

**On-Load Tap Changer**

Mfr: HYUNI Type:
# Steps: 5 Boost: + % Buck: - %
PSN-Fnd: PSN-Left:

**Connections**

H 1 - H 0 | H 0 - H 1 | H - H

| | N | I | Detc Psn | Ltc Psn | Test kV | mA | watts | mA | watts | mA | watts | | INS RTG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 1 | 1 | 10 | 36.330 | 110.90 | 36.880 | 130 | | | I | |
| 2 | | | 1 | 2 | 10 | 36.360 | 110.60 | 36.960 | 130 | | | I | |
| 3 | | | 1 | 3 | 10 | 36.370 | 110.50 | 36.960 | 130.30 | | | I | |
| 4 | | | 1 | 4 | 10 | 36.380 | 110.40 | 36.980 | 130 | | | I | |
| 5 | | | 1 | 5 | 10 | 36.380 | 110.40 | 36.940 | 129.70 | | | I | |
| 6 | | | 2 | 1 | 10 | 37.700 | 116.50 | 38.280 | 135.40 | | | I | |
| 7 | | | 2 | 2 | 10 | 37.690 | 116.50 | 38.320 | 135.50 | | | I | |
| 8 | | | 2 | 3 | 10 | 37.690 | 116.50 | 38.340 | 135.80 | | | I | |
| 9 | | | 2 | 4 | 10 | 37.690 | 116.50 | 38.360 | 136 | | | I | |

# Analysis, Excitation Current and Watts
# Phase Patterns

**Two Similar and One Lower (HLH)**

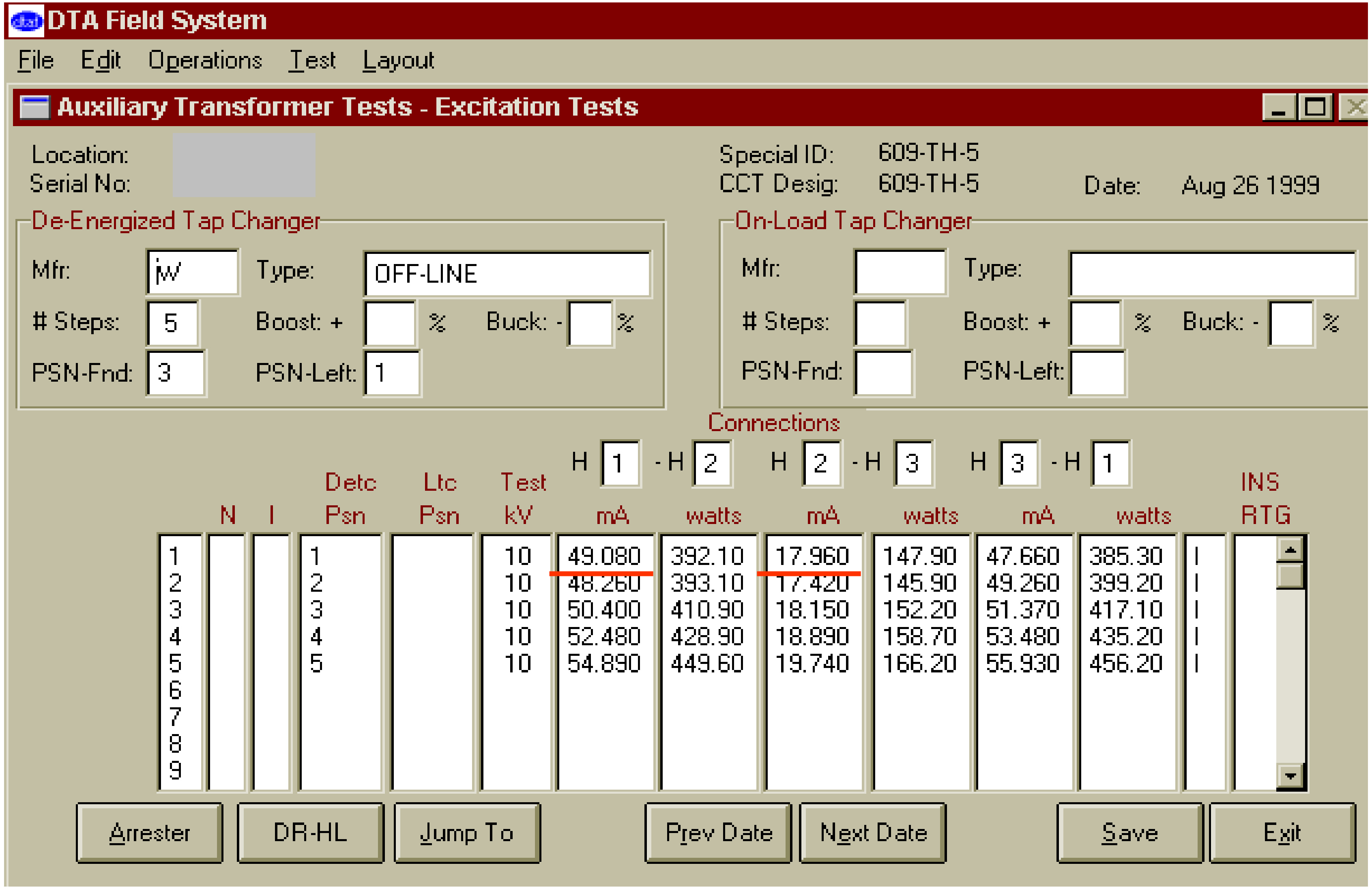
Most Common.

Three Legged Core.

Shell Form with Delta Secondary Winding.

Regular Test Procedure.

# Analysis, Excitation Current and Watts
# Phase Patterns



DTA Field System

File Edit Operations Test Layout

Auxiliary Transformer Tests - Excitation Tests

Location: Special ID: 609-TH-5
Serial No: CCT Desig: 609-TH-5 Date: Aug 26 1999

De-Energized Tap Changer
Mfr: W Type: OFF-LINE
# Steps: 5 Boost: + % Buck: - %
PSN-Fnd: 3 PSN-Left: 1

On-Load Tap Changer
Mfr: Type:
# Steps: Boost: + % Buck: - %
PSN-Fnd: PSN-Left:

Connections: H1 - H2 | H2 - H3 | H3 - H1

| | N | I | Detc Psn | Ltc Psn | Test kV | H1-H2 mA | H1-H2 watts | H2-H3 mA | H2-H3 watts | H3-H1 mA | H3-H1 watts | | INS RTG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 1 | | 10 | 49.080 | 392.10 | 17.960 | 147.90 | 47.660 | 385.30 | I | |
| 2 | | | 2 | | 10 | 48.260 | 393.10 | 17.420 | 145.90 | 49.260 | 399.20 | I | |
| 3 | | | 3 | | 10 | 50.400 | 410.90 | 18.150 | 152.20 | 51.370 | 417.10 | I | |
| 4 | | | 4 | | 10 | 52.480 | 428.90 | 18.890 | 158.70 | 53.480 | 435.20 | I | |
| 5 | | | 5 | | 10 | 54.890 | 449.60 | 19.740 | 166.20 | 55.930 | 456.20 | I | |
| 6 | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | |

Arrester | DR-HL | Jump To | Prev Date | Next Date | Save | Exit

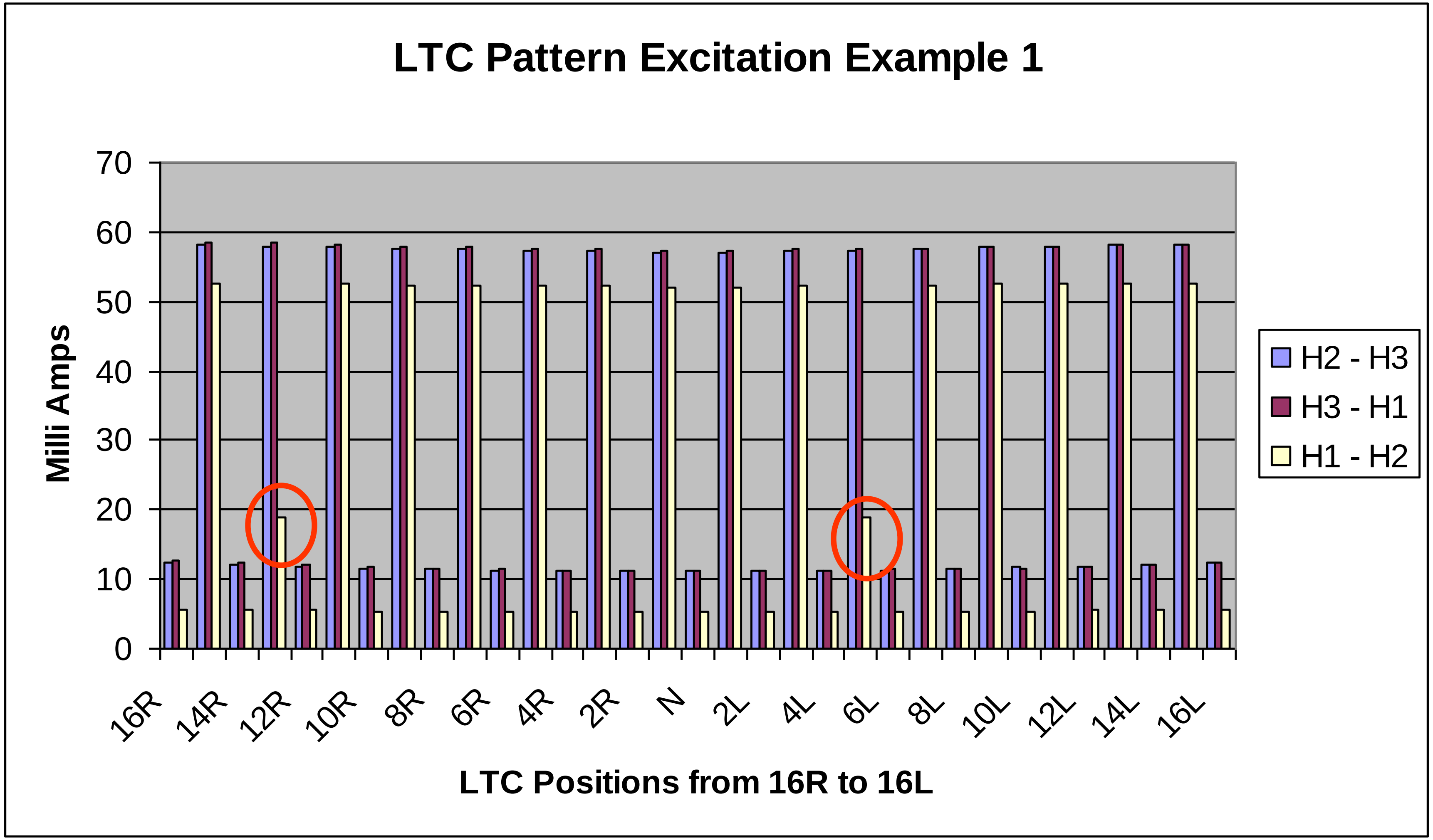
**Appears that H1 and H3 are rolled**

# Excitation Test
# Delta Wye Transformer Example

13 Raise and 5 Raise indicate trouble on H1-H2

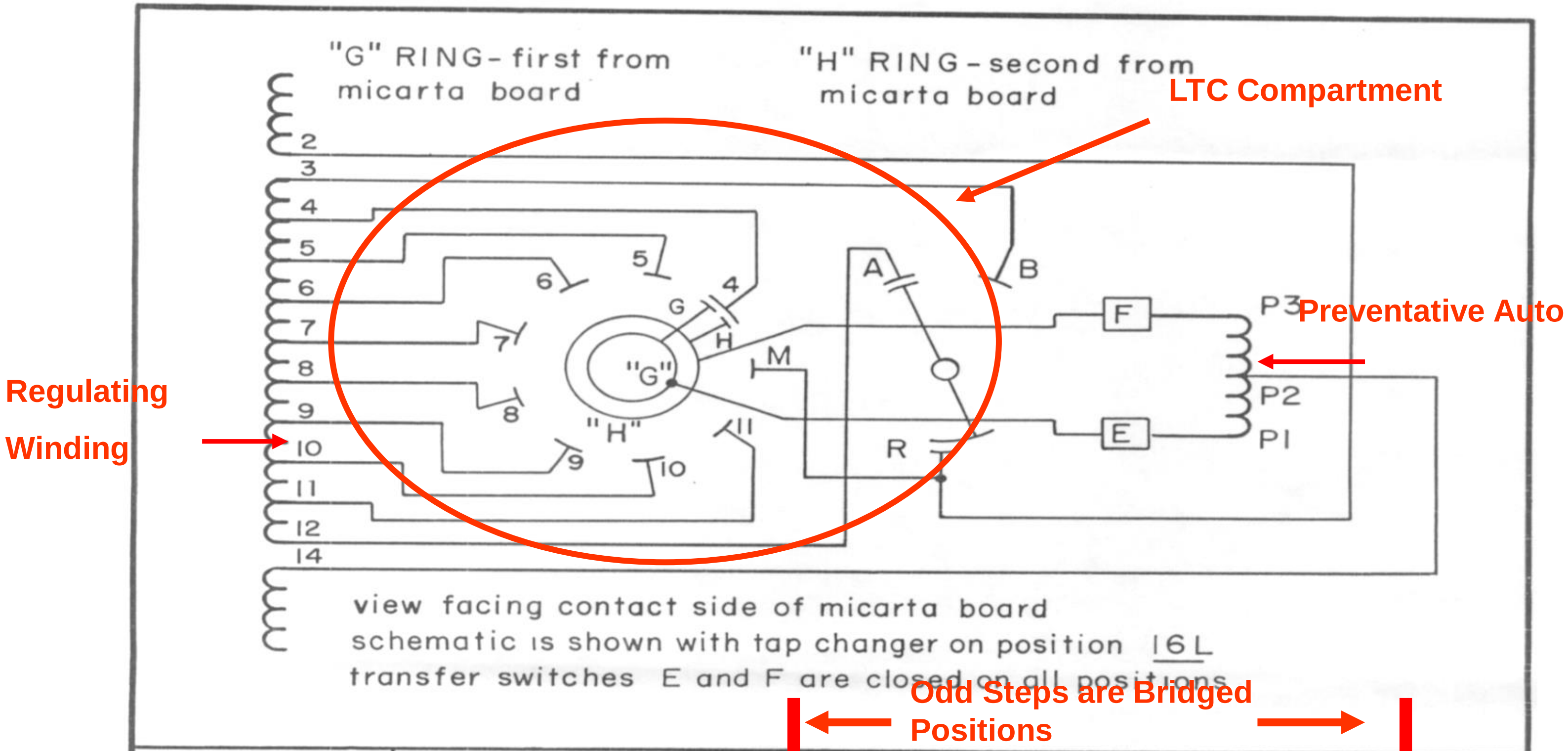
| | | | H2 - H3 | | | H3 - H1 | | | H1 - H2 | |
|---|---|---|---|---|---|---|---|---|---|---|
| **DETC** | **LTC** | **Test kV** | **mA** | **Watts** | **X** | **mA** | **Watts** | **X** | **mA** | **Watts** |
| C | 16R | 10 | 12.296 | 78.44 | L | 12.658 | 79.492 | L | 5.687 | 34.371 |
| C | 15R | 10 | 58.192 | 85.977 | L | 58.575 | 86.383 | L | 52.597 | 42.547 |
| C | 14R | 10 | 12.041 | 76.574 | L | 12.346 | 77.386 | L | 5.592 | 33.684 |
| C | **13R** | 10.004 | 57.945 | 84.218 | L | 58.399 | 84.737 | L | **18.88** | 64.341 |
| C | 12R | 10 | 11.806 | 74.91 | L | 12.095 | 75.705 | L | 5.508 | 33.08 |
| C | 11R | 10 | 57.814 | 82.606 | L | 58.126 | 82.778 | L | 52.498 | 41.292 |
| C | 10R | 10 | 11.603 | 73.513 | L | 11.793 | 73.903 | L | 5.431 | 32.559 |
| C | 9R | 10 | 57.674 | 81.387 | L | 57.976 | 81.384 | L | 52.423 | 40.84 |
| C | 8R | 10 | 11.427 | 72.348 | L | 11.614 | 72.692 | L | 5.367 | 32.118 |
| C | 7R | 10 | 57.55 | 80.469 | L | 57.828 | 80.187 | L | 52.376 | 40.52 |
| C | 6R | 10 | 11.315 | 71.439 | L | 11.455 | 71.578 | L | 5.314 | 31.765 |
| C | 5R | 10 | 57.433 | 79.813 | L | 57.67 | 79.299 | L | 52.263 | 40.295 |
| C | 4R | 10 | 11.202 | 70.714 | L | 11.33 | 70.783 | L | 5.272 | 31.504 |
| C | 3R | 10.001 | 57.338 | 79.241 | L | 57.514 | 78.788 | L | 52.236 | 40.205 |
| C | 2R | 10 | 11.124 | 70.27 | L | 11.227 | 70.238 | L | 5.245 | 31.299 |
| C | 1R | 10 | 56.972 | 79.277 | L | 57.203 | 78.823 | L | 51.893 | 40.315 |
| C | N | 9.999 | 11.094 | 70.122 | L | 11.202 | 70.039 | L | 5.238 | 31.235 |
| C | 1L | 10.001 | 57.121 | 78.981 | L | 57.364 | 78.354 | L | 52.068 | 39.925 |
| C | 2L | 10 | 11.125 | 70.181 | L | 11.242 | 70.213 | L | 5.254 | 31.308 |
| C | 3L | 10.001 | 57.334 | 78.933 | L | 57.467 | 78.394 | L | 52.258 | 39.901 |
| C | 4L | 10 | 11.205 | 70.706 | L | 11.268 | 70.548 | L | 5.29 | 31.474 |
| C | 5L | 10 | 57.415 | 79.564 | L | 57.586 | 78.935 | L | **18.82** | 63.081 |
| C | 6L | 9.999 | 11.343 | 71.481 | L | 11.383 | 71.247 | L | 5.331 | 31.736 |
| C | 7L | 10 | 57.626 | 80.416 | L | 57.687 | 79.703 | L | 52.381 | 40.389 |
| C | 8L | 10 | 11.485 | 72.475 | L | 11.483 | 72.073 | L | 5.385 | 32.101 |

# Graph


LTC Pattern Excitation Example 1
Milli Amps
0
10
20
30
40
50
60
70
16R
14R
12R
10R
8R
6R
4R
2R
N
2L
4L
6L
8L
10L
12L
14L
16L
LTC Positions from 16R to 16L
H2 - H3
H3 - H1
H1 - H2

# Delta Wye Transformer Example 1

The nameplate was examined. 13R and 5L steps shared the same contact.




POSITION — LOWER

| CONTACT | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 (G) connects to | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 11 | 11 | M |
| P3 (H) connects to | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 11 | 11 |
| R connects to | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |

POSITION — N / RAISE

| CONTACT | N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 (G) connects to | M | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 11 | 11 |
| P3 (H) connects to | M | M | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 11 |
| R connects to | A | B | B | B | B | B | B | B | B | B | B | B | B | B | B | B | B |

# Analysis, Excitation Current and Watts Phase Patterns

Determining Phase Patterns:

- The Doble Test Assistant Considered Measurements similar if:

  (1) Currents are between 0 and 50 mA and are within 10% of each value

  (2) Currents are greater than 50 mA and are within 5% of each value

# Analysis, Excitation Current and Watts Phase Patterns

- **Three Similar Phase Currents (SSS)**
  - 4 or 5 Legged Cores
  - Shell Form with Non Delta Connected Secondary
  - 3 Single Phase Transformers Connected as a Three Phase Transformer.

# Analysis, Excitation Current and Watts Phase Patterns

**Two Similar and One Higher (LHL)**

- Delta Connected Primary Performed Using the Alternate Method
- Wye Connected Primary, Neutral is Not Accessible, Measuring Two Phases in Series
- High Capacitance Windings and Low Loss Core

# Analysis, Excitation Current and Watts Phase Patterns

Transformer Excitation Current Test Procedure 3 Phase, Wye Connected Windings Without an Accessible H0 Bushing

| Test No. | Measure | Test Mode | Energize | UST | Float |
|---|---|---|---|---|---|
| 1 | H3-H0+H0-H1 | UST | H3 | H1 | H2,X1,X2,X3 |
| 2 | H1-H0+H0-H2 | UST | H1 | H2 | H3,X1,X2,X3 |
| 2 | H2-H0+H0-H3 | UST | H2 | H3 | H1,X1,X2,X3 |

Note: If Low Voltage Winding is Wye-Connected - Ground X0

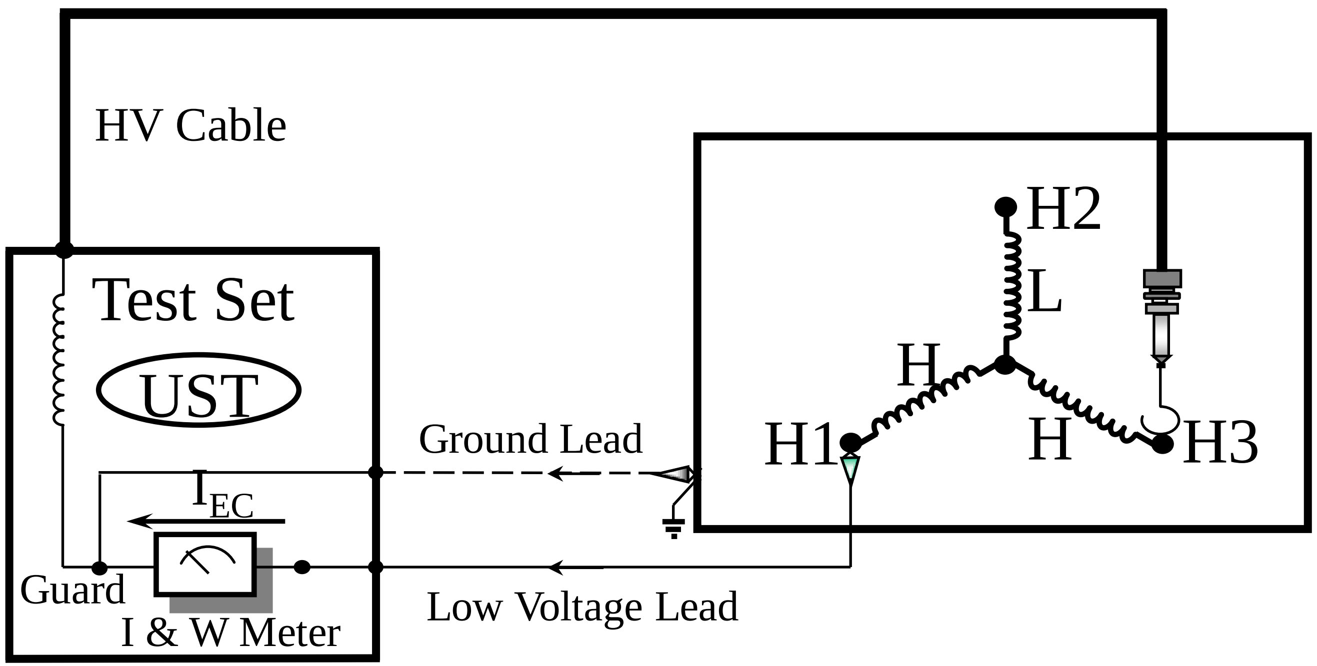
# Wye Connected Windings Without

# Accessible H0 Bushing

# Test 1: Measure H3 to H1

Energize: H3, UST: H1, Float: H2,X1,X2,X3

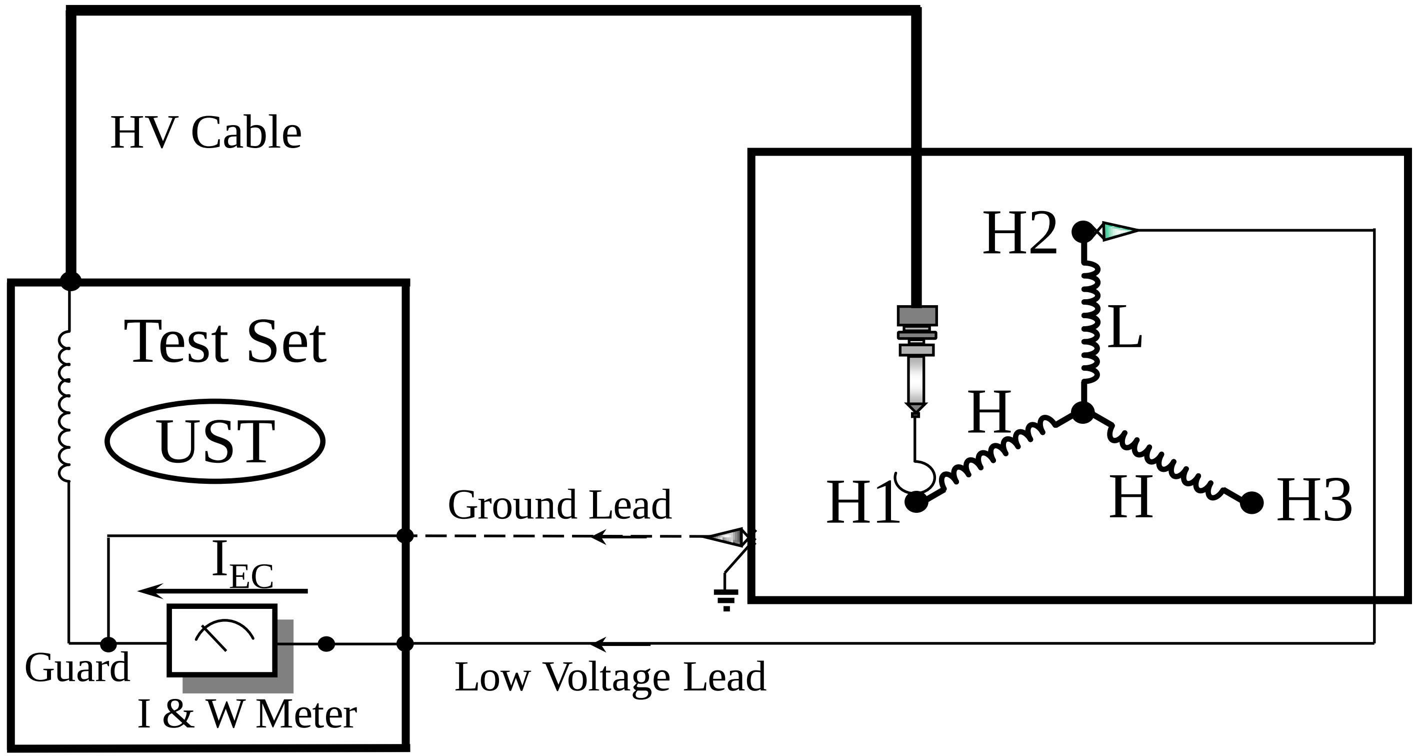
Note: If Low Voltage Winding is Wye-Connected - Ground X0



# Test 2: Measure H1 to H2

Energize H1, UST H2, Float H3,X1,X2,X3

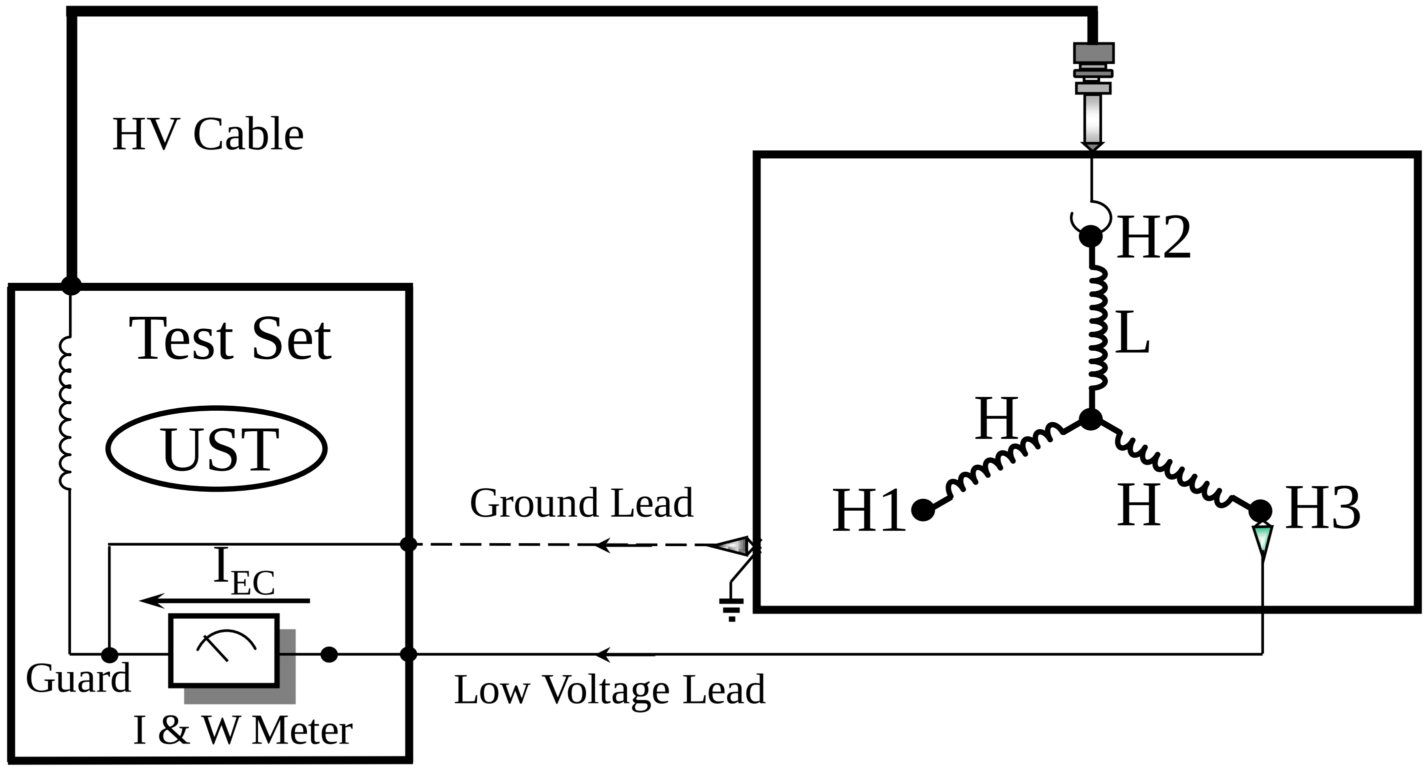
Note: If Low Voltage Winding is Wye-Connected - Ground X0



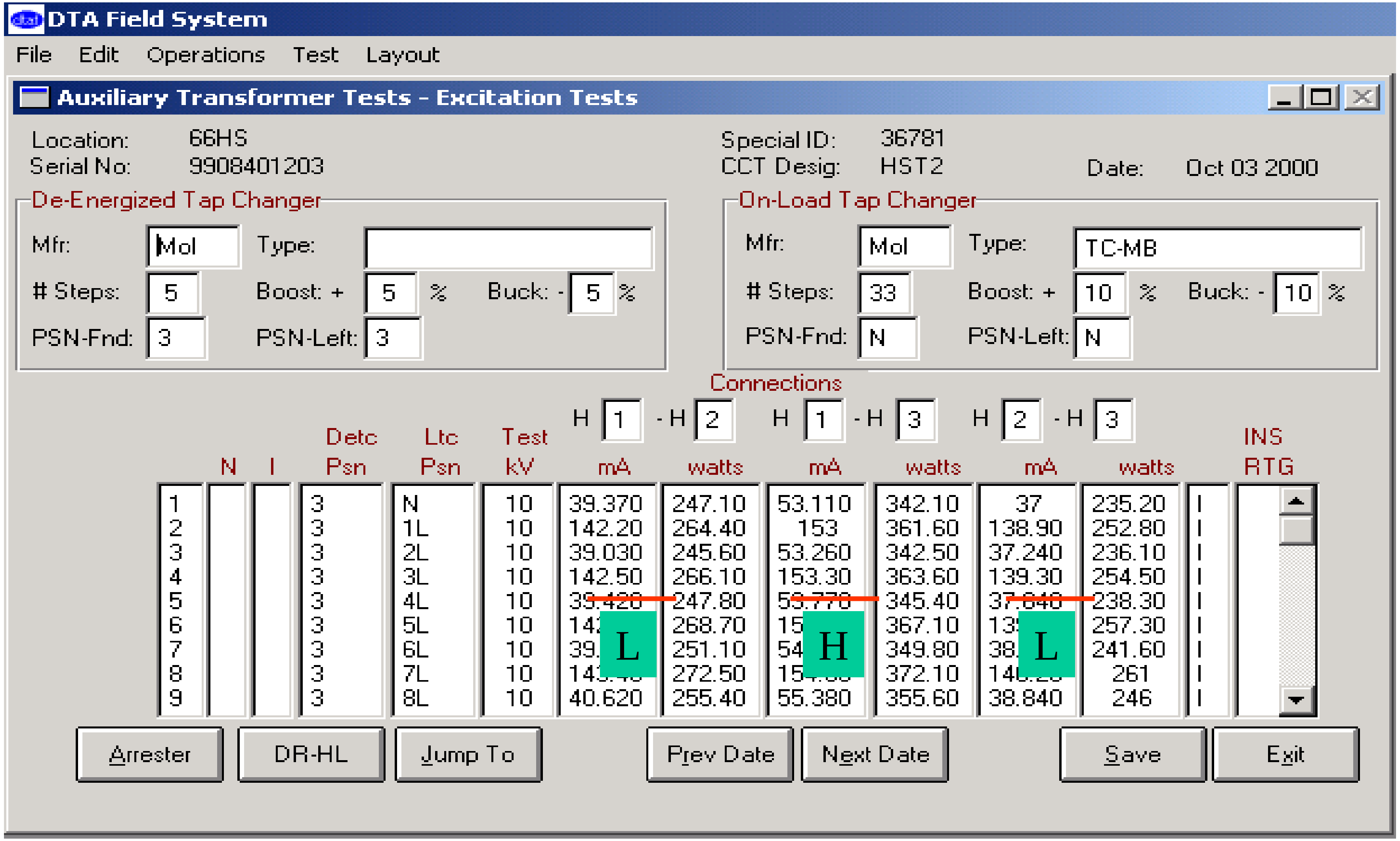
# Test 3: Measure H2 to H3

Energize: H2, UST: H3,  Float: H1,X1,X2,X3

Note: If Low Voltage Winding is Wye-Connected - Ground X0



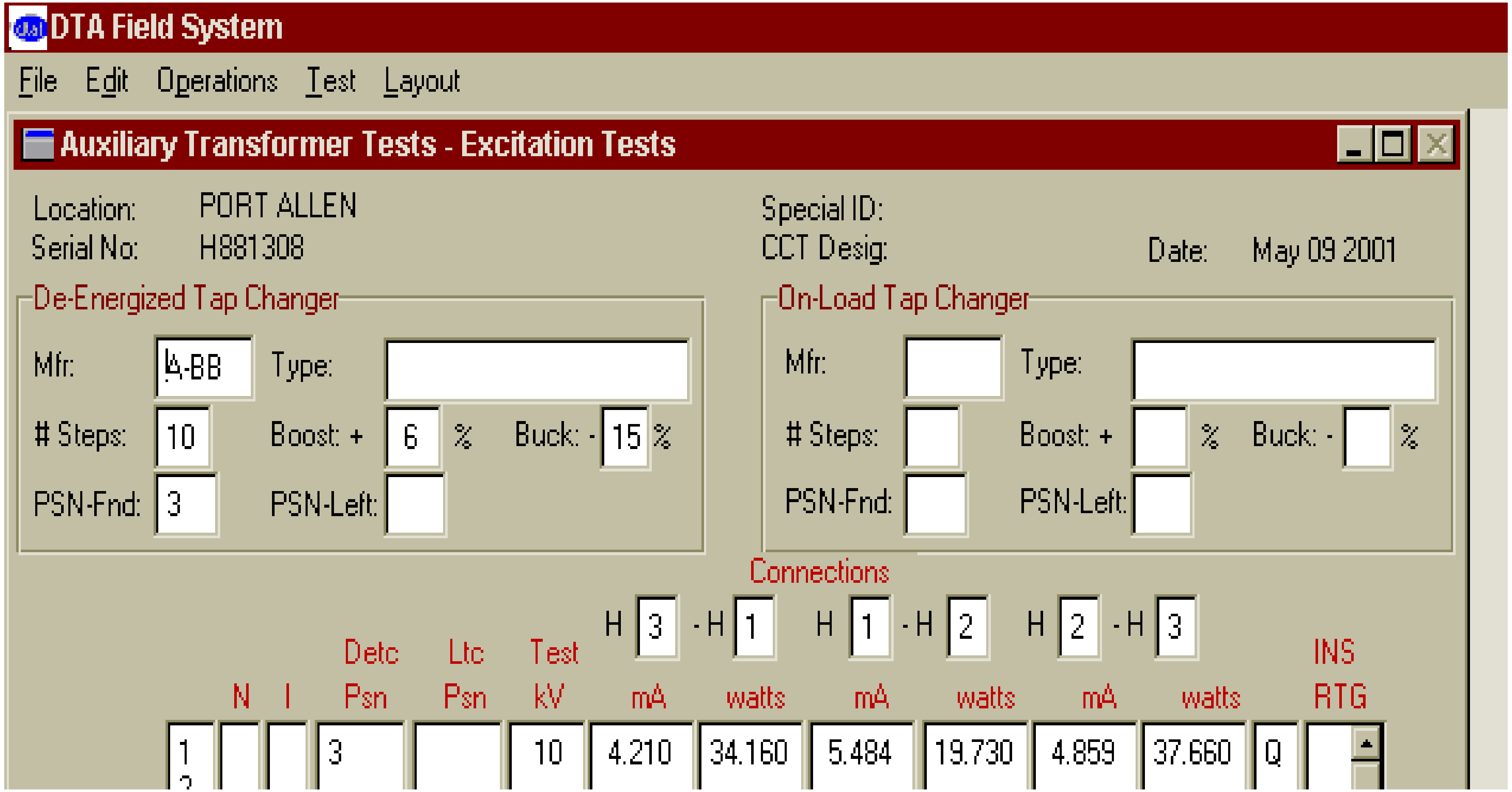
# Wye Connected Windings
# Without Accessible H0 Bushing




| | N | I | Detc Psn | Ltc Psn | Test kV | H1-H2 mA | H1-H2 watts | H1-H3 mA | H1-H3 watts | H2-H3 mA | H2-H3 watts | | INS RTG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 3 | N | 10 | 39.370 | 247.10 | 53.110 | 342.10 | 37 | 235.20 | I | |
| 2 | | | 3 | 1L | 10 | 142.20 | 264.40 | 153 | 361.60 | 138.90 | 252.80 | I | |
| 3 | | | 3 | 2L | 10 | 39.030 | 245.60 | 53.260 | 342.50 | 37.240 | 236.10 | I | |
| 4 | | | 3 | 3L | 10 | 142.50 | 266.10 | 153.30 | 363.60 | 139.30 | 254.50 | I | |
| 5 | | | 3 | 4L | 10 | 39.420 | 247.80 | 53.770 | 345.40 | 37.640 | 238.30 | I | |
| 6 | | | 3 | 5L | 10 | 14[illegible] | 268.70 | 15[illegible] | 367.10 | 13[illegible] | 257.30 | I | |
| 7 | | | 3 | 6L | 10 | 39.[illegible] | 251.10 | 54[illegible] | 349.80 | 38.[illegible] | 241.60 | I | |
| 8 | | | 3 | 7L | 10 | 14[illegible] | 272.50 | 15[illegible] | 372.10 | 14[illegible] | 261 | I | |
| 9 | | | 3 | 8L | 10 | 40.620 | 255.40 | 55.380 | 355.60 | 38.840 | 246 | I | |

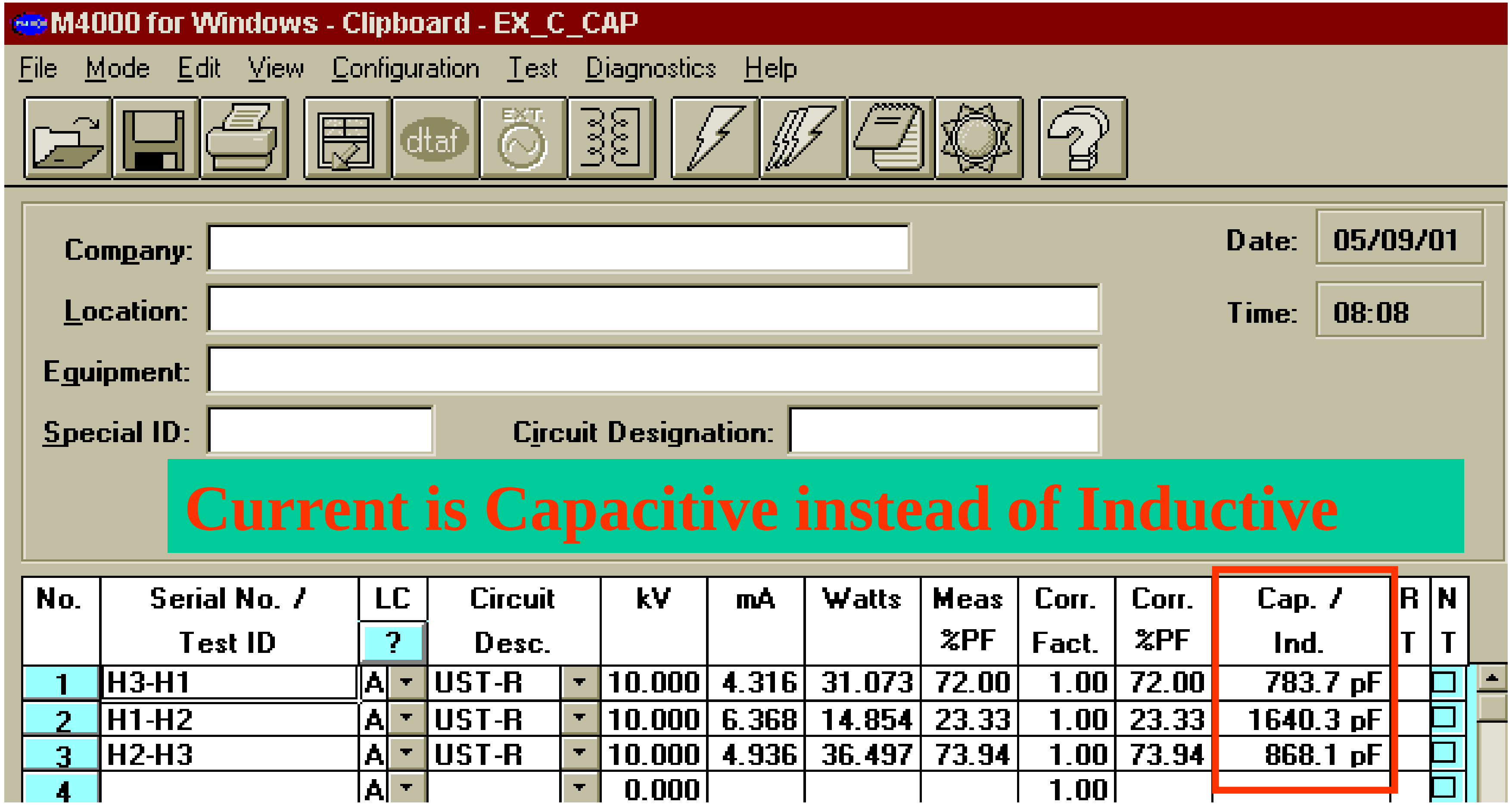
# Transformer Excitation Current and Watts, Test Procedure, Three Phase

## LHL Pattern - When HLH Pattern Expected



# Transformer Excitation Current and Watts, Test Procedure, Three Phase

## LHL Pattern - When HLH Pattern Expected



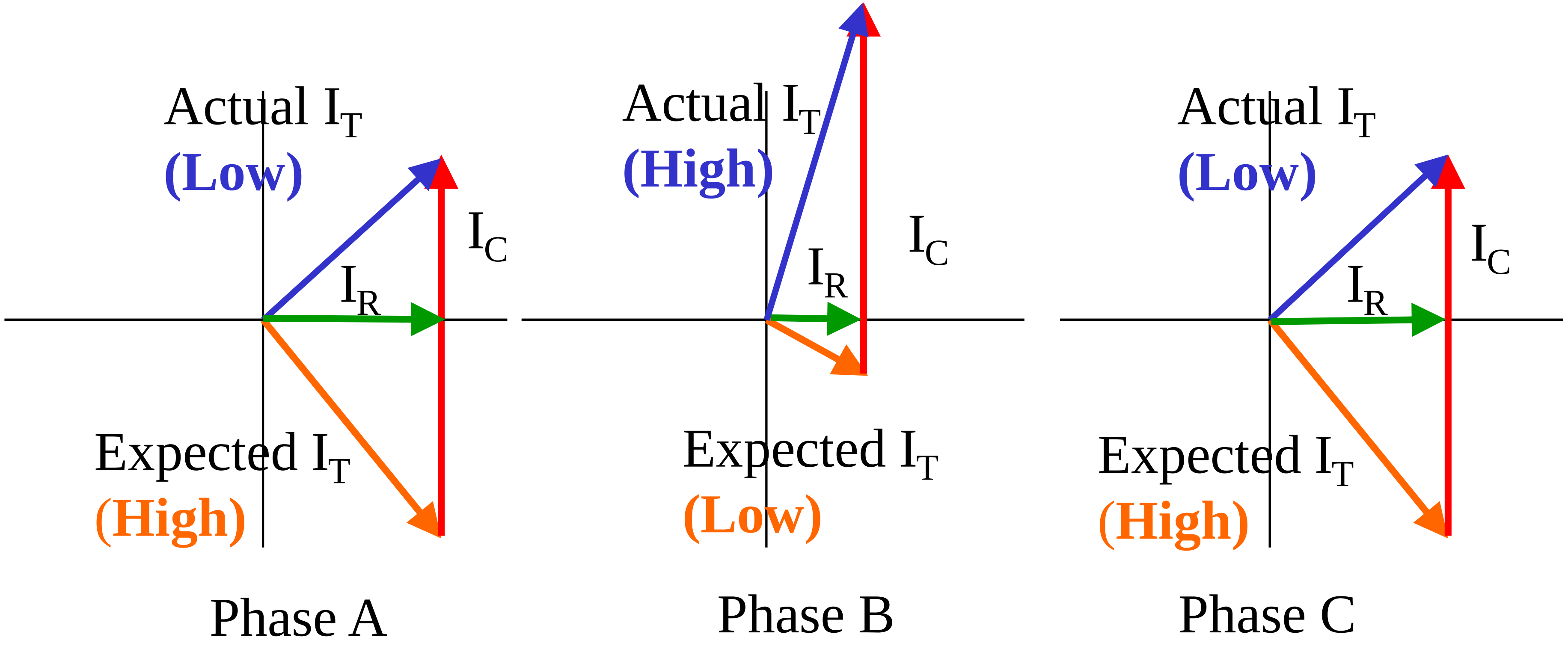

| No. | Serial No. / Test ID | LC ? | Circuit Desc. | kV | mA | Watts | Meas %PF | Corr. Fact. | Corr. %PF | Cap. / Ind. | RT | NT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | H3-H1 | A | UST-R | 10.000 | 4.316 | 31.073 | 72.00 | 1.00 | 72.00 | 783.7 pF | | ☐ |
| 2 | H1-H2 | A | UST-R | 10.000 | 6.368 | 14.854 | 23.33 | 1.00 | 23.33 | 1640.3 pF | | ☐ |
| 3 | H2-H3 | A | UST-R | 10.000 | 4.936 | 36.497 | 73.94 | 1.00 | 73.94 | 868.1 pF | | ☐ |
| 4 | | A | | 0.000 | | | | 1.00 | | | | ☐ |

# Transformer Excitation Current and Watts, Test Procedure, Three Phase

## LHL Pattern When HLH Pattern Expected

Added Capacitance Current of the Winding = $I_C$

Watts ($I_R$) has the HLH Pattern



# Analysis - Problems That Can Be Detected

**Windings**

•Turn-To-Turn Winding Insulation Failure Causing a Short Circuit or Resistive Connection

•Winding to Ground Short for a Grounded Winding

•Open Windings (Main, Tap, Reactor)

•High Resistance Conductor Connections

•Phase-To-Phase Electrical Tracking

# Analysis - Problems That Can Be Detected

**Tap Changer**

- Misalignment
- Mechanical Problems
- Coking and Wear of LTC and DETC Contacts

**Core**

- Abnormal Circulating Currents in the Core From:
  - Clamping Components
  - Multiple Core Grounds
- Core Lamination Insulation Damage
- Core Joint Dislocations

# Oil Circuit Breakers

# Dead-Tank Oil Circuit Breaker

**Recommended Tests:**

Power-Factor

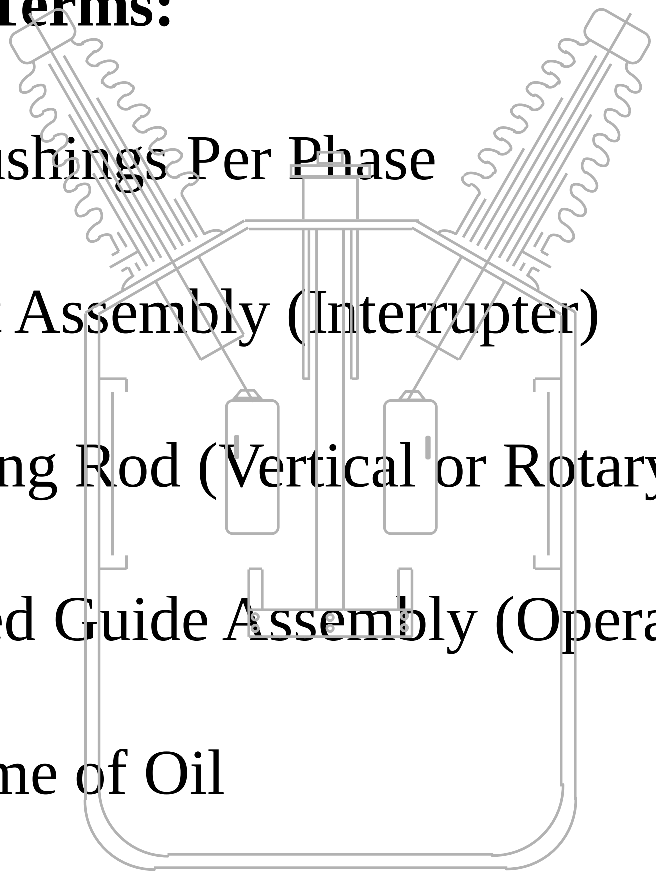
Time & Travel

Contact Resistance

CGE, 260 kV
type FGK

# Oil Circuit Breaker Tests

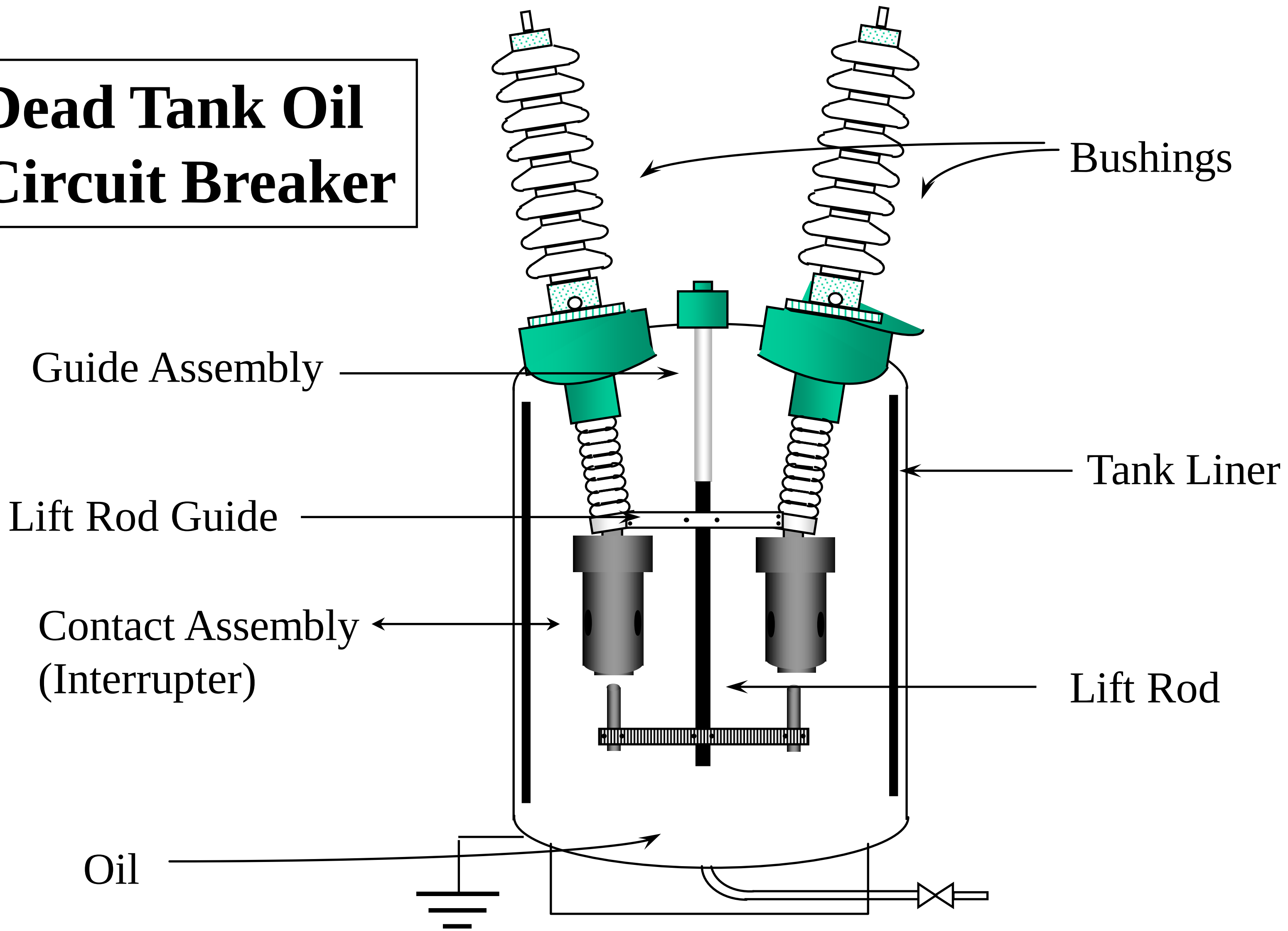
**In Simplified Terms:**



- Two Bushings Per Phase
- Contact Assembly (Interrupter)
- Operating Rod (Vertical or Rotary)
- Insulated Guide Assembly (Operating Rod)
- A Volume of Oil
- Tank Liner

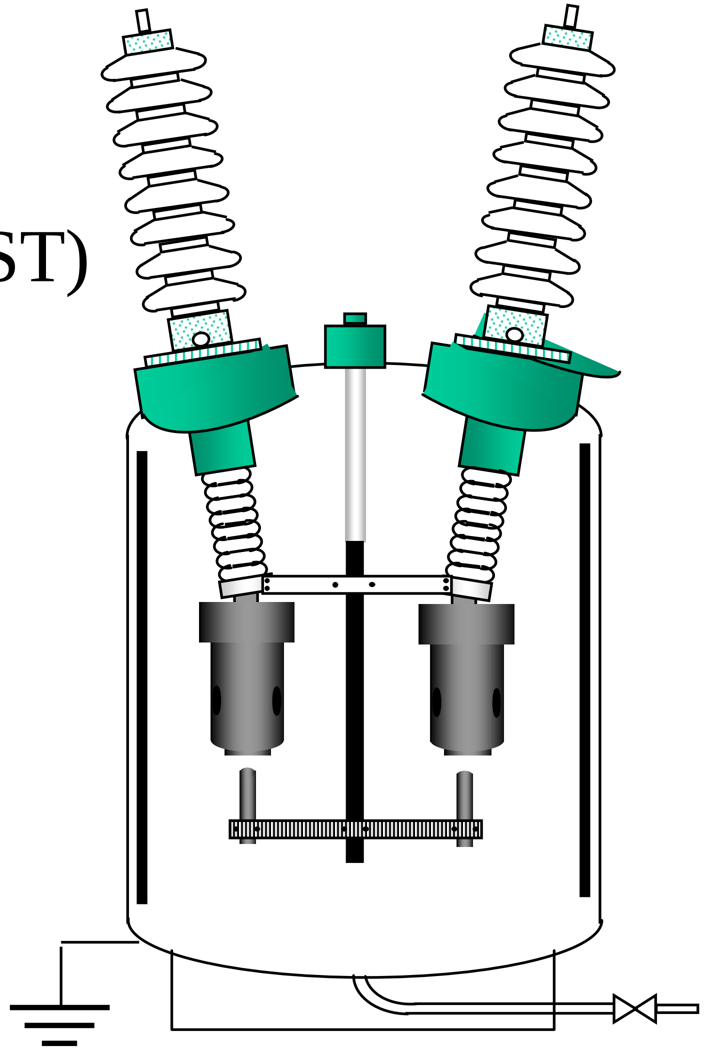
# Oil Circuit Breaker Tests

**Dead Tank Oil Circuit Breaker**



# Doble Recommended Tests (Minimum)

- Overall Circuit Breaker Test
  a. Six Open Breaker (GST)
  b. Three Closed Breaker (GST)
- Tank Loss Index
- Bushing Tests
- Oil Sample Test
- Miscellaneous
- Diagnostic



# Recommended Doble Test Voltages
# Oil Circuit Breakers

**Use Line to Ground Voltages**
**for the Line to Line Voltage Rating of the Breaker**

# Transformer Overall Tests

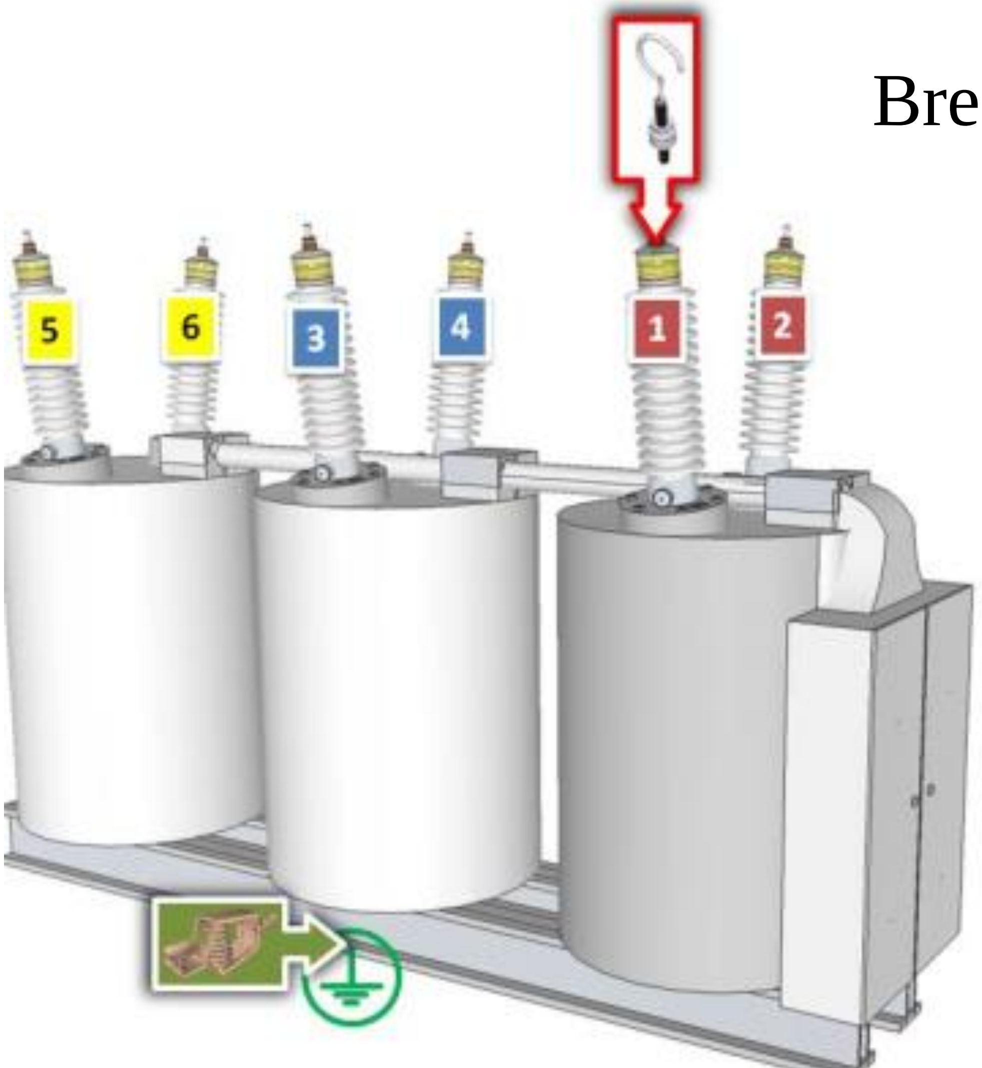
Examples of voltages and their calculated line to ground voltages.

**These are general guidelines.**

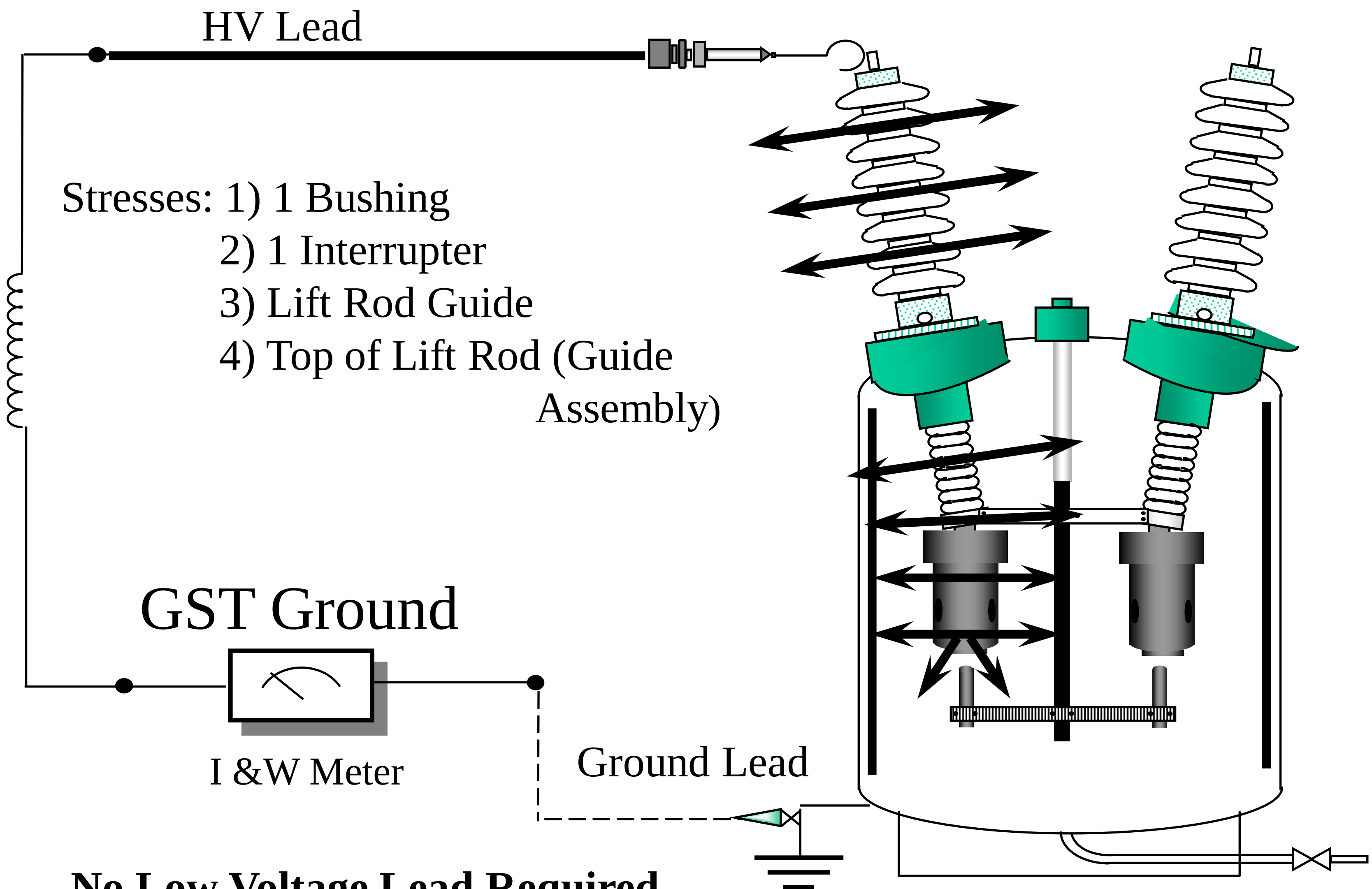
| Line to Line kV | Line to Ground Voltage |
|---|---|
| 17.32 kV | 10,000 |
| 13.8 kV | 7967 |
| 12.47 kV | 7200 |
| 4.16 kV | 2401 |
| 2.4 kV | 1385 |
| .48 kV | 277 |

# Overall Test Procedure
# Tests 1-6

Breaker is Open



# Open Circuit Breaker Test




**No Low Voltage Lead Required**

# Open Breaker Test

Major Contribution of Watts-Loss:

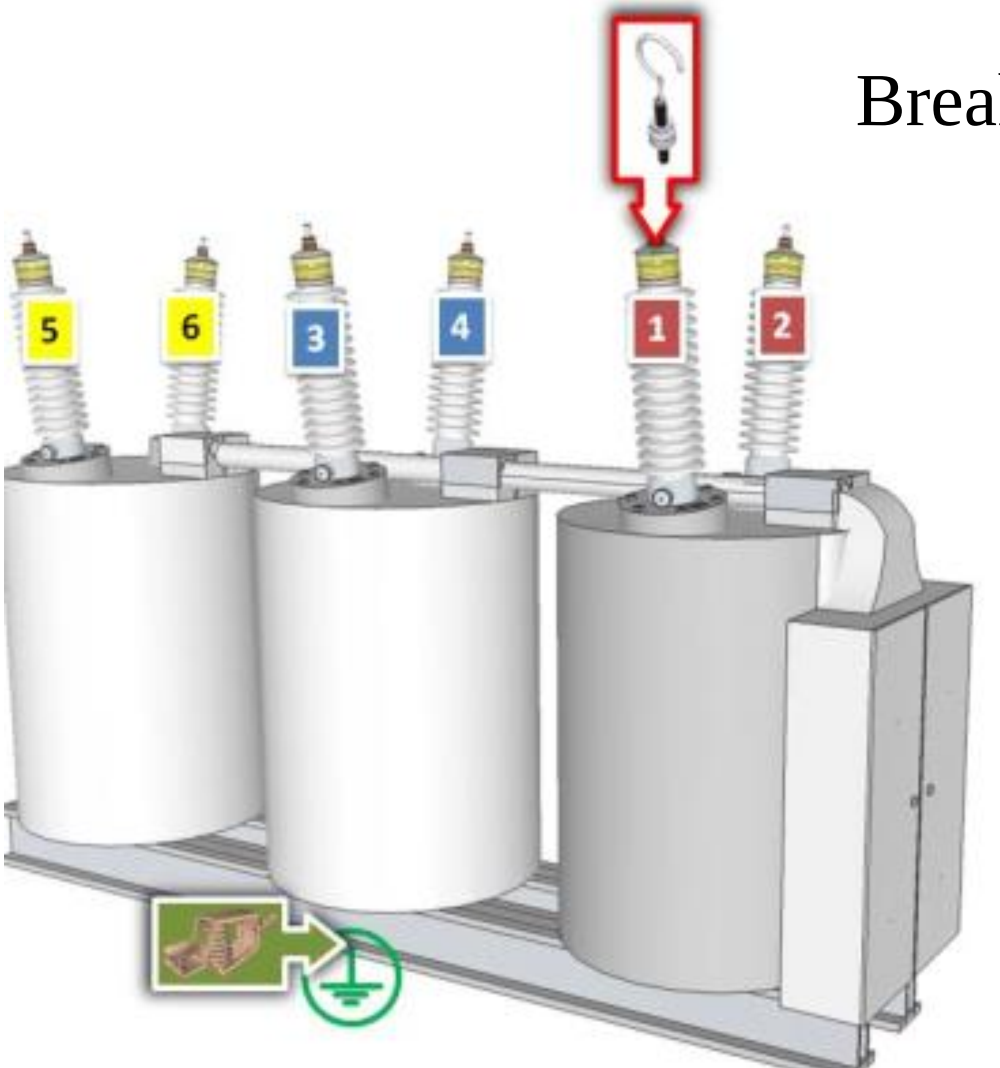
- Bushing
- Contact Assembly (Interrupter)
- Lift-Rod Guide
- Upper Lift-Rod

Lesser Contribution of Watts-Loss:

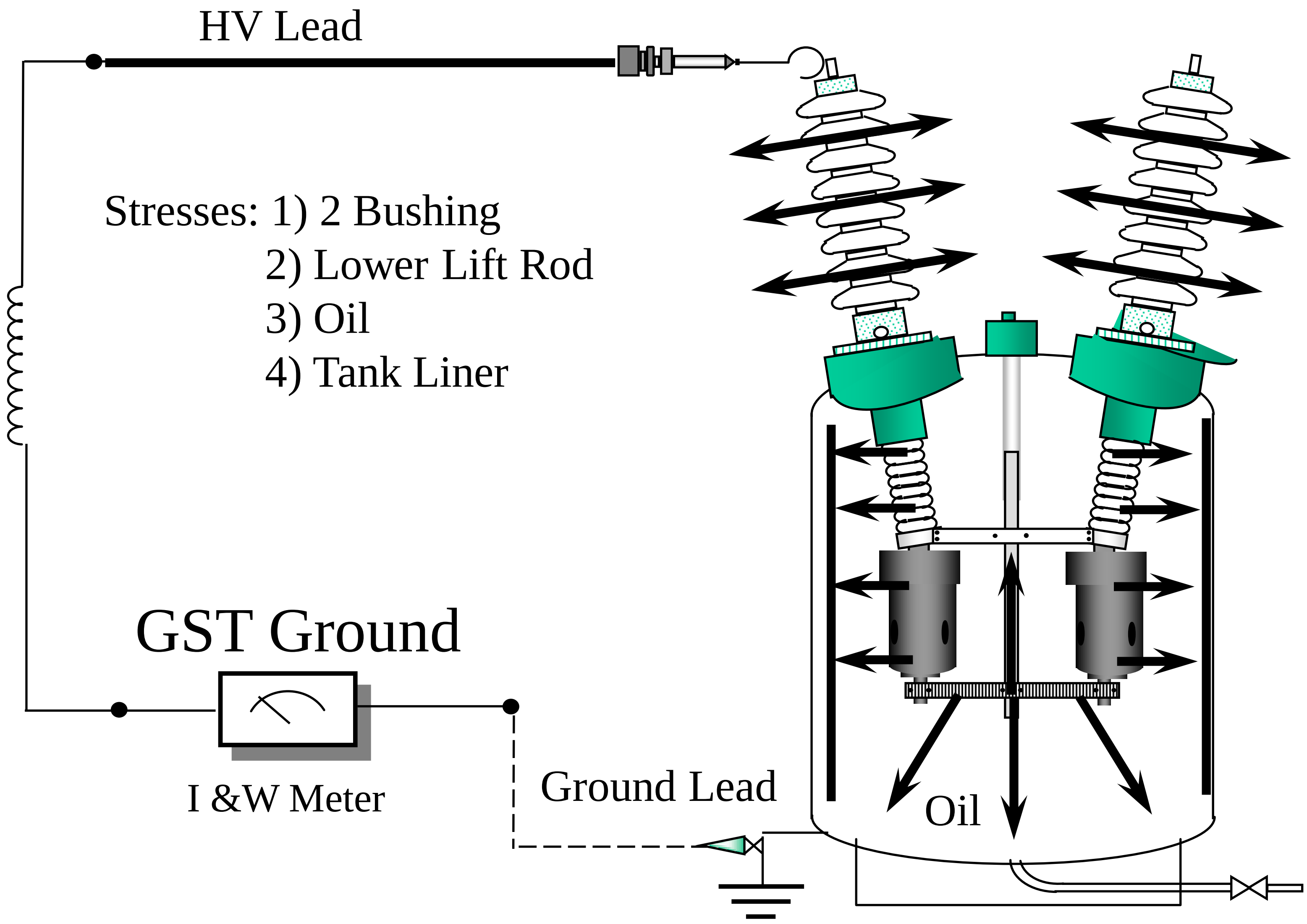
- Tank Liner
- Oil

# Overall Test Procedure
# Tests 7-9

Breaker is Closed



# Closed Breaker Test



# Closed Breaker Test

Major Contribution of Watts-Loss:

- Bushing (2)
- Oil
- Lower Lift-Rod
- Tank Liner

Lesser Contribution of Watts-Loss:

- Contact Assembly (Interrupter)
- Lift-Rod Guide

# Tank Loss Index( TLI )

•Bushings Comprise the Largest Portion of the Oil Circuit Breaker Insulation System

•A Bad Bushing Will Be Indicated in the Open and Closed Breaker Tests.

•To Analyze the Condition of the Internal Parts of the OCB, Tank Loss Index (TLI) was Developed

TLI = Closed Breaker Watts - ($\Sigma$ Open Breaker Watts )
(For Each Phase)

# Tank Loss Index( TLI )

**Closed Breaker – Sum of the Open Breaker**

**TLI** = **2 Bushings** + Lower Lift Rod + Oil + Tank Liner -(**2 Bushings** + 2 Lift Rod Guides + 2 Top of Lift Rods +2 Interrupters)

= Lower Lift Rod+ Oil +Tank Liner - 2 Interrupters - Lift Rod Guides - 2 Top of Lift Rods

As a General Rule: TLI Tends to Be Negative

# Tank Loss Index: Component Failures

**TLI** = Lower Lift Rod+ Oil +Tank Liner - 2 Interrupters - Lift Rod Guides - 2 Top of Lift Rods

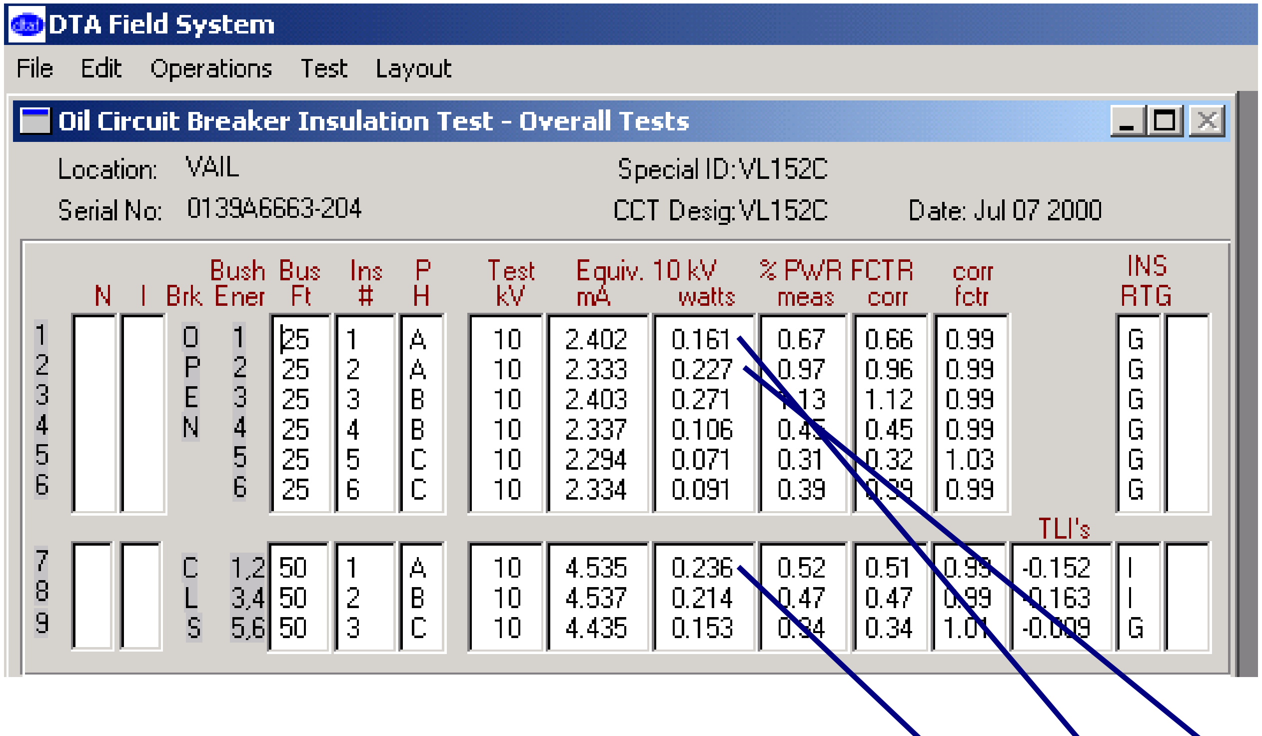
What would happen to TLI if:

- Water Content of the Oil Increases…..
- Carbon is Collecting on the Interrupters…
- Tank Liner Becomes Saturated With Water
- Lift Rod Guide is Deteriorating Due to Corona Activity…

# Guideline Tank-Loss Indexes (TLI) Oil Circuit Breakers

| | Tank Loss Index | | | | |
|---|---|---|---|---|---|
| 2.5 kV | Above -15 mW | Between -10 mW and -15 mV | -10 mW to +7.5 mW | Between +7.5 mW and +15 mW | Above +15 mW |
| 10 kV | Above -0.20 W | Between -0.10 W and -0.20 W | -0.10 W to +0.05 W | Between +0.05 W and +0.10 W | Above +0.10 W |
| | Investigate Immediately | Retest on a more frequent basis. | Normal for most breaker types. Place on a normal routine test schedule. | Retest on a more frequent basis. | Investigate Immediately |
| | Lift-Rod guide assembly, contact assembly (Interrupter), and upper portion of lift rod. | | | Lift rod, Tank Oil, tank liner, and auxiliary contact support insulation. | |

# Calculating Tank Loss Index



DTA Field System

File Edit Operations Test Layout

Oil Circuit Breaker Insulation Test - Overall Tests

Location: VAIL Special ID:VL152C

Serial No: 0139A6663-204 CCT Desig:VL152C Date: Jul 07 2000

| | N | I | Brk | Bush Ener | Bus Ft | Ins # | P H | Test kV | Equiv. 10 kV mA | watts | % PWR FCTR meas | corr | corr fctr | TLI's | INS RTG | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | O | 1 | 25 | 1 | A | 10 | 2.402 | 0.161 | 0.67 | 0.66 | 0.99 | | G | |
| 2 | | | P | 2 | 25 | 2 | A | 10 | 2.333 | 0.227 | 0.97 | 0.96 | 0.99 | | G | |
| 3 | | | E | 3 | 25 | 3 | B | 10 | 2.403 | 0.271 | 1.13 | 1.12 | 0.99 | | G | |
| 4 | | | N | 4 | 25 | 4 | B | 10 | 2.337 | 0.106 | 0.45 | 0.45 | 0.99 | | G | |
| 5 | | | | 5 | 25 | 5 | C | 10 | 2.294 | 0.071 | 0.31 | 0.32 | 1.03 | | G | |
| 6 | | | | 6 | 25 | 6 | C | 10 | 2.334 | 0.091 | 0.39 | 0.39 | 0.99 | | G | |
| 7 | | | C | 1,2 | 50 | 1 | A | 10 | 4.535 | 0.236 | 0.52 | 0.51 | 0.99 | -0.152 | I | |
| 8 | | | L | 3,4 | 50 | 2 | B | 10 | 4.537 | 0.214 | 0.47 | 0.47 | 0.99 | -0.163 | I | |
| 9 | | | S | 5,6 | 50 | 3 | C | 10 | 4.435 | 0.153 | 0.34 | 0.34 | 1.01 | -0.009 | G | |

$$TLI_A = CBW_7 - (OBW_1+OBW_2) = 0.236 - (0.161+ 0.227) = - 0.152W$$

$$TLI_B = CBW_8 - (OBW_3+OBW_4) = 0.214 - (0.271+ 0.106) = - 0.163W$$

$$TLI_C = CBW_9 - (OBW_5+OBW_6) = 0.153 - (0.071+ 0.091) = - 0.009W$$

# Analysis of
# Oil Circuit Breaker
# Condition

# Currents Do Not Add Up

**DTA Field System**

File Edit Operations Test Layout

**Oil Circuit Breaker Insulation Test - Overall Tests**

Location: OCB 8A  Special ID:

Serial No: 1-37Y5139  CCT Desig:  Date: Mar 10 1983

| | N | I | Brk | Bush Ener | Bus Ft | Ins # | P H | Test kV | Equiv. 10 kV mA | Equiv. 10 kV watts | % PWR FCTR meas | % PWR FCTR corr | corr fctr | TLI's | INS RTG | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | O | 1 | 0 | 0 | A | 10 | 2.200 | 0.240 | 1.09 | 1.05 | 0.96 | | G | |
| 2 | | | P | 2 | 0 | 0 | A | 10 | 2 | 0.240 | 1.20 | 1.15 | 0.96 | | G | |
| 3 | | | E | 3 | 0 | 0 | B | 10 | 2.100 | 0.240 | 1.14 | 1.09 | 0.96 | | G | |
| 4 | | | N | 4 | 0 | 0 | B | 10 | 2.200 | 0.280 | 1.27 | 1.22 | 0.96 | | G | |
| 5 | | | | 5 | 0 | 0 | C | 10 | 2.200 | 0.280 | 1.27 | 1.22 | 0.96 | | G | |
| 6 | | | | 6 | 0 | 0 | C | 10 | 2.100 | 0.220 | 1.05 | 1.01 | 0.96 | | G | |
| 7 | | | C | 1,2 | 0 | 0 | A | 10 | 2 | 0.240 | 1.20 | 1.15 | 0.96 | -0.240 | I | |
| 8 | | | L | 3,4 | 0 | 0 | B | 10 | 4.300 | 0.520 | 1.21 | 1.16 | 0.96 | 0.0000 | G | |
| 9 | | | S | 5,6 | 0 | 0 | C | 10 | 4.200 | 0.440 | 1.05 | 1.01 | 0.96 | -0.060 | G | |

ID Scre

Note: Nun

other bushings must be floating.

