The Overall Power Factor Test: In-Depth

Author Biography

Brandon Dupuis received a B.S. Electrical Engineering from the University of Maine. He joined OMICRON electronics Corp, in 2013, where he presently holds the position of Regional Application Specialist for transformer testing. Brandon's focus is currently on standard and advanced electrical diagnostics for power transformers and circuit breakers. Presently, Brandon is a well-known OMICRON instructor teaching electrical transformer diagnostic testing theory, application, and test result analysis, which includes both presentations and hands-on training. Brandon is an active member of the IEEE/PES Transformers Committee.

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2019 OMICRON Academy Transformer Trainings

January 30th and 31st – Houston, TX
https://www.omicronenergy.com/en/events/training/detail/electrical-diagnostic-testing-of-power-transformers/471/

April 16th and 17th – Toronto, ON
https://www.omicronenergy.com/en/events/training/detail/electrical-diagnostic-testing-of-power-transformers/472/

August 28th and 29th – Houston, TX
https://www.omicronenergy.com/en/events/training/detail/electrical-diagnostic-testing-of-power-transformers/171/

The Overall Power Factor Test: In-Depth

1) Power Factor Testing: The Fundamentals

2) Power Factor Testing: Test Procedures

3) Power Factor Testing: Case Studies

Power Factor Testing: The Fundamentals

The Overall Power Factor Test

- The Overall Power Factor Test is used to test the integrity of the **insulation system** of a transformer
- The Overall Power Factor Test can identify the following **insulation** defects,
  - **Naturally aged, deteriorated, and/or contaminated insulation**
  - **Overheated insulation**
  - **Moisture ingress**, which is one of the main “transformer killers”
  - **Localized insulation failures,** such as a partial or full short-circuit to ground, or between the windings

The Overall Power Factor Test

- The insulation system of a power transformer is complex, and is compromised of one or more of the following insulation components,
  - ❑ **The insulating fluid**
  - ❑ **The winding-to-ground insulation system**
  - ❑ **The winding-to-winding insulation system (aka the interwinding insulation system)**
  - ❑ **The Primary (H) bushing insulation system**
  - ❑ **The Secondary (X) bushing insulation system**
  - ❑ **The load tap-changer (LTC) insulation system**
  - ❑ **The core-to-ground insulation system** - The Insulation Resistance Test is most-appropriate for testing the core-to-ground insulation system of a transformer
  - ❑ **The turn-to-turn insulation system** – The Exciting Current, TTR, and SFRA tests are most-appropriate for testing the turn-to-turn insulation system of a transformer

Investigating a Questionable Overall Power Factor Test

- **Main-Tank Oil Screen Tests**: DGA, Oil Quality, and Moisture in Oil
- **LTC Oil Screen Tests**: DGA, Oil Quality, and Moisture in Oil
- **Bushing H Power Factor Measurements**: C1, C2, and/or Energized Collar
- **Bushing X Power Factor Measurements**: C1, C2, and/or Energized Collar
- **The Voltage Tip-Up Test**: testing at different voltages (2kV, 4kV, 6kV, 8kV, etc.)
- **The Variable Frequency Power Factor Test**: testing at different frequencies (15Hz–400Hz)
- **Dielectric Frequency Response Test**: testing at different frequencies (.01mHz - 1kHz)
- **The Insulation Resistance Test**: PI and DAR

➢ See “The Value of Performing Power Factor Sweep Measurements” paper and PowerPoint for in-depth information regarding these Power Factor Sweep Tests

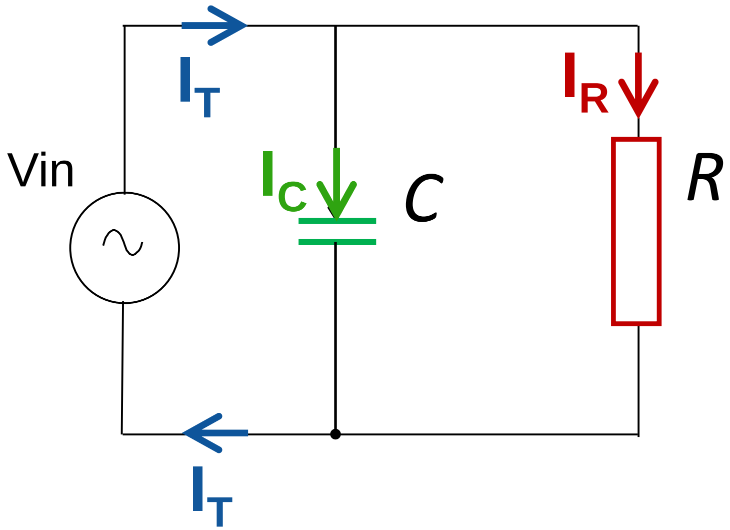
Power Factor Testing in it’s Simplest Form

Step 1: Apply an **AC Voltage** across an insulation system

Step 2: Measure the **Total Current**, the **Resistive Current**, and the **Capacitive Current**, flowing through the insulation system

Step 3: Calculate the percent Power Factor = I_R / I_T

- In general, the lower the Power Factor percentage value, the healthier the insulation system
- However, there is such a thing as “abnormally low” and “negative” Power Factor values, which are typically caused by one of the “big three of Power Factor testing”



“The Power Factor Checklist"

- **The Power Factor measurement is highly sensitive, and is one of the most difficult measurements to “get right”** (i.e. to perform correctly)

- The **“Power Factor checklist”** is a series of steps that must be observed, when performing a Power Factor measurement on an insulation system, to ensure that the correct measurement is obtained

- **Failure to observe all the steps in the “Power Factor checklist” often results in “bad” Power Factor measurements** (i.e. invalid Power Factor measurements)

“The Power Factor Checklist"

- ❑ **Is the transformer tank solidly grounded to earth-potential?**
- ❑ **Is the test-equipment solidly grounded to earth-potential?**
- ❑ **Are the bushing terminals of the transformer completely disconnected and isolated from any cable, bus-bar, support insulators, surge arrestors, etc.?**
  - ❑ When applying a test-voltage of 10kV, a minimum clearance of 3in. must be observed (which is the minimum distance required between the bushing terminals that are energized, and any other surface at a different potential)
  - ❑ Avoid using a rubber blanket or any other insulator to isolate the bushing terminals from any other surface at a different potential
- ❑ **Are the surfaces of the bushings clean and dry? People often do not respect how significantly moisture on the bushings can influence a Power Factor measurement**
  - ❑ If the bushings have a porcelain exterior → use Windex or Colonite
  - ❑ If the bushings have a silicone exterior → use a clean, dry rag

“The Power Factor Checklist"

- ❑ **Are the groups of bushing terminals short-circuited together (i.e. all HV bushing terminals shorted together, all LV bushing terminals shorted together, etc.)?**
  - ❑ Use bare copper, to short-circuit the bushing terminals together – Do not use insulated leads!
  - ❑ Connect the shorting jumpers as tightly as possible from bushing terminal-to-bushing terminal
- ❑ **Remove all in-service grounds from any neutral bushing terminals –** For example, remove the in-service ground-connection from the X0 bushing terminal, if applicable
- ❑ **Place the LTC in any off-neutral tap-position** - Some LTCs have a “tie-in resistor”, which may be inserted into the test-circuit when the LTC is in the Neutral tap-position. This “tie-in resistor” can influence a Power Factor measurement
- ❑ **Ensure that the HV cable is “in the clear”**, and that the last two feet of the HV cable is not touching any surface of the transformer (e.g. the transformer tank, the bushing surfaces, etc.)

“The Power Factor Checklist”

- ❑ Do not Power Factor test in the rain
- ❑ Avoid testing in high-humidity situations
- ❑ Do not Power Factor test when the temperature of the oil is close-to, or below, 5°C
- ❑ Power Factor test after lunch, if possible

The "Big Three" of Power Factor Testing

- **In nearly all cases, a "questionable" or "abnormal" Power Factor measurement is caused by one of the following three things**,

    1. User-error

    2. The test-environment

    3. Compromised insulation

- **Most of the time, a "questionable" or "abnormal" Power Factor measurement is caused by one of the first two items listed above**

- The test-equipment operator must troubleshoot, and retest, to determine which of the three items listed above is causing a "questionable" or "abnormal" Power Factor measurement

Factors that Can Influence the Overall Power Factor Test

- **User-error** – Always review the “Power Factor Test Checklist” prior to testing
- **The test-environment:** rain, high-humidity, snow, unusually cold temperatures, and unusually hot temperatures can influence a Power Factor measurement
- **The insulating fluid temperature at the time of the test**
    - Theoretically, the higher the oil temperature, the higher the Power Factor value will be
    - Theoretically, the lower the oil temperature, the lower the Power Factor value will be
    - Typically, the measured Power Factor value will not change significantly if the measurement is performed with an oil temperature in the range of 5°C-35°C (this is my recommended range of “high comfortability”)
    - Temperature correcting Power Factor measurements is not an exact science

Factors that Can Influence the Overall Power Factor Test: Temperature Correction

- Temperature correcting Power Factor measurements is not an exact science
- **In fact, I typically do not recommend using temperature correction factors, when performing and analyzing Power Factor measurements**
- **Instead, simply document the following "test-environment conditions"**, which may be used to justify an "abnormal" Power Factor measurement
    - ❑ The ambient temperature
    - ❑ The relative humidity
    - ❑ The top oil temperature
    - ❑ The winding temperature
    - ❑ Document any rain or snow

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Factors that Can Influence the Overall Power Factor Test: Temperature Correction

- **If documented, the “test-environment conditions” can later be used to justify an “abnormal” Power Factor measurement**
- **Remember, correction factors can always be applied and tuned after a Power Factor measurement has been completed – The key is to first obtain the correct measurement**
- Remember...
  - ❑ Do not Power Factor test in the rain
  - ❑ Avoid testing in high-humidity situations
  - ❑ Do not Power Factor test when the temperature of the oil is close-to, or below, 5°C
  - ❑ Power Factor test after lunch, if possible

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Factors that Can Influence the Overall Power Factor Test: The Insulating Fluid Type

- **Mineral oil**
  - Mineral Oil is by far the most common insulating fluid type
  - The range of Power Factor values that we typically see for transformers filled with mineral oil, is smaller, relative to transformers filled with all the other fluid types
  - Transformers filled with mineral oil are typically easier to assess, relative to transformers filled with other fluid types
- **Natural ester**
  - Transformers filled with an ester fluid tend to test with higher Power Factor values relative to transformers filled with mineral oil
  - The range of Power Factor values that we typically see for transformers filled with an ester fluid, is larger, relative to transformers filled with mineral oil
  - Transformers filled with an ester fluid are typically more difficult to assess, relative to transformers filled with mineral oil

Factors that Can Influence the Overall Power Factor Test: Insulating Fluid Type

- **Silicone**
  - Transformers filled with a silicone fluid tend to test with higher Power Factor values relative to transformers filled with mineral oil
  - The range of Power Factor values that we typically see for transformers filled with a silicone fluid, is larger, relative to transformers filled with mineral oil
  - Transformers filled with a silicone fluid are typically more difficult to assess, relative to transformers filled with mineral oil
- **Dry-type insulation**
  - Dry-type transformers tend to test with higher Power Factor values relative to transformers filled with all the different fluid types
  - The range of Power Factor values that we typically see for dry-type transformers, is larger, relative to transformers filled with all the different fluid types
  - Dry-type transformers are probably the most-difficult type to assess

Factors that Can Influence the Overall Power Factor Test

- **The Transformer's Size (MVA rating)**
  - In general, the higher the MVA rating of a transformer, the smaller the range of Power Factor values that we typically see
  - In general, the lower the MVA rating of a transformer, the larger the range of Power Factor values that we typically see
  - Therefore, assessing the Power Factor Test on a relatively large power transformer is often easier, than assessing the Power Factor Test on a relatively small distribution transformer
- **The Transformer's Age** – In general, the longer the transformer has been in-service, the higher the Power Factor values we expect to see
- **The Bushing Insulation** – The insulation of the bushings are "baked into" the winding-to-ground (GST) Power Factor measurements

Factors that Can Influence the Overall Power Factor Test: The Bushing Insulation

- **The insulation of the bushings are "baked into" the winding-to-ground (GST) Power Factor measurements**
    - The High-Voltage (H) bushings influence the CH measurement
    - The Low-Voltage (X) bushings influence the CL measurement
    - The Tertiary-Voltage (Y) bushings influence the CT measurement
- **The Inter-winding (UST) Power Factor measurements outlined below, are not influenced by the condition of the bushing insulation**
    - CHL
    - CLT (for a three-winding transformer)
    - CHT (for a three-winding transformer)

Factors that Can Influence the Overall Power Factor Test: The Bushing Insulation

A transformer's bushing insulation may...

