Knowledge Is Power[SM]

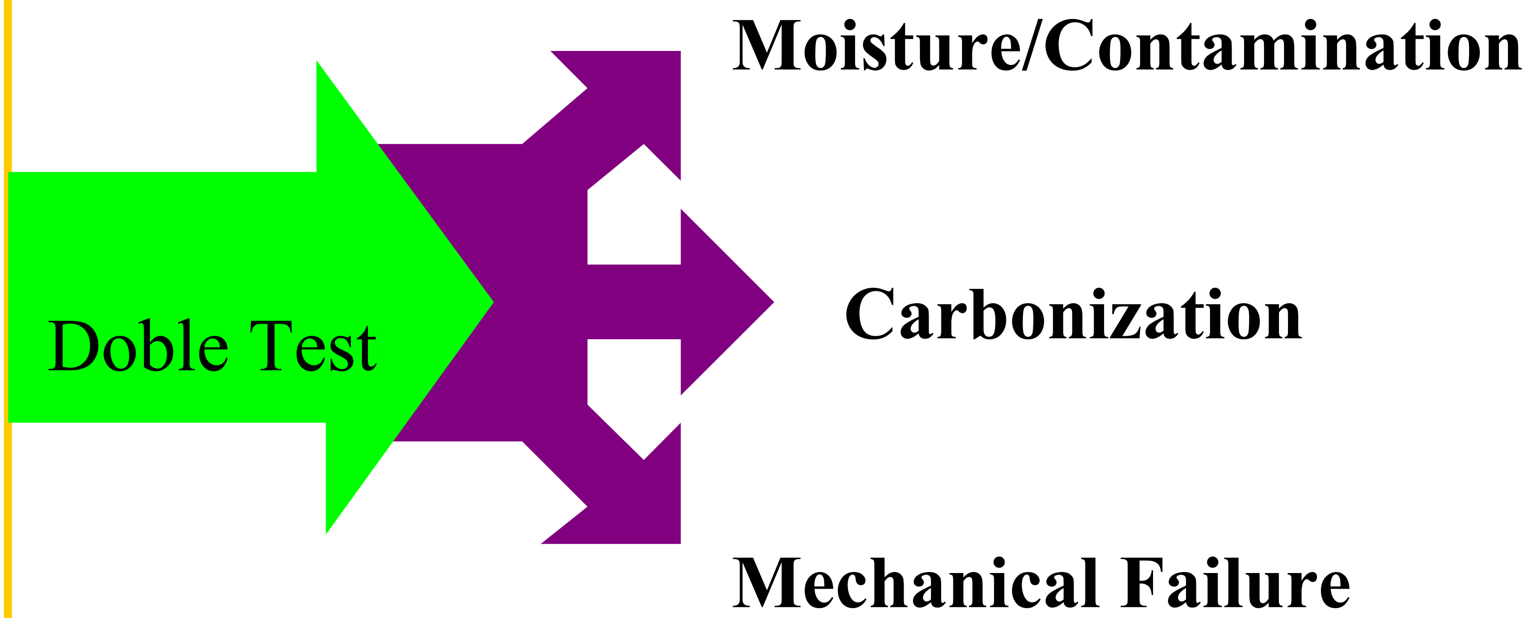
Apparatus Maintenance and Power Management for Energy Delivery

Transformer Testing

PROPRIETARY INFORMATION

Power and Distribution Transformers

The Doble dielectric-loss and power factor test as applied to transformers are the most comprehensive tests for insulation assessment.



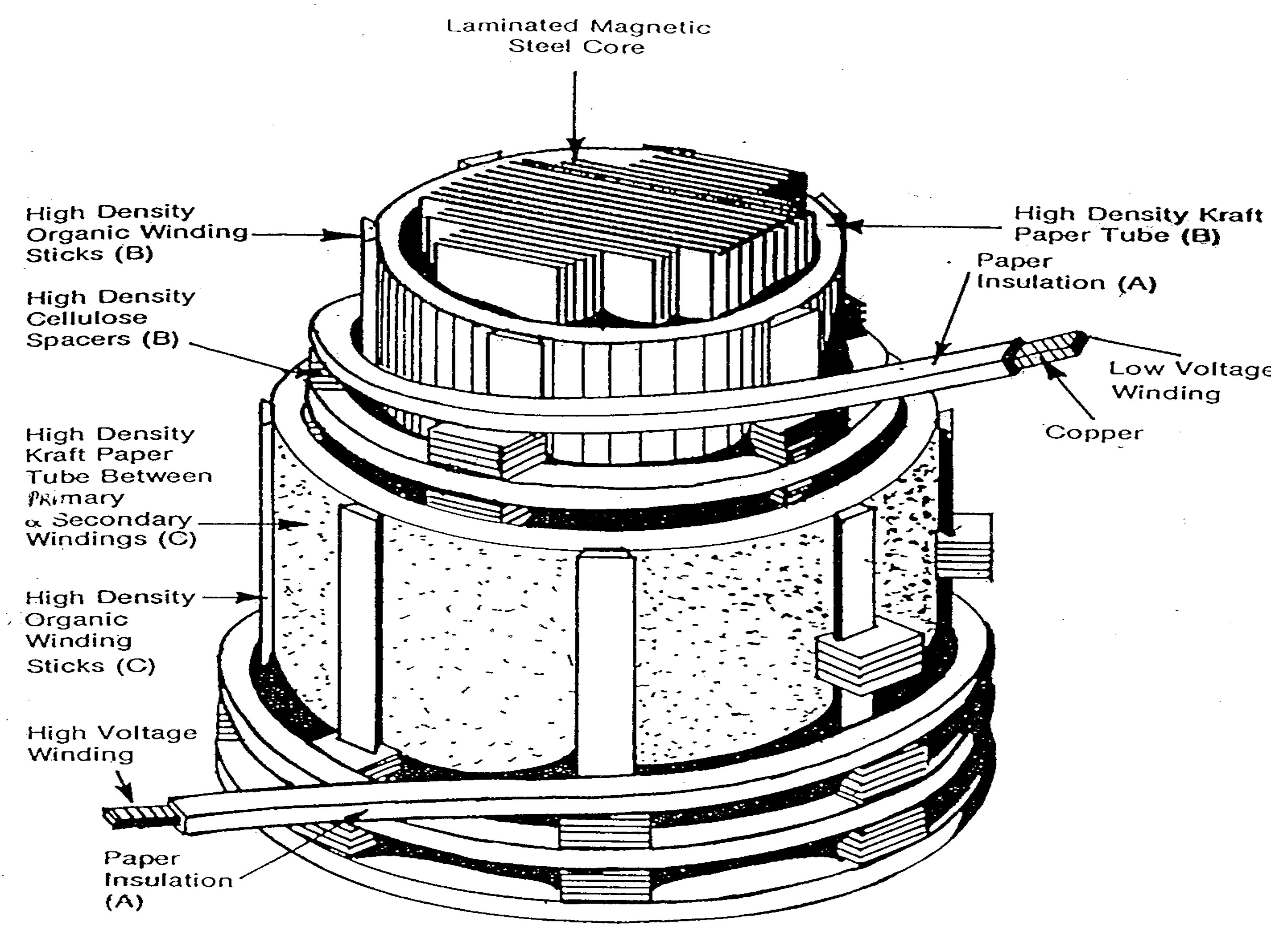
The test technique makes it possible to segregate the specimen into major components
for more effective analysis of test results.

Transformer General Types

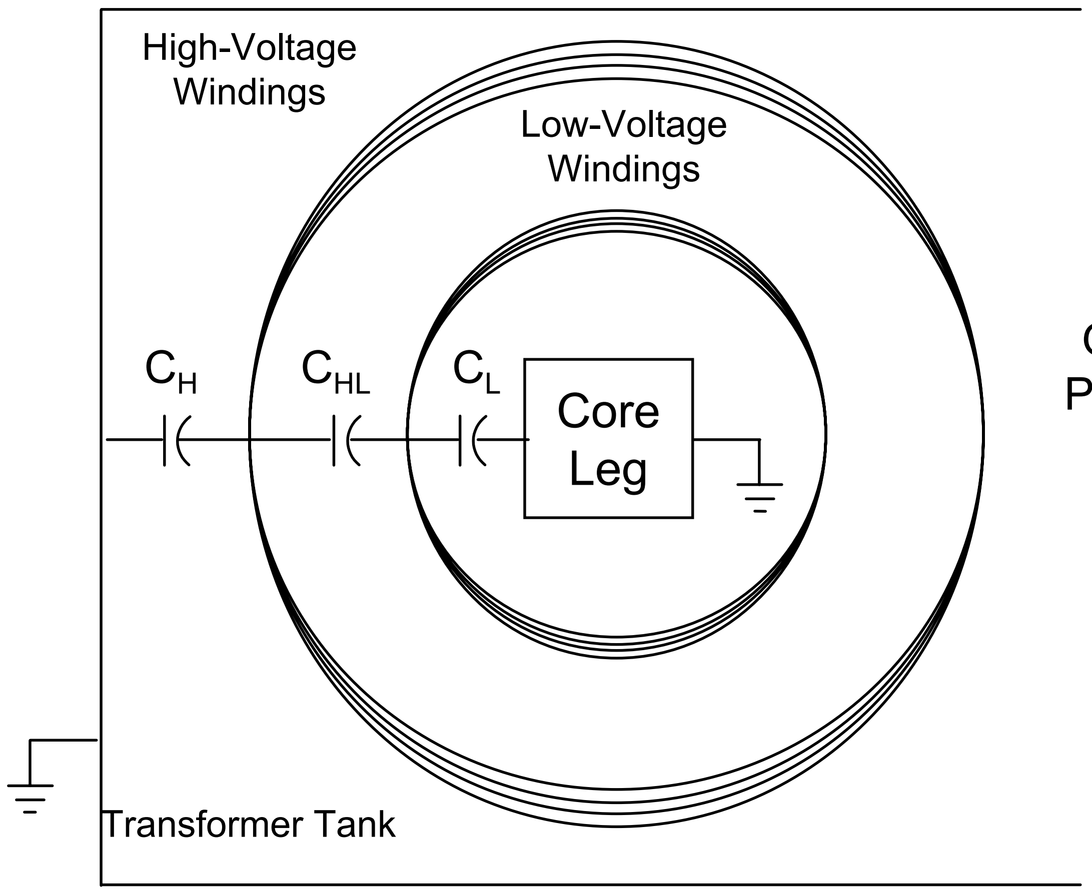
Power and distribution transformers may be either single-phase or three-phase

- Three-Winding
- Two-Winding
- Autotransformer (with or without a tertiary winding)

They may be liquid-insulated, gas-insulated, or dry-type. For test purposes, the procedure used depends on the number of accessible, separate windings.