**Check If Breaker was Open**

# Bushing Problem Identified

**DTA Field System**

File Edit Operations Test Layout

**Oil Circuit Breaker Insulation Test - Overall Tests**

Location: VAIL  Special ID: VL152C

Serial No: 0139A6663-204  CCT Desig: VL152C  Date: Jun 29 2000

| | N | I | Brk | Bush Ener | Bus Ft | Ins # | P H | Test kV | Equiv. 10 kV mA | Equiv. 10 kV watts | % PWR FCTR meas | % PWR FCTR corr | corr fctr | TLI's | INS RTG | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | O | 1 | 25 | 1 | A | 10 | 2.414 | 0.197 | 0.82 | 0.81 | 0.99 | | G | |
| 2 | | | P | 2 | 25 | 2 | A | 10 | 2.338 | 0.109 | 0.47 | 0.47 | 0.99 | | G | |
| 3 | | | E | 3 | 25 | 3 | B | 10 | 2.401 | 0.145 | 0.60 | 0.59 | 0.99 | | G | |
| 4 | | | N | 4 | 25 | 4 | B | 10 | 2.338 | 0.126 | 0.54 | 0.53 | 0.99 | | G | |
| 5 | | | | 5 | 25 | 5 | C | 10 | 2.534 | 3.413 | 13.47 | 13.3 | 0.99 | | I | |
| 6 | | | | 6 | 25 | 6 | C | 10 | 2.336 | 0.120 | 0.51 | 0.50 | 0.99 | | G | |
| 7 | | | C | 1,2 | 50 | 1 | A | 10 | 4.547 | 0.276 | 0.61 | 0.60 | 0.99 | -0.030 | G | |
| 8 | | | L | 3,4 | 50 | 2 | B | 10 | 4.553 | 0.260 | 0.57 | 0.56 | 0.99 | -0.011 | G | |
| 9 | | | S | 5,6 | 50 | 3 | C | 10 | 4.659 | 3.548 | 7.62 | 7.54 | 0.99 | 0.015 | I | |

ID Screen | Bushing | Jump To | Prev Date | Next Date | Save | Exit

Note: Numbers in BUSH ENER column indicate bu
other bushings must be floating.

GE Type U Bushings

# Bushing Problem Identified

**DTA Field System**

File Edit Operations Test Layout

**Oil Circuit Breaker Insulation Test - Bushing Tests**

Location: VAIL — Special ID: VL152C

Serial No: 0139A6663-204 — CCT Desig: VL152C — Date: Jun 29 2000

| | N | I | Nameplate Serial # | | C(pF) | %PF | Test kV | Equiv. 10kV mA | watts | % PWR FCTR meas | corr | corr fctr | meas C(pF) | INS RTG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 1727917 | C1 | 363 | .33 | 10 | 1.350 | 0.061 | 0.45 | 0.45 | 0.99 | 358.20 | G |
| 2 | | | 1727916 | | 363 | .32 | 10 | 1.349 | 0.041 | 0.30 | 0.30 | 0.99 | 357.80 | G |
| 3 | | | 1727915 | | 362 | .33 | 10 | 1.340 | 0.067 | 0.50 | 0.50 | 0.99 | 355.40 | G |
| 4 | | | 1727914 | | 363 | .32 | 10 | 1.355 | 0.059 | 0.44 | 0.44 | 0.99 | 359.40 | G |
| 5 | | | 1727918 | | 363 | .33 | 10 | 1.365 | 0.266 | 1.95 | 1.93 | 0.99 | 362 | I |
| 6 | | | 1727913 | | 364 | .34 | 10 | 1.353 | 0.046 | 0.34 | 0.34 | 0.99 | 358.90 | G |
| 1 | | | 1727917 | | 2550 | | 2 | 9.652 | 0.353 | 0.37 | 0.37 | 1.00 | 2560 | G |
| 2 | | | [illegible] | | [illegible] | | 2 | 10.750 | 0.360 | 0.33 | 0.33 | 1.00 | 2852 | G |
| 3 | | | [illegible] | | [illegible] | | 2 | 10.860 | 0.404 | 0.37 | 0.37 | 1.00 | 2882 | G |
| 4 | | | [illegible] | | [illegible] | | 2 | 10.590 | 0.349 | 0.33 | 0.33 | 1.00 | 2809 | G |
| 5 | | | 1727918 | | 2827 | | 2 | 52.080 | 505.80 | 97.12 | 97.1 | 1.00 | 3208 | I |
| 6 | | | 1727913 | | 2826 | | 2 | 10.670 | 0.339 | 0.32 | 0.32 | 1.00 | 2832 | G |

GE Type U Bushings

Overall | Hot Collar | Jump To | Prev Date | Next Date | Save | Exit

# Check Condition of Bushings

- **Bushings Comprise the Largest Portion of the Oil Circuit Breaker Insulation System**
- **A Bad Bushing Will Show Up in Both the Open and Closed Circuit Breaker Tests**

# Tank-Loss Index

| EXAMPLE # 1 | I (mA) | Watts | % PF |
|---|---|---|---|
| 1 (Open) | 1.150 | 0.07 | 0.61 |
| 2 (Open) | 1.150 | 0.07 | 0.61 |
| 7 (Closed) | 2.300 | 0.11 | 0.50 |

**TLI = 0.11 - (0.07 + 0.07) = - 0.03 watts**

**Comments: Test results are normal.**

# Tank-Loss Index

| **Example #2** | I(mA) | Watts | %PF |
|---|---|---|---|
| 1(OPEN) | 1.15 | 0.07 | 0.61 |
| 2(OPEN) | 1.2 | 0.22 | 1.83 |
| 7(CLOSED) | 2.3 | 0.13 | 0.56 |

TLI = 0.13 - (0.07 + 0.22) = -0.16

Comments:

High Negative TLI “Wet” Interrupter on Bushing No. 2
or High Losses Near Bushing No. 2

May be the Lift Rod Guide Assembly

High Power Factor on Bushing No. 2, Test Bushing to Confirm

# Tank-Loss Index

| **Example #3** | I(mA) | Watts | %PF |
|---|---|---|---|
| 1(OPEN) | 1.15 | 0.07 | 0.61 |
| 2(OPEN) | 1.2 | 0.22 | 1.83 |
| 7(CLOSED) | 2.35 | 0.26 | 1.11 |

TLI = 0.26 - (0.07 + 0.22) = -0.03

Comments:

Normal TLI

Bushing No. 2 May Be Contaminated.

Test Bushing to Confirm.

# Tank-Loss Index

| **Example #4** | I(mA) | Watts | %PF |
|---|---|---|---|
| 1(OPEN) | 1.2 | 0.15 | 1.25 |
| 2(OPEN) | 1.2 | 0.15 | 1.25 |
| 7(CLOSED) | 2.3 | 0.11 | 0.48 |

TLI = 0.11 - (0.15 + 0.15) = -0.19

Comments:

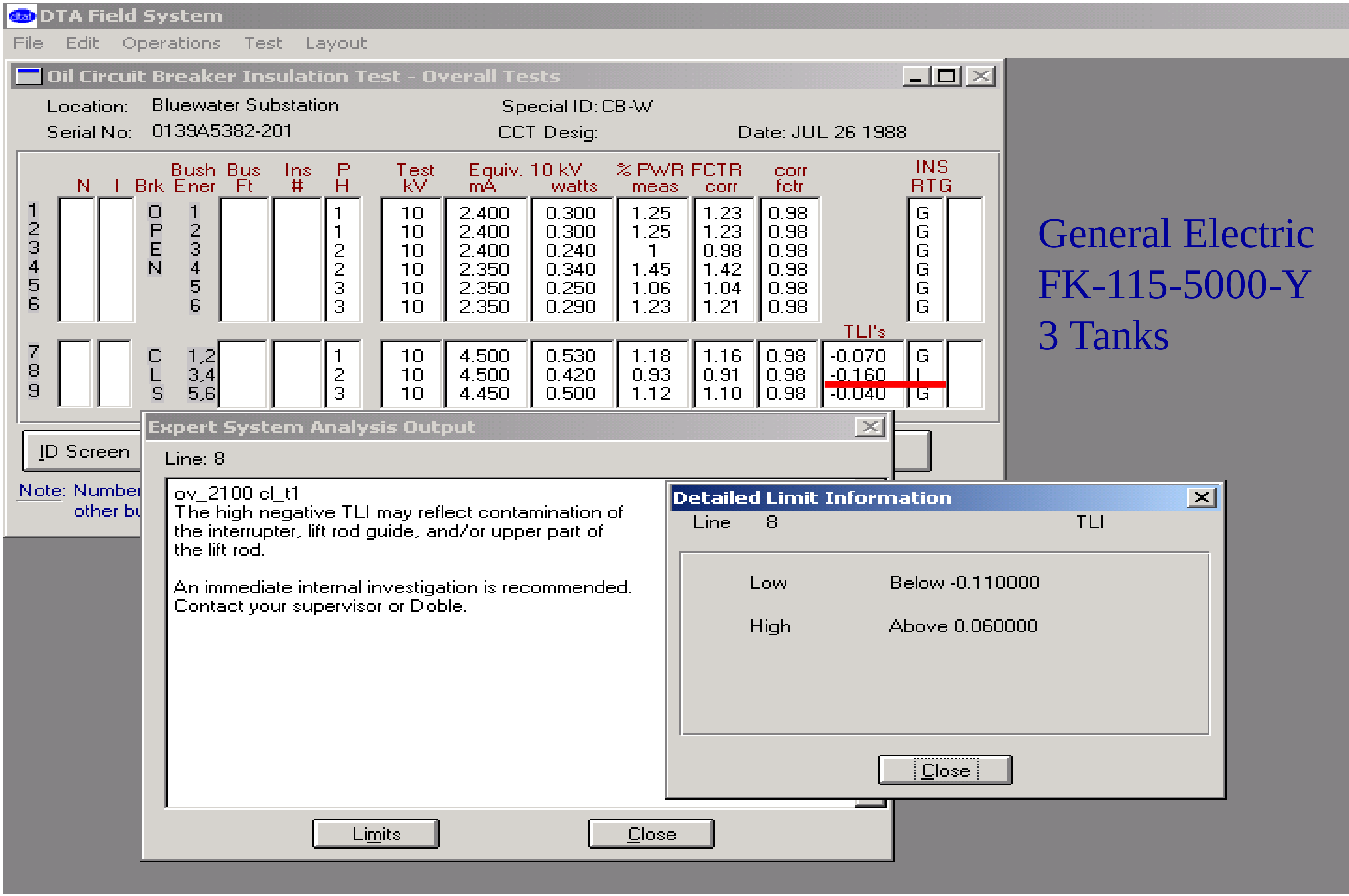
High Negative TLI

Bushing May Be OK -Test to Confirm

Possible Problems:

- Deteriorated Operating-Rod Guide
- Upper Portion of Lift Rod
- Contaminated Interrupter Assemblies

# Tank-Loss Index Example - DTA




General Electric
FK-115-5000-Y
3 Tanks

# Oil Circuit Breaker Test Summary

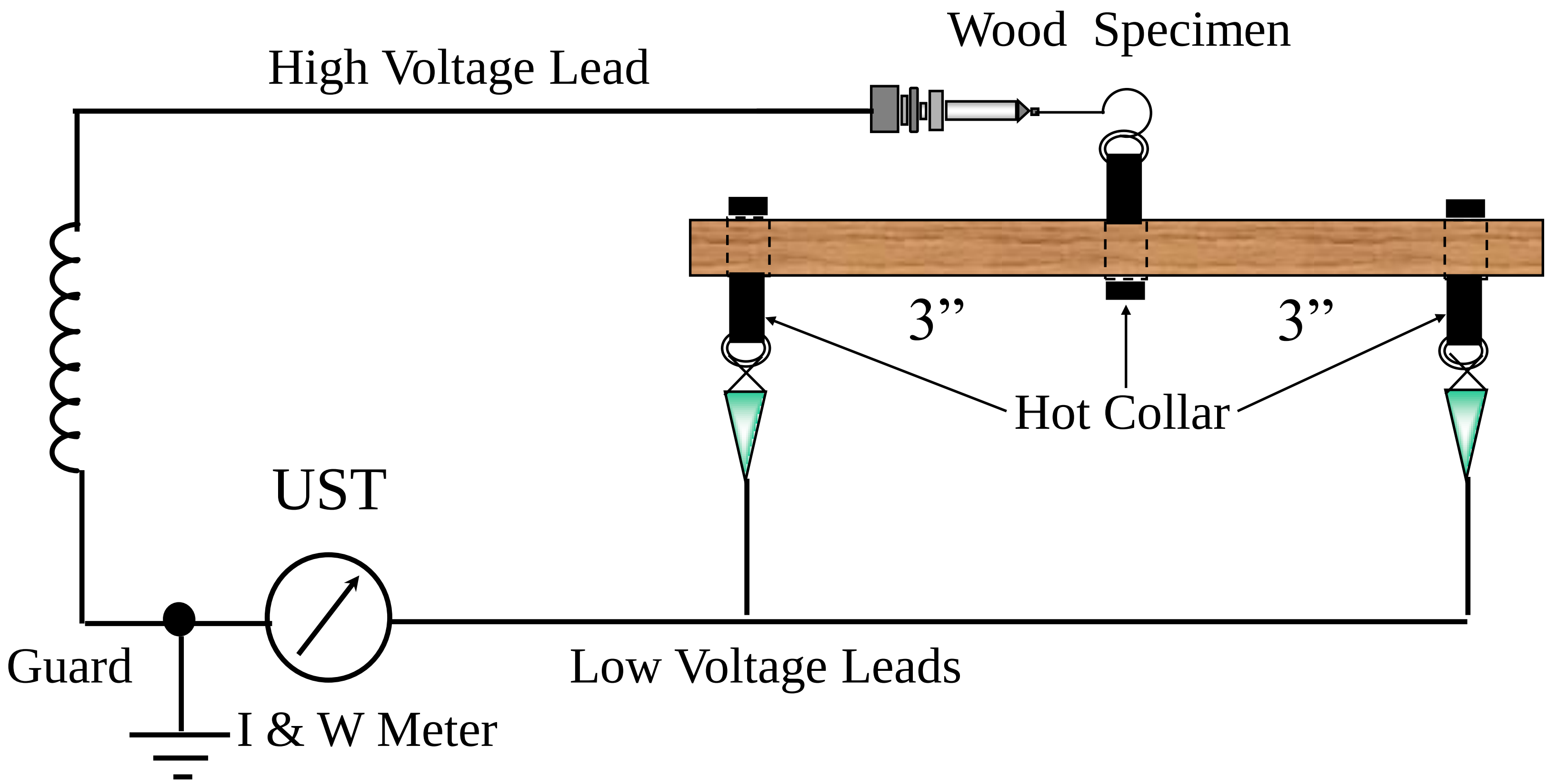
- Measure I, W and %PF
- Calculate Tank-Loss Index (TLI)
- TLI = Closed OCB Watts - Sum 2 Open OCB Watts
- %PF Corrected Using Bushing Type and Ambient Temperature
- Interpret Test Results on a Per Phase Basis

# Wood and Other Insulating Members

- The Insulating Properties of Wood or Other Insulating Members Can Be Measured

- This Dielectric Measurement is a Valuable Tool When Investigating High Power Factors From Other Dielectric Tests
  - Example: High Negative TLI Which May Indicate a Breaker Lift Rod Problem

# Wood and Other Insulating Members



# Wood and Other Insulating Members

## Recommended Power Factor Test Limits:

**<u>Used</u>**

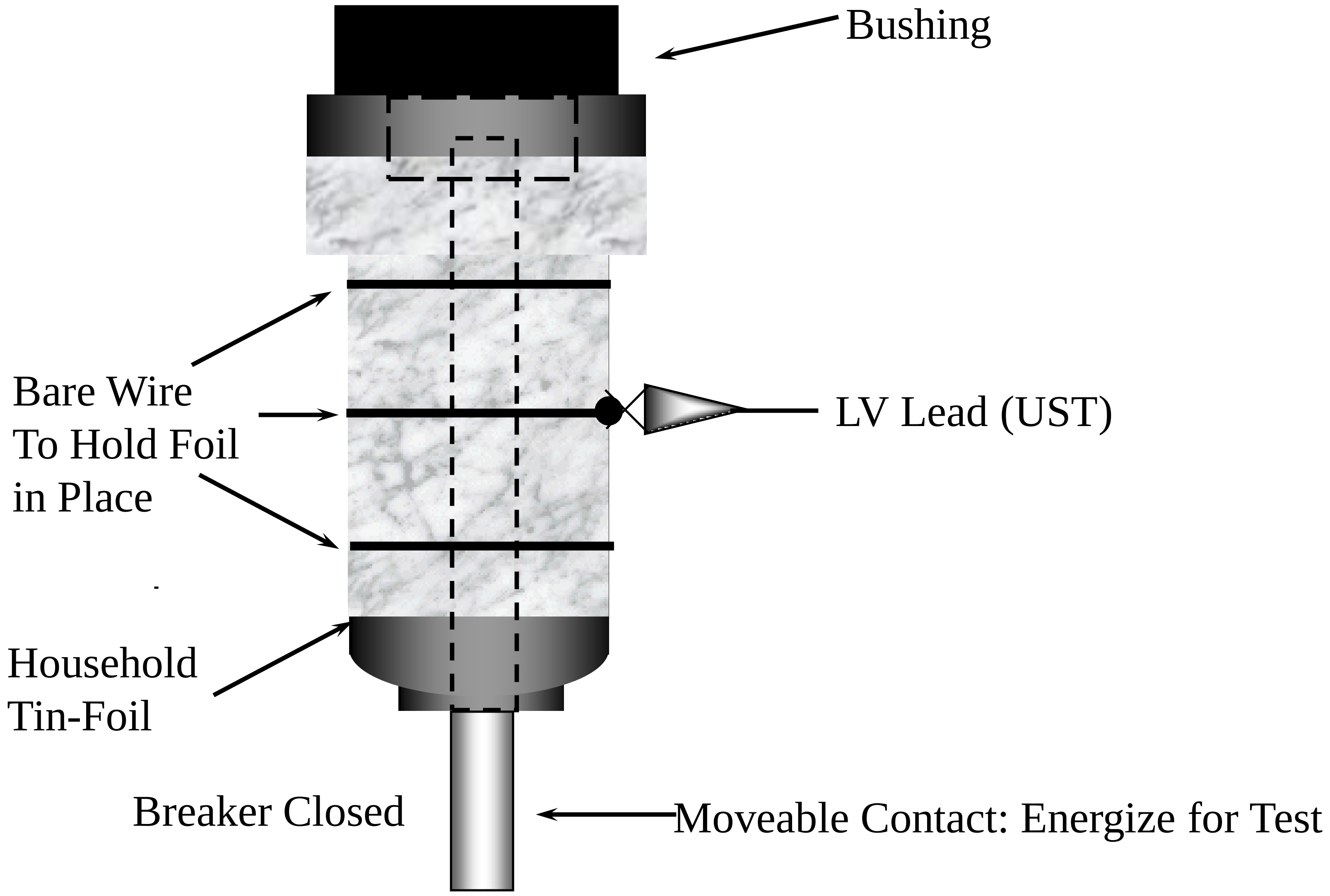
Breaker Lift-Rods:
0.20 Watts/3” @ 10 kV

Plastic Coated Members:
0.15 Watts/3” @ 10 kV

**<u>New or Excellent Condition</u>**

0.02 Watts/3” @ 10 kV

# Interrupters - Investigative Tests



# Interrupters - Investigative Tests

**Power Factors for Interrupters**
**(General Guideline)**

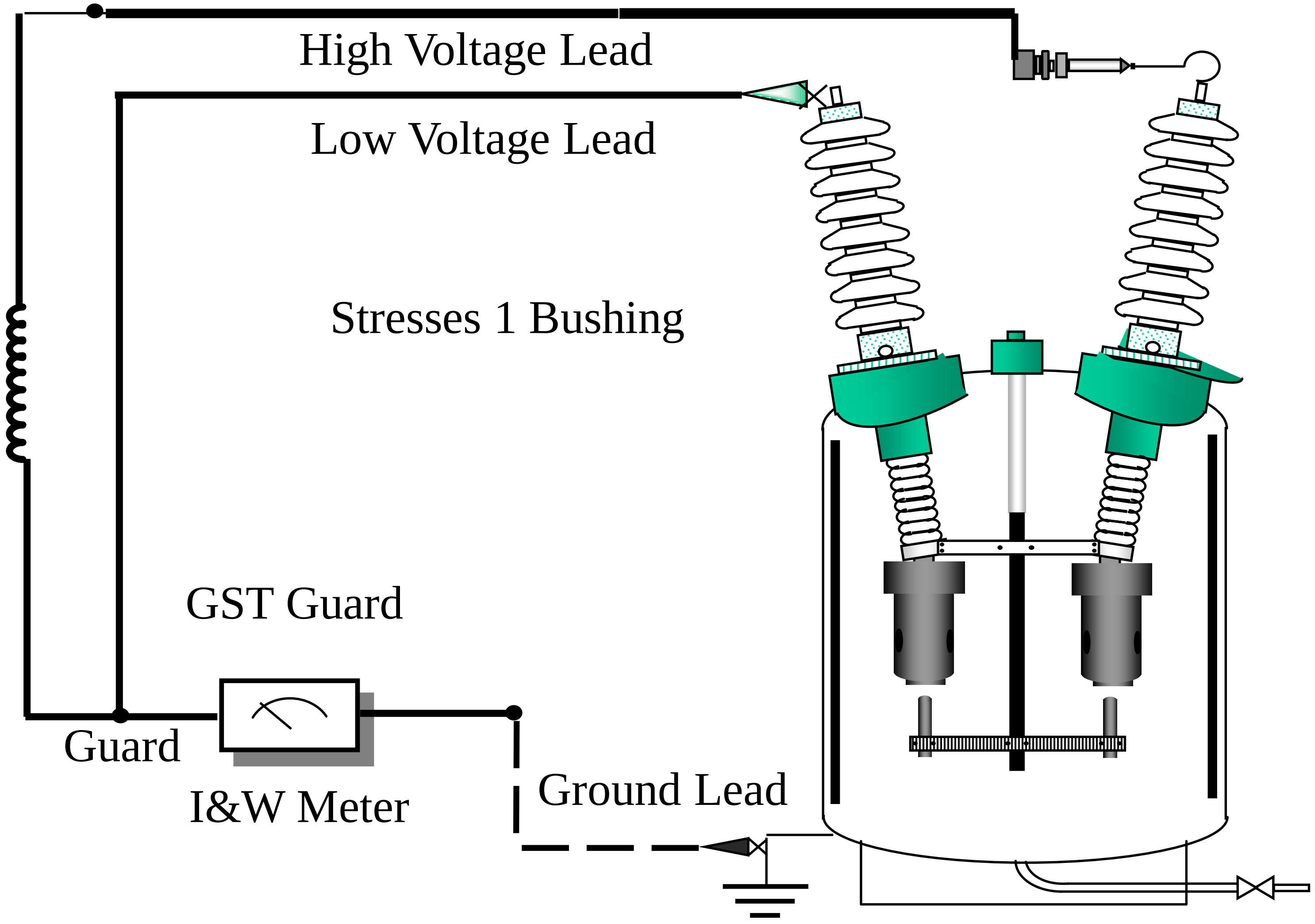
| | |
|---|---|
| Good: | 10-30% |
| Questionable/Grey area: | 30-50% |
| Bad: | >50% |

- Alternate Test Method:
  Wrap Additional Tin Foil Around the Bottom of the Interrupter With the Breaker in the Open Position

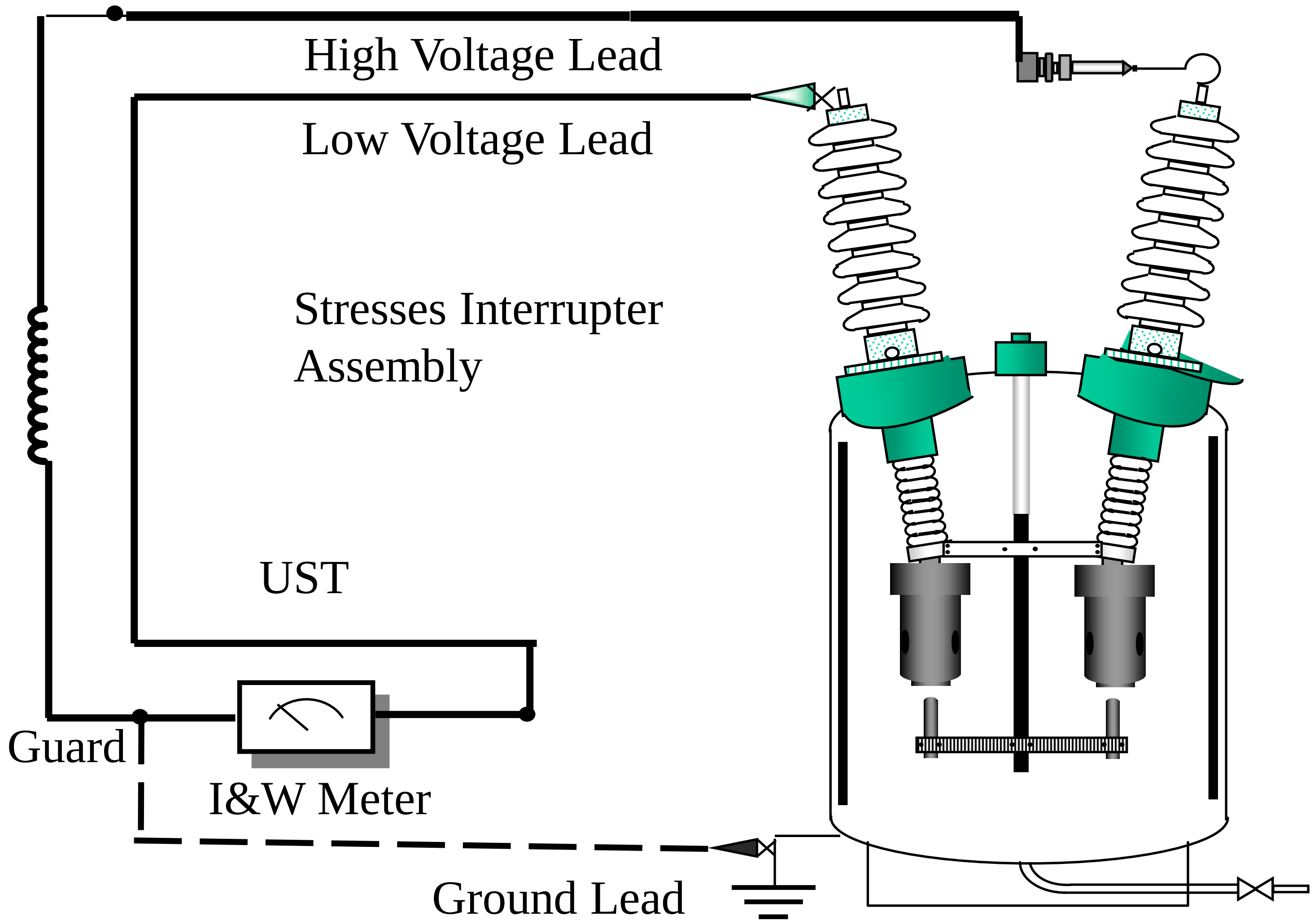
# Recloser Tests

- Reclosers Are Tested as Oil Circuit Breakers
- If Unexpected Results are Obtained, Recloser May Have a Resistor Assembly Between Lower Bushing Terminals
  - Perform Alternate Tests 1-6 by Guarding One Bushing and Energizing the Opposite Bushing on the Same Phase
  - Alternate Tests Include Three UST Tests - One Per Phase

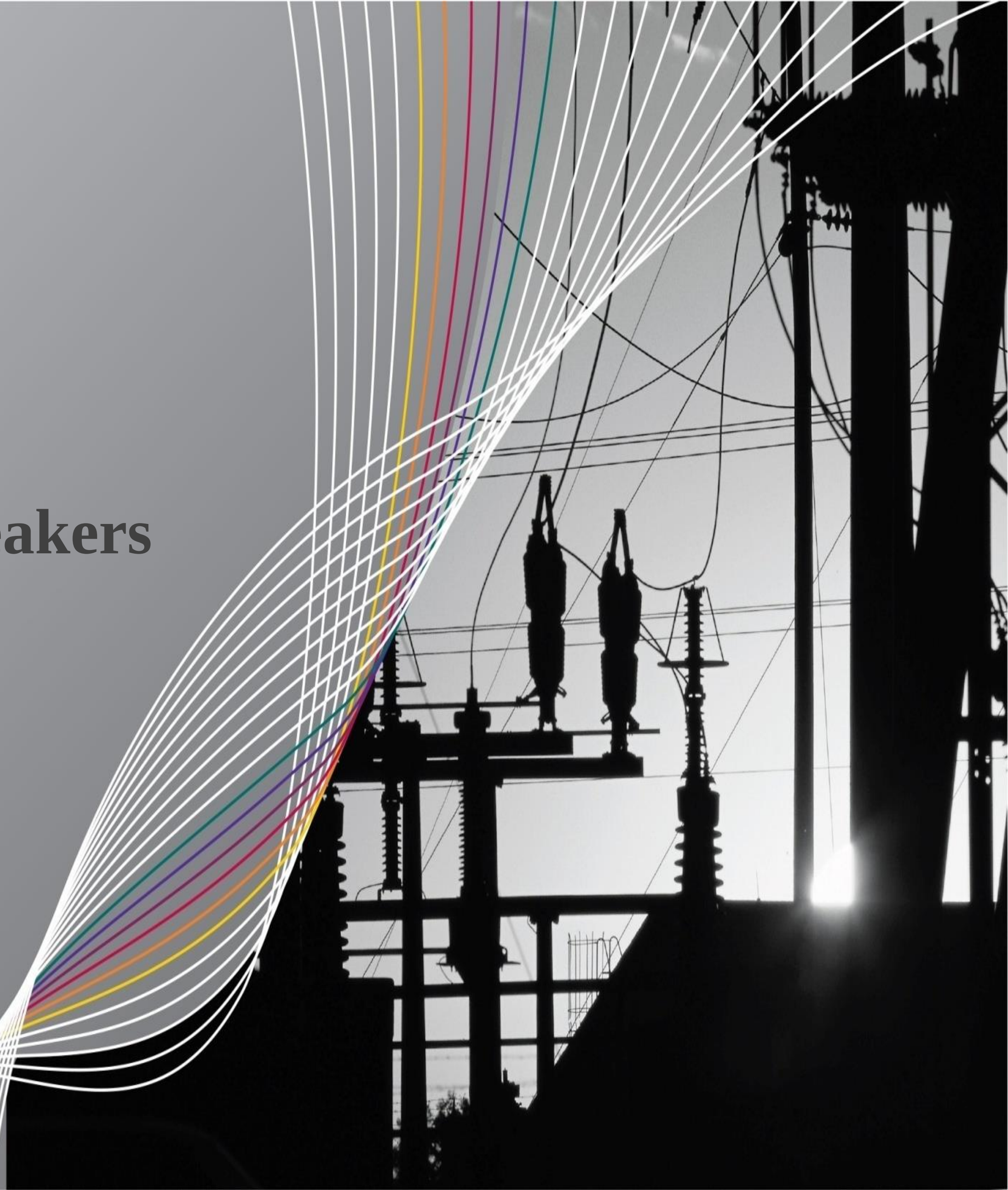
# Alternate Recloser Tests 1-6



# Alternate Recloser Tests 10-12



# SF6
# Dead Tank Breakers



# Grounded Tank SF6 Breaker

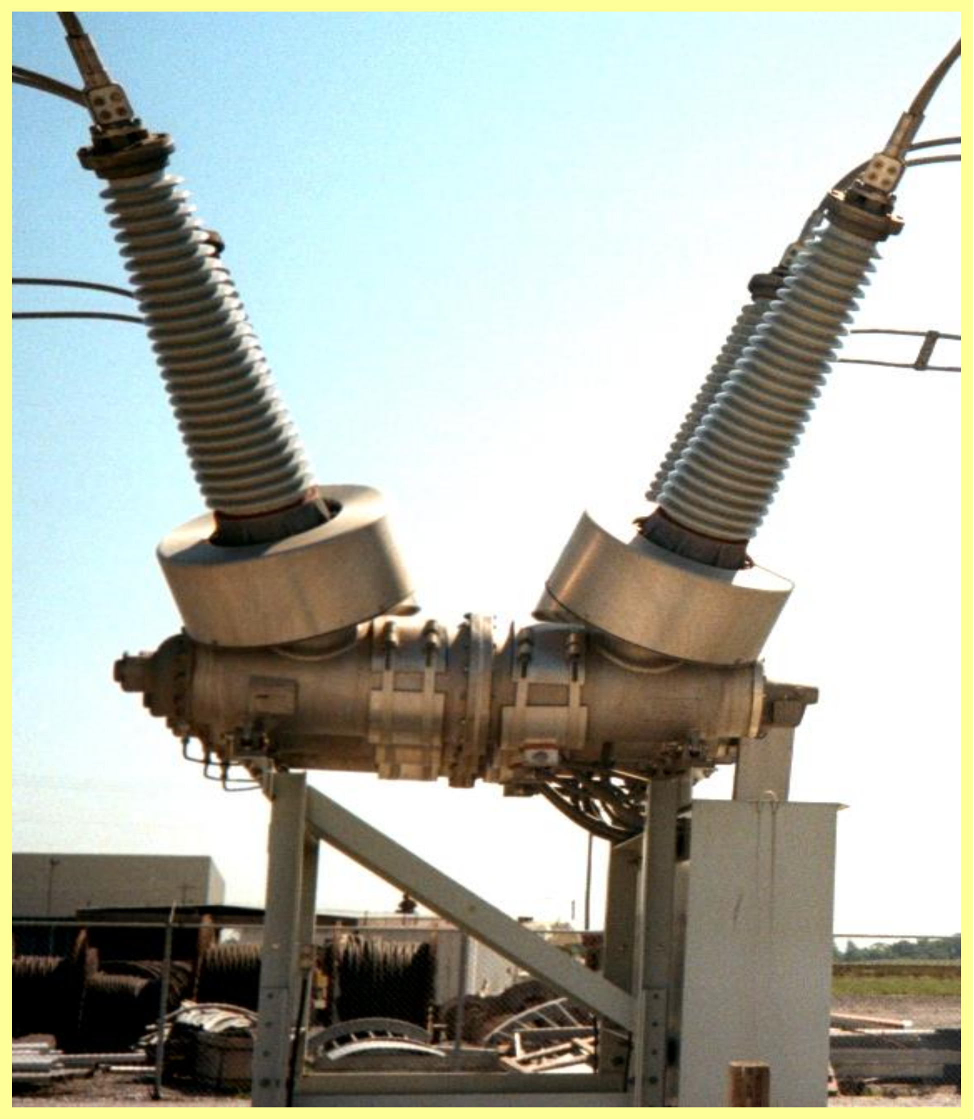


ABB 169-PM-40-20

# Grounded Tank SF6 Breaker

**Overall Test Procedure:**

- Disconnect Bus-work
- Record  I, W, & C
- Record %PF if I > 300 μA
- Test Results Should Compare:
    - Between Phases
    - Previous Tests
    - Similar Units
    - Limit Files

# Grounded Tank SF6 Breakers

**Test Procedure:**

- Overall Tests
- Bushing Hot-Collar Tests
- Capacitor
- Miscellaneous
- Diagnostic

# Grounded Tank SF6 Circuit Breakers

**Test Voltage**

Rated 15 kV and above: 10 kV for all overall tests

**Rated <15 kV:**

Initial Test:

1. 2 kV
2. Rated Operating L-G Voltage
3. 10% and 25% Above Rated Operating L-G Voltage

Routine Follow-Up Tests:

1. 10% and 25% above rated L-G voltage

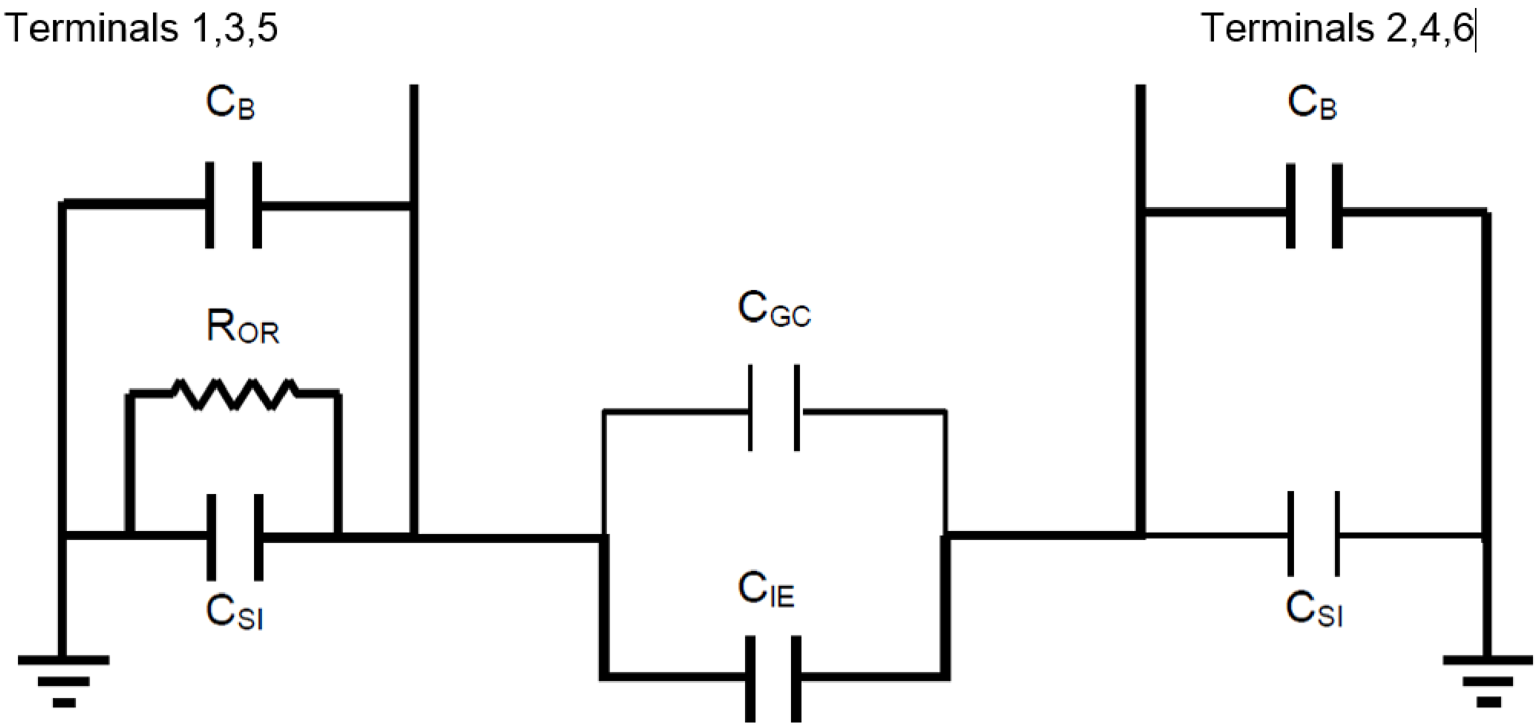
# Single Contact Grounded Tank Breakers

# Circuit Breaker Layout

- Look at the drawings as not all layouts are the same

- Most common layouts for which bushing designation is based on cabinet location but not always

# Dielectric Circuit Single Contact Dead Tank Breaker




<u>Insulation Components</u>

$C_B$ – Bushing

$C_{GC}$ – Grading Capacitor

$C_{SI}$ – Support Insulator

$C_{IE}$ – Interrupter Envelope

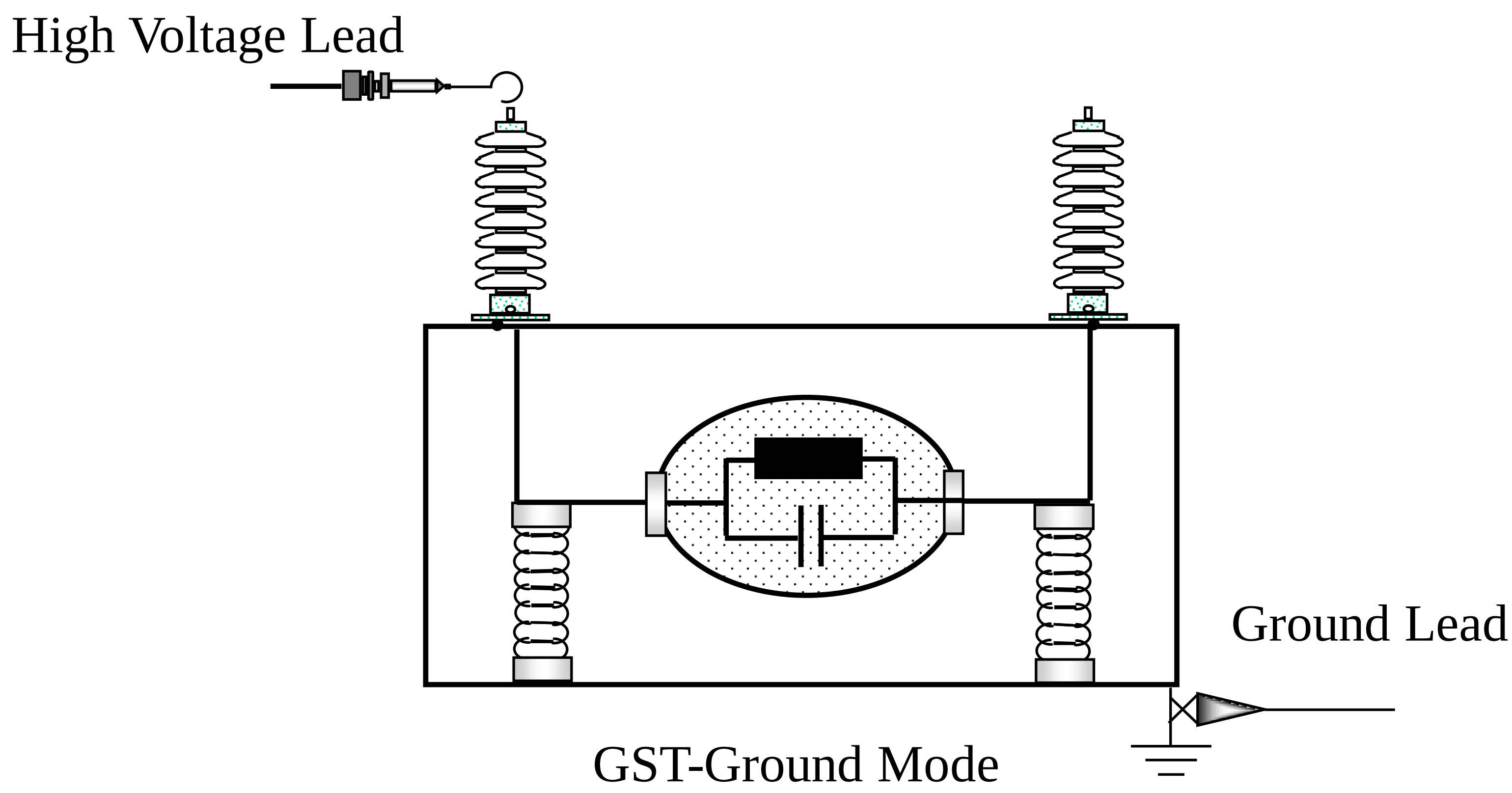
$R_{OR}$ – Operating Rod

# Test Procedure for Single Contact Breaker

| Test No. | Breaker Position | Test Mode | Terminal Energized | Terminal Floating | Terminal UST | Insulation Measured |
|---|---|---|---|---|---|---|
| 1 | OPEN | GST-GROUND | 1 | 2 | - | $C_B + C_{SI} + R_{OR}$ |
| 2 | OPEN | GST-GROUND | 2 | 1 | - | $C_B + C_{SI}$ |
| 3 | OPEN | GST-GROUND | 3 | 4 | - | $C_B + C_{SI} + R_{OR}$ |
| 4 | OPEN | GST-GROUND | 4 | 3 | - | $C_B + C_{SI}$ |
| 5 | OPEN | GST-GROUND | 5 | 6 | - | $C_B + C_{SI} + R_{OR}$ |
| 6 | OPEN | GST-GROUND | 6 | 5 | - | $C_B + C_{SI}$ |
| 7 | OPEN | UST | 1 | - | 2 | $C_{IE} + C_{GC}$ |
| 8 | OPEN | UST | 3 | - | 4 | $C_{IE} + C_{GC}$ |
| 9 | OPEN | UST | 5 | - | 6 | $C_{IE} + C_{GC}$ |

# Dead Tank SF6 Breaker Tests

## Tests No. 1 - 6



# Dead Tank SF6 Breaker Tests

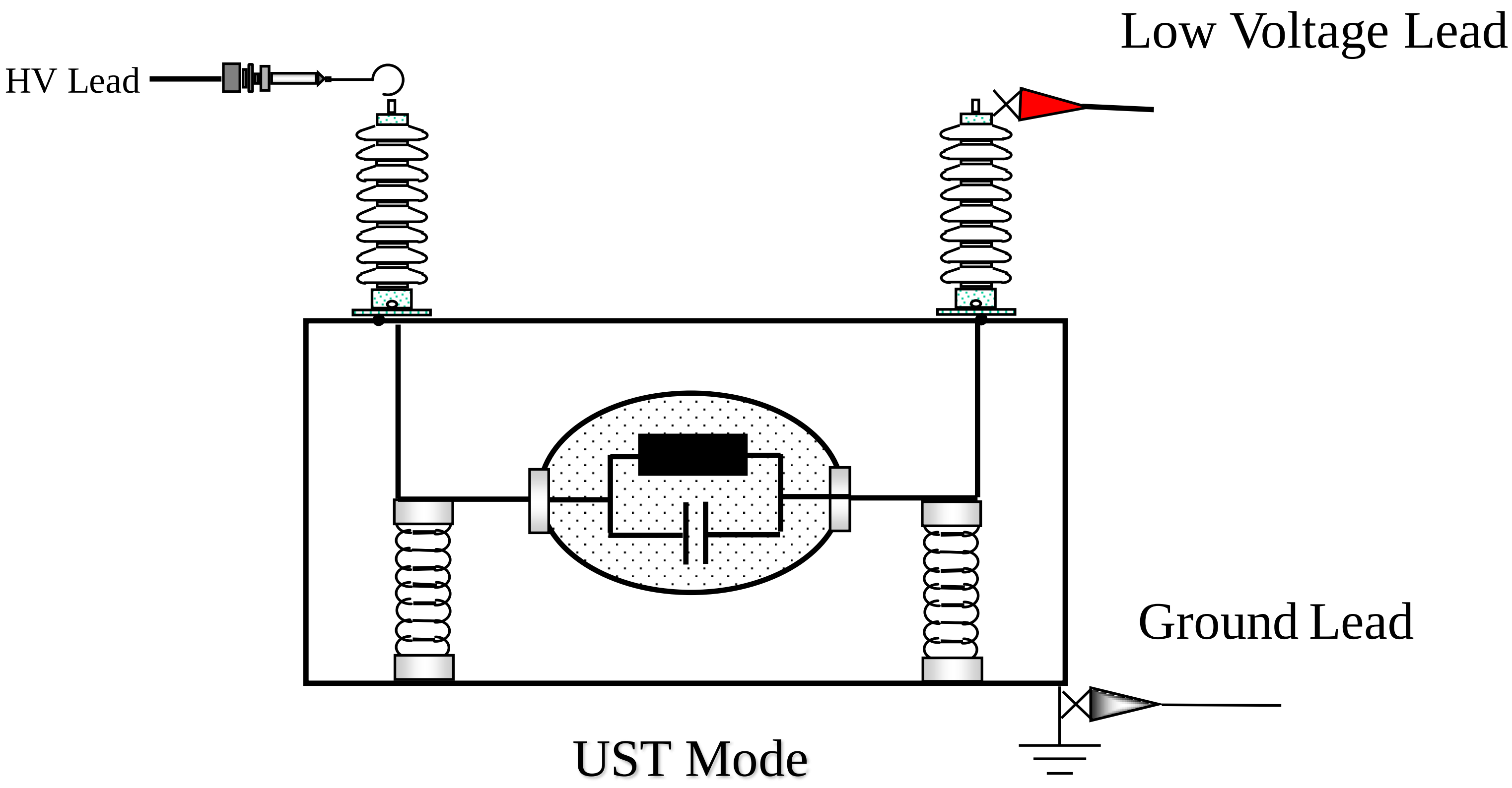
## Tests No. 1 - 6

- Stresses
    - Bushings
    - Support Insulators

- Test Mode: GST-Ground

# Dead Tank SF6 Breaker Tests

## Tests No. 7 - 9



# Dead Tank SF6 Breaker Tests

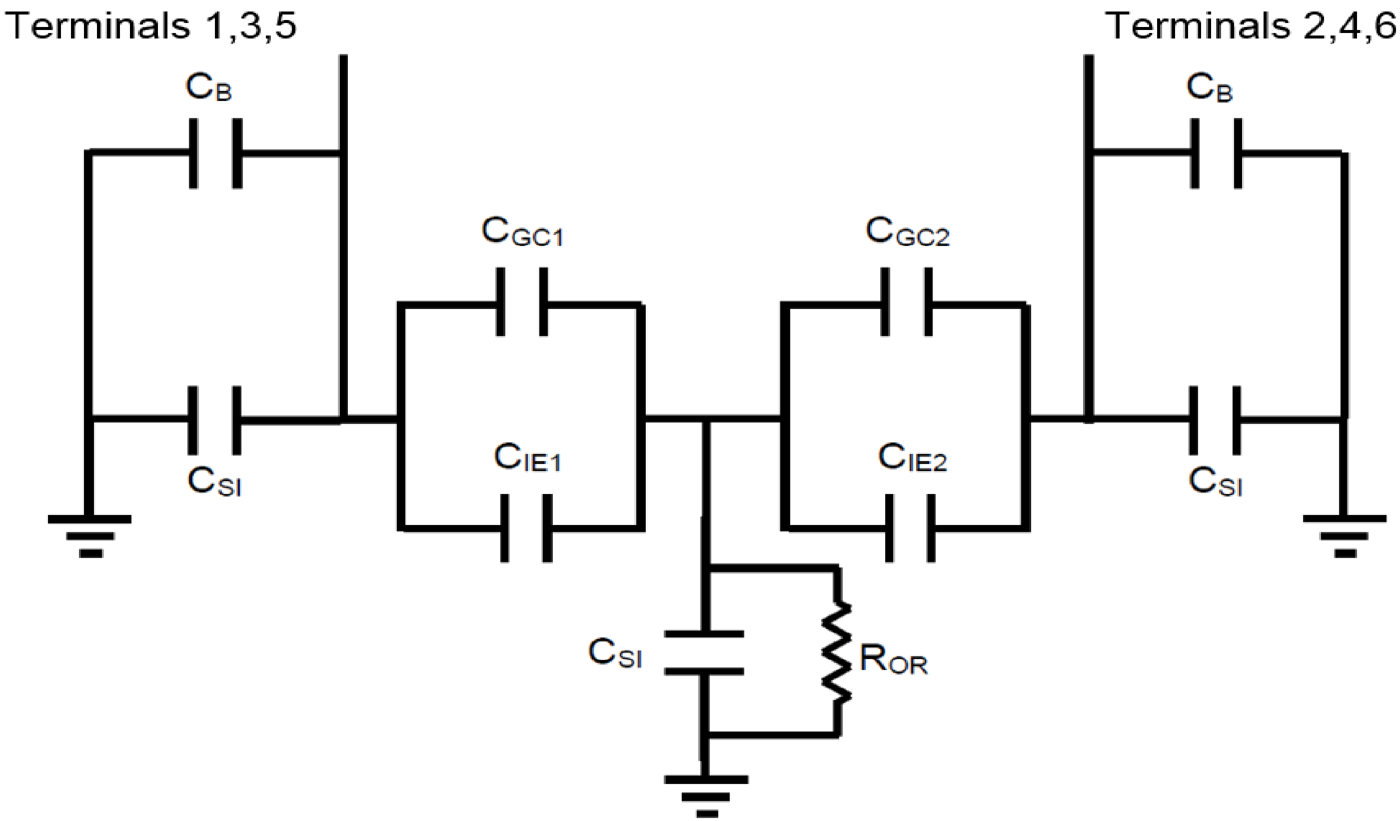
## Tests No. 7 - 9

- Stresses
  - SF6 Gas
  - Grading Capacitors and Resistors

- Test Mode: UST

# Multi-Contact Grounded Tank Breakers

# Dielectric Circuit for Multi-Contact Design for Dead Tank Breaker




Insulation Components

$C_B$ – Bushing

$C_{GC}$ – Grading Capacitor

$C_{SI}$ – Support Insulator

$C_{IE}$ – Interrupter Envelope

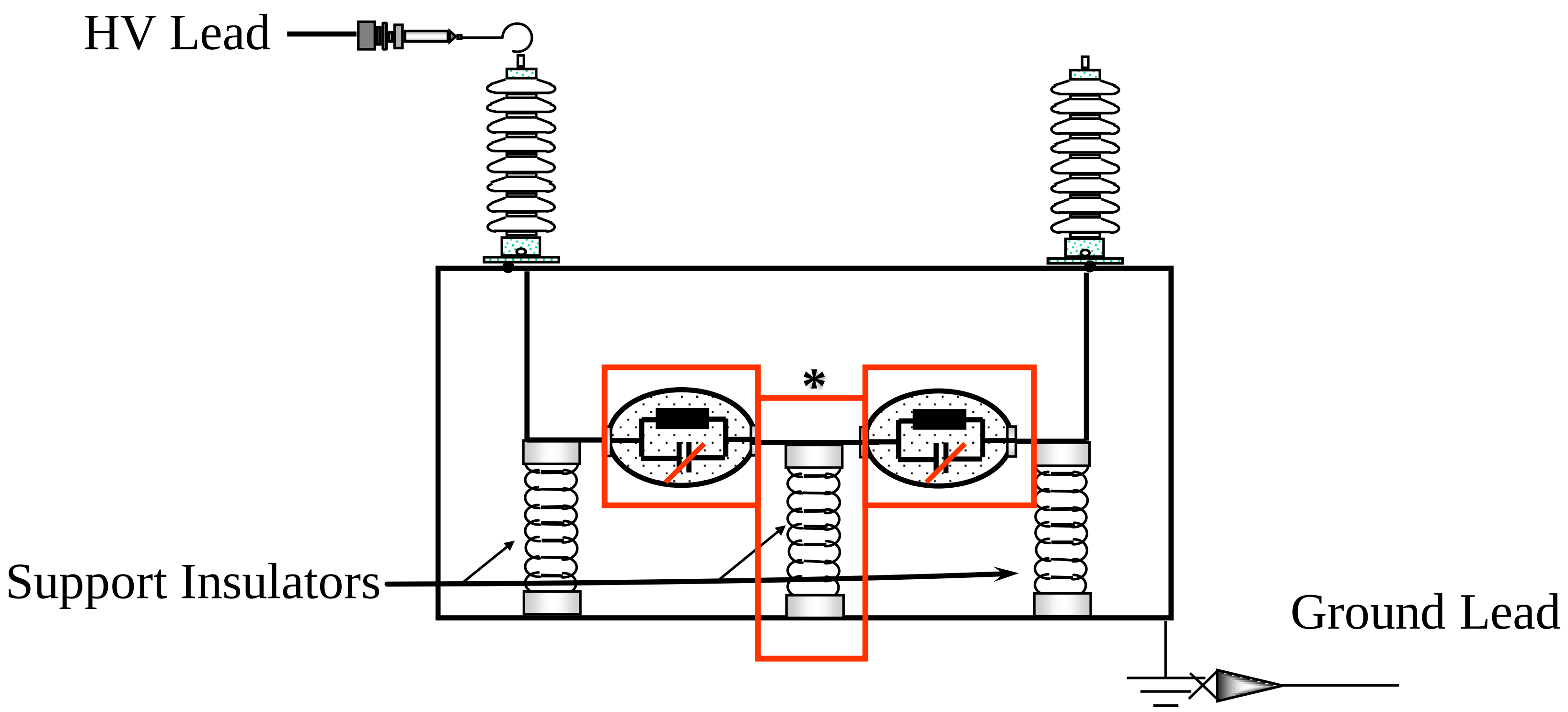
$R_{OR}$ – Operating Rod

# Test Procedure for Multiple Contact Breaker

| Test No. | Breaker Position | Test Mode | Terminal Energized | Terminal Floating | Terminal UST | Insulation Measured |
|---|---|---|---|---|---|---|
| **1** | Open | GST-Ground | 1 | 2 | - | $C_B + C_{SI}$ |
| **2** | Open | GST-Ground | 2 | 1 | - | $C_B + C_{SI}$ |
| **3** | Open | GST-Ground | 3 | 4 | - | $C_B + C_{SI}$ |
| **4** | Open | GST-Ground | 4 | 3 | - | $C_B + C_{SI}$ |
| **5** | Open | GST-Ground | 5 | 6 | - | $C_B + C_{SI}$ |
| **6** | Open | GST-Ground | 6 | 5 | - | $C_B + C_{SI}$ |
| **7** | Open | UST | 1 | - | 2 | $C_{IE\ 1\&2} + C_{GC\ 1\&2}$ |
| **8** | Open | UST | 3 | - | 4 | $C_{IE\ 1\&2} + C_{GC\ 1\&2}$ |
| **9** | Open | UST | 5 | - | 6 | $C_{IE\ 1\&2} + C_{GC\ 1\&2}$ |
| **10** | Closed | GST-Ground | 1 or 2 | - | - | $(2)C_B + (3)C_{SI} + R_{OR}$ |
| **11** | Closed | GST-Ground | 3 or 4 | - | - | $(2)C_B + (3)C_{SI} + R_{OR}$ |
| **12** | Closed | GST-Ground | 5 or 6 | - | - | $(2)C_B + (3)C_{SI} + R_{OR}$ |

# Grounded Tank SF6 Breaker - Closed Position

## Tests No. 10, 11 & 12




GST-Ground
Measures Support Insulators

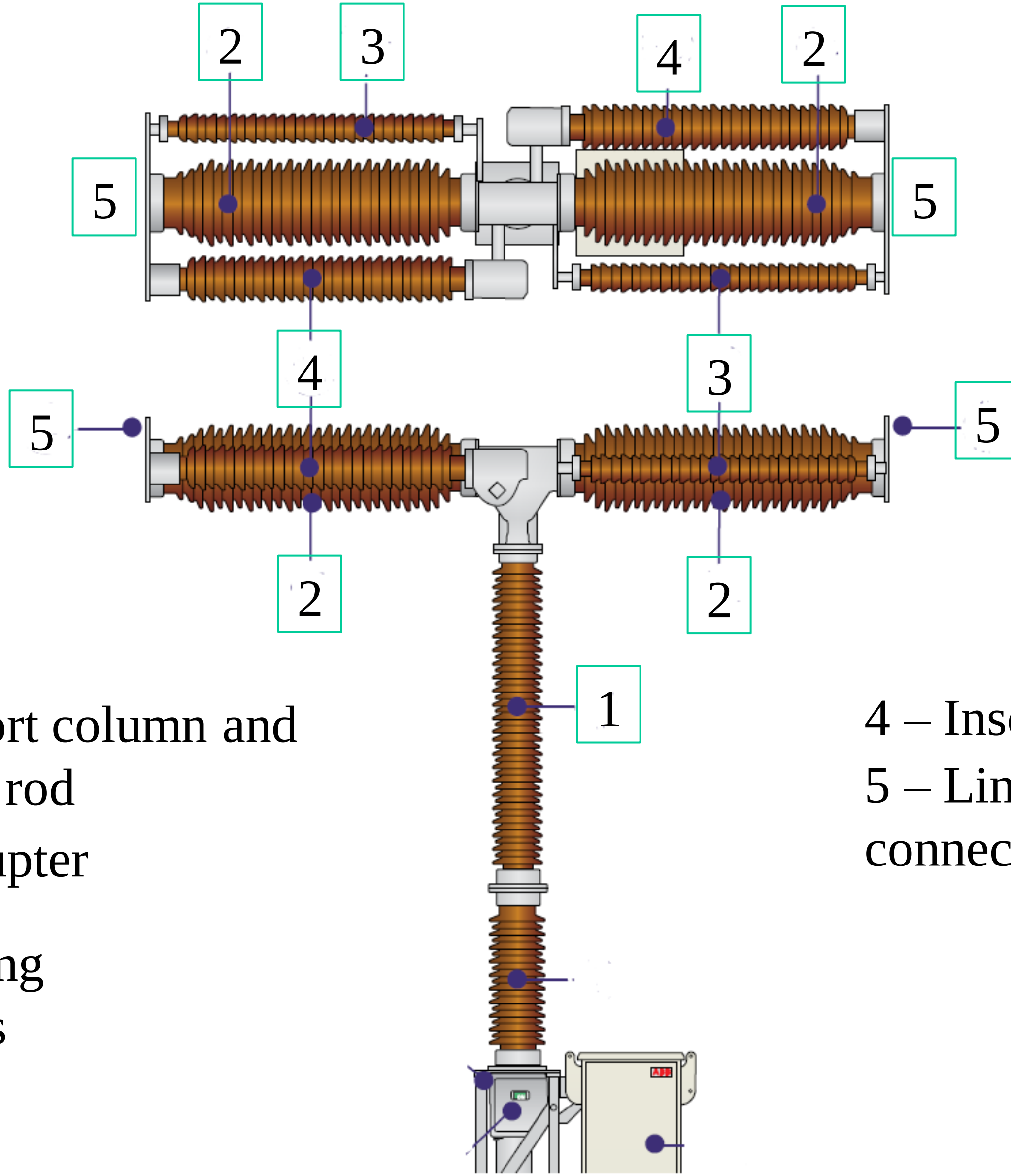
# Grounded Tank SF6 Breaker – Closed Position

***Note:**

To Test the Intermediate Support Insulator The Breaker Must Be Tested In The Closed Position With The GST-Ground Circuit

# Live Tank Breakers

# Live Tank Circuit Breakers




1 – Support column and operating rod

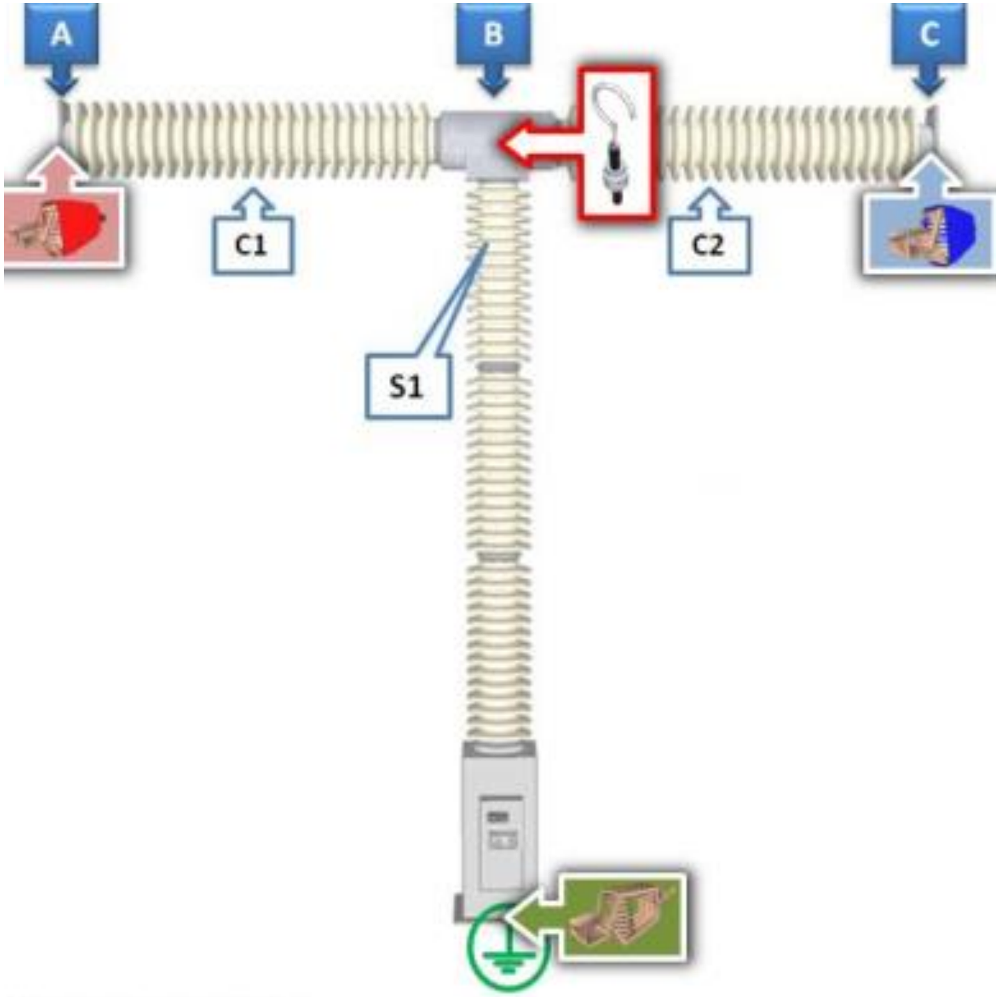
2 – Interrupter chamber

3 – Grading capacitors

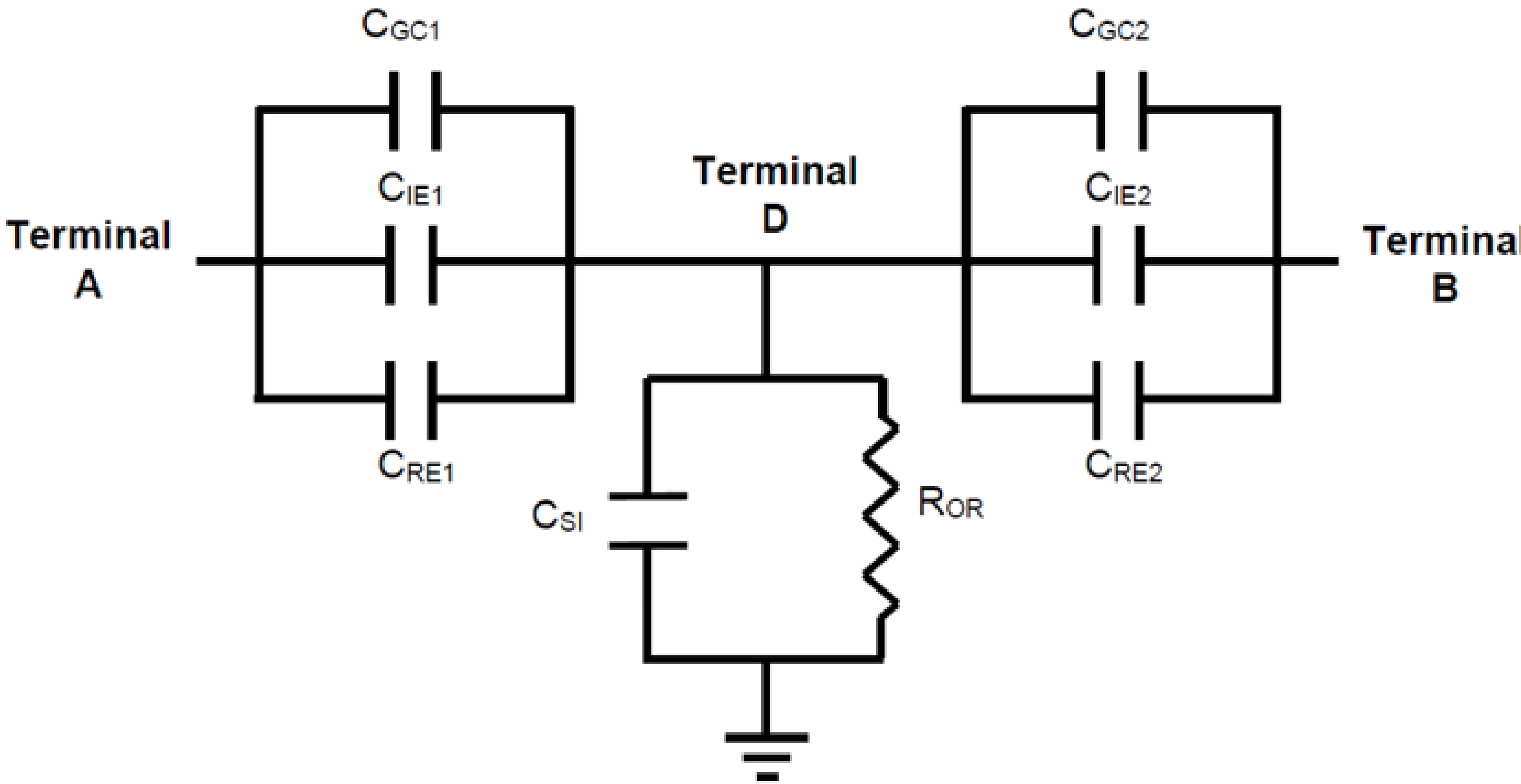
4 – Insertion resistors

5 – Line or bus connections

# Test Procedure for T and Y Type Live Tank Breakers



# Dielectric Circuit for Type T Live Tank Circuit Breaker



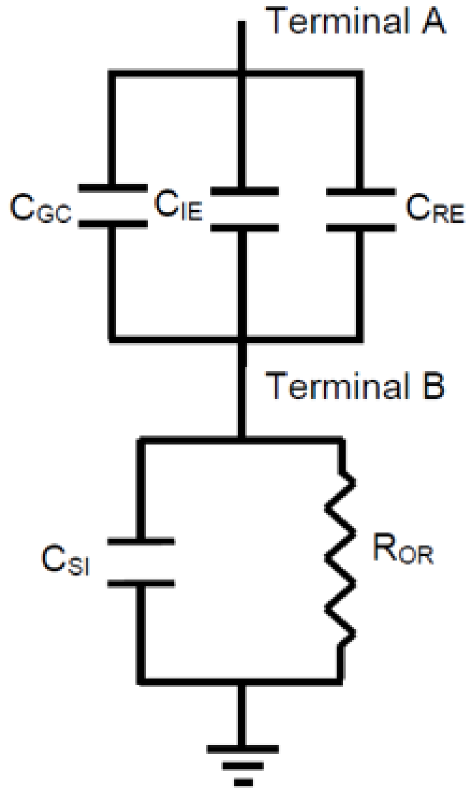

.