1) **Adversely effect a Power Factor measurement** – For example, a "bad bushing" on the primary-side, may increase the CH Power Factor value, and may make it appear that there exists an issue involving the main-tank insulation system of the transformer

2) **Improve a Power Factor measurement** – For example, a "healthy bushing" on the primary-side, may decrease the CH Power Factor value, which may mask a problem involving the main-tank insulation system of the transformer

3) **Have a negligible effect on the Overall Power Factor measurements** – For example, if the Capacitance of the winding-insulation is significantly larger than the Capacitance of the bushings, than the bushings will have little effect on the Overall Power Factor Test

Factors that Can Influence the Overall Power Factor Test: The Bushing Insulation

- If a transformer tests with an “abnormally high” CH or CL Power Factor value, then we first need to determine whether or not the issue involves the bushing insulation

- Fortunately, we can subtract the contribution of the bushings, from the Overall Power Factor values, if the C1 Power Factor measurement can be performed on the bushings

    - For example, if the C1 Power Factor measurement can be performed on the High-Voltage (H) bushings, then the contribution of the H bushings can be subtracted from the CH measurement

    - For example, if the C1 Power Factor measurement can be performed on the Low-Voltage (X) bushings, then the contribution of the X bushings can be subtracted from the CL measurement

Factors that Can Influence the Overall Power Factor Test: The Bushing Insulation

- For example, if the C1 Power Factor measurement can be performed on the High-Voltage (H) bushings, then the contribution of the H bushings can be subtracted from the CH measurement
- In the example below, the CH value is “higher than normal”, so we first need to determine whether or not the issue involves the High-Voltage (H) bushing insulation
- Hopefully a “higher than normal” Overall Power Factor value is due to a “bad bushing”, which is relatively easier to resolve, as opposed to a main-tank winding-insulation issue, which is difficult to correct

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	2012	12MVA	115kV	12.47kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	0.57%	0.58%	0.01%
CL	0.29%	0.30%	0.01%
CHL	0.29%	0.29%	0.00%

The Overall Power Factor Test: Analysis Strategies

1) **Time-based comparison (aka "trending")**

    - Having previous test results to compare to, certainly helps to better-assess the condition of the insulation system under test

    - In general, if the Power Factor value increases over time, then the condition of the insulation system has worsened, since the previous test date

2) **Applying industry limits**

3) **Similar unit comparison (aka "sister unit comparison")**

    - Always compare the asset's serial numbers before comparing the Overall Power Factor Test results amongst sister units – sister unit assets typically have similar serial numbers

    - Always compare the asset's measured Capacitance (pF) values before comparing Overall Power Factor Test results. Sister unit assets typically have similar measured Capacitance (pF) values

Typical Overall Power Factor Test Limits

Typical Overall Power Factor Limits		
Measurement	"Investigate" Limit	"High-Risk" Limit
Oil-Filled Transformers < 230kV	0.5%	1%
Oil-Filled Transformers ≥ 230kV	0.4%	1%

The Overall Power Factor Test – General Rules

- For an oil-and-paper insulation system, a Power Factor value in the range of 0.15%-0.3% is ideal
- New, oil-filled power transformers typically test with Overall Power Factor values below 0.3%
- For service-aged two-winding power transformers, the CL Power Factor value is often higher, relative to the CH and CHL Power Factor values
- Most service-aged two-winding power transformers test with CH and CHL values below 0.4%; therefore, I tend to use a limit of 0.4% for the CH and CHL measurement
- Most service-aged two-winding power transformers test with a CL value below 0.5%; therefore, I tend to use a limit of 0.5% for the CL measurement

“Abnormally Low” or “Negative” Power Factor Values

- **When testing an oil-and-paper insulation system, an “abnormally low” Power Factor value is typically defined as a Power Factor value below 0.1%**
- **An “abnormally low” or negative Power Factor value is typically caused by a “high resistive path to ground”**, which could be due to one of the following,
  - **User-error** – Always review the “Power Factor Test Checklist” prior to testing
  - **The test-environment:** rain, high-humidity, snow, unusually cold temperatures, and unusually hot temperatures
  - A **“low capacitance specimen”**, which is typically defined as a test specimen that has a Capacitance (pF) value below 80pF
  - A **loose or poorly connected bushing ground flange –** This is typically only relevant when performing the C1 and C2 Power Factor measurements
  - **Compromised insulation**

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Analyzing the Measured Capacitance (pF) Value

- **In general, the measured Capacitance (pF) value for a power transformer should not change over time**
- **If the measured Capacitance (pF) value of an Overall Power Factor measurement deviates by more than 2-3% relative to a previous measurement, then the measurement should be investigated**
- A change in Capacitance (pF) indicates that something has physically/mechanically changed since the previous Power Factor measurement was performed
- The Capacitance (pF) value of an Overall Power Factor measurement is not very sensitive, so if the Capacitance does change by more then 2-3%, then it is actually possible that something significant has changed
- The **SFRA and Leakage Reactance** tests are more sensitive to “mechanical failures”, relative to the Capacitance measurement – In other words, they are more likely to “see” a “mechanical change”, relative to the Capacitance measurement

What Could Cause the Measured Capacitance (pF) Value to Change?

- **User-Error**

- **The Bushing Terminal Connections -** Were the bushing terminals completely isolated from the bus, from the surge arrestors, from the support insulators, etc. when both Overall Power Factor measurements were performed? Introducing external insulation may change the measured Capacitance (pF) value

- **The “Core-Ground Connection”**

  - Is it possible that the core-ground connection was not “made” when the Power Factor measurement was performed?

  - Did the transformer lose its core-ground connection?

  - Typically, a “loss of core-ground” will change the CL Capacitance value

- **The Insulating Fluid State** - Was the transformer filled with its insulating fluid when both Overall Power Factor measurements were performed?

What Could Cause the Measured Capacitance (pF) Value to Change?

- **The Bushing State** - When the Overall Power Factor measurements were performed, did the transformer have the same exact bushings installed? For example, was the factory Overall Power Factor Test performed with the bushings not-installed or with "test bushings"?

- **The LTC Position** - Was the Overall Power Factor measurement performed with the LTC in the same tap-position, for the Overall Power Factor measurements that are being compared?

- **A Mechanical Failure within the Main-Tank** – For example, winding movement or winding deformation within the main-tank of the transformer can cause the Capacitance to change

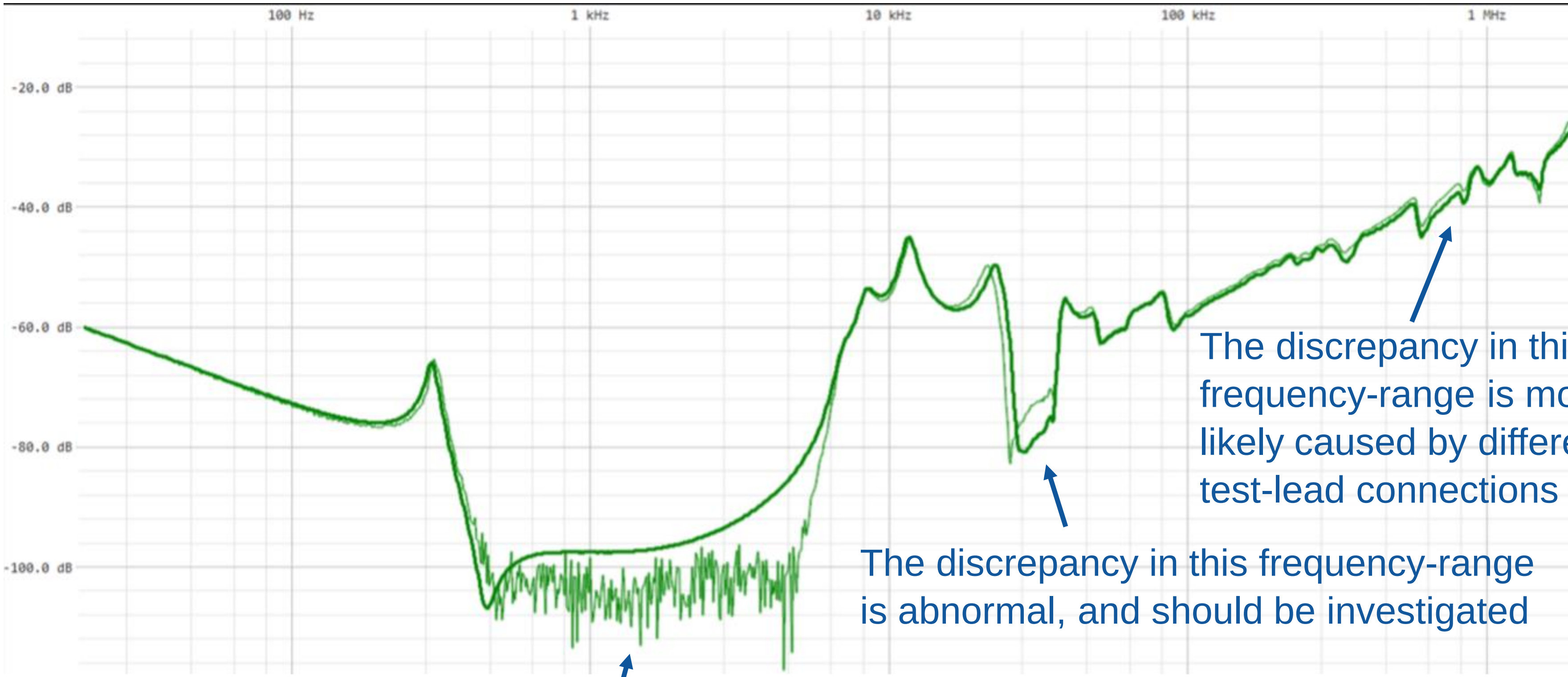
➢ **The SFRA and Leakage Reactance tests should be used to confirm that a "mechanical change" has occurred within the main-tank of a power transformer**

Analyzing the Measured Capacitance Value: Case Study

Two-Winding Transformer, ABB, 138kV-13.09kV, 20MVA			
Measurement	Factory Capacitance Measurement	Field Capacitance Measurement	Percent Change
CH	2426pF	2461pF	1.44%
CL	7338pF	8716pF	18.7%
CHL	3583pF	3557pF	-0.73%

Analyzing the Measured Capacitance Value: Case Study

Factory vs. Field SFRA Results - H2-H1 Open-Circuit Test (Phase-B)