Laminated Magnetic Steel Core
High Density Organic Winding Sticks (B)
High Density Kraft Paper Tube (B)
Paper Insulation (A)
High Density Cellulose Spacers (B)
Low Voltage Winding
Copper
High Density Kraft Paper Tube Between Primary & Secondary Windings (C)
High Density Organic Winding Sticks (C)
High Voltage Winding
Paper Insulation (A)

Physical Representation of Three-Phase Two-Winding Transformer



One of Three Phases Shown

Doble Transformer Testing
Two-Winding Transformers

Doble tests:

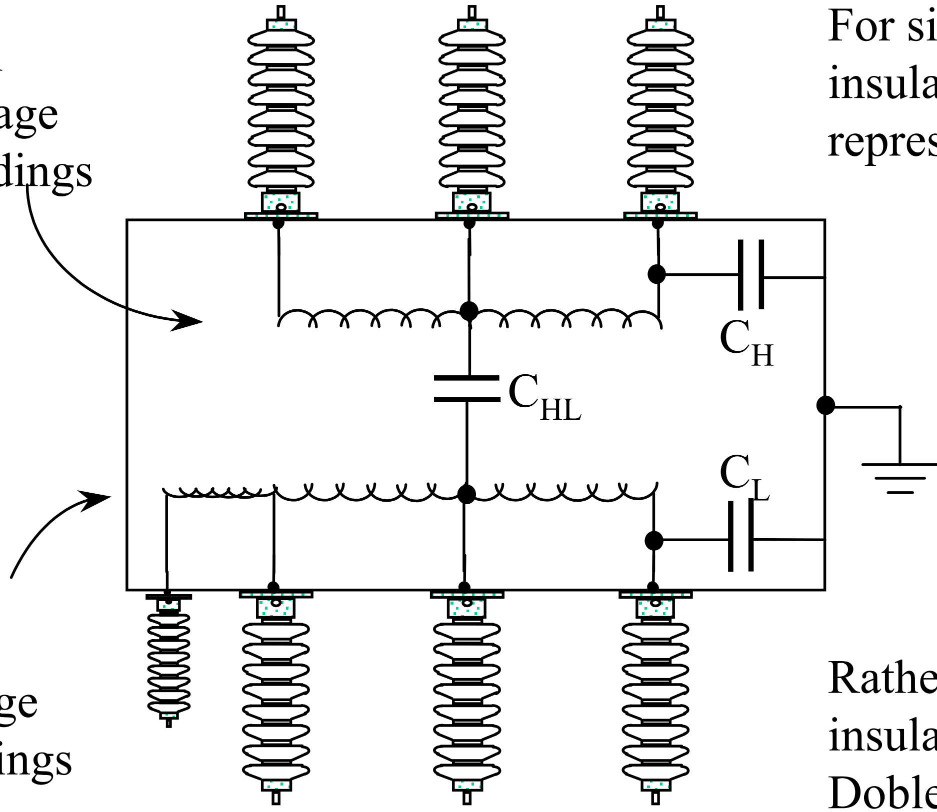
- Overall (C_H, C_L, C_{HL})
- Bushings (C_1, C_2, Hot Collar)
- Oil (Field Power Factor, Laboratory DGA, etc.)
- Excitation Current Test
- Doble Turns Ratio Test
- Leakage Reactance

Testing Preparations

- Transformer should be de-energized and isolated from the system.
- Transformer should be properly grounded.
- All terminals (including neutrals) must be connected together to eliminate winding inductance affect on measurements.
- If equipped with LTC, it should be set to an off neutral position.

Transformer Insulation Systems

High Voltage Windings



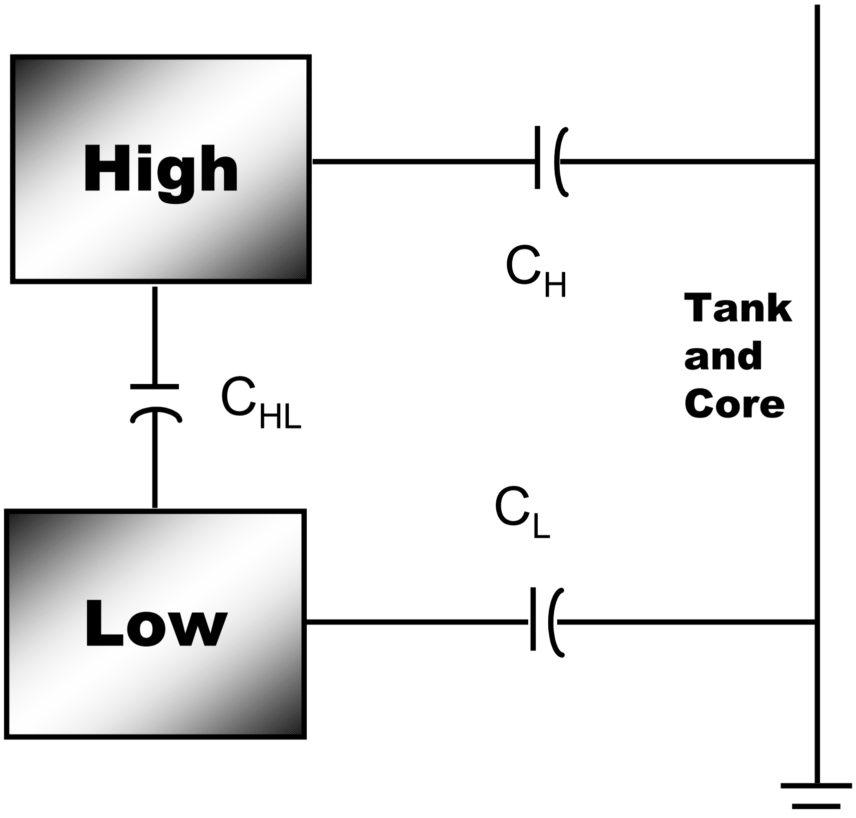
Low Voltage Windings

For simplicity, transformer insulation is grouped into three representative insulation systems

CH
CL
CHL

Rather than measure all the insulation systems together, the Doble Test allows the testers to measure them individually.

Dielectric Circuit: Two-Winding Transformer

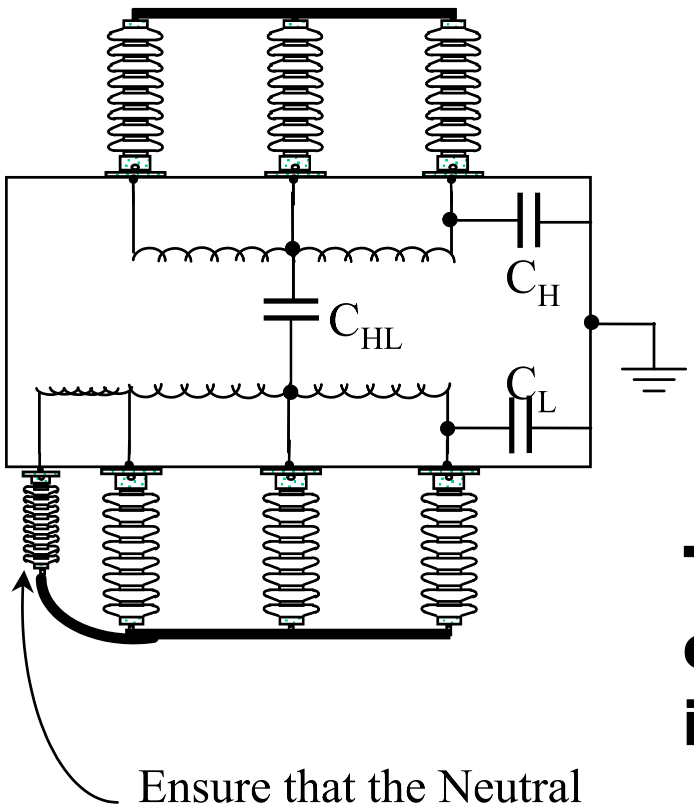


C_H - Insulation between High-Voltage conductors and grounded Tank & Core (H Bushings-Winding Insulation-Structural Insulating Members-Oil)

C_L - Insulation between Low-Voltage conductors and grounded Tank & Core (X Bushings - Winding Insulation-Structural Insulating Members-Oil)

C_{HL} - Insulation between High- and Low-Voltage Windings (Winding Insulation-Barriers-Oil)

The Overall Test



Ensure that the Neutral Bushing is also shorted and disconnected from Ground

Before you start the overall test:

- Short Circuit High Voltage Windings
- Short Circuit Low Voltage Windings
- Disconnect the neutral bushing from ground

This is one of the most common sources of error in test results!

Test Procedure: Two-Winding Transformer

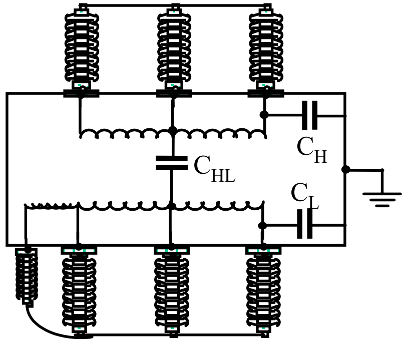
Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
1	GST	HIGH	LOW	----	----	C_H+C_{HL}
2	GST	HIGH	----	LOW	----	C_H
3	GST	LOW	HIGH	----	----	C_L+C_{HL}
4	GST	LOW	----	HIGH	----	C_L