Insulation Components

$C_{GC}$ – Grading Capacitor
$C_{IE}$ – Interrupter Envelope
$C_{RE}$ – Resistor Envelope
$C_{SI}$ – Support Insulator
$R_{OR}$ – Operating Rod

# Candlestick or “I” Type Live Tank Breaker

# Dielectric Circuit for Candlestick Live Tank Breaker




Insulation Components

$C_{GC}$ – Grading Capacitor

$C_{IE}$ – Interrupter Envelope

$C_{RE}$ – Resistor Envelope

$C_{SI}$ – Support Insulator

$R_{OR}$ – Operating Rod

# Test Procedure for Candlestick or I Type Live Tank Breakers

| Test No. | Breaker Position | Test Mode | Terminal Energized | Terminal Guarded | Terminal UST | Insulation Measured |
|---|---|---|---|---|---|---|
| 1 | OPEN | UST | B | - | A | $C_{IE} + C_{GC} + C_{RE}$ |
| 2 | OPEN | GST-GUARD | B | A | - | $C_{SI} + R_{OR}$ |

# Analysis of Test Results: Dead Tank SF6

Open Breaker Tests

- Evaluate I, W, %PF
- For Charging Current of less then 300 micro-amps, Power Factor May Not Be Significant and More Emphasis is Given to Watts-loss Values
- Due to the Wide Range of Contacts, Grading Capacitors, Grading Resistors That Are Available in SF6 Breakers, Data Should be Compared To
  - The Doble Test-Data-Reference-Book
  - Similar Units
  - Previous Results

# Analysis of Test Results: Dead Tank SF6

Closed Breaker Tests

- Evaluate I, W, and %PF

- Results Are Compared With
  - The Doble Test Data Reference Book
  - Previous Results on a Per Phase Basis
  - Similar Units

# Additional Tests Dead Tank SF6 Breakers

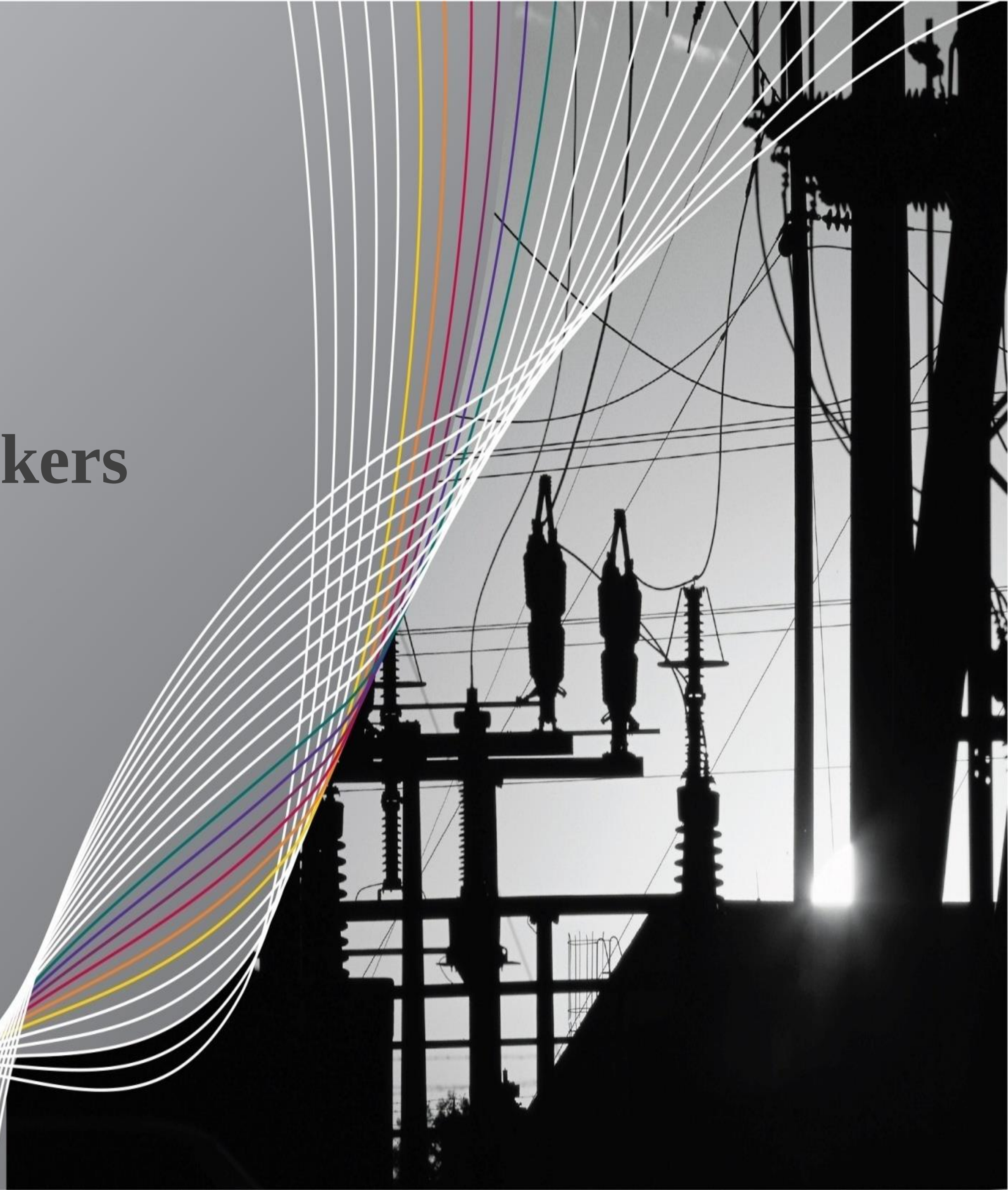
- If Moisture is Suspect Due to High Watts and %PF, Cycling the Breaker Several Times May Improve the Test Result
  - Conduct a DEW POINT Analysis to Confirm the Presence of Moisture

- If Bushings Are Equipped With Potential Taps or Test Taps, Perform the Following Bushing Tests
  - C1(Main Core Insulation)
  - C2 (Bushing Tap Insulation)

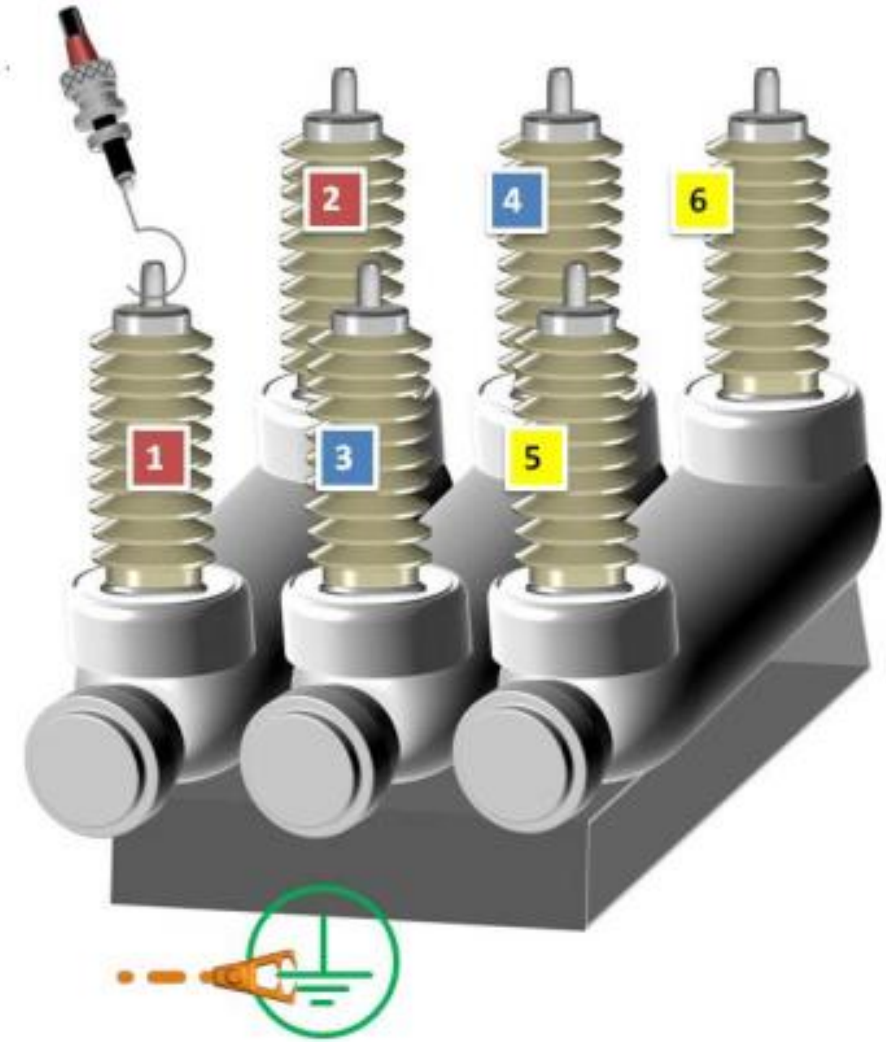
# Additional Tests Dead Tank SF6 Breakers

- SF6 Filled Bushings Should be Tested by the Single-Hot Collar Method or by the Multiple-Hot Collar Method
  - The Presence of Contamination or Cracks Along the Inside Weathershed Could be Detected
  - Compare Test Results to Similar Units
  - Single Hot Collar Test Results Should Yield 0.1 Watts or Less for Acceptable Test Results
  - Consider Performing the Test at Multiple Voltages to See if a Problem is Voltage Sensitive

# Vacuum Breakers



# Vacuum Circuit Breaker



# Vacuum Circuit Breakers

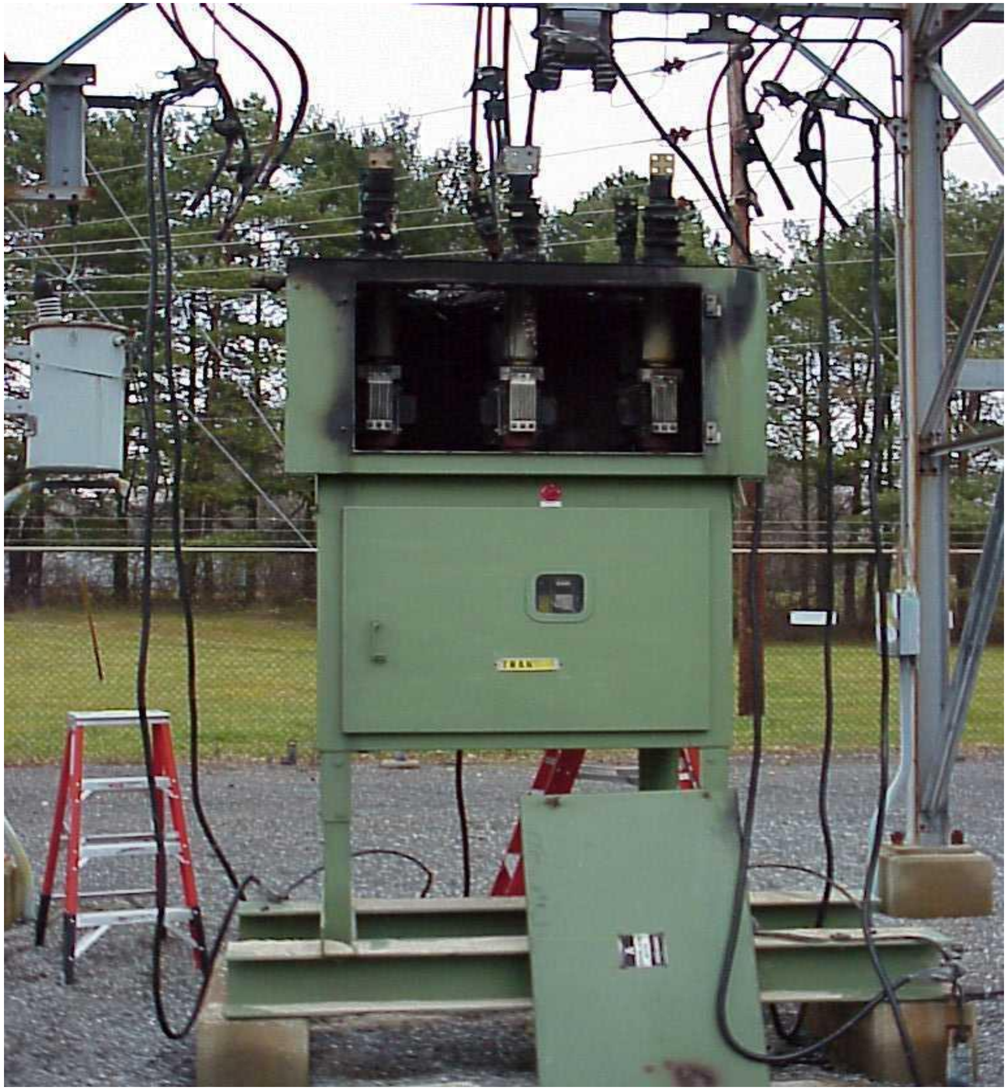
<u>Power Factor Test Procedure</u>

**SAME TEST PROCEURE AS SF6**

Switch gear Cubicle

- Open-Breaker Tests (6 Tests)
- Open-Breaker UST Tests (3 Tests)
- Diagnostic (Questionable Results)

# Vacuum Circuit Breakers



# Vacuum Circuit Breakers

Power Factor Test Procedure

Free-Standing

- Bushings (Hot-Collar)
- Open-Breaker Tests (6 Tests)
- Open-Breaker UST Tests (3 Tests
- Diagnostic (Questionable Results)

# Vacuum Circuit Breakers & Reclosers

**<u>Test Voltage</u>**

Rated 15 kV and Above: 10 kV for all Overall Tests

**<u>Rated <15 kV:</u>**

**Initial Test:**

1. Low Voltage (2 kV). (Basic Insulation Power Factor)
2. Rated L-G Voltage
3. 10% and 25% above rated. L-G voltage

**Routine Follow-Up Tests:**

1. 10% and 25% above rated L-G voltage

# Vacuum Circuit Breakers & Reclosers

NOTE: Test Voltage

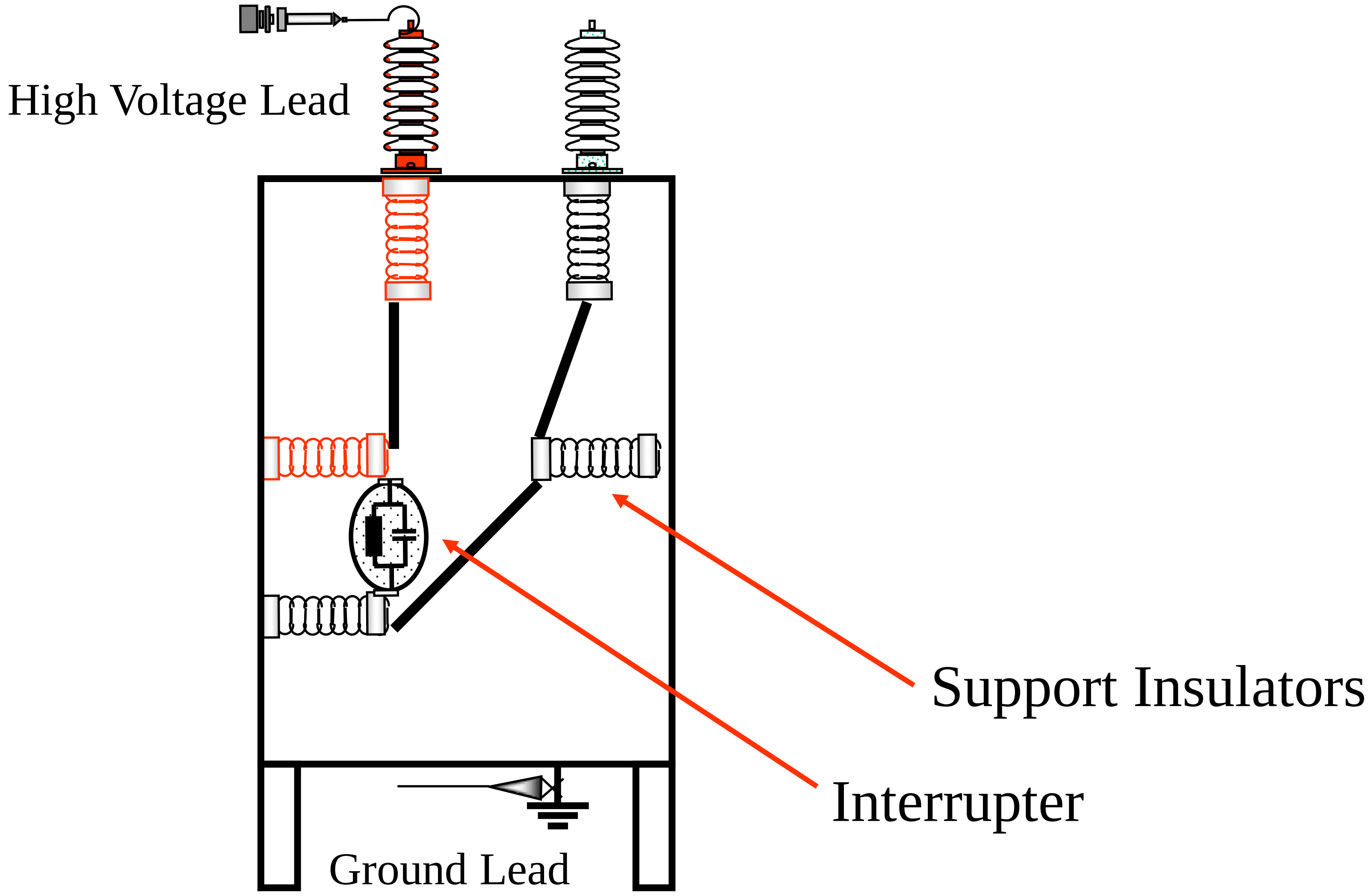
For 15 kV Vacuum Breakers Operating at 13.8 kV

- Initial Test
    - Tests Should be Conducted at 2, 8, 8.8, to 10 kV
- Future Tests
    - The Highest Test Voltage Without Appreciable Corona

# Overall Test Procedure
# Vacuum Circuit Breakers/Reclosers

| Test No. | Breaker Position | Test Mode | Bushing Energized | Bushing Floating | Bushing UST |
|---|---|---|---|---|---|
| 1 | OPEN | GST | 1 | 2 | - |
| 2 | OPEN | GST | 2 | 1 | - |
| 3 | OPEN | GST | 3 | 4 | - |
| 4 | OPEN | GST | 4 | 3 | - |
| 5 | OPEN | GST | 5 | 6 | - |
| 6 | OPEN | GST | 6 | 5 | - |
| 7 | OPEN | UST | 1 | - | 2 |
| 8 | OPEN | UST | 3 | - | 4 |
| 9 | OPEN | UST | 5 | - | 6 |

# Outdoor Vacuum Breaker Tests

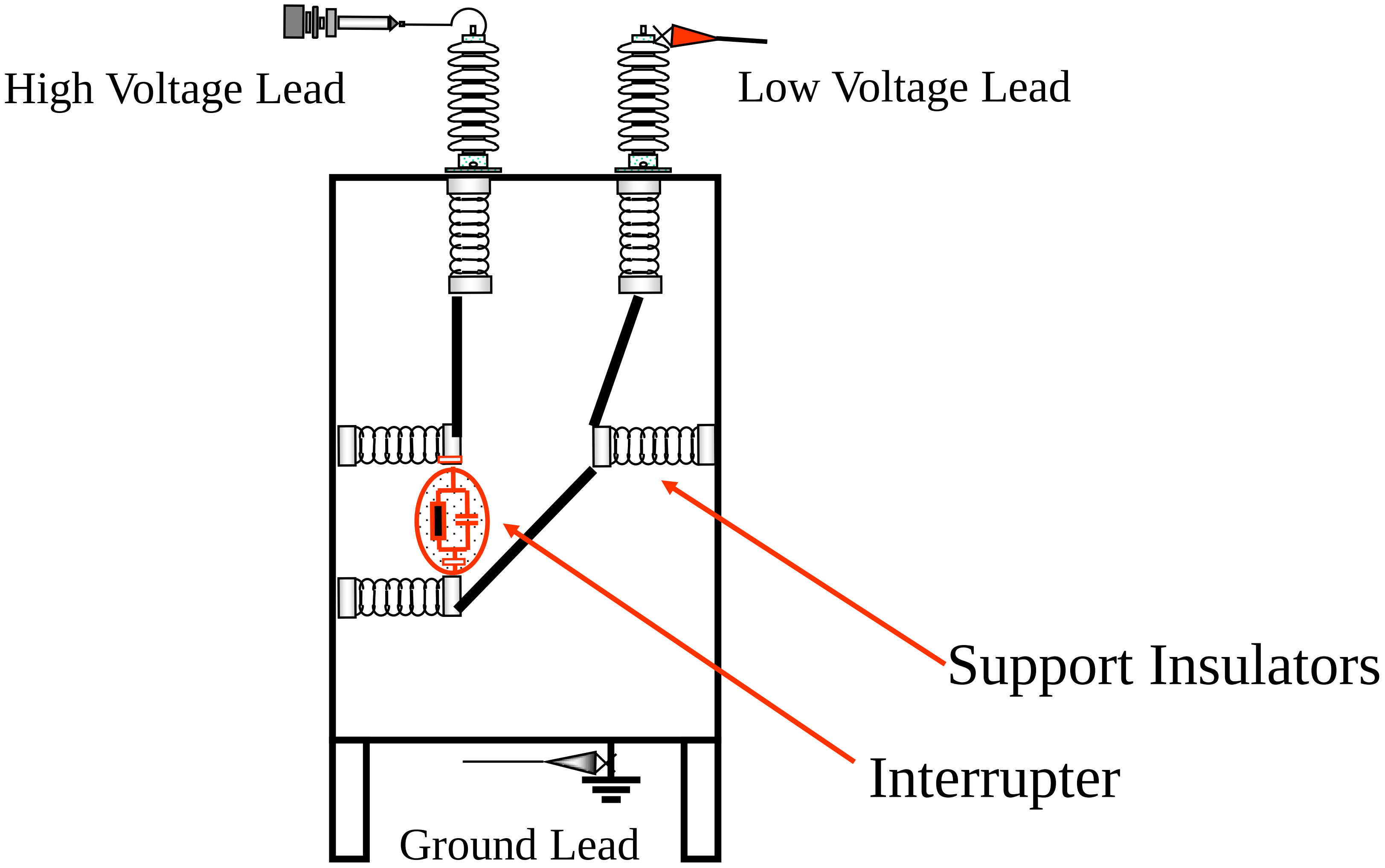


# Outdoor Vacuum Breaker Tests

Open Breaker Tests 1-6:

- Energize each of the six phase bushings
- Test Mode: GST-Ground

# Outdoor Vacuum Breaker Tests



# Outdoor Vacuum Breaker Tests

Open Breaker Tests 7-9:

- Energize One Bushing of Each Phase
- Low Voltage Lead Connected to Opposite Bushing of Energized Phase
- Test Mode: UST

# Vacuum Circuit Breakers & Reclosers

**Test 1-6 Stresses**

- Bushings
- Support Insulators
- Phase Barriers
- Operating Rod

**Test 7-9 Stresses**

- Vacuum Interrupter

# Vacuum Circuit Breaker- Test Analysis

**Open Breaker Tests:**

- Tests 1-6 dominated by bushings. Also includes operating rod, any support insulation, and any phase barriers
- I, W (Charging Current is expected to be small so Power Factor is not calculated)
- The current and watts for Tests 1-6 are compared with each other, with previous results, and other similar breakers on the system
- The Watts-Loss should be compared to the Test Data Reference Book
- Under Dry Conditions Vacuum Bottles should have losses approaching zero for tests 7-9. Compare phases to each other
- If High UST losses are present, a defective bottle or surface conditions

# Vacuum Circuit Breaker- Test Analysis

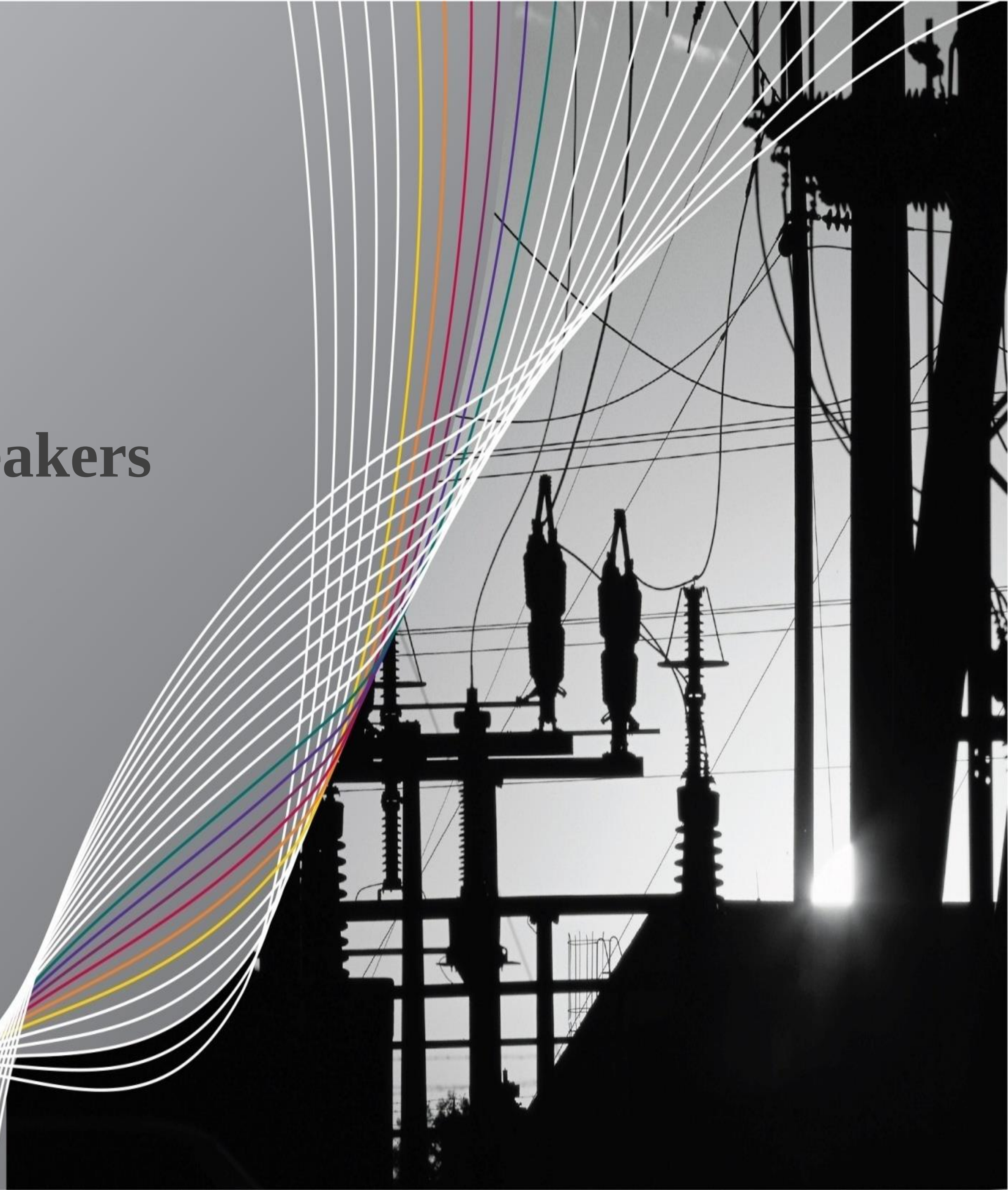
**Open Breaker Tests: (Contd.)**

- The Watts-Loss Should Be Compared to the Doble Test Data Reference Book
- Under Dry Conditions Vacuum Bottles Normally Have Losses Approaching Zero for Tests 7-9.  Compare Phases to Each Other
- High UST Losses Indicate a Defective Bottle or a Contaminated Surface Condition Exists

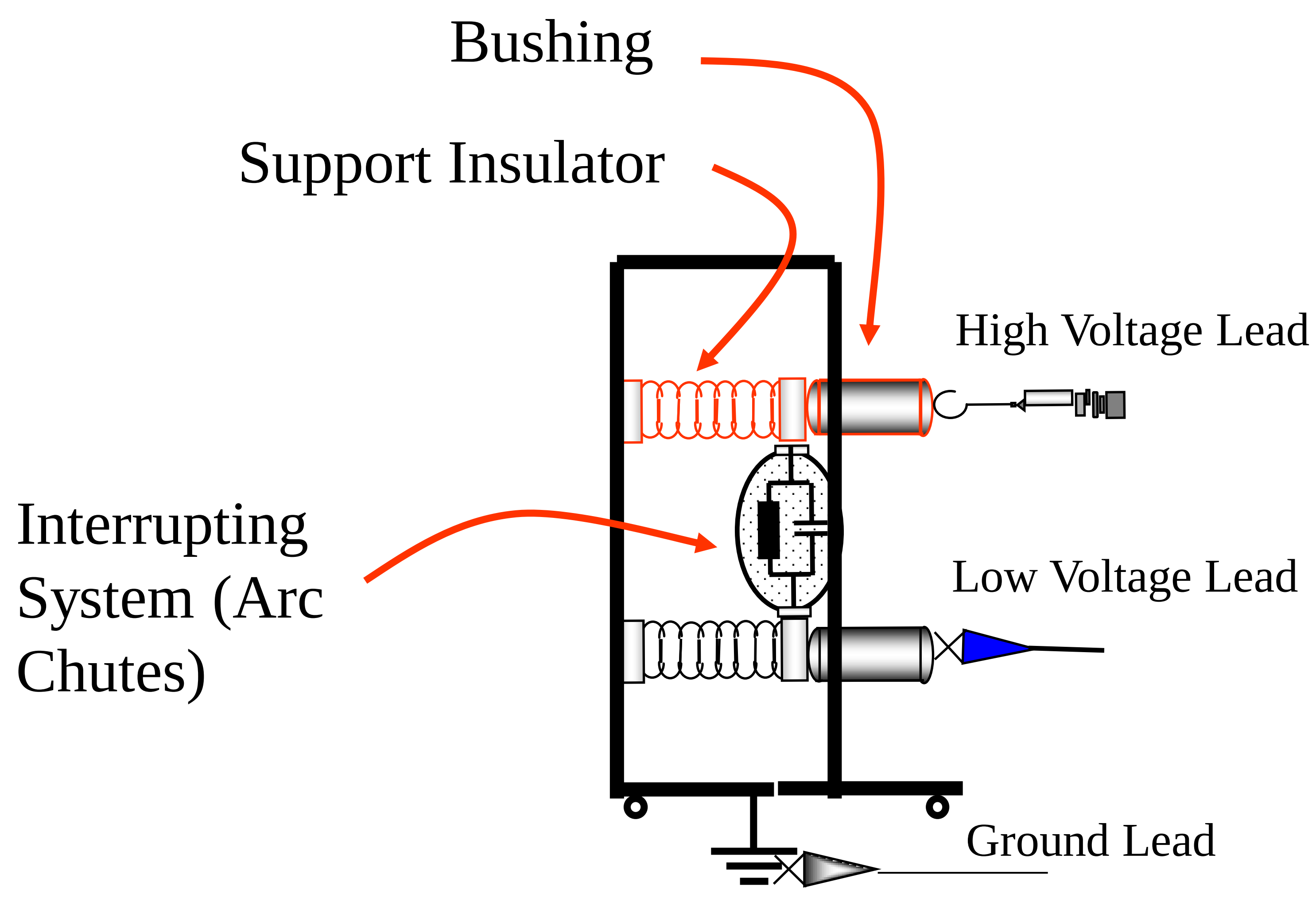
**Troubleshooting Steps:**

- Clean the surface of the bottle
- Apply Heat to the bottle
- Use a guard collar

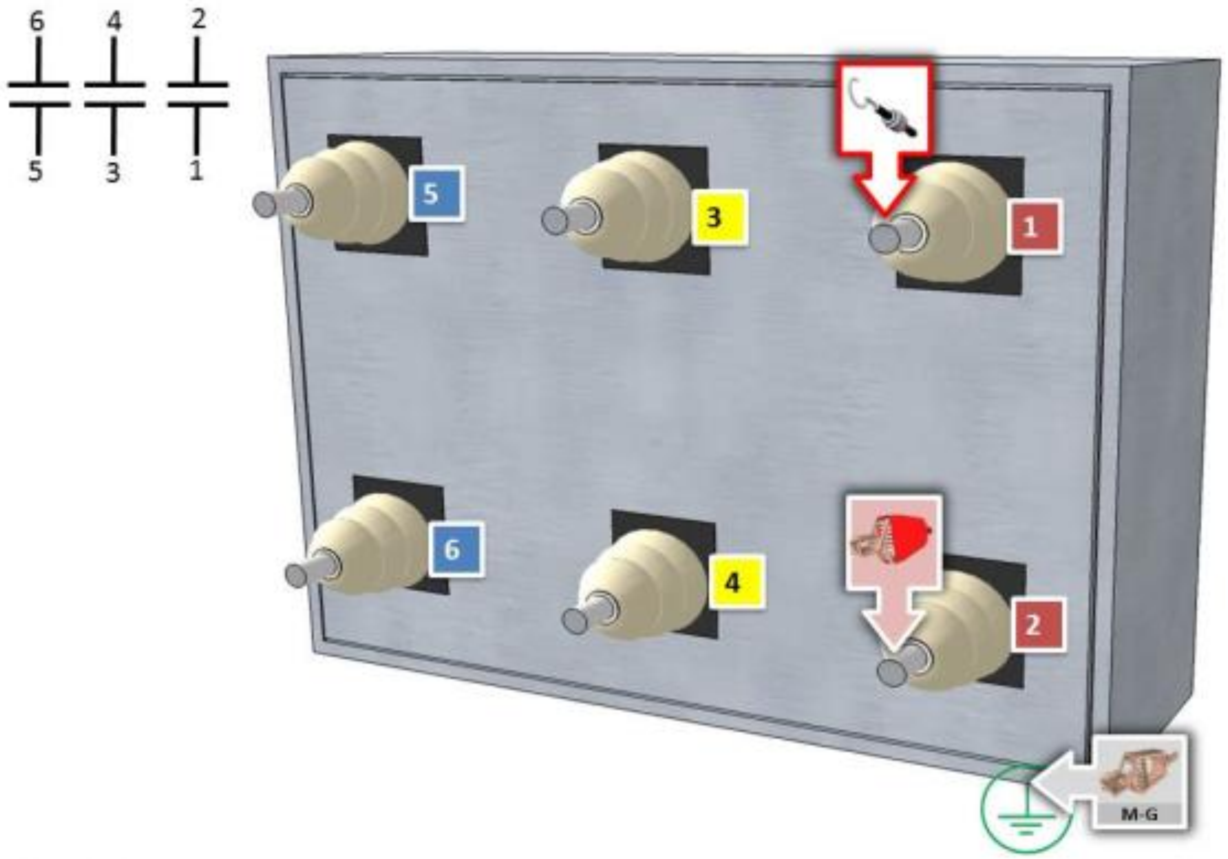
# Air Circuit Breakers



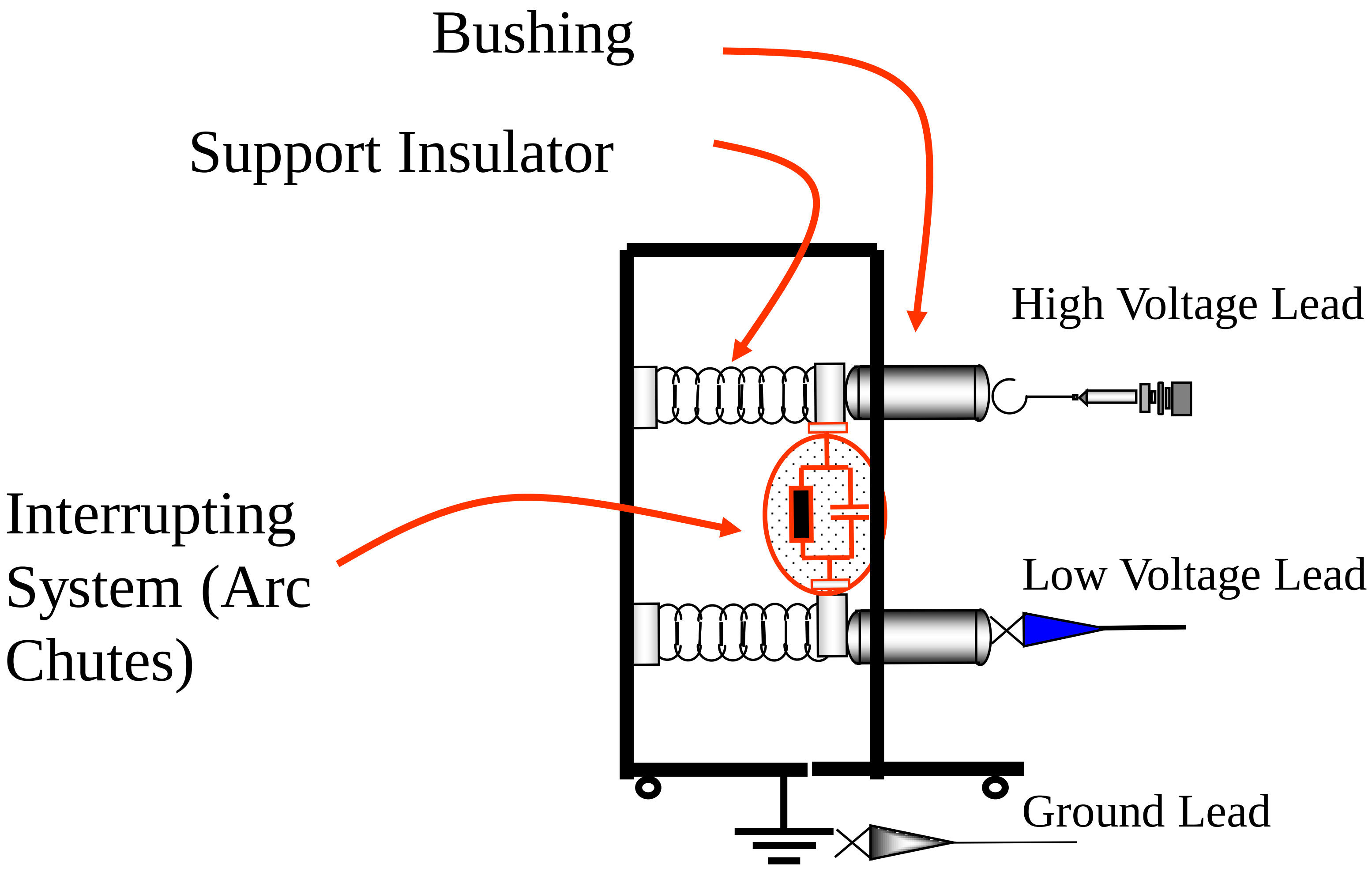
# Air-Magnetic Circuit Breaker



# Air-Magnetic Circuit Breaker



# Air-Magnetic Circuit Breaker



# Air-Magnetic Circuit Breaker

- Open Breaker tests 7-9:
  - Energize One Bushing of a Phase
  - Place the Low Voltage Lead On the Opposite Phase Bushing
  - Test Mode: UST

# DTAPro Test Procedure
# Air-Magnetic Circuit Breaker

**Overall Test Setup**

| Connections | | | | Inputs | | | Test Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # | Breaker | HV Lead | Red Measure Lead | Phase | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) |
| 1 | Open | 1 | 2 | A | * | * | * | * | * | * | * |
| 2 | | 2 | 1 | | * | * | * | * | * | * | * |
| 3 | | 3 | 4 | B | * | * | * | * | * | * | * |
| 4 | | 4 | 3 | | * | * | * | * | * | * | * |
| 5 | | 5 | 6 | C | * | * | * | * | * | * | * |
| 6 | | 6 | 5 | | * | * | * | * | * | * | * |
| 7 | | 1 | 2 | A | * | * | * | * | * | * | * |
| 8 | | 3 | 4 | B | * | * | * | * | * | * | * |
| 9 | | 5 | 6 | C | * | * | * | * | * | * | * |

# DTAF Test Procedure
# Air-Magnetic Circuit Breaker

All Tests - BREAKER OPEN

| # | N | Test Mode | ENG | GAR | PH | Test kV | mA | Watts | % PF Meas. | % PF Corr. | Corr. Factor | Cap. (pF) | Arc Chutes | Rtg | Rtg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ☐ | GAR | 1 | 2 | | | | | | | | | | | |
| 2 | ☐ | GAR | 2 | 1 | | | | | | | | | | | |
| 3 | ☐ | GAR | 3 | 4 | | | | | | | | | | | |
| 4 | ☐ | GAR | 4 | 3 | | | | | | | | | | | |
| 5 | ☐ | GAR | 5 | 6 | | | | | | | | | | | |
| 6 | ☐ | GAR | 6 | 5 | | | | | | | | | | | |
| 7 | ☐ | UST | 1 | 2 | | | | | | | | | | | |
| 8 | ☐ | UST | 3 | 4 | | | | | | | | | | | |
| 9 | ☐ | UST | 5 | 6 | | | | | | | | | | | |

# Air-Magnetic Circuit Breaker

Test Procedure - Breaker Open

- Record I, W and %PF
- No Temperature Correction
- Tests 1, 3 and 5 Should Compare
- Tests 2, 4 and 6 Should Compare
    - -Main Influence - Bushing
- Tests 7 Through 9 Should Compare
    - -Condition of the arc chutes

# Air-Magnetic Circuit Breaker

**<u>Test Data Analysis</u>**

- Tests 1 to 6
  - Dominated by Bushings
  - Includes Operating Rod, Puffer Assembly, Phase Barriers
- Tests 7, 8, and 9
  - Condition of Arc-Chute
  - Very Low Current, Evaluate Losses
- Diagnostic Tests Performed With Phase Barriers and Arc-Chutes Removed

# Air-Magnetic Circuit Breaker

## Test Data Analysis

- If Current is Greater Than 200 μA, Evaluate % PF
- No Temperature Correction
- Compare results:
  - Among Similar Test Specimens (Among Phases)

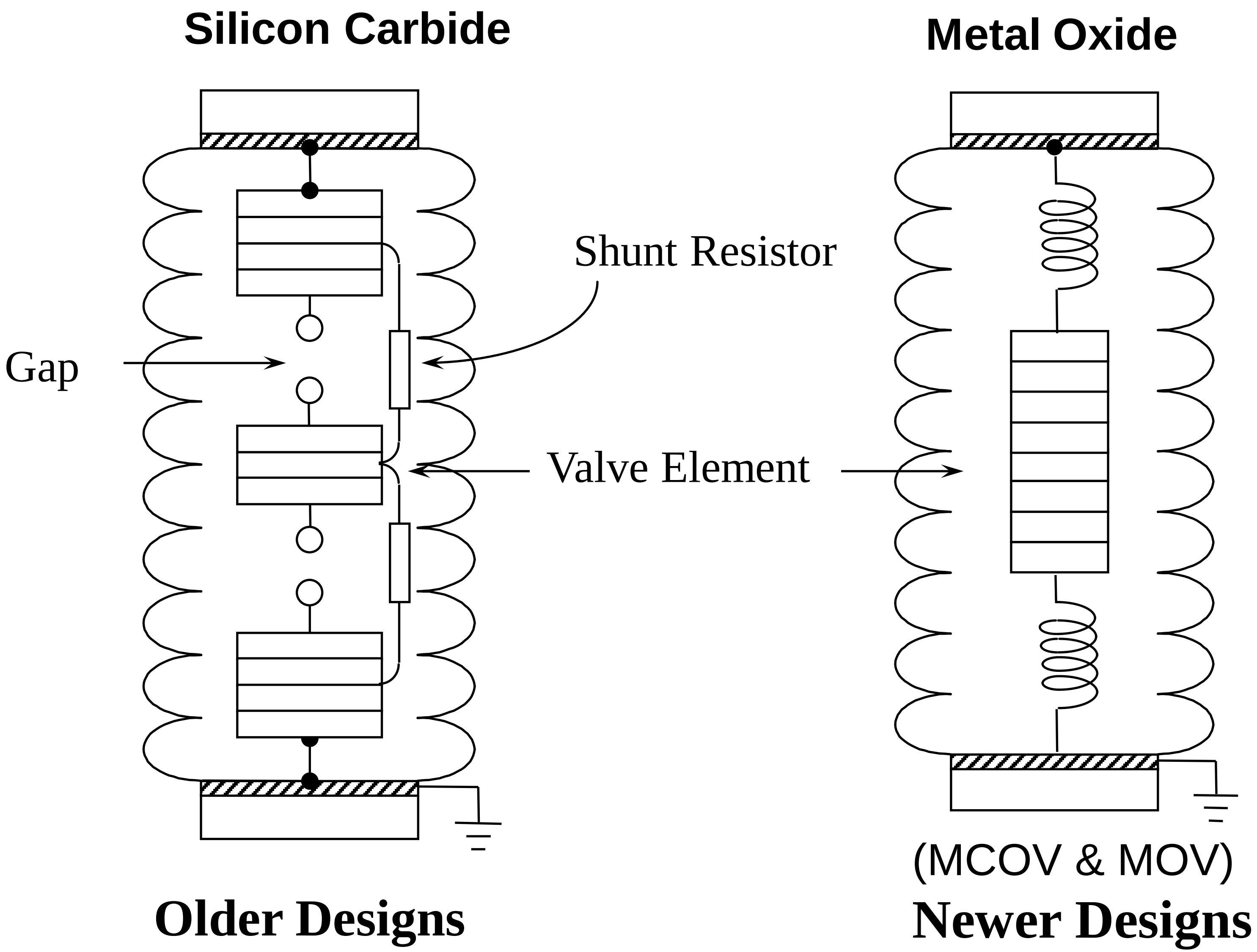
    Tests 1, 3, and 5

    Tests 2, 4, and 6

    Tests 7, 8, and 9
  - Compare Results to Any Previous Tests, Similar Breakers, and to similar breakers using DTA Web

# Surge Arresters

# Surge Arresters



# Surge Arresters Description

Normal Condition ==> Insulator

Instant of Disturbance ==> Conductor

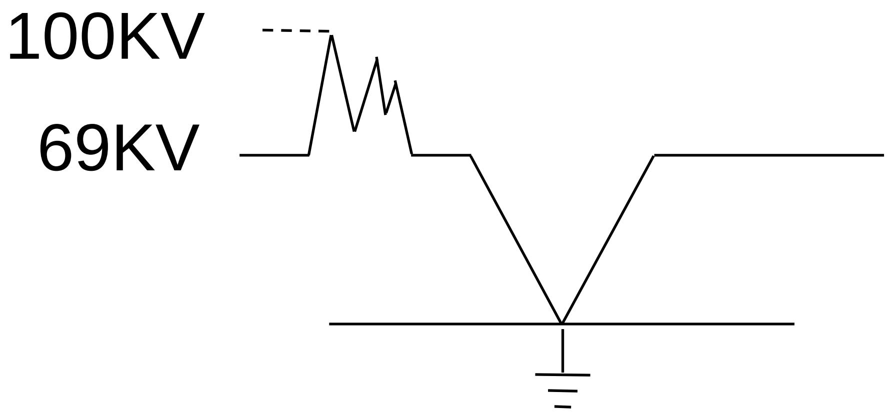
Passing of Disturbance ==> Insulator

Non-Linear Volt-Ampere Characteristic

Dielectric-Loss Test - Not a Test of The Arrester's Protective Characteristics

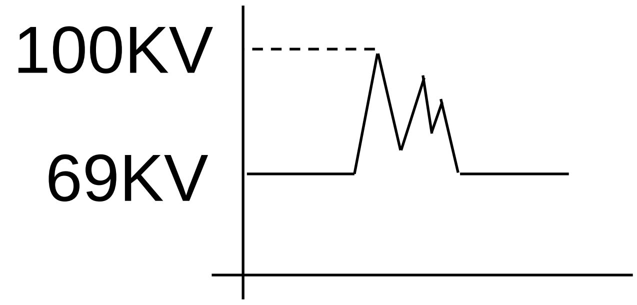
# Surge Arresters

## Silicon Carbide




- Over design ratings it dissipates the impulse
- Drops down to zero
- Generates its own impulse

## Metal Oxide




- Over design ratings it dissipates the impulse
- Clamps the voltage
- Doesn’t drop to zero
- Doesn’t generate its own impulse

# Surge Arrester Test Voltages

- To make comparisons meaningful, arresters must be tested at the same voltage levels
- Clean all porcelain surfaces to minimize surface leakage

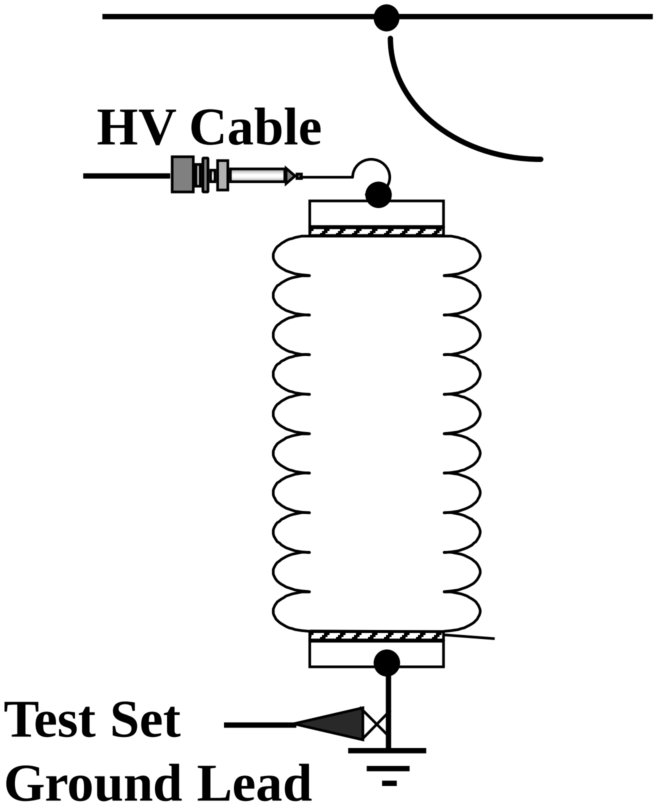
# Surge Arresters Test Voltages

| ARRESTER TYPE | KV RATING | 10KV | 2.5KV |
|---|---|---|---|
| Silicon Carbide | 3.0 | 2.5 | 2.5 |
| | 4.5 | 4.0 | 2.5 |
| | 6.0 | 5.0 | 2.5 |
| | 7.5 | 7.0 | 2.5 |
| | 9.0 | 7.5 | 2.5 |
| | 12.0 and Above | 10 | 2.5 |
| Metal Oxide | 2.7 to 3.0 | 2.0 | 2.0 |
| | 4.5 to 12.0 | 2.5 | 2.5 |
| | 15.0 and Above | 10 | 2.5 |

**Refer to Tabulation in the Doble Test Data-Reference Book**

# Single Unit Arrester

1. Bus must be disconnected from top of unit.
2. Place HV test lead as shown.
3. If discharge counter present, place jumper from bottom of arrester to ground, bypassing the counter.
4. Connect test set ground to grounded structure supporting arrester stack.
5. Use a GST-Ground test circuit.

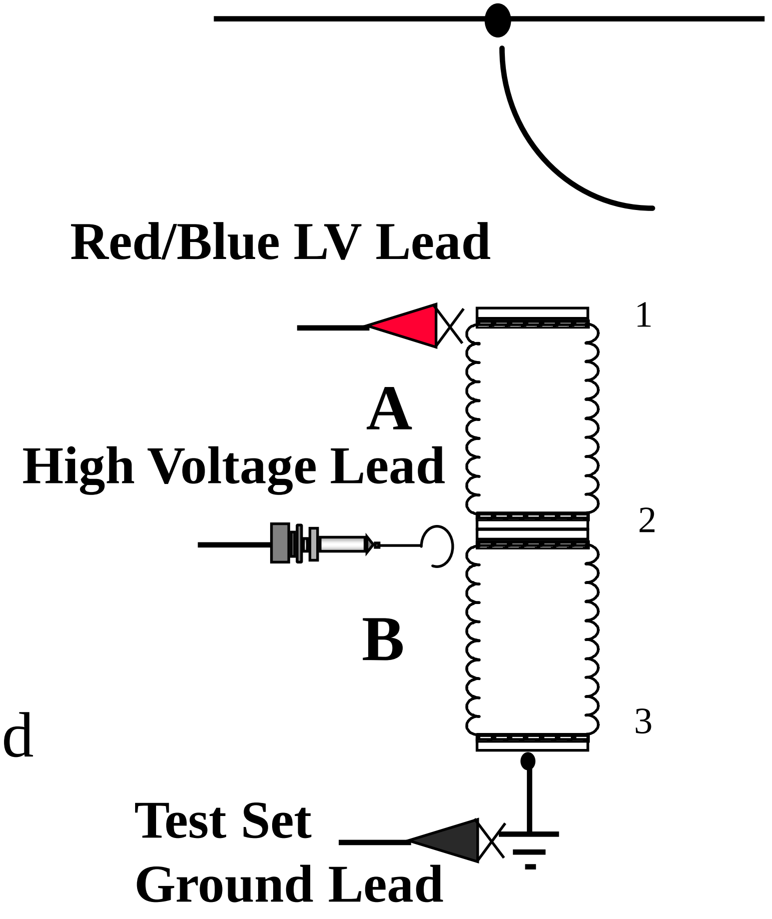


# Two Unit Arrester Stack

1. Place test leads as shown. Colors may be interchanged. Bus must be disconnected from top unit.

2. If discharge counter present, place jumper from bottom of B to ground, bypassing the counter.

3. Connect test set ground to grounded structure supporting arrester stack.



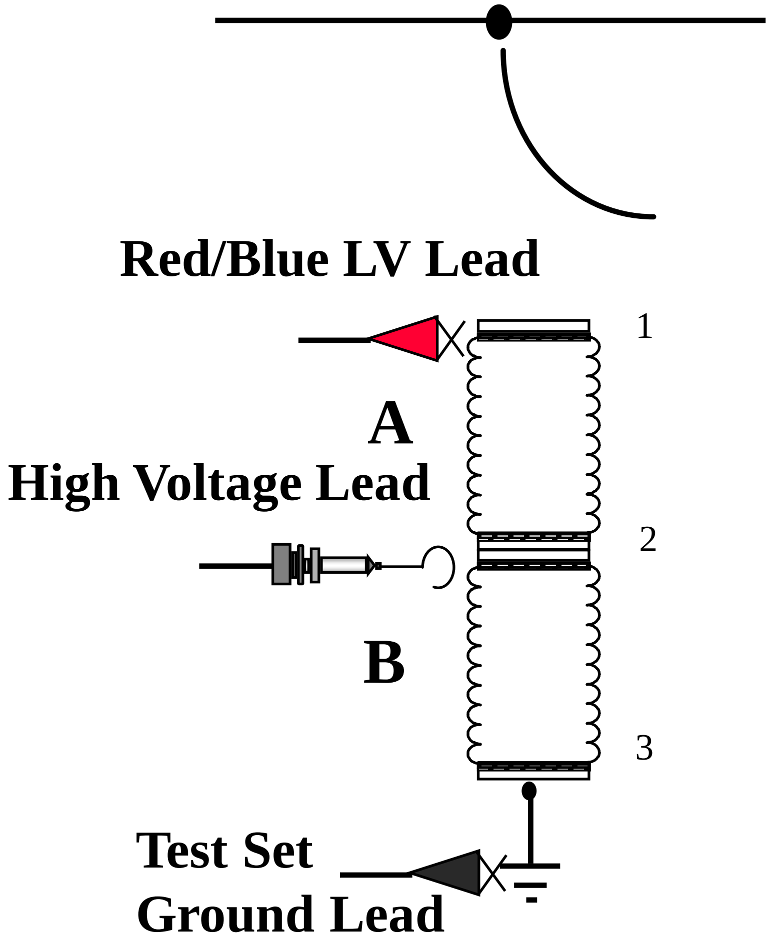
# Two Unit Arrester Stack

4. A and B must be measured one at a time as follows:

| **Choose This Circuit** | **To Measure** |
| --- | --- |
| UST Measure Red | A |
| GST Guard Red | B |

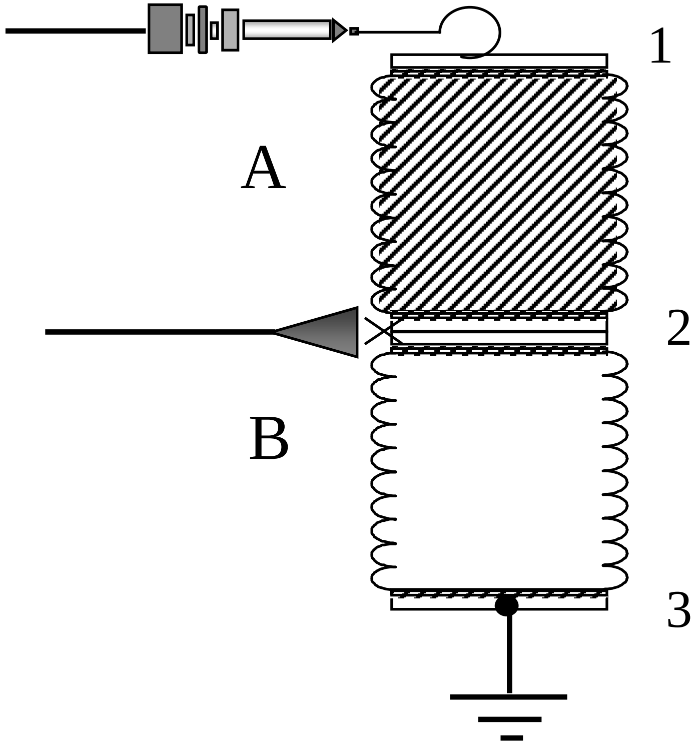
5. Use the **multiple** test choice to speed testing.

6. This example uses the Red lead. The blue lead could have been used instead, and all test circuit choices would then have the red replaced by blue.



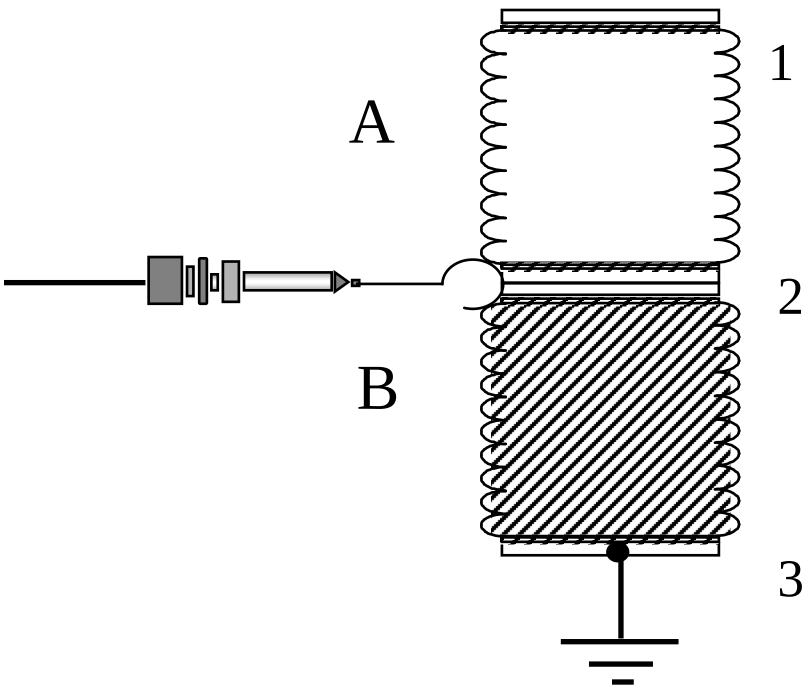
# Test Method 1 - Dual-Stack Arresters

Test #1




| No. | Mode | Energize | Ground | Measure |
|---|---|---|---|---|
| 1 | GST | 1 | 2 | A |

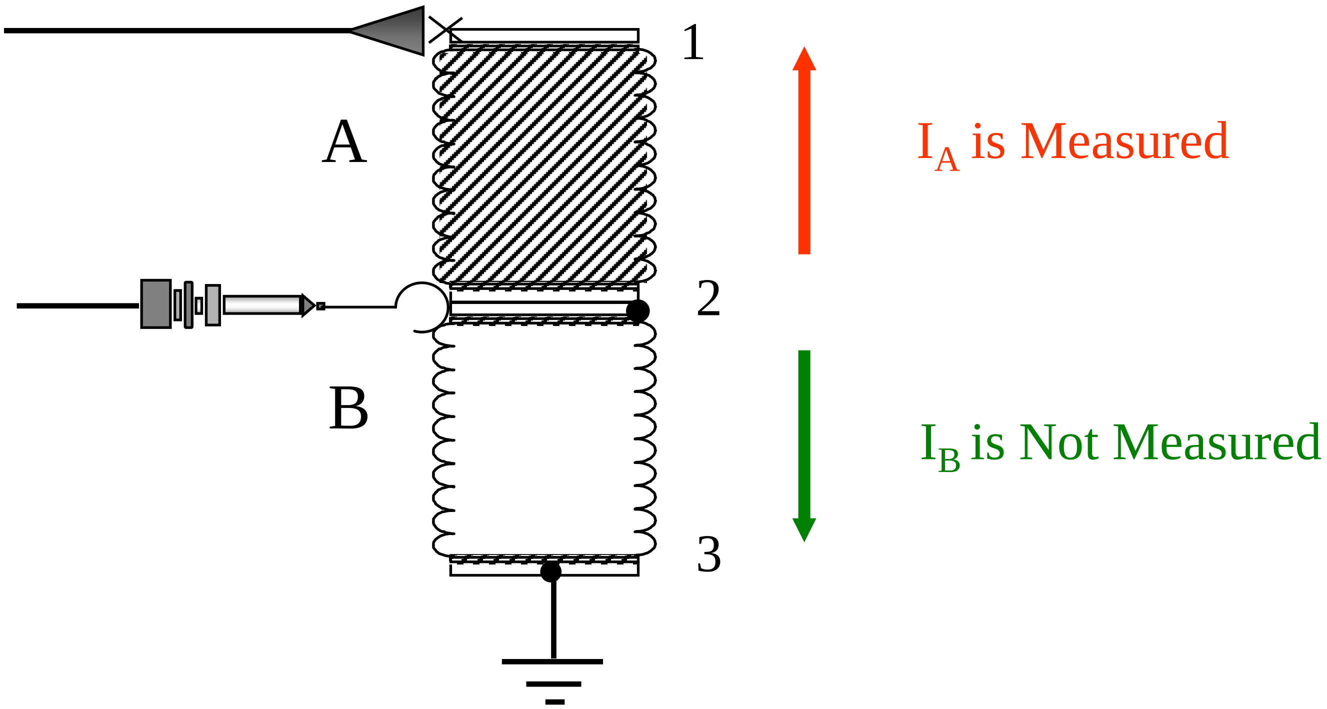
# Test Method 1 - Dual-Stack Arresters




| No. | Mode | Energize | Ground | Measure |
|---|---|---|---|---|
| 2 | GST | 2 | 3 | B |

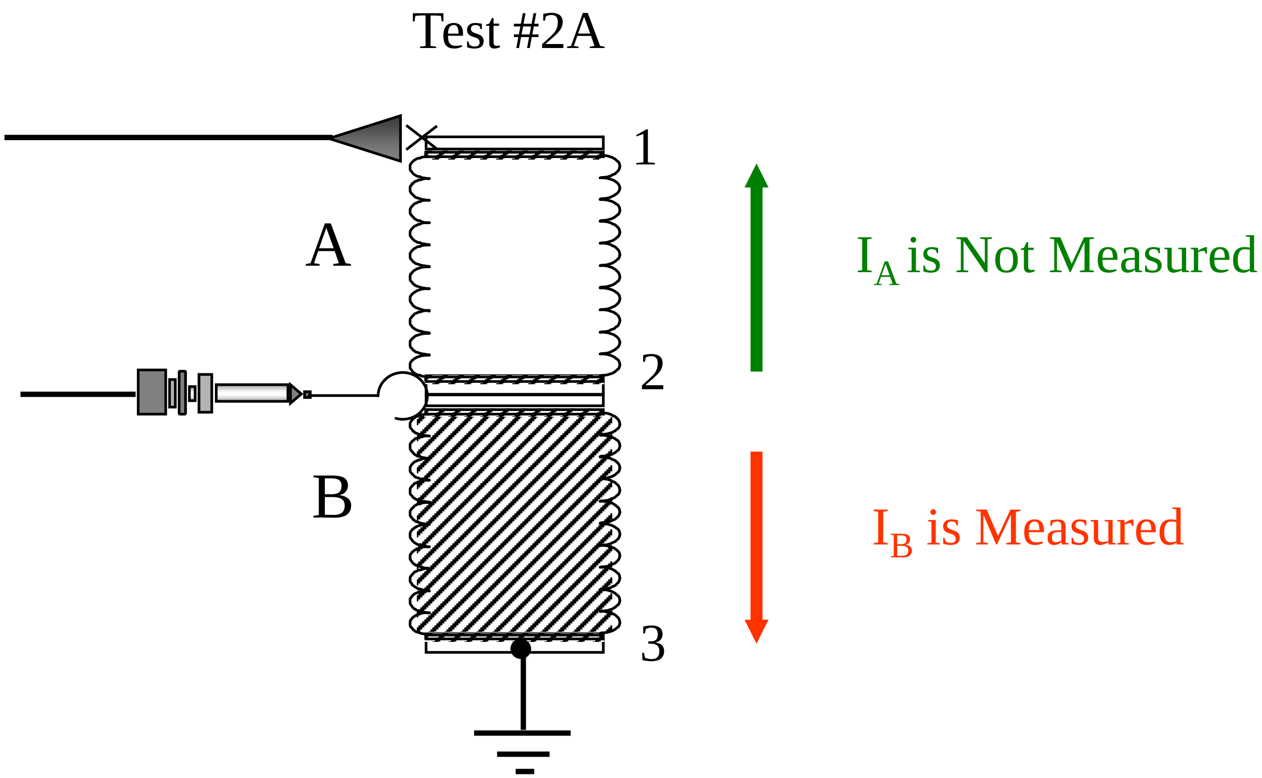
# Test Method 2 - Dual-Stack Arresters

Test #1A




| No. | Mode | Energize | Ground | Guard | UST | Measure |
|---|---|---|---|---|---|---|
| 1A | UST | 2 | 3 | ---- | 1 | A |

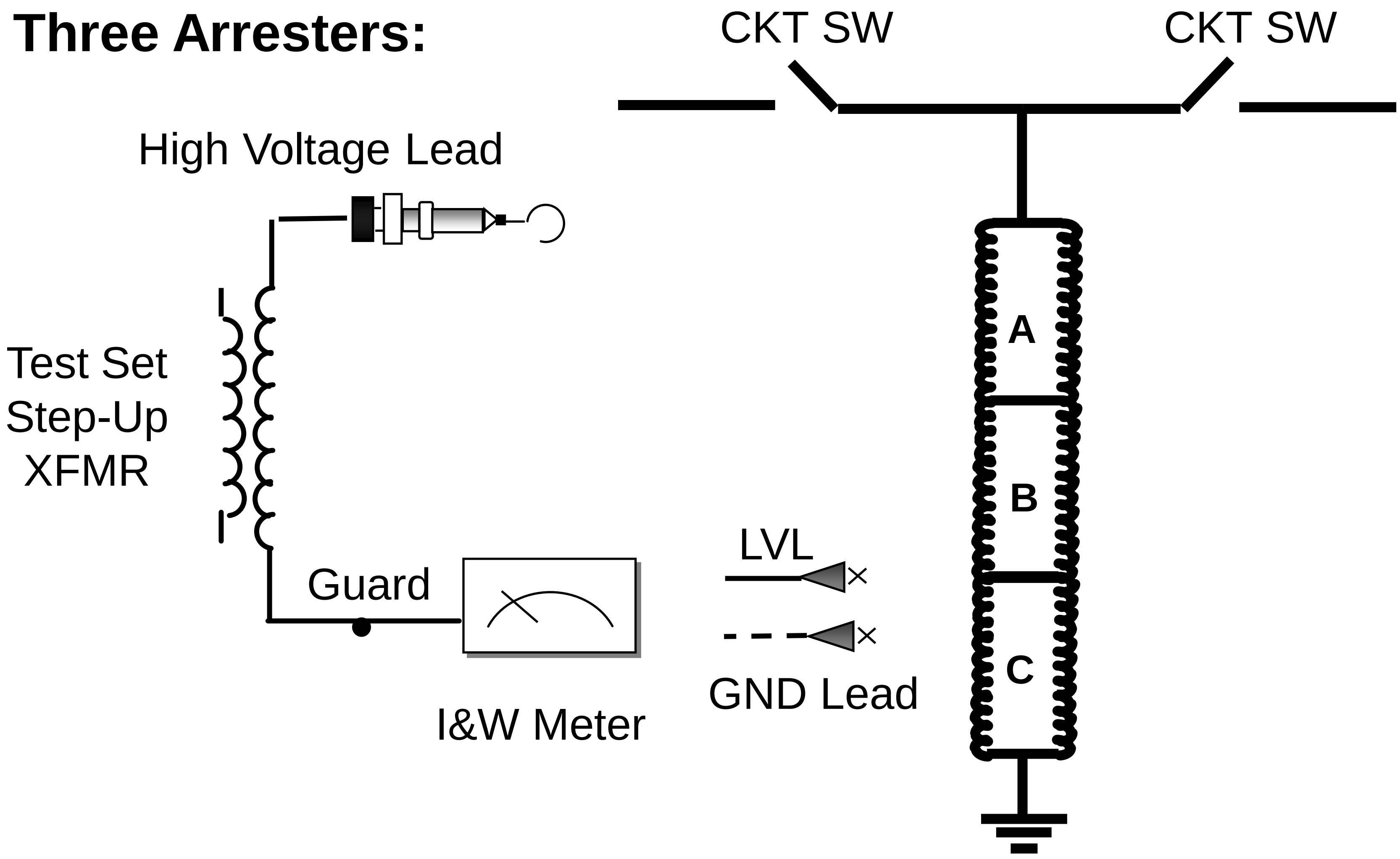
# Test Method 2 - Dual-Stack Arresters




| No. | Mode | Energize | Ground | Guard | UST | Measure |
|---|---|---|---|---|---|---|
| 2A | GST | 2 | 3 | 1 | ---- | B |

# Surge Arresters

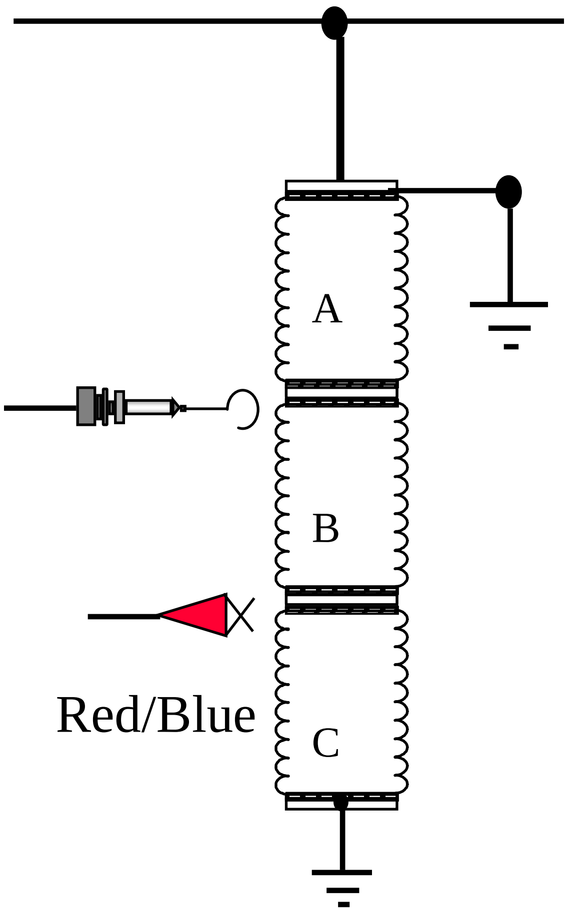
**Three Arresters:**



# Three Unit Arrester Stack

# Bus Connected To Top & Grounded

1. Place test leads as shown. Colors may be interchanged.
2. If discharge counter present, place jumper from bottom of C to ground, bypassing the counter.
3. Connect test set ground to grounded structure supporting arrester stack.

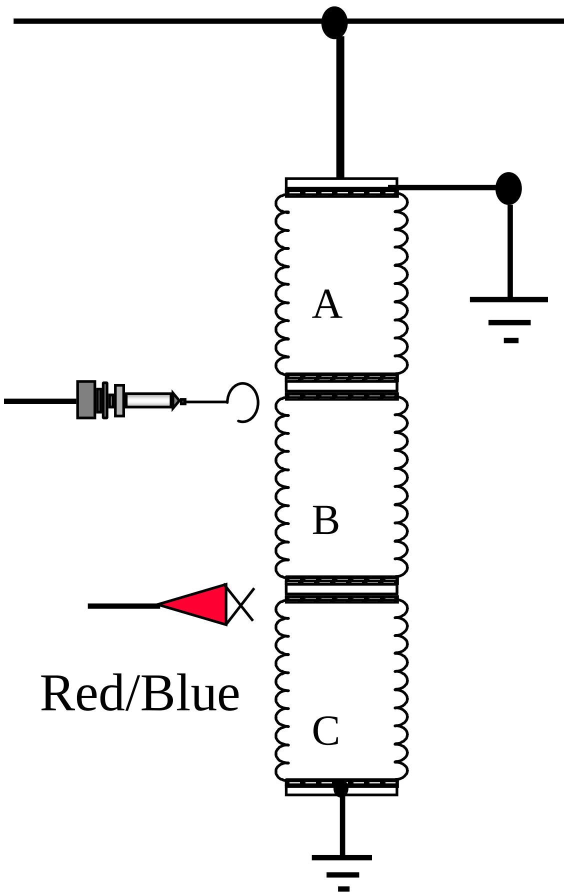


# Three Unit Arrester Stack
# Bus Connected To Top & Grounded

4. A, B, and C must be measured one at a time as follows:

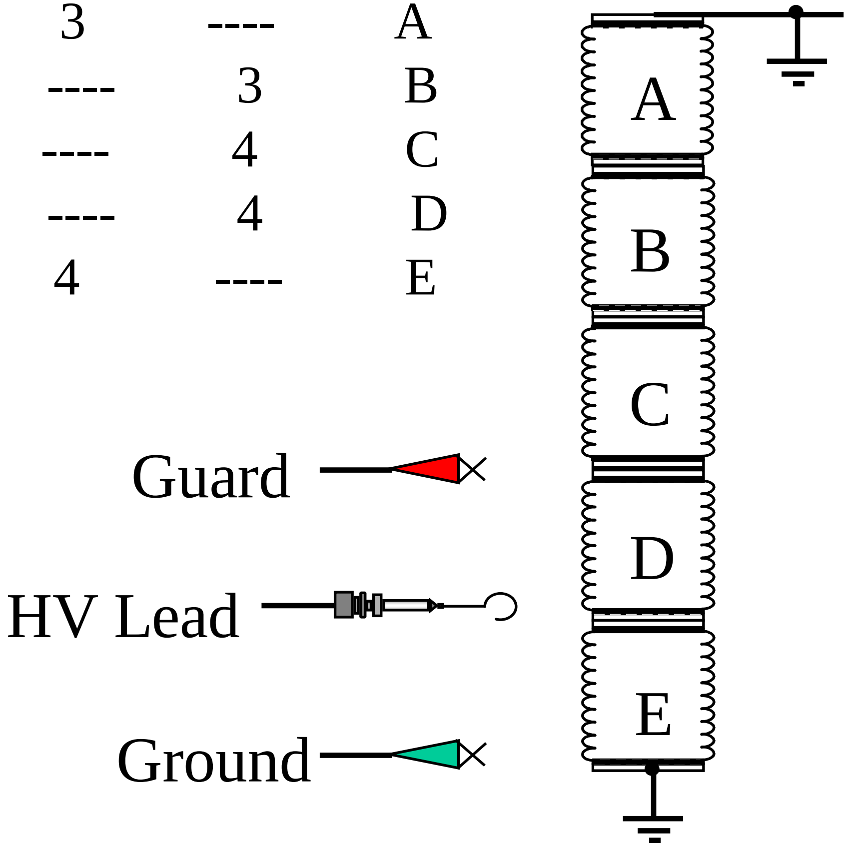
| Choose This Circuit | To Measure |
|---|---|
| GST Guard Red | A |
| UST Measure Red | B |

5. Use the **multiple** test choice to speed testing.
6. To measure C, remove HV cable and LV leads. Replace **HV cable** between B and C. Replace **Red LV** lead between A and B. Use **GST-Guard Red** circuit. Blue lead may be used instead of red lead. If blue lead used, test circuit would then be GST-Guard Blue.



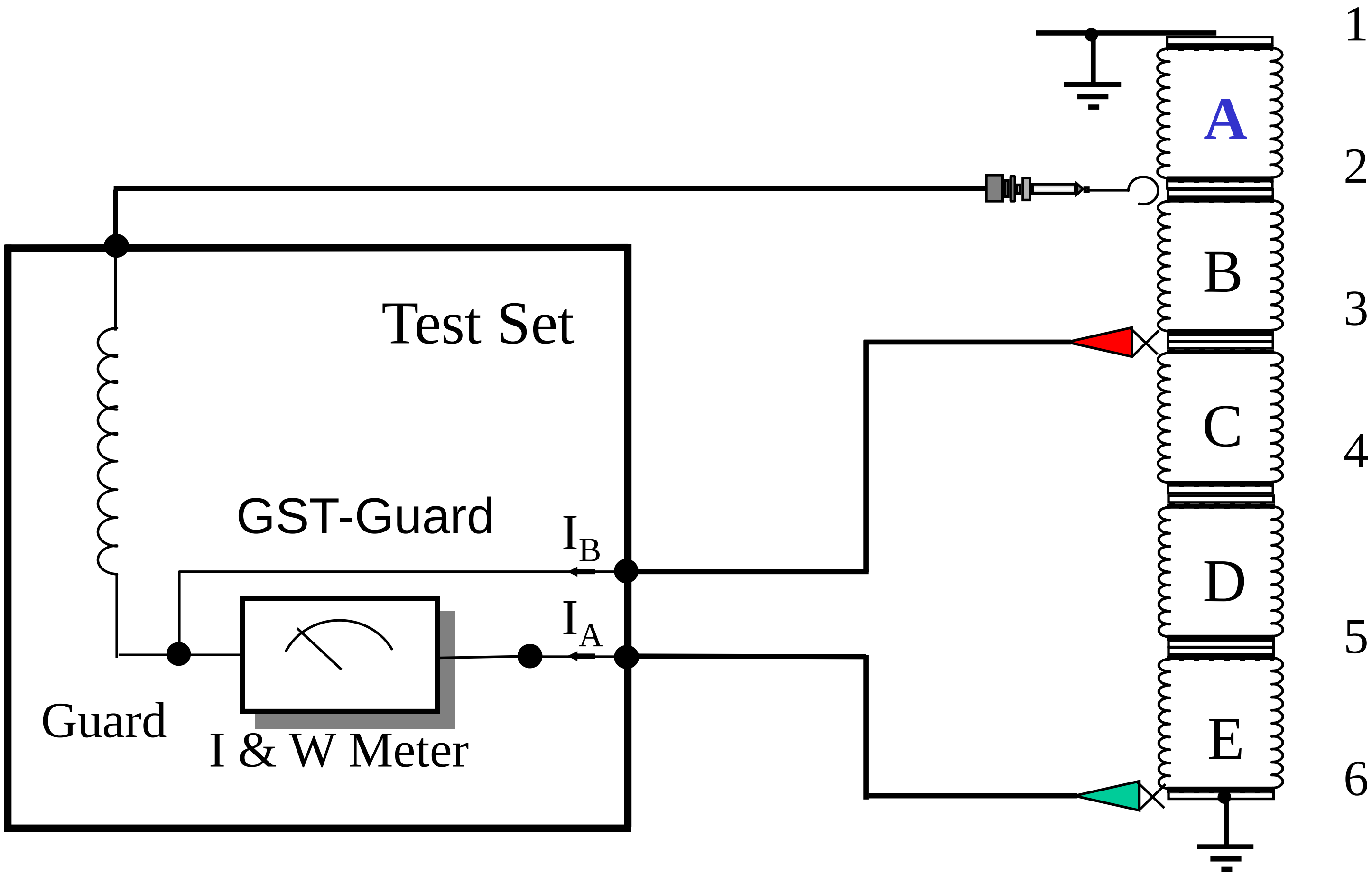
# Testing Multi-Stack Arresters

| Test No. | Test Mode | Energize | Ground | Guard | UST | Measure |
|---|---|---|---|---|---|---|
| 1 | GST | 2 | 1,6 | 3 | ---- | A |
| 2 | UST | 2 | 1,6 | ---- | 3 | B |
| 3 | UST | 3 | 1,6 | ---- | 4 | C |
| 4 | UST | 5 | 1,6 | ---- | 4 | D |
| 5 | GST | 5 | 1,6 | 4 | ---- | E |



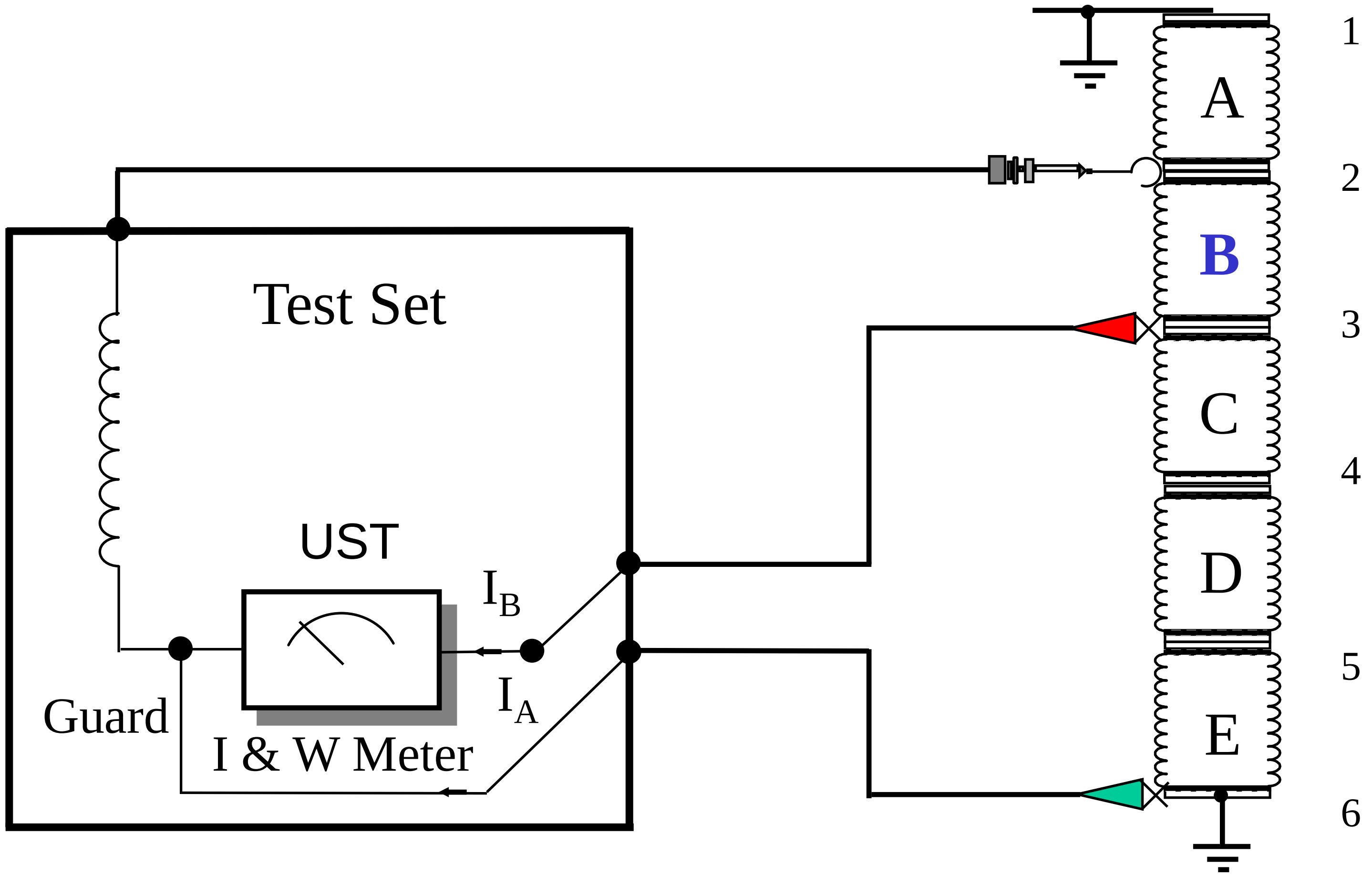
# Testing Multi-Stack Arresters

| Test No. | Test Mode | Energize | Ground | Guard | UST | Measure |
|---|---|---|---|---|---|---|
| 1 | GST | 2 | 1,6 | 3 | ---- | A |



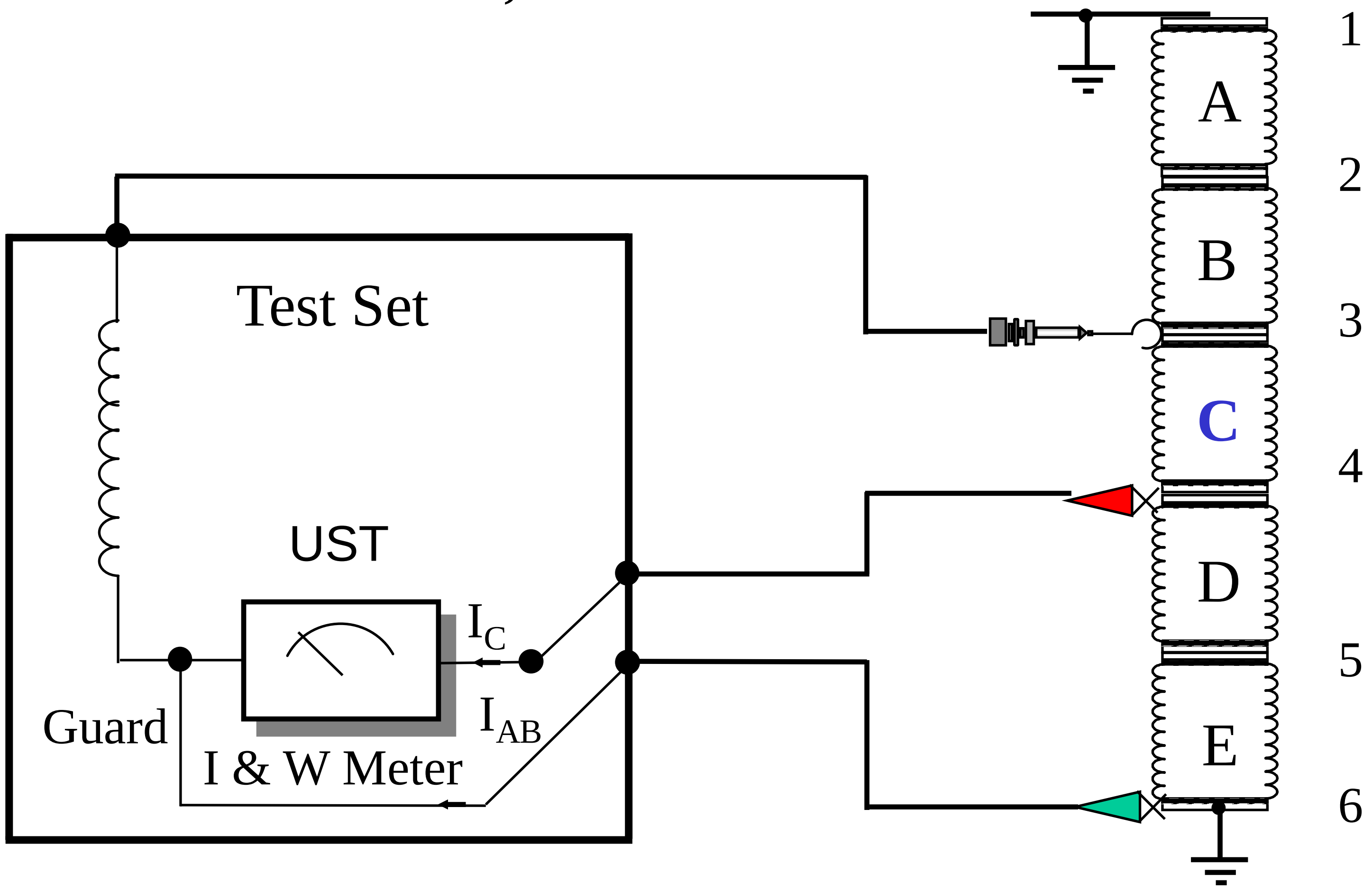
# Testing Multi-Stack Arresters

| Test No. | Test Mode | Energize | Ground | Guard | UST | Measure |
|---|---|---|---|---|---|---|
| 2 | UST | 2 | 1,6 | ---- | 3 | B |



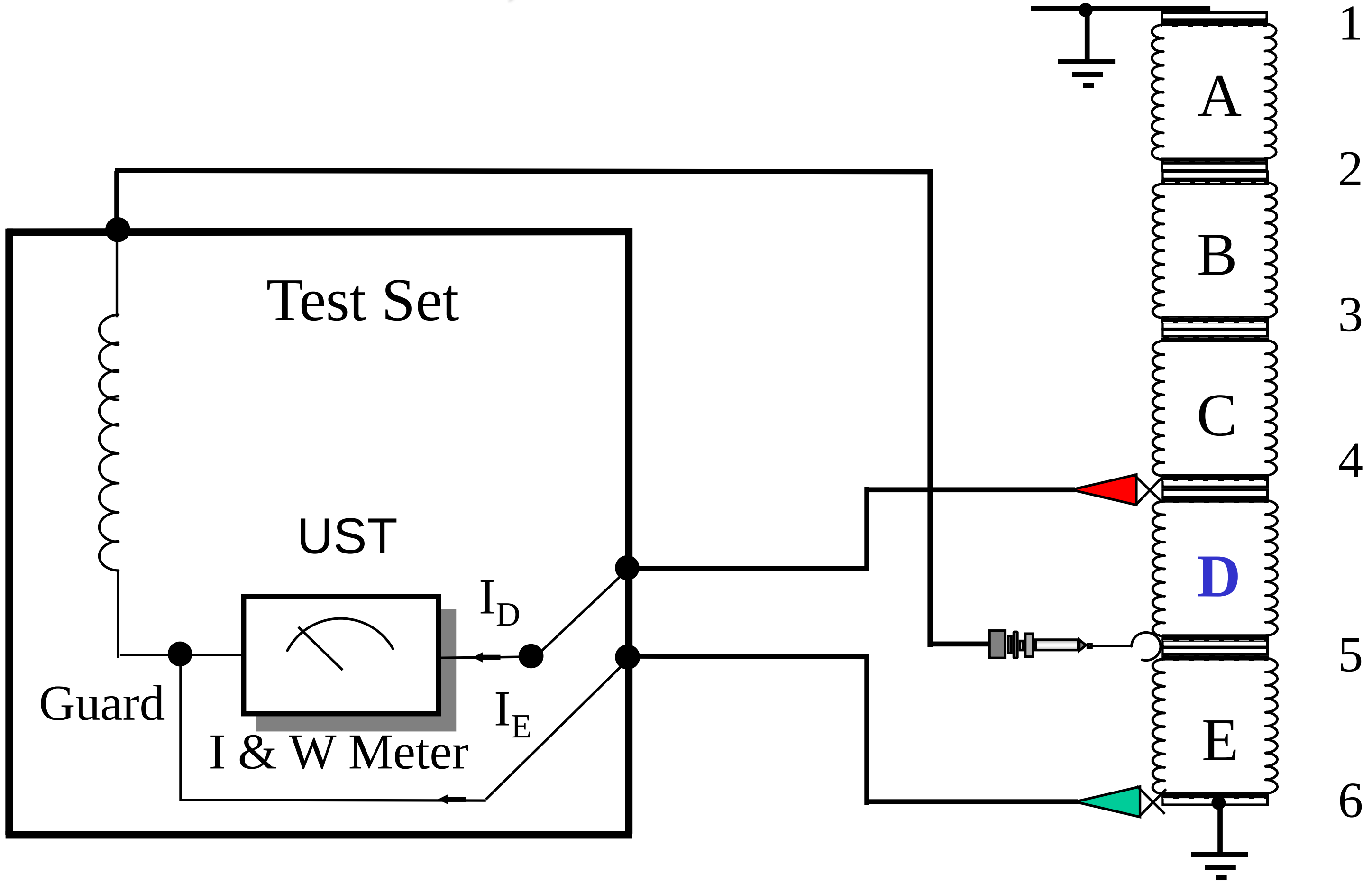
# Testing Multi-Stack Arresters

| Test No. | Test Mode | Energize | Ground | Guard | UST | Measure |
| --- | --- | --- | --- | --- | --- | --- |
| 3 | UST | 3 | 1,6 | ---- | 4 | C |



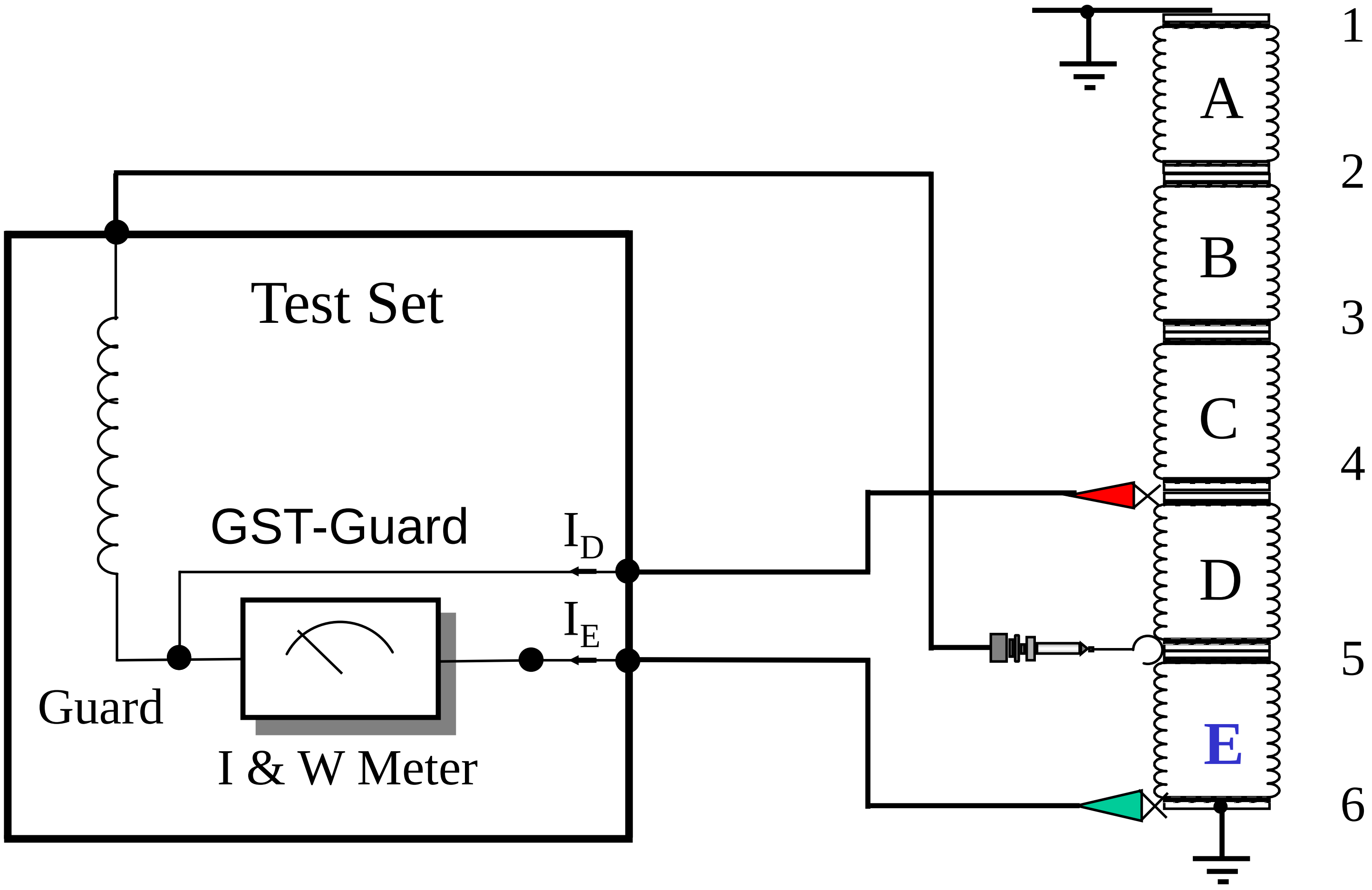
# Testing Multi-Stack Arresters

| Test No. | Test Mode | Energize | Ground | Guard | UST | Measure |
|---|---|---|---|---|---|---|
| 4 | UST | 5 | 1,6 | ---- | 4 | D |



# Testing Multi-Stack Arresters

| Test No. | Test Mode | Energize | Ground | Guard | UST | Measure |
|---|---|---|---|---|---|---|
| 5 | GST | 5 | 1,6 | 4 | ---- | E |



# Arrester Test Results Analysis

Refer to Published Tabulations

Compare Losses Obtained for Similar Units Tested Under Same Conditions

Any Deviation, Either Higher or Lower, Should Be Investigated

Rating Are Based On Watts-Loss Values

%PF Not Calculated

Temperature Correction Unnecessary

# Surge Arresters Test Results Analysis

## Metal Oxide

### Higher Than Normal Losses

- Contamination by Moisture, Dirt or Dust
- Corroded Gaps in Early Designs (newer designs gapless)

### Lower Than Normal Losses

- Discontinuities in Internal Electrical Configuration

# Surge Arresters Test Results Analysis

## Silicon Carbide

### Higher Than Normal Losses

- Contamination by Moisture, Dirt or Dust
- Corroded Gaps

### Lower than Normal Losses

- Broken Shunting Resistors
- Poor Contact and Open Circuits Between Elements

### Change in Currents

- Mechanical Damages

# Handling Suspect Arresters

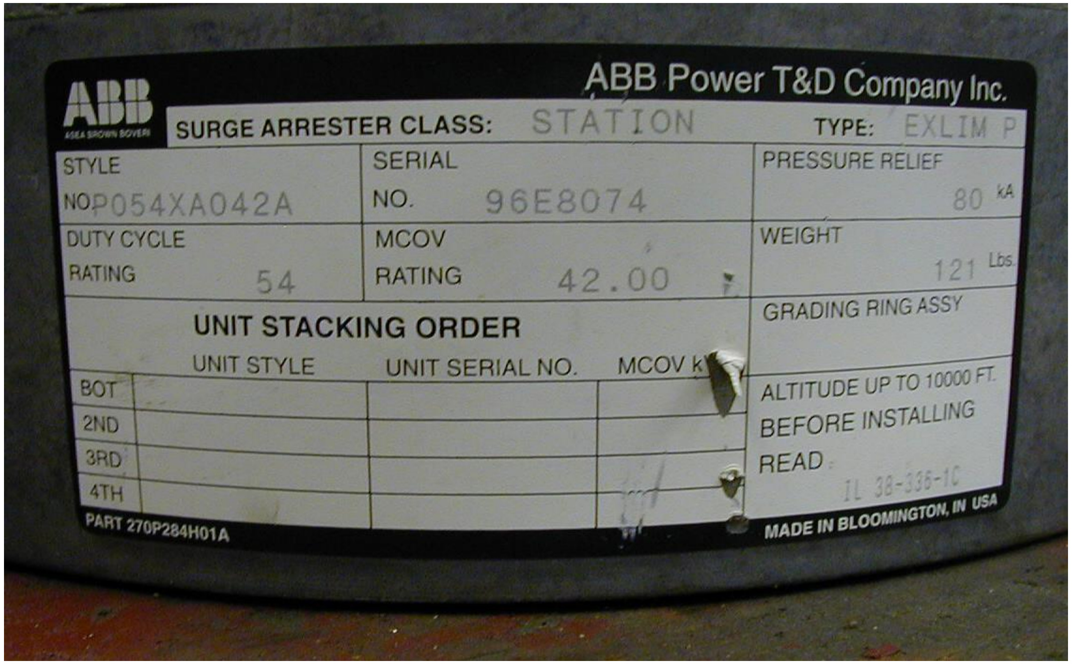
- A damaged seal-gapped arrester should be handled with care.  Due to the increased pressure caused by the destruction of internal elements, a defective arrester may be an explosive hazard.