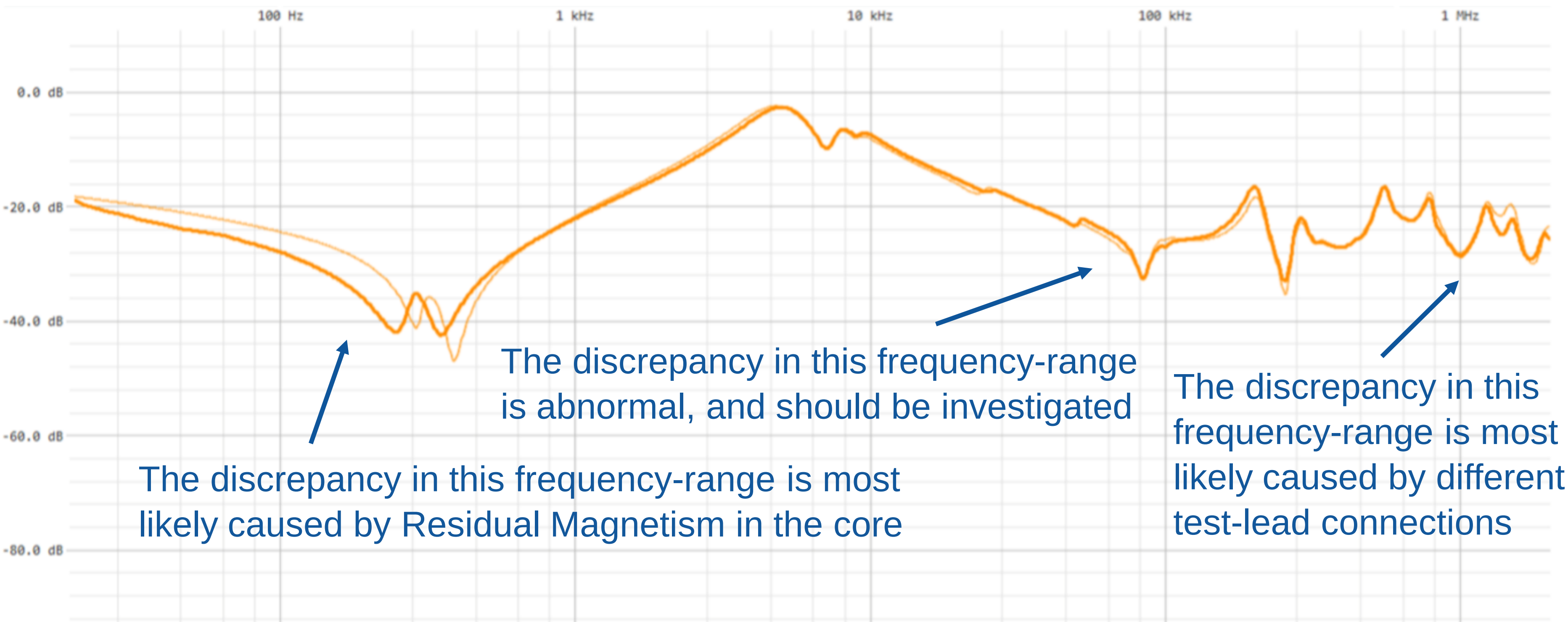
The discrepancy in this frequency-range is most likely caused by different test-lead connections

The discrepancy in this frequency-range is abnormal, and should be investigated

The discrepancy in this frequency-range is most likely caused by Residual Magnetism in the core

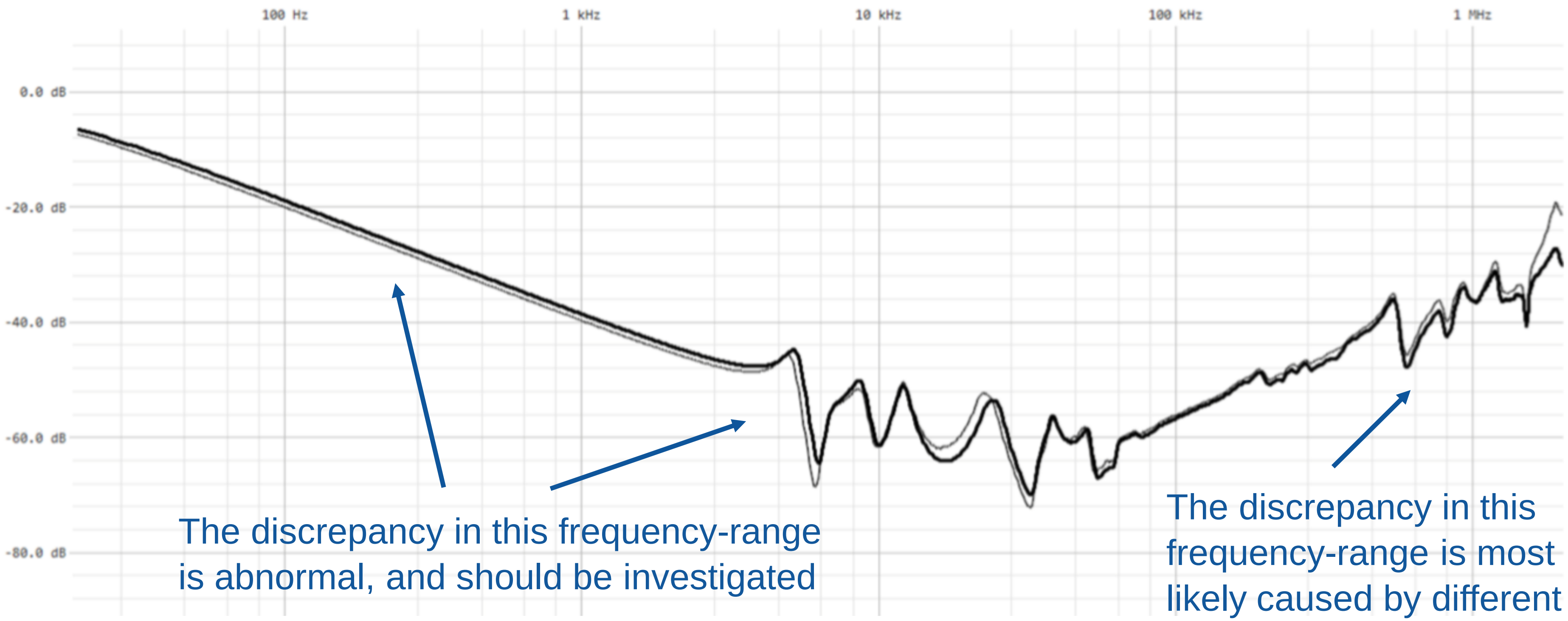
Analyzing the Measured Capacitance Value: Case Study

Factory vs. Field SFRA Results - X1-X0 Open-Circuit Test (Phase-A)



Analyzing the Measured Capacitance Value: Case Study

Factory vs. Field SFRA Results – H3-H2 Short-Circuit Test (Phase-C)



The discrepancy in this frequency-range is abnormal, and should be investigated

The discrepancy in this frequency-range is most likely caused by different test-lead connections

Analyzing the Measured Capacitance Value: Case Study

- The measured CL Capacitance (pF) value changed by 18.7%, when comparing the field and factory Overall Power Factor Test results
- There is a noticeable discrepancy when comparing the field and factory SFRA traces, for all three phases
- **Upon further investigation, the customer determined that the factory measurements were performed with the “core-ground strap” disconnected, while the field measurements were performed with the “core-ground strap” connected**

Power Factor Testing: Test Procedures

Power Factor Test-Equipment Overview

- **The high-voltage (10kV) injection lead** – Used to apply an AC voltage across the insulation system under test
- **The current measurement leads (red-A and blue-B)** – Used to measure the AC current flowing through the insulation system under test
- **The test-instrument ground lead**
    - ❑ Typically connected to the transformer tank-ground
    - ❑ Used to solidly ground the test-equipment to earth-ground potential
    - ❑ Used as a measurement lead, to measure the insulation that is connected to ground
- **The "guard-circuit"** - Used to isolate and measure different pieces of insulation, while reducing the number of test connections required to do so

The “Guard-Circuit" and the "Test Modes"

- The **“guard-circuit”** is used to isolate and measure different pieces of insulation, while reducing the number of test-connections required to do so
- Due to the **“guard-circuit”**, often-times more than one piece of insulation can be isolated and tested, while using a single test-connection
- The state of the Ground lead, the Red-A lead, and the Blue-B lead, is described by the **“test mode”** that is selected when performing a Power Factor test
- The three main Power Factor **“test modes”** are,

  1) **Grounded Specimen Test** (GST)
  2) **Grounded Specimen Test with Guard** (GST-guard or GST-g)
  3) **Ungrounded Specimen Test** (UST)

The “Guard-Circuit" and the "Test Modes"

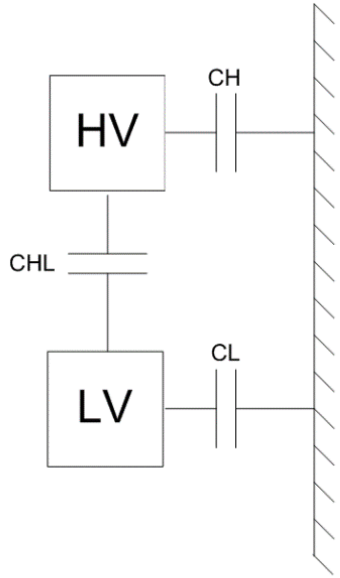
1) **Grounded Specimen Test (GST)**
   - The insulation components that are connected to ground are measured
   - The insulation components that are connected to the Red-A and Blue-B leads are measured (if connected to the test-specimen and to the test-equipment)
2) **Grounded Specimen Test with Guard (GST-guard or GST-gA)**
   - The insulation components that are connected to ground are measured
   - The insulation components that are connected to the Red-A lead and the Blue-B lead may be “guarded”, depending on which “test mode” is used (GST-gA vs. GST-gB vs. GST-gA+B)
3) **Ungrounded Specimen Test (UST)**
   - The insulation components that are connected to ground are guarded (i.e. excluded from the Power Factor measurement)
   - The insulation components that are connected to the Red-A and Blue-B leads may be measured, depending on which “test mode” is used (UST-A vs. UST-B)

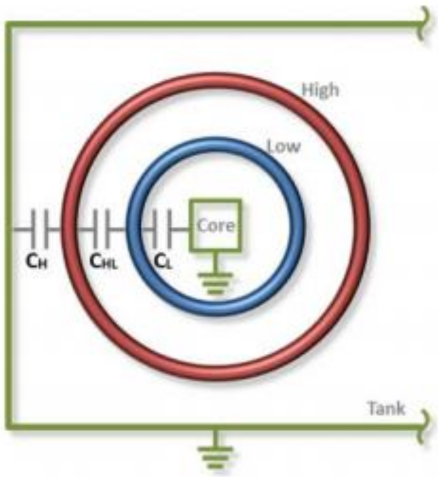
The Overall Power Factor Test on a Two-Winding Transformer

1. **CH:** The high-voltage winding-to-ground insulation system, including the primary-side (H) bushing insulation

2. **CL:** The low-voltage winding-to-ground insulation system, including the secondary-side (X) bushing insulation

3. **CHL:** The high-voltage to low-voltage (inter-winding) insulation system, which does *not* include the bushing insulation





The CHL Measurement on a Two-Winding Transformer

- The CHL measurement is not influenced by the bushing insulation
- The CHL measurement is more resistant to the test environment (i.e. less-influenced by moisture on the surfaces of the bushings)
- Much of the paper insulation is located between the primary and secondary windings
- The CHL measurement is a solid indicator of moisture within the transformer
- The CHL measurement is probably the most reliable measurement for assessing the condition of the main-tank insulation system

The Overall Power Factor Test on a Two-Winding Transformer

Block 1: injection at H

Insulation Under Test

Measured Values

Start all

		No.	Measurement	Test mode	Sweep	V test	Freq.	V out	I out @10 kV	Watt losses @10 kV	PF meas	PF corr	Cap. meas
Start	+	1	ICH+ICHL	GST	None	10.00 kV	60.00 Hz						
Start	+	2	ICH	GSTg-A	None	10.00 kV	60.00 Hz						
Start	+	3	ICHL	UST-A	None	10.00 kV	60.00 Hz						

Cross check: calculated ICHL

Block 2: injection at X

Test Modes Used

Start all

		No.	Measurement	Test mode	Sweep	V test	Freq.	V out	I out @10 kV	Watt losses @10 kV	PF meas	PF corr	Cap. meas
Start	+	4	ICL+ICLH	GST	None	7.00 kV	60.00 Hz						
Start	+	5	ICL	GSTg-A	None	7.00 kV	60.00 Hz						
Start	+	6	ICLH	UST-A	None	7.00 kV	60.00 Hz						