Calculated Results: Test 1 minus Test 2 C_{HL}

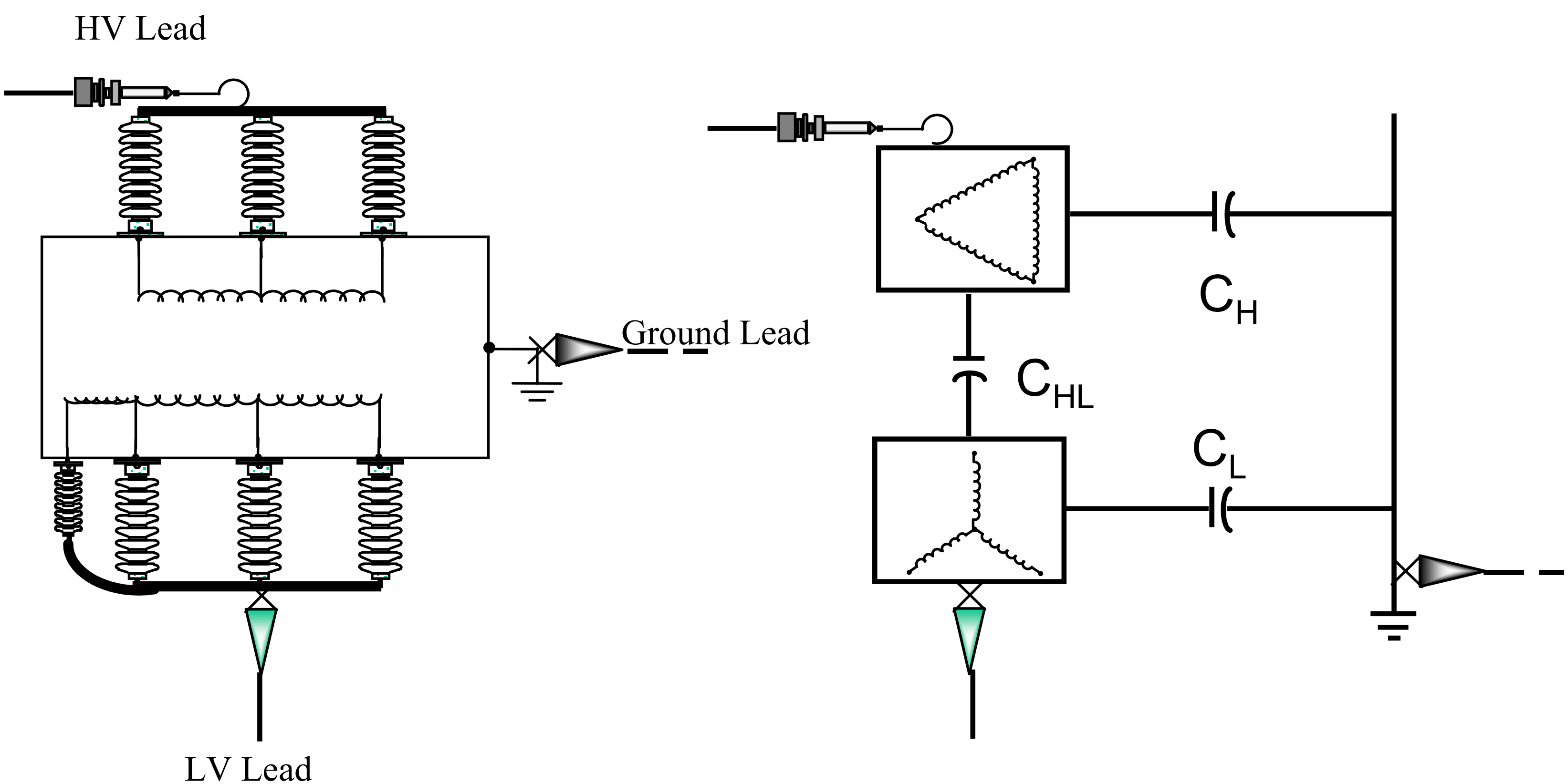
Test 3 minus Test 4 C_{HL}

Alternative Test for C_{HL}

Test No.	Test Mode	Energize	Ground	Guard	UST	Measure
5	UST	HIGH	----	----	LOW	C_{HL}
6	UST	LOW	----	----	HIGH	C_{HL}

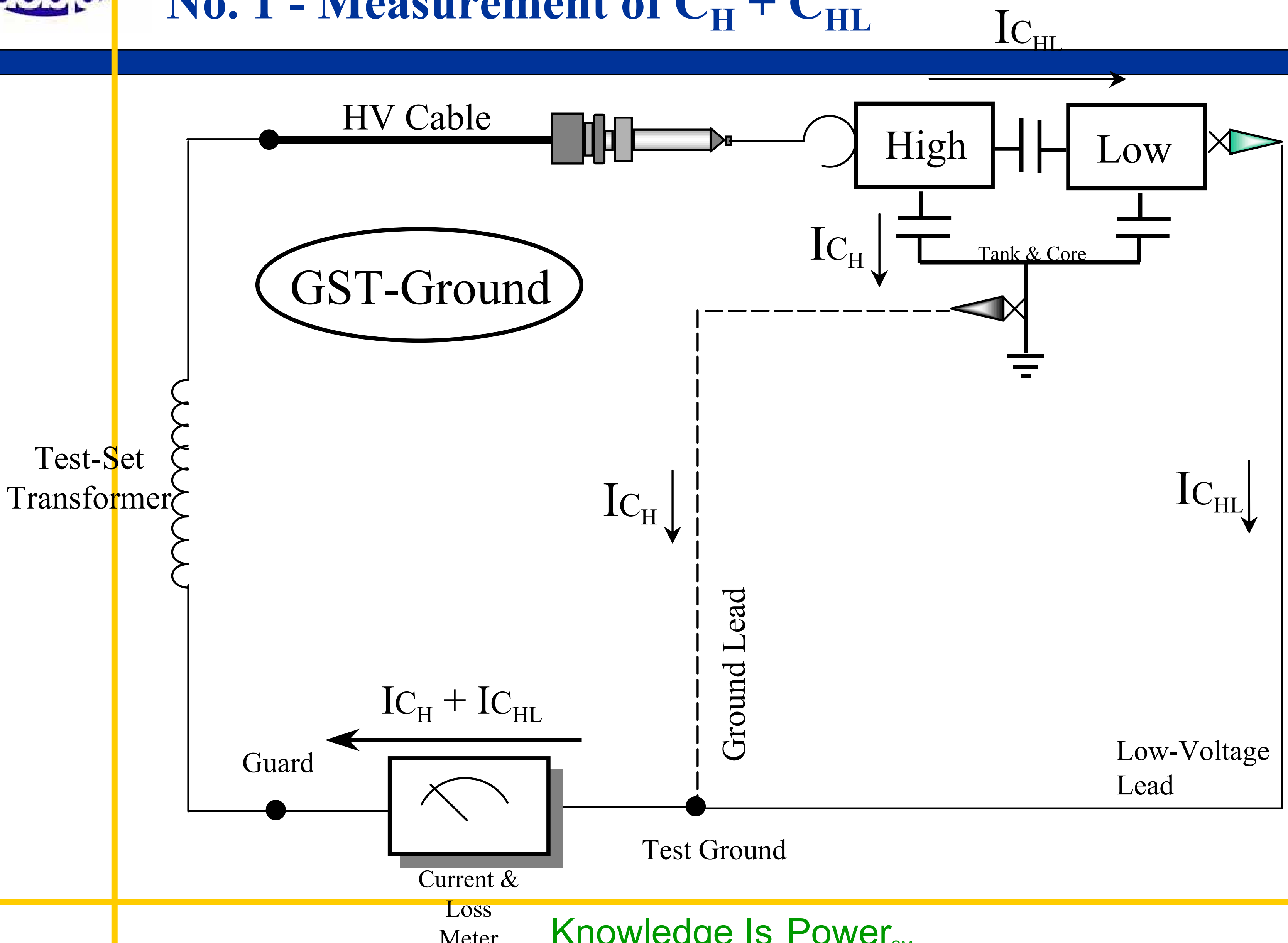


Transformer Test Procedures -- Three Phase Two-Winding



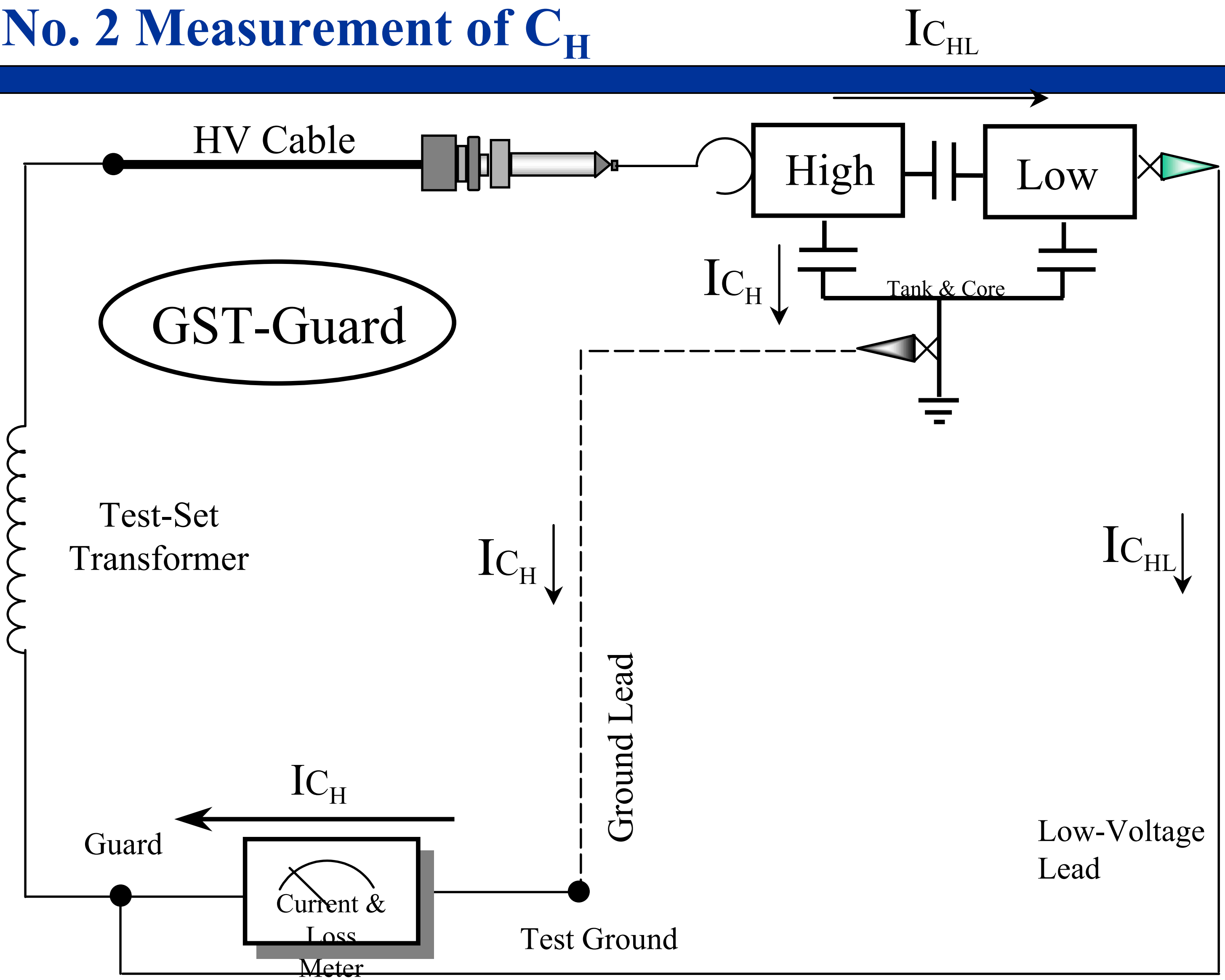
Test Connections for Test Nos. 1, 2 and Direct UST