- If the decision is made to disassemble a suspect unit, ensure that the chamber is properly vented.

- Do not simply “throw away” defective arresters.

- Any suspect arrester should be vented and discharged before disposal.

# Surge Arresters



# Surge Arrester
# Test Data
# Examples

# Hand-Written Data Sheet

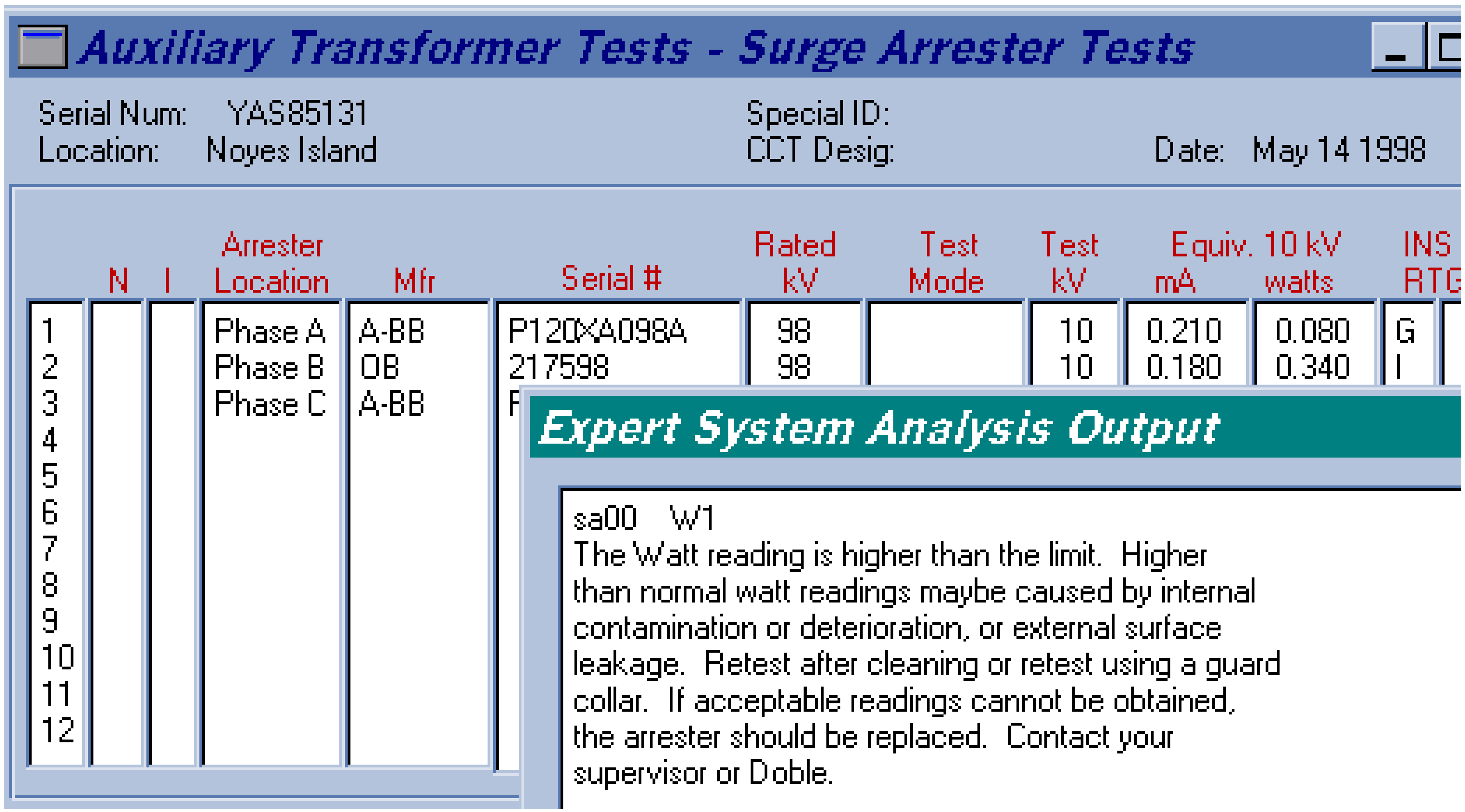
The middle phase OB arrester, type 217598 is rated Good by the technician

| | | | | mA | | | Watts | | Arrester Type | | | Rating |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HS LA | | | | | | | | | | | | |
| Ø1 | 10 | 21 | 10 | 210 | 8 | .01 | .08 | | ABB | P120XA098A | 98kV | G |
| Ø2 | ↓ | 18 | ↓ | 180 | 34 | ↓ | .34 | | OB | 217598 | 98kV | ↓ |
| Ø3 | ↓ | 21 | ↓ | 210 | 5 | ↓ | .05 | | ABB | P120XA098A | 98kV | ↓ |

| Surge Arrester | μA | Watts | Rating |
|---|---|---|---|
| Φ1- ABB P120XA098A | 210 | 0.08 | G |
| Φ2- OB 217598 | 180 | 0.34 | G |
| Φ3- ABB P120XA098A | 210 | 0.05 | G |

# Example:

*Original bad data flagged by DTA:  This arrester was left in service and subsequently failed .*



# Example of Problem Arresters

DTA Field System

File Edit Operations Test

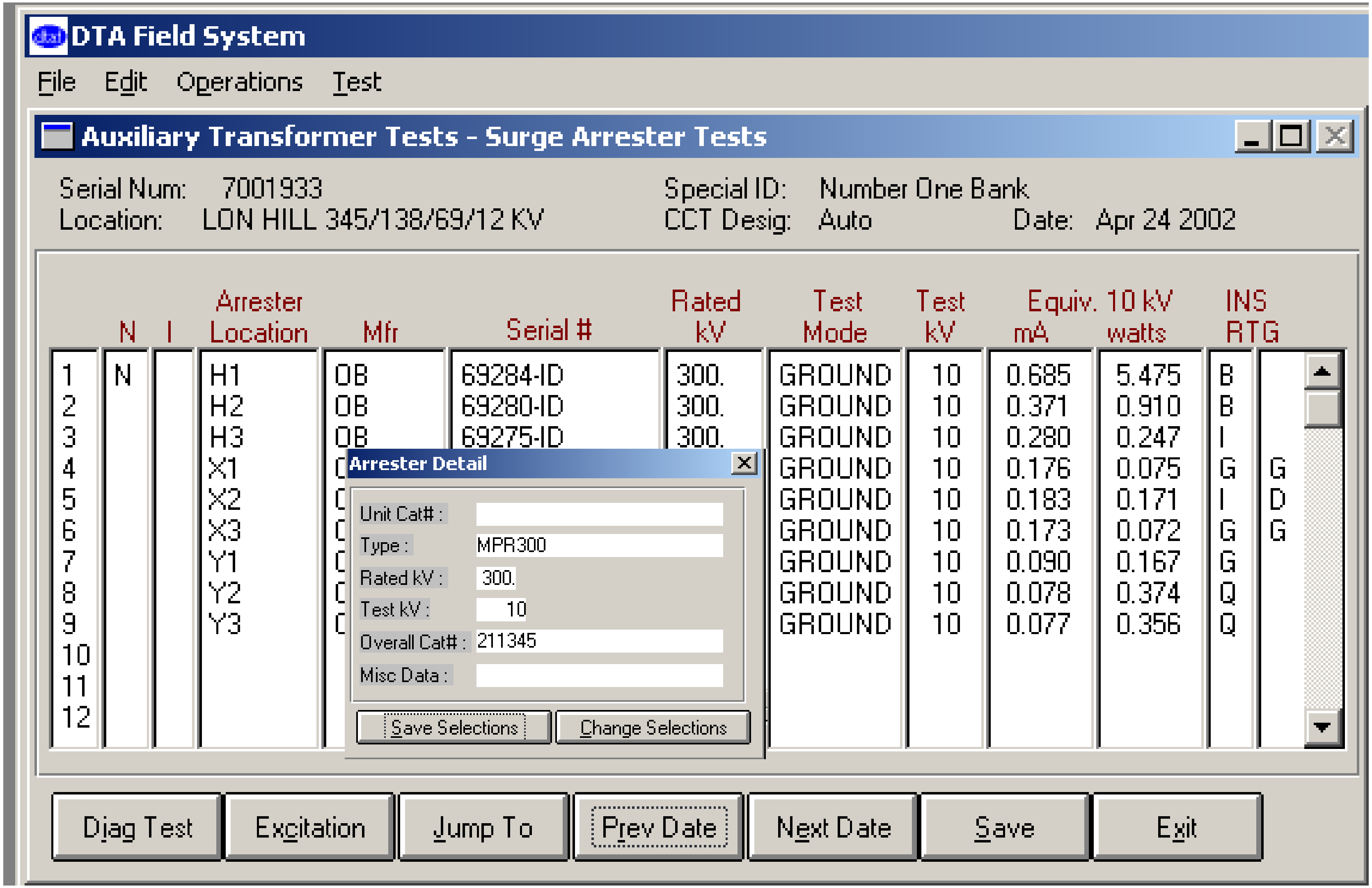
**Auxiliary Transformer Tests - Surge Arrester Tests**

Serial Num: 7001933
Location: LON HILL 345/138/69/12 KV
Special ID: Number One Bank
CCT Desig: Auto
Date: Apr 24 2002

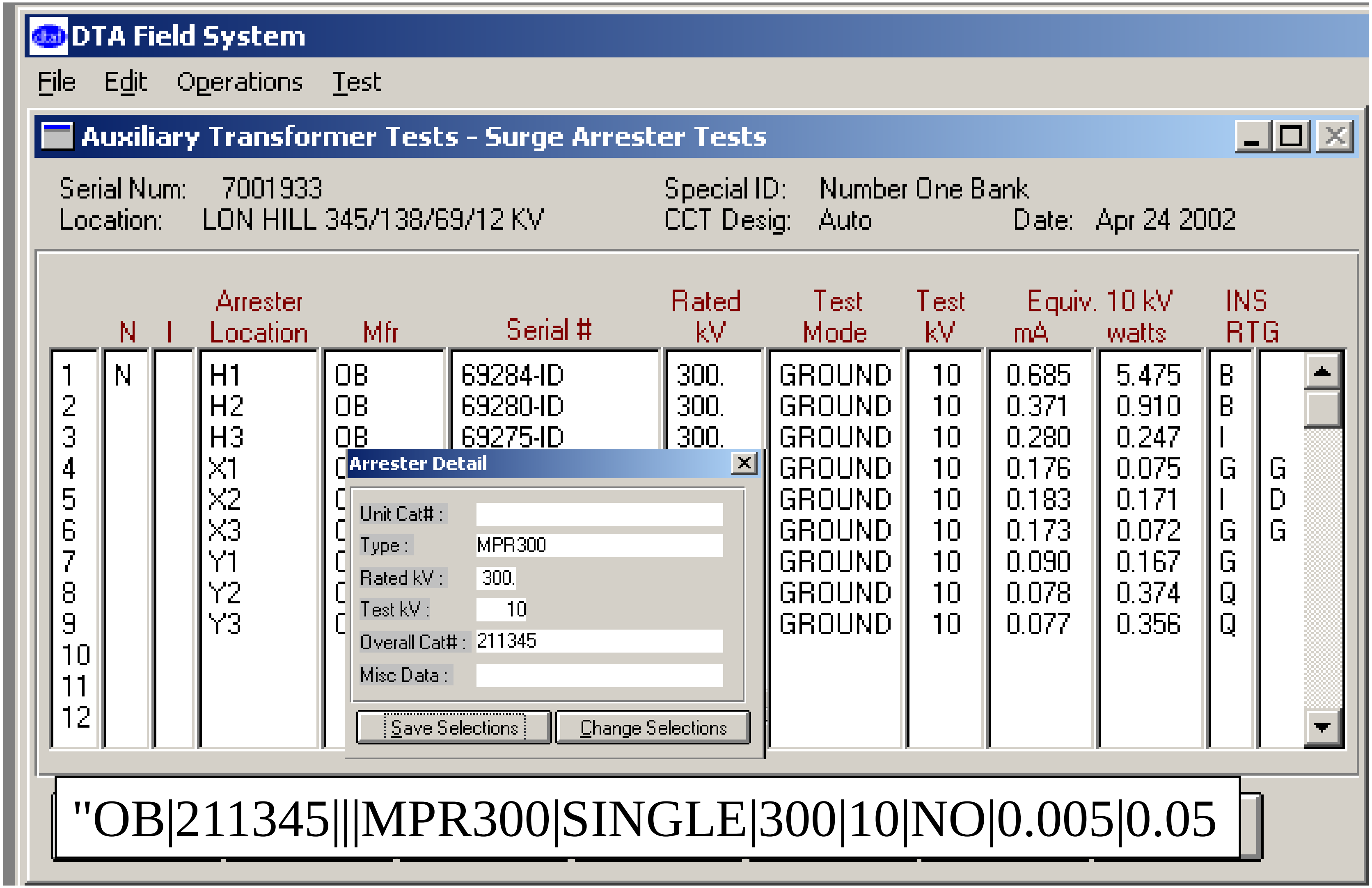
| | N | I | Arrester Location | Mfr | Serial # | Rated kV | Test Mode | Test kV | Equiv. 10 kV mA | Equiv. 10 kV watts | INS | RTG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | N | | H1 | OB | 69284-ID | 300. | GROUND | 10 | 0.685 | 5.475 | B | |
| 2 | | | H2 | OB | 69280-ID | 300. | GROUND | 10 | 0.371 | 0.910 | B | |
| 3 | | | H3 | OB | 69275-ID | 300. | GROUND | 10 | 0.280 | 0.247 | I | |
| 4 | | | X1 | OB | 69740-CH | 120. | GROUND | 10 | 0.176 | 0.075 | G | G |
| 5 | | | X2 | OB | 69760-CH | 120. | GROUND | 10 | 0.183 | 0.171 | I | D |
| 6 | | | X3 | OB | 69758-CH | 120. | GROUND | 10 | 0.173 | 0.072 | G | G |
| 7 | | | Y1 | OB | 15MPA51621B | 15.0 | GROUND | 10 | 0.090 | 0.167 | G | |
| 8 | | | Y2 | OB | 15MPA51617B | 0.0 | GROUND | 10 | 0.078 | 0.374 | Q | |
| 9 | | | Y3 | OB | 15MPA51619B | 0.0 | GROUND | 10 | 0.077 | 0.356 | Q | |
| 10 | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | |

Diag Test | Excitation | Jump To | Prev Date | Next Date | Save | Exit

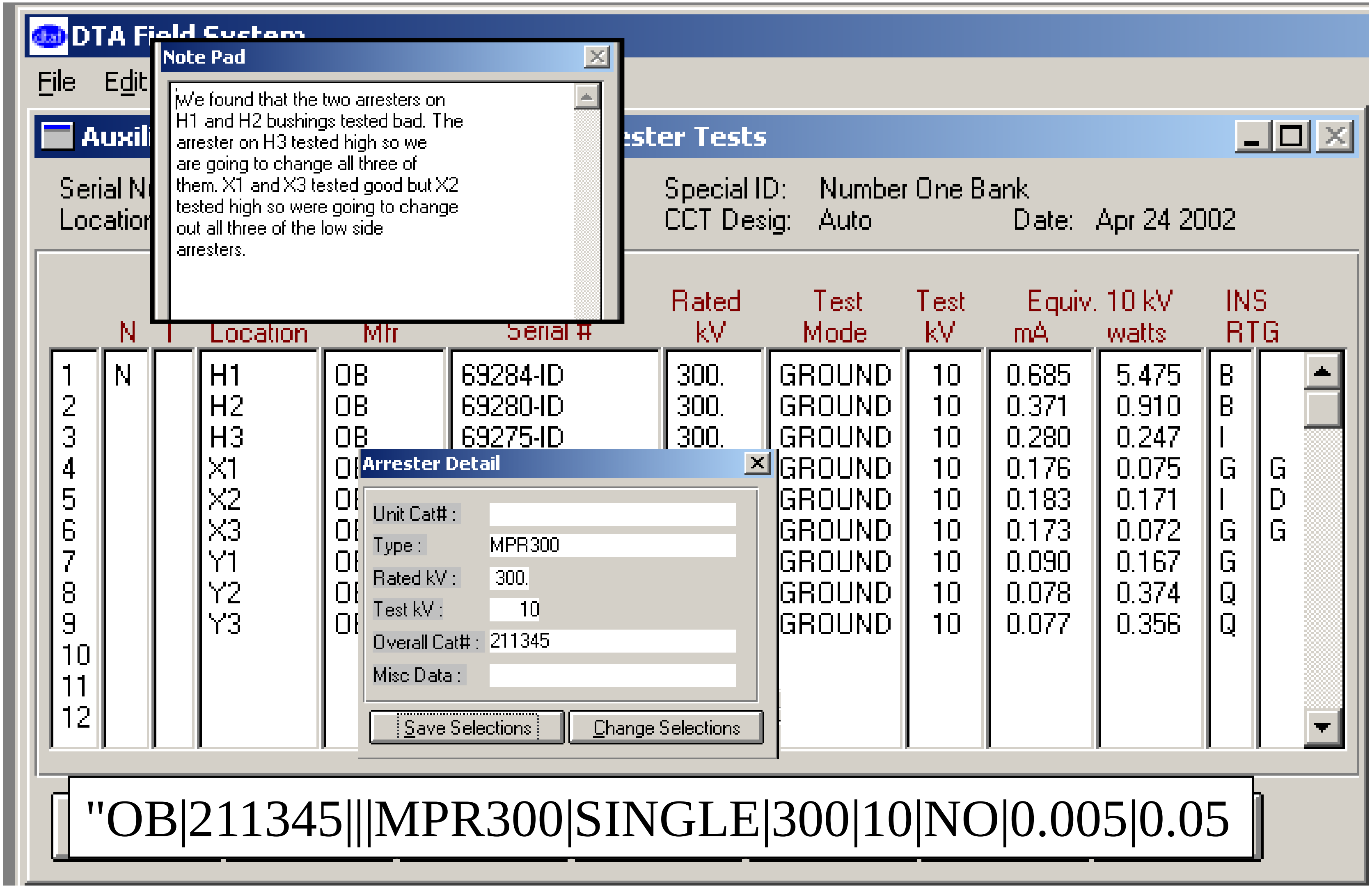
# Example of Problem Arresters



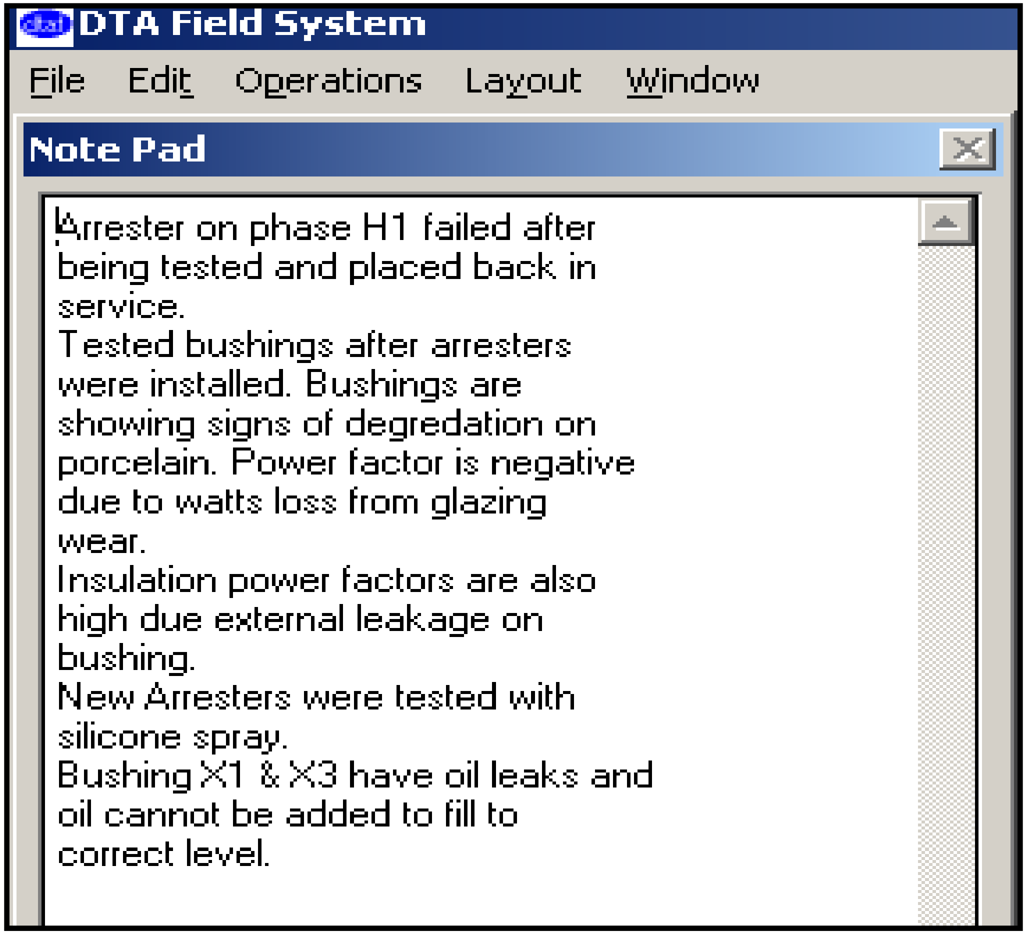
# Example of Problem Arresters




"OB|211345|||MPR300|SINGLE|300|10|NO|0.005|0.05


DTA Field System
File Edit
Auxili… …ester Tests
Serial N…
Location
Special ID: Number One Bank
CCT Desig: Auto
Date: Apr 24 2002
Note Pad
We found that the two arresters on H1 and H2 bushings tested bad. The arrester on H3 tested high so we are going to change all three of them. X1 and X3 tested good but X2 tested high so were going to change out all three of the low side arresters.
N
I
Location
Mfr
Serial #
Rated kV
Test Mode
Test kV
Equiv. 10 kV mA
watts
INS RTG
1 N H1 OB 69284-ID 300. GROUND 10 0.685 5.475 B
2 H2 OB 69280-ID 300. GROUND 10 0.371 0.910 B
3 H3 OB 69275-ID 300. GROUND 10 0.280 0.247 I
4 X1 GROUND 10 0.176 0.075 G G
5 X2 GROUND 10 0.183 0.171 I D
6 X3 GROUND 10 0.173 0.072 G G
7 Y1 GROUND 10 0.090 0.167 G
8 Y2 GROUND 10 0.078 0.374 Q
9 Y3 GROUND 10 0.077 0.356 Q
10
11
12
Arrester Detail
Unit Cat# :
Type : MPR300
Rated kV : 300.
Test kV : 10
Overall Cat# : 211345
Misc Data :
Save Selections
Change Selections
"OB|211345|||MPR300|SINGLE|300|10|NO|0.005|0.05

# Examples of Problem Arrester




- Arresters could not be replaced. The H1 arrester failed hours after being energized.

# Potential Transformers

# Potential Transformers (PTs)

H1 H2

H1

H0 (Stubby bushing)

# Why Do We Test?

- Prevent catastrophic failures and loss of apparatus
- Reliability

  *Not only provides for equipment reliability but can often times improve morale of personnel (not always replacing damaged equipment)*
- Avoid injury to personnel
- Prevent collateral damage to other equipment
- Insurance underwriters often require equipment to be tested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# Why Do We Test?


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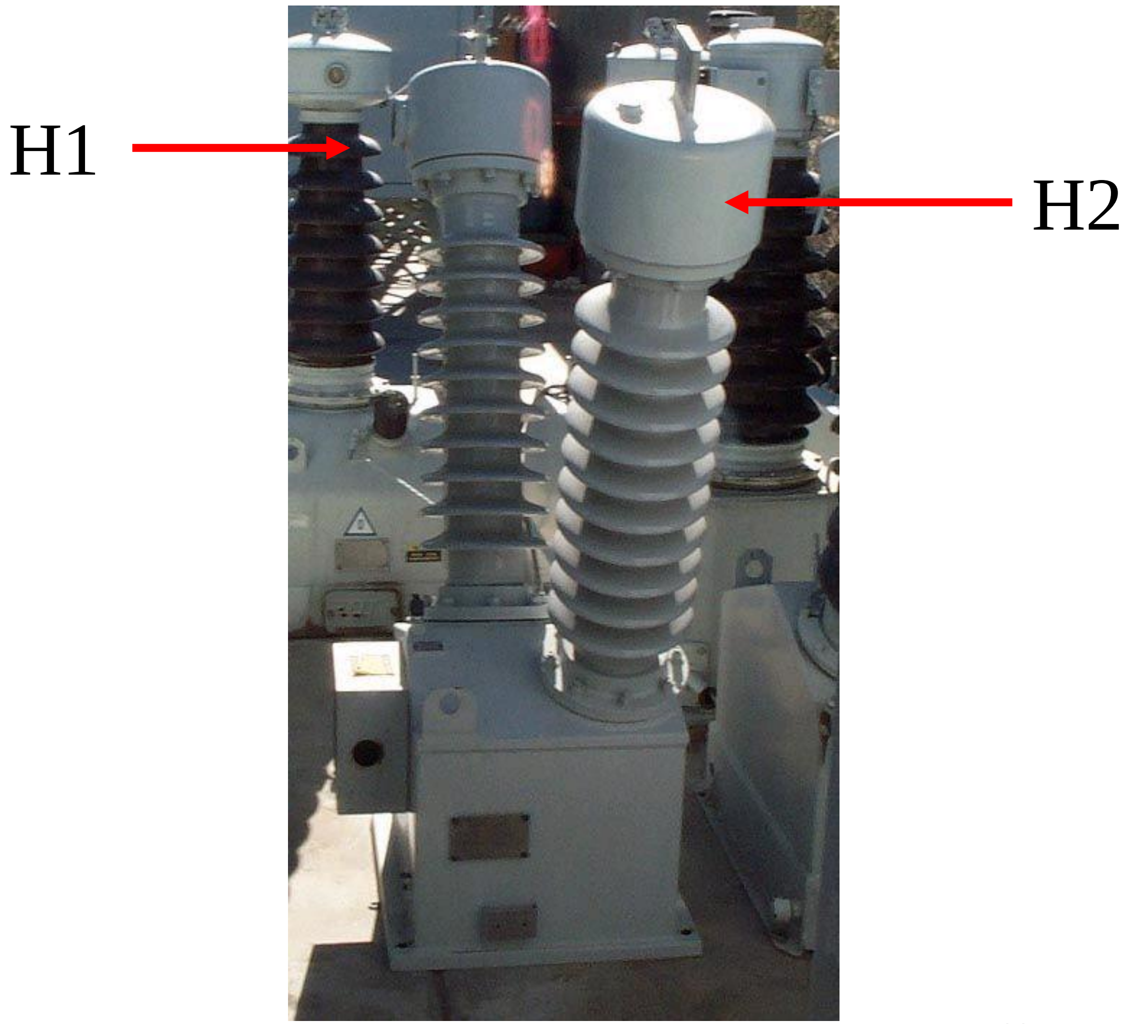
# Why Do We Test?

# Line to Line Potential Transformer



# Potential Transformers

Liquid-Filled Line-to-Line PTs Rated Below 15 kV Insulation Class

| PT Voltage Rating | Test Voltage (kV) |
|---|---|
| 7.2 to 8.7 | 5.0 |
| 4.2 to 5.0 | 2.5 |
| 2.4 | 2.0 |

*For Unit Rated 15 kV and Above, perform test series at 10 kV

Liquid-Filled Line-to-Ground PTs

a) Perform test series at the rated voltage of the neutral bushing.

b) Cross-Checks are performed at 10 kV or rated Line-to-Ground Voltage (whichever is lower)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# Potential Transformers

<u>Dry-Type Line-to-Line PTs Rated Below 15 kV Insulation Class</u>

| **PT Voltage Rating** | **Test Voltage (kV)** |
|---|---|
| Overall | a. 2 kV |
| | b. Line-to-Ground Voltage |
| | c. 10% to 25% Above Line-to-Ground operating Voltage |
| Cross-Check | a. 2 kV |
| | b. Line-to-Ground Operating Voltage |
| Exciting Current | a. Line-to-Ground Operating Voltage |

<u>Dry-Type Line-to-Ground PTs Rated Below 15 kV Insulation Class</u>

a) Perform test series at a voltage not to exceed the neutral bushing rating as was outlined in the previous section.

b) Cross-Checks are performed at 10 kV or rated Line-to-Ground Voltage (whichever is lower)

*For Units rated above 15 kV, the complete test series is performed at 2 and 10 kV

# Test Procedure - Single Phase PTs

## DTAF Program

| | N | Test Mode | ENG | GND | GAR | UST | Test kV | mA | Watts | % PF Meas. | % PF Corr. | Corr. Factor | Cap. (pF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ☐ | GND | H1,H2 | X1,Y1 | | | | | | | | | |
| 2 | ☐ | GAR | H1 | X1,Y1 | H2 | | | | | | | | |
| 3 | ☐ | GAR | H2 | X1,Y1 | H1 | | | | | | | | |
| 4 | ☐ | UST | H1 | X1,Y1 | | H2 | | | | | | | |
| 5 | ☐ | UST | H2 | X1,Y1 | | H1 | | | | | | | |
| 6 | ☐ | GND | H1,H2 | X1,Y1 | @2kV | | 2.0 | | | | | | |

Supplemental Tests

| | N | Test Mode | ENG | GND | GAR | UST | Test kV | mA | Watts | % PF Meas. | % PF Corr. | Corr. Factor | Cap. (pF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ☐ | UST | H1,H2 | Y1 | | X1 | | | | | | | |
| 2 | ☐ | UST | H1,H2 | X1 | | Y1 | | | | | | | |
| 3 | ☐ | GAR | H1 | | H2,X1,Y1 | | | | | | | | |
| 4 | ☐ | GAR | H2 | | H1,X1,Y1 | | | | | | | | |


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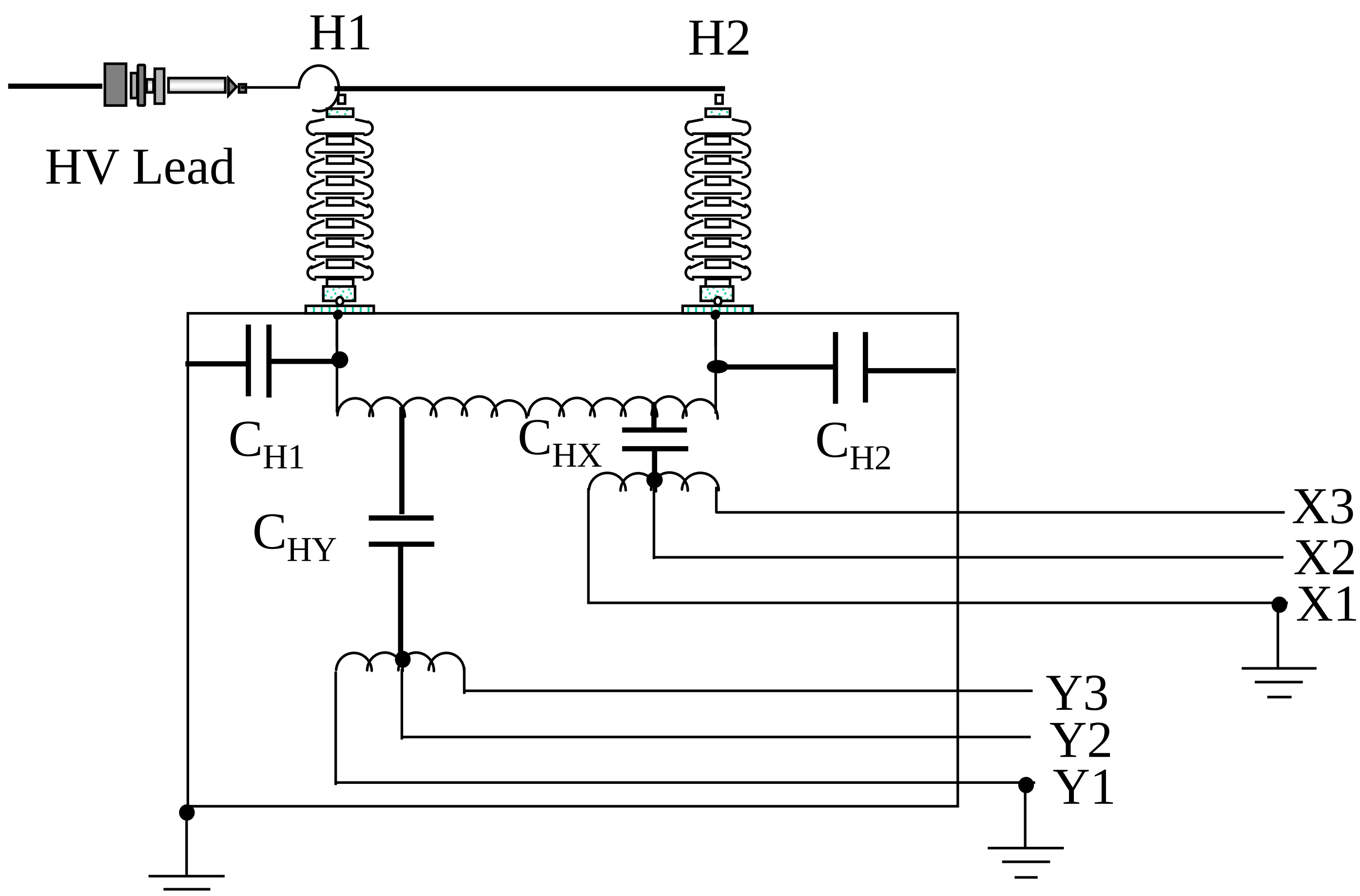
# Test Procedure Using DTAF Program

**Test #1** : GST Ground - No LV Lead Required

**Measure:** CH1+CHX+CHY+CH2





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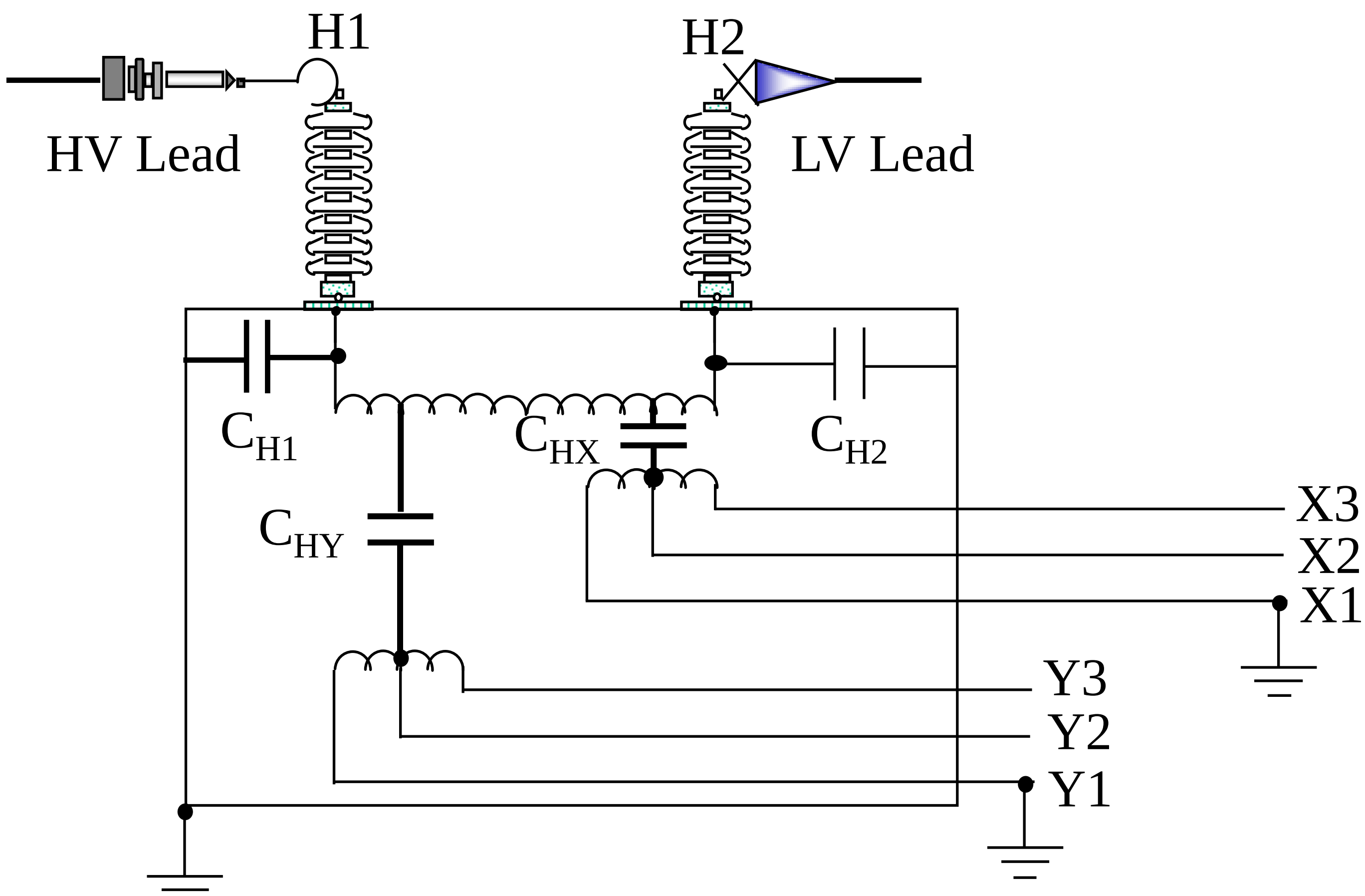
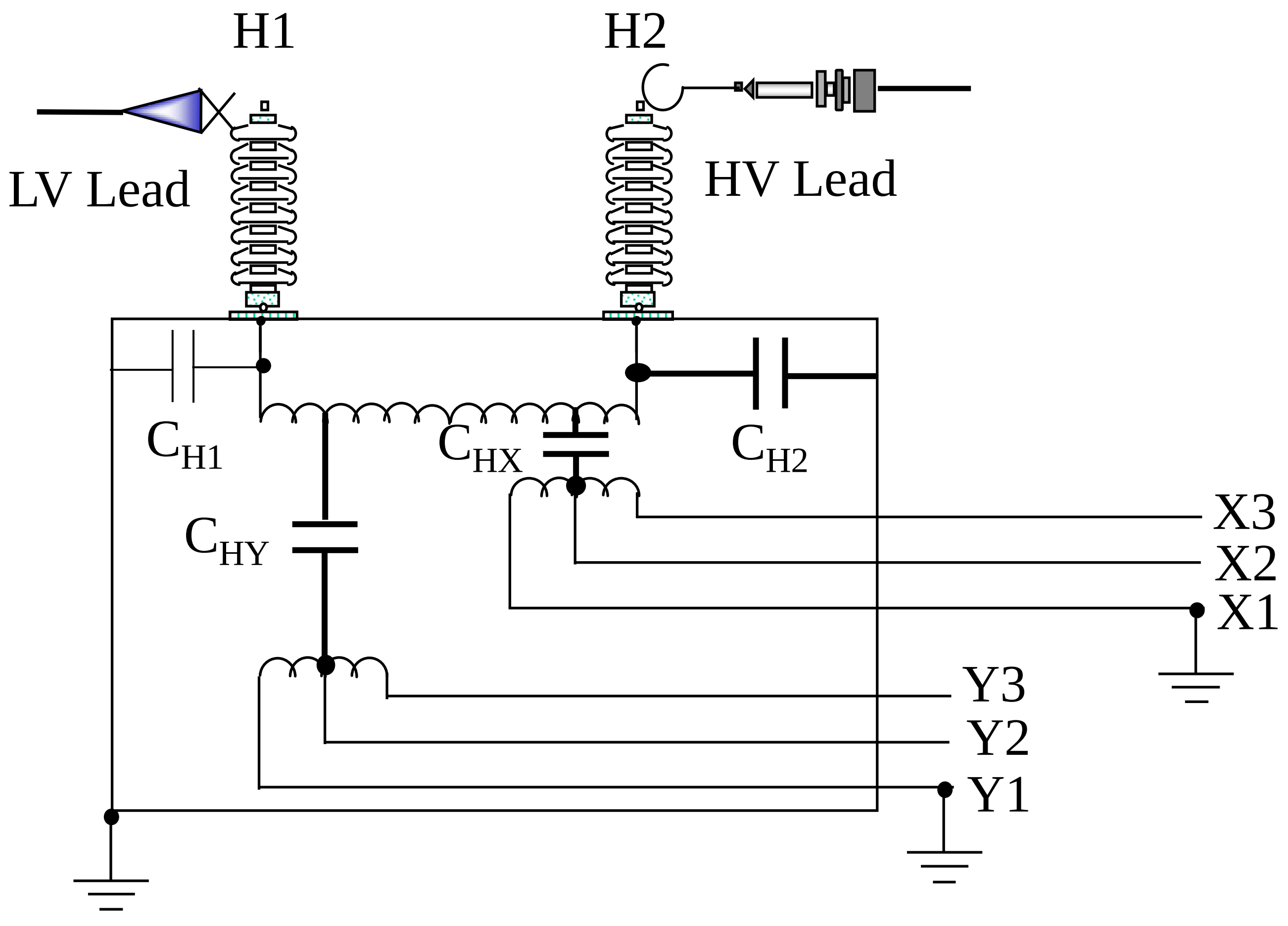
**Test #2:** GST-Guard (Cross-Check Test #1)

• **Measure:** CH1+ 1/2CHX + 1/2CHY



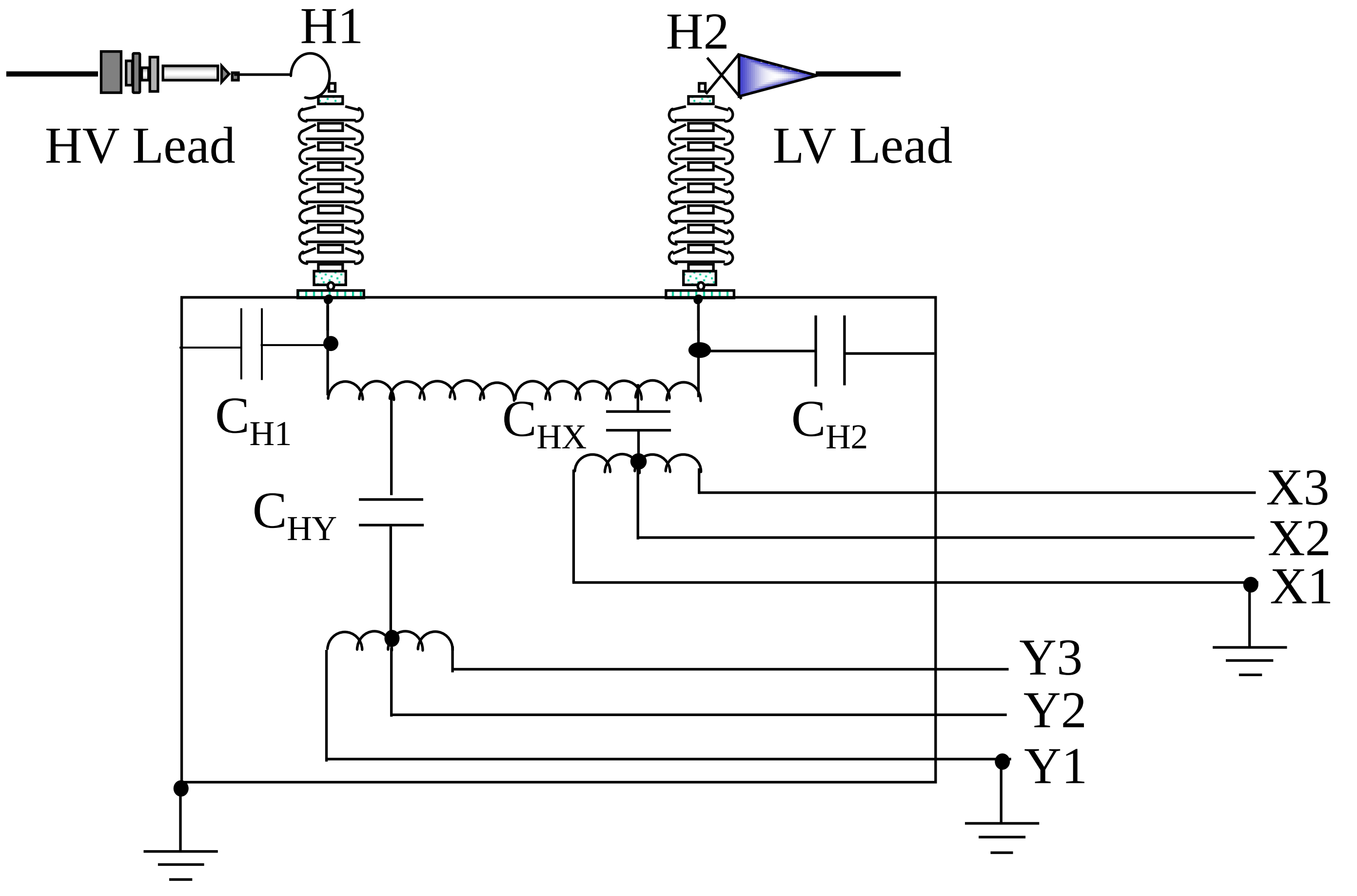
**Test #3:** GST-Guard (Cross-Check Test #2)

•**Measure:** CH2+ 1/2CHX + 1/2CHY



**Test #4:** Ungrounded Specimen Test (UST)

**Measure**: Excitation Current





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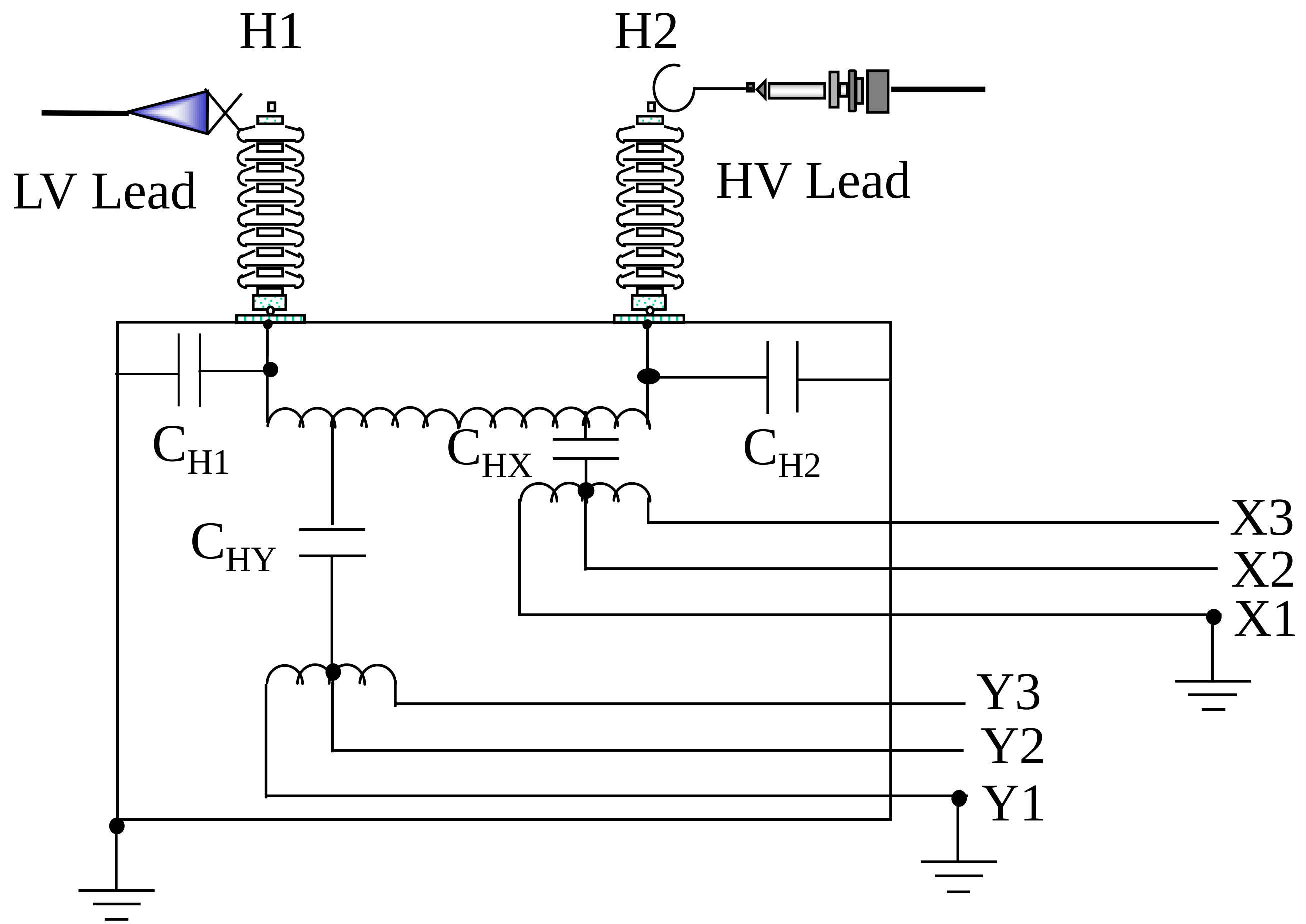
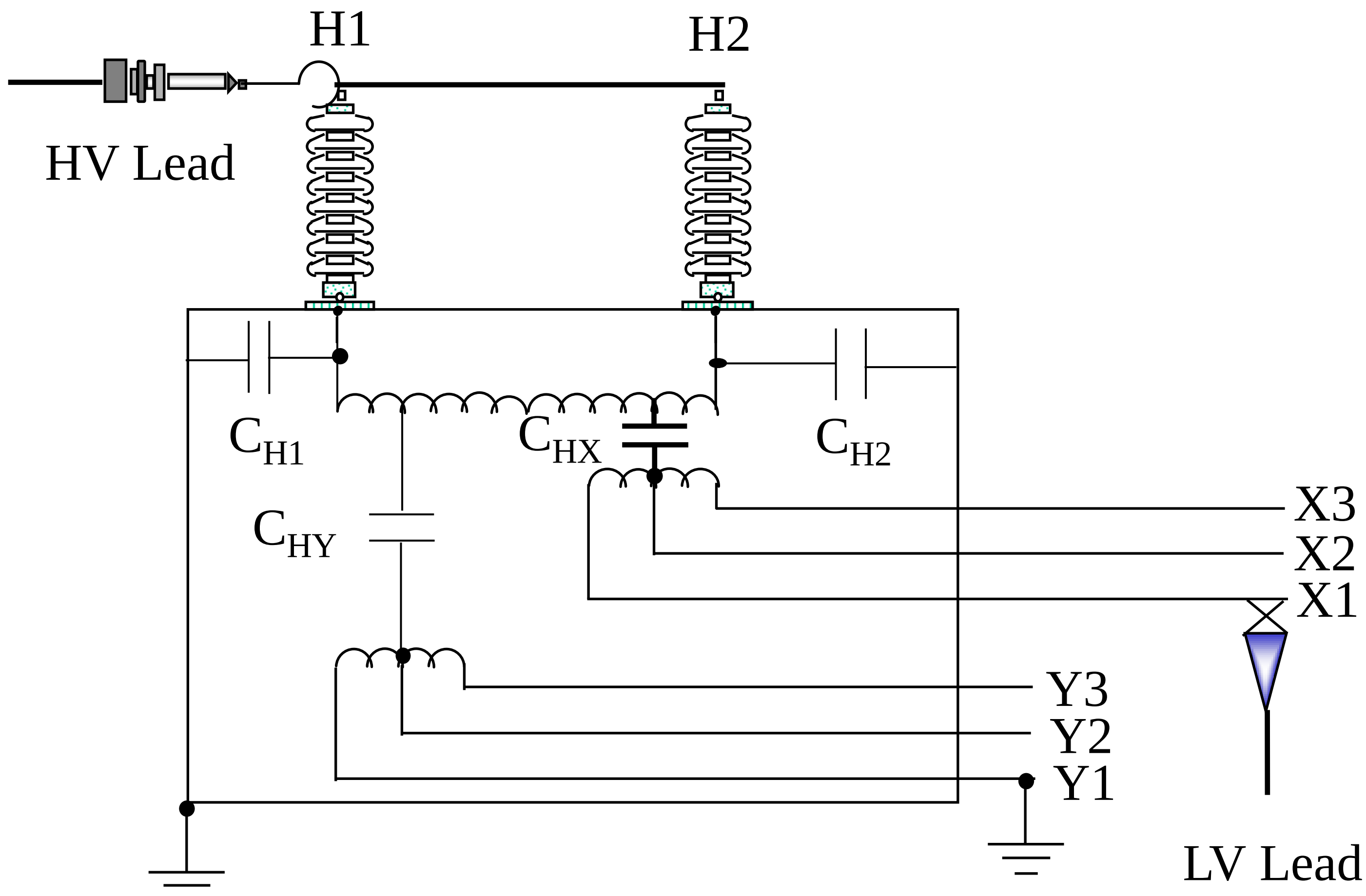
**Test #5:** Ungrounded Specimen Test (UST)
**Measure**: Excitation Current



# Supplemental Tests

**Test #6** : UST

**Measure:** $C_{HX}$





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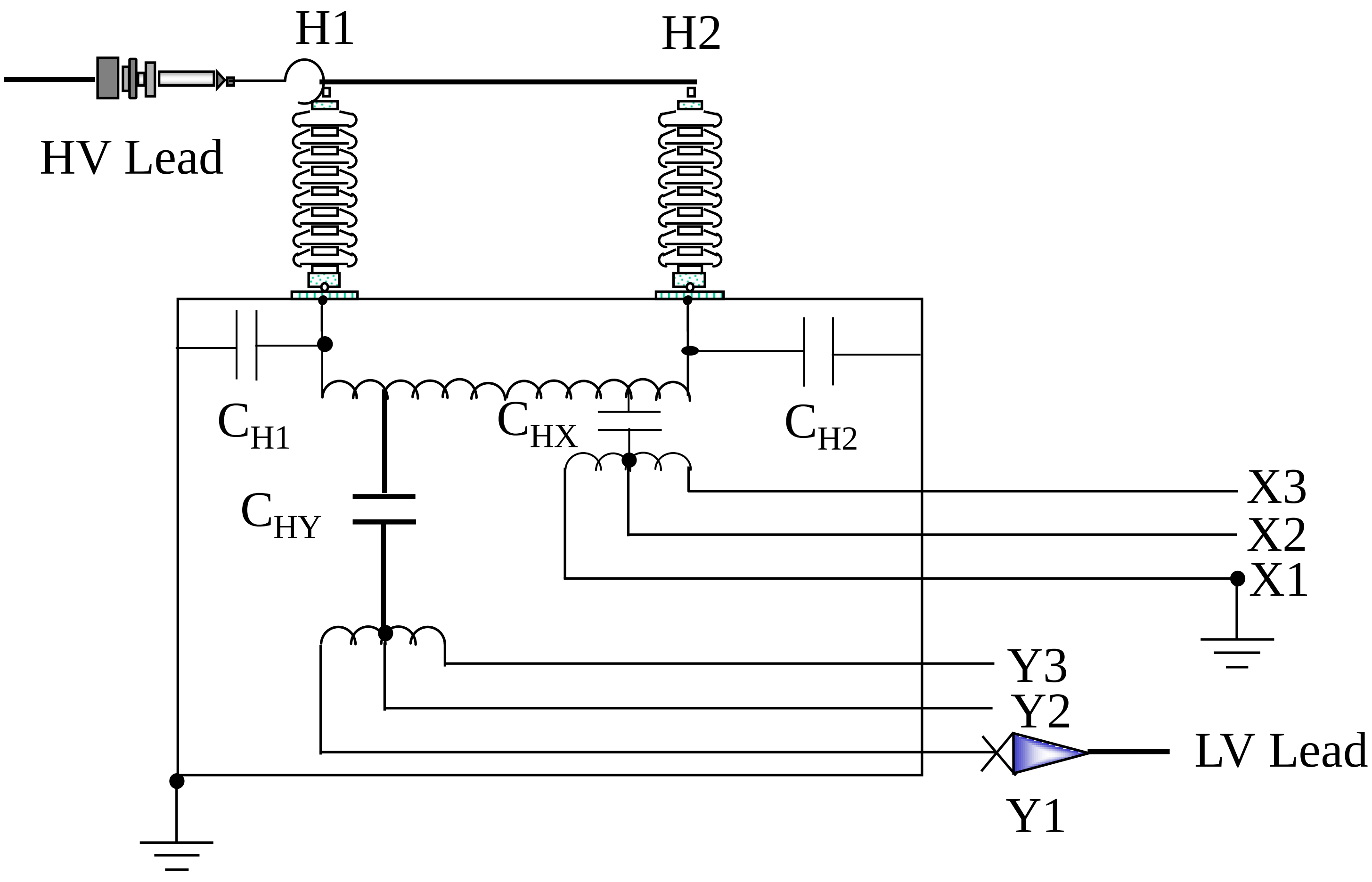
# Supplemental Tests

**Test #7** : UST

**Measure:** $C_{HY}$





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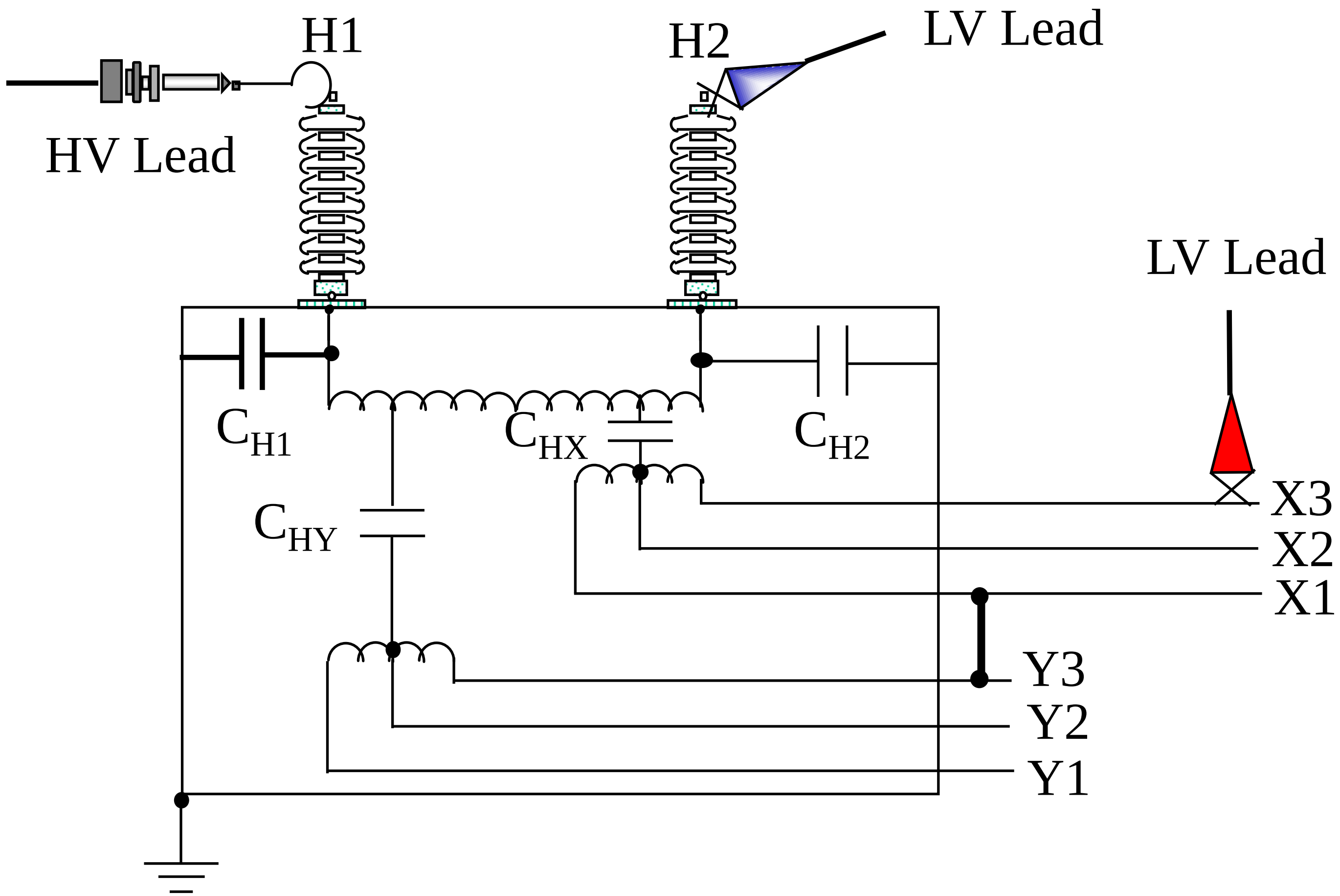
# Supplemental Tests

**Test #8:** GST-Guard Red & Blue

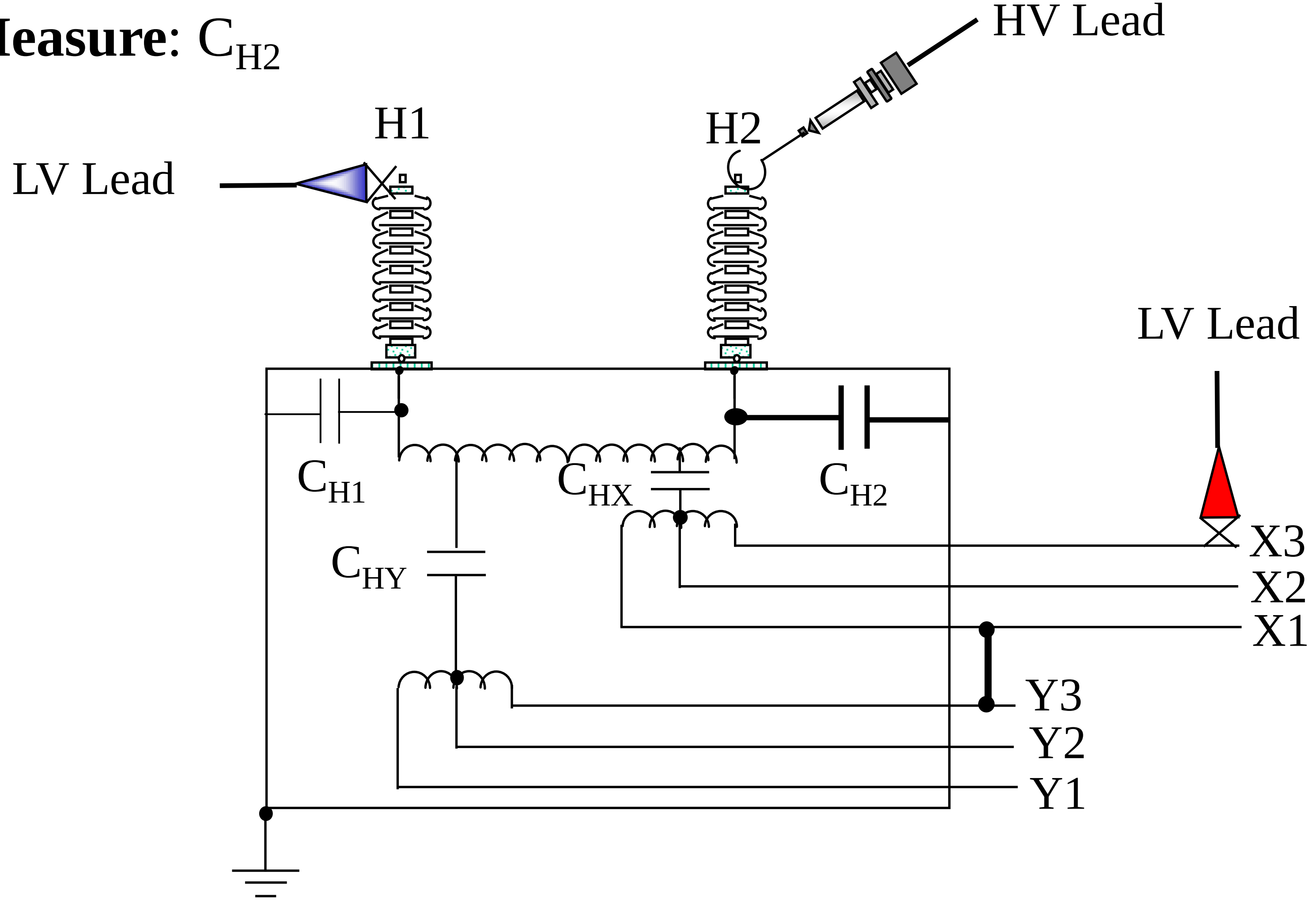
**Measure**: $C_{H1}$



# Supplemental Tests

**Test #9:** GST-Guard Red & Blue

**Measure**: $C_{H2}$



# Test Procedure - Single Phase PTs

## DTAPro Program

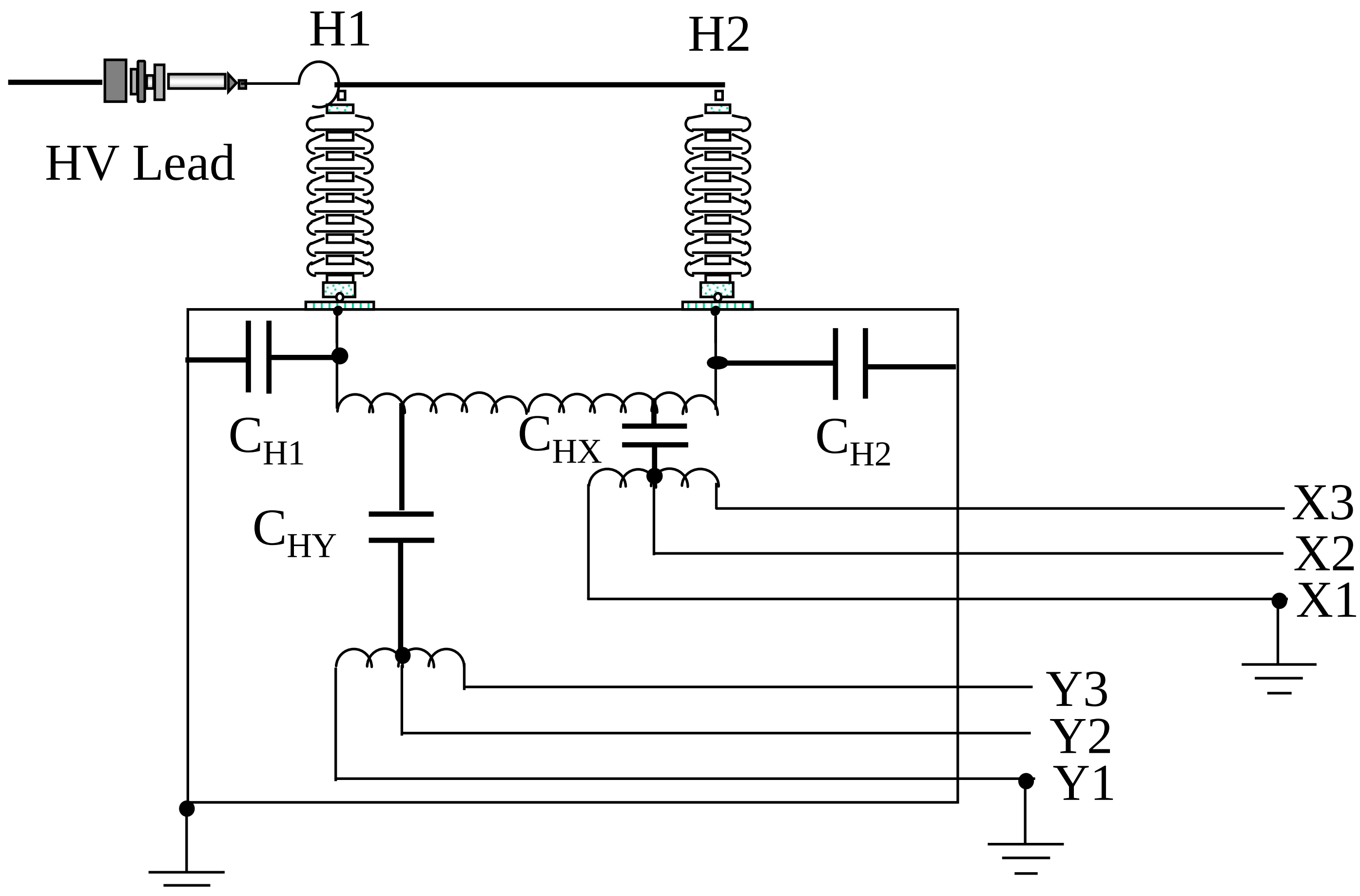
**Overall Test Setup**

| Connections | | | | Inputs | | Test Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| # | HV Lead | Ground | Red Measure Lead | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) |
| 1 | H1, H2 | X1, Y1 | Unused | * | * | * | * | * | * | * |
| 2 | | | | 2.000 | * | * | * | * | * | * |
| 3 | H1 | | H2 | * | * | * | * | * | * | * |
| 4 | H2 | | H1 | * | * | * | * | * | * | * |
| 5 | H1 | | H2 | * | * | * | * | | | |
| 6 | H2 | | H1 | * | * | * | * | | | |
| **Supplemental Tests** | | | | | | | | | | |
| 7 | H1, H2 | Y1 | X1 | * | * | * | * | * | * | * |
| 8 | | X1 | Y1 | * | * | * | * | * | * | * |
| 9 | H1 | Unused | H2, X1, Y1 | * | * | * | * | * | * | * |
| 10 | H2 | | H1, X1, Y1 | * | * | * | * | * | * | * |

# Test Procedure Using DTAPro Program

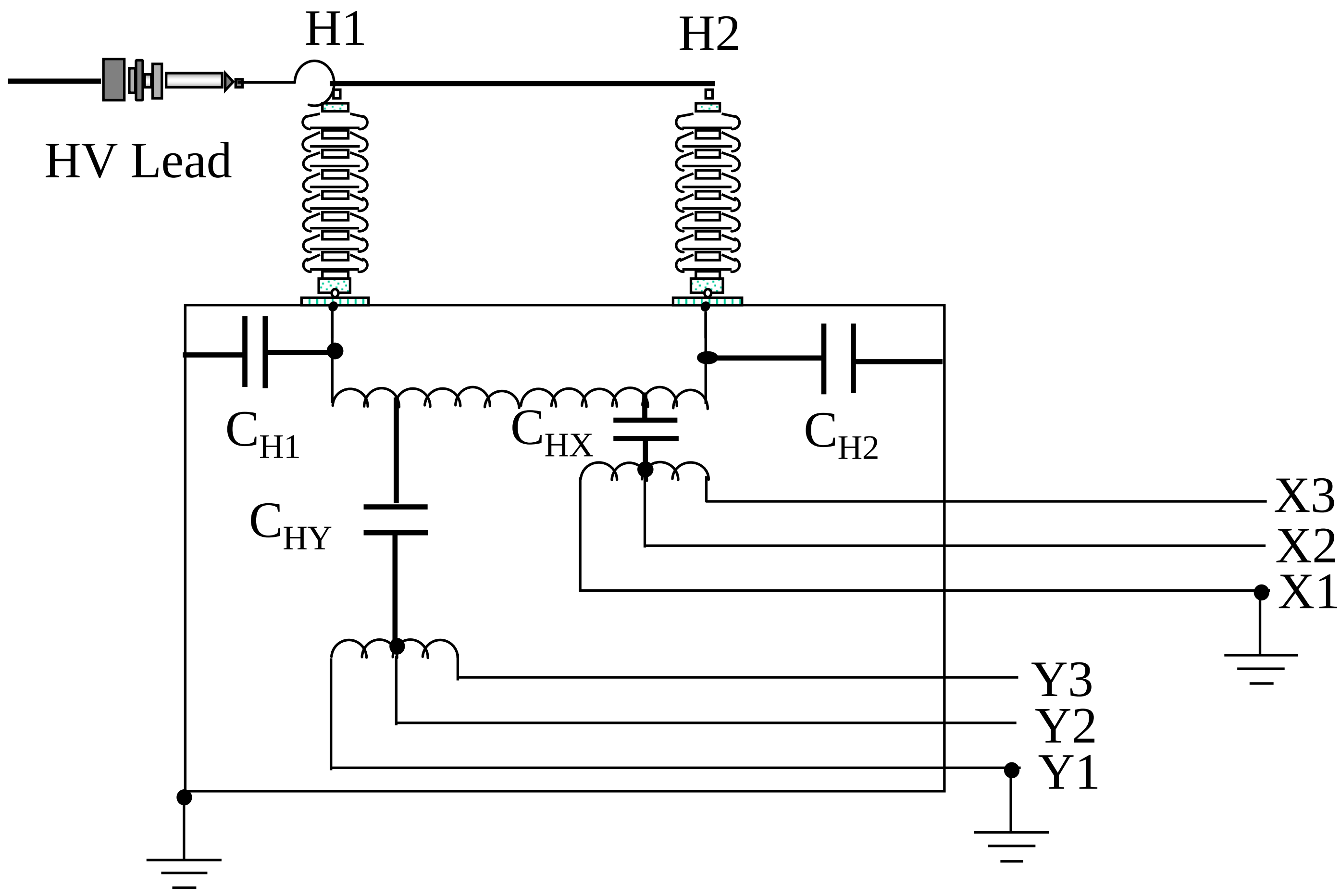
**Test #1** : GST Ground - No LV Lead Required

**Measure:** CH1+CHX+CHY+CH2



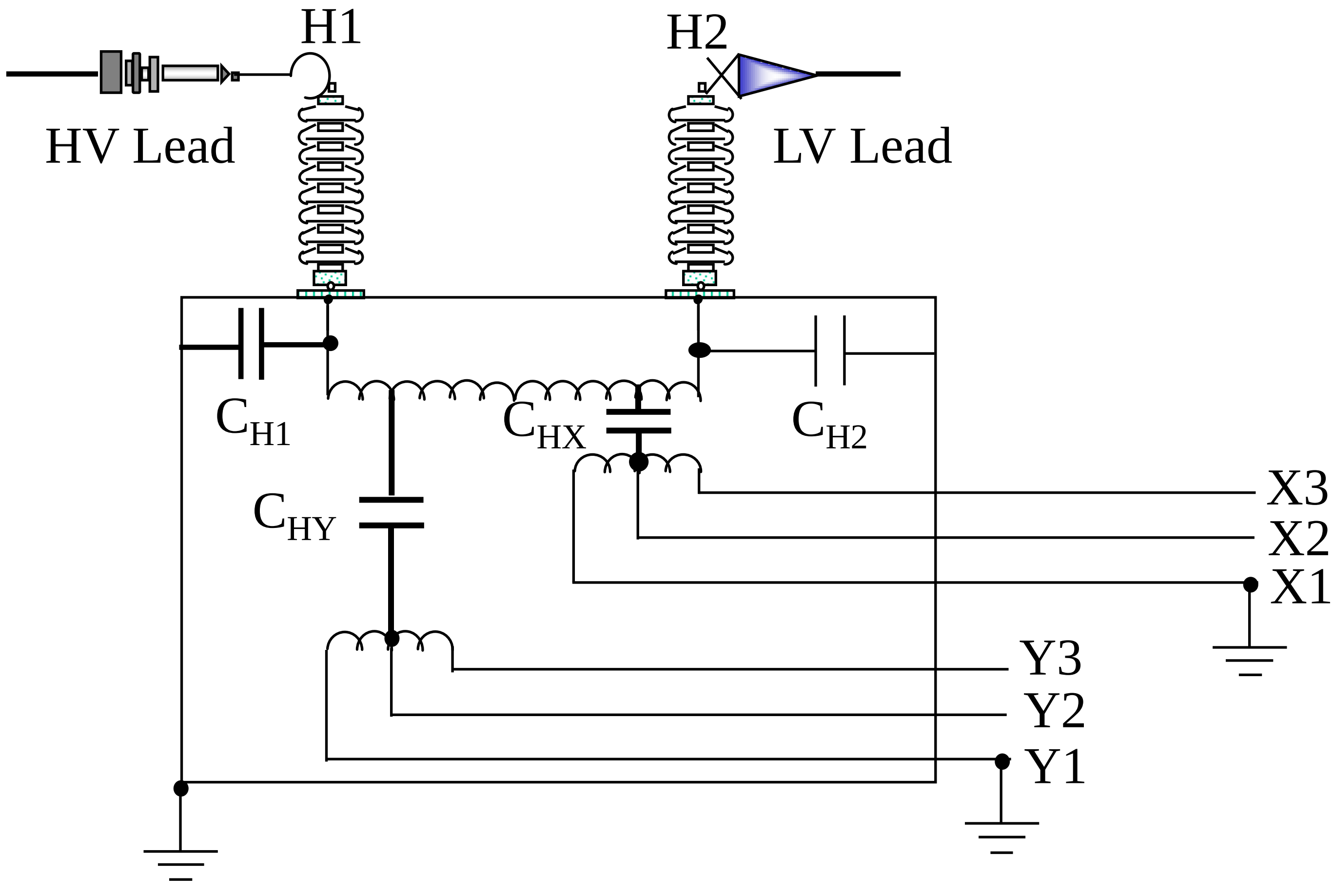
**Test #2** : GST Ground - No LV Lead Required