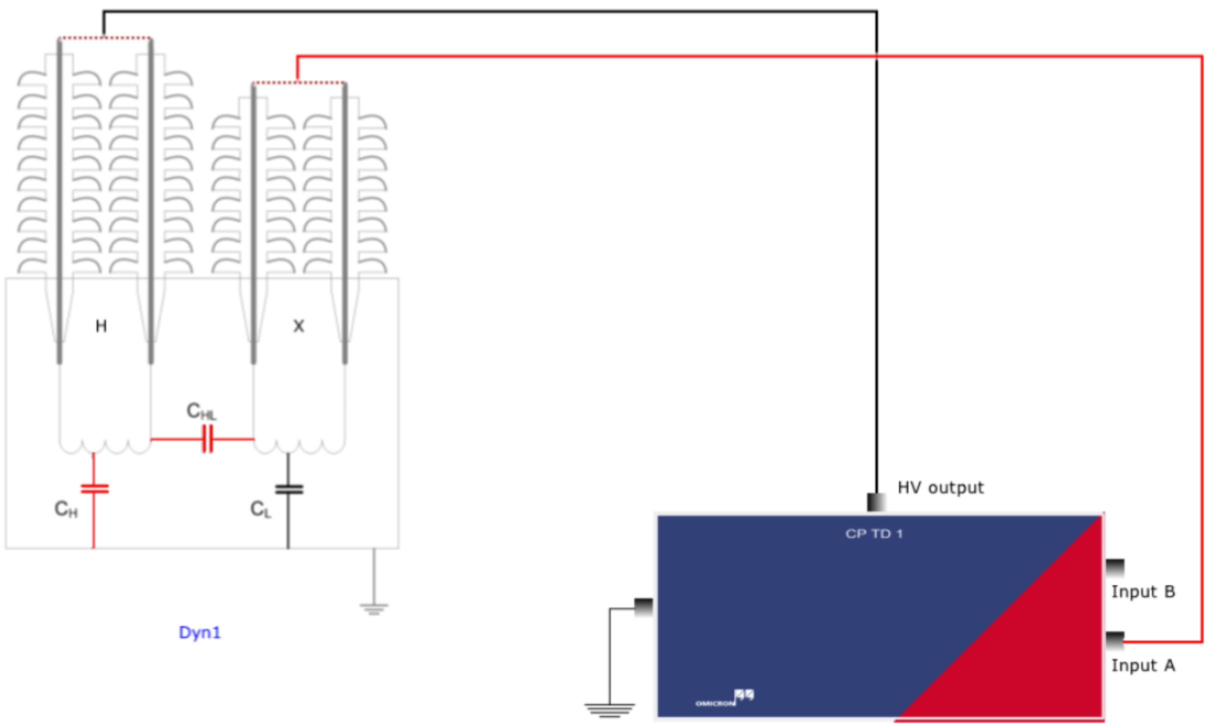
Cross check: calculated ICLH

Cross check

Test	I out	Watt losses	PF	Cap.	Assessment
ICHL					Not assessed
ICLH					

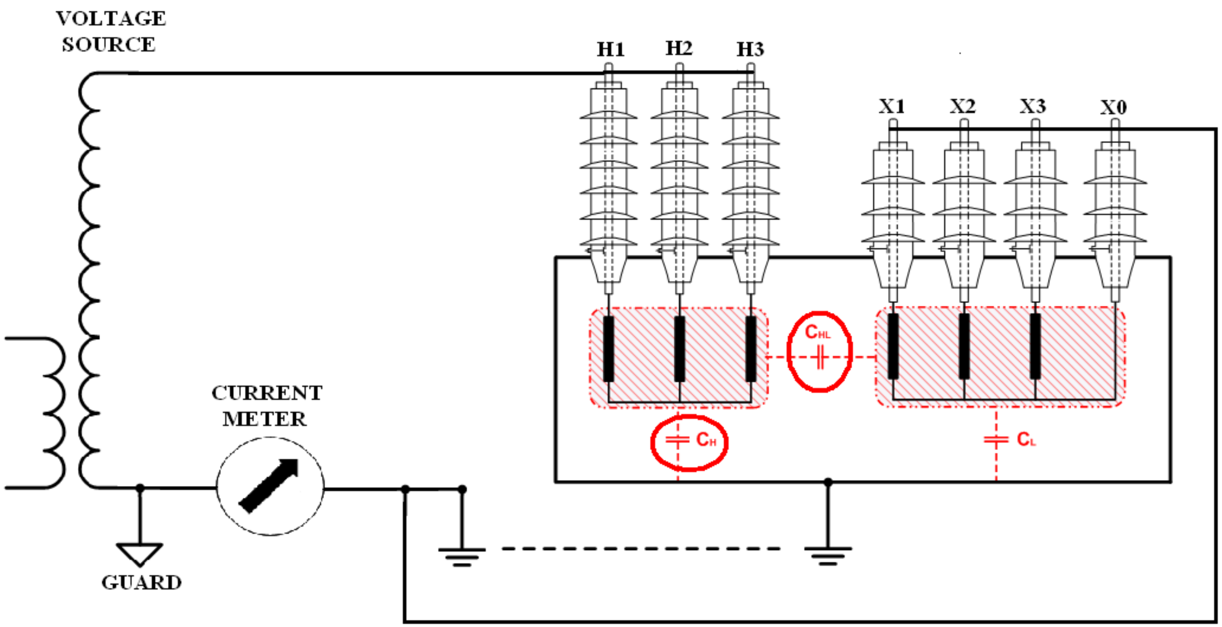
"Cross-Checks"

Two-Winding Transformer: "High-Side Injection Tests"



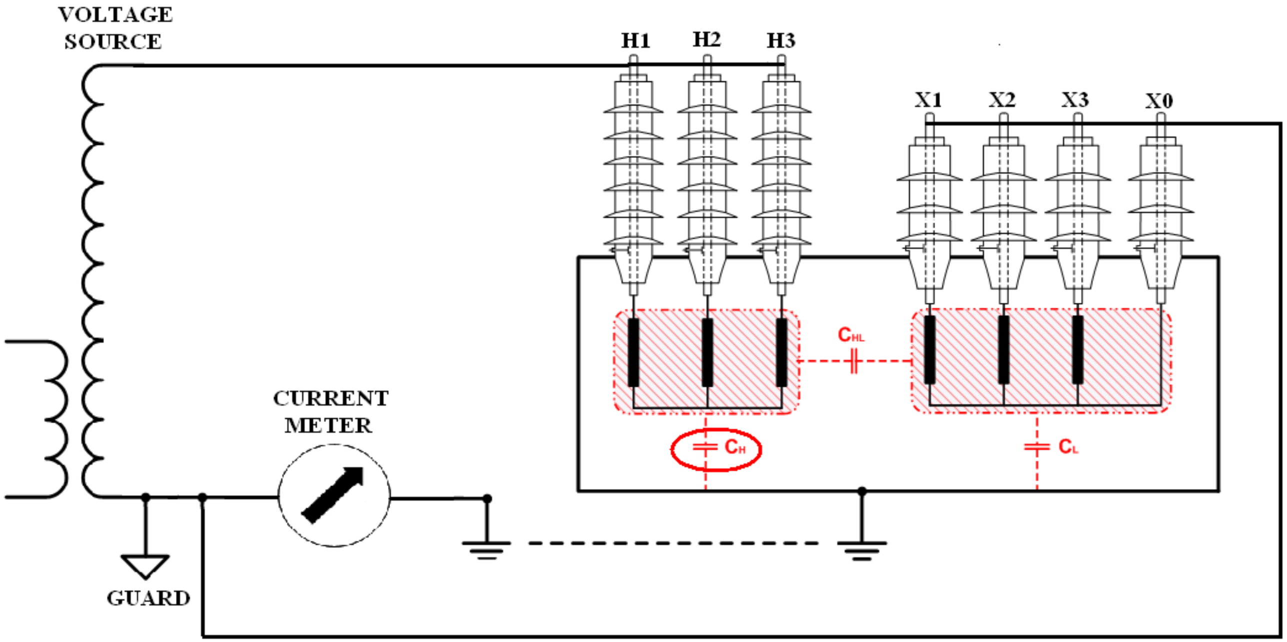
No.	Measurement	Test mode	Sweep	V test	Freq.	V out	I out	Watt losses	PF meas	PF corr	Cap. meas
1	ICH+ICHL	GST	None	10.00 kV	60.00 Hz						
2	ICH	GSTg-A	None	10.00 kV	60.00 Hz						
3	ICHL	UST-A	None	10.00 kV	60.00 Hz						

Two-Winding Transformer: "High-Side Injection Tests"



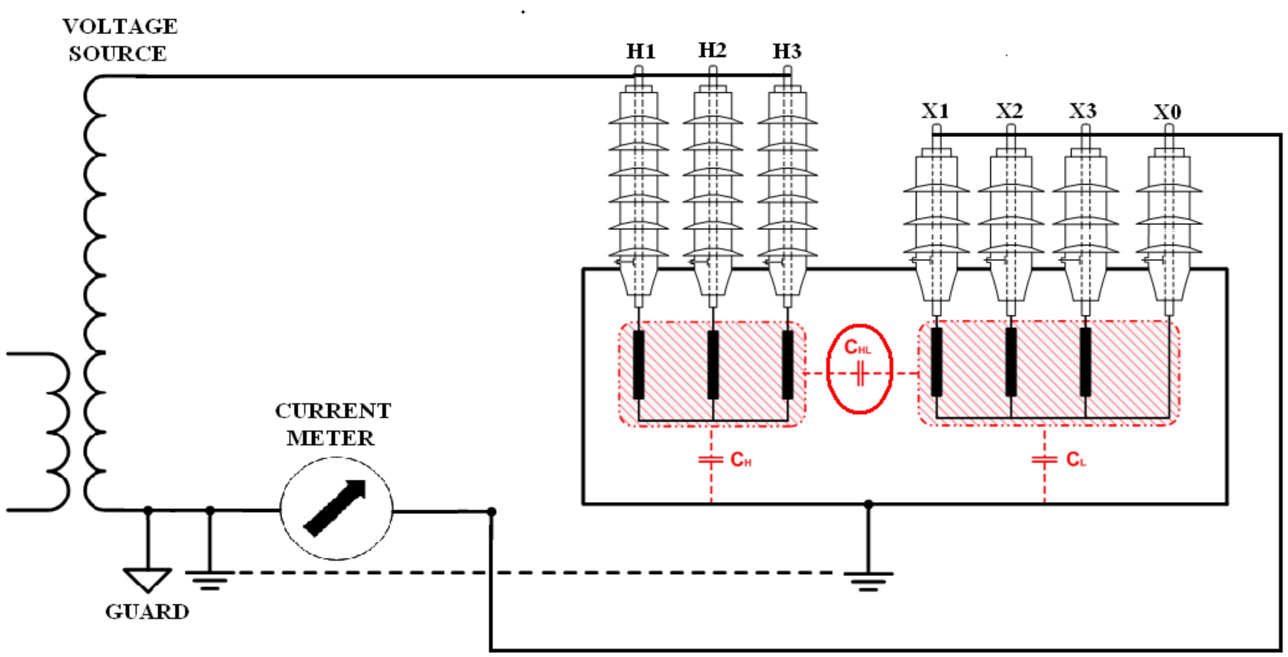
No.	Measurement	Test mode	Sweep	V test	Freq.	V out	I out	Watt losses	PF meas	PF corr	Cap. meas
1	ICH+ICHL	GST	None	10.00 kV	60.00 Hz						
2	ICH	GSTg-A	None	10.00 kV	60.00 Hz						
3	ICHL	UST-A	None	10.00 kV	60.00 Hz						

Two-Winding Transformer: "High-Side Injection Tests"



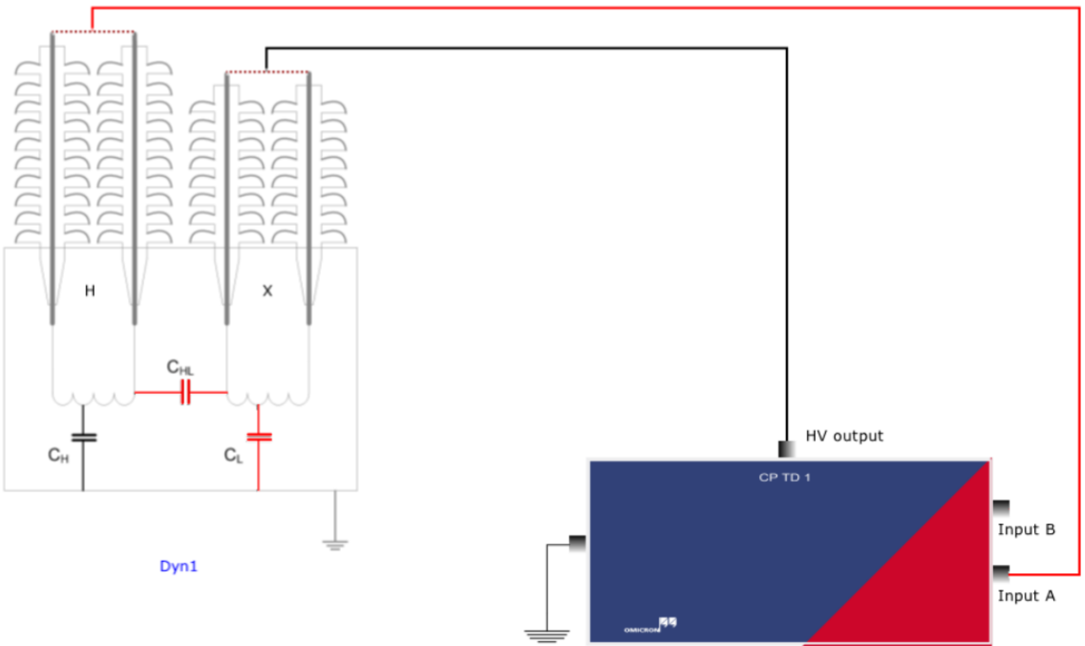
No.	Measurement	Test mode	Sweep	V test	Freq.	V out	I out	Watt losses	PF meas	PF corr	Cap. meas
1	ICH+ICHL	GST	None	10.00 kV	60.00 Hz						
2	ICH	GSTg-A	None	10.00 kV	60.00 Hz						
3	ICHL	UST-A	None	10.00 kV	60.00 Hz						