Two-Winding Transformer Test Procedure
No. 1 - Measurement of $C_H + C_{HL}$



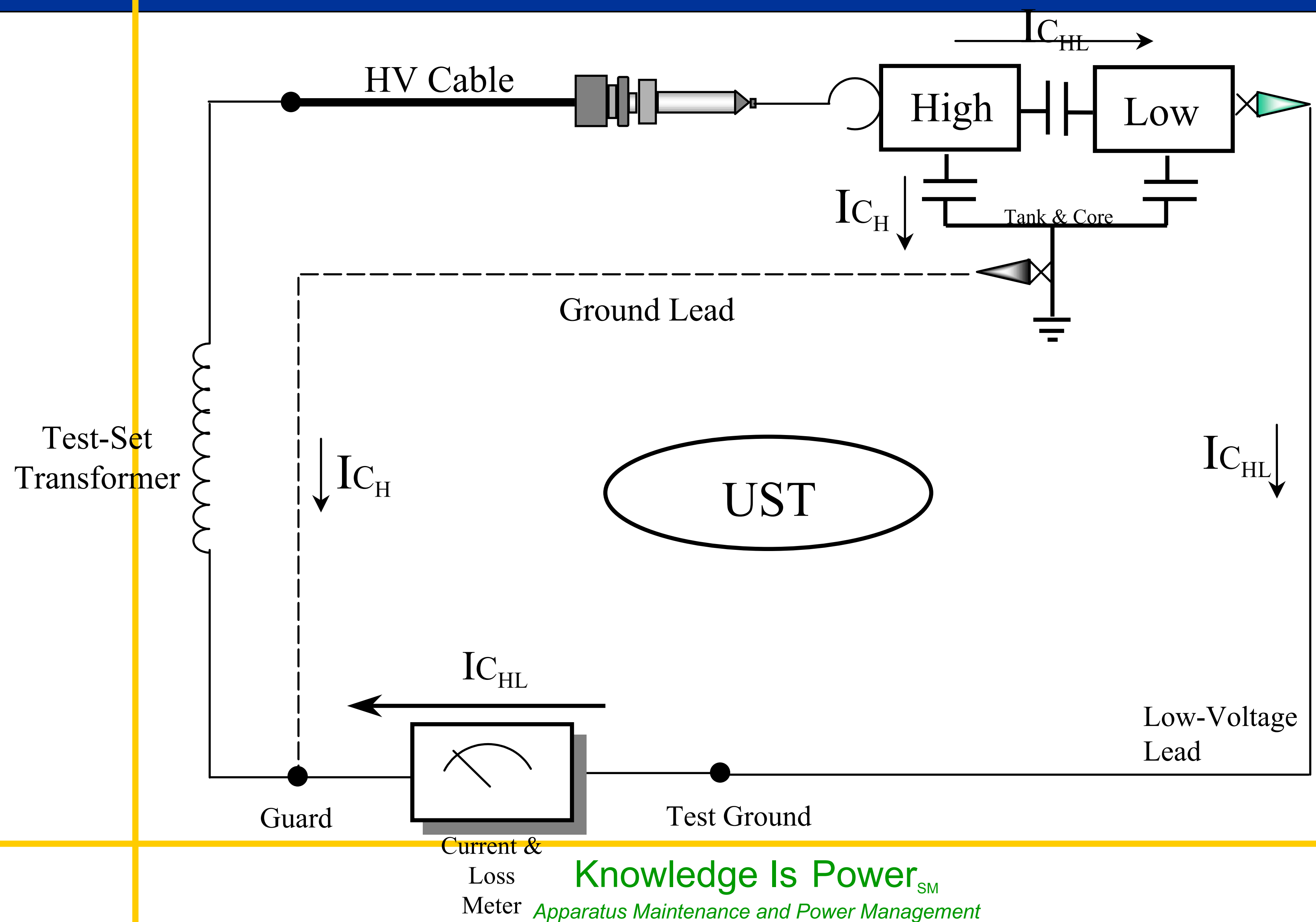
Two-Winding Transformer Test Procedure

No. 2 Measurement of C_H

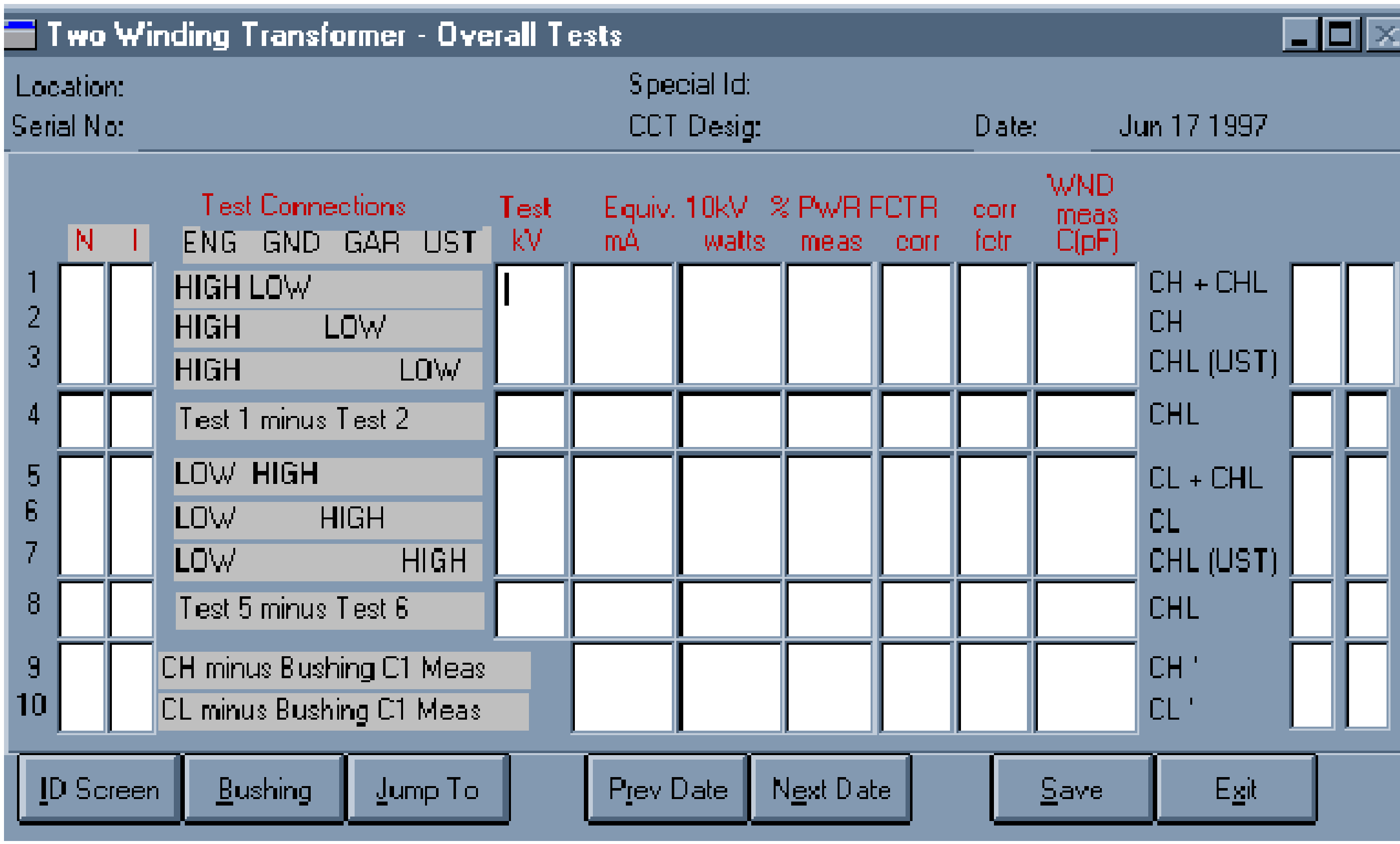


Two-Winding Transformer Test Procedure

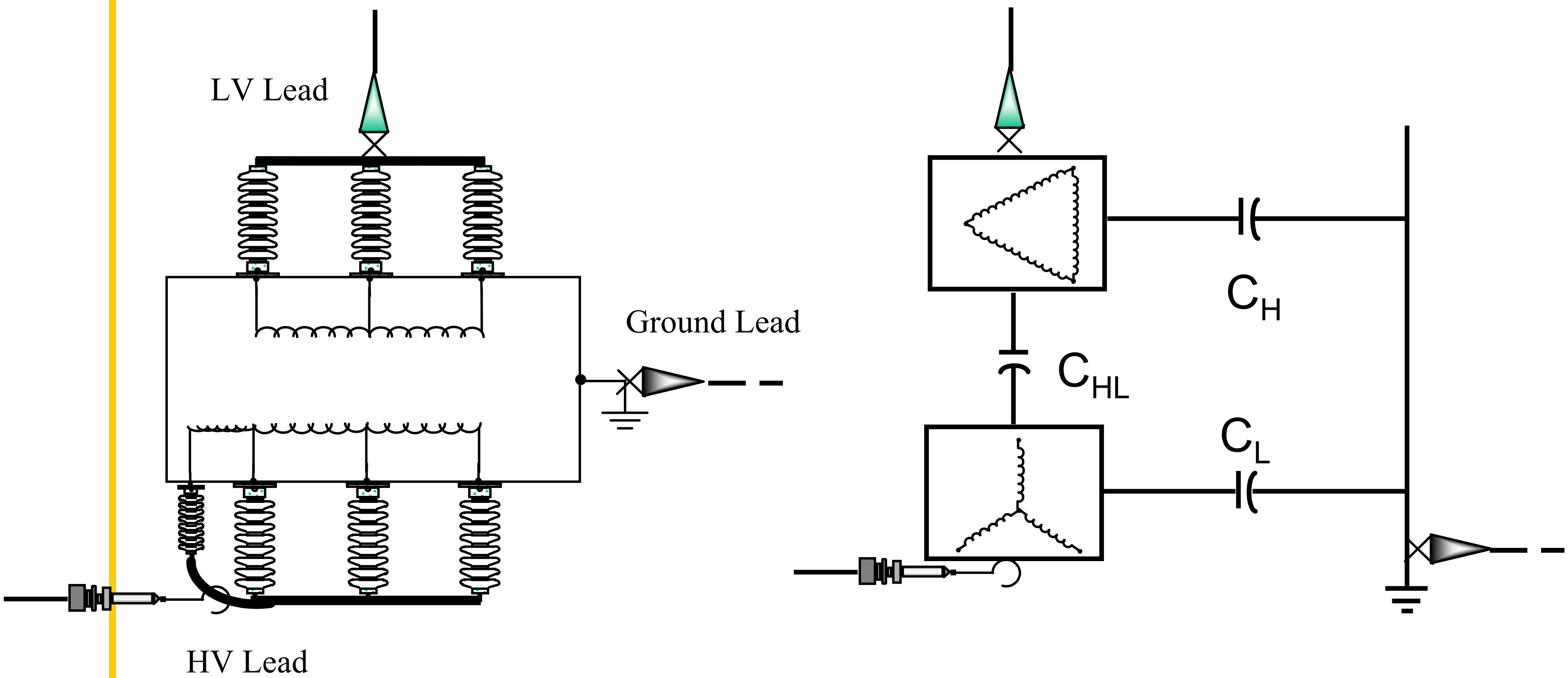
No. 3 - Direct UST - Measurement of C_{HL}