**Measure:** CH1+CHX+CHY+CH2



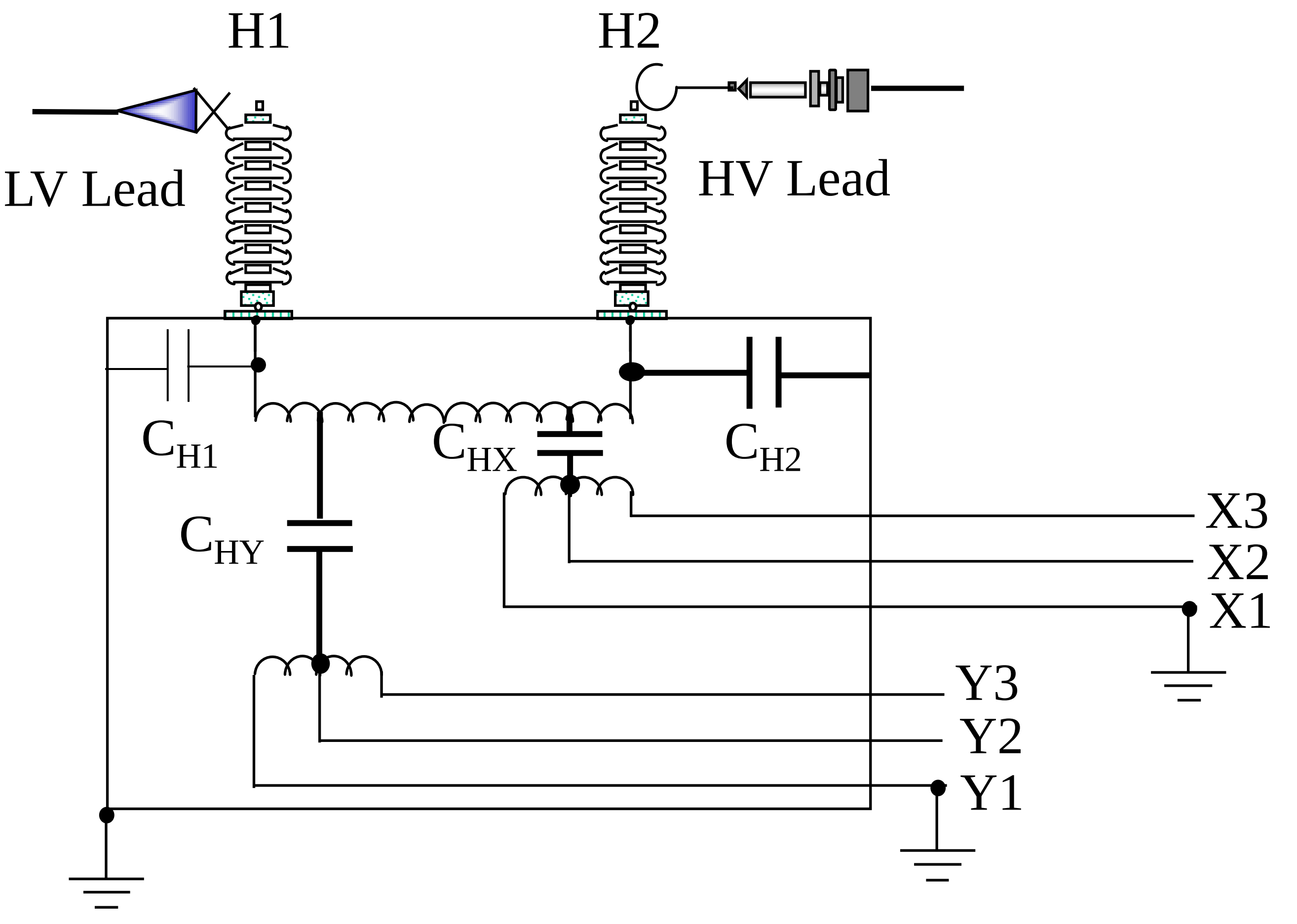
**Test #3:** GST-Guard (Cross-Check Test #1)

- **Measure:** CH1+ 1/2CHX + 1/2CHY

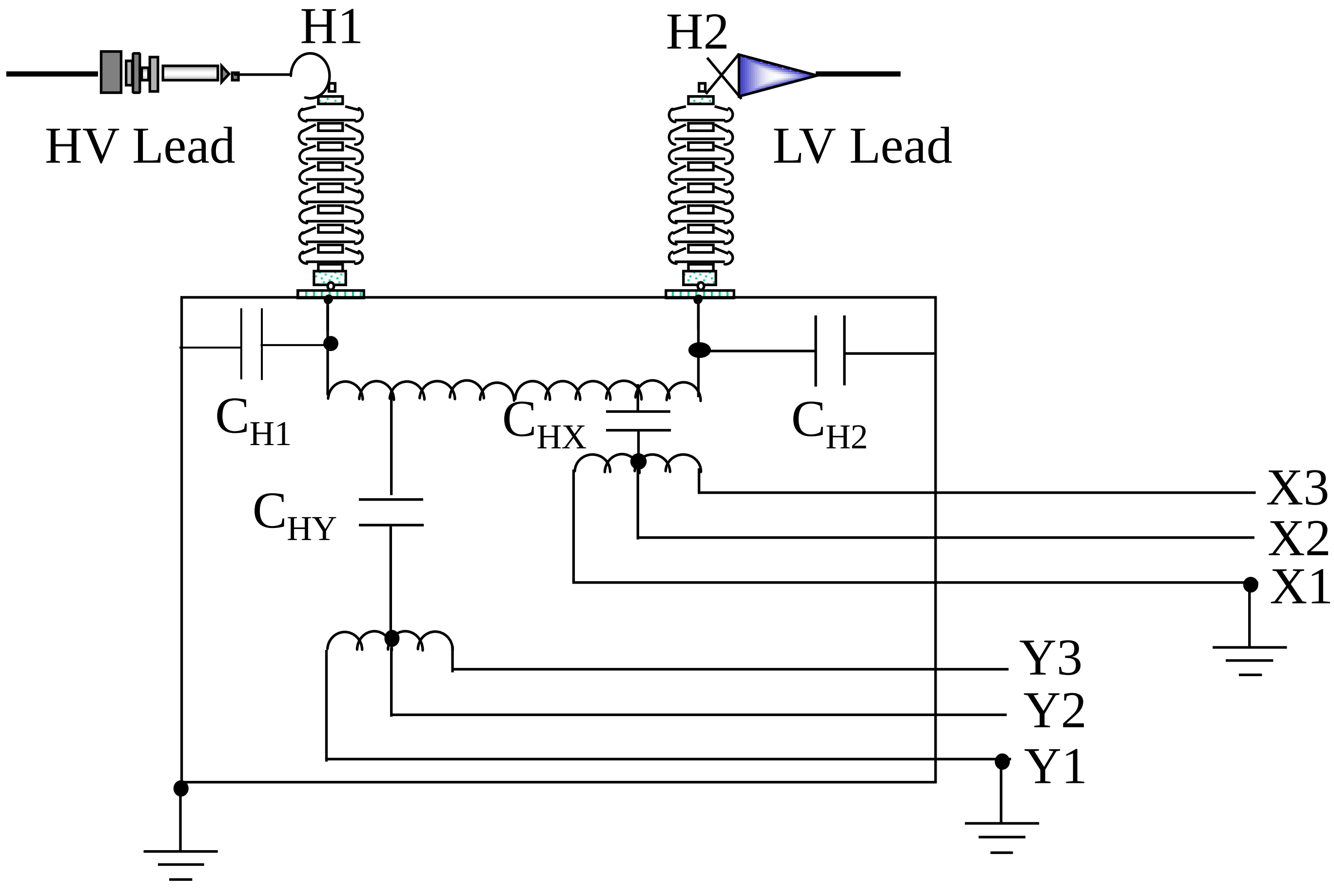


**Test #4:** GST-Guard (Cross-Check Test #2)

•**Measure:** CH2+ 1/2CHX + 1/2CHY



**Test #5:** Ungrounded Specimen Test (UST)
**Measure**: Excitation Current





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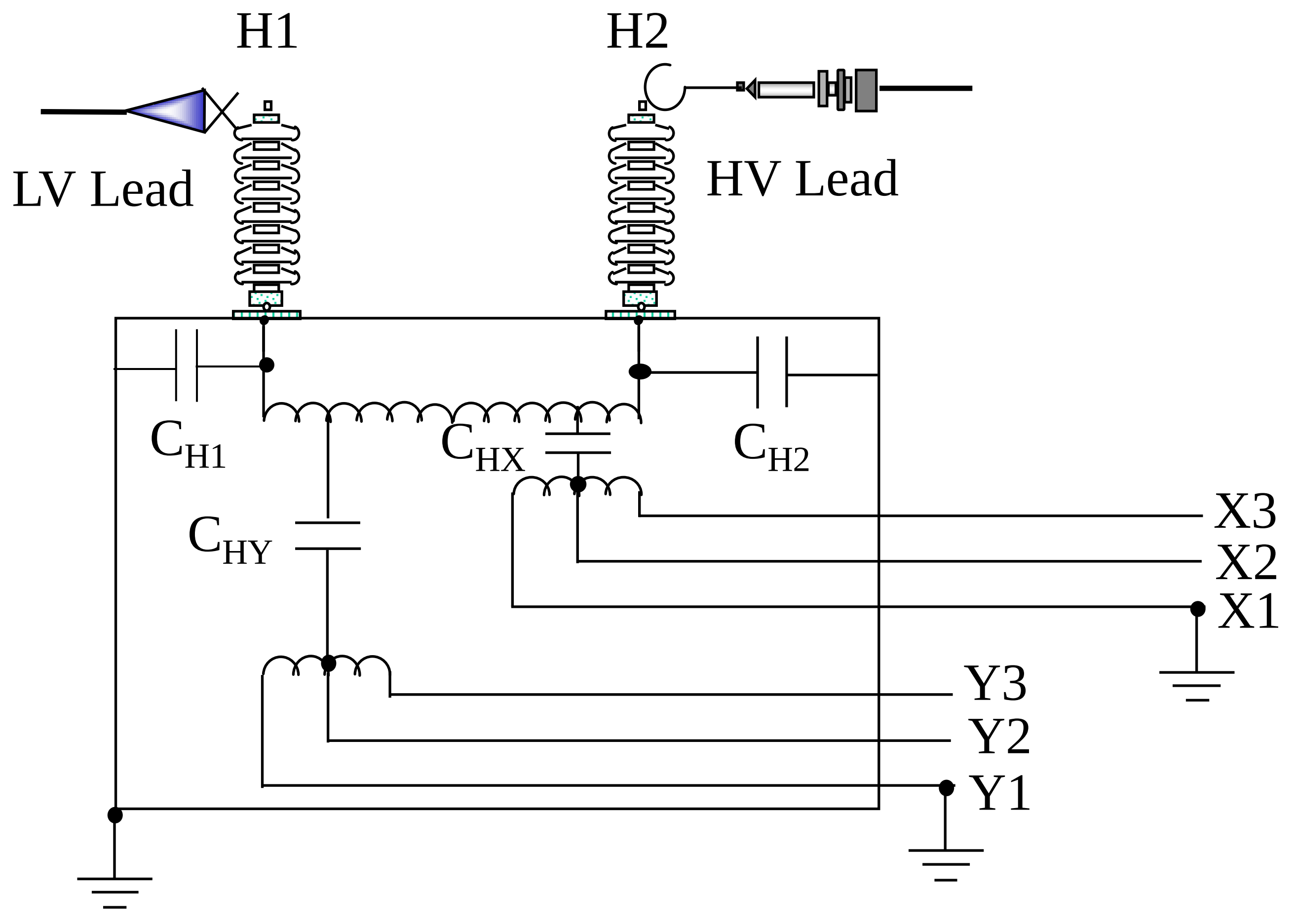
**Test #6:** Ungrounded Specimen Test (UST)

**Measure**: Excitation Current





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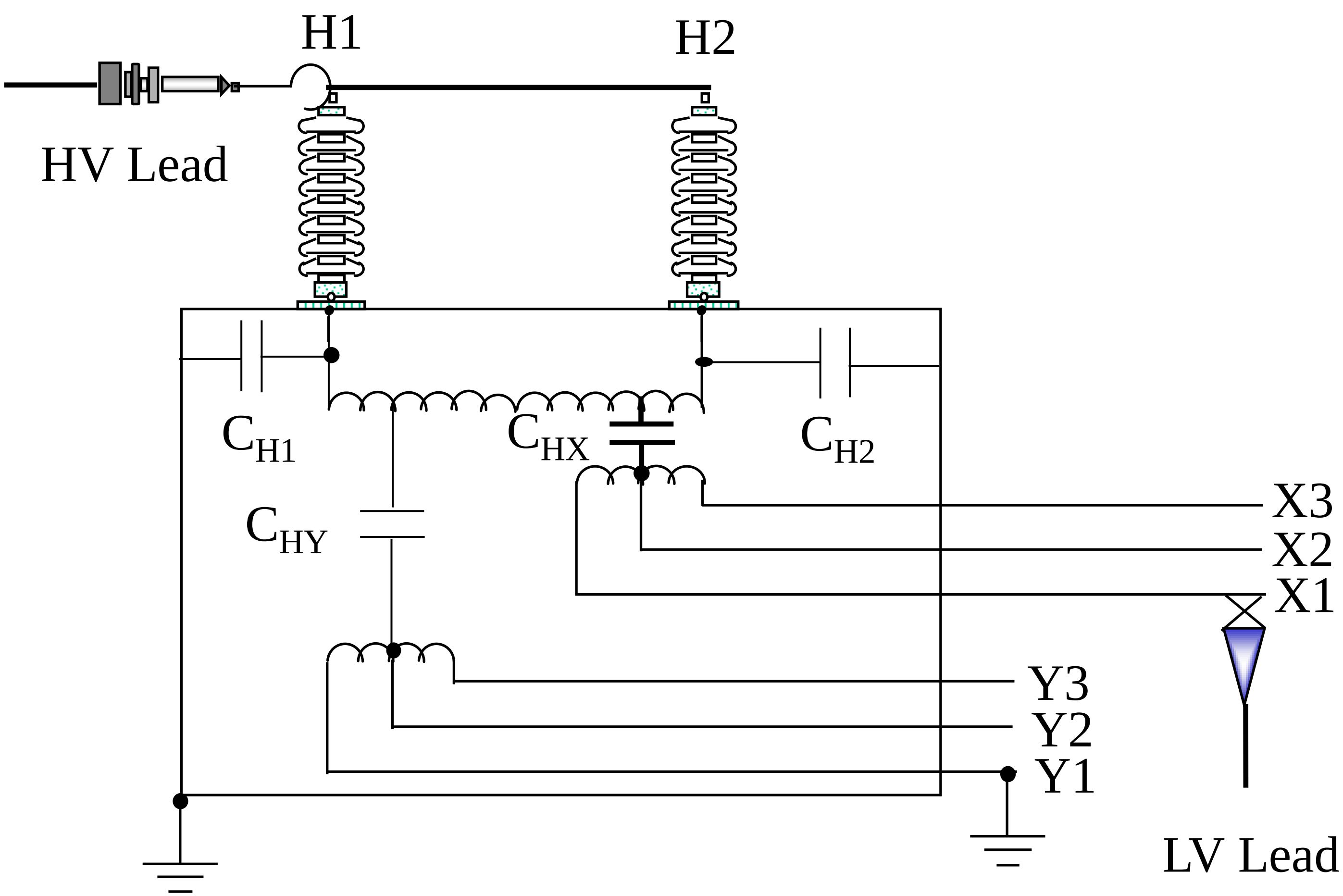
# Supplemental Tests

**Test #7** : UST

**Measure:** $C_{HX}$





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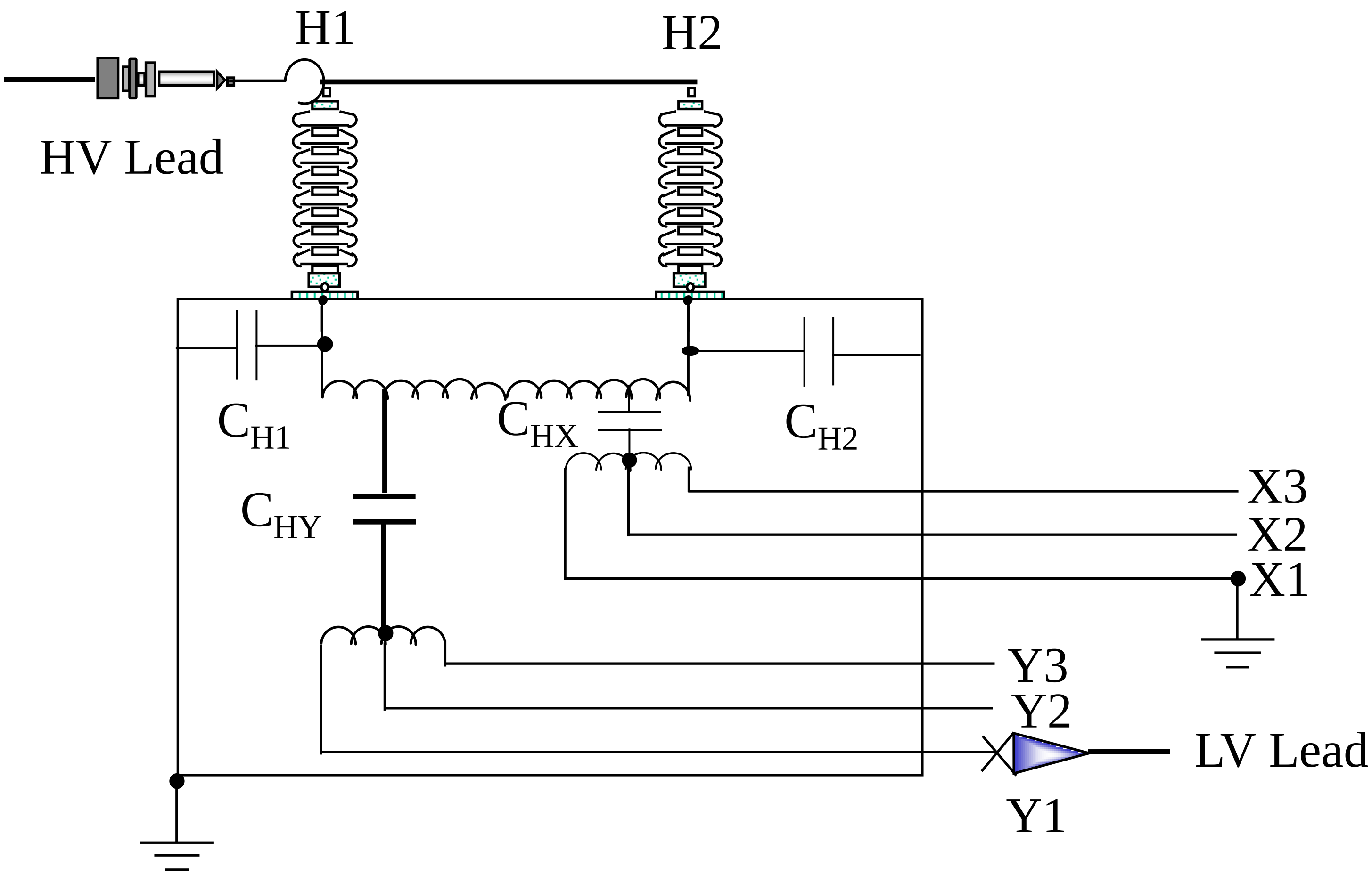
# Supplemental Tests

**Test #8** : UST

**Measure:** $C_{HY}$





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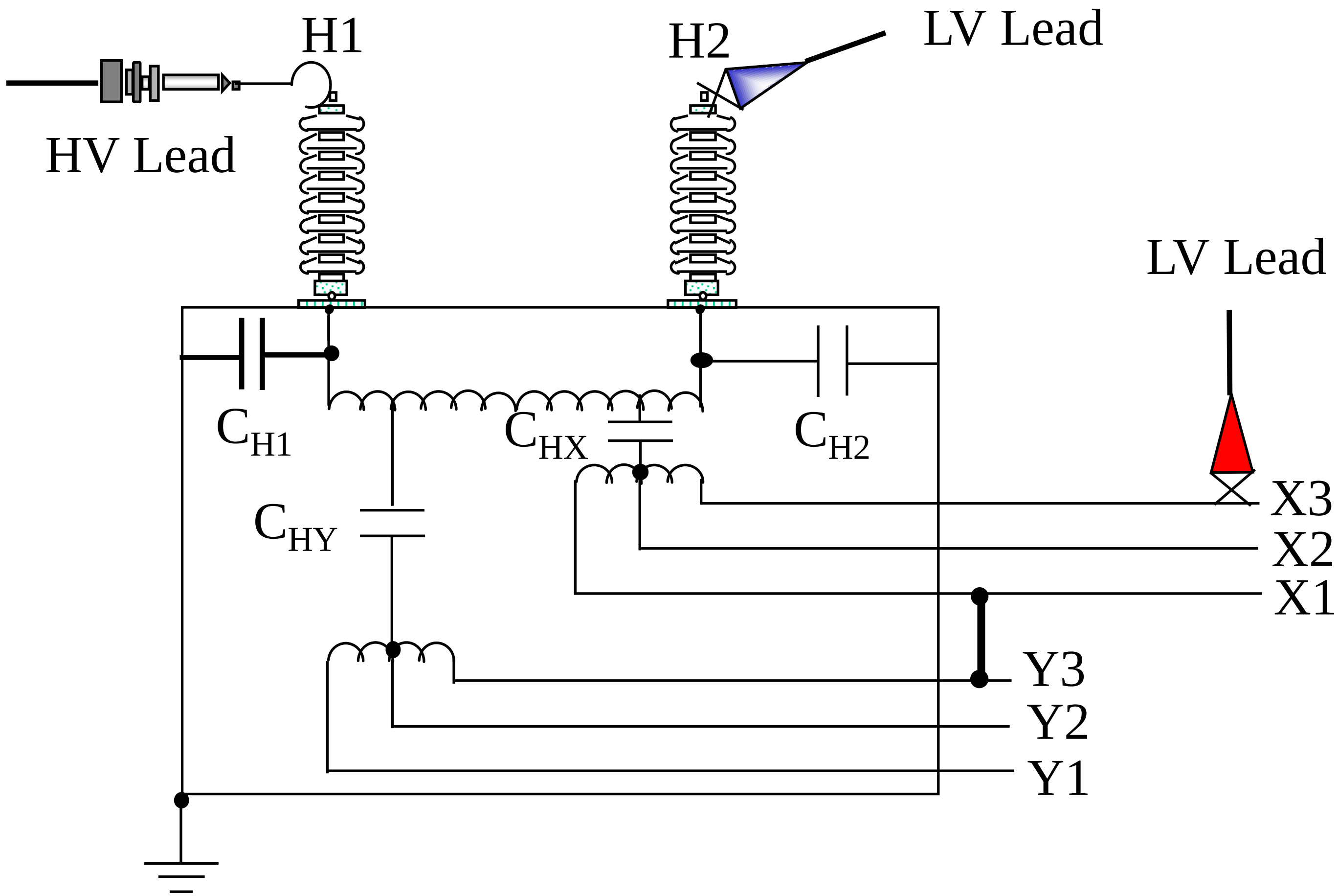
# Supplemental Tests

**Test #9:** GST-Guard Red & Blue

**Measure**: $C_{H1}$





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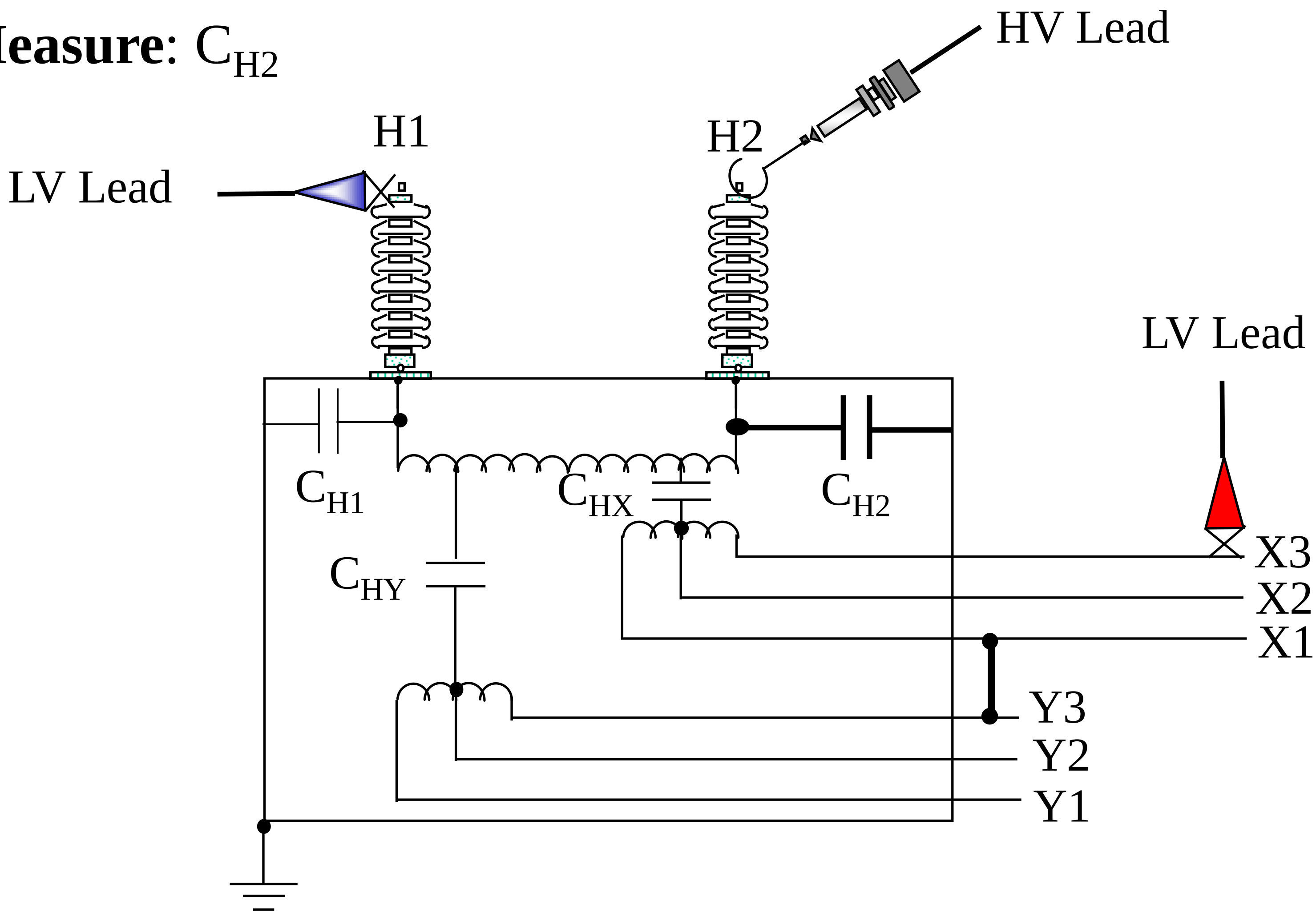
# Supplemental Tests

**Test #10:** GST-Guard Red & Blue

**Measure**: $C_{H2}$





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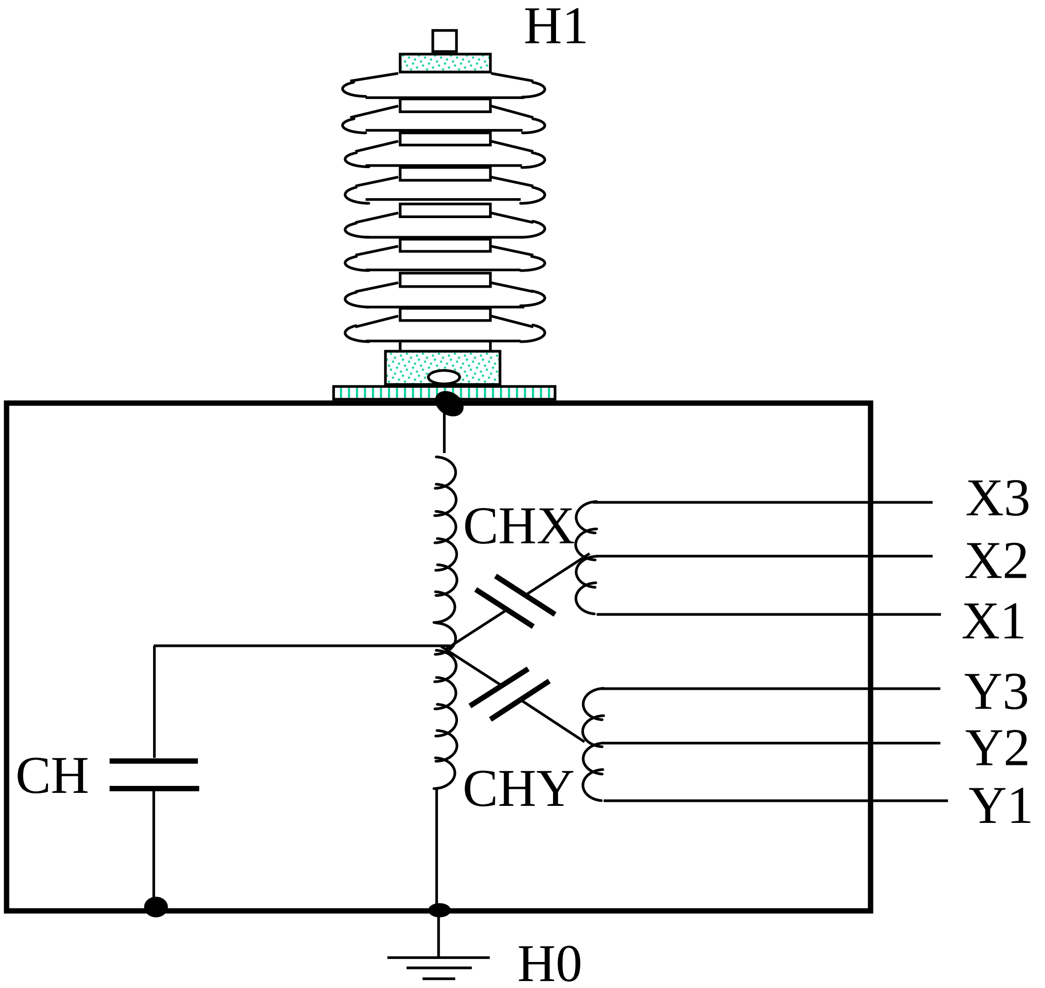
# Internally Grounded PT




Neutral Shown Internally Grounded

# Internally Grounded PT

**Test Procedure**

| Test No. | Mode | Energize | Ground | Guard | UST |
|---|---|---|---|---|---|
| 1 | UST | H1 | HO | ---- | X1,Y1 |
| 2 | GST | H1 | HO | X1,Y1 | ---- |

**Test No. 1**: Measures Line-End Inter-winding Insulation

**Test No. 2:** Measure Excitation Current

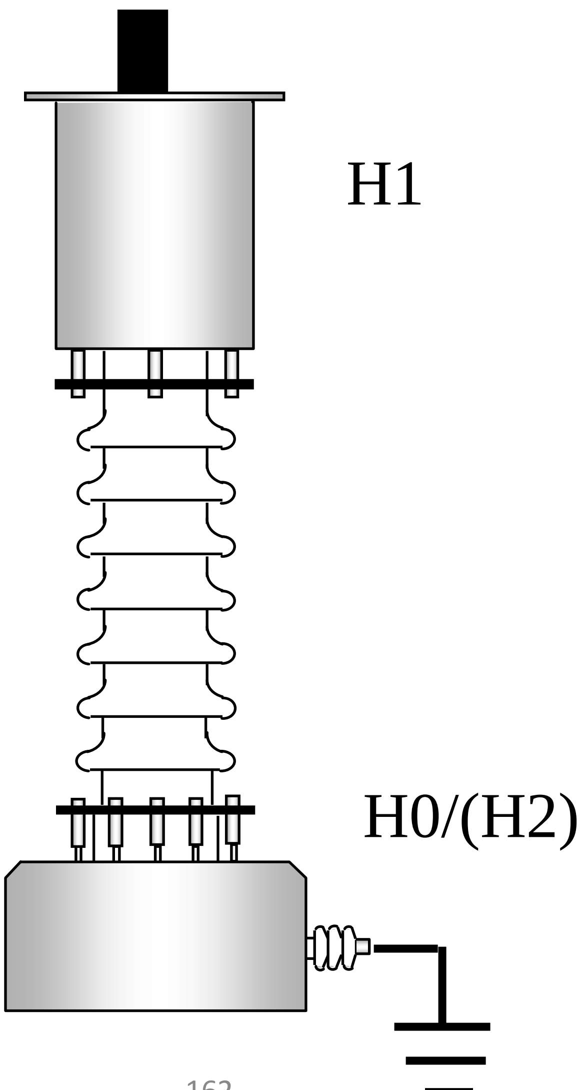
# Line to Ground PT

H1

H0/H2
(Stubby
bushing)

# Line to Ground PT

TEST PROCEDURES ARE THE SAME AS FOR THE 2 BUSHING



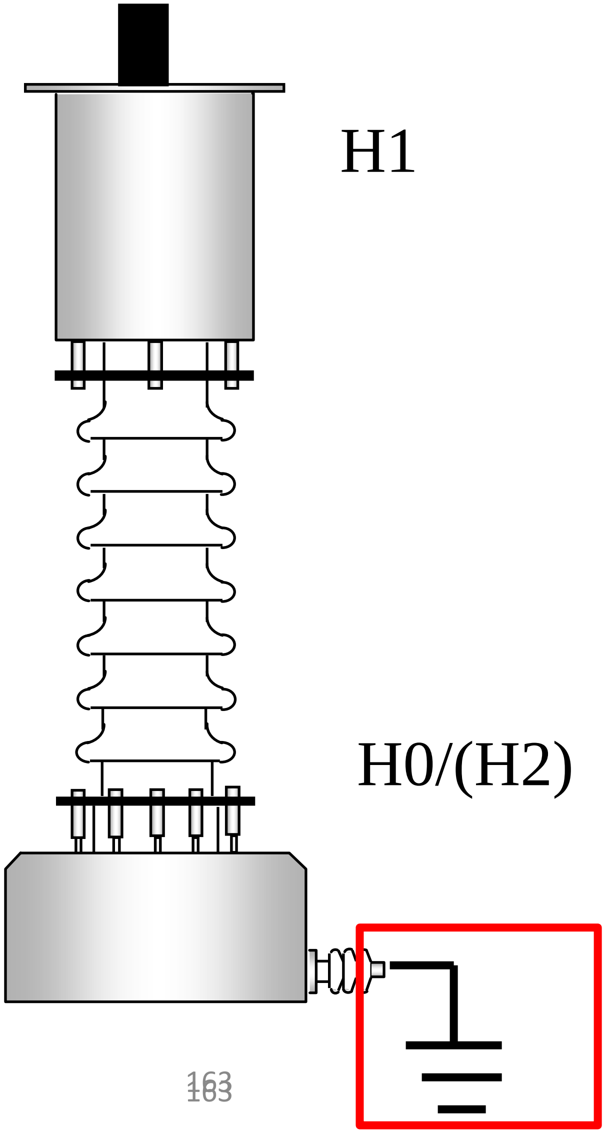

**LOWER TEST VOLTAGE REQUIRED WHEN H0 IS ENERGIZED**

# Line to Ground PT

Note that the H0 bushing is smaller and is grounded!

Ground is removed and a reduced voltage used when the H0 is energized!

NOTE: Test Voltage for Tests 1, 3, 4, 5 Limited by Rating of Neutral Bushing (2/5 kV)





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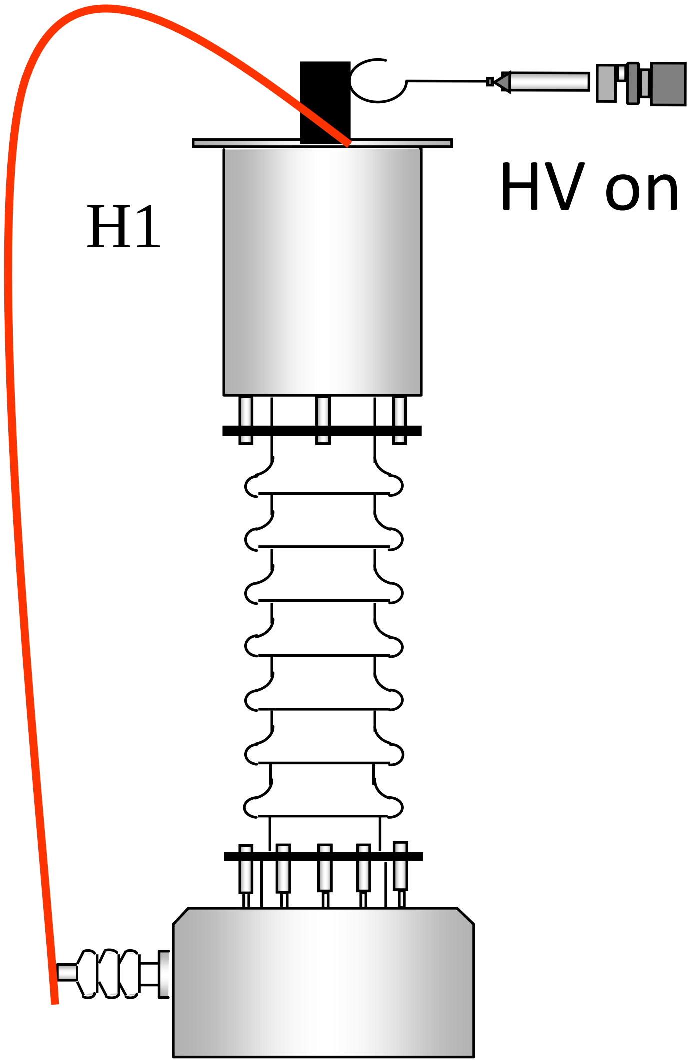
# Single Phase Line to Ground PT

Test 1 Overall DTAF
(Tests 1 and 2 for DTAPro)

H1 & H0 Jumpered

GST – no LV lead is required

The secondary windings are grounded for tests 1-5





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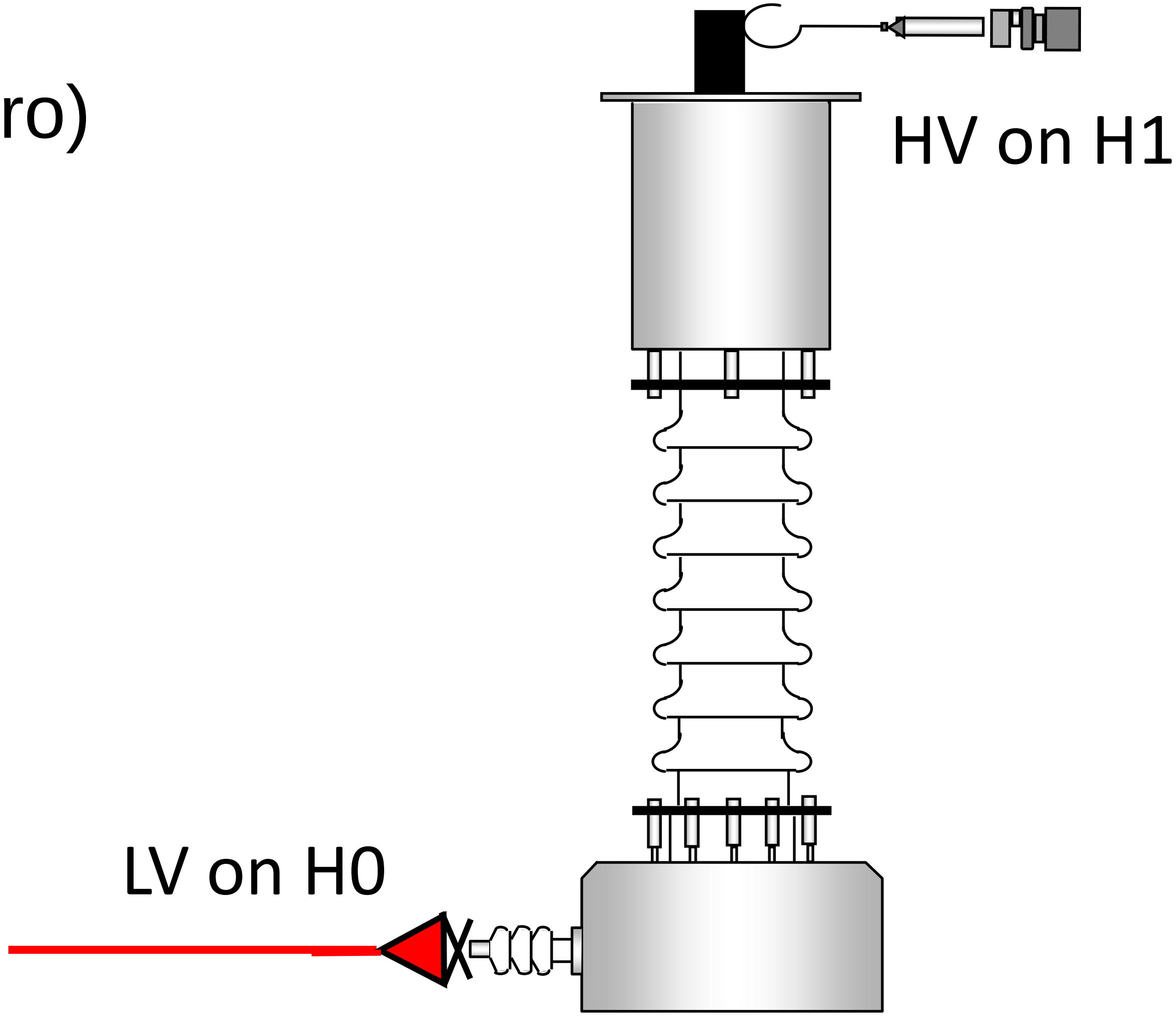
# Single Phase Line to Ground PT

Test 2 DTAF
(Test 3 DTAPro)

Cross Check

GST - Guard

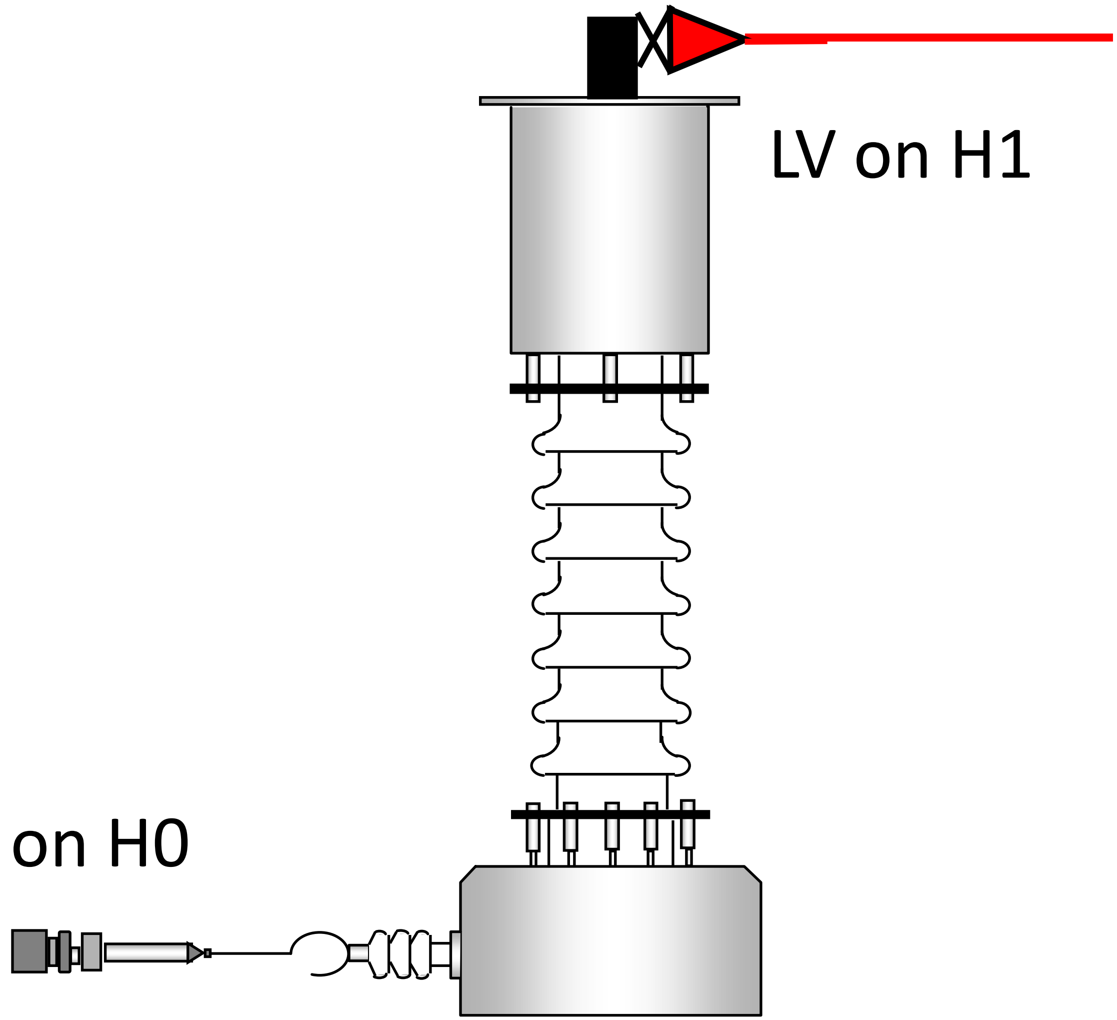


# Single Phase Line to Ground PT

Test 3 DTAF
(Test 4 DTAPro)

Cross Check

GST - Guard





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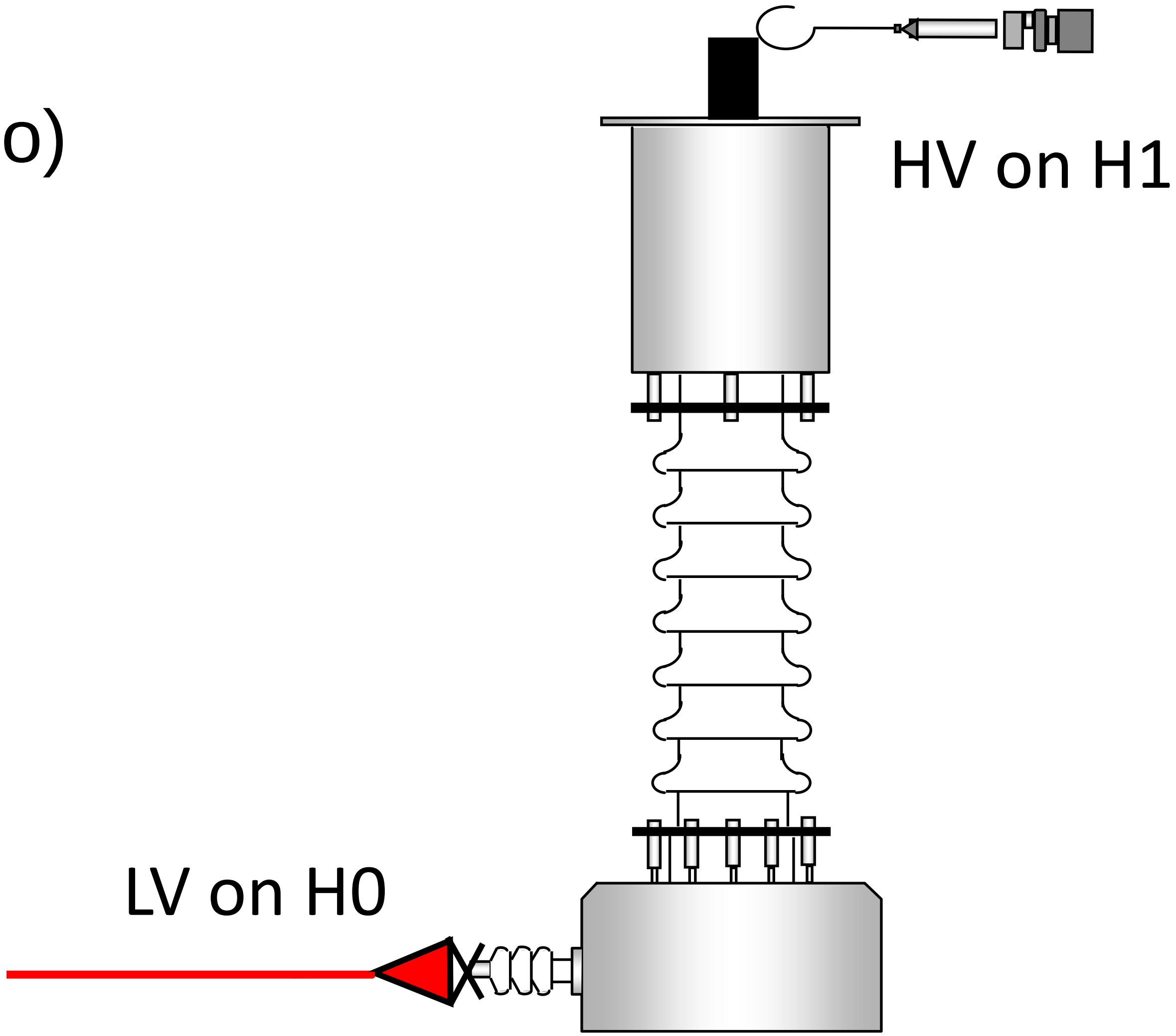
# Single Phase Line to Ground PT

Test 4 DTAF
Test 5 DTAPro)

Excitation

UST

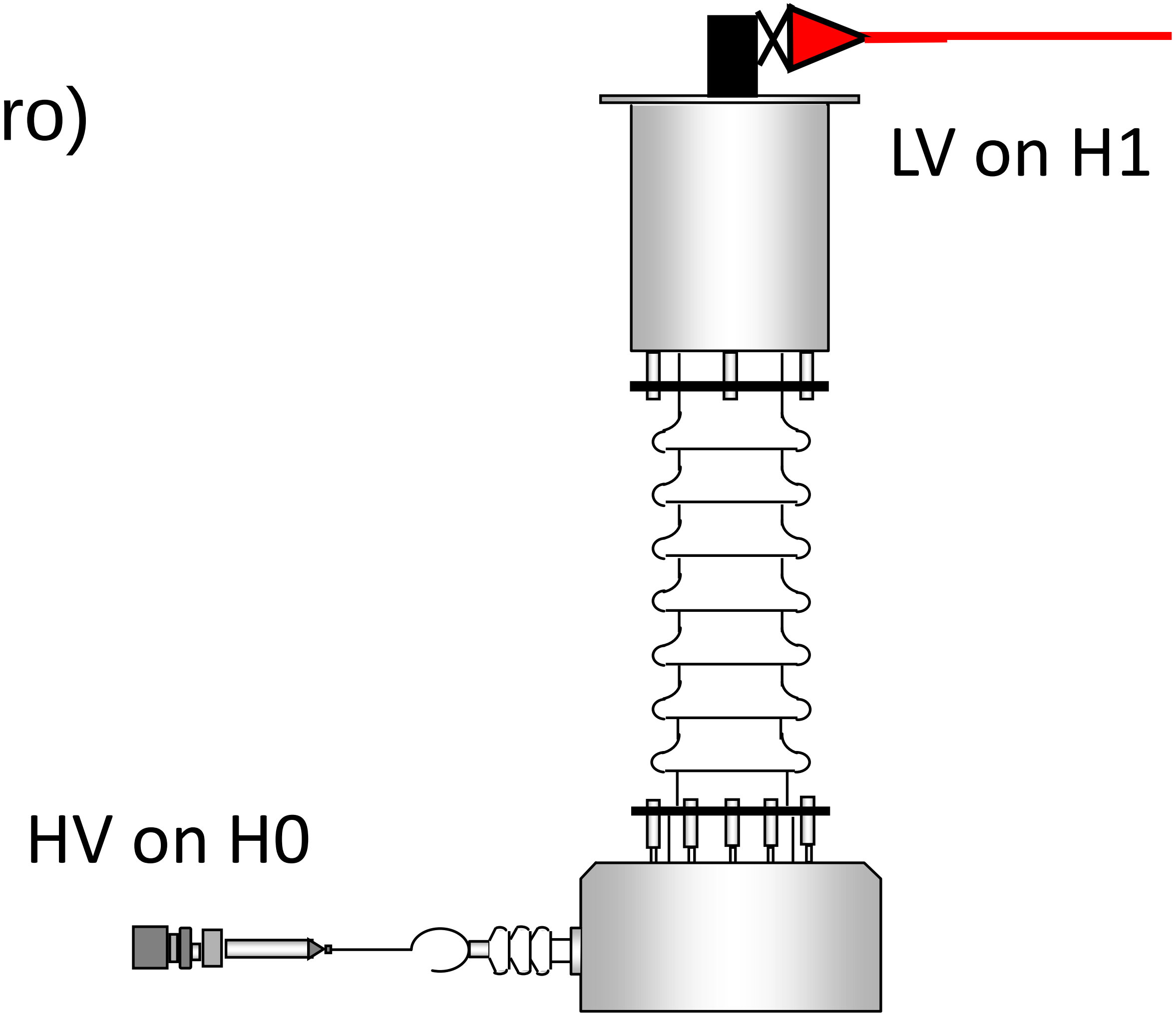


# Single Phase Line to Ground PT

Test 5 DTAF
(Test 6 DTAPro)

Excitation

UST



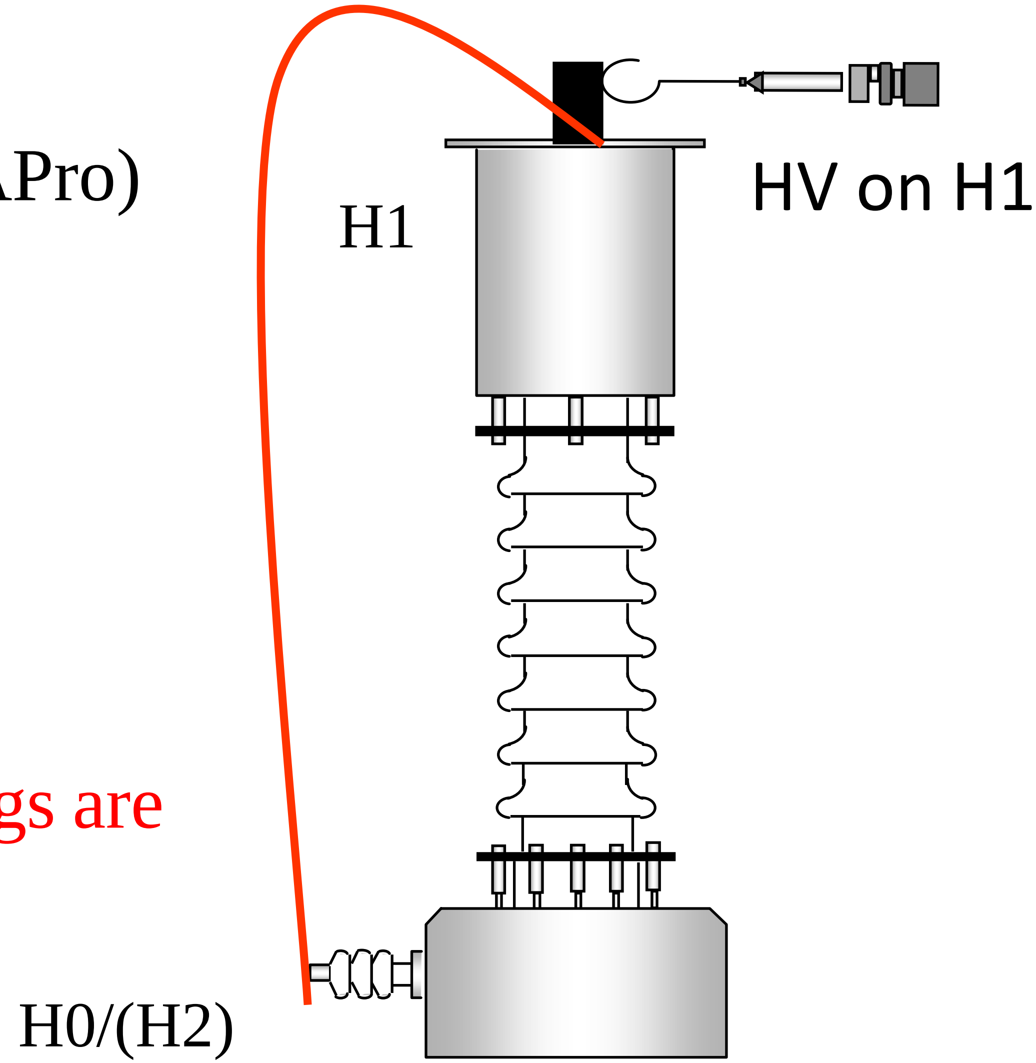
# Single Phase Line to Ground PT

Test 6 Overall DTAF
(Tests 1 and 2 for DTAPro)

H1 & H0 Jumpered

GST – no LV lead is required

The secondary windings are grounded for tests 1-5



# Test Procedure-Single-Phase PT - DTA

| | N | Test Mode | ENG | GND | GAR | UST | Test kV | mA | Watts | % PF Meas. | % PF Corr. | Corr. Factor | Cap. (pF) | Rtg | Rtg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ☐ | GND | H1,H2 | X1,Y1 | | | 0.99 | 4.518 | 0.2310 | 0.51 | 0.33 | 0.64 | 1198.5 | G | G |
| 2 | ☐ | GAR | H1 | X1,Y1 | H2 | | 10.0 | 1.480 | 0.0410 | 0.28 | 0.18 | 0.64 | 392.51 | G | G |
| 3 | ☐ | GAR | H2 | X1,Y1 | H1 | | 1.00 | 3.036 | 0.1890 | 0.62 | 0.40 | 0.64 | 805.25 | G | G |
| 4 | ☐ | UST | H1 | X1,Y1 | | H2 | 0.99 | 0.1480 | 1.381 | | | | | Q | G |
| 5 | ☐ | UST | H2 | X1,Y1 | | H1 | 1.00 | 0.1440 | 1.401 | | | | | Q | G |
| 6 | ☐ | GND | H1,H2 | X1,Y1 | @2kV | | 2.0 | | | | | | | | |

**Should be "EQUAL"**

Supplemental Tests

**1.480 + 3.036 = 4.516 mA**    **0.0410 + 0.1890 = 0.230 Watts**

| | N | Test Mode | ENG | GND | GAR | UST | Test kV | mA | Watts | % PF Meas. | % PF Corr. | Corr. Factor | Cap. (pF) | Rtg | Rtg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ☐ | UST | H1,H2 | Y1 | | X1 | | | | | | | | | |
| 2 | ☐ | UST | H1,H2 | X1 | | Y1 | | | | | | | | | |
| 3 | ☐ | GAR | H1 | | H2,X1,Y1 | | | | | | | | | | |
| 4 | ☐ | GAR | H2 | | H1,X1,Y1 | | | | | | | | | | |

# Analysis of Results: PTs

- Compare Overall Power Factor Test Values to Previous Test Results

- Compare Overall Power Factor Values to Similar Units (Test-Data-Reference-Book)

- Compare Cross-Check Power Factors
  - Most PTs Test Results are Similar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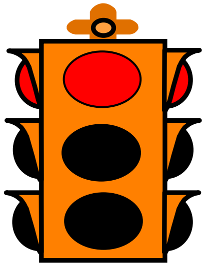
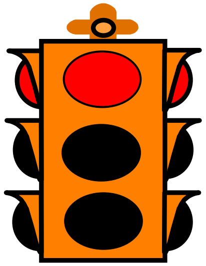
# PT #1 – First Test

| Test | Nomenclature | Test kV | I (mA) | Watts | Measured % PF | Corrected % PF |
|---|---|---|---|---|---|---|
| 1 | Overall | 10 | 1.323 | 1.744 | 13.18 | 14.6 |
| 2 | Cross-Check 1 | 10 | 1.275 | 0.029 | 0.23 | 0.26 |
| 3 | Cross-check 2 | 10 | 2.393 | 0.101 | 0.42 | 0.47 |
| | Summation of Cross-checks | | 3.668 | 0.130 | | |



# PT # 2 – First Test

| Test | Nomenclature | Test kV | I (mA) | Watts | Measured % PF | Corrected % PF |
|---|---|---|---|---|---|---|
| 1 | Overall | 10 | 1.374 | 1.717 | 12.5 | |
| 2 | Cross-Check 1 | 10 | 1.325 | 0.031 | 0.23 | |
| 3 | Cross-check 2 | 10 | 2.428 | 0.104 | 0.43 | |
| | Summation of Cross-checks | | 3.753 | 0.135 | | |

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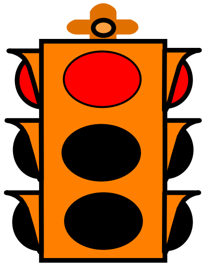
# PT # 3 – First Test

| Test | Nomenclature | Test kV | I (mA) | Watts | Measured % PF | Corrected % PF |
|---|---|---|---|---|---|---|
| 1 | Overall | 10 | 3.78 | 0.835 | 2.24 | |
| 2 | Cross-Check 1 | 10 | 1.283 | 0.030 | 0.23 | |
| 3 | Cross-check 2 | 10 | 2.432 | 0.107 | 0.43 | |
| | Summation of Cross-checks | | 3.715 | 0.137 | | |

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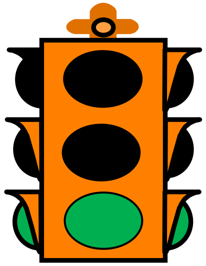
- Test voltage should be limited to either 2 or 5 kV for Tests 1 and 3.
- The overall Power Factors are very high and the summation of the current and losses for the Cross-Checks do not agree.
- H1 and H0 bushings were not connected together for the tests.

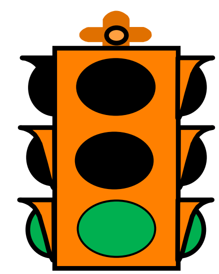
# PT # 1 – As Left

| Test | Nomenclature | Test kV | I (mA) | Watts | Measured % PF | Corrected % PF |
|---|---|---|---|---|---|---|
| 1 | Overall | 5 | 3.775 | 0.134 | 0.35 | 0.39 |
| 2 | Cross-Check 1 | 10 | 1.281 | 0.029 | 0.23 | 0.26 |
| 3 | Cross-check 2 | 5 | 2.429 | 0.105 | 0.43 | 0.48 |
| | Summation of Cross-checks | | 3.710 | 0.134 | | |
| 4 | Excitation Current 1 | 5 | 0.197 | | | |
| 5 | Excitation Current 2 | 5 | 0.205 | | | |



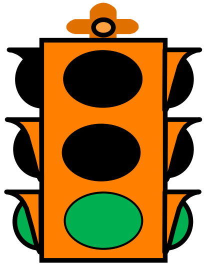
# PT # 2 – As Left

| Test | Nomenclature | Test kV | I (mA) | Watts | Measured % PF | Corrected % PF |
|---|---|---|---|---|---|---|
| 1 | Overall | 5 | 3.823 | 0.133 | 0.35 | 0.42 |
| 2 | Cross-Check 1 | 10 | 1.324 | 0.031 | 0.23 | 0.27 |
| 3 | Cross-check 2 | 5 | 2.426 | 0.102 | 0.42 | 0.50 |
| | Summation of Cross-checks | | 3.750 | 0.133 | | |
| 4 | Excitation Current 1 | 5 | 0.205 | | | |
| 5 | Excitation Current 2 | 5 | 0.205 | | | |



# PT # 3 – As Left

| Test | Nomenclature | Test kV | I (mA) | Watts | Measured % PF | Corrected % PF |
|---|---|---|---|---|---|---|
| 1 | Overall | 5 | 3.724 | 0.127 | 0.34 | 0.38 |
| 2 | Cross-Check 1 | 10 | 1.275 | 0.028 | 0.22 | 0.24 |
| 3 | Cross-check 2 | 5 | 2.389 | 0.099 | 0.41 | 0.46 |
| | Summation of Cross-checks | | 3.664 | 0.127 | | |
| 4 | Excitation Current 1 | 5 | 0.201 | | | |
| 5 | Excitation Current 2 | 5 | 0.201 | | | |

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# Analysis of Results: PTs

**Examples:**

**PT #1**

| Test No. | mA | Watts | %PF |
|---|---|---|---|
| 1 (Overall) | 2.540 | 0.104 | 0.41 |
| 2 (H1 Cross-check) | 1.256 | 0.056 | 0.45 |
| 3 (H0 Cross-check) | 1.248 | 0.046 | 0.37 |

**PT #2**

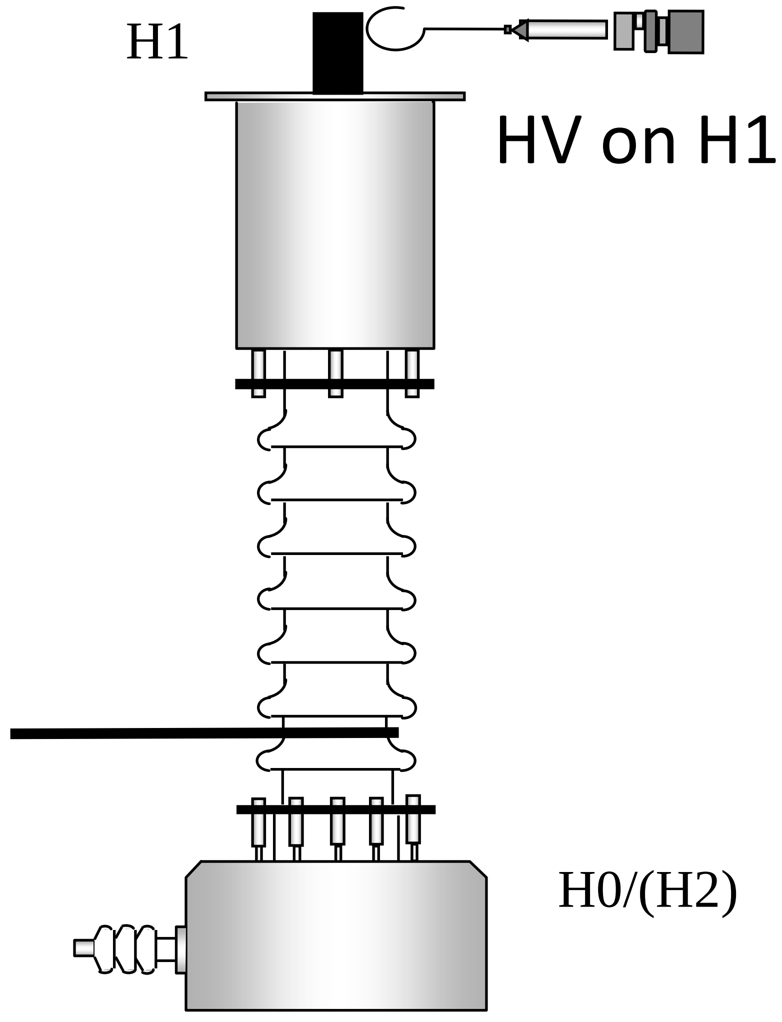
High power factor when the H1 bushing is energized

| Test No. | mA | Watts | %PF |
|---|---|---|---|
| 1 (Overall) | 2.650 | 0.354 | 1.32 |
| 2 (H1 Cross-check) | 1.356 | 0.313 | 2.31 |
| 3 (H0 Cross-check) | 1.248 | 0.055 | 0.44 |

# Single Phase Line to Ground PT

Troubleshooting
high power factor

GST – Guard
Guard Collar is
near base of porcelain



# Current Transformers

# Test Procedure

- Short Primary Windings
- Ground all Secondary Windings
- Perform  Overall Test in GST Ground Mode
- Perform Tap Test C1 and C2  (If Test Tap Installed)

# CT Test Voltage

**<u>Liquid Filled</u>**

•15 kV and Above:  10 kV

•Below 15 kV: Test Voltage Equal to or Below Nameplate Operating Line to Ground (L-to-G) Voltage

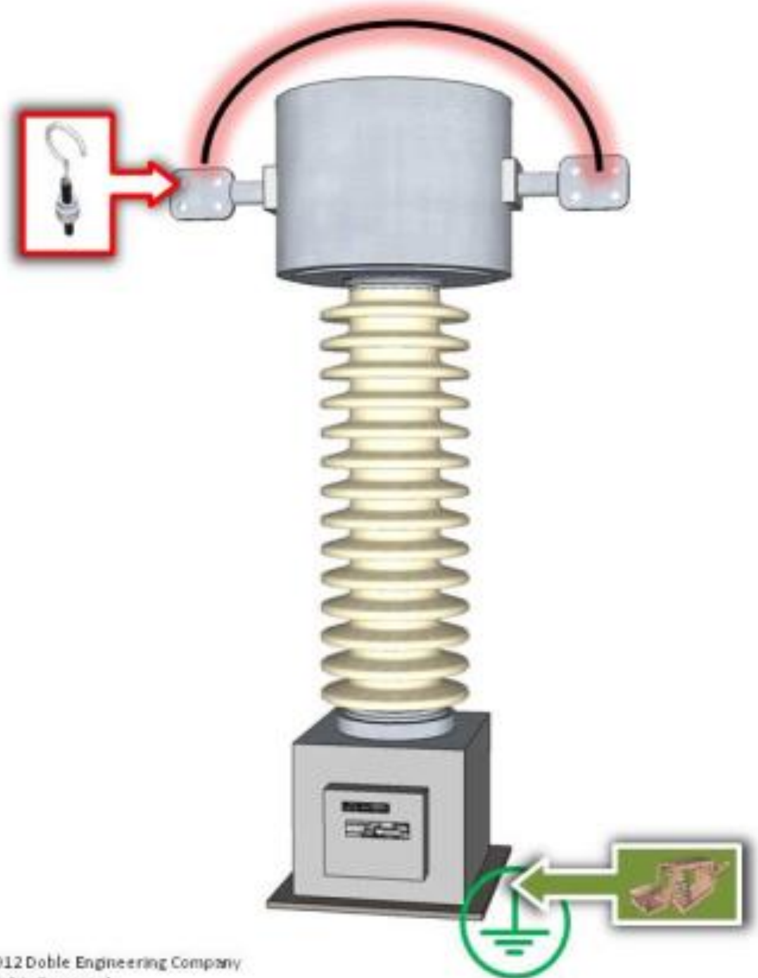
**<u>Dry-Type</u>**

•15 kV and Above:  2 kV
10 kV*

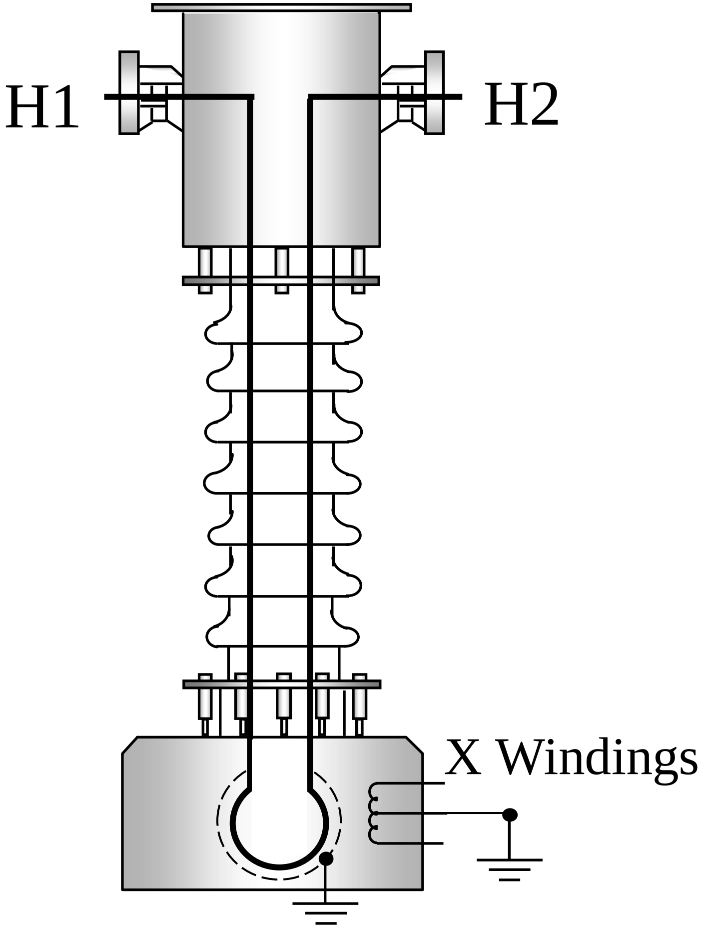
•Below 15 kV:  2 kV
L-to-G Voltage *
10% to 25% Above Operating L-to-G Voltage

* Note: Tip-Up Tests

# Current Transformers (CTs)

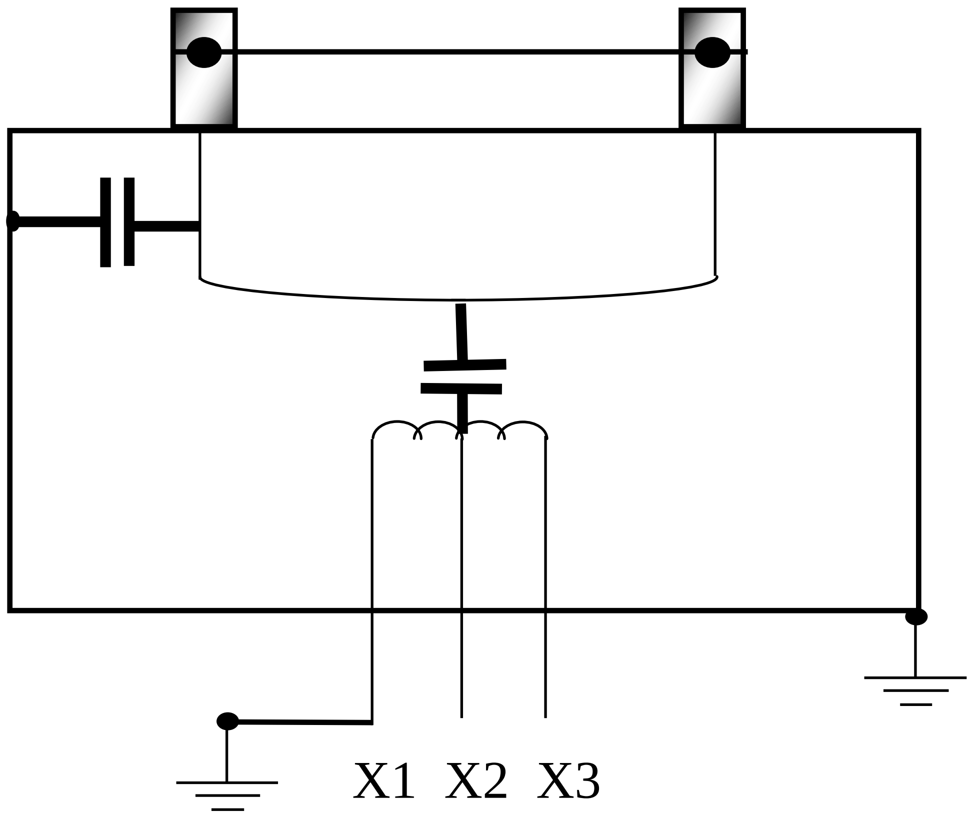


# Current Transformers (CTs)




CT Without Test Tap

# Current Transformers (CTs)




CT Without Test Tap

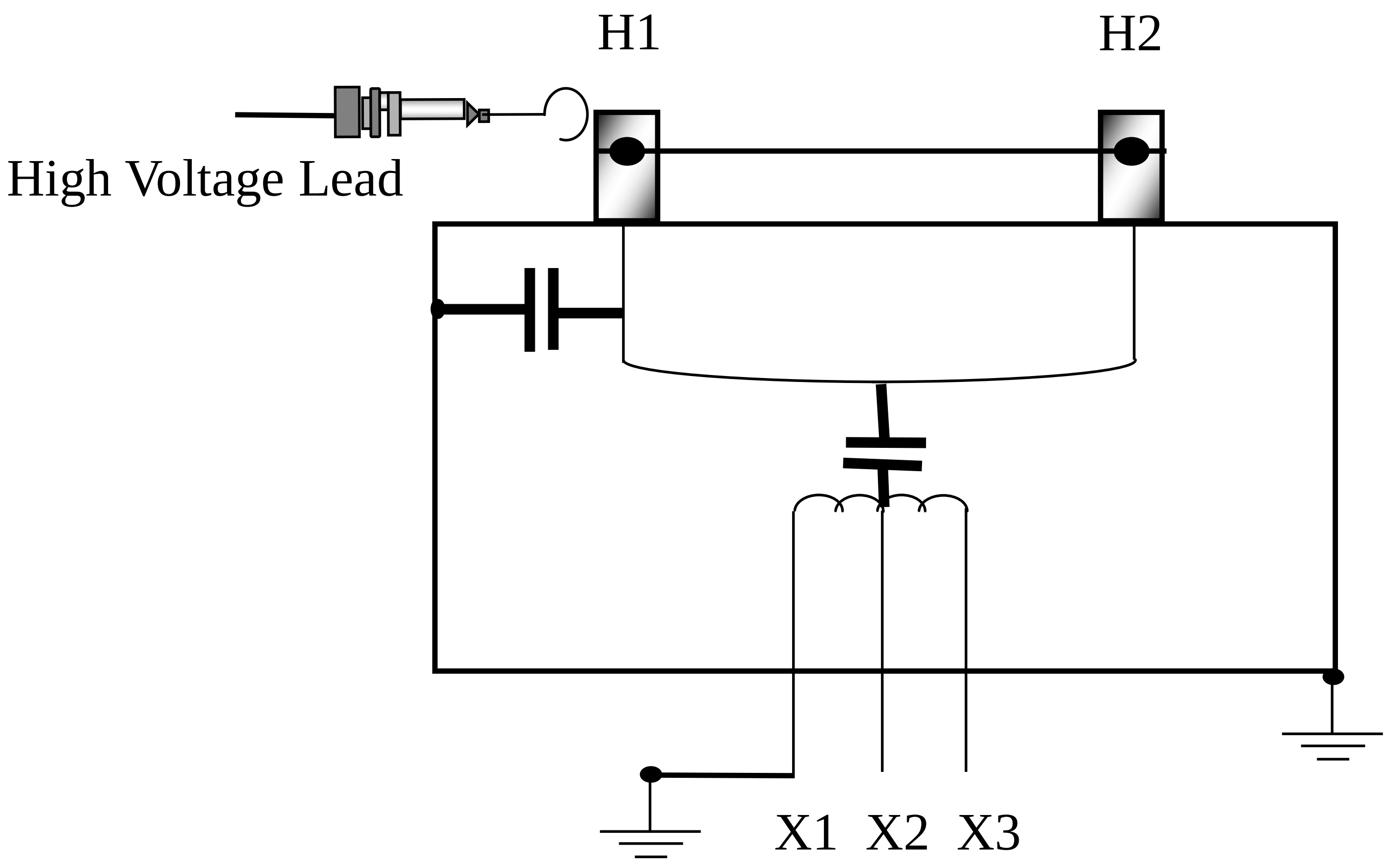
# Test Procedure

## Test Procedure: CTs Without Test Taps

| Test No. | Energize | Ground | UST | Guard |
|---|---|---|---|---|
| 1 (Overall) | Primary | Secondary | ---- | ---- |