Two-Winding Transformer: "High-Side Injection Tests"



No.	Measurement	Test mode	Sweep	V test	Freq.	V out	I out	Watt losses	PF meas	PF corr	Cap. meas
1	ICH+ICHL	GST	None	10.00 kV	60.00 Hz						
2	ICH	GSTg-A	None	10.00 kV	60.00 Hz						
3	ICHL	UST-A	None	10.00 kV	60.00 Hz						

Two-Winding Transformer: “Low-Side Injection Tests"



No.	Measurement	Test mode	Sweep	V test	Freq.	V out	I out	Watt losses	PF meas	PF corr	Cap. meas
4	ICL+ICLH	GST	None	10.00 kV	60.00 Hz						
5	ICL	GSTg-A	None	10.00 kV	60.00 Hz						
6	ICLH	UST-A	None	10.00 kV	60.00 Hz						

The Overall Power Factor Test on a Three-Winding Transformer

1. **CH:** The high-voltage winding-to-ground insulation system, including the primary-side bushing insulation

2. **CL:** The low-voltage winding-to-ground insulation system, including the secondary-side bushing insulation

3. **CT:** The tertiary winding-to-ground insulation system, including the tertiary-side bushing insulation

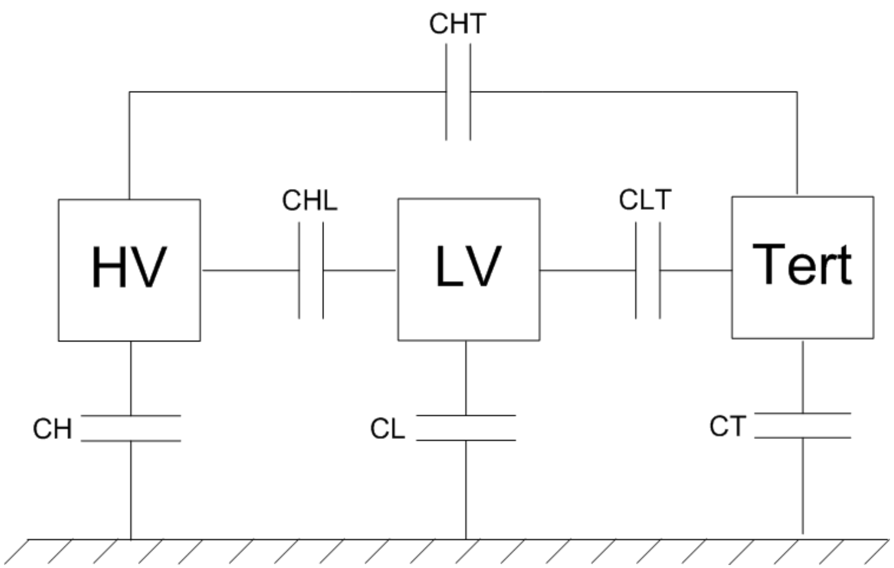
4. **CHL:** The high-voltage to low-voltage (inter-winding) insulation system, which does not include any bushing insulation

5. **CLT:** The low-voltage to tertiary-voltage (inter-winding) insulation system, which does not include any bushing insulation

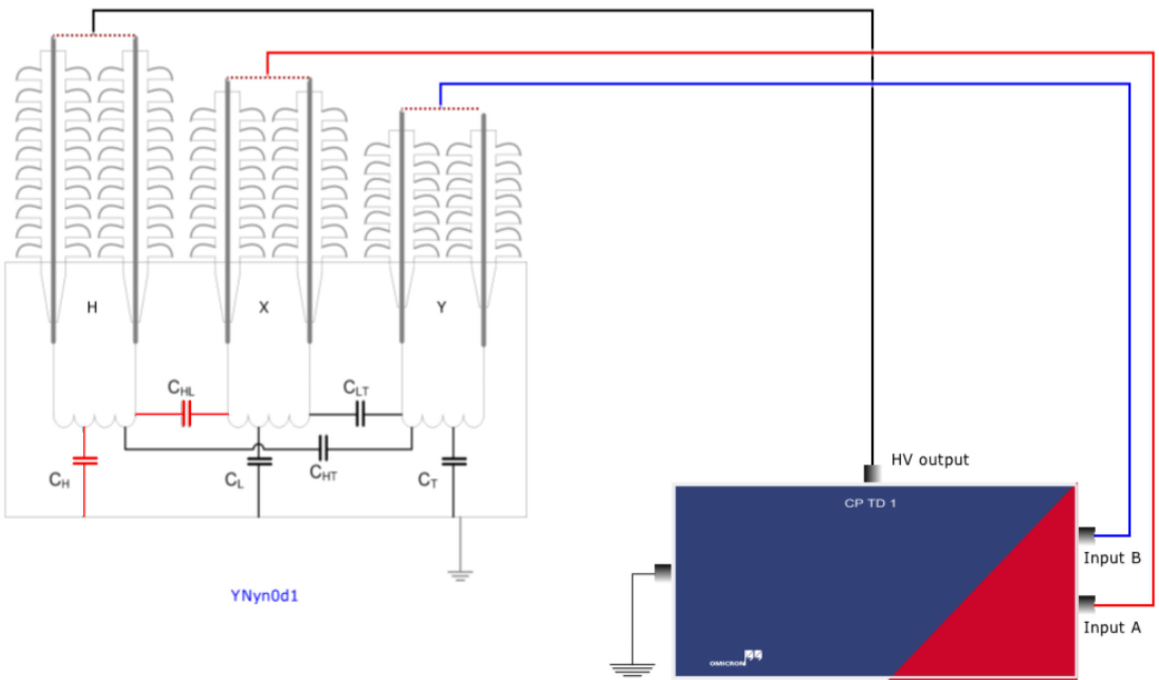
6. **CHT:** The high-voltage to tertiary-voltage (inter-winding) insulation system, which does not include any bushing insulation

The Overall Power Factor Test on a Three-Winding Transformer

- For a three-winding transformer, a total of six insulation measurements are possible
- However, in many cases, not all of the inter-winding insulation components (CHL, CLT, or CHT) can be measured, due to the construction of the windings
- If the three windings are concentrically wound, with the primary-winding being the “outer-winding”, and the tertiary-winding being the “innermost-winding”, then typically, the CHT measurement is not useful for assessing the condition of the transformer

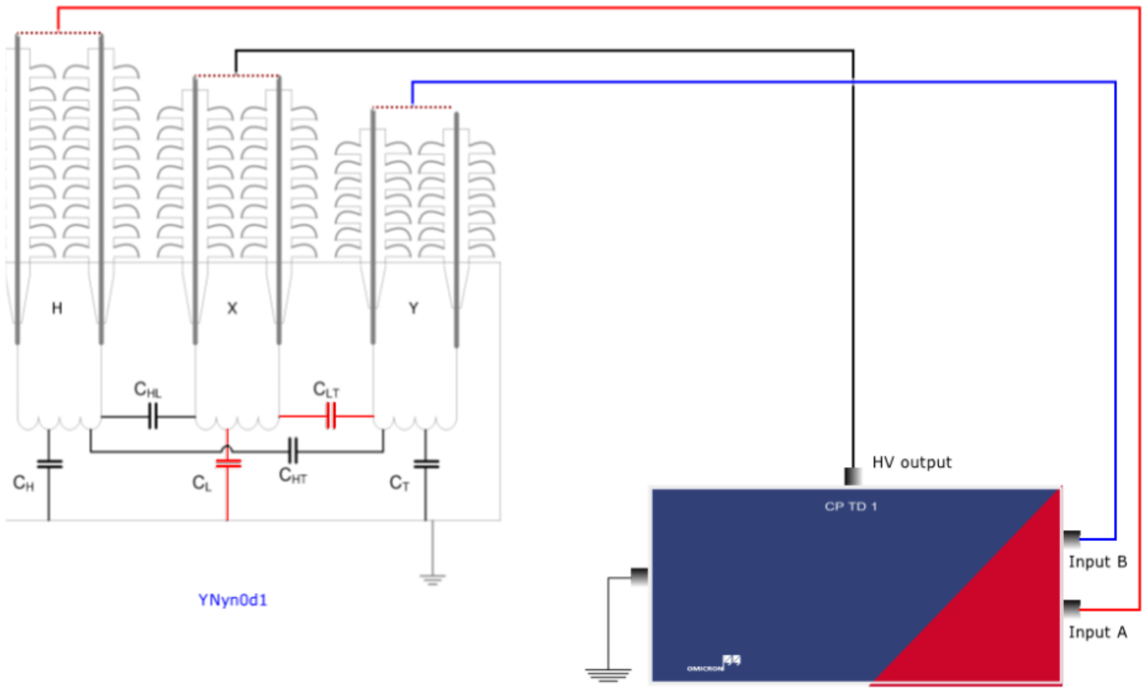


Three-Winding Transformer: "High-Side Injection Tests"



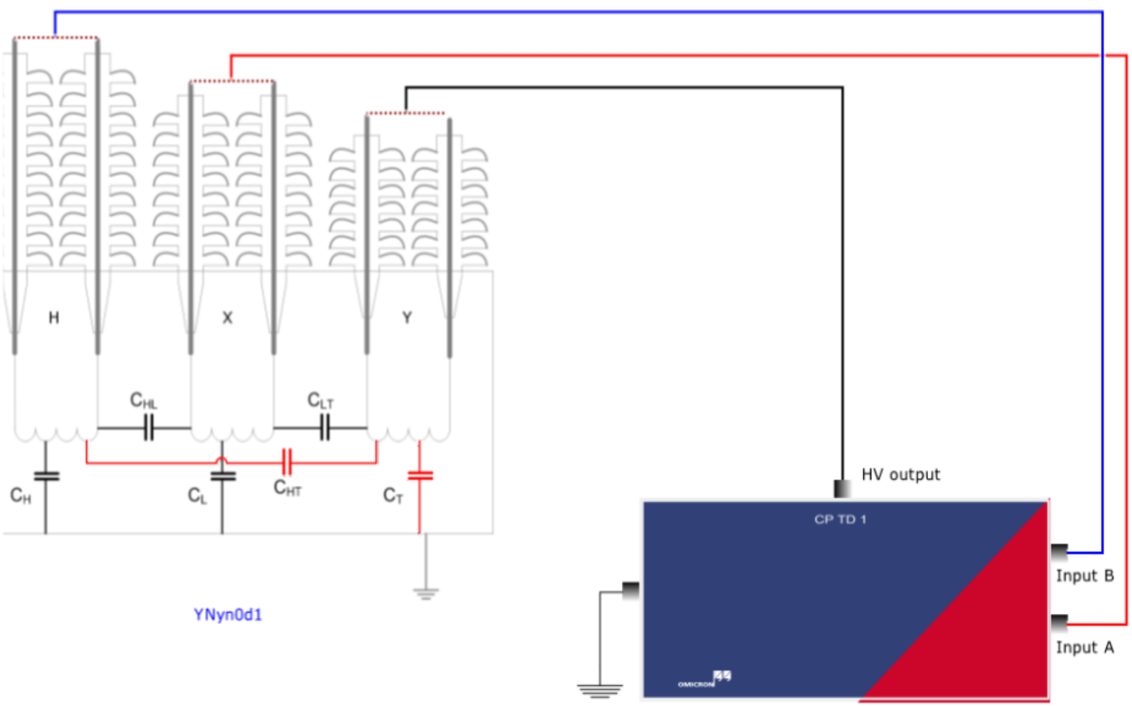
No.	Measurement	Test mode	Sweep	V test	Freq.	V out	I out	Watt losses	PF meas	PF corr	Cap. meas
1	ICH+ICHL	GSTg-B	None	10.00 kV	60.00 Hz						
2	ICH	GSTg-A+B	None	10.00 kV	60.00 Hz						
3	ICHL	UST-A	None	10.00 kV	60.00 Hz						