DTA Test Procedure: Two-Winding Transformer



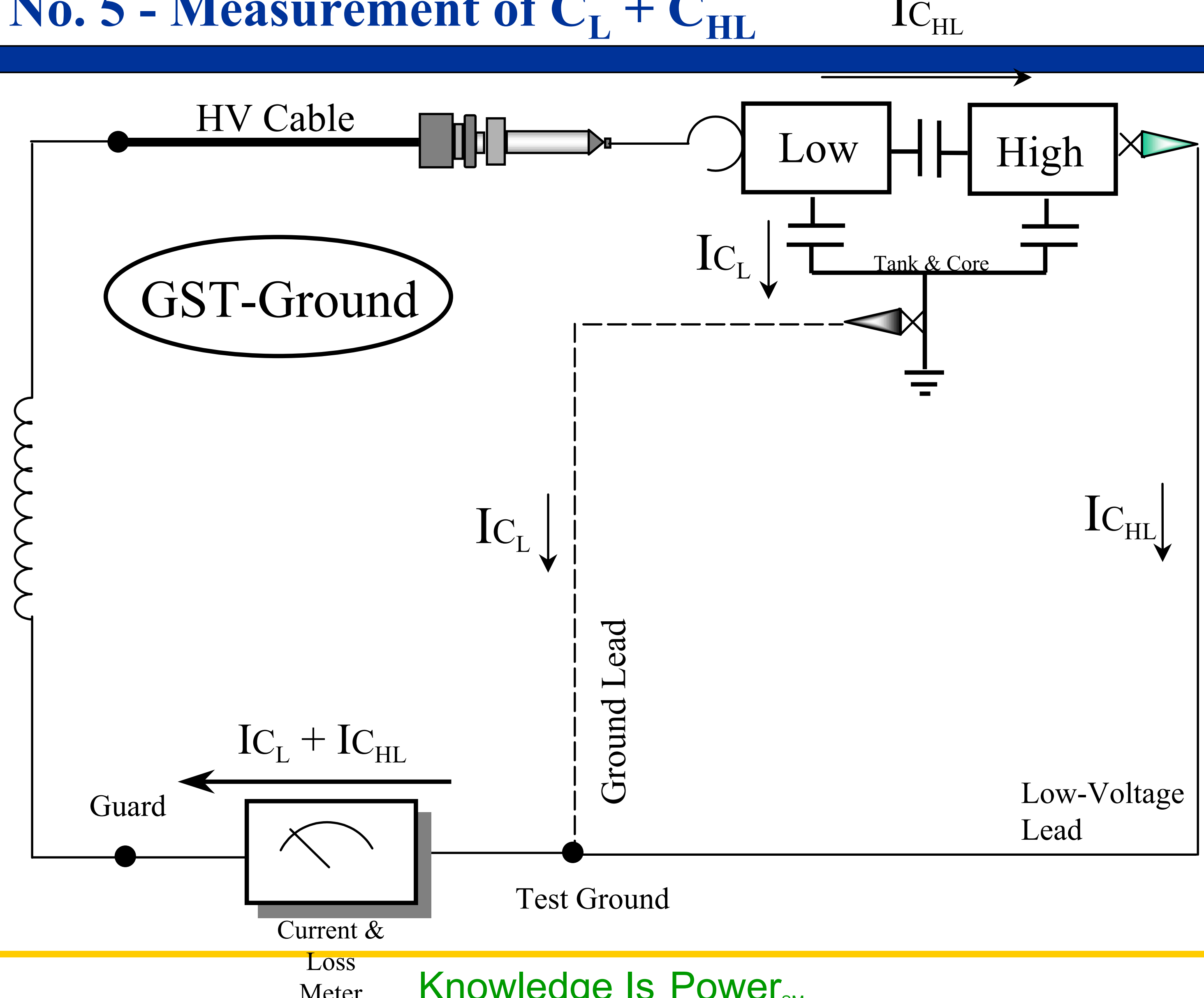
Transformer Test Procedures -- Three Phase Two-Winding



Test Connections for Test Nos. 3,4 and Direct UST

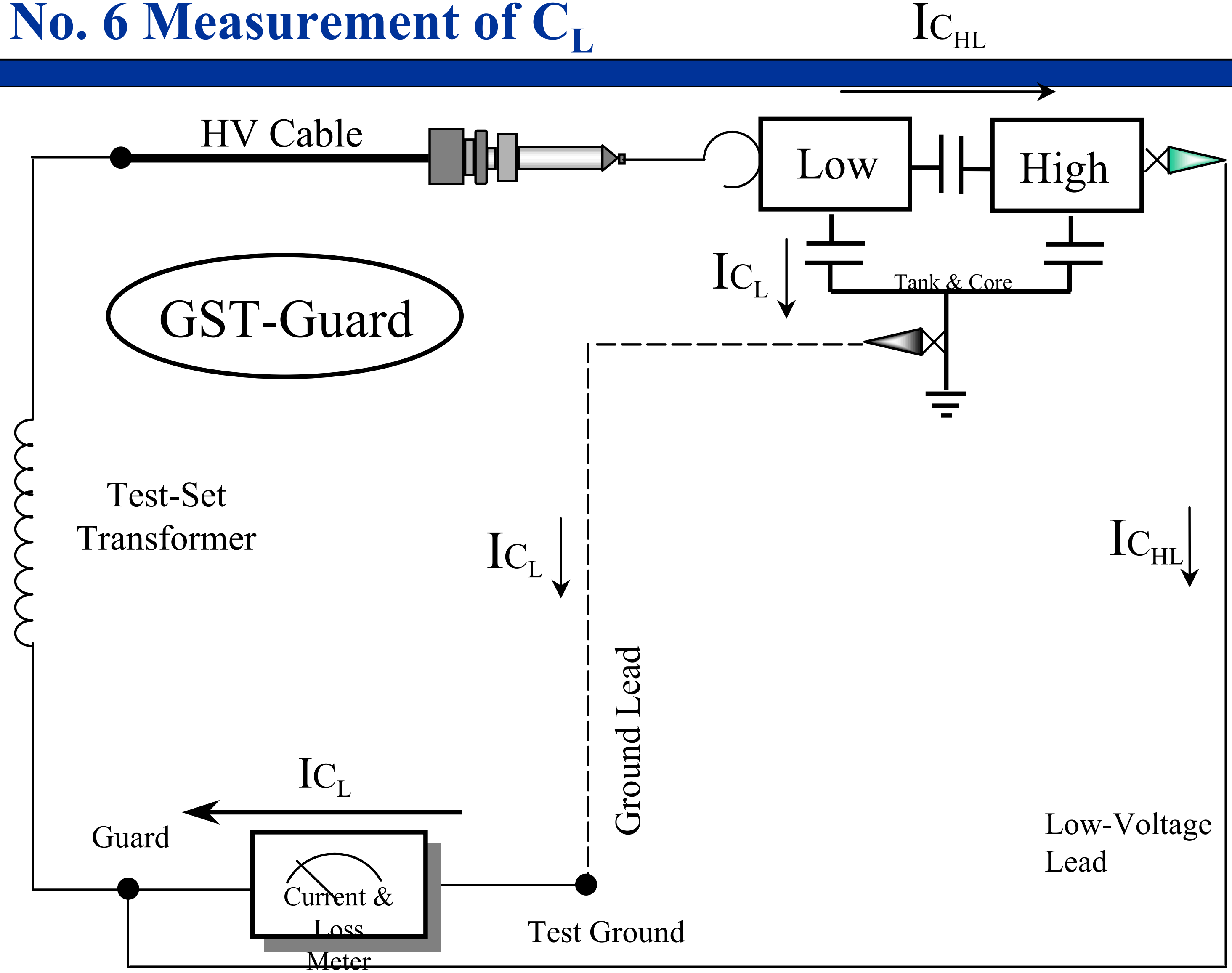
Two-Winding Transformer Test Procedure

No. 5 - Measurement of $C_L + C_{HL}$

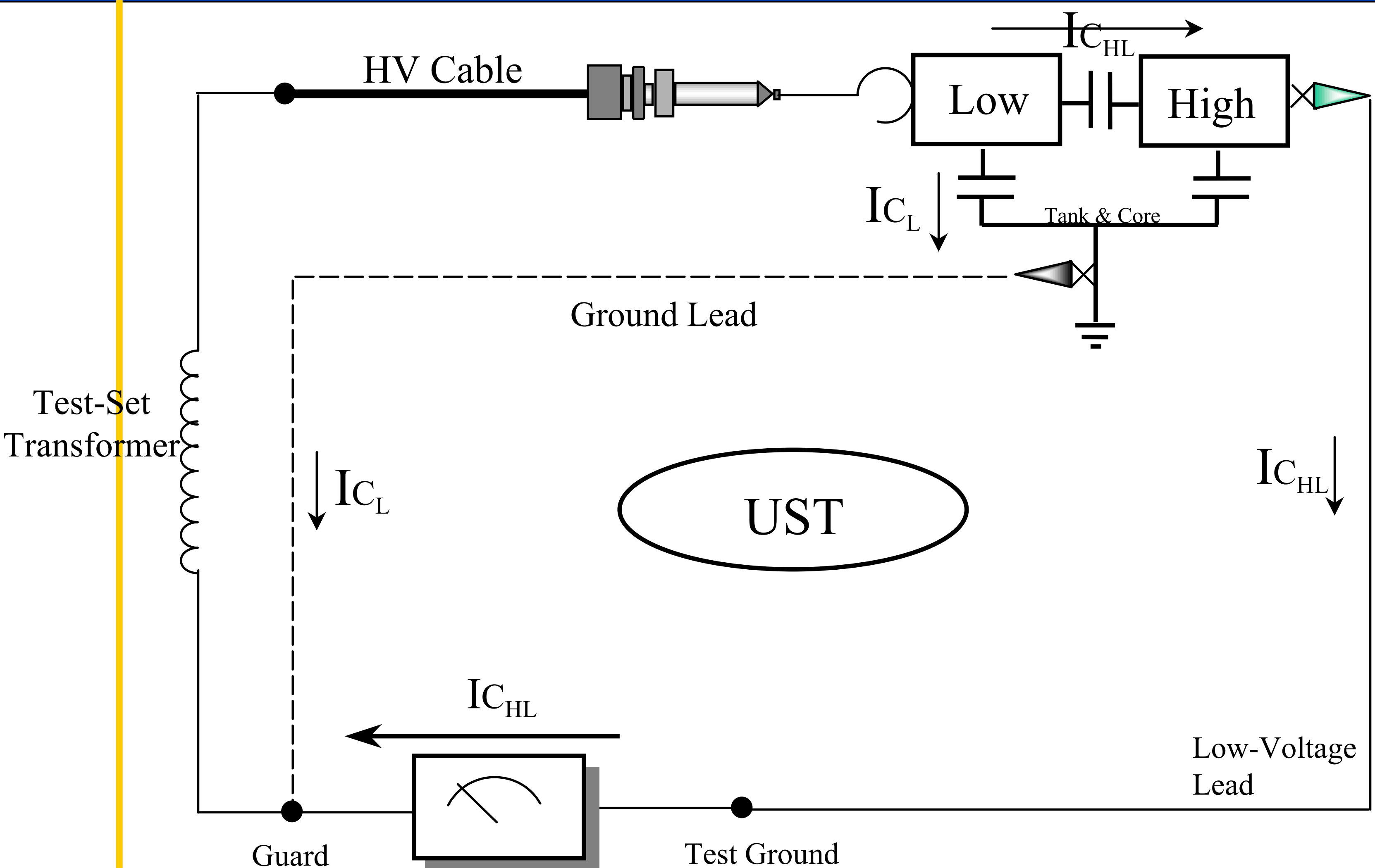


Two-Winding Transformer Test Procedure

No. 6 Measurement of C_L



Two-Winding Transformer Test Procedure
No. 7 - Direct UST - Measurement of C_{HL}



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

*Transformer Winding Rating (kV)	Test (kV)
12 and Above	10
5.04 to 8.72	5
2.4 to 4.8	2
Below 2.4	1

*Phase to Phase

Recommended Doble Power-Factor Test Voltages for Liquid-Filled Type Power and Distribution Transformers Tested in the Absence of Insulating Liquid and Under Atmospheric Air/Gas Pressure (Not Under Vacuum)

Transformer Winding Rating (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
Wye Windings and Single Phase w/ Neutral	
12 and Above	1
Below 12	0.5

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

Transformer Winding Rating (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

GENERAL GUIDELINES!