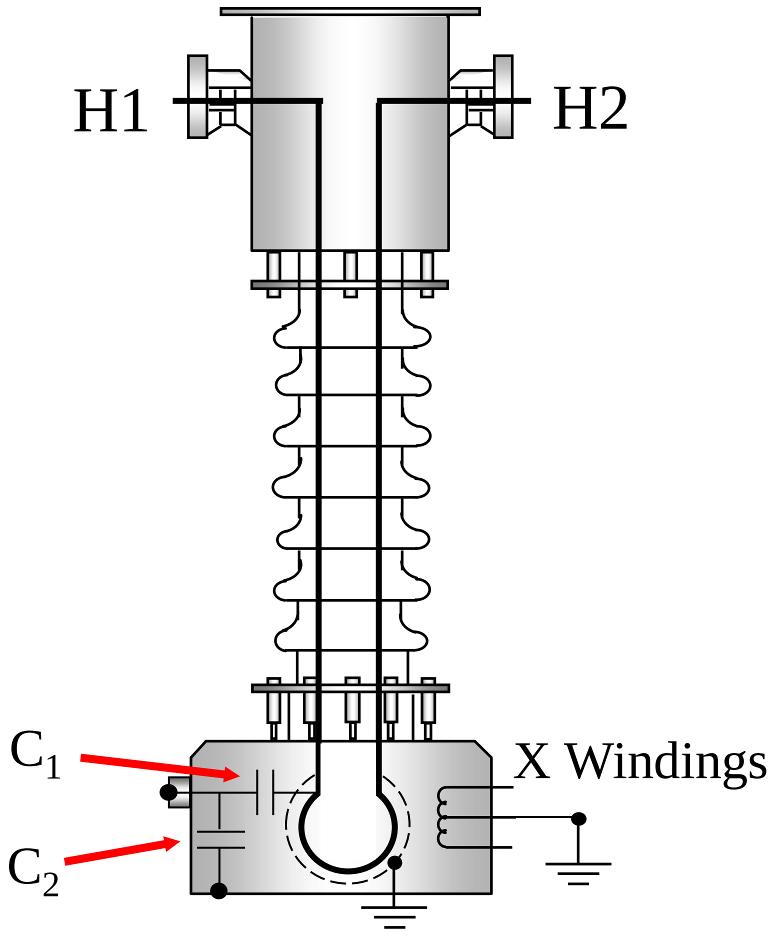
# Test Procedure

## Test No. 1: GST- Ground



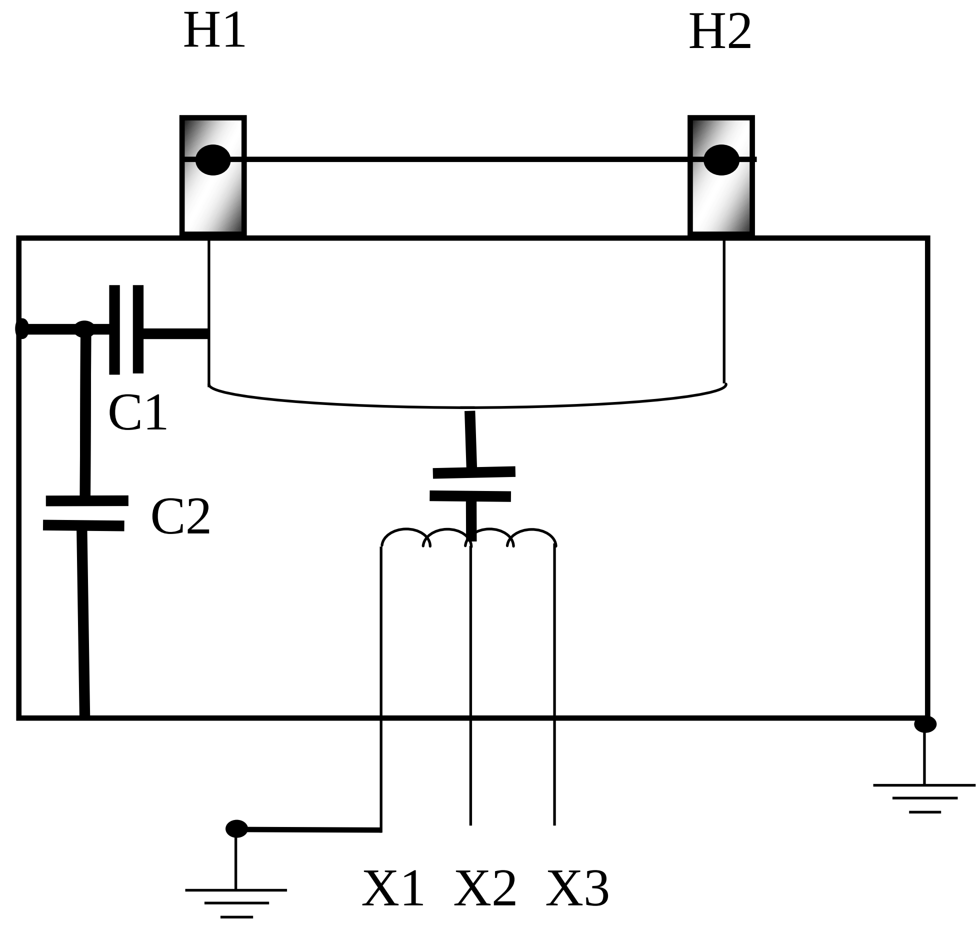

CT Without Test Tap

# Current Transformers (CTs)




CT With Test Tap

# Current Transformers (CTs)




CT With Test Tap

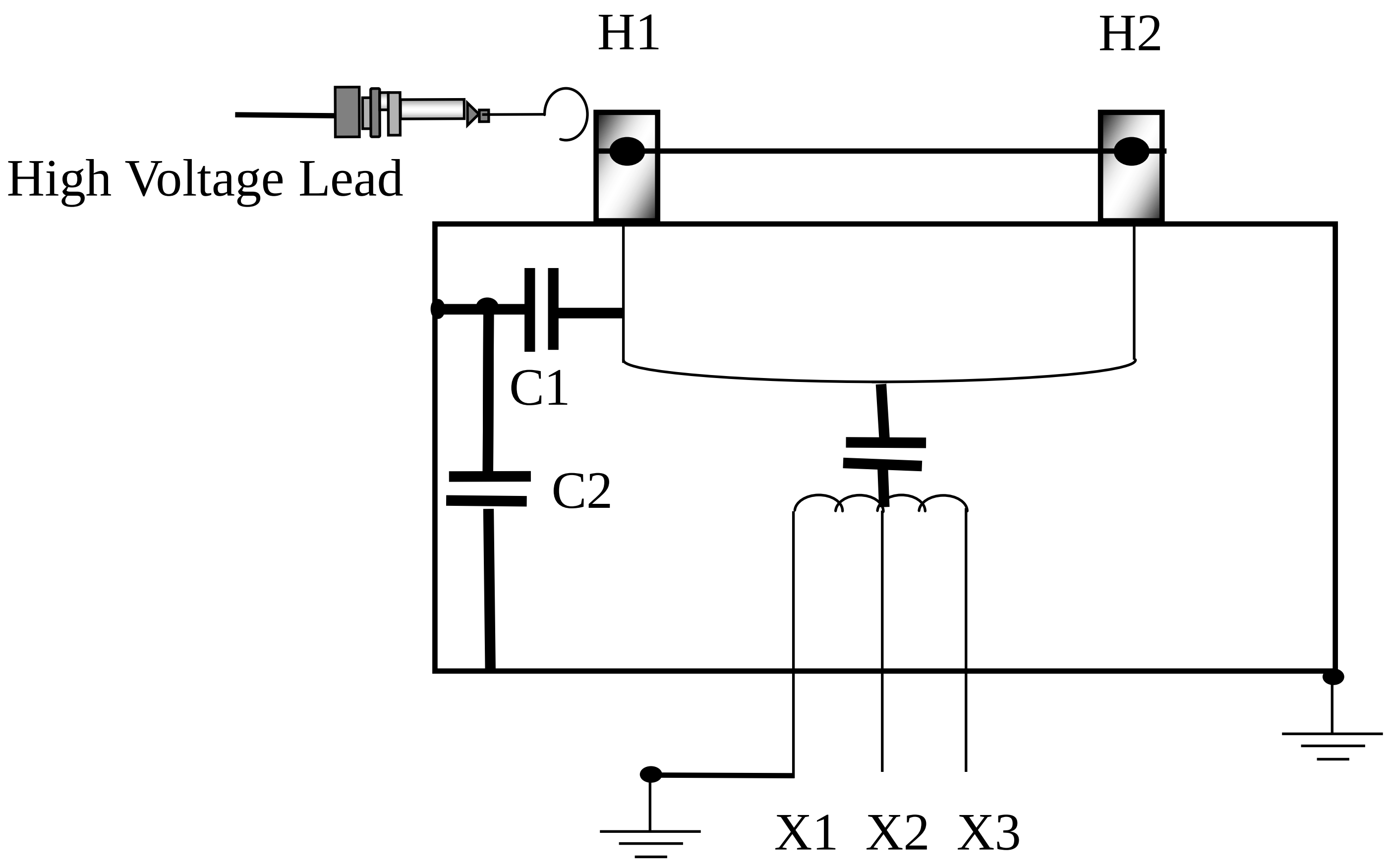
# Test Procedure

## Test Procedure: CTs With Test Taps

| Test No. | Energize | Ground | UST | Guard |
|---|---|---|---|---|
| 1 (Overall) | Primary | Secondary | ---- | ---- |
| 2 (C1) | Primary | Secondary | Tap | ---- |
| 3 (C2) | Tap | Secondary | ---- | Primary |

# Test Procedure

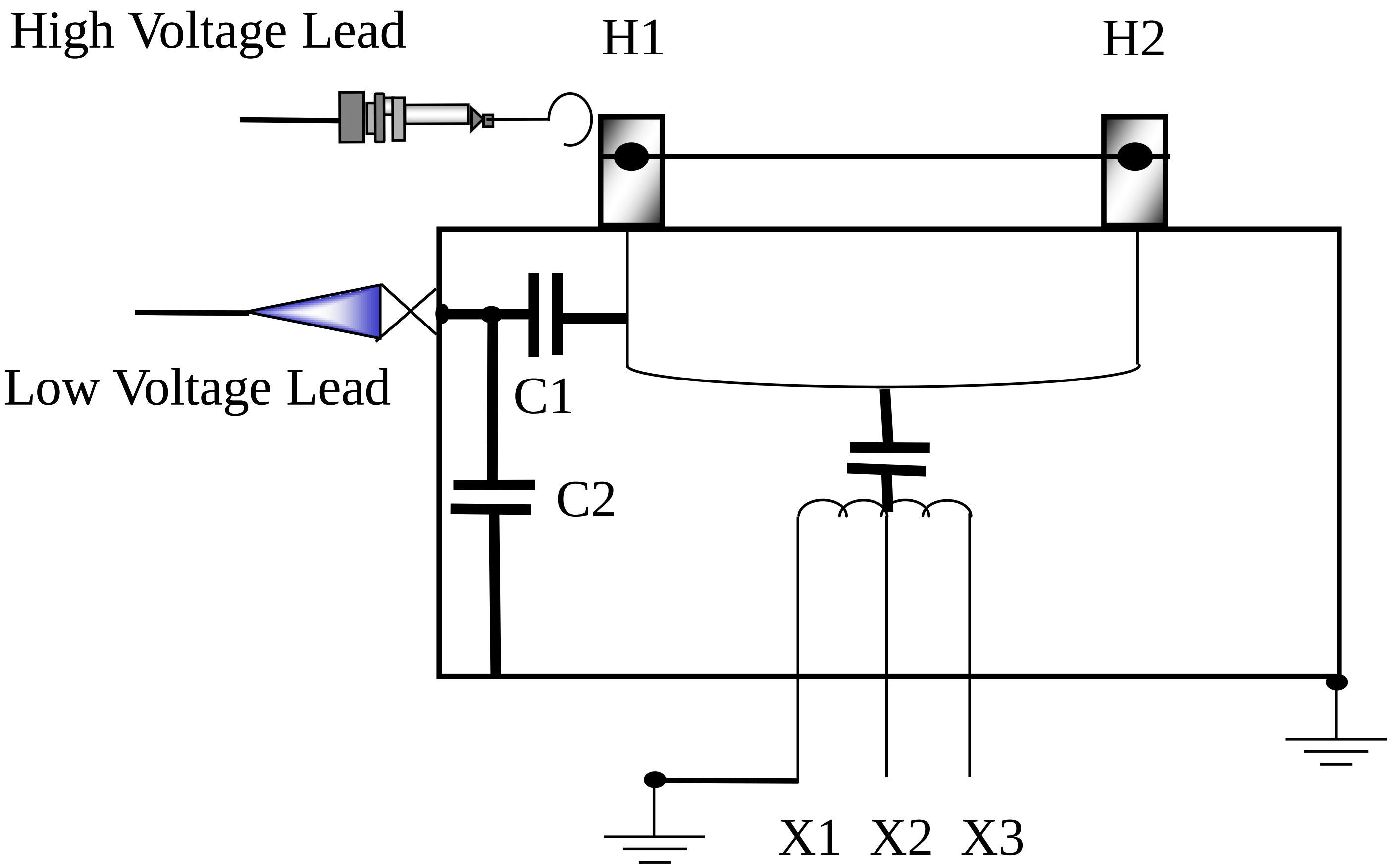
## Test No. 1: GST- Ground




CT With Test Tap

# Test Procedure

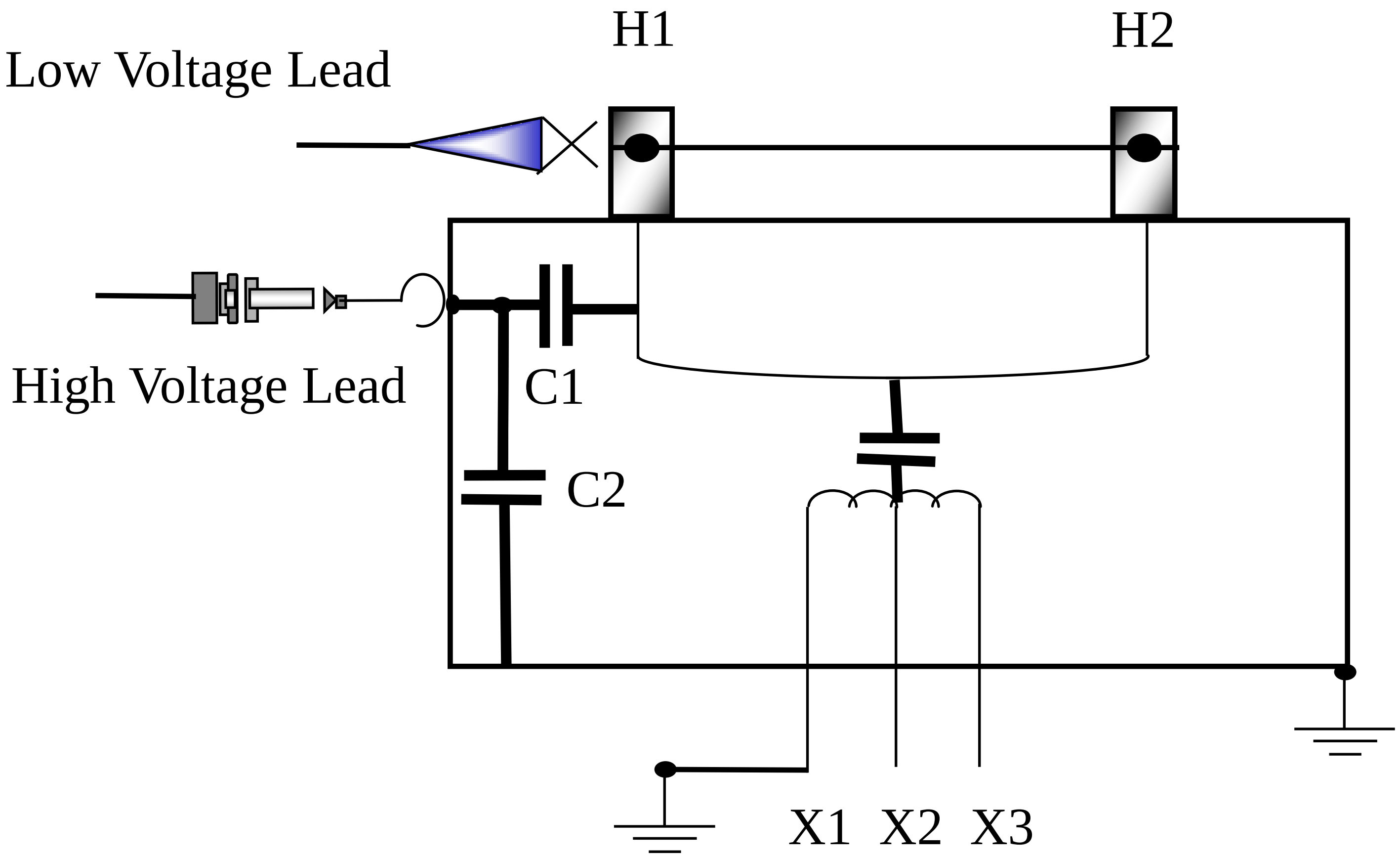
## Test No. 2: UST




CT With Test Tap

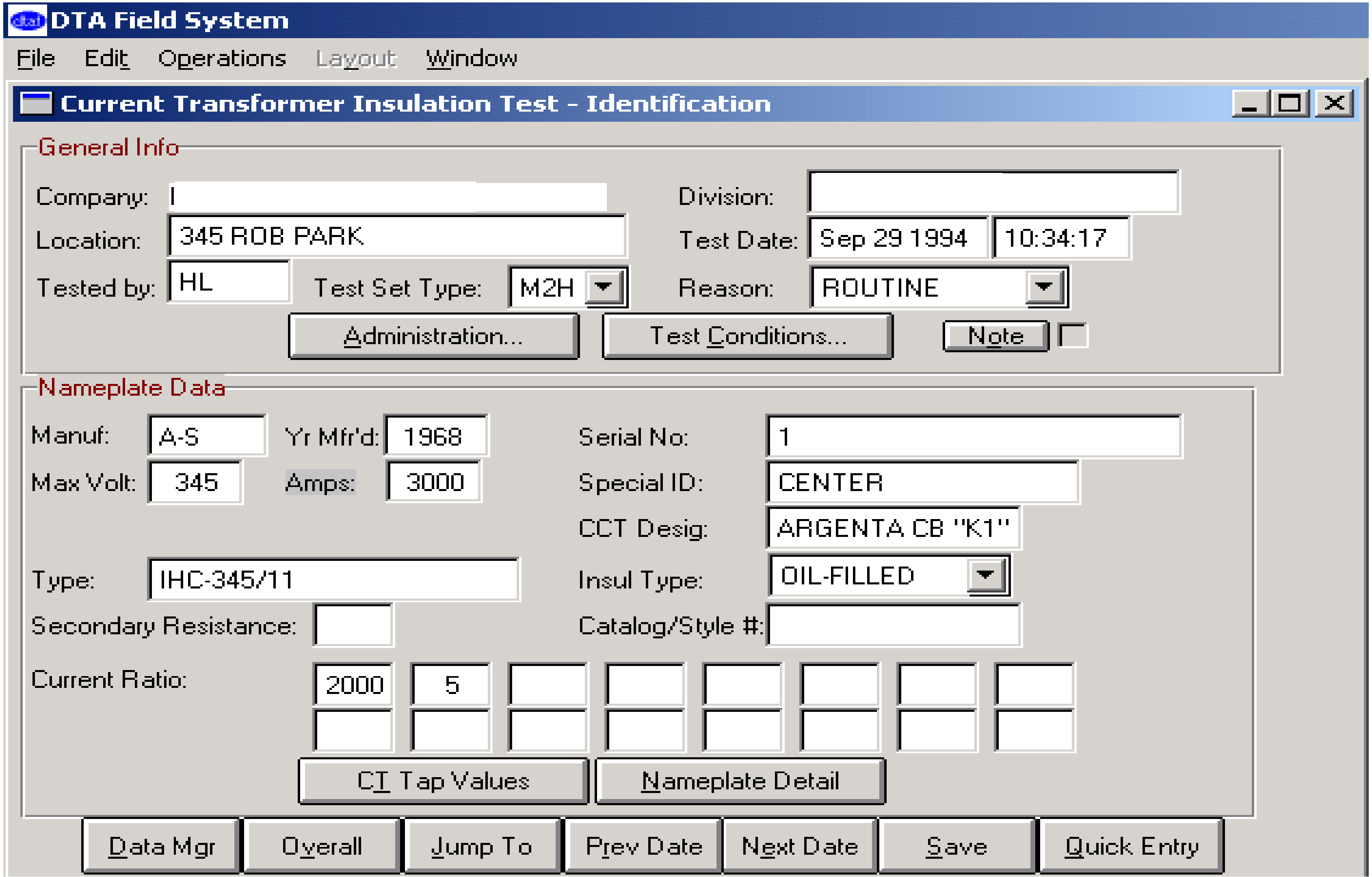
# Test Procedure

## Test No. 3: GST-Guard

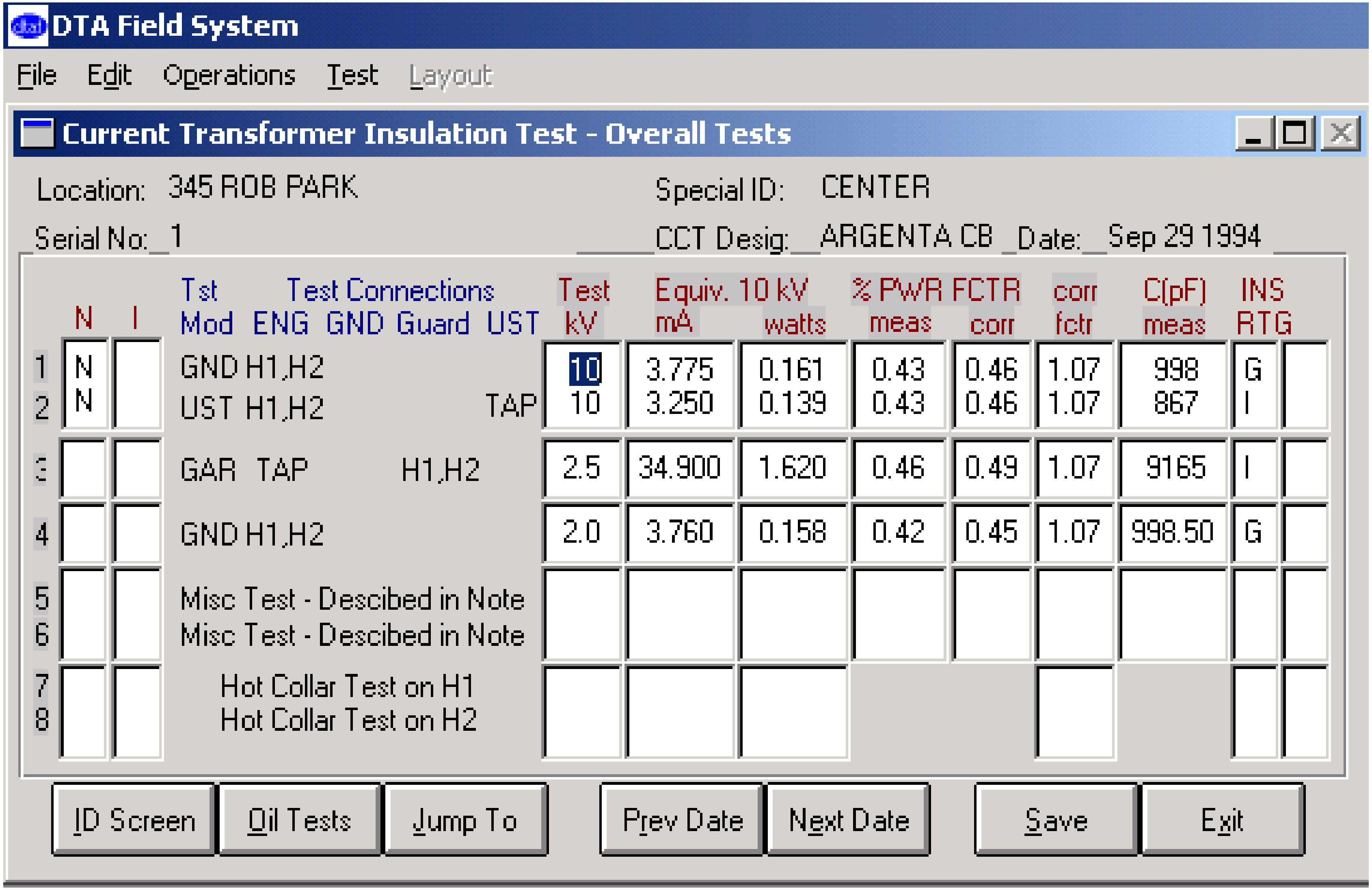



CT With Test Tap

# Current Transformers - DTA



# Current Transformers - DTA



DTA Field System

File Edit Operations Test Layout

Current Transformer Insulation Test - Overall Tests

Location: 345 ROB PARK Special ID: CENTER

Serial No: 1 CCT Desig: ARGENTA CB Date: Sep 29 1994

| | N | I | Tst Mod | Test Connections ENG | GND | Guard | UST | Test kV | Equiv. 10 kV mA | watts | % PWR FCTR meas | corr | corr fctr | C(pF) meas | INS RTG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | N | | GND | H1,H2 | | | | 10 | 3.775 | 0.161 | 0.43 | 0.46 | 1.07 | 998 | G |
| 2 | N | | UST | H1,H2 | | | TAP | 10 | 3.250 | 0.139 | 0.43 | 0.46 | 1.07 | 867 | I |
| 3 | | | GAR | TAP | | H1,H2 | | 2.5 | 34.900 | 1.620 | 0.46 | 0.49 | 1.07 | 9165 | I |
| 4 | | | GND | H1,H2 | | | | 2.0 | 3.760 | 0.158 | 0.42 | 0.45 | 1.07 | 998.50 | G |
| 5 | | | Misc Test - Descibed in Note | | | | | | | | | | | | |
| 6 | | | Misc Test - Descibed in Note | | | | | | | | | | | | |
| 7 | | | Hot Collar Test on H1 | | | | | | | | | | | | |
| 8 | | | Hot Collar Test on H2 | | | | | | | | | | | | |

ID Screen | Oil Tests | Jump To | Prev Date | Next Date | Save | Exit

# Analysis

- Calculate Power Factor
- Compare Test Results to identical apparatus

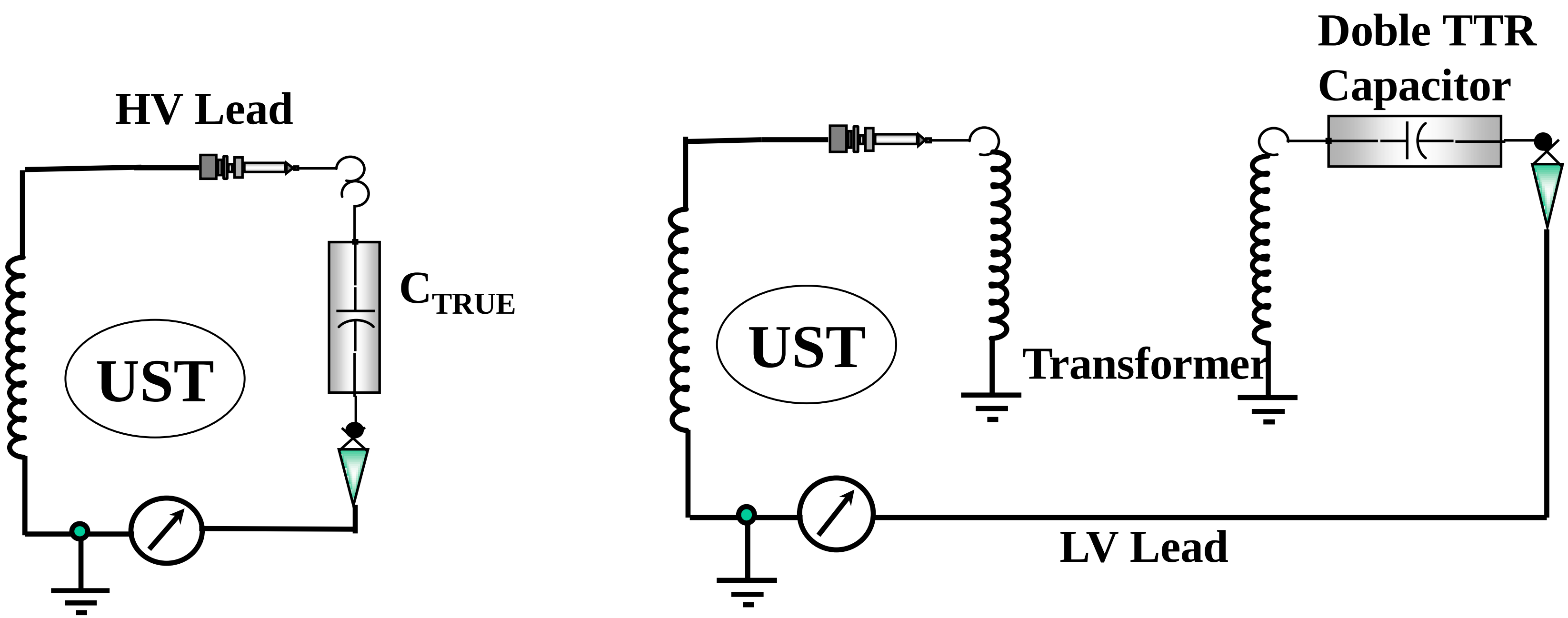
# Doble
# Current Transformer
# Supplemental Tests

## Basic Principle

- Basic Theory for Power Transformer Tests and Data Interpretation Also Applies to CT’s
- Apply Test Voltage Across Full Winding With the Highest Number of Turns:
  - Minimizes Test Current
  - No Step-Up Voltage
- Excitation Current Tests Can be Performed at Multiple Test Voltages for Saturation Curve

# Doble
# Current Transformer
# Turn Ratio Test

# Doble Transformer Turn Ratio Test

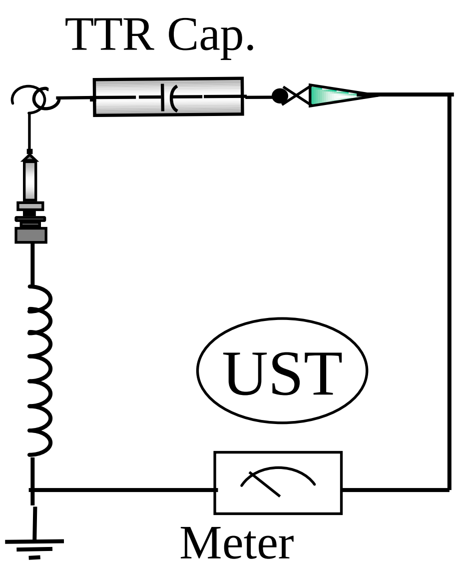



$$C_{True} = \frac{I_C}{10\ kV\ x\ \omega}$$

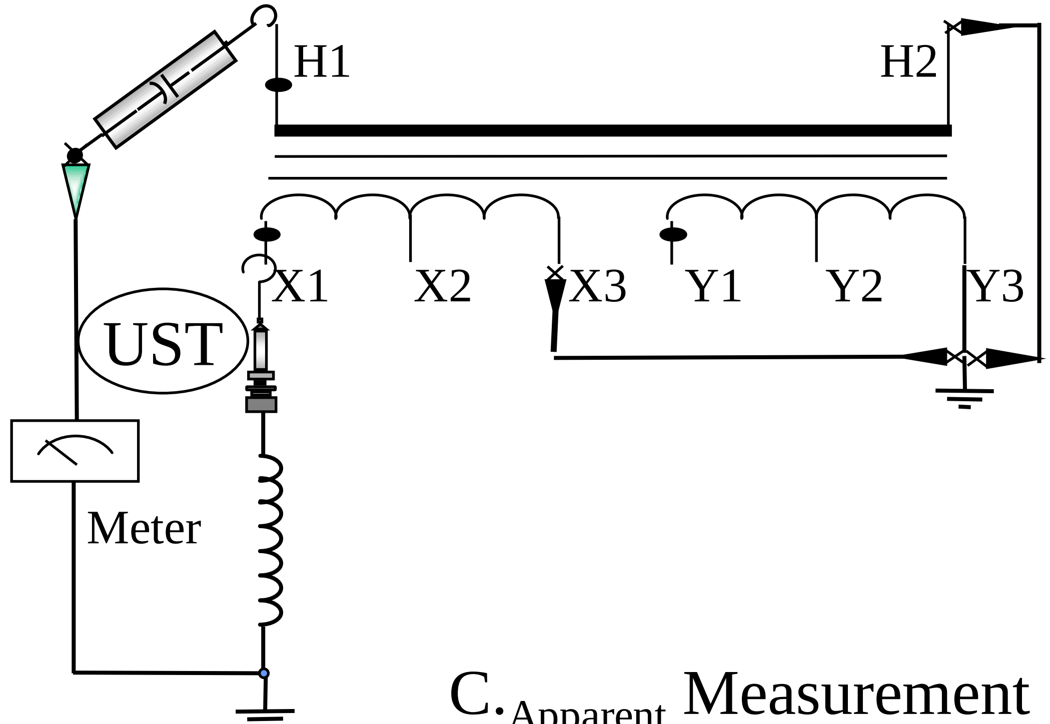
$$C_{Apparent} = \frac{I_C/N}{10\ kV\ x\ \omega}$$

**Ratio N** ⟶ $N = C_{True}/C_{Apparent}$

# Doble Transformer Turn Ratio Test




C.$_{True}$ Measurement




C.$_{Apparent}$ Measurement

**Turns Ratio N** ⟶ $\mathbf{N = C_{True}/C_{Apparent}}$

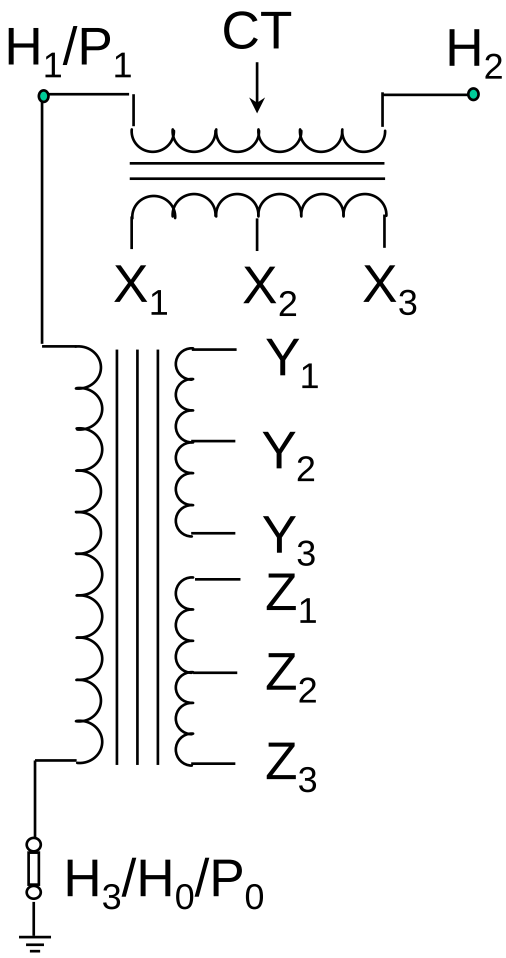
Note: Test Voltage Based on Nameplate

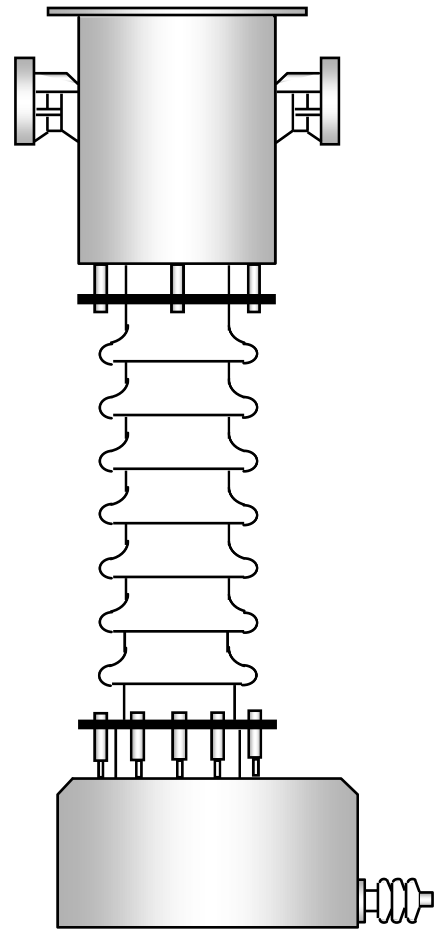
# Metering Outfits
# PT/CT Comibnation

# Single-Phase M O - Connections

**Use the same test form as the single phase potential transformer/ Voltage transformer:**

# Single Phase Metering Outfit



# Single-Phase M O - Connections

**M O Connections:**

- Base Terminal - One End of PT Primary

- Top Terminals (2) - Connected to the Line
  - Full Line Voltage in Service
  - Terminals Correspond to Either End of CT Primary
  - One Terminal also Corresponds to One End of the PT Primary

- Case Terminal Near Base - Grounded in Service
  - Terminal Designation Varies With Manufacturer

# Recommended Test Voltage

Dry-Type MO Rated 15 kV Insulation Class And Below

| MO Voltage Rating | Test Voltage (kV) |
|---|---|
| Overall | a. 2 kV<br>b. Line-to-Ground Voltage*<br>c. 10% to 25% Above Line-to-Ground operating Voltage |
| Cross-Check | a. 2 kV<br>b. Line-to-Ground Operating Voltage |
| Excitation Current | a. Line-to-Ground Operating Voltage |

*Note: Power Factor Tip Up Test

Test kV Limited by Rating of Neutral Bushing (2/5 kV)

# Recommended Test Voltage

Liquid Filled MO's Rated 15 kV Insulation Class and Above

- Perform Over-all Winding Tests at 2 kV
- Perform Over-all Winding Test - 10 kV*
- Perform Cross-Check Tests at 10 kV or Rated Line-to-Ground Voltage, Whichever is Lower

*Note: Tip-Up Test

Test kV Limited by Rating of Neutral Bushing (2/5 kV)

# Test Procedure for Metering Outfits

**Test Preparation**:

•Short Circuit All Primary Windings (Current & Potential)

•Connect One Side of Secondary Windings to Ground

•Ground All Spare Units Under Test

- Connect External Ground to Unit Housing

# Test Procedure -Single Phase M O

| Test No. | Test Mode | Energize | Ground | Guard | UST | Description |
|---|---|---|---|---|---|---|
| 1 | GST | $H_1/P_1, H_2, H_3$ | $X_1, Y_1, Z_1$ | - | - | Overall |
| 2 | GST | $H_1/P_1$ | $X_1, Y_1, Z_1$ | $H_3$ | - | Cross-Check |
| 3 | GST | $H_3$* | $X_1, Y_1, Z_1$ | $H_1/P_1$ | - | Cross-Check |
| 4 | UST | $H_1/P_1$ | $X_1, Y_1, Z_1$ | - | $H_3$ | Excitation Test |
| 5 | UST | $H_3$* | $X_1, Y_1, Z_1$ | - | $H_1/P_1$ | Excitation Test |

*Test kV Limited by Rating of Neutral Bushing (2/5 kV)

Test Voltage Applied for Tests 4 & 5 Should Be the Same for Comparison

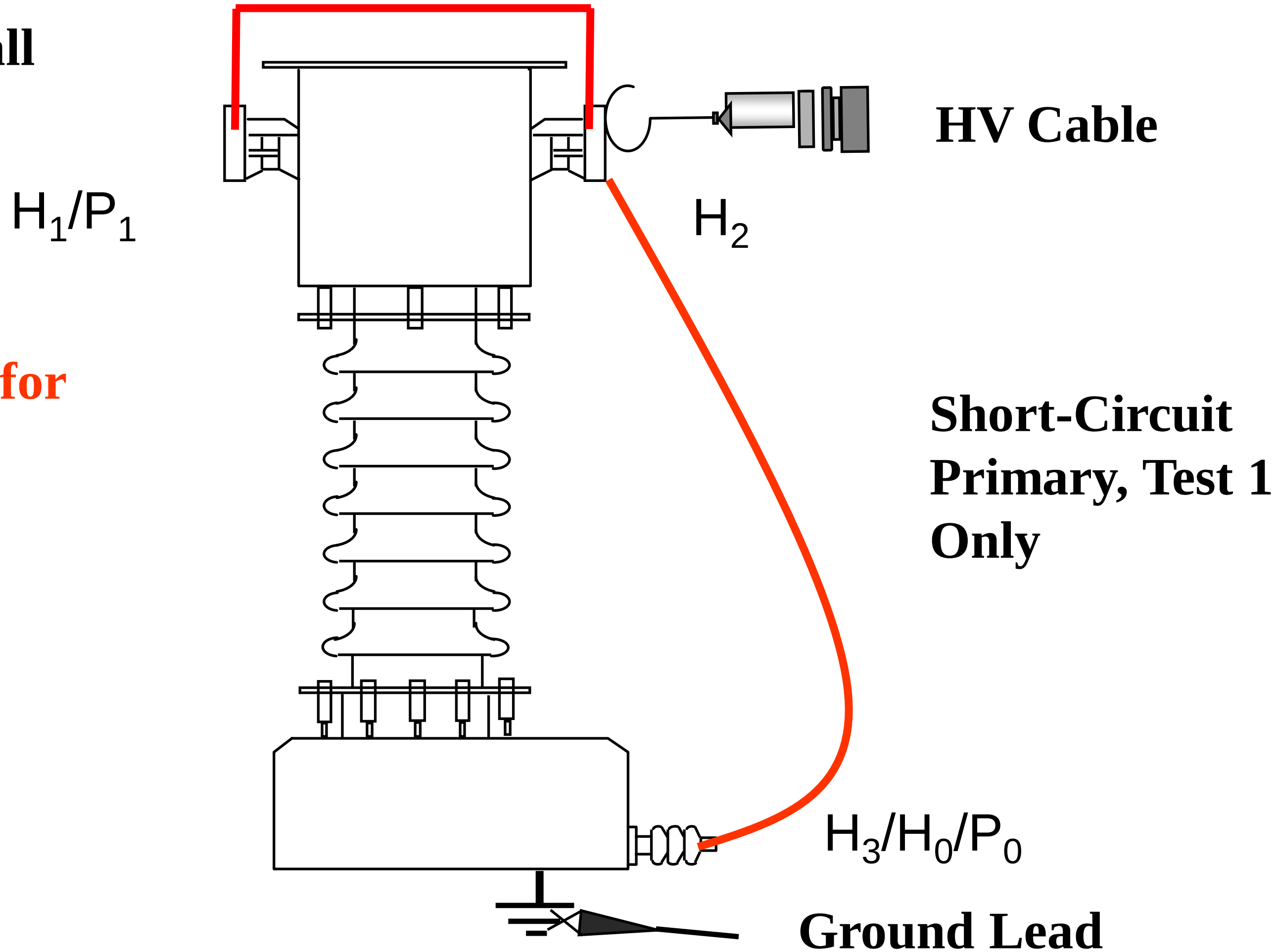
**ALL S**pare Metering Outfits Tested in Storage - Housing
Must be Grounded Externally

# Test Procedure - Single Phase M O

**Test 1: GST-Ground**

**Measure: Overall**

**Lower Voltage for This Test**

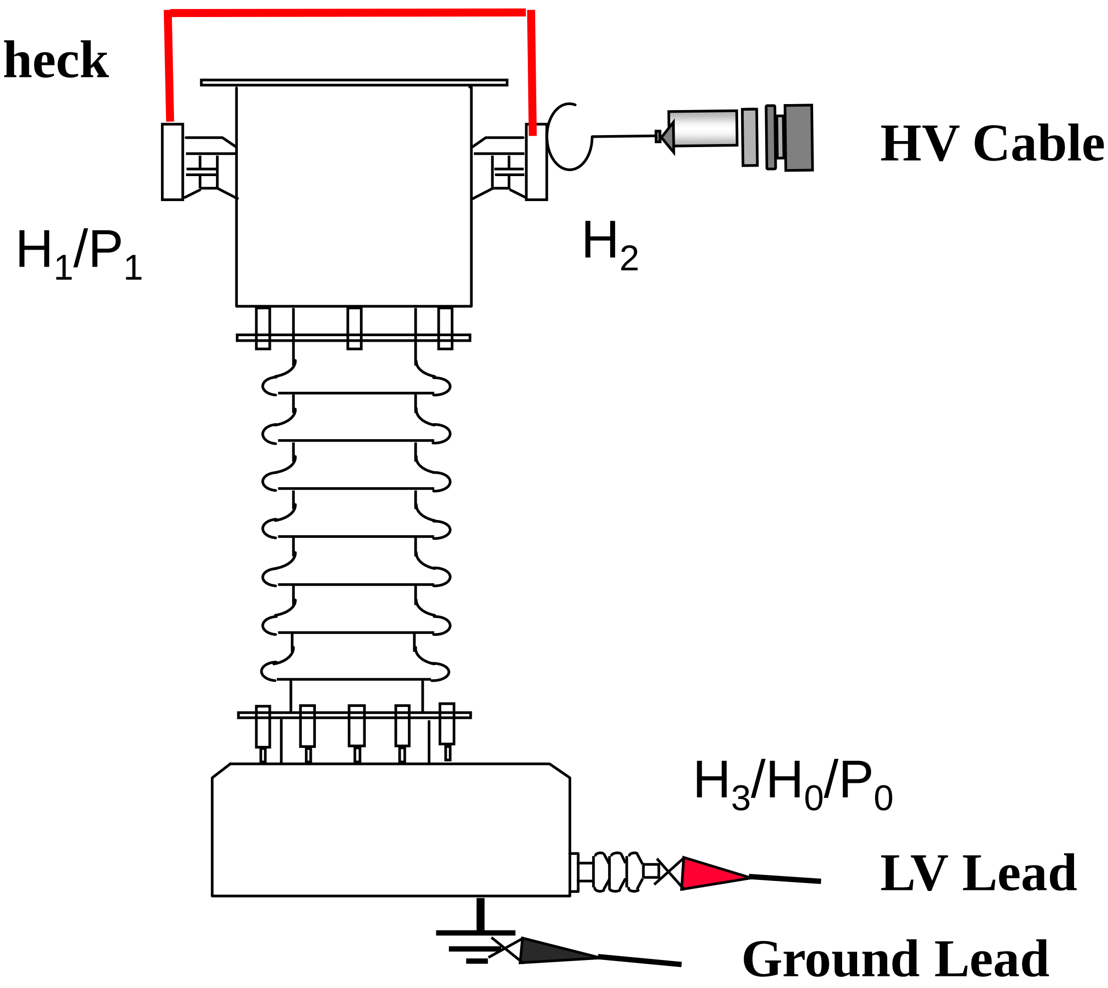



Test kV Limited by Rating of Neutral Bushing (2/5 kV)

# Test Procedure - Single Phase M O

**Test 2: GST-Guard**

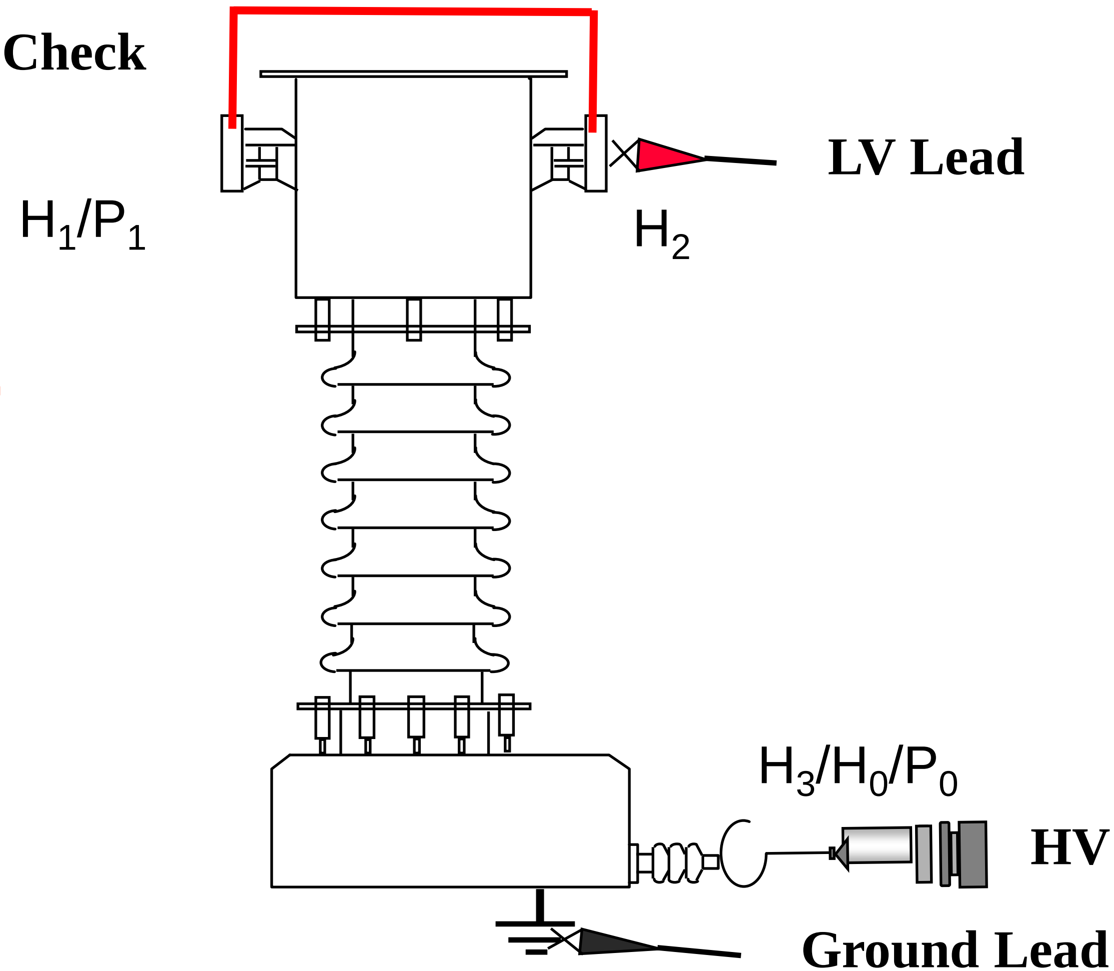
**Measure: #1 Cross-Check**



# Test Procedure - Single Phase M O

**Test 3: GST-Guard**

**Measure: #2 Cross-Check**




**Lower Voltage for This Test**

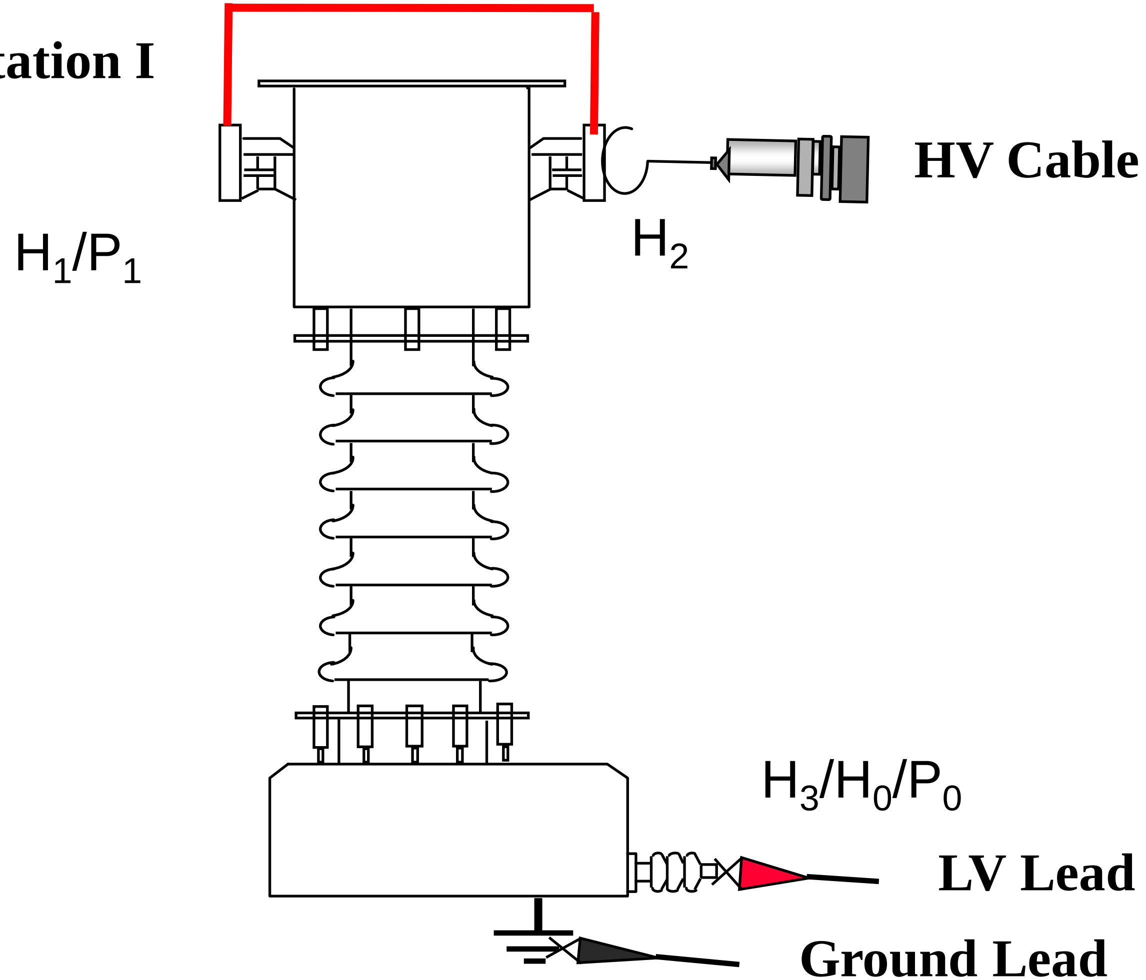
Test kV Limited by Rating of Neutral Bushing (2/5 kV)

# Test Procedure - Single Phase M O

**Test 4: UST**

**Measure: Excitation I**

**Lower Voltage for This Test**

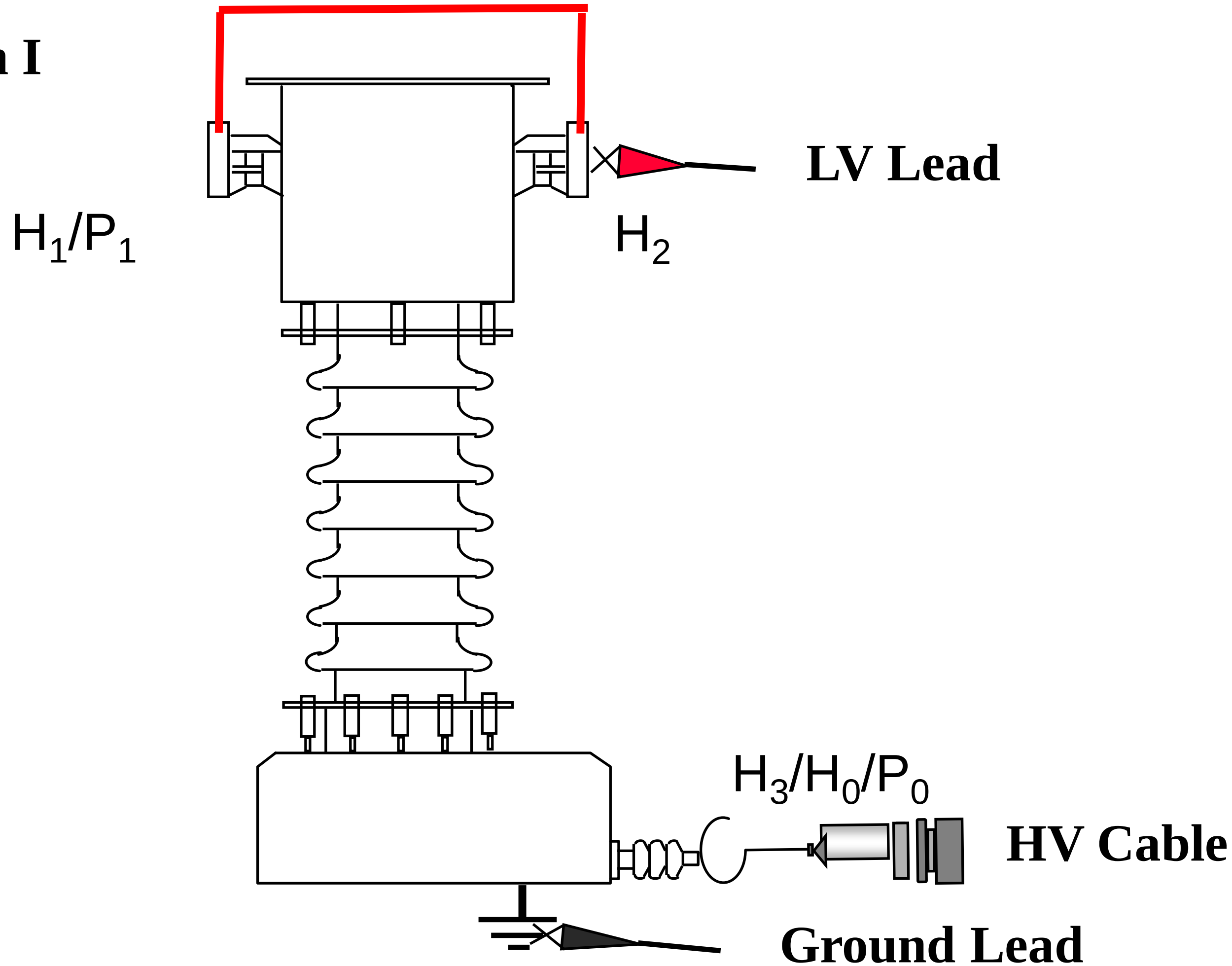


# Test Procedure - Single Phase M O

**Test 5: UST**

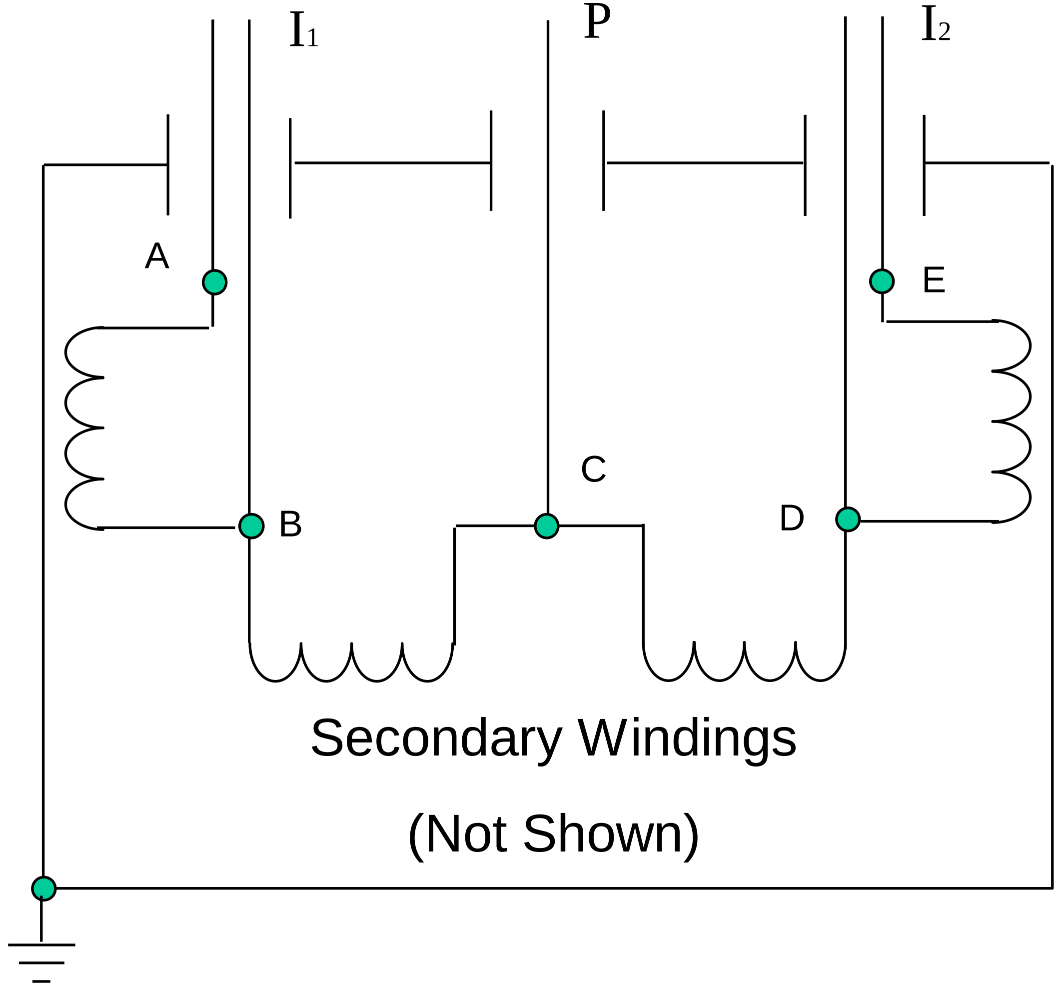
**Measure: Excitation I**

**Lower Voltage for This Test**




Test kV Limited by Rating of Neutral Bushing (2/5 kV)

# Three Phase Metering Outfit (MOs)



# Test Procedure - 3 Phase M O

| Test No. | Test Mode | Energize | Ground | Guard | UST | Description |
|---|---|---|---|---|---|---|
| 1 | GST | $I_1$,P,$I_2$ | $X_1$,$Y_1$ | - | - | Overall |
| 2 | GST | $I_1$ | $X_1$,$Y_1$ | P,$I_2$ | - | $I_1$ Cross-Check |
| 3 | GST | P | $X_1$,$Y_1$ | $I_1$,$I_2$ | - | P Cross-Check |
| 4 | GST | $I_2$ | $X_1$$Y_1$ | $I_1$,P | - | $I_2$ Cross-Check |
| 5 | UST | $I_1$ | $X_1$,$Y_1$ | - | $I_2$,P | Excitation Test |
| 6 | UST | $I_2$ | $X_1$,$Y_1$ | - | $I_1$,P | Excitation Test |

* **ALL S**pare Metering Outfits Tested in Storage - Housing Must be Grounded Externally

# Analysis of Results: MO's

•Compare Overall Power Factor Test Values to Previous Test Results

•Compare Overall Power Factor Values to Similar Units (Doble Test-Data-Reference-Book)

•Compare the Sums of Cross-Check Currents & Watt-Loss Values to the Over-All Test Results

# Analysis of Results: MO's

- Compare Excitation Current Test Results Performed at Both Ends of The Winding (Test Voltage Must be the Same for Both Tests)

# CCVTs

Single Stack

Two Stack

# CCVTs

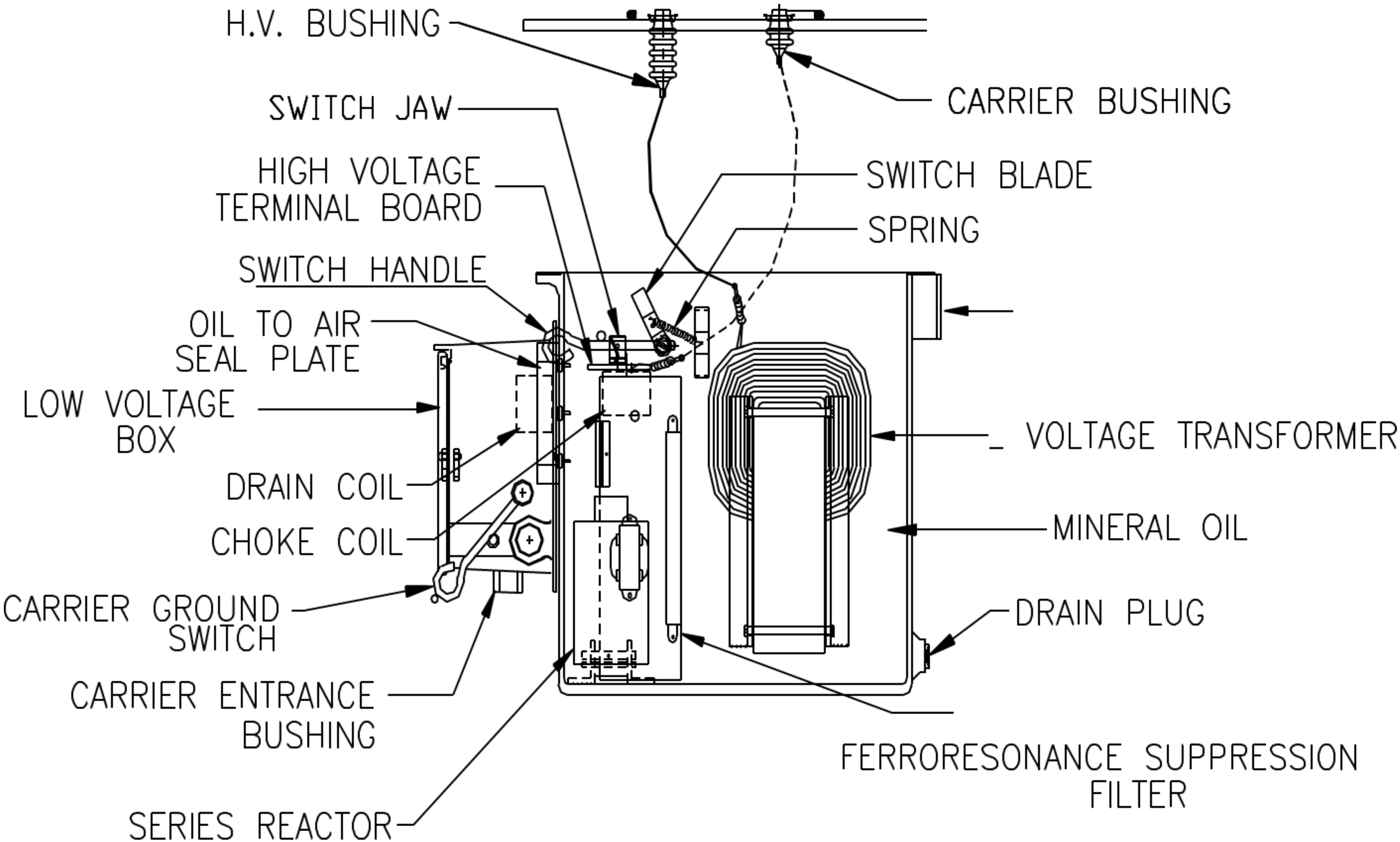


221

If you can test a Single Stack then you can test any CCVT

The difficult part is knowing what to disconnect in the base


222


H.V. BUSHING
CARRIER BUSHING
SWITCH JAW
HIGH VOLTAGE TERMINAL BOARD
SWITCH BLADE
SPRING
SWITCH HANDLE
OIL TO AIR SEAL PLATE
LOW VOLTAGE BOX
VOLTAGE TRANSFORMER
DRAIN COIL
CHOKE COIL
MINERAL OIL
CARRIER GROUND SWITCH
DRAIN PLUG
CARRIER ENTRANCE BUSHING
FERRORESONANCE SUPPRESSION FILTER
SERIES REACTOR


223

# What is a CCVT?

A capacitance coupled voltage transformer (CCVT) is a transformer used in a power system to step down extra high voltage signals and provide a low voltage signal.

CCVTs are typically used for measuring voltages in excess of 100kV where the use of a wound primary winding is not economical.

Disadvantage of this type of transformer is with ferroresonance and over-voltage transient problems


224

# Applications for CCVTs

Accurate transformation of primary system voltage into secondary output voltages suitable for :

- Relaying / Protection CCVT

- Metering CCVT

- Power Line Carrier Coupling (CCVT/CC)


225

# Applications for CCVTs

- TRV Mitigation for CB (CCVT/CC)
- Harmonics monitoring (CCVT/CC)
- Power supply for SS and remote area (CCVT)
- Except HVAC (CCVT)
- Improves SS insulation withstand (CCVT/CC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# Significance of Tests

- Capacitance Pack Deterioration or Failures Indicated by Changes in Capacitance
- Contamination of Capacitance Stack or Base Box Indicated by Changes in Power Factor


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# Capacitor Nomenclature

- C2, the Auxiliary capacitor is the largest capacitor in picofarads
- C1-1 (B1-POT) sits on top of C2, both are located in the first porcelain unit
- C1-2, C1-3, and so forth are found in additional stacked porcelain units on CCVT's with higher voltage ratings.

Nameplate capacitances may not exist for C1-1; this value may require calculation from the given $C_{total}$, which is often the series combination of C2 and C1-1 (B1-CAR).

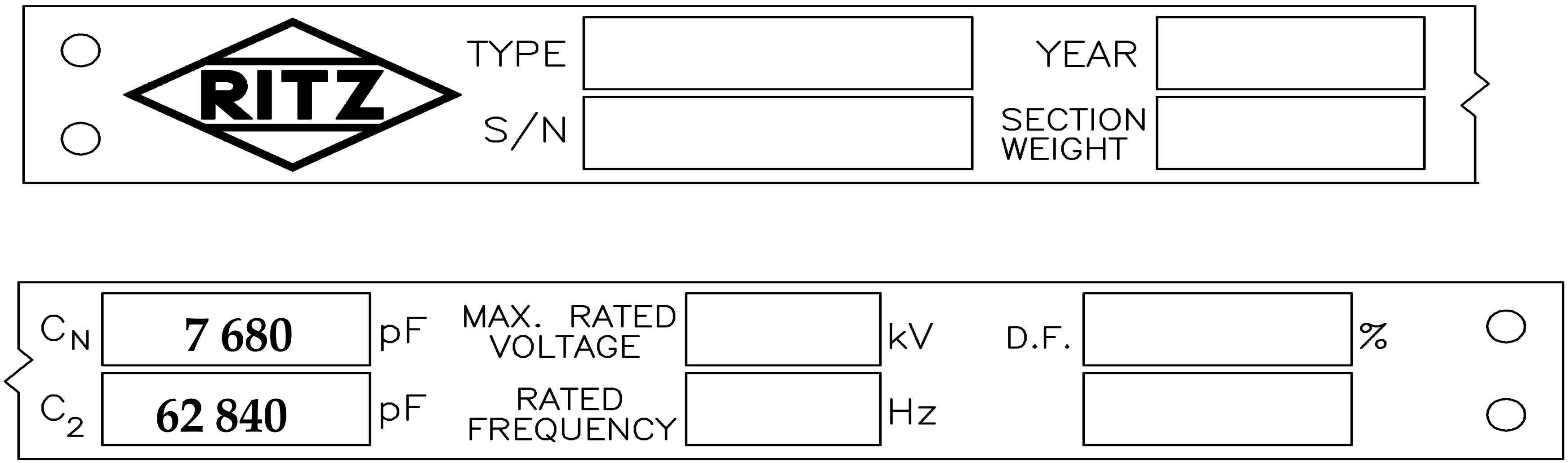

228

# Capacitor Nomenclature

- If C1 is provide instead of C1-1 you may have to perform some calculations to determine the value of C1-1

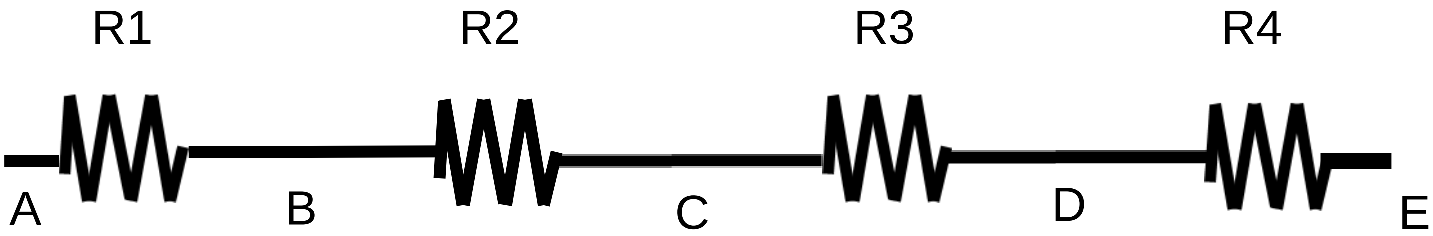

229

# Capacitor section nameplate-Ritz



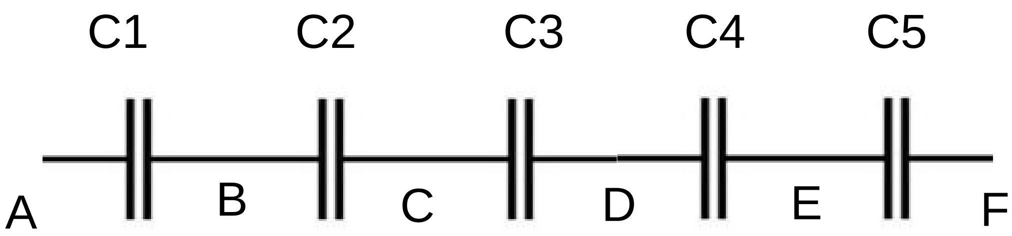

$$\frac{1}{C_{1-1}} = \frac{1}{7680} - \frac{1}{62840}$$

$$C_{1-1} = 8750\,pF$$



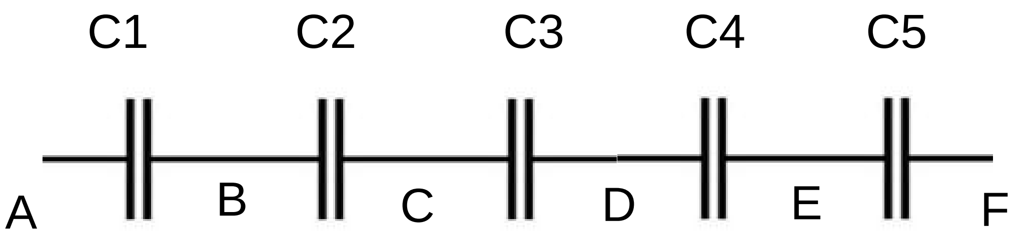

To Measure the following resistors

| R1 | R2 | R3 | R4 | R1-R3 |
|---|---|---|---|---|
| **A-B** | **B-C** | **C-D** | **D-E** | **A-D** |




Measure the following capacitors

| C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|
| **A-B** | **B-C** | **C-D** | **D-E** | **E-F** |




Measure the following capacitors

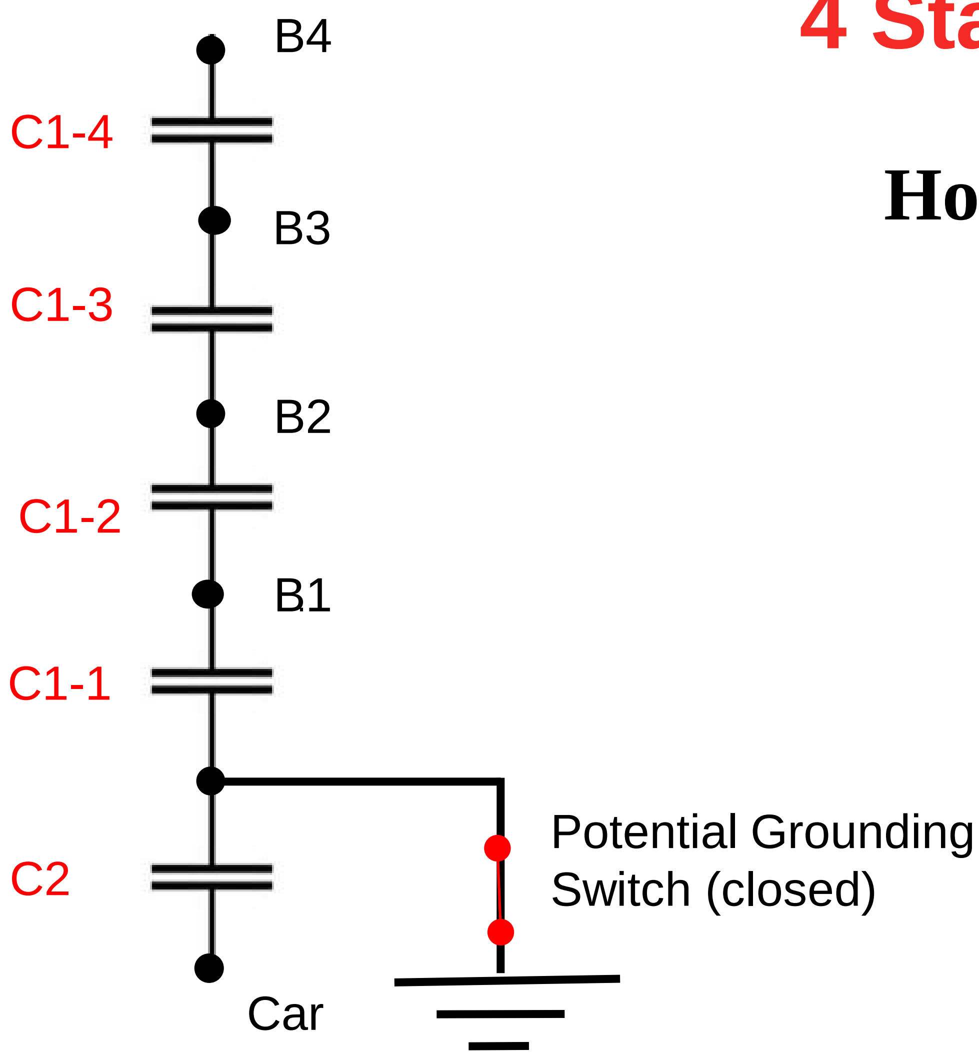
C4 – C5

**D-F**

# Now, Let's Rotate this circuit 90 degrees and give different identification to each capacitor


234

# 4 Stack CCVT




**How do we measure**

**C2**

**C1-1**

**C1-2**

**C1-3**

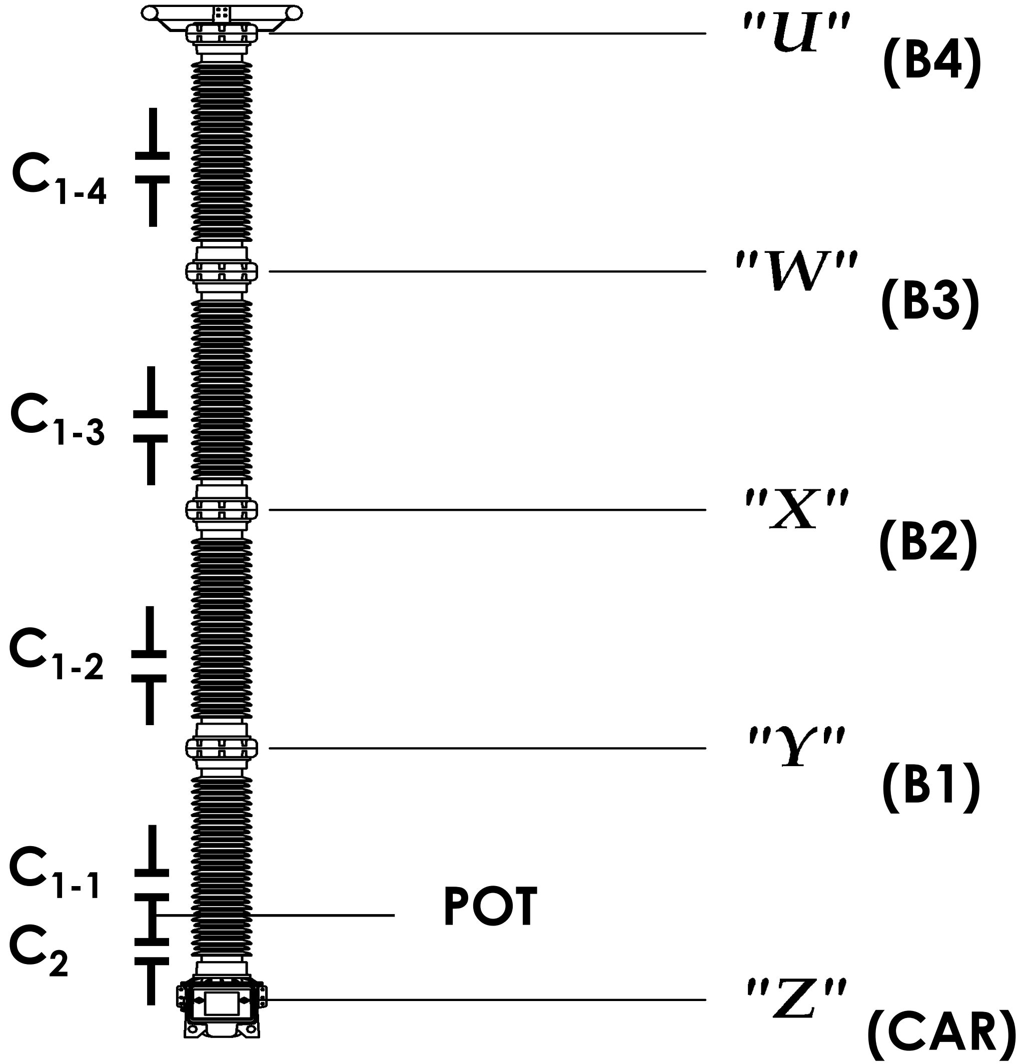
**C1-4**

**C1-1/C2**

# Test Points and Nomenclature

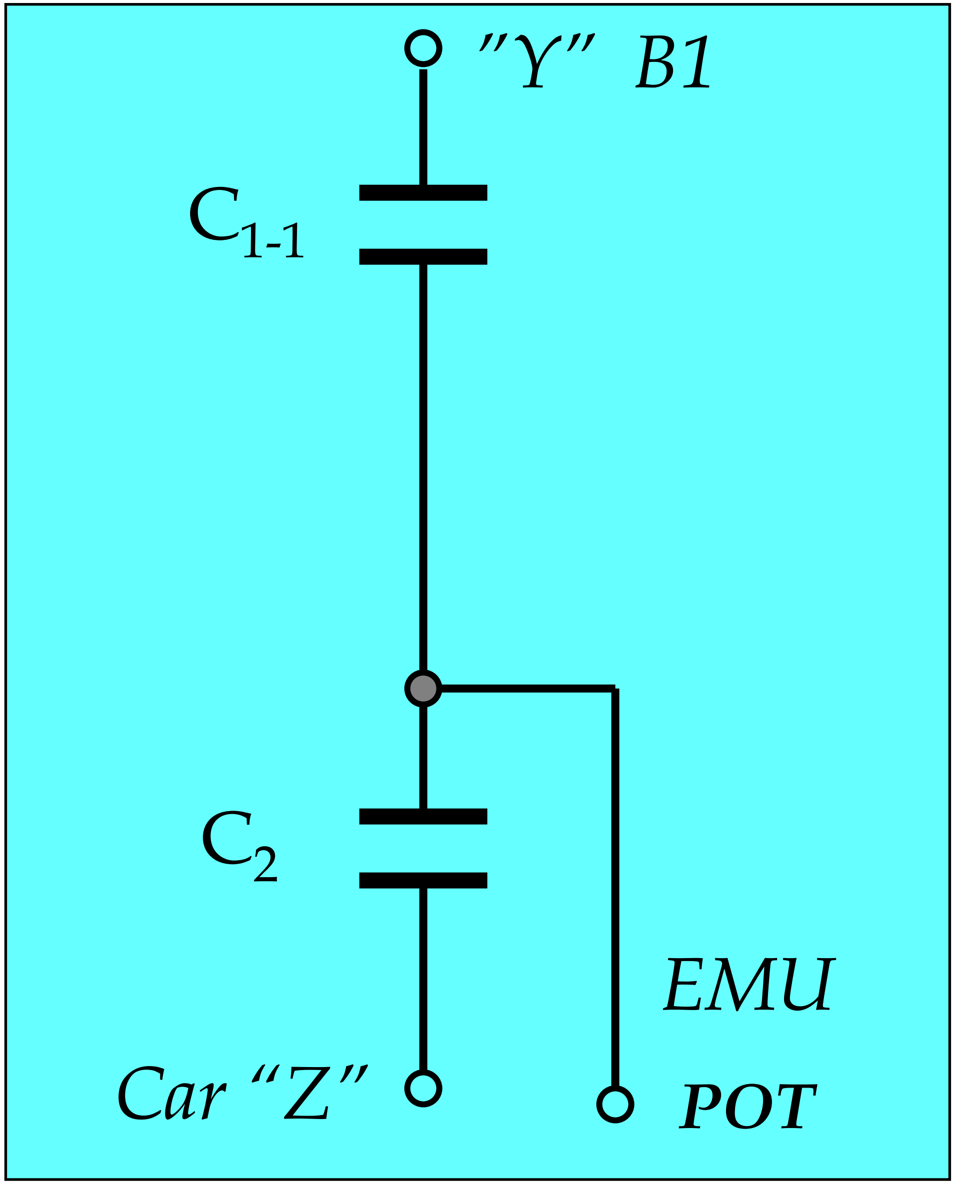
**800 kV**

**CCVT**

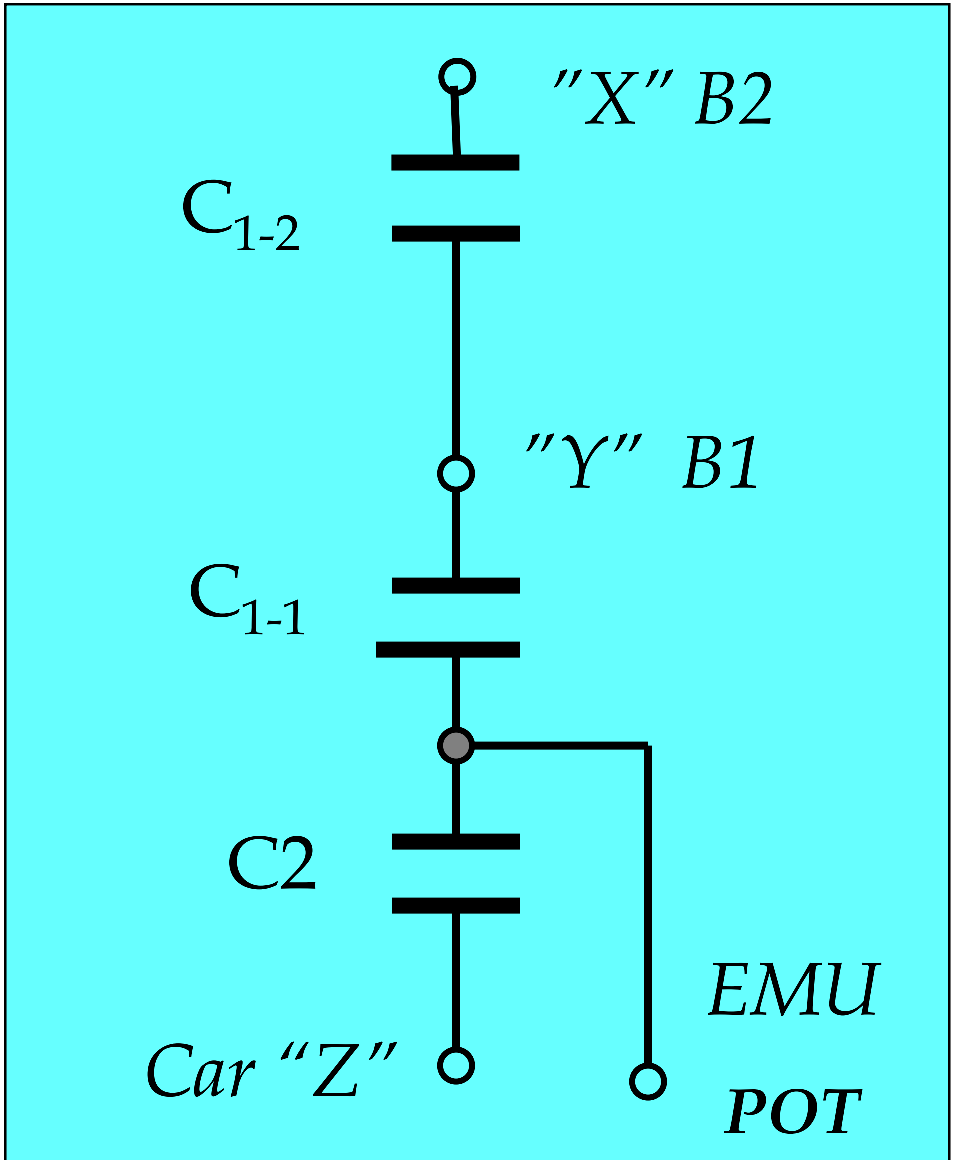



( ) – Doble Nomenclature

# Capacitor voltage divider




# Capacitor voltage divider




# Power Factor Testing CCVTs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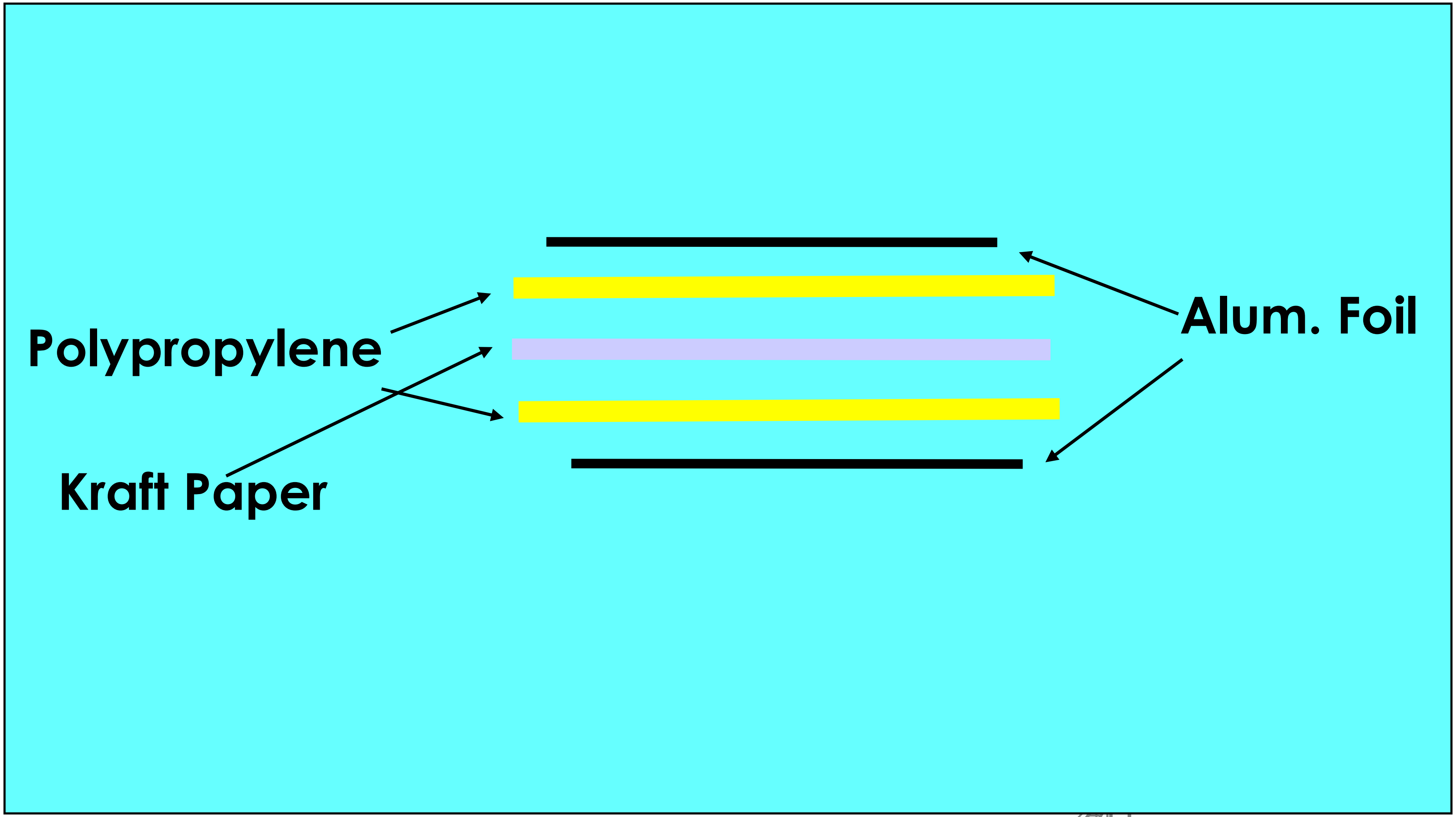
# Materials & Power Factor