Three-Winding Transformer: "Low-Side Injection Tests"



No.	Measurement	Test mode	Sweep	V test	Freq.	V out	I out	Watt losses	PF meas	PF corr	Cap. meas
4	ICL+ICLT	GSTg-A	None	10.00 kV	60.00 Hz						
5	ICL	GSTg-A+B	None	10.00 kV	60.00 Hz						
6	ICLT	UST-B	None	10.00 kV	60.00 Hz						

Three-Winding Transformer: “Tertiary-Side Injection Tests"



No.	Measurement	Test mode	Sweep	V test	Freq.	V out	I out	Watt losses	PF meas	PF corr	Cap. meas
7	ICT+ICTH	GSTg-A	None	10.00 kV	60.00 Hz						
8	ICT	GSTg-A+B	None	10.00 kV	60.00 Hz						
9	ICTH	UST-B	None	10.00 kV	60.00 Hz						

The Overall Power Factor Test on a Three-Winding Transformer with a Buried Tertiary

The test procedure is identical to a two-winding transformer test plan,

1. **CH:** The high-voltage winding-to-ground insulation system, including the primary-side bushing insulation

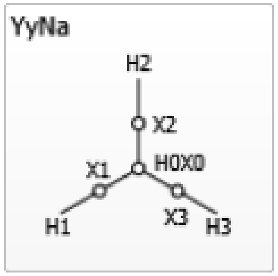
2. **CL:** The low-voltage winding-to-ground insulation system, including the secondary-side bushing insulation

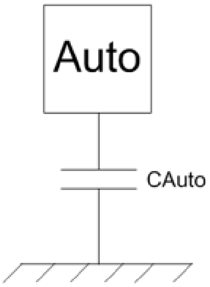
3. **CHL:** The high-voltage to low-voltage (inter-winding) insulation system, which does *not* include the bushing insulation – the most reliable for assessing the condition of the main-tank insulation system

The Overall Power Factor Test on an Autotransformer without a Tertiary

- For this transformer type, only one Power Factor measurement can be performed, using the GST test-mode

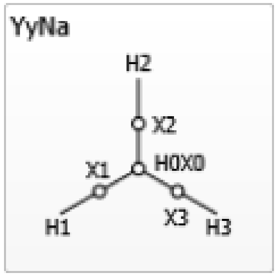
  1. Short-circuit all seven bushing terminals together
  2. Remove the in-service ground connection from the H0X0 bushing terminal
  3. Review the “Power Factor Checklist”
  4. Energize all seven bushing terminals with the high-voltage injection lead, and measure the insulation to ground

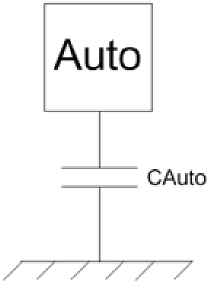




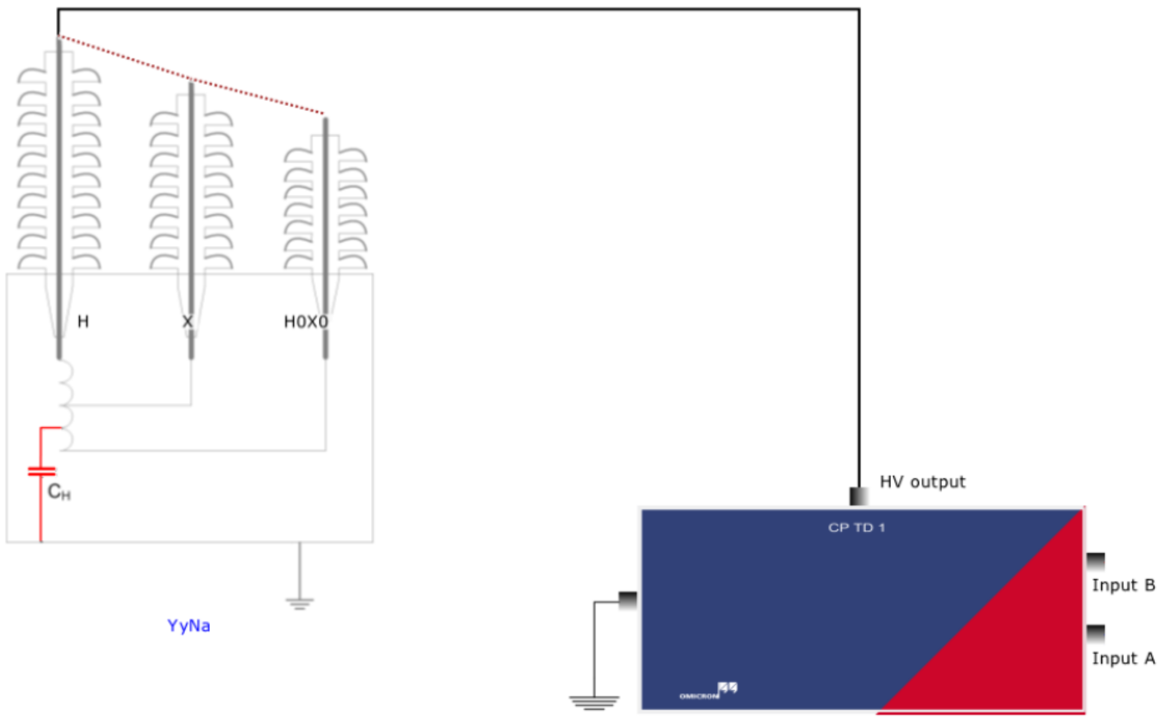
The Overall Power Factor Test on an Autotransformer without a Tertiary

- The red-A current measurement lead is not used during this measurement – Please disconnect it completely from the test-equipment
- **The test-voltage for this test, is typically dictated by the voltage-rating of the low-voltage winding and/or the H0X0 bushing terminal – Please ensure that the test-voltage does not exceed the voltage-rating of either**





The Overall Power Factor Test on an Autotransformer without a Tertiary



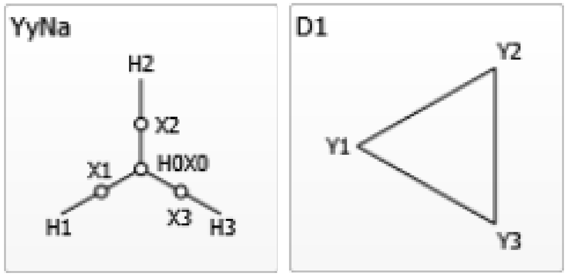
The Overall Power Factor Test on an Autotransformer with a Tertiary

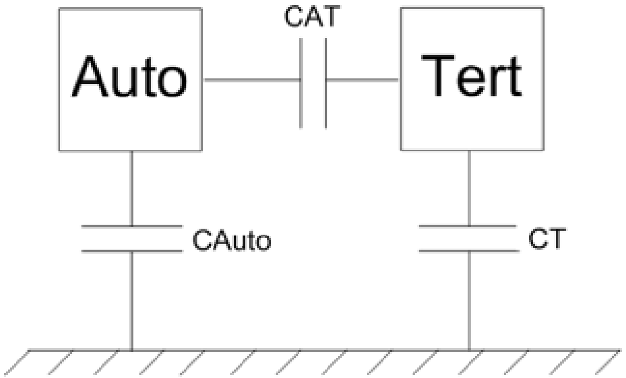
The test procedure is similar to a two-winding transformer test plan,

1. **CAuto:** The Autotransformer winding-to-ground insulation system, including the Autotransformer bushing insulation

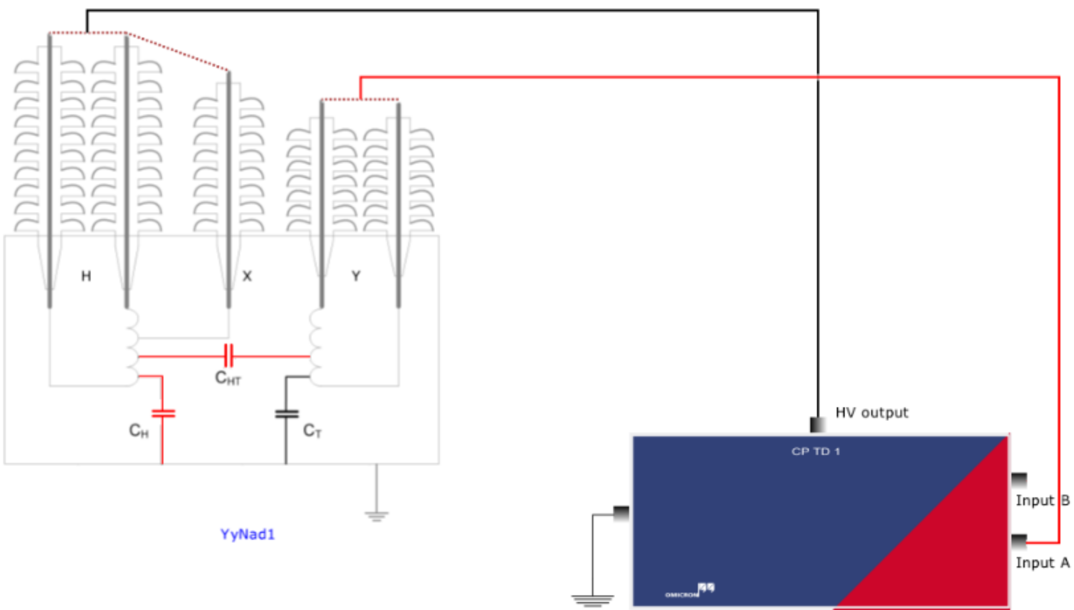
2. **CT:** The Tertiary winding-to-ground insulation system, including the Tertiary bushing insulation

3. **CAT:** The Autotransformer to Tertiary (inter-winding) insulation system, which does *not* include the bushing insulation – the most reliable for assessing the condition of the main-tank insulation system



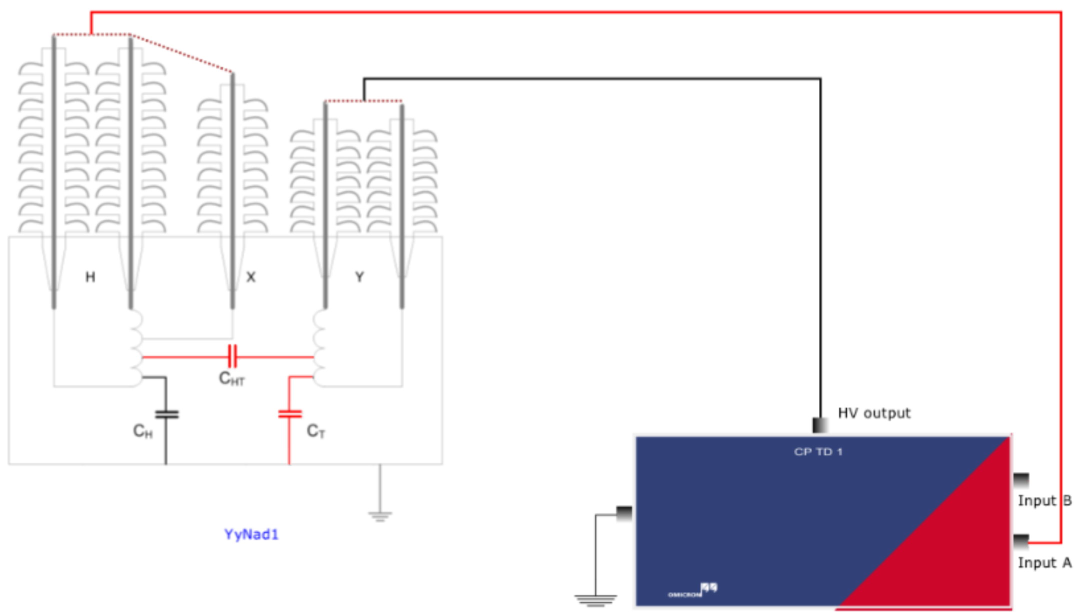


The Overall Power Factor Test on an Autotransformer with a Tertiary



No.	Measurement	Test mode	Sweep	V test	Freq.	V out	I out	Watt losses	PF meas	PF corr	Cap. meas
1	ICH+ICHT	GST	None	10.00 kV	60.00 Hz						
2	ICH	GSTg-A	None	10.00 kV	60.00 Hz						
3	ICHT	UST-A	None	10.00 kV	60.00 Hz						