•Less Than 0.5%	--	GOOD
•>.5% but <1.0%	--	DETERIORATED
•>.5% but <1.0% and increasing	--	INVESTIGATE
•Greater than 1.0%	--	BAD

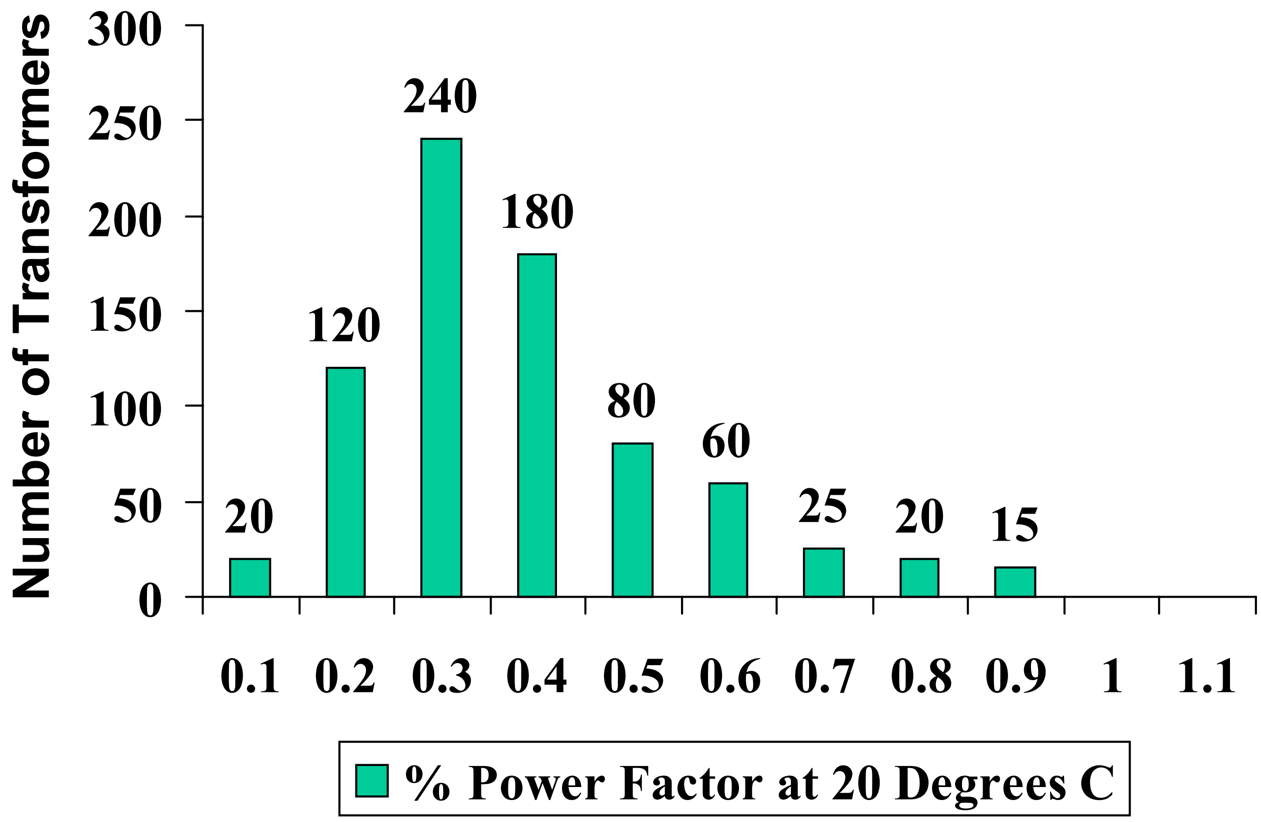
Transformer Limits

Rating	Type	New	Used
0 - 500 KVA	Distribution	1.0%	2.0%
> 500 KVA	Power	.5%	1.0%

THESE ARE GENERAL GUIDELINES

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

C_H Power Factors for Power Transformers

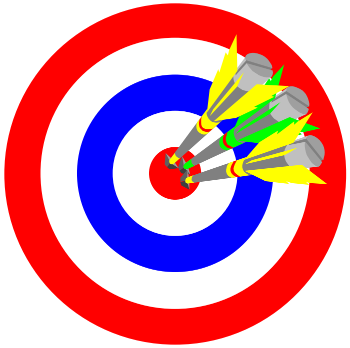


Transformer Excitation - Current Test

The Doble Excitation Current Test has been Effective in finding:

Abnormal Core Grounds

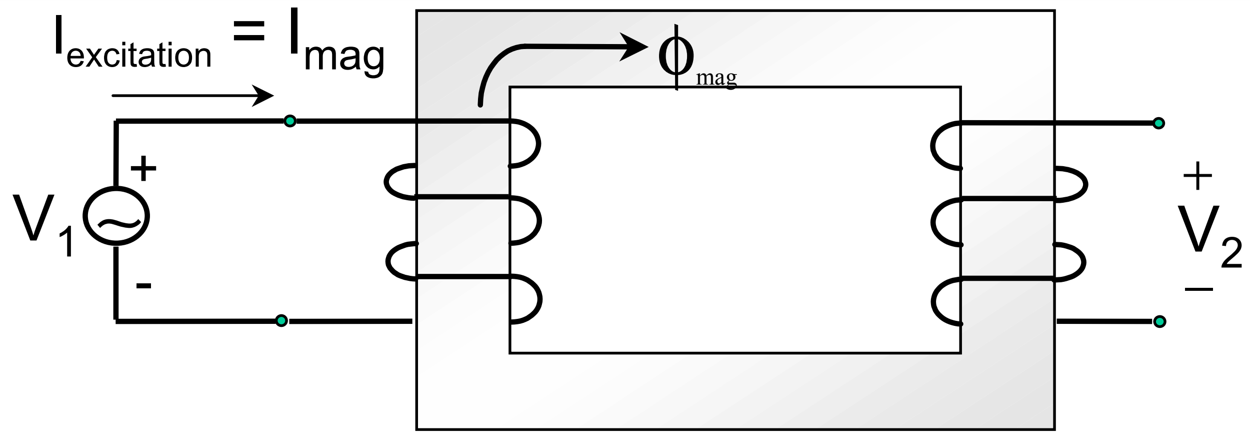
Manufacturing Defects



LTC Problems

Winding Faults: Shorts, Open Circuits

Excitation Current Principles: No Load



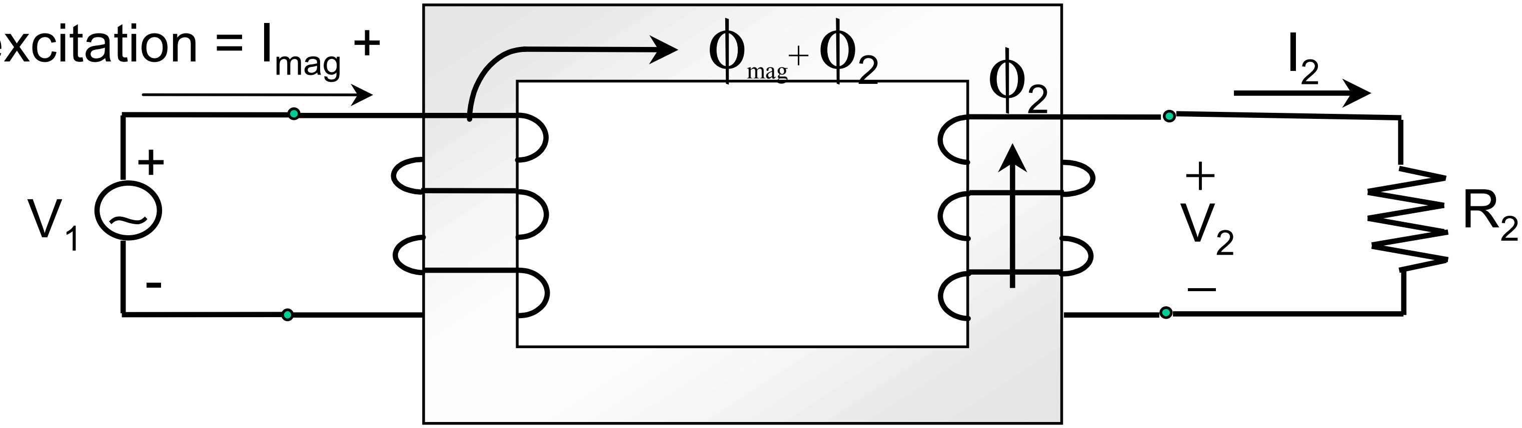
1) **When an AC Voltage Source, such as a Doble Test Set, is placed on a transformer, a small current will flow.**

2) **This small current is the *Magnetizing Current*: the current required to magnetize the Transformer core with the *Magnetic Flux* f_{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

Iexcitation = I_{mag} + I_2



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

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

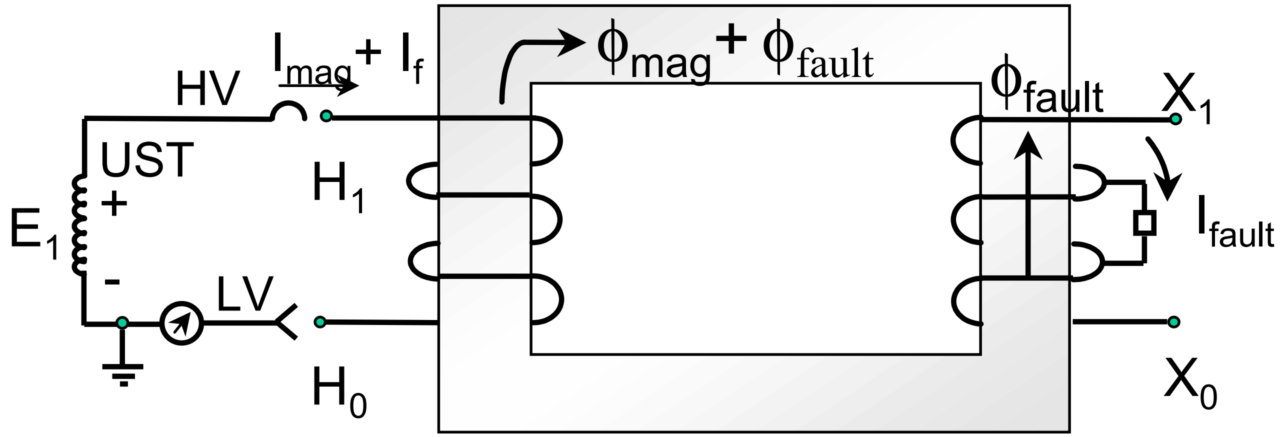
2) The Current I_2 will in-turn create an Opposing Magnetic Flux f_2.