- Dielectric: kraft paper and polypropylene film
- Electrode: Aluminum foil
- Connection: Tinned copper tabs

| Type of insulation system | Power factor @ $V_{rated}$ [%] | Comment |
|---|---|---|
| Paper/Mineral oil | 0.40 | High polar material content |
| Polypropylene/paper/ synthetic oil | 0.080 | Low polar material content |

# Arrangement of mixed dielectric capacitor element



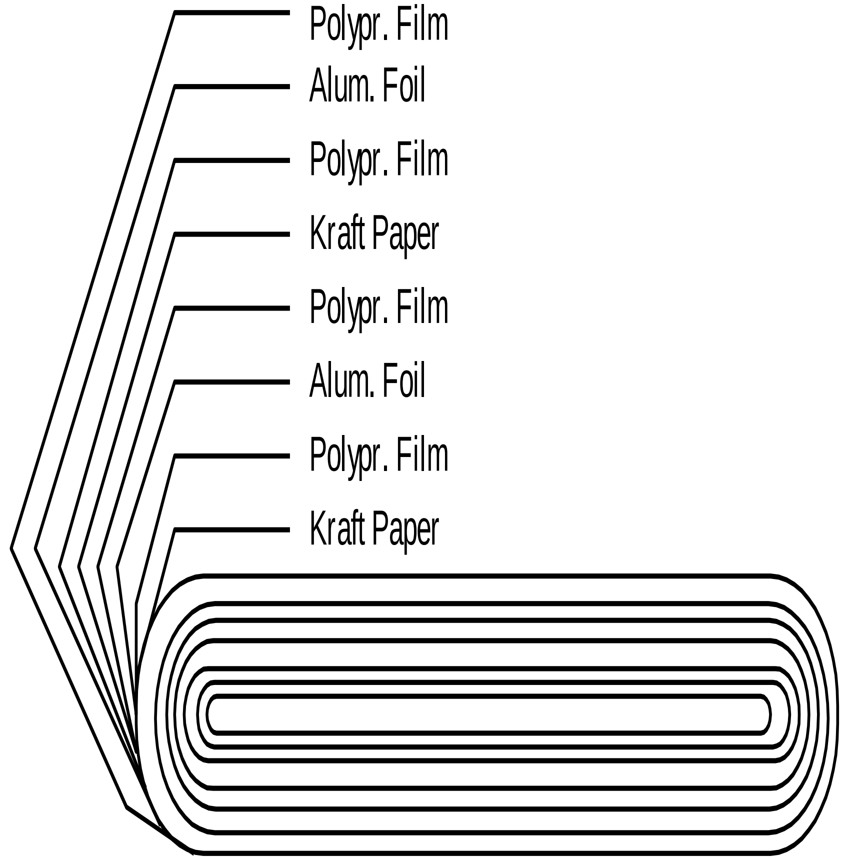
# CCVT/CC Construction
# Capacitor element

<u>Construction</u>

- Electrode - Aluminum foil
- Dielectric spacer material

  i) Hazy polypropylene film

  ii) Kraft paper
- Connection – Tinned Cu tabs
- Synthetic Fluid : PXE, SAS40 or Jarylec



# Capacitor Element

# Capacitor Stack

# Capacitor Nomenclature

- The first step is to gather all of the nameplate information.  In this case there are 3 nameplates for a two-stack CCVT.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# Nameplates

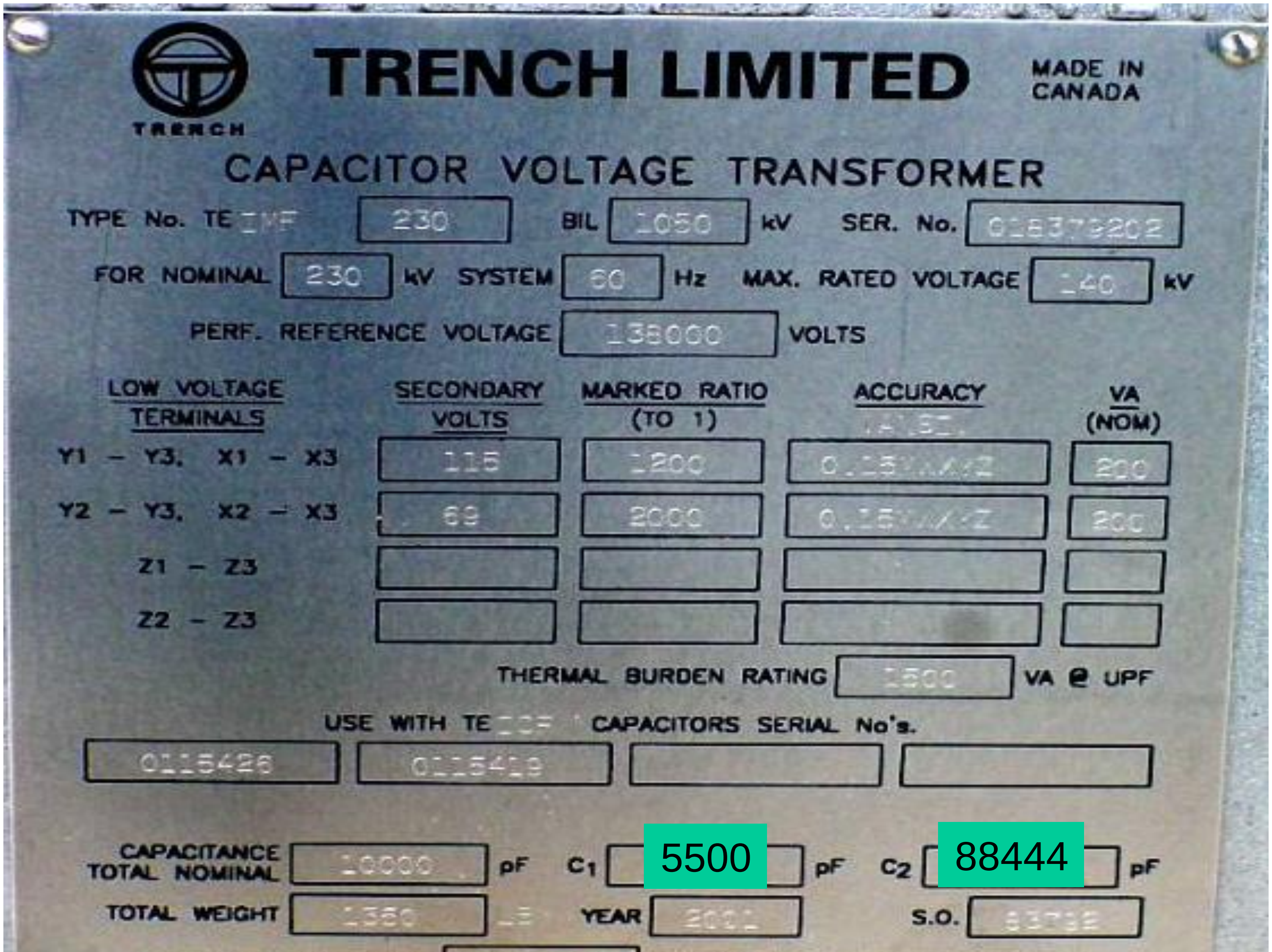
1st On the door where the secondary output is located

2nd On the bottom flange of the top stack capacitor (C1-2)

3rd On the top flange of the bottom stack of capacitors (C1-1,C2 series)

All of this information needs to be recorded so that it can be entered in the DTAF program.

# Nameplate on Door



# Nameplate at Bottom of Top Unit

# Nameplate at Top of Bottom Unit

# Capacitor Nomenclature

- The C2 capacitor is always the largest capacitor
- The capacitance of the C1-1 in series with the C2 is less than the C1-1

# Test Points

- The Top of Each Porcelain Section
- The Potential Grounding Switch
- The Carrier Terminal
- The Transformer Grounding Link (Alternate Test Only)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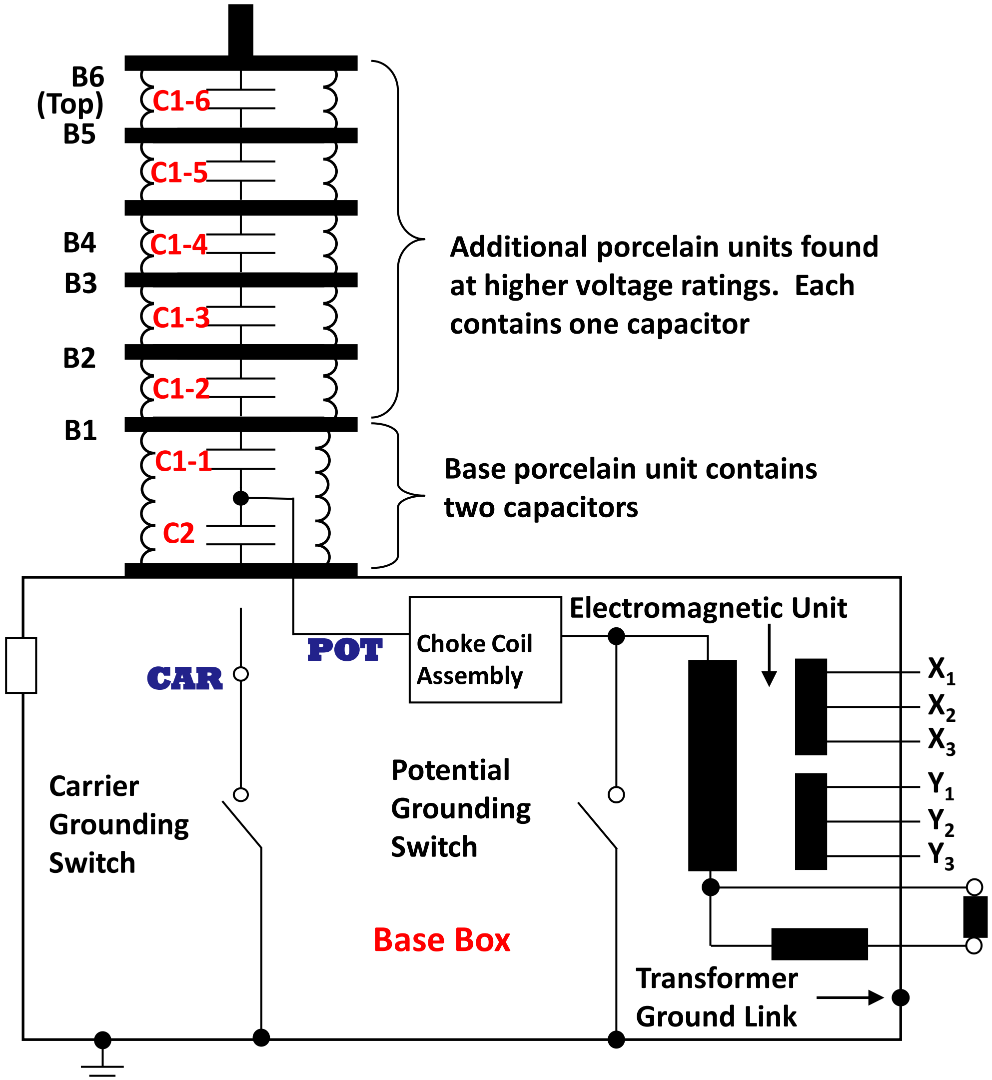
# Modern CCVT






252

# The CAR Terminal

- Older CCVT's
  - Carrier (CAR) Bushing Accessible for Testing
  - Potential (POT) Bushing Accessible for Testing

- Newer CCVT's
  - CAR Bushing Accessible for Testing
  - POT Bushing Not Accessible For Testing
  - Max Test Voltage 2 kV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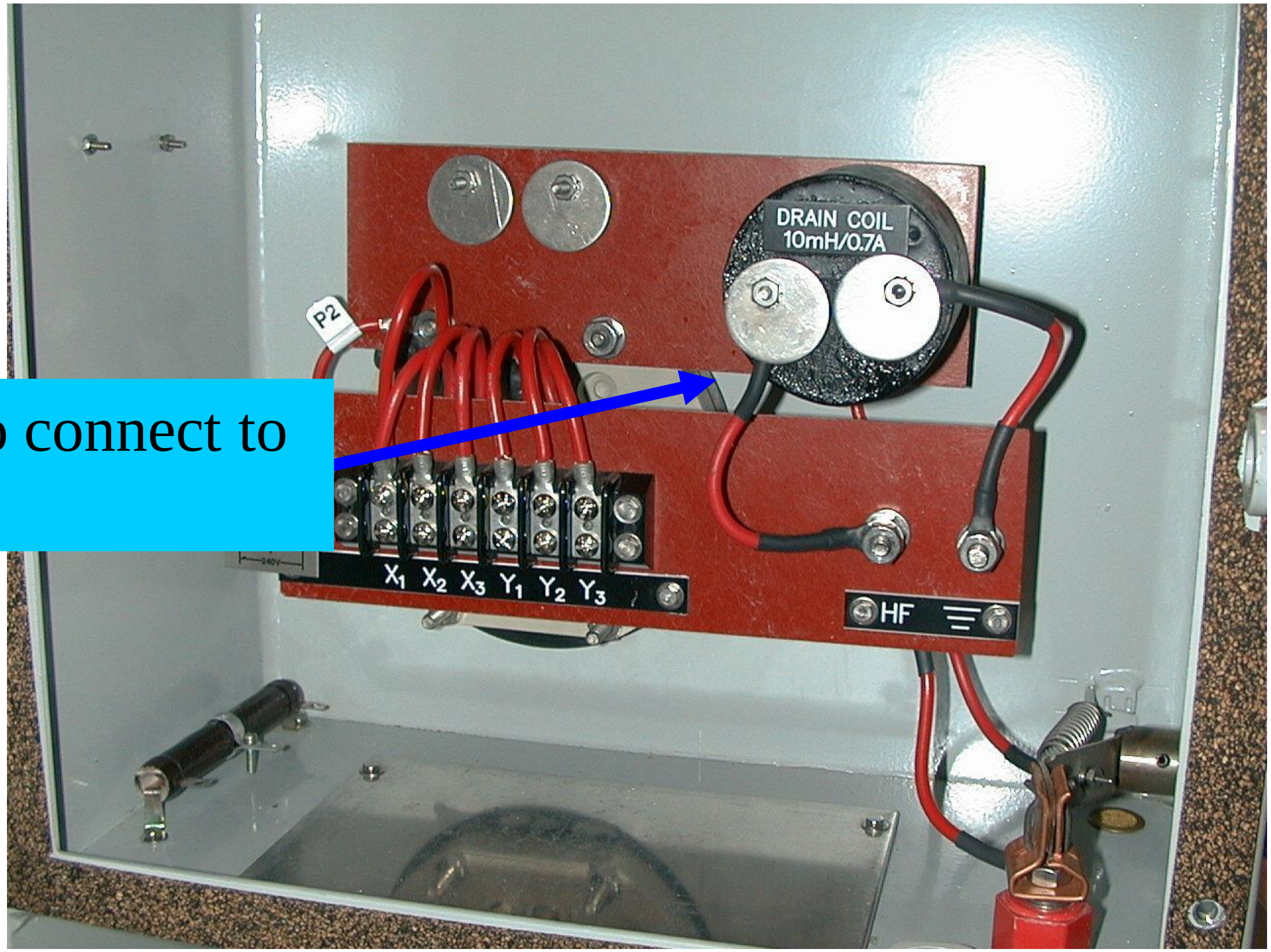
# CAR And POT Bushing ( Older Units)

# The CAR Terminal (Newer Units)

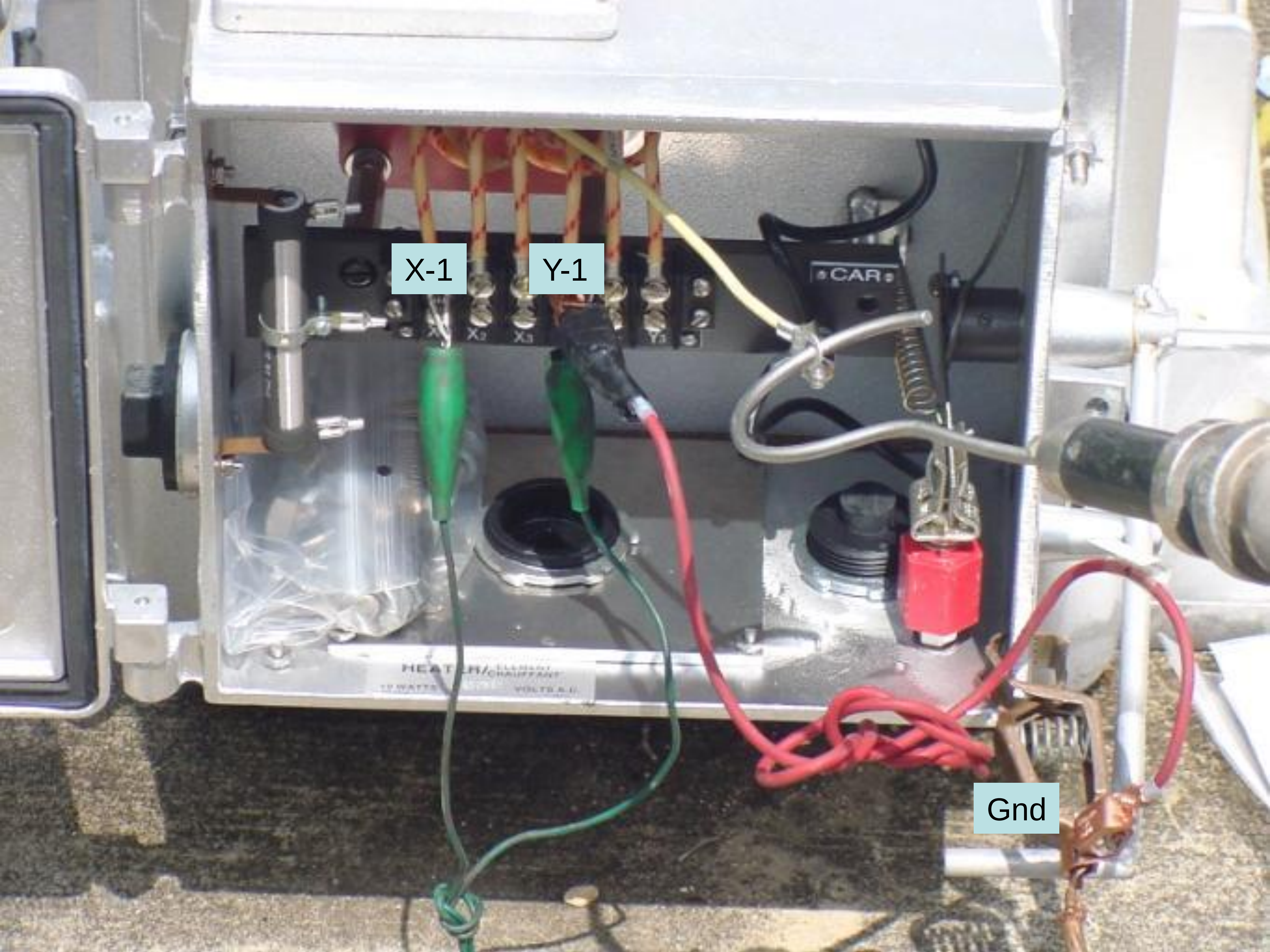
- CAR Terminal Accesible
- Bushing Not Accessible For Testing
- Max Test Voltage 2 kV

# Typical Ritz Junction Box

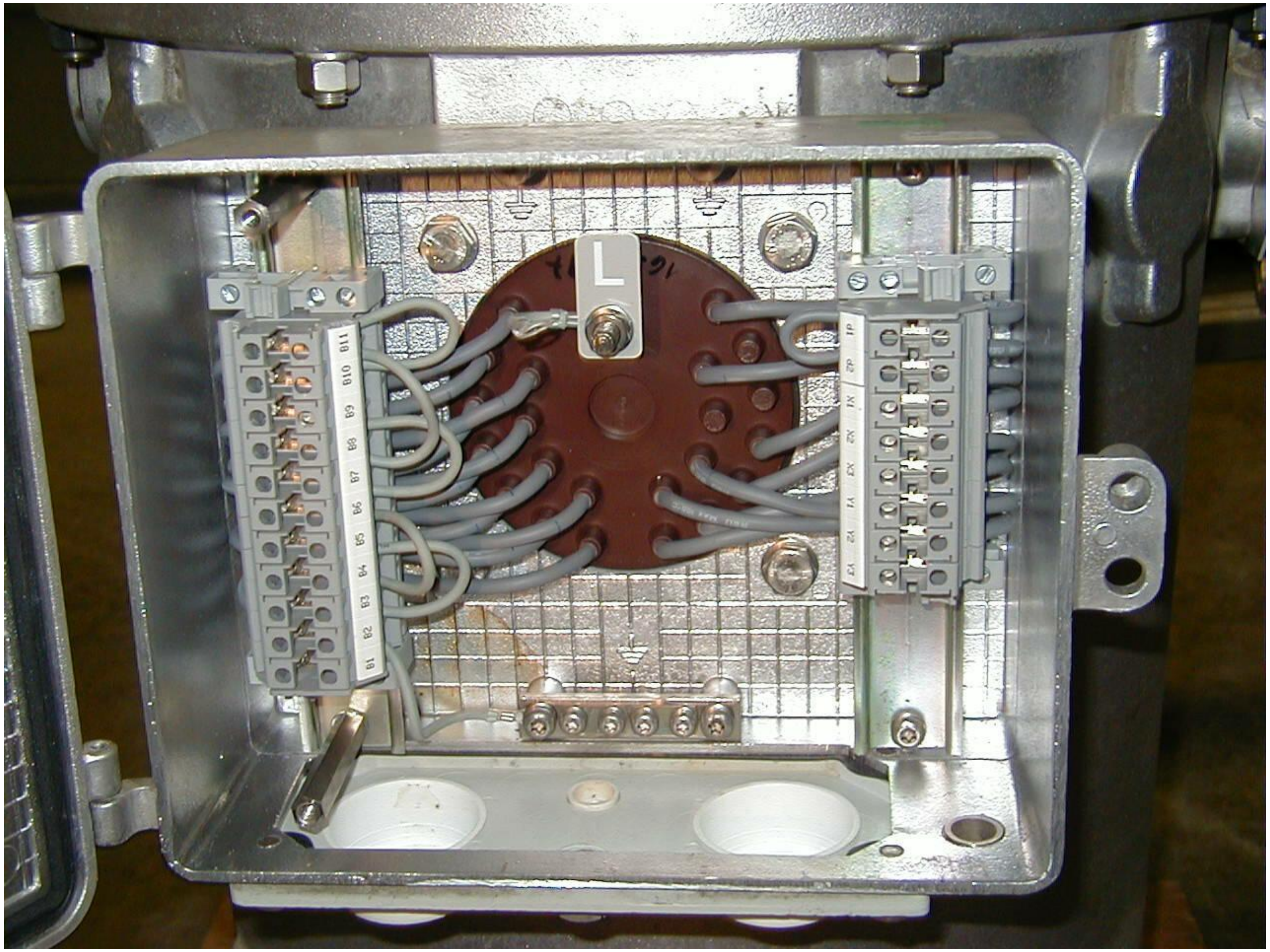
# With CAR Lead “HF”




HF wire to connect to HV cable

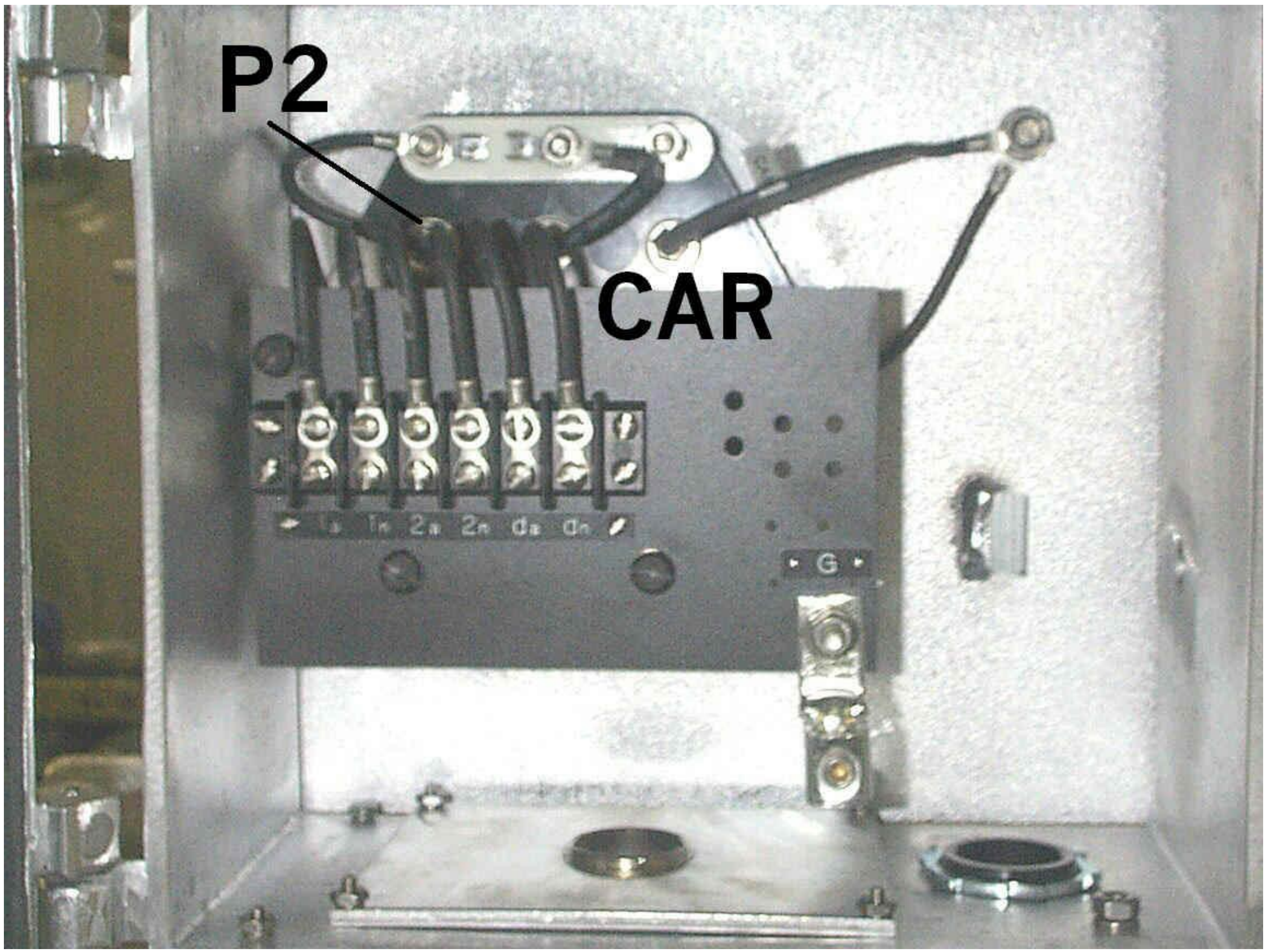

X-1
Y-1
CAR
Gnd

# Typical ABB Junction Box
# With CAR Lead "L"



# Typical Trench Junction Box

# With CAR Terminal Grounded



# Test Procedures For Individual Capacitors

- De-energize capacitor by disconnecting from power line.
- Ground and discharge each porcelain unit.
- Close carrier (S1), if present, and potential (S2) grounding switches.


260

# Test Procedures For Individual Capacitors

- Isolate CAR terminal from ground, drain coil, or carrier accessory lead.

- Test capacitors individually, measuring percent power factor and capacitance.


261

# Analysis of Results

- Capacitance Should Not Vary From Nameplate By More Than 1.0% On Modern Units

- Power Factor on Older Units With Paper/Oil Construction Should Not Exceed 0.5%

- Power Factor on Newer Paper/Film/Synthetic Fluid Units Usually Run Below 0.1% and Should Not Exceed 0.2%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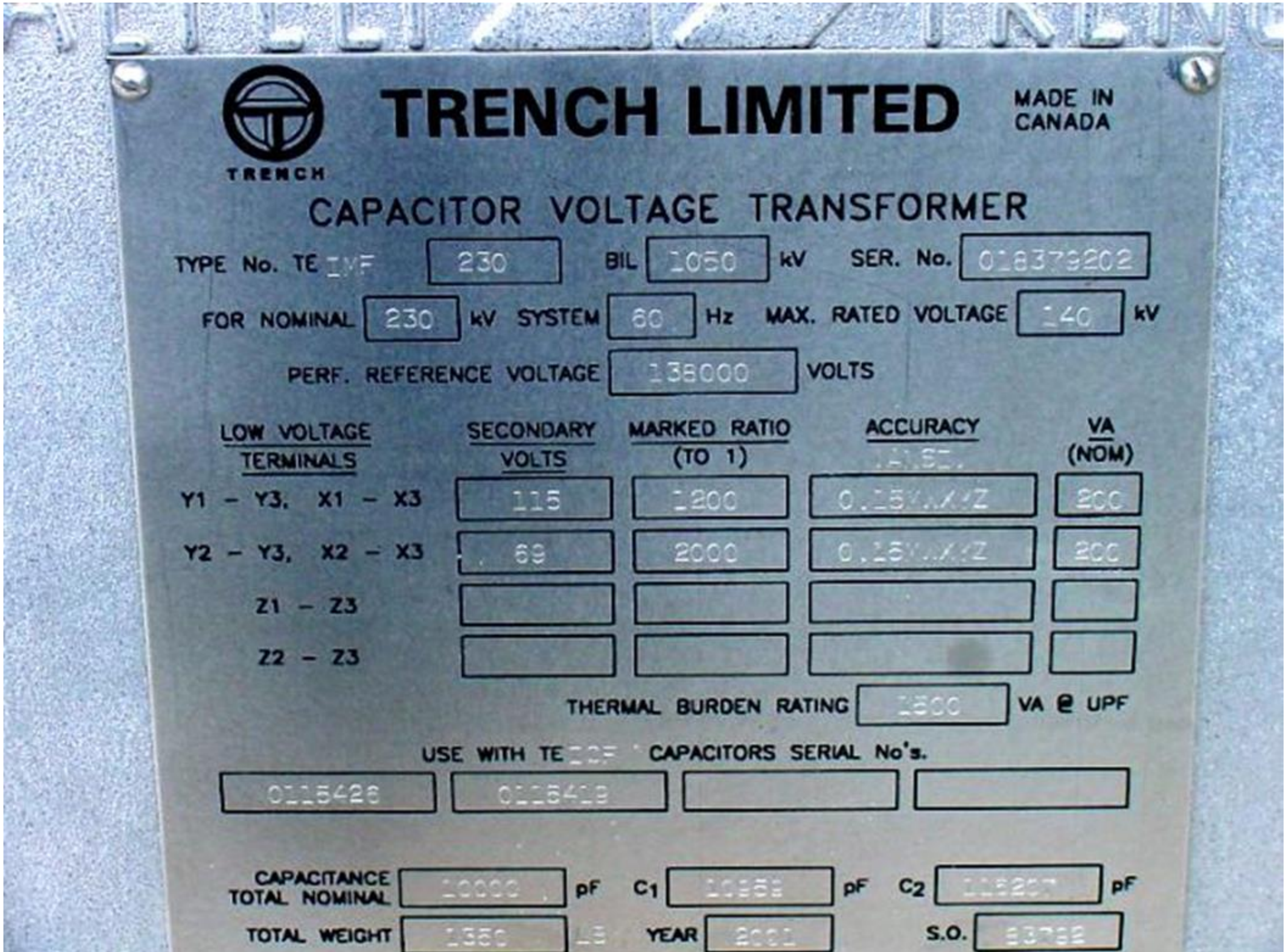
# Summary

- Identify and isolate CAR terminal; replace after testing!
- Test capacitors individually with POT switch closed.
- Any series test of C2 and C1-1 combined  must be made with POT switch open and transformer ground link removed.
- Observe both capacitance and percent power factor upper limits.

# Voltage Ratio



## Voltage Ratio

There is another test that is strongly recommended when testing CCVTs. That is the voltage ratio test. A known series of values 1kV to 10kV in 1kV steps is applied via the high voltage hook to the high voltage terminal (4-hole pad) of the CCVT. The secondary output is read by connecting voltmeters on terminals X1 to X3, Y1 to Y3, X2 to X3, and Y2 to Y3.


265

# Voltage Ratio

The actual value should fall well within a +/-5% from calculated. Expected would be +/-1%. The nameplate will give you the nominal applied system voltage, and also the secondary outputs for each of the secondary outputs.


266 266

# Voltage Ratio

- Apply 10 kV to top of CCVT and measure the following points:
- Perform a voltage ratio test to confirm the ratios of the CCVT
  - ✓ X1-X3, Y1-Y3 (1200/1 = 10000/1200 = 8.333v)
  - ✓ X2-X3, Y2-Y3 (2000/1 = 10000/2000 = 5.0v)

**A CCVT with an acceptable power factor can still have a ratio problem. Analyze all data!**


267

# Insulating Fluid

# Receiving, Storage and Handling of Oil

– Purchase oil as per ASTM-3487 or Doble TOPS
– Stored & transported in dedicated containers
– Test oil before using it in apparatus
– Avoid handling oil during adverse weather conditions to minimize moisture ingress
– Check for material compatibility (hoses, pumps)
– Do not mix oils from different apparatuses
– Do not mix different types of fluids

# Sampling of Insulating Mineral Oil

Two different methods from ASTM:

D 923: Standard Method of Sampling Electrical Insulating Liquids

D 3613: Standard method of Sampling Electrical Insulating Oils for Gas Analysis and Determination of Water Content

# Sampling of Insulating Mineral Oil

– Protect from outside contamination
– Relative Humidity < 70%
– Flush drain valve prior to sample collection
– Consider specific gravity. If specific gravity <1, free water will sink, take sample from bottom of tank
– Avoid sampling below freezing temperature (32$^{o}$ F)
– Consider remaining oil volume in apparatus
– Do not sample if a negative internal pressure exists
– Do not sample from energized instrument transformers

# Sampling of Insulating Mineral Oil

- The oil lab is only as “Good” as the sample provided.
- Temperature has to be provided for relative saturation to be calculated

# Sampling of Insulating Mineral Oil

Recommended Containers:

| | |
|---|---|
| General Sampling | glass bottles |
| | polyethylene bottles |
| | aluminum or tin cans |
| DGA Sampling | glass syringes |
| | stainless steel cylinders |

Note: glass containers help visual inspection.

# SAMPLE IDENTIFICATION

☐ From Factory Run
☐ Core Type
☐ Shell Type
PCB Content (ppm): ☐ greater than 499

☐ Free Breathing
☐ Sealed Conservator
☐ Gas Blanketed
☐ Open Conservator

**S/N** ______________________ Syringe # ______________________

Company ______________________________________ Date ______________

Substation _________________________ Transformer ______________________

Previous Doble Report No. __________ Cable ☐ Potential Trans. ☐ Current Trans. ☐

Mfr. ____________________ kV __________ MVA __________ Mfr. Yr. __________

Cooling: FOA, etc. ______________ Unit has a LTC: Yes ☐ No ☐

Oil Capacity ____________ gal. Oil Type: Mineral ☐ Silicone ☐ Other ☐ __________

**TEMP:** Ambient °C __________ Top Oil °C __________ **Humidity %** __________

Sampled by: ______________________ Unit's REF #: ______________________

**Sampling Point:** Main Tank–Top ☐ or Bottom ☐; LTC ☐ Other ______________

LTC Type: Break-in-oil ☐ Vacuum ☐ Mfr./Model: ______________________

LTC Tank: Free Breathing ☐ Silica Gel Breaker ☐ Sealed ☐

**Test Requested:** **Gas** ☐ **$H_2O$** ☐ **Mini Screen** ☐ **PCB** ☐ **Other** ______________

doble

**Ship To: Doble Engineering Company**
85 Walnut Street
Watertown, MA 02472-4037

**FOR RUSH SERVICE PLEASE CHECK HERE** ☐

***PLEASE RETURN ORIGINAL AND 2 COPIES***

OIL FORM 08 Rev. 03 10/09/98

# Common Tests used for in-service Transformer Oil

| Test | To Detect |
| --- | --- |
| Color | Rapid deterioration or serious contamination |
| Dielectric Strength | Contaminants (water & conducting particles) |
| Interfacial Tension | Polar contaminants |
| Neutralization Number | Acid degradation products |
| Power Factor | Unsatisfactory electrical properties, deterioration by-products |
| Pour Point | Contamination raising the pour point |
| Specific Gravity | Solvents, other oils, organic materials |

# Common Tests used for in-service Transformer Oil

| Test | To Detect |
|---|---|
| Viscosity | Solvents, other oils, organic materials |
| Water Content | Presence of dissolved water |
| PCB Content | PCB concentration |
| Inhibitor Content | Depletion of oxidation inhibitor |
| Dissolved Gas-in-oil | Incipient transformer faults |
| Metals-in-oil | Dissolved or particulate metals |

# Transformer Oil Testing Frequency

**<u>Annual (recommended)</u>**

- Dielectric Strength (D877 or D1816)
- Dissolved Gas Analysis
- Water Content (D1533B)

**<u>Every three to five years</u>**

- Annual Tests
- Interfacial Tension (D971)
- Neutralization Number (D974)
- Inhibitor Content (D2668)
- Power Factor (D924)
- Physical Tests

# Transformer Oil Screening Tests

**Utility:**

Color

Dielectric Breakdown

Interfacial Tension

Neutralization Number

Pour Point

Power Factor (25C & 100C)

Specific Gravity

Viscosity

Inhibitor Content

Water Content

PCB Content

**Mini Screen:**

Inhibitor Content

Neutralization Number

Water Content

Interfacial Tension

# Transformer Oil Screening Tests

**7-Part Industrial:**

Color/Visual

Dielectric Breakdown

Interfacial Tension

Neutralization Number

Power Factor (25C)

Specific Gravity

Water Content

**5-Part Industrial:**

Color/Visual

Dielectric Breakdown

Neutralization Number

Specific Gravity

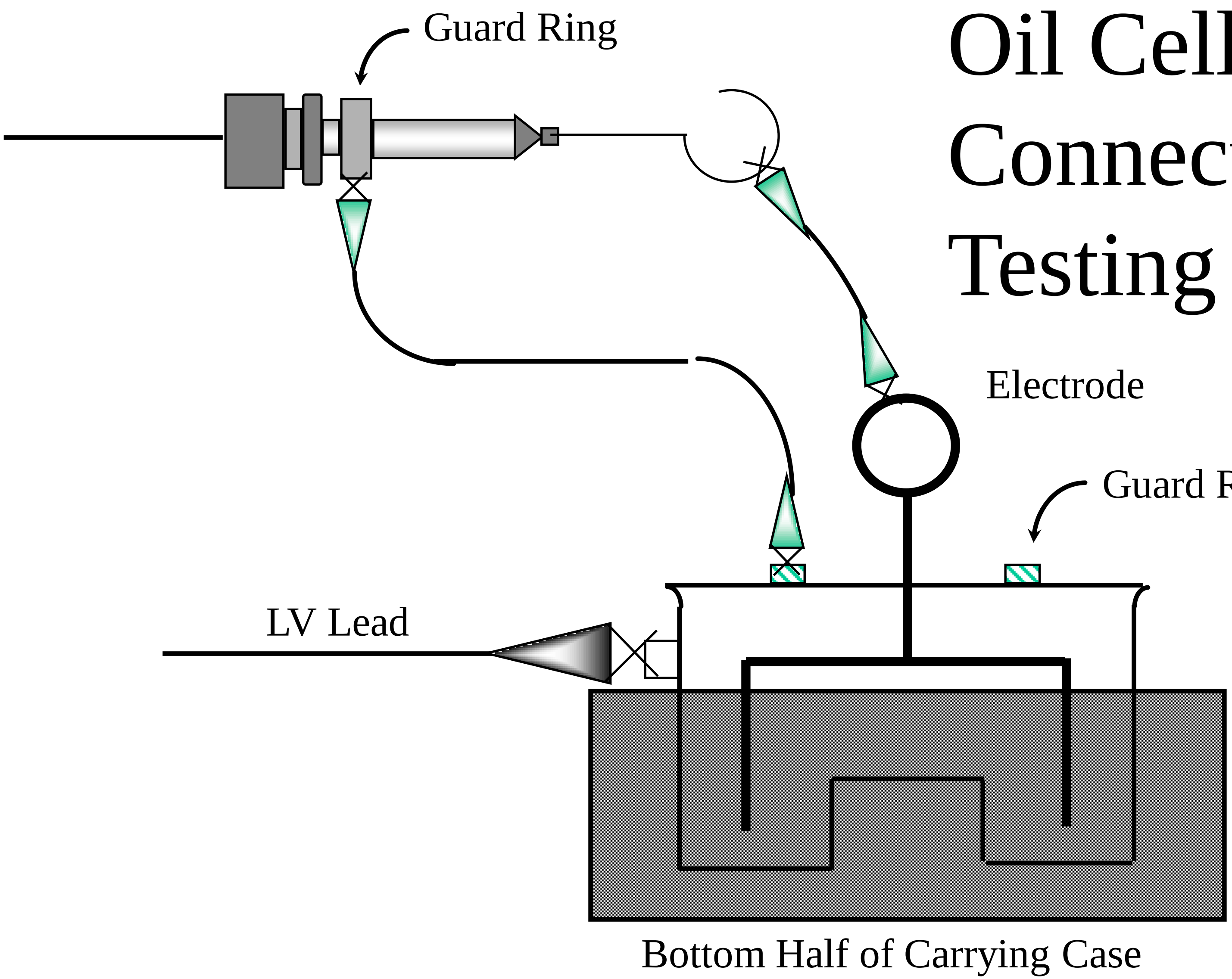
Water Content

# Limits for in-service oils

| | =<69kV | >69=<288kV | >288kV |
|---|---|---|---|
| Dielectric Breakdown Voltage D877, kV minimum | 26 | 30 | * |
| Dielectric Breakdown Voltage D1816, 0.04" gap, kV minimum | 20 | 20 | 25 |
| Power factor @ 25 C D924, max. | 0.5 | 0.5 | 0.5 |
| Water Content D1533B, ppm max. | 35 | 25 | 20 |
| Visual Exam | clear & bright | clear & bright | clear & bright |

* D877 is not as sensitive to dissolved water as D1816, should not be used in EHV apparatus

# Oil Cell Test: Connected for Testing



# Oil Cell Power Factor Test

**Test Voltage:** 10 kV

**Test Results:** New Oil <= 0.05%

Used Oil <= 0.50%

After taking Oil Power Factor Test, Immediately Take the Temperature and apply Temperature Correction.

**Test Set Check: (Dry Oil Cell)**

Test Voltage: 5 kV

Current: 400-450 uA

Watts: almost 0 Watts

# Dissolved Gas-in-Oil

| Gas | Chemical Symbol | Acceptable Limits |
|---|---|---|
| Hydrogen | $H_2$ | 100 |
| Oxygen | $O_2$ | |
| Nitrogen | $N_2$ | |
| Methane | $CH_4$ | 100 |
| Carbon Monoxide | $CO$ | 250 |
| Ethane | $C_2H_6$ | 60 |
| Carbon Dioxide | $CO_2$ | |
| Ethylene | $C_2H_4$ | 100 |
| Acetylene | $C_2H_2$ | 5 |

These limits were common to 90% of the transformer population included in the database

# Key Gas Analysis

| Condition | Key Gas |
|---|---|
| **Arcing** | High concentration of hydrogen and acetylene, with minor quantities of methane and ethylene.<br>**Key gas - Acetylene** |
| **Corona** | Low-energy electrical discharge creates hydrogen and methane, with lesser quantities of ethane and ethylene.<br>**Key gas - Hydrogen** |
| **Overheated Oil** | Includes ethylene and methane, and lesser quantities of hydrogen and ethane.<br>**Key gas - Ethylene** |
| **Overheated Cellulose** | Carbon dioxide and carbon monoxide are evolved from over-heated cellulose. Hydrocarbon gasses will be formed if the fault involves an oil-impregnated structure.<br>**Key gas - Carbon Monoxide** |

# Gases Produced during Overheating

| Temperature of Overheating | Gas | Chemical Symbol |
|---|---|---|
| Low Temperature (~120$^{o}$ ) | Methane | $CH_4$ |
| | Ethane | $C_2H_6$ |
| | Ethylene | $C_2H_4$ |
| High Temperature (>700$^{o}$ C) | Acetylene | $C_2H_2$ |

# CASE STUDIES

# CASE STUDIES
# Transformers

# Case Study 1 -Transformer

Mfr. – ITE

Date -1972

kVA – 750

2400/480   D-Y

Routine maintenance

| Test | Measured | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 2.5 | 12.920 | 3.605 | 2.23 | 0.80 | 3426 |
| 2 | CH | 2.5 | 4.911 | 1.268 | 2.06 | 0.80 | 1302 |
| 3 | CHL (UST) | 2.5 | 8.018 | 2.338 | 2.34 | 0.80 | 2125 |
| 4 | CHL | | 8.009 | 2.337 | 2.34 | 0.80 | 2124 |
| 5 | CL + CHL | 1.0 | 18.710 | 5.620 | 2.40 | 0.80 | 4963 |
| 6 | CL | 1.0 | 10.700 | 3.282 | 2.46 | 0.80 | 2838 |
| 7 | CHL (UST) | 1.0 | 8.018 | 2.336 | 2.33 | 0.80 | 2125 |
| 8 | CHL | | 8.010 | 2.338 | 2.34 | 0.80 | 2125 |
| 9 | CH’ | | | | | | |
| 10 | CL’ | | | | | | |

- Wet Windings and contaminated oil
- Watts are now 1/10 of the as found tests
- Current was affected by the dielectric of the oil

| Test | Measured | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 2.5 | 11.810 | 0.327 | 0.249 | 0.90 | 3134 |
| 2 | CH | 2.5 | 4.552 | 0.143 | 0.31 | 0.90 | 1207 |
| 3 | CHL (UST) | 2.5 | 7.271 | 0.182 | 0.25 | 0.90 | 1928 |
| 4 | CHL | | 7.258 | 0.184 | 0.25 | 0.90 | 1927 |
| 5 | CL + CHL | 1.0 | 17.040 | 0.541 | 0.286 | 0.90 | 4521 |
| 6 | CL | 1.0 | 9.777 | 0.356 | 0.36 | 0.90 | 2593 |
| 7 | CHL (UST) | 1.0 | 7.271 | 0.179 | 0.25 | 0.90 | 1928 |
| 8 | CHL | | 7.263 | 0.185 | 0.25 | 0.90 | 1928 |
| 9 | CH’ | | | | | | |
| 10 | CL’ | | | | | | |

After baking windings and new oil

# Case Study 2 - Transformer

| Test | Measured | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 10 | 32.380 | 2.558 | 0.789 | 1.0 | 8591 |
| 2 | CH | 10 | 9.969 | 1.855 | 1.86 | 1.0 | 2644 |
| 3 | CHL (UST) | 10 | 22.390 | 0.694 | 0.31 | 1.0 | 5941 |
| 4 | CHL | | 22.411 | 0.703 | 0.31 | 1.0 | 5947 |
| 5 | CL + CHL | 2 | 40.720 | 1.484 | 0.364 | 1.0 | 10803 |
| 6 | CL | 2 | 18.320 | 0.737 | 0.40 | 1.0 | 4860 |
| 7 | CHL (UST) | 2 | 22.400 | 0.734 | 0.33 | 1.0 | 5942 |
| 8 | CHL | | 22.400 | 0.747 | 0.33 | 1.0 | 5943 |
| 9 | CH’ | | 7.753 | -0.151 | -0.19 | 1.0 | 2058.8 |
| 10 | CL’ | | | | | | |

# C1 Tests

| Test | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|
| H1 | 10 | 0.761 | 0.798 | 10.5 | 1.0 | 200.7 |
| H2 | 10 | 0.736 | 0.653 | 8.87 | 1.0 | 194.5 |
| H3 | 10 | 0.555 | 0.555 | 7.72 | 1.0 | 190 |

# C2 Test

| Test | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|
| H1 | .5 | 2.203 | 2.634 | 13.02 | 1.0 | 532.2 |

The watts are higher for the C1 tests than for the CH  which is 1.855 watts

0.798 + 0.653 + 0.555 = 2.006 watts

1.855 – 2.006 = -0.151 watts

# Case Study 3 -Transformer

Mfr. – GE

Date -2001

kVA – 5000

12000/480   D-Y

Acceptance Tests

| Test | Measured | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 10 | 15.800 | 1.012 | 0.55 | 0.86 | 4192 |
| 2 | CH | 10 | 5.195 | 0.793 | 1.32 | 0.86 | 1377 |
| 3 | CHL (UST) | 10 | 10.610 | 0.252 | 0.21 | 0.86 | 2814 |
| 4 | CHL | | 10.605 | 0.219 | 0.18 | 0.86 | 2815 |
| 5 | CL + CHL | .5 | 44.050 | 2.232 | 0.43 | 0.86 | 11686 |
| 6 | CL | .5 | 33.440 | 1.978 | 0.51 | 0.86 | 8871 |
| 7 | CHL (UST) | .5 | 10.610 | 0.271 | 0.22 | 0.86 | 2814 |
| 8 | CHL | | 10.610 | 0.254 | 0.21 | 0.86 | 2815 |
| 9 | CH’ | | | | | | |
| 10 | CL’ | | | | | | |

# Hot Collar Tests

| Test | Test mode | Skirt | Test kV | mA | watts |
|---|---|---|---|---|---|
| H1 | Ground | 1 | 10 | 0.094 | 0.175 |
| H2 | Ground | 1 | 10 | 0.477 | 4.187 |
| H3 | Ground | 1 | 10 | 0.095 | 0.072 |
| Retest | | | | | |
| H1 | Ground | 1 | 10 | | |
| H2 | Ground | 1 | 10 | 0.098 | 0.189 |
| H3 | Ground | 1 | 10 | | |

# Case Study 4 - Transformer

| Test | Measured | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 10 | 33.080 | 16.220 | | 1.01 | 8765 |
| 2 | CH | 10 | 12.860 | 3.612 | 2.84 | 1.01 | 3411 |
| 3 | CHL (UST) | 10 | 20.210 | 12.610 | 6.30 | 1.01 | 5352 |
| 4 | CHL | | 20.220 | 12.608 | 6.30 | 1.01 | 5354 |
| 5 | CL + CHL | 10 | 59.360 | 23.630 | | 1.01 | 15734 |
| 6 | CL | 10 | 39.140 | 11.040 | 2.85 | 1.01 | 10380 |
| 7 | CHL (UST) | 10 | 20.210 | 12.610 | 6.30 | 1.01 | 5353 |
| 8 | CHL | | 20.220 | 12.590 | 6.29 | 1.01 | 5354 |
| 9 | CH’ | | 8.133 | 3.495 | 4.34 | 1.01 | 2157.4 |
| 10 | CL’ | | 35.668 | 10.813 | 3.06 | 1.01 | 9459.3 |

# C1

| Test | C (pF) | % PF | Test kV | mA | Watts | Corr. PF | Meas. pF |
|---|---|---|---|---|---|---|---|
| H1 | 415 | .24 | 10 | 1.573 | 0.042 | 0.27 | 417.2 |
| H2 | 415 | .24 | 10 | 1.572 | 0.037 | 0.24 | 416.8 |
| H3 | 418 | .24 | 10 | 1.582 | 0.038 | 0.24 | 419.6 |

# C2

| Test | C (pF) | % PF | Test kV | mA | Watts | Corr. PF | Meas. pF |
|---|---|---|---|---|---|---|---|
| H1 | 1833 | .26 | 2.5 | 6.925 | 0.184 | 0.27 | 1836 |
| H2 | 1808 | .28 | 2.5 | 6.822 | 0.176 | 0.26 | 1809 |
| H3 | 1845 | .26 | 2.5 | 6.958 | 0.188 | 0.27 | 1845 |

Excellent example of “averaged power factor” as the power factor for the CH’ is 4.34% without the bushings and 2.84% with the bushings.  The good bushings were masking the bad windings.

# Case Study 5 - Transformer

Background

- High side bushings were replaced
- Load Tap Changer was open all week for maintenance
- Routine test after repairs

| Test | Measured | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 10 | 28.510 | 0.934 | ----- | 1.08 | 7564 |
| 2 | CH | 10 | 10.110 | -0.040 | -.0 | 1.08 | 2683 |
| 3 | CHL (UST) | 10 | 18.400 | 0.988 | 0.58 | 1.08 | 4880 |
| 4 | CHL | | 18.400 | 0.974 | 0.57 | 1.08 | 4881 |
| 5 | CL + CHL | 10 | 71.340 | 42.440 | ----- | 1.08 | 18889 |
| 6 | CL | 10 | 52.960 | 41.420 | 8.45 | 1.08 | 14008 |
| 7 | CHL (UST) | 10 | 18.390 | 0.991 | 0.58 | 1.08 | 4879 |
| 8 | CHL | | 18.380 | 1.020 | 0.59 | 1.08 | 4881 |
| 9 | CH’ | | | | | | |
| 10 | CL’ | | | | | | |

Mfr.: FPE

Year Mfr. 1976

Tank Type: N2 Blanketed

Phases: 3

Config: Delta – Wye

Coolant: Oil

KV: 138 / 69 MVA / 15/20/25

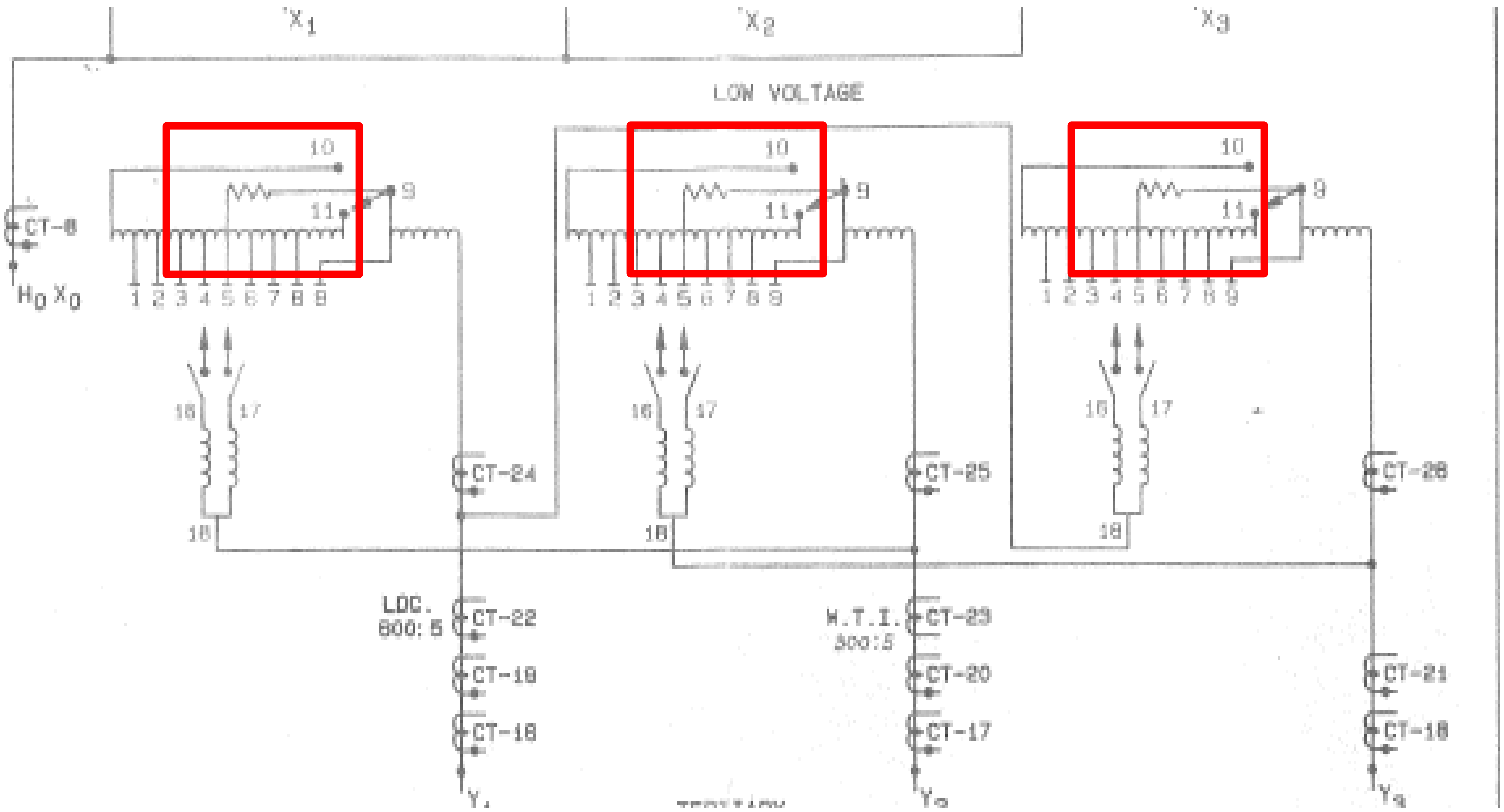
LTC: Y

Top Oil Temperature: 17 degree C

- Federal Pacific Electric tested with the Load Tap Changer (LTC) in the neutral position.

- This tap changer has resistors in the neutral position.

- Always test with LTC off neutral


X1
X2
X3
LOW VOLTAGE
CT-8
H0 X0
10
9
11
1 2 3 4 5 6 7 8 9
16
17
18
CT-24
CT-25
CT-26
LDC.
600:5
CT-22
CT-19
CT-18
W.T.I.
CT-23
CT-20
CT-17
CT-21
CT-18
Y1
Y2
Y3

| Test | Measured | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | CH + CHL | 10 | 28.510 | 0.949 | ----- | 0.96 | 7562 |
| 2 | CH | 10 | 10.090 | 0.316 | 0.30 | 0.96 | 2677 |
| 3 | CHL (UST) | 10 | 18.390 | 0629 | 0.33 | 0.96 | 4883 |
| 4 | CHL | | 18.430 | 0.633 | 0.33 | 0.96 | 4885 |
| 5 | CL + CHL | 10 | 72.160 | 3.144 | ----- | 0.96 | 19148 |
| 6 | CL | 10 | 53.750 | 2.487 | 0.46 | 0.96 | 14263 |
| 7 | CHL (UST) | 10 | 18.410 | 0.629 | 0.34 | 0.96 | 4883 |
| 8 | CHL | | 18.410 | 0.657 | 0.36 | 0.96 | 4885 |
| 9 | CH’ | | | | | | |
| 10 | CL’ | | | | | | |

Retest with LTC off neutral

# Case Study 6 - Transformer

Background

- 2002 CL capacitance and 2004 capacitance do not match
- Routine tests

| Test | Measured | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 10 | 24.47 | 1.296 | ---- | 0.80 | 6492 |
| 2 | CH | 10 | 3.915 | 0.212 | 0.43 | 0.80 | 1038 |
| 3 | CHL (UST) | 10 | 20.56 | 1.080 | 0.42 | 0.80 | 5454 |
| 4 | CHL | | 20.55 | 1.084 | 0.42 | 0.80 | 5454 |
| 5 | CL + CHL | .24 | 44.87 | 2.398 | ---- | 0.80 | 11902 |
| 6 | CL | .24 | 24.33 | 1.289 | 0.42 | 0.80 | 6454 |
| 7 | CHL (UST) | .24 | 20.59 | 20.59 | 0.42 | 0.80 | 5461 |
| 8 | CHL | | 20.54 | 20.54 | 0.42 | 0.80 | 5448 |
| 9 | CH’ | | | | | | |
| 10 | CL’ | | | | | | |

2002 Test

| Test | Measured | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 10 | 24.39 | 1.113 | ---- | 1.0 | 6471 |
| 2 | CH | 10 | 3.905 | 0.170 | 0.44 | 1.0 | 1035 |
| 3 | CHL (UST) | 10 | 20.49 | 0.942 | 0.46 | 1.0 | 5435 |
| 4 | CHL | | 20.48 | 0.943 | 0.46 | 1.0 | 5436 |
| 5 | CL + CHL | .24 | 24.38 | 1.151 | ---- | 1.0 | 6469 |
| 6 | CL | .24 | 3.907 | 0.176 | 0.45 | 1.0 | 1036 |
| 7 | CHL (UST) | .24 | 20.48 | 0.970 | 0.47 | 1.0 | 5434 |
| 8 | CHL | | 20.47 | 0.970 | 0.48 | 1.0 | 5433 |
| 9 | CH’ | | | | | | |
| 10 | CL’ | | | | | | |

2002 capacitance was 6454 – 2004 capacitance 1036

| Test | Measured | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 10 | 24.39 | 1.113 | ---- | 1.0 | 6471 |
| 2 | CH | 10 | 3.905 | 0.170 | 0.44 | 1.0 | 1035 |
| 3 | CHL (UST) | 10 | 20.49 | 0.942 | 0.46 | 1.0 | 5435 |
| 4 | CHL | | 20.48 | 0.943 | 0.46 | 1.0 | 5436 |
| 5 | CL + CHL | .24 | 24.38 | 1.151 | ---- | 1.0 | 6469 |
| 6 | CL | .24 | 3.907 | 0.176 | 0.45 | 1.0 | 1036 |
| 7 | CHL (UST) | .24 | 20.48 | 0.970 | 0.47 | 1.0 | 5434 |
| 8 | CHL | | 20.47 | 0.970 | 0.48 | 1.0 | 5433 |
| 9 | CH’ | | | | | | |
| 10 | CL’ | | | | | | |

Leads not changed – tested high side again

# Case Study 7 - Transformer

Background

- Acceptance tests on new transformer
- Data called in by owner of equipment
- Owner questioned test report

| Test | Measured | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 2 | 11.76 | 0.600 | ---- | 0.71 | 3121 |
| 2 | CH | 2 | 3.040 | 0.955 | 2.23 | 0.71 | 805.9 |
| 3 | CHL (UST) | 2 | 8.729 | -0.350 | -0.3 | 0.71 | 2315 |
| 4 | CHL | | 8.720 | -0.355 | -0.3 | 0.71 | 2315 |
| 5 | CL + CHL | 1 | 15.23 | 1.634 | ---- | 0.71 | 4041 |
| 6 | CL | 1 | 6.514 | 1.952 | 2.13 | 0.71 | 1727 |
| 7 | CHL (UST) | 1 | 8.729 | -0.330 | -0.3 | 0.71 | 2315 |
| 8 | CHL | | 8.716 | -0.318 | -0.3 | 0.71 | 2314 |

1st Testing Company

| Test | Insulation | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 2 | 11.76 | 0.600 | ---- | 0.71 | 3121 |
| 2 | CH | 2 | 3.040 | 0.955 | 2.23 | 0.71 | 805.9 |
| 3 | CHL (UST) | 2 | 8.729 | -0.350 | -0.3 | 0.71 | 2315 |
| 4 | CHL | | 8.720 | -0.355 | -0.3 | 0.71 | 2315 |
| 5 | CL + CHL | 1 | 15.23 | 1.634 | ---- | 0.71 | 4041 |
| 6 | CL | 1 | 6.514 | 1.952 | 2.13 | 0.71 | 1727 |
| 7 | CHL (UST) | 1 | 8.729 | -0.330 | -0.3 | 0.71 | 2315 |
| 8 | CHL | | 8.716 | -0.318 | -0.3 | 0.71 | 2314 |

1st Testing Company – Test report submitted report to customer wit negative numbers

| Test | Insulation | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 10 | 11.82 | 0.314 | ---- | 0.80 | 3135 |
| 2 | CH | 10 | 3.206 | 0.111 | 0.28 | 0.80 | 850.4 |
| 3 | CHL (UST) | 10 | 8.616 | 0.205 | 0.19 | 0.80 | 2285 |
| 4 | CHL | | 8.614 | 0.203 | 0.19 | 0.80 | 2284.6 |
| 5 | CL + CHL | 1 | 15.49 | 0.335 | ---- | 0.80 | 4109 |
| 6 | CL | 1 | 6.874 | 0.123 | 0.14 | 0.80 | 1823 |
| 7 | CHL (UST) | 1 | 8.616 | 0.191 | 0.18 | 0.80 | 2285 |
| 8 | CHL | | 8.616 | 0.212 | 0.20 | 0.80 | 2286 |

Retest by 2nd Testing Company

- Transformer was not grounded
- Diagnostics tester from 1st testing company did not question negative results
- Negative results questioned by owner
- Diagnostics tester from 2nd testing company grounded the transformer
- **Who would you use in the future!!!!!!!**

# Case Study 8 - Transformer

Mfr. – Efacec - USA

Configuration – Wye – Delta

Tank Type – Sealed conservator

MVA – 900

kV – 230 /25

Acceptance tests

# Transformer 8

- Was informed that the first transformer received failed (no additional data)
- Owner had major concerns with data as testing company could not provide answers for the results obtained

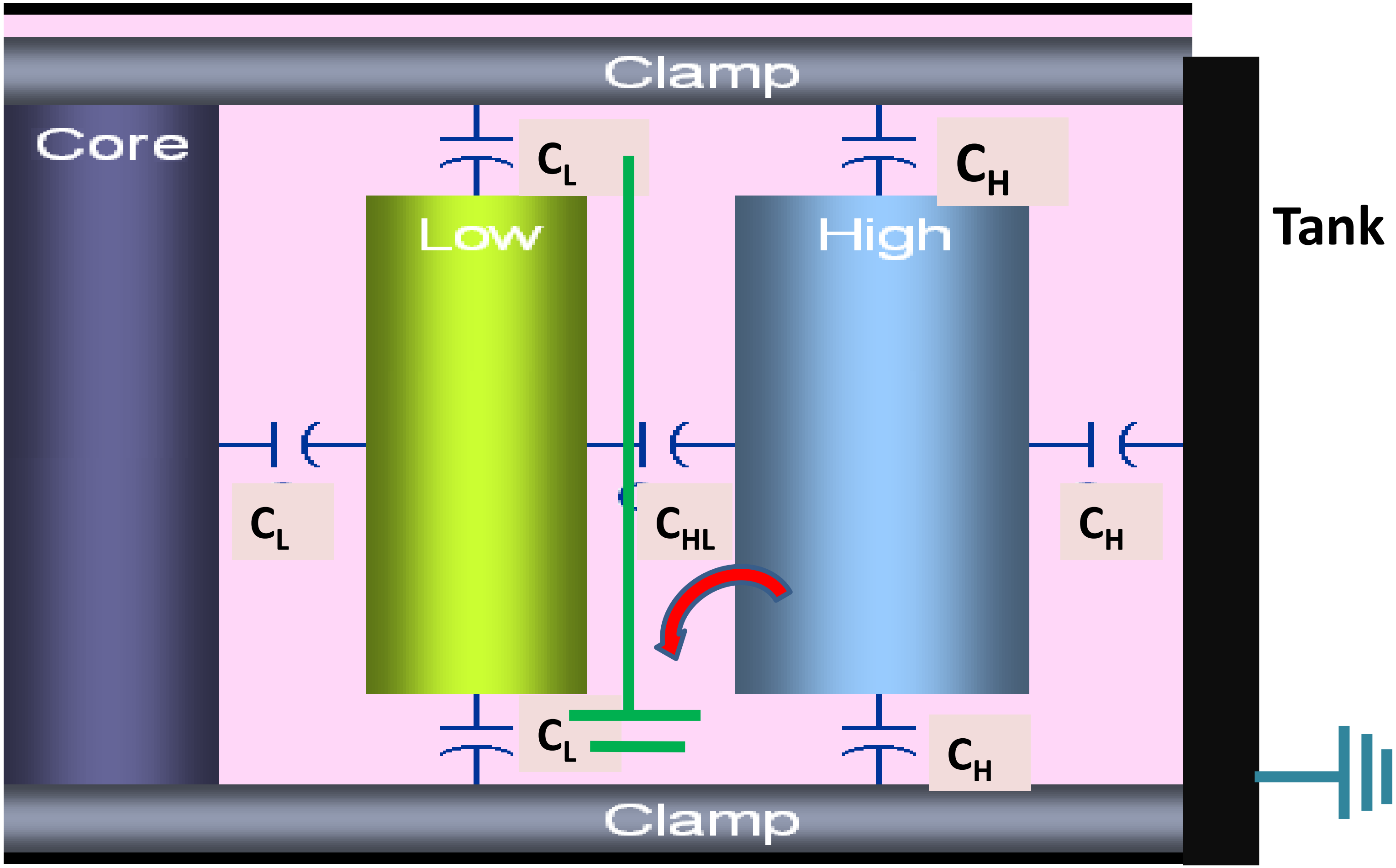
| Test | Measured | Test kV | mA | Watts | % PF | Corr. Fac. | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 10 | 262.11 | 10.905 | ---- | 1.0 | 69525.8 |
| 2 | CH | 10 | 258.45 | 10.918 | 0.42 | 1.0 | 68555.6 |
| 3 | CHL (UST) | 10 | 3.633 | 0.021 | 0.06 | 1.0 | 963.55 |
| 4 | CHL | | 3.660 | -0.013 | -0.04 | 1.0 | 970.20 |
| 5 | CL + CHL | 3.001 | 677.76 | 27.797 | ---- | 1.0 | 179779.7 |
| 6 | CL | 3.000 | 674.08 | 27.728 | 0.41 | 1.0 | 178803.1 |
| 7 | CHL (UST) | 2.999 | 3.639 | 0.0180 | 0.05 | 1.0 | 965.27 |
| 8 | CHL | | 3.680 | 0.069 | 0.19 | 1.0 | 976.00 |
| 9 | CH’ | | 251.37 | 10.732 | 0.43 | 1.0 | 66678.49 |
| 10 | CL’ | | 640.06 | 26.768 | 0.42 | 1.0 | 169780.40 |

Acceptance tests

| Windings | Test Voltage | Capacitance | Power Factor |
|---|---|---|---|
| HV / LV + Earth | 10 | 69730.10 | 0.38 |
| HV / Earth | 10 | 68736.80 | 0.39 |
| HV / LV | 10 | 974.95 | 0.22 |
| LV / HV + Earth | 4 | 180580.50 | 0.38 |
| LV / Earth | 3 | 179551.50 | 0.38 |
| LV / HV | 3 | 975.32 | 0.25 |
| HV + LV / Earth | 3 | 248473.00 | 0.39 |

Factory tests

- Shielded transformer
  - Very high voltage transformation
  - Variable frequency drives on secondary


Clamp
Core
$C_L$
$C_H$
Low
High
Tank
$C_L$
$C_{HL}$
$C_H$
$C_L$
$C_H$
Clamp

# Case Study 9 - Transformer

Mfr. – Efacec - USA

Configuration – Wye – Wye – Delta

Tank Type – Sealed conservator

MVA – 900

kV – 230 / 36.5 / 13.2

Factory tests

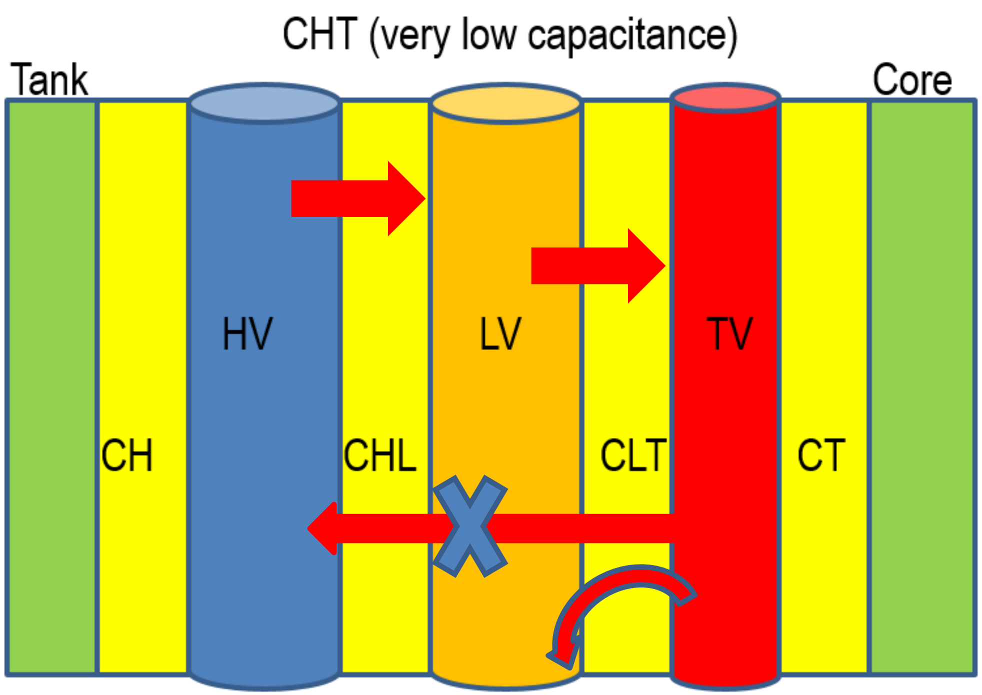
| Meas. | Test kV | mA | Watts | %PF | Corr Fctr | Cap(pF) |
|---|---|---|---|---|---|---|
| CH + CHL | 10.001 | 46.790 | 1.692 | | 1.00 | 12411.5 |
| CH | 10.000 | 15.628 | 0.8020 | 0.51 | 1.00 | 4145.4 |
| CHL(UST) | 10.001 | 31.148 | 0.8810 | 0.28 | 1.00 | 8262.1 |
| CHL | | 31.162 | 0.890 | 0.29 | 1.00 | 8266.100 |
| CL + CLT | 10.001 | 62.773 | 2.508 | | 1.00 | 16650.7 |
| CL | 10.001 | 25.510 | 1.211 | 0.47 | 1.00 | 6766.4 |
| CLT(UST) | 10.000 | 37.247 | 1.320 | 0.35 | 1.00 | 9880.1 |
| CLT | | 37.263 | 1.297 | 0.35 | 1.00 | 9884.300 |
| CT + CHT | 10.001 | 66.249 | 2.199 | 0.33 | 1.00 | 17572.4 |
| CT | 10.001 | 65.953 | 2.111 | 0.32 | 1.00 | 17494.0 |
| CHT(UST) | 10.001 | 0.2860 | 0.0820 | 2.87 | 1.00 | 75.813 |
| CHT | | 0.296 | 0.088 | 2.97 | 1.00 | 78.400 |
| CH+CL+CT | 10.001 | 107.22 | 4.122 | 0.38 | 1.00 | 28439.8 |

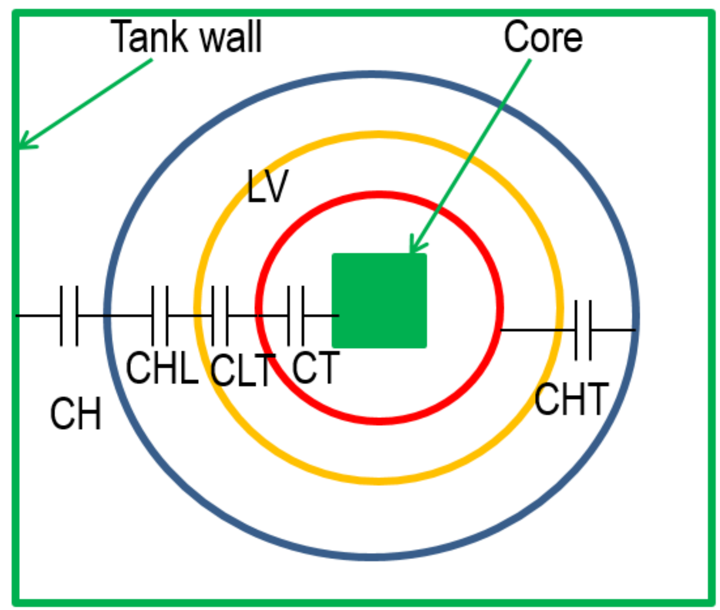
| Meas. | Test kV | mA | Watts | %PF | Corr Fctr | Cap(pF) |
|---|---|---|---|---|---|---|
| CH + CHL | 10.001 | 46.790 | 1.692 | | 1.00 | 12411.5 |
| CH | 10.000 | 15.628 | 0.8020 | 0.51 | 1.00 | 4145.4 |
| CHL(UST) | 10.001 | 31.148 | 0.8810 | 0.28 | 1.00 | 8262.1 |
| CHL | | 31.162 | 0.890 | 0.29 | 1.00 | 8266.100 |
| CL + CLT | 10.001 | 62.773 | 2.508 | | 1.00 | 16650.7 |
| CL | 10.001 | 25.510 | 1.211 | 0.47 | 1.00 | 6766.4 |
| CLT(UST) | 10.000 | 37.247 | 1.320 | 0.35 | 1.00 | 9880.1 |
| CLT | | 37.263 | 1.297 | 0.35 | 1.00 | 9884.300 |
| CT + CHT | 10.001 | 66.249 | 2.199 | 0.33 | 1.00 | 17572.4 |
| CT | 10.001 | 65.953 | 2.111 | 0.32 | 1.00 | 17494.0 |
| CHT(UST) | 10.001 | 0.2860 | 0.0820 | 2.87 | 1.00 | 75.813 |
| CHT | | 0.296 | 0.088 | 2.97 | 1.00 | 78.400 |
| CH+CL+CT | 10.001 | 107.22 | 4.122 | 0.38 | 1.00 | 28439.8 |

We saw this type of results on a shielded transformer

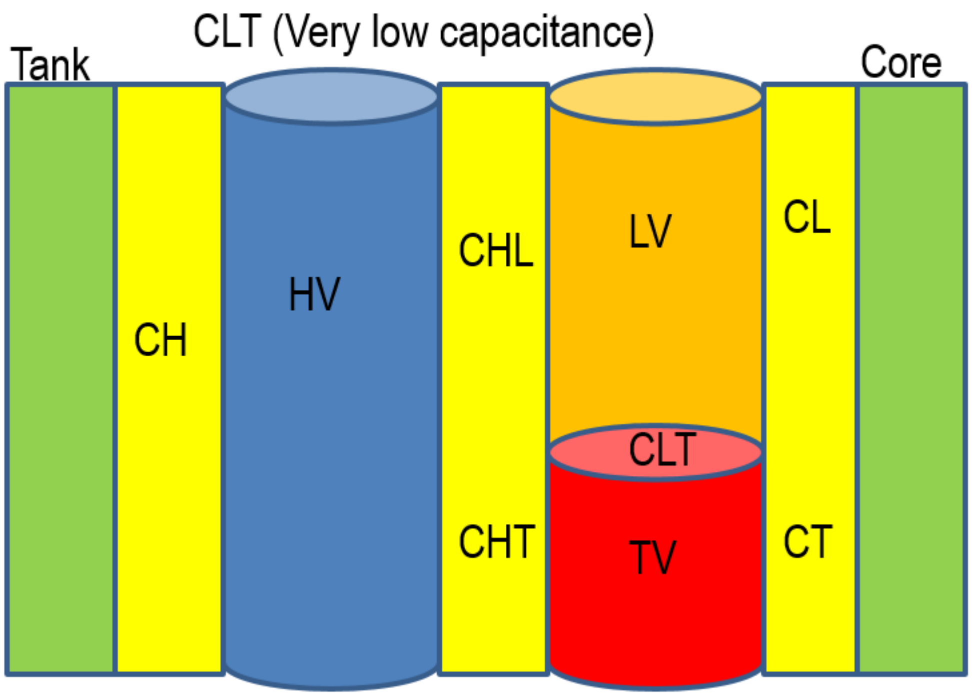
- ❖Is the transformer shielded?
- ❖Do we have a defective low voltage lead?
- ❖Do we have a defective test set?
- ❖Do we have a test procedure issue?