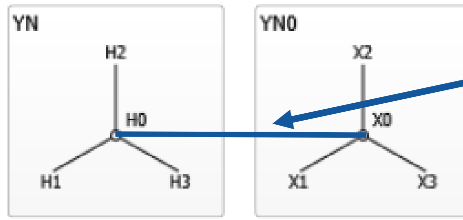
The Overall Power Factor Test on an Autotransformer with a Tertiary

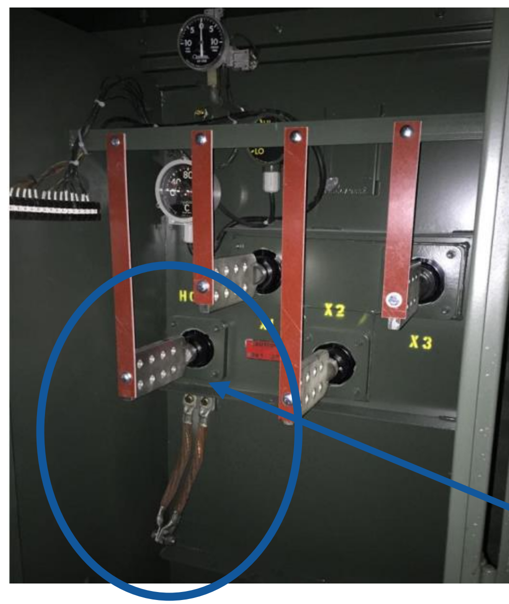


No.	Measurement	Test mode	Sweep	V test	Freq.	V out	I out	Watt losses	PF meas	PF corr	Cap. meas
4	ICT+ICTH	GST	None	10.00 kV	60.00 Hz						
5	ICT	GSTg-A	None	10.00 kV	60.00 Hz						
6	ICTH	UST-A	None	10.00 kV	60.00 Hz						

The Overall Power Factor Test on a Two-Winding Wye-Wye with an Internally Bonded Neutral

Internally Bonded Neutral



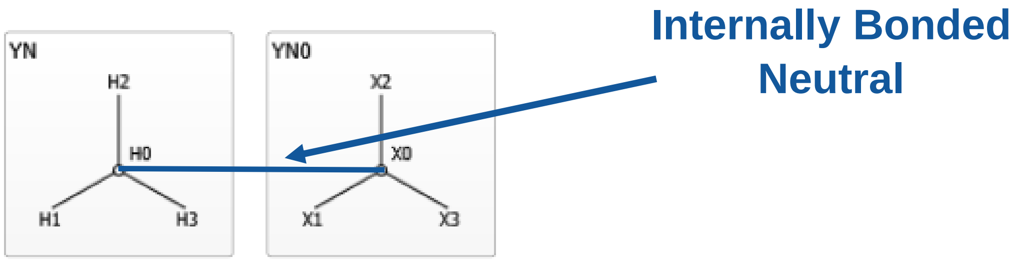


H0X0 Bushing Terminal

The Overall Power Factor Test on a Two-Winding Wye-Wye with an Internally Bonded Neutral

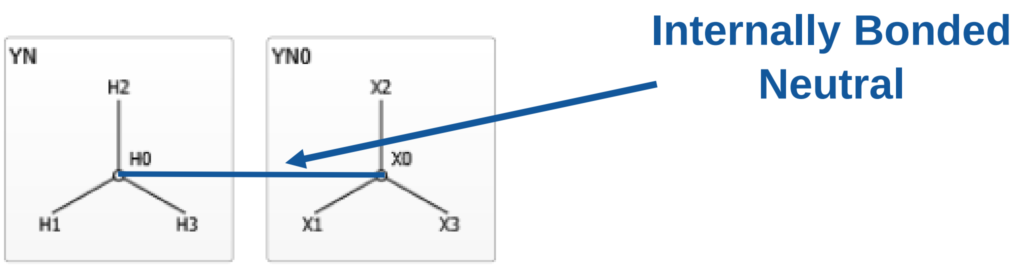
- The test procedure is similar to an Autotransformer (without a tertiary) test plan
- For this transformer type, only one Power Factor measurement can be performed, using the GST test-mode

1. Short-circuit all seven bushing terminals together
2. Remove the in-service ground connection from the H0X0 bushing terminal
3. Review the “Power Factor Checklist”
4. Energize all seven bushing terminals with the high-voltage injection lead, and measure the insulation to ground



The Overall Power Factor Test on a Two-Winding Wye-Wye with an Internally Bonded Neutral

- The red-A current measurement lead is not used during this measurement – Please disconnect it completely from the test-equipment
- **The test-voltage for this test, is typically dictated by the voltage-rating of the low-voltage winding and/or the H0X0 bushing terminal – Please ensure that the test-voltage does not exceed the voltage-rating of either**



The Overall Power Factor Test: *Case Studies

*Note, the following Case Studies include Overall Power Factor measurements performed at 60Hz only. For additional Case Studies, and for examples of the Power Factor Frequency Sweep Test, please see my “Value of Performing Power Factor Sweep Measurements” paper and PowerPoint

*Additionally, all cases provided are of power transformers filled with mineral-oil

Examples of an Abnormally High CH Power Factor Value

Abnormally High CH Power Factor Values – Points of Emphasis

When an "abnormally-high" CH Power Factor value is obtained, and only the CH Power Factor value is "higher than normal", then I recommend focusing on the following possible causes,

1. **User-error**

2. **The test-environment**

3. **The High-Voltage (H) bushing insulation** – Perform the C1 Power Factor Test on the High-Voltage (H) bushing insulation, if possible, to determine whether or not the "abnormally-high" CH Power Factor value is due to a "bad bushing"

4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the High-Voltage (H) side – Always test in an off-neutral tap-position

5. **A "localized" insulation failure, involving the main-tank-high-voltage-winding-to-ground insulation system**

Abnormally High CH Power Factor Value – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	2012	12MVA	115kV	12.47kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	0.57%	0.58%	0.01%
CL	0.29%	0.30%	0.01%
CHL	0.29%	0.29%	0.00%

1. **User-error?**
2. **The test-environment?**
3. **The High-Voltage (H) bushing insulation?** Perform the C1 Power Factor Test on the High-Voltage (H) bushing insulation, if possible, to determine whether or not the “abnormally-high” CH Power Factor value is due to a “bad bushing”
4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the High-Voltage (H) side? Always test in an off-neutral tap-position
5. **A “localized” insulation failure, involving the main-tank-high-voltage-winding-to-ground insulation system?**

Abnormally High CH Power Factor Value – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1981	30MVA	161kV	13.8kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	0.56%	0.56%	0.00%
CL	0.39%	0.40%	0.01%
CHL	0.19%	0.19%	0.00%

1. **User-error?**

2. **The test-environment?**

3. **The High-Voltage (H) bushing insulation?** Perform the C1 Power Factor Test on the High-Voltage (H) bushing insulation, if possible, to determine whether or not the “abnormally-high” CH Power Factor value is due to a “bad bushing”

4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the High-Voltage (H) side? Always test in an off-neutral tap-position

5. **A “localized” insulation failure, involving the main-tank-high-voltage-winding-to-ground insulation system?**

Abnormally High CH Power Factor Value – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	2001	30MVA	161kV	13.8kV
Overall Power Factor Test Results				

Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	-	0.55%	-
CL	-	0.33%	-
CHL	-	0.19%	-

1. **User-error?**
2. **The test-environment?**
3. **The High-Voltage (H) bushing insulation?** Perform the C1 Power Factor Test on the High-Voltage (H) bushing insulation, if possible, to determine whether or not the "abnormally-high" CH Power Factor value is due to a "bad bushing"
4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the High-Voltage (H) side? Always test in an off-neutral tap-position
5. **A "localized" insulation failure, involving the main-tank-high-voltage-winding-to-ground insulation system?**

Examples of an Abnormally High CL Power Factor Value

Abnormally High CL Power Factor Values – Points of Emphasis

When an “abnormally-high” CL Power Factor value is obtained, and only the CL Power Factor value is “higher than normal”, then I recommend focusing on the following possible causes,

1. **User-error**

2. **The test-environment**

3. **The Low-Voltage (X) bushing insulation** – Perform the C1 Power Factor Test on the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the “abnormally-high” CL Power Factor value is due to a “bad bushing”

4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the Low-Voltage (X) side – Always test in an off-neutral tap-position

5. **A “localized” insulation failure, involving the main-tank-low-voltage-winding-to-ground insulation system**

Abnormally High CL Power Factor Value – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1984	20MVA	115kV	13.2kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	0.33%	0.34%	0.01%
CL	0.51%	0.54%	0.03%
CHL	0.22%	0.23%	0.01%

1. **User-error?**
2. **The test-environment?**
3. **The Low-Voltage (X) bushing insulation?** Perform the C1 Power Factor Test on the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the "abnormally-high" CL Power Factor value is due to a "bad bushing"
4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the Low-Voltage (X) side? Always test in an off-neutral tap-position
5. **A "localized" insulation failure, involving the main-tank-low-voltage-winding-to-ground insulation system?**

Abnormally High CL Power Factor Value – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1997	880MVA	345kV	22.8kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	0.35%	0.35%	0.00%
CL	0.91%	0.98%	0.07%
CHL	0.36%	0.36%	0.00%

1. **User-error?**
2. **The test-environment?**
3. **The Low-Voltage (X) bushing insulation?** Perform the C1 Power Factor Test on the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the "abnormally-high" CL Power Factor value is due to a "bad bushing"
4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the Low-Voltage (X) side? Always test in an off-neutral tap-position
5. **A "localized" insulation failure, involving the main-tank-low-voltage-winding-to-ground insulation system?**

Abnormally High CL Power Factor Value – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1992	33MVA	115kV	12.47kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	0.33%	0.33%	0.00%
CL	0.80%	0.86%	0.06%
CHL	0.23%	0.23%	0.00%

1. **User-error?**

2. **The test-environment?**

3. **The Low-Voltage (X) bushing insulation?** Perform the C1 Power Factor Test on the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the "abnormally-high" CL Power Factor value is due to a "bad bushing"

4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the Low-Voltage (X) side? Always test in an off-neutral tap-position

5. **A "localized" insulation failure, involving the main-tank-low-voltage-winding-to-ground insulation system?**

Abnormally High CL Power Factor Value – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1980	20MVA	67kV	13.8kV
Overall Power Factor Test Results				

Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	0.22%	0.22%	0.00%
CL	0.76%	0.76%	0.00%
CHL	0.24%	0.24%	0.00%

1. **User-error?**
2. **The test-environment?**
3. **The Low-Voltage (X) bushing insulation?** Perform the C1 Power Factor Test on the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the “abnormally-high” CL Power Factor value is due to a “bad bushing”
4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the Low-Voltage (X) side? Always test in an off-neutral tap-position
5. **A “localized” insulation failure, involving the main-tank-low-voltage-winding-to-ground insulation system?**

Abnormally High CL Power Factor Value – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1986	10MVA	43.8kV	12.47kV
Overall Power Factor Test Results				
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF	
CH	-	0.37%	-	
CL	-	0.57%	-	
CHL	-	0.21%	-	

1. **User-error?**
2. **The test-environment?**
3. **The Low-Voltage (X) bushing insulation?** Perform the C1 Power Factor Test on the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the “abnormally-high” CL Power Factor value is due to a “bad bushing”
4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the Low-Voltage (X) side? Always test in an off-neutral tap-position
5. **A “localized” insulation failure, involving the main-tank-low-voltage-winding-to-ground insulation system?**

Abnormally High CL Power Factor Value – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1980	12MVA	66kV	13.8kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	-	0.40%	-
CL	-	0.73%	-
CHL	-	0.22%	-

1. **User-error?**

2. **The test-environment?**

3. **The Low-Voltage (X) bushing insulation?** Perform the C1 Power Factor Test on the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the "abnormally-high" CL Power Factor value is due to a "bad bushing"

4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the Low-Voltage (X) side? Always test in an off-neutral tap-position

5. **A "localized" insulation failure, involving the main-tank-low-voltage-winding-to-ground insulation system?**