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 Testing

Finding a Turn-to-Turn Fault



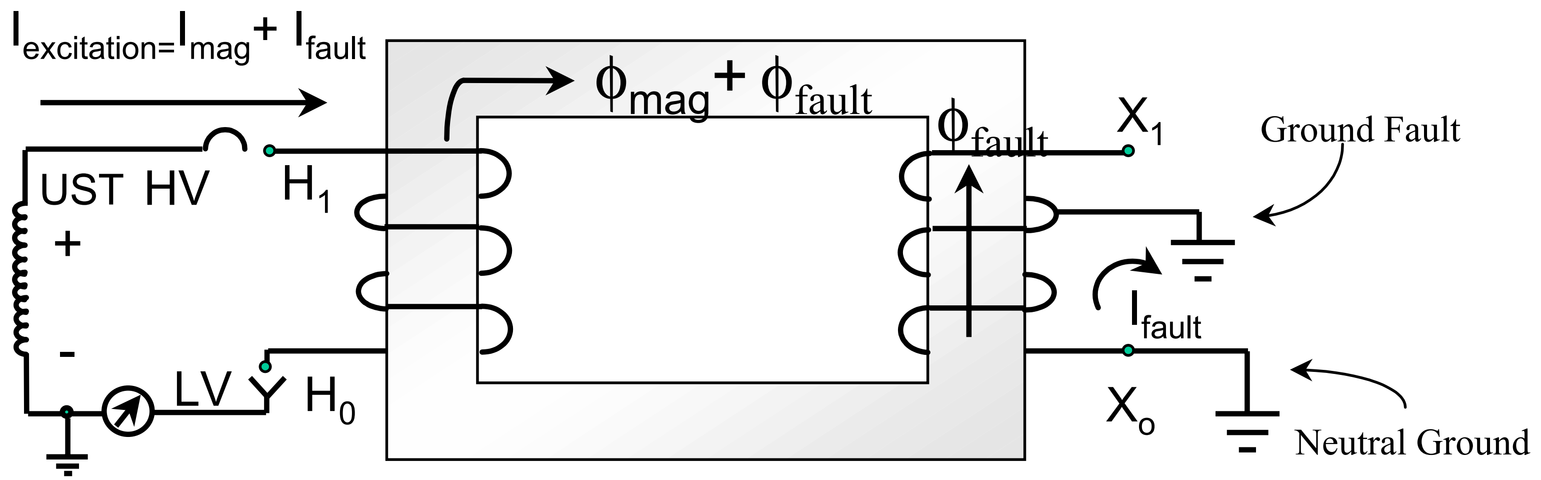
1) If a fault develops in the secondary windings, this fault will act as a load across the faulted windings drawing a current I_{fault}.

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

Result: A Fault will cause Excitation Current to Increase

Excitation Current Testing

Grounded Windings



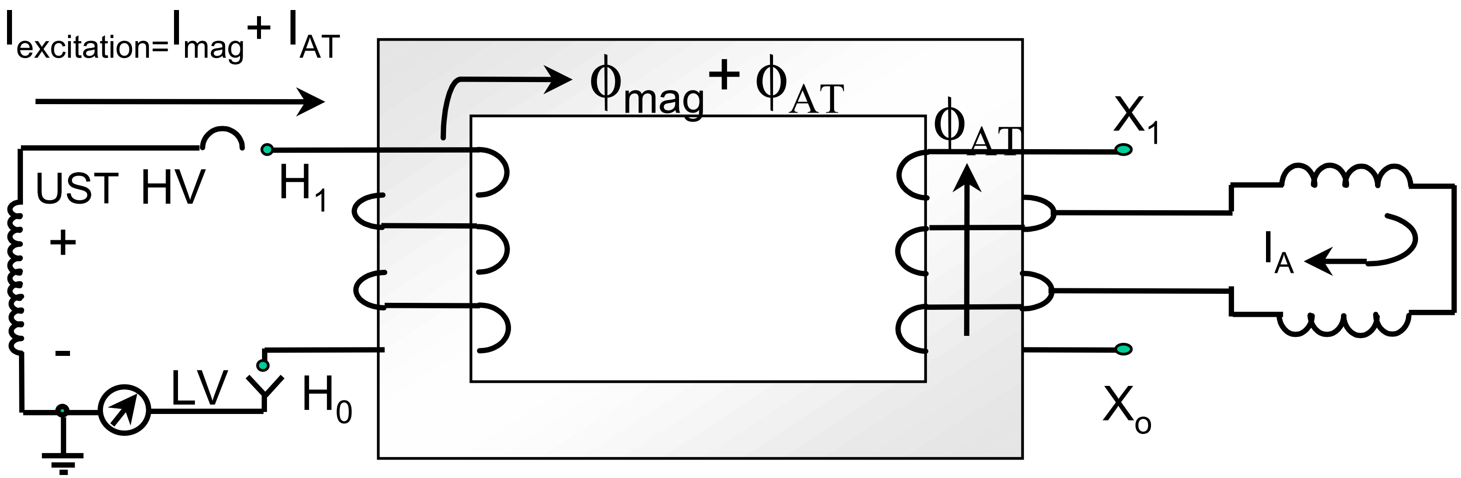
1)If the secondary winding has a grounded neutral and one of the windings develops a fault to ground, grounded windings will draw a fault current.

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

Result: A grounded winding on a transformer with a grounded neutral will cause the Excitation Current to go up.

Excitation Current Testing

Preventive Autotransformer



When a preventive 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 goes up.

Excitation Current Testing: Results

When analyzing Excitation Current, you expect to see a pattern of

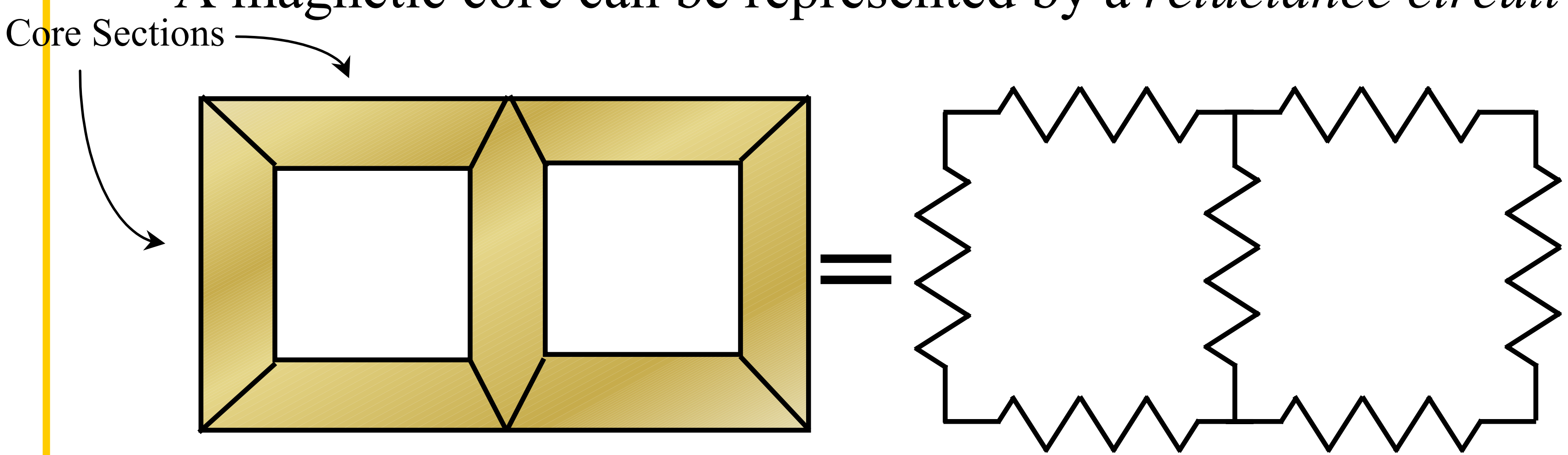
<u>Two Similar Highs</u> and <u>One Low</u>**

<u>**Reference Paper:</u>
<u>A Further Study of Excitation Current Patterns</u>
<u>Jill Duplessis</u>
<u>Spring Conference 2002</u>

Excitation Current-*The Pattern*

In a magnetic core, the *Reluctance* of the steel acts much the same to resist magnetic flux as a resistor does to current.