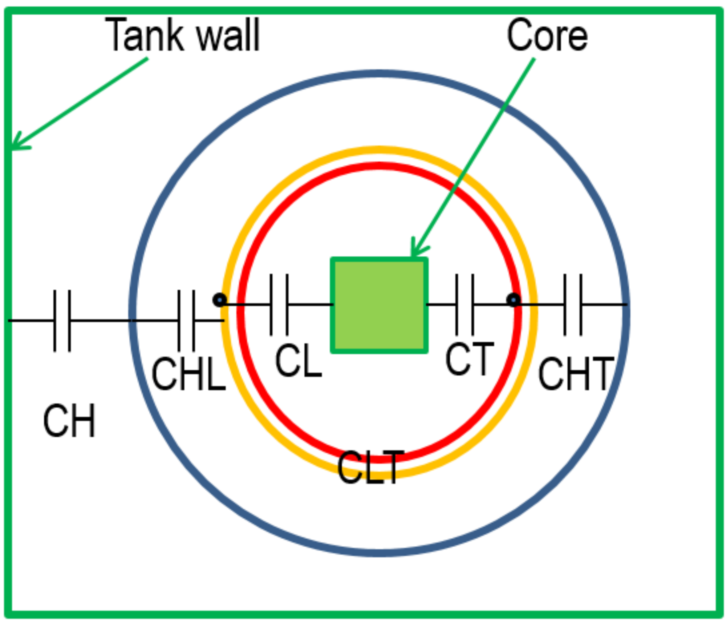
# Transformer tertiary configurations - Tertiary inside the low voltage winding closer to core not on same insulation tube



# Transformer tertiary configurations - Tertiary stacked on top of low voltage winding on same insulation tube



# Case Study 10 - Transformer

Mfr. – Westinghouse

Generator Step Up

kV – 69 / 13.8

Mfr. Date 1973

Routine

# November 7, 2016 Tests

| Test | Meas. | kV | mA | Watts | % PF | CF | Cap. pF |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 10 | 34.150 | 1.503 | 0.441 | 1.002 | 10980.050 |
| 2 | CH | 10 | 9.768 | 0.450 | 0.461 | 1.002 | 3140.520 |
| 3 | CHL (UST) | 10 | 24.369 | 1.065 | 0.438 | 1.002 | 7835.110 |
| 4 | CHL | | 24.383 | 1.053 | 0.432 | 1.002 | 7839.530 |
| 5 | CL + CHL | 10 | 57.800 | 16.908 | 2.930 | 1.002 | 18575.900 |
| 6 | CL | 10 | 33.434 | 14.876 | 4.456 | 1.002 | 10739.000 |
| 7 | CHL (UST) | 10 | 24.367 | 1.066 | 0.438 | 1.002 | 7835.105 |
| 8 | CHL | | 24.366 | 2.032 | 0.835 | 1.002 | 7836.900 |

# Retest - November 17, 2016 Tests

| Test | Meas. | kV | mA | Watts | % PF | CF | Cap. pF |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 10 | 41.343 | 1.875 | 0.454 | 1.0 | 10966.750 |
| 2 | CH | 10 | 11.855 | 0.656 | 0.554 | 1.0 | 3144.690 |
| 3 | CHL (UST) | 10 | 29.474 | 1.219 | 0.414 | 1.0 | 7818.370 |
| 4 | CHL | | 29.488 | 1.219 | 0.413 | 1.0 | 7822.060 |
| 5 | CL + CHL | 10 | 69.555 | 5.080 | 0.730 | 1.0 | 18450.100 |
| 6 | CL | 10 | 40.069 | 3.888 | 0.970 | 1.0 | 10628.450 |
| 7 | CHL (UST) | 10 | 29.471 | 1.231 | 0.418 | 1.0 | 7817.520 |
| 8 | CHL | | 29.486 | 1.192 | 0.404 | 1.0 | 7821.650 |

# March 25, 2013 Tests

| Test | Meas. | kV | mA | Watts | % PF | CF | Cap. pF |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 10 | 41.358 | 1.848 | 0.45 | 1.0 | 10970.7 |
| 2 | CH | 10 | 11.809 | 0.5840 | 0.49 | 1.0 | 3132.6 |
| 3 | CHL (UST) | 10 | 29.533 | 1.273 | 0.43 | 1.0 | 7834.3 |
| 4 | CHL | | 29.549 | 1.264 | 0.43 | 1.0 | 7838.1 |
| 5 | CL + CHL | 10 | 69.509 | 3.948 | 0.57 | 1.0 | 18438.0 |
| 6 | CL | 10 | 39.968 | 2.700 | 0.68 | 1.0 | 10601.6 |
| 7 | CHL (UST) | 10 | 29.529 | 1.277 | 0.43 | 1.0 | 7833.2 |
| 8 | CHL | | 29.541 | 1.248 | 0.42 | 1.0 | 78 |

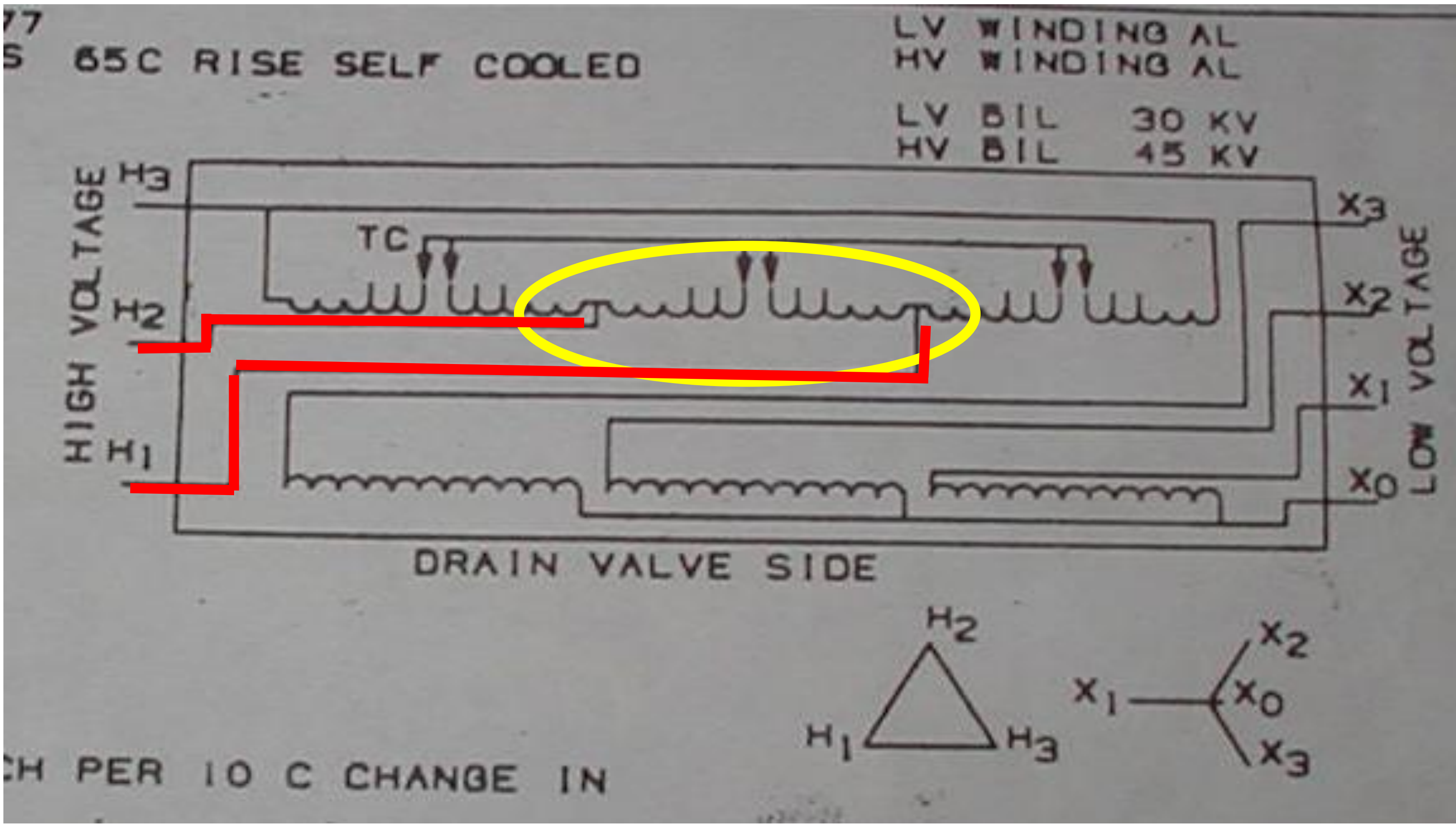
| | 11-7-2016 | | | 11-17-2016 | | |
|---|---|---|---|---|---|---|
| Measured | Ma | Watts | Cap | mA | Watts | Cap |
| CH + CHL | 34.150 | 1.503 | 10980.050 | 41.343 | 1.875 | 10966.750 |
| CH | 9.768 | 0.450 | 3140.520 | 11.855 | 0.656 | 3144.690 |
| CHL | 24.369 | 1.065 | 7835.110 | 29.474 | 1.219 | 7818.370 |
| CHL | 24.383 | 1.053 | 7839.530 | 29.488 | 1.219 | 7822.060 |
| CL + CHL | 57.800 | 16.908 | 18575.900 | 69.555 | 5.080 | 18450.100 |
| CL | 33.434 | 14.876 | 10739.000 | 40.069 | 3.888 | 10628.450 |
| CHL | 24.367 | 1.066 | 7835.105 | 29.471 | 1.231 | 7817.520 |
| CHL | 24.366 | 2.032 | 7836.900 | 29.486 | 1.192 | 7821.650 |

| | 3-25-2013 | | | 11-17-2016 | | |
|---|---|---|---|---|---|---|
| Measured | Ma | Watts | Cap | mA | Watts | Cap |
| CH + CHL | 41.343 | 1.848 | 10970.7 | 41.343 | 1.875 | 10966.750 |
| CH | 11.809 | 0.5840 | 3132.6 | 11.855 | 0.656 | 3144.690 |
| CHL | 29.533 | 1.273 | 7834.3 | 29.474 | 1.219 | 7818.370 |
| CHL | 29.549 | 1.264 | 7838.1 | 29.488 | 1.219 | 7822.060 |
| CL + CHL | 69.509 | 3.948 | 18438.0 | 69.555 | 5.080 | 18450.100 |
| CL | 39.968 | 2.700 | 10601.6 | 40.069 | 3.888 | 10628.450 |
| CHL | 29.529 | 1.277 | 7833.2 | 29.471 | 1.231 | 7817.520 |
| CHL | 29.541 | 1.248 | 7836.4 | 29.486 | 1.192 | 7821.650 |

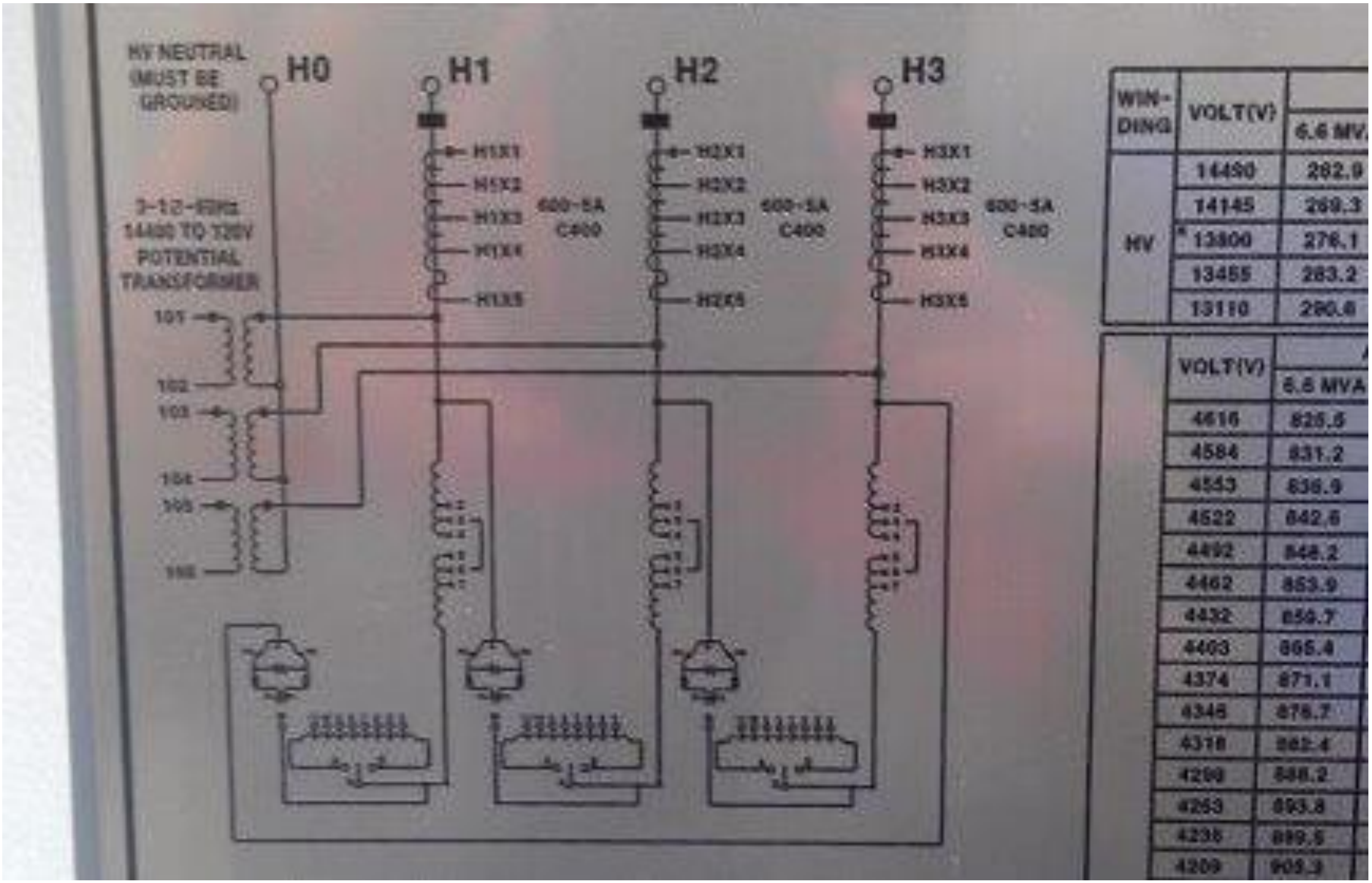
# CASE STUDIES
## Exciting Current

# Exciting Current

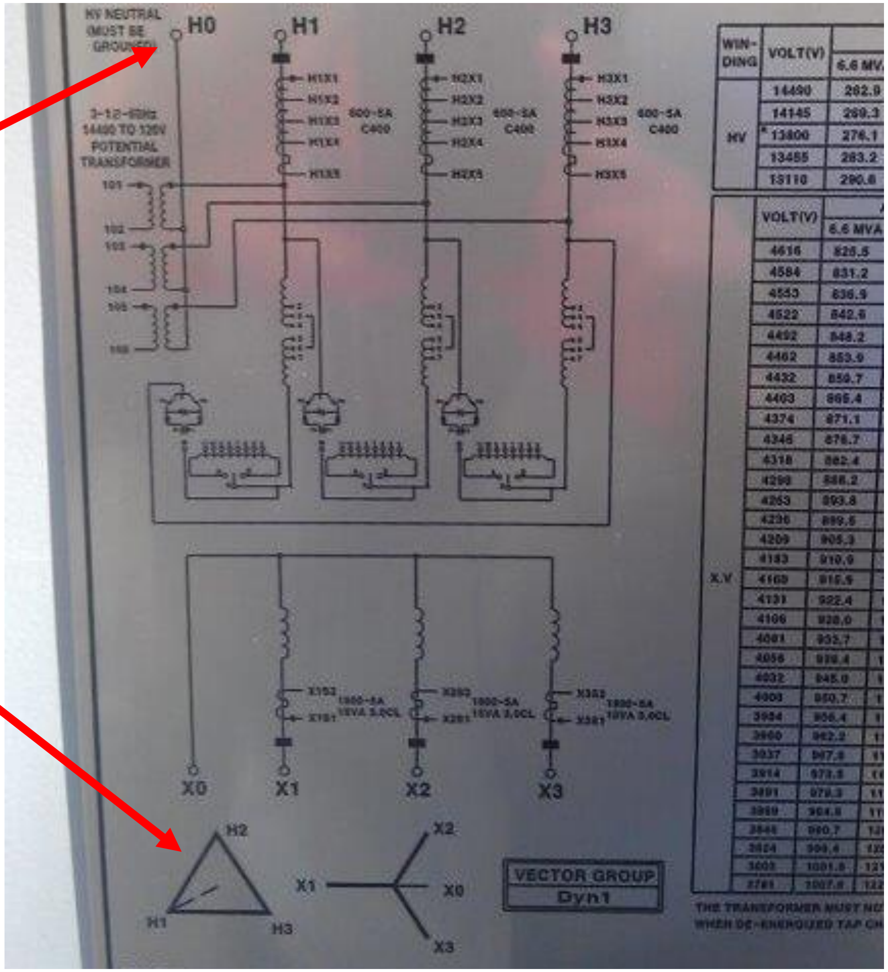
- Normally have 2 Highs and 1 Lower
- Middle winding is usually the lowest
- Open circuit test
- Have to observe a tap pattern and a phase pattern


77
S 65C RISE SELF COOLED
LV WINDING AL
HV WINDING AL
LV BIL 30 KV
HV BIL 45 KV
HIGH VOLTAGE
H3
H2
H1
TC
X3
X2
X1
X0
LOW VOLTAGE
DRAIN VALVE SIDE
H2
H1
H3
X2
X1
X0
X3
CH PER 10 C CHANGE IN

How would you perform exciting current tests on this transformer?

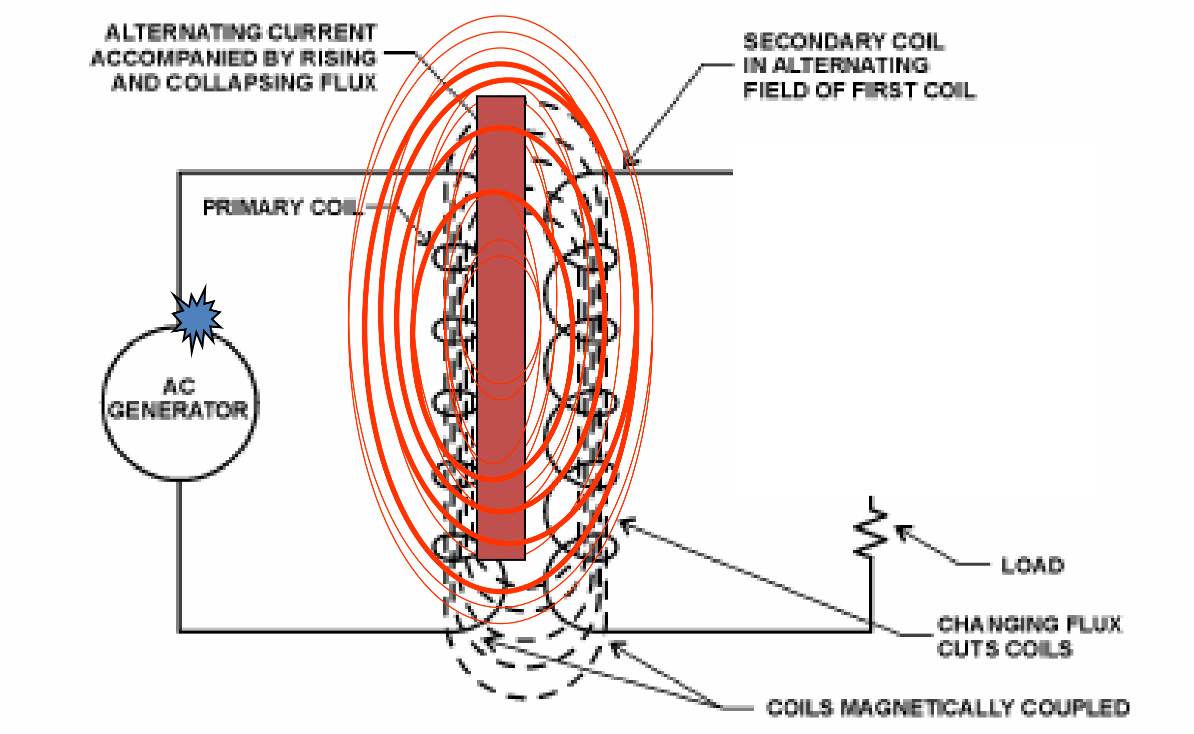

HV NEUTRAL (MUST BE GROUNDED)
H0
H1
H2
H3
H1X1
H1X5
H2X1
H2X5
H3X1
H3X5
600-5A C400
POTENTIAL TRANSFORMER
WIN-DING
VOLT(V)
6.6 MVA
HV
14490
14145
*13800
13455
13110
282.9
276.1
283.2
4616
4584
4553
4522
4492
4462
4432
4403
4374
4346
4318
4290
4263
4236
4209
825.5
831.2
836.9
842.6
848.2
853.9
859.7
865.4
871.1
876.7
893.8
899.5
905.3

This is a Delta – Wye with a H0 bushing



# The Excitation Test
# What it measures

- The Excitation Test measures the current needed to magnetize the core and generate the Magnetic Field in the Windings.
- A broader definition would be the current that flows when the transformer is energized with an ac voltage source under no-load conditions.



# Case Study 11 – Transformer

## Exciting Current

Mfr. – Westinghouse

Configuration – Delta – Wye

Tank Type – Sealed

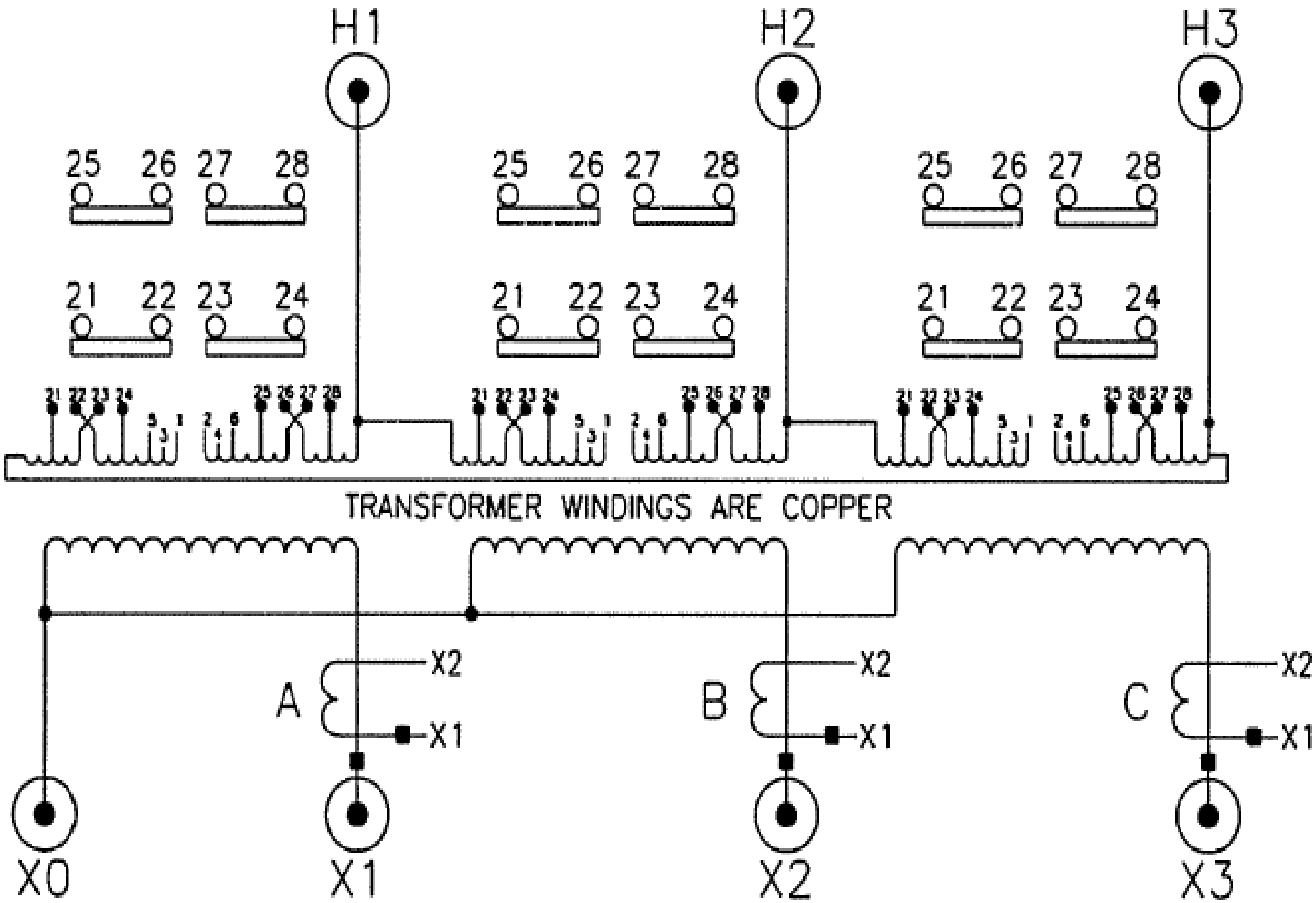
Acceptance

| | | H1 – H2 | | H2 – H3 | | H3 – H1 | |
|---|---|---|---|---|---|---|---|
| DETC | Test kV | mA | Watts | mA | Watts | mA | Watts |
| 1 | 10 | 49.080 | 392.10 | 17.96 | 147.90 | 47.660 | 385.30 |
| 2 | 10 | 48.260 | 393.10 | 17.420 | 145.90 | 49.260 | 399.20 |
| 3 | 10 | 50.400 | 410.90 | 18.150 | 152.20 | 51.370 | 417.10 |
| 4 | 10 | 52.480 | 428.90 | 18.890 | 158.70 | 53.48 | 435.20 |
| 5 | 10 | 54.890 | 449.60 | 19.740 | 166.20 | 55.930 | 456.20 |

2 Highs and 1 Lower as expected – But do we have a good pattern?

| | | H1 – H2 | | H2 – H3 | | H3 – H1 | |
|---|---|---|---|---|---|---|---|
| DETC | Test kV | mA | Watts | mA | Watts | mA | Watts |
| 1 | 10 | 49.080 | 392.10 | 17.96 | 147.90 | 47.660 | 385.30 |
| 2 | 10 | 48.260 | 393.10 | 17.420 | 145.90 | 49.260 | 399.20 |
| 3 | 10 | 50.400 | 410.90 | 18.150 | 152.20 | 51.370 | 417.10 |
| 4 | 10 | 52.480 | 428.90 | 18.890 | 158.70 | 53.48 | 435.20 |
| 5 | 10 | 54.890 | 449.60 | 19.740 | 166.20 | 55.930 | 456.20 |

H2 – H3 is the lowest instead of H1 – H2


H1
H2
H3
25 26 27 28
21 22 23 24
25 26 27 28
21 22 23 24
25 26 27 28
21 22 23 24
TRANSFORMER WINDINGS ARE COPPER
A
X2
X1
B
X2
X1
C
X2
X1
X0
X1
X2
X3

| | | H3 – H2 | | H2 – H1 | | H1 – H3 | |
|---|---|---|---|---|---|---|---|
| | | H1 – H2 | | H2 – H3 | | H3 – H1 | |
| DETC | Test kV | mA | Watts | mA | Watts | mA | Watts |
| 1 | 10 | 49.080 | 392.10 | 17.96 | 147.90 | 47.660 | 385.30 |
| 2 | 10 | 48.260 | 393.10 | 17.420 | 145.90 | 49.260 | 399.20 |
| 3 | 10 | 50.400 | 410.90 | 18.150 | 152.20 | 51.370 | 417.10 |
| 4 | 10 | 52.480 | 428.90 | 18.890 | 158.70 | 53.48 | 435.20 |
| 5 | 10 | 54.890 | 449.60 | 19.740 | 166.20 | 55.930 | 456.20 |

H1 and H3 appear to be identified incorrectly

# Case Study 12 - Transformer

## Overall and Exciting Current

Mfr. – ABB

Configuration – Delta – Wye

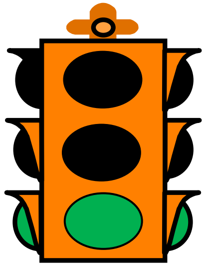
Tank Type – Sealed

MVA – 20

kV – 34.5 / 4.16 Routine

| Test | Measured | Test kV | mA | Watts | % PF | CF | Capacitance |
|---|---|---|---|---|---|---|---|
| 1 | CH + CHL | 10 | 61.581 | 1.692 | ---- | 0.96 | 16334.7 |
| 2 | CH | 10 | 15.352 | 0.451 | 0.28 | 0.96 | 4072.2 |
| 3 | CHL (UST) | 10 | 46.226 | 1.227 | 0.26 | 0.96 | 12261.7 |
| 4 | CHL | | 46.229 | 1.241 | 0.26 | 0.96 | 12262.5 |
| 5 | CL + CHL | 2 | 98.95 | 3.756 | ---- | 0.96 | 26246.9 |
| 6 | CL | 2 | 52.716 | 2.400 | 0.44 | 0.96 | 13983.1 |
| 7 | CHL (UST) | 2 | 46.237 | 1.391 | 0.29 | 0.96 | 12264.6 |
| 8 | CHL | | 46.234 | 1.356 | 0.28 | 0.96 | 12263.8 |

# Overall Power Factor Tests



# Exciting Current Tests

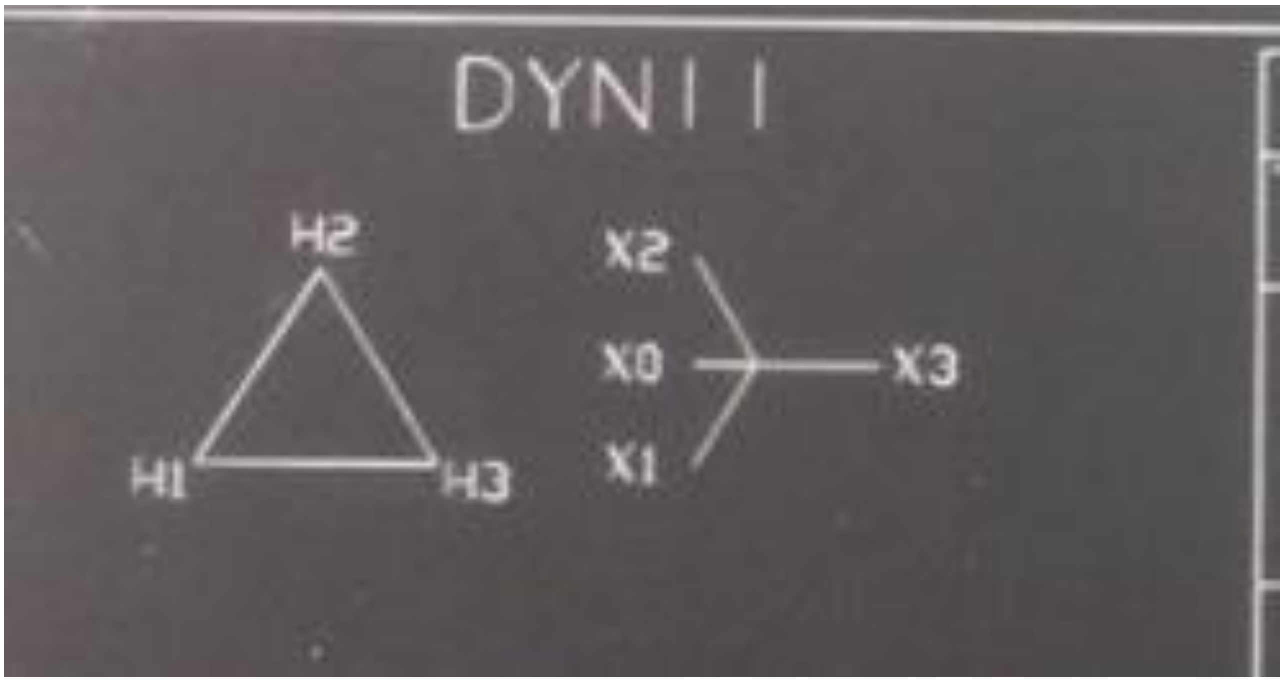
| | | H3 – H1 | | H1 – H2 | | H2 – H3 | |
|---|---|---|---|---|---|---|---|
| DETC | Test kV | mA | Watts | mA | Watts | mA | Watts |
| 3 | 5 | 98.941 | 839.85 | 111.25 | 895.22 | 46.071 | 425.66 |
| 3 | 5 | 98.971 | 839.92 | 108.50 | 880.78 | 45.377 | 421.32 |

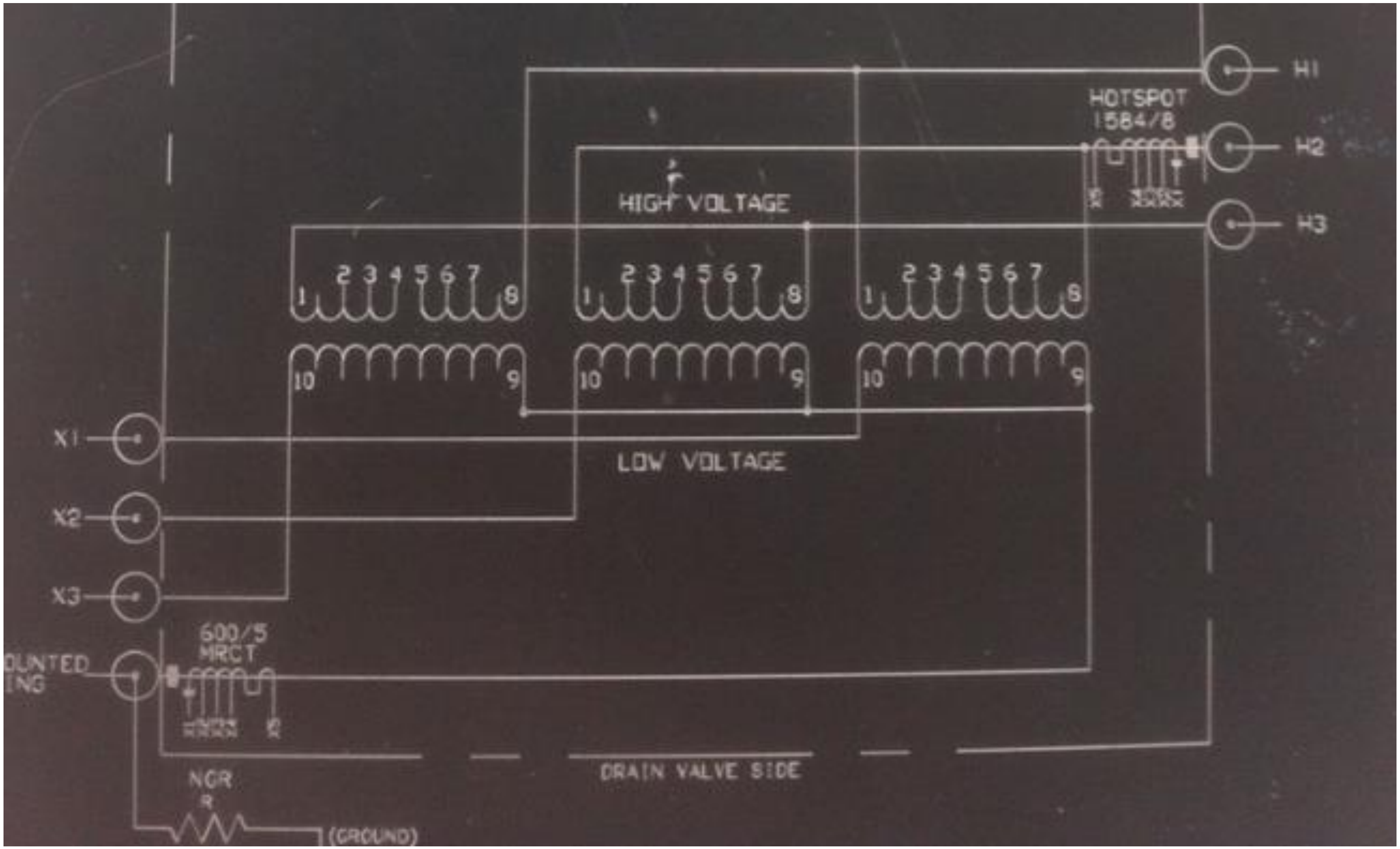
# Exciting Current Tests

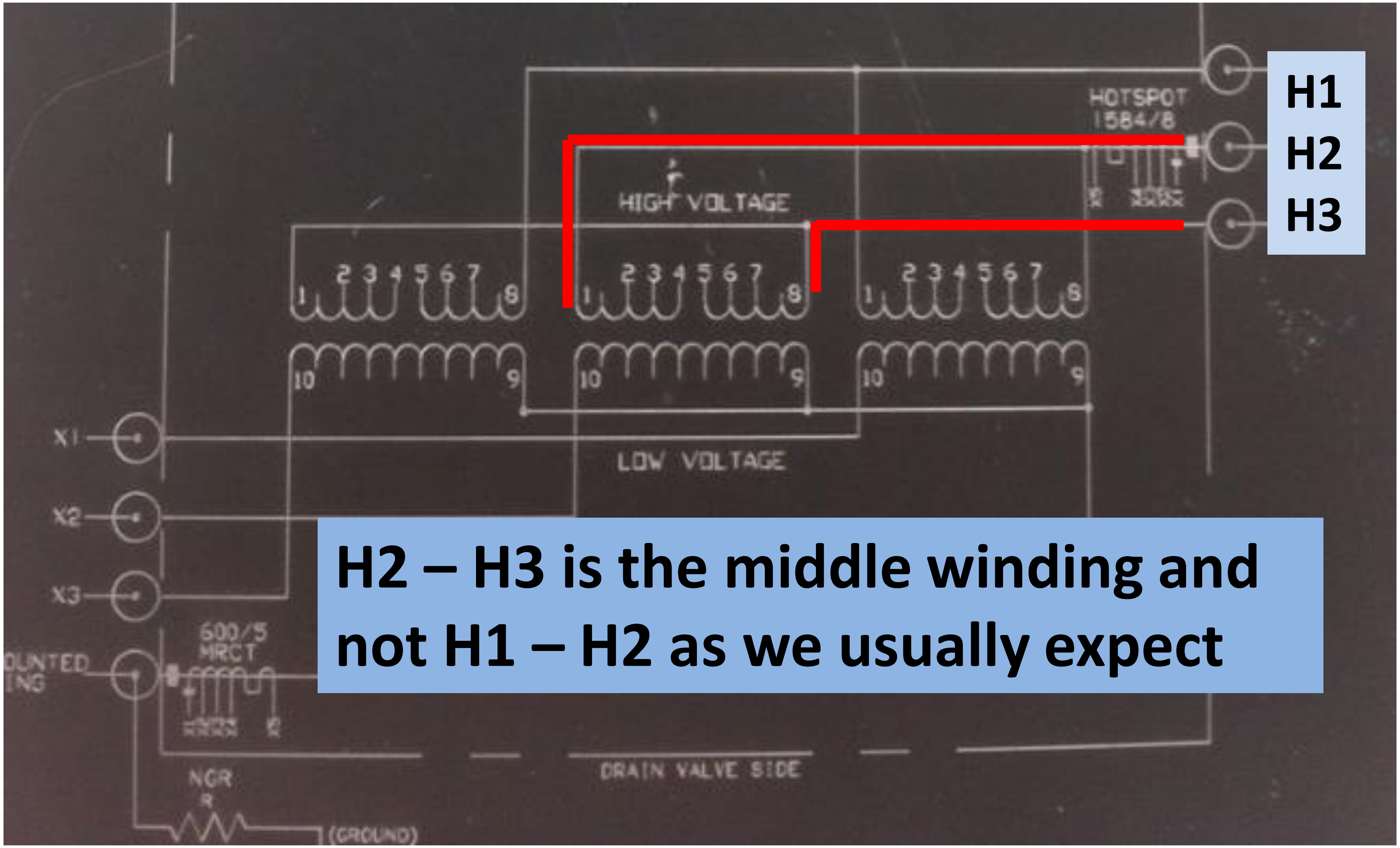
| | | H1 – H3 | | H3 – H2 | | H2 – H1 | |
|---|---|---|---|---|---|---|---|
| | | **H3 – H1** | | **H1 – H2** | | **H2 – H3** | |
| DETC | Test kV | mA | Watts | mA | Watts | mA | Watts |
| 3 | 5 | 98.941 | 839.85 | 111.25 | 895.22 | 46.071 | 425.66 |
| 3 | 5 | 98.971 | 839.92 | 108.50 | 880.78 | 45.377 | 421.32 |
| | | H | | H | | L | |

2 Highs and 1 Lower – but do we have a good pattern

What if bushings 1 and 3 were mis-labeled?


DYN11
H2
H1
H3
X2
X0
X3
X1

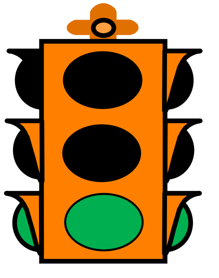

H1
HOTSPOT
1584/8
H2
HIGH VOLTAGE
H3
1 2 3 4 5 6 7 8
10 9
X1
LOW VOLTAGE
X2
X3
600/5
MRCT
DUNTED
ING
DRAIN VALVE SIDE
NGR
R
(GROUND)




**H2 – H3 is the middle winding and not H1 – H2 as we usually expect**

# Exciting Current Tests

| | | H3 – H1 | | H1 – H2 | | H2 – H3 | |
|---|---|---|---|---|---|---|---|
| DETC | Test kV | mA | Watts | mA | Watts | mA | Watts |
| 3 | 5 | 98.941 | 839.85 | 111.25 | 895.22 | 46.071 | 425.66 |
| 3 | 5 | 98.971 | 839.92 | 108.50 | 880.78 | 45.377 | 421.32 |

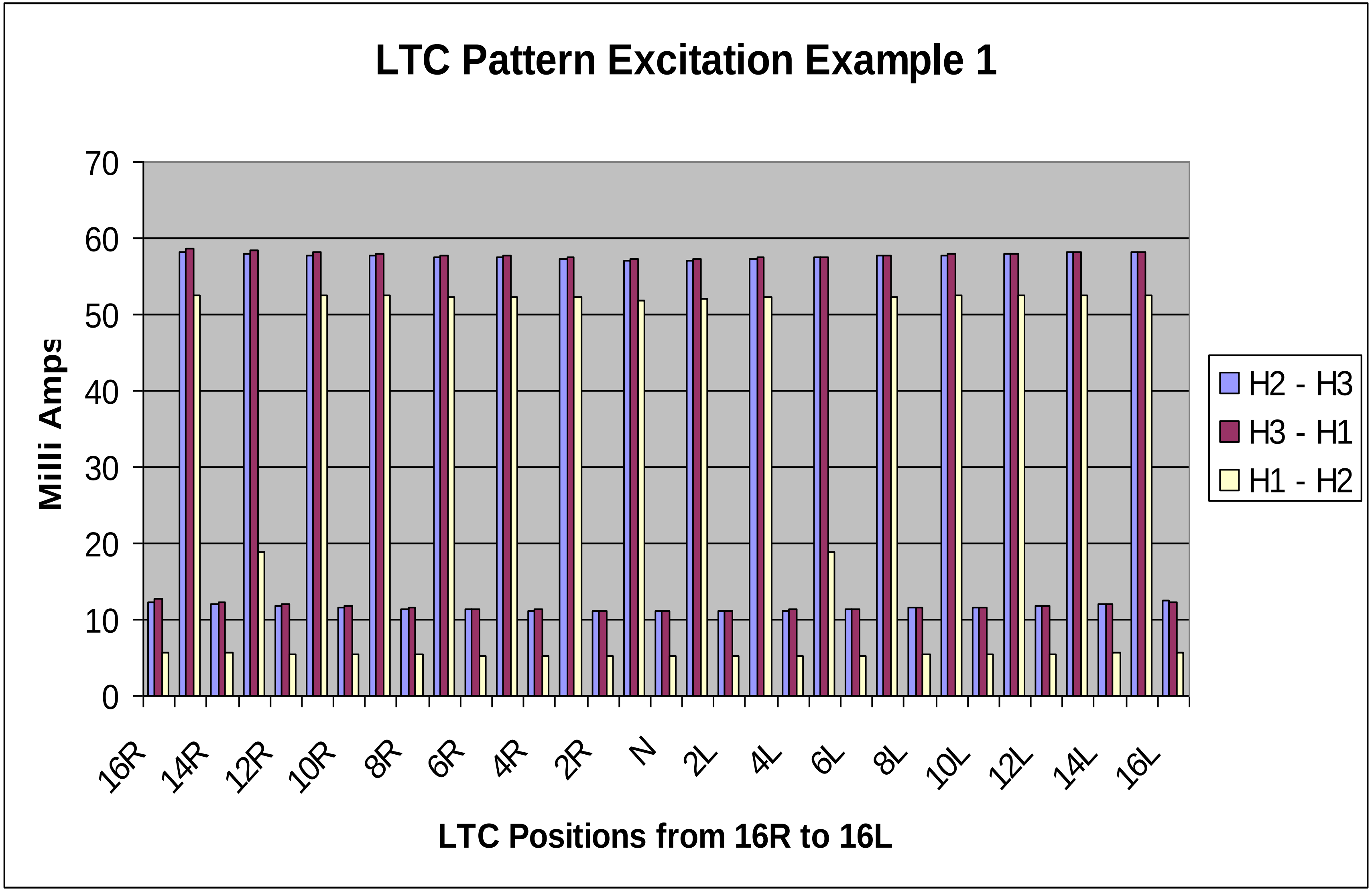


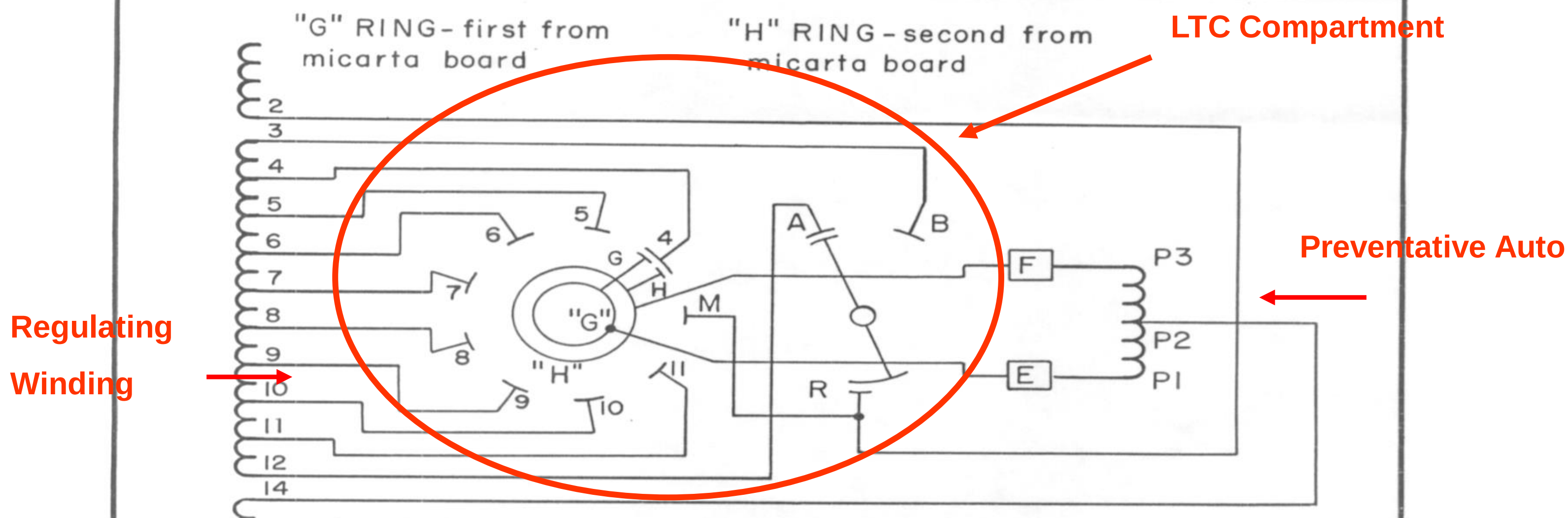
# Case Study 13 – Exciting Current

- Where are the “odd” currents
- Review the tap pattern and the phase pattern

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **H2 - H3** | | | **H3 - H1** | | | **H1 - H2** | |
| **DETC** | **LTC** | **Test kV** | **mA** | **Watts** | **X** | **mA** | **Watts** | **X** | **mA** | **Watts** |
| C | 16R | 10 | 12.296 | 78.44 | L | 12.658 | 79.492 | L | 5.687 | 34.371 |
| C | 15R | 10 | 58.192 | 85.977 | L | 58.575 | 86.383 | L | 52.597 | 42.547 |
| C | 14R | 10 | 12.041 | 76.574 | L | 12.346 | 77.386 | L | 5.592 | 33.684 |
| C | **13R** | 10.004 | 57.945 | 84.218 | L | 58.399 | 84.737 | L | 18.88 | 64.341 |
| C | 12R | 10 | 11.806 | 74.91 | L | 12.095 | 75.705 | L | 5.508 | 33.08 |
| C | 11R | 10 | 57.814 | 82.606 | L | 58.126 | 82.778 | L | 52.498 | 41.292 |
| C | 10R | 10 | 11.603 | 73.513 | L | 11.793 | 73.903 | L | 5.431 | 32.559 |
| C | 9R | 10 | 57.674 | 81.387 | L | 57.976 | 81.384 | L | 52.423 | 40.84 |
| C | 8R | 10 | 11.427 | 72.348 | L | 11.614 | 72.692 | L | 5.367 | 32.118 |
| C | 7R | 10 | 57.55 | 80.469 | L | 57.828 | 80.187 | L | 52.376 | 40.52 |
| C | 6R | 10 | 11.315 | 71.439 | L | 11.455 | 71.578 | L | 5.314 | 31.765 |
| C | 5R | 10 | 57.433 | 79.813 | L | 57.67 | 79.299 | L | 52.263 | 40.295 |
| C | 4R | 10 | 11.202 | 70.714 | L | 11.33 | 70.783 | L | 5.272 | 31.504 |
| C | 3R | 10.001 | 57.338 | 79.241 | L | 57.514 | 78.788 | L | 52.236 | 40.205 |
| C | 2R | 10 | 11.124 | 70.27 | L | 11.227 | 70.238 | L | 5.245 | 31.299 |
| C | 1R | 10 | 56.972 | 79.277 | L | 57.203 | 78.823 | L | 51.893 | 40.315 |
| C | N | 9.999 | 11.094 | 70.122 | L | 11.202 | 70.039 | L | 5.238 | 31.235 |
| C | 1L | 10.001 | 57.121 | 78.981 | L | 57.364 | 78.354 | L | 52.068 | 39.925 |
| C | 2L | 10 | 11.125 | 70.181 | L | 11.242 | 70.213 | L | 5.254 | 31.308 |
| C | 3L | 10.001 | 57.334 | 78.933 | L | 57.467 | 78.394 | L | 52.258 | 39.901 |
| C | 4L | 10 | 11.205 | 70.706 | L | 11.268 | 70.548 | L | 5.29 | 31.474 |
| C | 5L | 10 | 57.415 | 79.564 | L | 57.586 | 78.935 | L | 18.82 | 63.081 |
| C | 6L | 9.999 | 11.343 | 71.481 | L | 11.383 | 71.247 | L | 5.331 | 31.736 |
| C | 7L | 10 | 57.626 | 80.416 | L | 57.687 | 79.703 | L | 52.381 | 40.389 |
| C | 8L | 10 | 11.485 | 72.475 | L | 11.483 | 72.073 | L | 5.385 | 32.101 |
| C | 9L | 10 | 57.764 | 81.568 | L | 57.845 | 80.774 | L | 52.433 | 40.806 |
| C | 10L | 9.999 | 11.686 | 73.735 | L | 11.662 | 73.248 | L | 5.45 | 32.541 |
| C | 11L | 10 | 57.95 | 83.104 | L | 57.978 | 82.156 | L | 52.499 | 41.374 |
| C | 12L | 10 | 11.897 | 75.202 | L | 11.865 | 74.673 | L | 5.524 | 33.073 |
| C | 13L | 10.001 | 58.079 | 84.821 | L | 58.088 | 83.689 | L | 52.469 | 42.037 |
| C | 14L | 10 | 12.124 | 76.869 | L | 12.095 | 76.293 | L | 5.614 | 33.672 |
| C | 15L | 10.001 | 58.259 | 86.606 | L | 58.257 | 85.577 | L | 52.552 | 42.763 |

| | | | H2 - H3 | | | H3 - H1 | | | H1 - H2 | |
|---|---|---|---|---|---|---|---|---|---|---|
| DETC | LTC | Test kV | mA | Watts | X | mA | Watts | X | mA | Watts |
| C | 16R | 10 | 12.296 | 78.44 | L | 12.658 | 79.492 | L | 5.687 | 34.371 |
| C | 15R | 10 | 58.192 | 85.977 | L | 58.575 | 86.383 | L | 52.597 | 42.547 |
| C | 14R | 10 | 12.041 | 76.574 | L | 12.346 | 77.386 | L | 5.592 | 33.684 |
| C | **13R** | 10.004 | 57.945 | 84.218 | L | 58.399 | 84.737 | L | **18.88** | 64.341 |
| C | 12R | 10 | 11.806 | 74.91 | L | 12.095 | 75.705 | L | 5.508 | 33.08 |
| C | 11R | 10 | 57.814 | 82.606 | L | 58.126 | 82.778 | L | 52.498 | 41.292 |
| C | 10R | 10 | 11.603 | 73.513 | L | 11.793 | 73.903 | L | 5.431 | 32.559 |
| C | 9R | 10 | 57.674 | 81.387 | L | 57.976 | 81.384 | L | 52.423 | 40.84 |
| C | 8R | 10 | 11.427 | 72.348 | L | 11.614 | 72.692 | L | 5.367 | 32.118 |
| C | 7R | 10 | 57.55 | 80.469 | L | 57.828 | 80.187 | L | 52.376 | 40.52 |
| C | 6R | 10 | 11.315 | 71.439 | L | 11.455 | 71.578 | L | 5.314 | 31.765 |
| C | 5R | 10 | 57.433 | 79.813 | L | 57.67 | 79.299 | L | 52.263 | 40.295 |
| C | 4R | 10 | 11.202 | 70.714 | L | 11.33 | 70.783 | L | 5.272 | 31.504 |
| C | 3R | 10.001 | 57.338 | 79.241 | L | 57.514 | 78.788 | L | 52.236 | 40.205 |
| C | 2R | 10 | 11.124 | 70.27 | L | 11.227 | 70.238 | L | 5.245 | 31.299 |
| C | 1R | 10 | 56.972 | 79.277 | L | 57.203 | 78.823 | L | 51.893 | 40.315 |
| C | N | 9.999 | 11.094 | 70.122 | L | 11.202 | 70.039 | L | 5.238 | 31.235 |
| C | 1L | 10.001 | 57.121 | 78.981 | L | 57.364 | 78.354 | L | 52.068 | 39.925 |
| C | 2L | 10 | 11.125 | 70.181 | L | 11.242 | 70.213 | L | 5.254 | 31.308 |
| C | 3L | 10.001 | 57.334 | 78.933 | L | 57.467 | 78.394 | L | 52.258 | 39.901 |
| C | 4L | 10 | 11.205 | 70.706 | L | 11.268 | 70.548 | L | 5.29 | 31.474 |
| C | 5L | 10 | 57.415 | 79.564 | L | 57.586 | 78.935 | L | **18.82** | 63.081 |
| C | 6L | 9.999 | 11.343 | 71.481 | L | 11.383 | 71.247 | L | 5.331 | 31.736 |
| C | 7L | 10 | 57.626 | 80.416 | L | 57.687 | 79.703 | L | 52.381 | 40.389 |
| C | 8L | 10 | 11.485 | 72.475 | L | 11.483 | 72.073 | L | 5.385 | 32.101 |
| C | 9L | 10 | 57.764 | 81.568 | L | 57.845 | 80.774 | L | 52.433 | 40.806 |
| C | 10L | 9.999 | 11.686 | 73.735 | L | 11.662 | 73.248 | L | 5.45 | 32.541 |
| C | 11L | 10 | 57.95 | 83.104 | L | 57.978 | 82.156 | L | 52.499 | 41.374 |
| C | 12L | 10 | 11.897 | 75.202 | L | 11.865 | 74.673 | L | 5.524 | 33.073 |
| C | 13L | 10.001 | 58.079 | 84.821 | L | 58.088 | 83.689 | L | 52.469 | 42.037 |
| C | 14L | 10 | 12.124 | 76.869 | L | 12.095 | 76.293 | L | 5.614 | 33.672 |
| C | 15L | 10.001 | 58.259 | 86.606 | L | 58.257 | 85.577 | L | 52.552 | 42.763 |
| C | 16L | 10.004 | 12.488 | 79.219 | L | 12.351 | 78.14 | L | 5.715 | 34.352 |


LTC Pattern Excitation Example 1
70
60
50
40
30
20
10
0
Milli Amps
16R
14R
12R
10R
8R
6R
4R
2R
N
2L
4L
6L
8L
10L
12L
14L
16L
LTC Positions from 16R to 16L
H2 - H3
H3 - H1
H1 - H2




view facing contact side of micarta board
schematic is shown with tap changer on position 16L
transfer switches E and F are closed on all positions

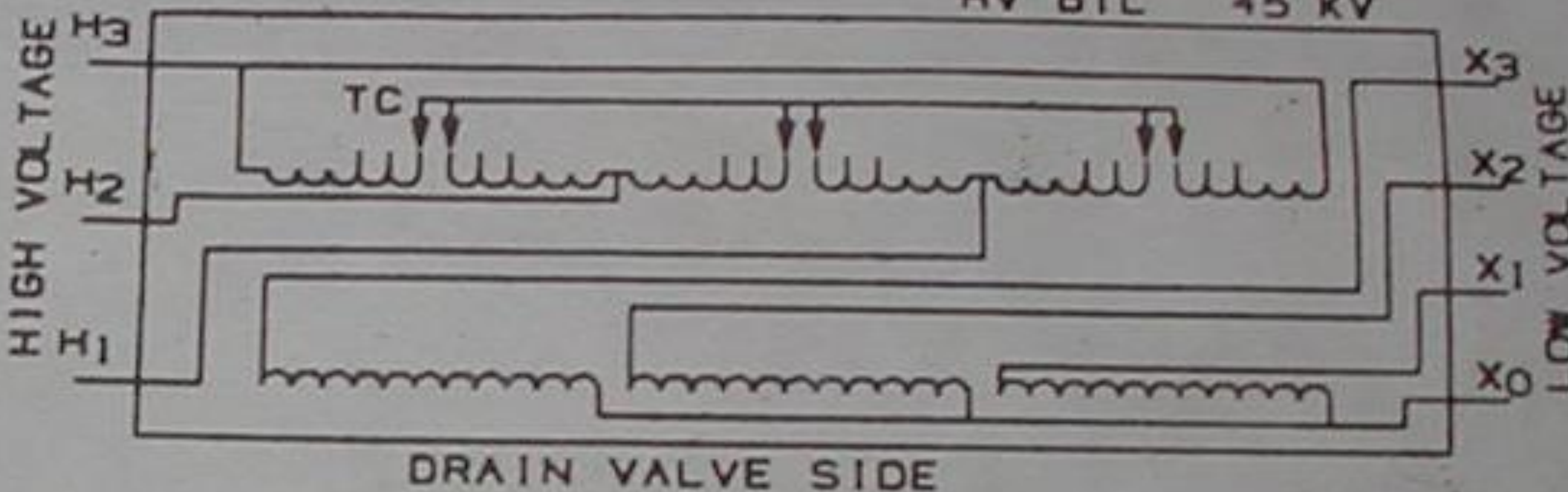
**Odd Steps are Bridged Positions**

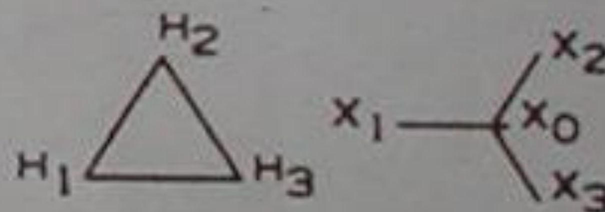
| CONTACT | POSITION | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LOWER | | | | | | | | | | | | | | | | | RAISE | | | | | | | | | | | | | | | |
| | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| P1 (G) connects to | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 11 | 11 | M | M | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 11 | 11 |
| P3 (H) connects to | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 11 | 11 | M | M | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 9 | 9 | 10 | 10 | 11 |
| R connects to | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | B | B | B | B | B | B | B | B | B | B | B | B | B | B | B | B |

77
S 65C RISE SELF COOLED

LV WINDING AL
HV WINDING AL

LV BIL 30 KV
HV BIL 45 KV




CH PER 10 C CHANGE IN

# CASE STUDIES
## Bushings

# Case Study 14 -Bushing

ABB O+C bushings

Mfr. 1995

kV – 138

Amp – 800

Type – Draw lead

# C1 Nameplated data

| | | |
|---|---|---|
| H1 | 0.21 % PF | 365 pF |
| H2 | 0.22 % PF | 365 pF |
| H3 | 0.22 % PF | 365 pF |

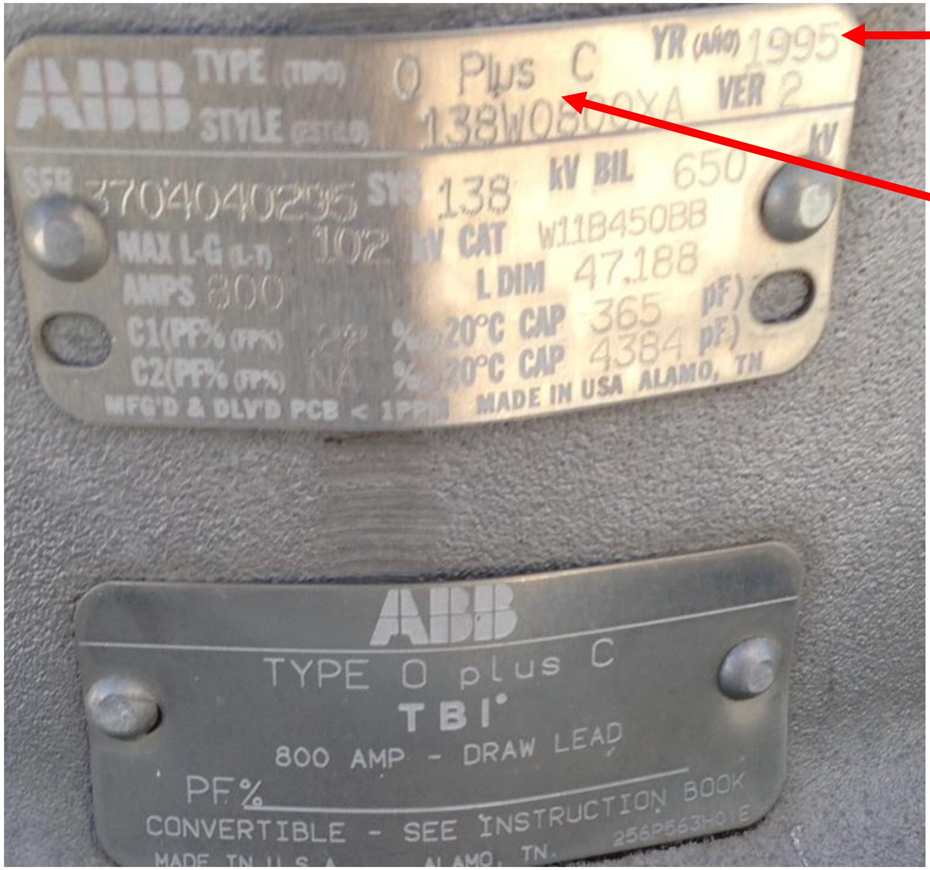


ABB TYPE (TIPO) O Plus C
YR (AÑO) 1995
STYLE (ESTILO) 138W0800XA
VER 2
SER 3704040295
SYS 138 kV BIL 650 kV
MAX L-G (L-T) 102 kV
CAT W11B450BB
AMPS 800
L DIM 47.188
C1(PF% (FP%) %@20°C CAP 365 pF)
C2(PF% (FP%) NA %@20°C CAP 4384 pF)
MFG'D & DLV'D PCB < 1PPM
MADE IN USA ALAMO, TN
ABB
TYPE O plus C
TBI
800 AMP - DRAW LEAD
PF%
CONVERTIBLE - SEE INSTRUCTION BOOK
256P563H01E
MADE IN U.S.A. ALAMO, TN.

1995

O+C

Nameplate

| | | |
|---|---|---|
| H1 | .21 % PF | 365 pF |
| H2 | .22 % PF | 365 pF |
| H3 | .22 % PF | 365 pF |

Actual

| | | |
|---|---|---|
| H1 | .212 % PF | 357.5 pF |
| H2 | .033 % PF | 358.1 pF |
| H3 | .213 % PF | 359.2 pF |

- Why is the C1 power factor lower than nameplate?
  - Contamination on lower porcelain
  - Internal contamination
  - Poor flange ground
- It helps to have prior test data / history of the bushings!!!!

# C1 History – Bushing H1

**History for C1**

Display History for Bushing H1

| Date | Inputs | | | Results | | | | | R |
|---|---|---|---|---|---|---|---|---|---|
| | Serial# | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | Ask FRANK™ |
| 7/31/2016 | 3704040195 | 10.002 | 1.05 | 1.348 | 0.027 | 0.202 | 0.212 | 357.5 | G Good |
| 3/9/2005 | 3704040195 | 10.000 | 0.95 | 1.342 | 0.008 | 0.060 | 0.057 | 356.0 | ! Investigate |
| 4/12/2000 | 3704040195 | 10.000 | 1.00 | 1.348 | 0.027 | 0.200 | 0.200 | 357.4 | G Good |

# C1 History – Bushing H2

**History for C1**

| Display History for Bushing | H2 |
|---|---|

| Date | Inputs | | | Results | | | | | Ratin[g] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Serial# | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | Ask FRANK™ | |
| 7/31/2016 | 3704040295 | 10.170 | 1.05 | 1.350 | 0.004 | 0.031 | 0.033 | 358.1 | Investigate | ... |
| 3/9/2005 | 3704040295 | 10.000 | 0.95 | 1.313 | -0.030 | -0.228 | -0.218 | 348.3 | Bad | ... |
| 4/12/2000 | 3704040295 | 10.000 | 1.00 | 1.351 | 0.027 | 0.200 | 0.200 | 358.2 | Good | ... |

# C1 History – Bushing H3

**History for C1**

Display History for Bushing H3

| Date | Inputs | | | Results | | | | | Ratin | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Serial# | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | Ask FRANK™ | |
| 7/31/2016 | 3704040395 | 10.002 | 1.05 | 1.354 | 0.028 | 0.203 | 0.213 | 359.2 | G Good | ... |
| 3/9/2005 | 3704040395 | 10.000 | 0.95 | 1.350 | 0.024 | 0.178 | 0.170 | 358.0 | G Good | ... |
| 4/12/2000 | 3704040395 | 10.000 | 1.00 | 1.350 | 0.027 | 0.200 | 0.200 | 358.0 | G Good | ... |

- Is there a problem?
- Review history of this type of bushing
- **ABB Service Advisory May 31, 2000**

## ABB Service Advisory May 31, 2000

ABB Alamo has received reports indicating that some O Plus C™ bushings in service have shown staining on the lower porcelain area. Reported incidences to date of the stained bushings in oil are confined to O Plus C ™ 115 kV and below, manufactured **in the 1990 to 1994 timeframe.** Our investigation confirms the staining process originates at the gasket joint.

- This bushing was manufactured in 1995 so it is not within the dates for the service advisory
- What steps do we take?

# Inspection of Bushing H2

# Inspection of Bushing H2

# After cleaning

# C1 Test Before and After Cleaning

**History for C1**

Display History for Bushing H2

| Date | Inputs | | | Results | | | | | Ratir | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Serial# | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | Ask FRANK™ | |
| 7/31/2016 | 3704040295 | 10.170 | 1.05 | 1.350 | 0.004 | 0.031 | 0.033 | 358.1 | Investigate | ... |
| 3/9/2005 | 3704040295 | 10.000 | 0.95 | 1.313 | -0.030 | -0.228 | -0.218 | 348.3 | Bad | ... |
| 4/12/2000 | 3704040295 | 10.000 | 1.00 | 1.351 | 0.027 | 0.200 | 0.200 | 358.2 | Good | ... |

| Date | Inputs | | | Results | | | | | Ra |
|---|---|---|---|---|---|---|---|---|---|
| | Serial# | Test kV | Corr. Factor | mA | Watts | PF (%) | PF Corr. (%) | Capacitance (pF) | Ask FRANK™ |
| 7/31/2016 | 3704040295 | 10.171 | 1.05 | 1.350 | 0.027 | 0.203 | 0.214 | 358.1 | Deteriora... |

# Case Study 15 -Bushing

Mfr. – Westinghouse

Type - O

kV – 115

Amp – 1200

Mfr. Date 1967-1968

Routine

# C1 Tests – As Found

| Test | PF | Cap | kV | mA | Watts | % PF | Cap |
|---|---|---|---|---|---|---|---|
| H1 | .45 | 349 | 10 | 1.327 | 0.063 | 0.49 | 351.89 |
| H2 | .43 | 349 | 10 | 1.329 | 0.064 | 0.50 | 352.52 |
| H3 | .45 | 350 | 10 | 1.326 | 0.064 | 0.50 | 351.83 |

# C2 Tests – As Found

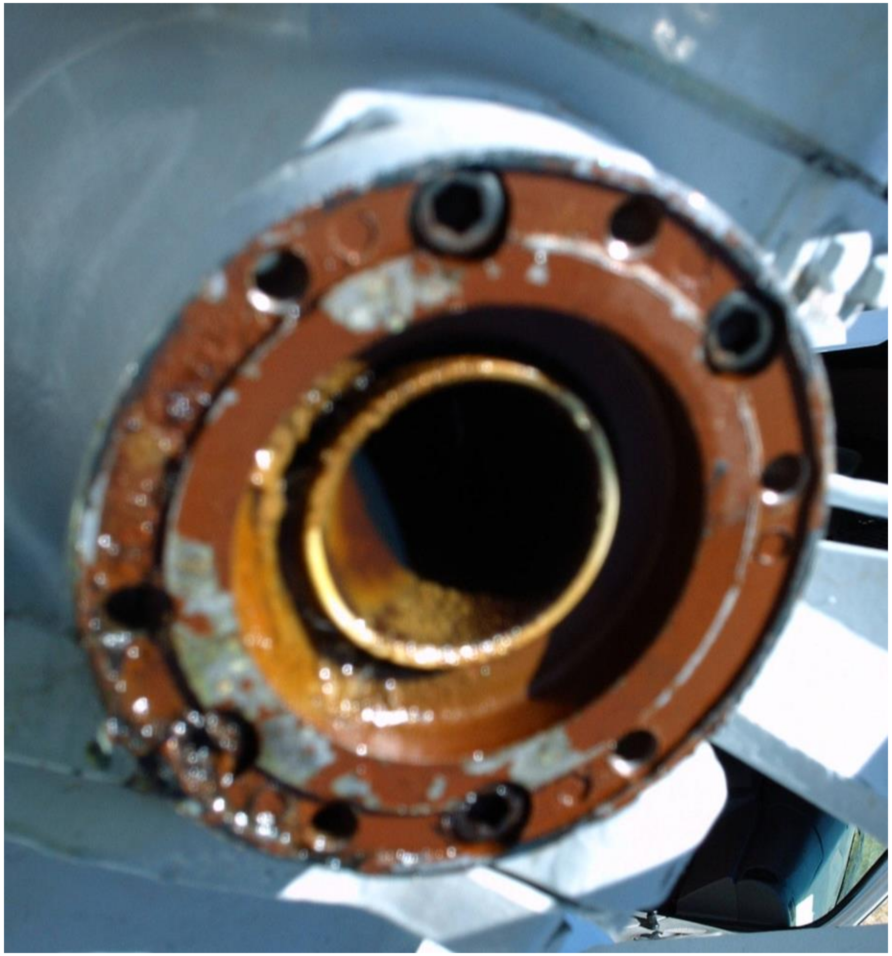
| Test | PF | Cap | kV | mA | Watts | % PF | Cap |
|---|---|---|---|---|---|---|---|
| H1 | | 2830 | 2 | 10.738 | 0.553 | 0.51 | 2848.4 |
| H2 | | 2745 | 2 | 10.438 | 1.637 | 1.57 | 2768.3 |
| H3 | | 2830 | 2 | 10.714 | 0.541 | 0.50 | 2841.9 |

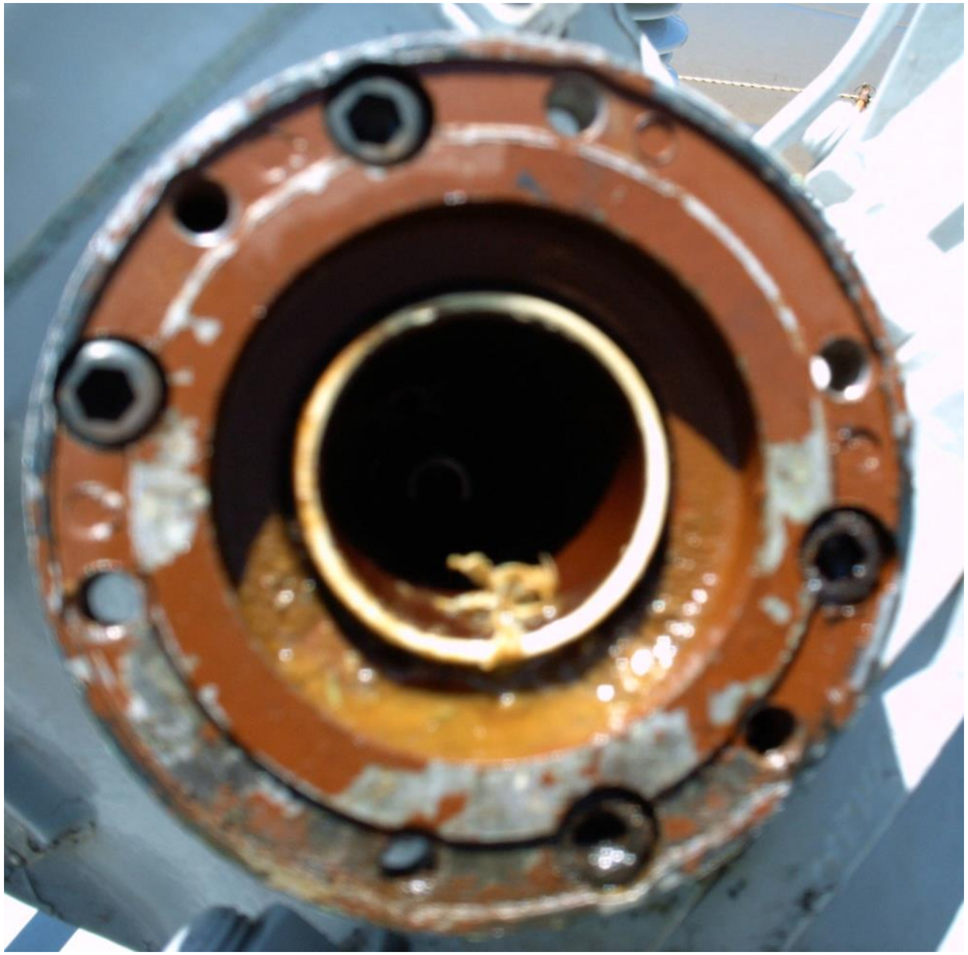
# C2 Tests – As Found

| Test | PF | Cap | kV | mA | Watts | % PF | Cap |
|---|---|---|---|---|---|---|---|
| H1 | | 2830 | 2 | 10.738 | 0.553 | 0.51 | 2848.4 |
| H2 | | 2745 | 2 | 10.438 | 1.637 | 1.57 | 2768.3 |
| H3 | | 2830 | 2 | 10.714 | 0.541 | 0.50 | 2841.9 |

Note the increase in watts
and power factor for H2

- The Westinghouse type O bushing has the tap compartment filled with oil
- Since there was an increase in watts the C2 compartment was suspected.
- Changed the fluid and cleaned up the covers and new gasket for the cover.





# C2 Tests – As Left

| Test | PF | Cap | kV | mA | Watts | % PF | Cap |
|---|---|---|---|---|---|---|---|
| H1 | | 2830 | 2 | 10.71 | 0.572 | 0.53 | 2840.5 |
| H2 | | 2745 | 2 | 10.38 | 0.570 | 0.53 | 2754.4 |
| H3 | | 2830 | 2 | 10.69 | 0.566 | 0.53 | 2836.3 |