A magnetic core can be represented by a *reluctance circuit*

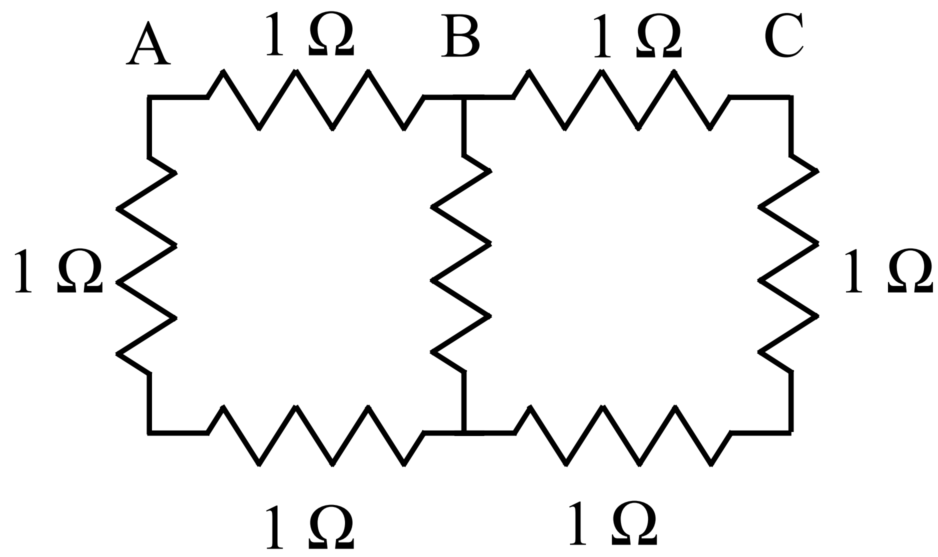


(a) Ferrous Core

(b) Reluctance Circuit

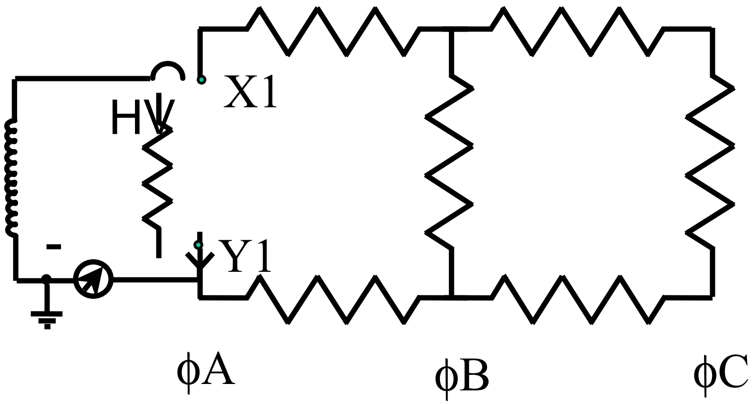
Excitation Current-*The Pattern*

For simplicity assume that each section has a reluctance of 1 Ω

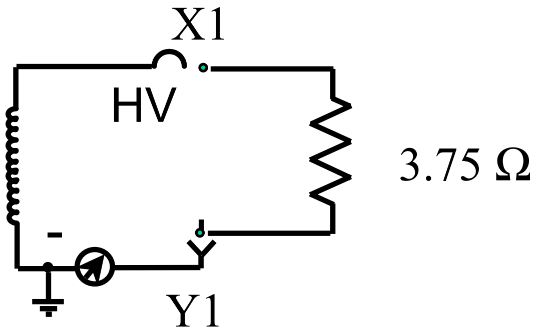


In this example we have a three legged core with three Phases

Excitation Current-*The Pattern*

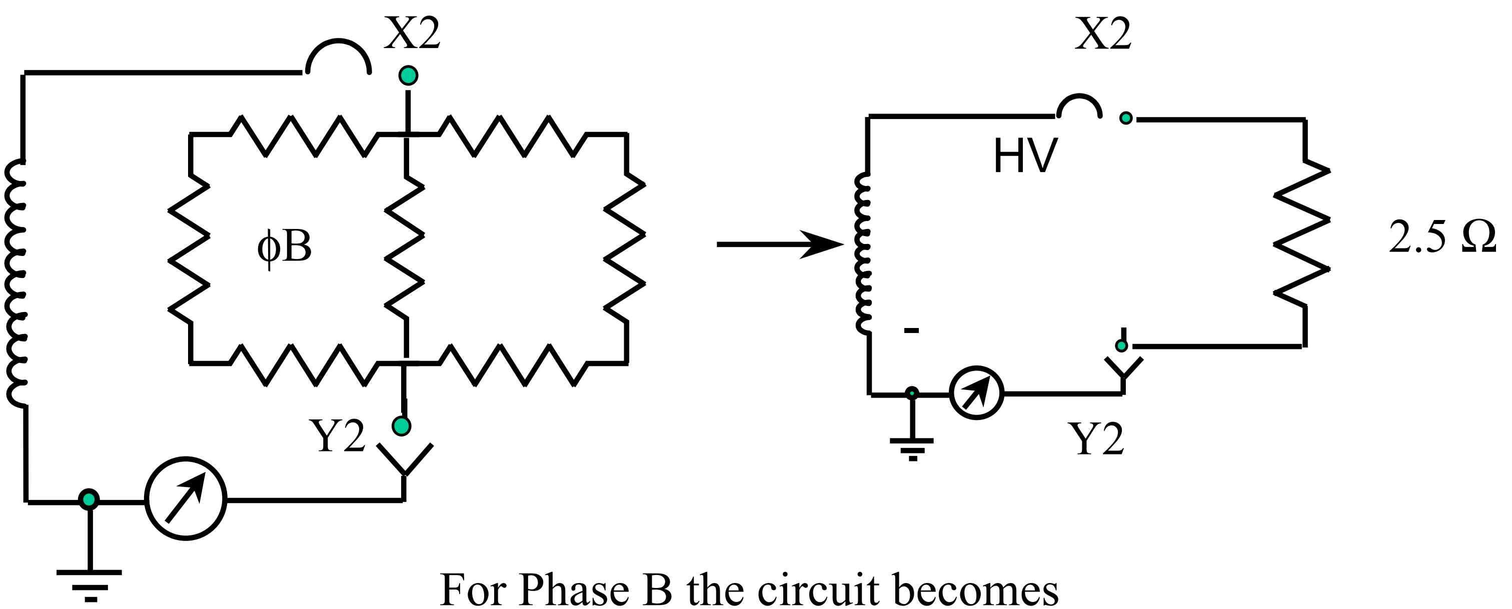


When the test set energizes Phase A The equivalent reluctance circuit becomes:



The same holds true when you energize Phase C

Excitation Current-*The Pattern*



For Phase B the circuit becomes

Conclusion: For phase A and C in our example the equivalent reluctance was 3.75 Ω, and for Phase B was 2.5 Ω : Two Highs and one Low. This general pattern holds true for most three phase transformers.

Excitation Current: Test Procedure

1) Remove the shorts
2) Set up the Test connections on the high side
3) Ground any terminals that are normally grounded during the test such as the Neutral Terminal on a Wye transformer.
4) All tests are performed in the UST Mode

<u>For ALL Transformers (New or Routine)</u>

•Test Positions of the LTC:

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

•Test Each Position of the DETC:
A,B,C,D,E with the LTC in Neutral

Excitation Current: Test Voltage

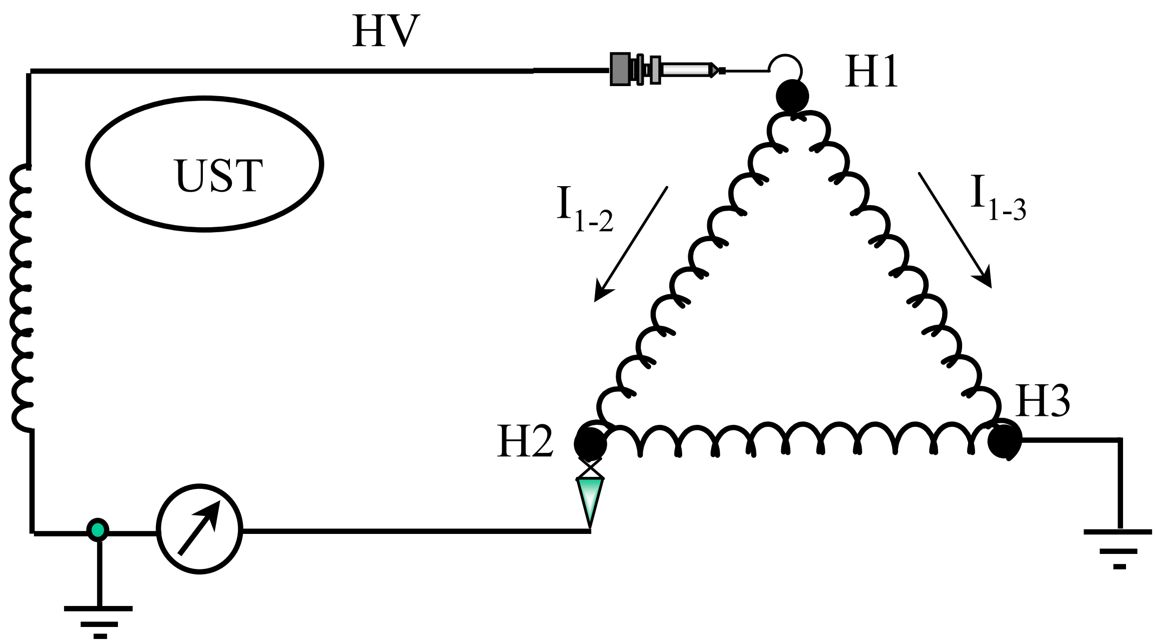
- Perform Excitation Tests at the Highest Voltage Possible.
- Test Each Phase at the same voltage.
- Perform subsequent Tests at the same Voltage for Future Comparison.
- If a Preventive Autotransformer is included in the transformer, it might not be possible to excite that position of the LTC. In this event, testing might be possible with the Preventive Autotransformer bypassed or at a lower voltage.
- If the Test set trips, choose a lower Voltage and repeat all three phases.

<u>M4K is rated for 300 mA at 10 kV</u>

10 kV	300 mA
9 kV	333 mA
8 kV	375 mA
7 kV	429 mA
6 kV	500 mA
5 kV	600 mA

Never allow test voltage to exceed rated L-L for Delta and L-G for Wye

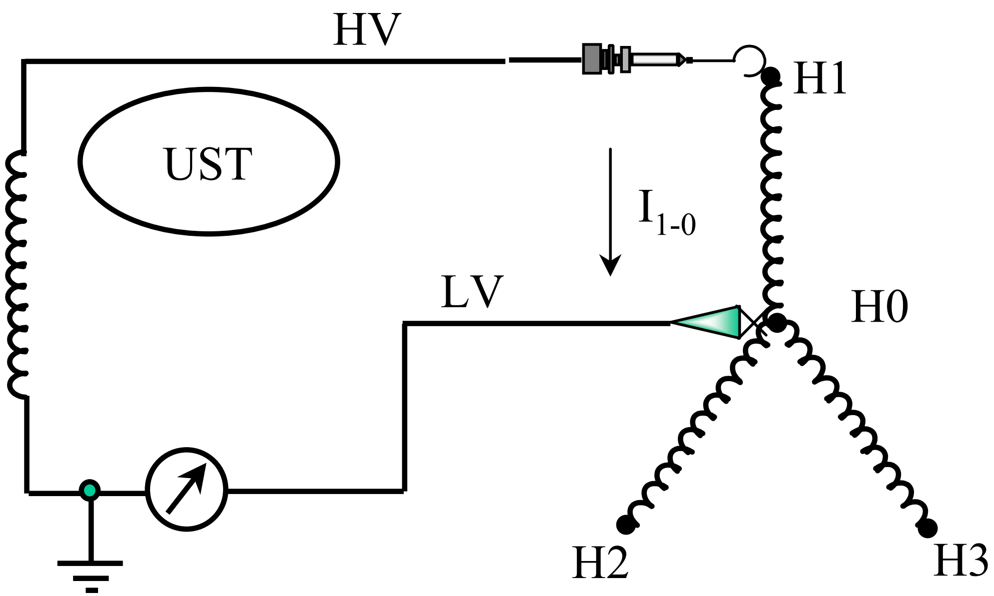
Excitation Test on Delta-Connected Primary Winding



Test No.	Measure
1	H1-H2
2	H2-H3
3	H3-H1

To Perform the Alternate test the HV and LV lead are simply reversed

Excitation Test on Wye-Connected Primary Winding



Test No.	Measure
1	H1-H0
2	H2-H0
3	H3-H0

Remember that the Excitation Current test is the only test where the Short Circuits are taken off of the bushings.

Excitation Current: Analysis of Results

(1) Compare Results to previous results. Ensure that the same voltage was used for both tests for numerical comparison

(2) Check the pattern. Two similar high and one low is normal though there are exceptions.

(3) If the core is magnetized (High, Medium, Low) you will be unable to compare results effectively and a true problem could be masked. The core should be demagnetized and retested.

(4) If unusual results are obtained, consider performing an alternate test to further investigate