Examples of Abnormally High CL and CHL Power Factor Values (i.e. at the same time)

Abnormally High CL and CHL Power Factor Value – Points of Emphasis

When both the CL and CHL Power Factor values are "abnormally-high", I recommend focusing on the following possible causes,

1. **User-error**

2. **The test-environment**

3. **The main-tank insulation system** – If the Power Factor measurements are valid, and the CHL Power Factor value is "higher than normal", then the compromised insulation probably exists inside the main-tank, at a minimum

4. **The Low-Voltage (X) bushing insulation** – In addition to compromised main-tank insulation, there may exist a "bad bushing" on the Low-Voltage (X) side. Perform the C1 Power Factor Test on the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the "abnormally-high" CL Power Factor value is due to a "bad bushing"

5. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the Low-Voltage (X) side – Always test in an off-neutral tap-position

Abnormally High CL and CHL Power Factor Value – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1971	7.5MVA	23kV	4.16kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	0.31%	0.31%	0.00%
CL	0.55%	0.55%	0.00%
CHL	0.73%	0.73%	0.00%

1. **User-error?**
2. **The test-environment?**
3. **The main-tank insulation system?** If the Power Factor measurements are valid, and the CHL Power Factor value is "higher than normal", then the compromised insulation probably exists inside the main-tank, at a minimum
4. **The Low-Voltage (X) bushing insulation?** In addition to compromised main-tank insulation, there may exist a "bad bushing" on the Low-Voltage (X) side. Perform the C1 Power Factor Test on the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the "abnormally-high" CL Power Factor value is due to a "bad bushing"
5. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the Low-Voltage (X) side? Always test in an off-neutral tap-position

Abnormally High CL and CHL Power Factor Value – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1995	15MVA	66kV	13.8kV
Overall Power Factor Test Results				
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF	
CH	-	0.29%	-	
CL	-	0.65%	-	
CHL	-	0.71%	-	

1. **User-error?**

2. **The test-environment?**

3. **The main-tank insulation system?** If the Power Factor measurements are valid, and the CHL Power Factor value is "higher than normal", then the compromised insulation probably exists inside the main-tank, at a minimum

4. **The Low-Voltage (X) bushing insulation?** In addition to compromised main-tank insulation, there may exist a "bad bushing" on the Low-Voltage (X) side. Perform the C1 Power Factor Test on the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the "abnormally-high" CL Power Factor value is due to a "bad bushing"

5. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the Low-Voltage (X) side? Always test in an off-neutral tap-position

Abnormally High CL and CHL Power Factor Value – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1988	10MVA	43.8kV	12.47kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	-	0.36%	-
CL	-	0.62%	-
CHL	-	0.59%	-

1. **User-error?**
2. **The test-environment?**
3. **The main-tank insulation system?** If the Power Factor measurements are valid, and the CHL Power Factor value is "higher than normal", then the compromised insulation probably exists inside the main-tank, at a minimum
4. **The Low-Voltage (X) bushing insulation?** In addition to compromised main-tank insulation, there may exist a "bad bushing" on the Low-Voltage (X) side. Perform the C1 Power Factor Test on the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the "abnormally-high" CL Power Factor value is due to a "bad bushing"
5. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the Low-Voltage (X) side? Always test in an off-neutral tap-position

Abnormally High CL and CHL Power Factor Value – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1967	12MVA	66kV	13.8kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	-	0.37%	-
CL	-	0.69%	-
CHL	-	0.51%	-

1. **User-error?**
2. **The test-environment?**
3. **The main-tank insulation system?** If the Power Factor measurements are valid, and the CHL Power Factor value is "higher than normal", then the compromised insulation probably exists inside the main-tank, at a minimum
4. **The Low-Voltage (X) bushing insulation?** In addition to compromised main-tank insulation, there may exist a "bad bushing" on the Low-Voltage (X) side. Perform the C1 Power Factor Test on the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the "abnormally-high" CL Power Factor value is due to a "bad bushing"
5. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on the Low-Voltage (X) side? Always test in an off-neutral tap-position

Examples of Abnormally High CH, CL, and CHL Power Factor Values

Abnormally High CH, CL, and CHL Power Factor Values – Points of Emphasis

When all three Power Factor values (CH, CL, and CHL) are “abnormally-high”, I recommend focusing on the following possible causes,

1. **User-error**

2. **The test-environment**

3. **The main-tank insulation system** – If the Power Factor measurements are valid, and the CHL Power Factor value is “higher than normal”, then the compromised insulation probably exists inside the main-tank, at a minimum

4. **The bushing insulation (H and/or X)** – In addition to compromised main-tank insulation, there may exist a “bad bushing” on either, or both, the High-Voltage (H) side and the Low-Voltage (X) side. Perform the C1 Power Factor Test on all the bushings, if possible, to determine whether or not the “abnormally-high” CH and CL Power Factor values are due to “bad bushing(s)”

5. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer – Always test in an off-neutral tap-position

- **Note, when all three Power Factor values (CH, CL, and CHL) are “abnormally-high”, the issue is often “moisture ingress”**

Abnormally High CH, CL, and CHL Power Factor Values – Points of Emphasis

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	2000	20MVA	115kV	13.2kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	0.63%	0.63%	0.00%
CL	0.65%	0.69%	0.04%
CHL	0.59%	0.61%	0.02%

1. **User-error?**
2. **The test-environment?**
3. **The main-tank insulation system?** If the Power Factor measurements are valid, and the CHL Power Factor value is "higher than normal", then the compromised insulation probably exists inside the main-tank, at a minimum
4. **The bushing insulation (H and/or X)?** In addition to compromised main-tank insulation, there may exist a "bad bushing" on either, or both, the High-Voltage (H) side and the Low-Voltage (X) side. Perform the C1 Power Factor Test on all the bushings, if possible, to determine whether or not the "abnormally-high" CH and CL Power Factor values are due to "bad bushing(s)"
5. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer? Always test in an off-neutral tap-position

Abnormally High CH, CL, and CHL Power Factor Values – Points of Emphasis

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1960	20MVA	67kV	13.2kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	-	0.68%	-
CL	-	0.62%	-
CHL	-	0.70%	-

1. **User-error?**
2. **The test-environment?**
3. **The main-tank insulation system?** If the Power Factor measurements are valid, and the CHL Power Factor value is “higher than normal”, then the compromised insulation probably exists inside the main-tank, at a minimum
4. **The bushing insulation (H and/or X)?** In addition to compromised main-tank insulation, there may exist a “bad bushing” on either, or both, the High-Voltage (H) side and the Low-Voltage (X) side. Perform the C1 Power Factor Test on all the bushings, if possible, to determine whether or not the “abnormally-high” CH and CL Power Factor values are due to “bad bushing(s)”
5. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer? Always test in an off-neutral tap-position

Abnormally High CH, CL, and CHL Power Factor Values – Points of Emphasis

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1994	12MVA	46kV	12.47kV
Overall Power Factor Test Results				

Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	-	0.62%	-
CL	-	0.61%	-
CHL	-	0.55%	-

1. **User-error?**

2. **The test-environment?**

3. **The main-tank insulation system?** If the Power Factor measurements are valid, and the CHL Power Factor value is "higher than normal", then the compromised insulation probably exists inside the main-tank, at a minimum

4. **The bushing insulation (H and/or X)?** In addition to compromised main-tank insulation, there may exist a "bad bushing" on either, or both, the High-Voltage (H) side and the Low-Voltage (X) side. Perform the C1 Power Factor Test on all the bushings, if possible, to determine whether or not the "abnormally-high" CH and CL Power Factor values are due to "bad bushing(s)"

5. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer? Always test in an off-neutral tap-position

Abnormally High CH, CL, and CHL Power Factor Values – Points of Emphasis

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1960	26MVA	115kV	69kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	0.49%	0.50%	0.01%
CL	0.67%	0.69%	0.02%
CHL	0.64%	0.64%	0.00%

1. **User-error?**
2. **The test-environment?**
3. **The main-tank insulation system?** If the Power Factor measurements are valid, and the CHL Power Factor value is "higher than normal", then the compromised insulation probably exists inside the main-tank, at a minimum
4. **The bushing insulation (H and/or X)?** In addition to compromised main-tank insulation, there may exist a "bad bushing" on either, or both, the High-Voltage (H) side and the Low-Voltage (X) side. Perform the C1 Power Factor Test on all the bushings, if possible, to determine whether or not the "abnormally-high" CH and CL Power Factor values are due to "bad bushing(s)"
5. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer? Always test in an off-neutral tap-position

Examples of Abnormally High CH and CL Power Factor Values

Abnormally High CH and CL Power Factor Values – Points of Emphasis

When both the CH and CL Power Factor values are “abnormally-high”, I recommend focusing on the following possible causes,

1. **User-error**

2. **The test-environment**

3. **The High-Voltage (H) and the Low-Voltage (X) bushing insulation** – Perform the C1 Power Factor Test on both the High-Voltage (H) and the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the “abnormally-high” CH and CL Power Factor values are due to “bad bushings”

4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on either the High-Voltage (H) side or the Low-Voltage (X) side – Always test in an off-neutral tap-position

5. **The main-tank insulation system** – If the Power Factor measurements are valid, and both the CH and CL Power Factor values are “higher than normal”, then in addition to one or more of the issues stated above, there may exist compromised insulation inside the main-tank of the transformer

Abnormally High CH and CL Power Factor Values – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1987	15MVA	66kV	13.8kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	-	0.78%	-
CL	-	1.29%	-
CHL	-	0.23%	-

1. **User-error?**
2. **The test-environment?**
3. **The High-Voltage (H) and the Low-Voltage (X) bushing insulation?** Perform the C1 Power Factor Test on both the High-Voltage (H) and the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the "abnormally-high" CH and CL Power Factor values are due to "bad bushings"
4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on either the High-Voltage (H) side or the Low-Voltage (X) side? Always test in an off-neutral tap-position
5. **The main-tank insulation system?** If the Power Factor measurements are valid, and both the CH and CL Power Factor values are "higher than normal", then in addition to one or more of the issues stated above, there may exist compromised insulation inside the main-tank of the transformer

Abnormally High CH and CL Power Factor Values – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1984	10MVA	43.8kV	12.47kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	-	0.82%	-
CL	-	0.52%	-
CHL	-	0.35%	-

1. **User-error?**
2. **The test-environment?**
3. **The High-Voltage (H) and the Low-Voltage (X) bushing insulation?** Perform the C1 Power Factor Test on both the High-Voltage (H) and the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the "abnormally-high" CH and CL Power Factor values are due to "bad bushings"
4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on either the High-Voltage (H) side or the Low-Voltage (X) side? Always test in an off-neutral tap-position
5. **The main-tank insulation system?** If the Power Factor measurements are valid, and both the CH and CL Power Factor values are "higher than normal", then in addition to one or more of the issues stated above, there may exist compromised insulation inside the main-tank of the transformer

Abnormally High CH and CL Power Factor Values – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1969	12MVA	66kV	13.8kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	-	0.83%	-
CL	-	0.64%	-
CHL	-	0.30%	-

1. **User-error?**
2. **The test-environment?**
3. **The High-Voltage (H) and the Low-Voltage (X) bushing insulation?** Perform the C1 Power Factor Test on both the High-Voltage (H) and the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the "abnormally-high" CH and CL Power Factor values are due to "bad bushings"
4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on either the High-Voltage (H) side or the Low-Voltage (X) side? Always test in an off-neutral tap-position
5. **The main-tank insulation system?** If the Power Factor measurements are valid, and both the CH and CL Power Factor values are "higher than normal", then in addition to one or more of the issues stated above, there may exist compromised insulation inside the main-tank of the transformer

Abnormally High CH and CL Power Factor Values – Case Study

Serial number	Mfg. Year	Rated Power	Voltage (Prim.)	Voltage (Sec.)
	1985	10MVA	43.8kV	12.47kV

Overall Power Factor Test Results			
Measurement	2kV PF	10kV PF	10kV PF – 2kV PF
CH	-	0.74%	-
CL	-	0.51%	-
CHL	-	0.31%	-

1. **User-error?**
2. **The test-environment?**
3. **The High-Voltage (H) and the Low-Voltage (X) bushing insulation?** Perform the C1 Power Factor Test on both the High-Voltage (H) and the Low-Voltage (X) bushing insulation, if possible, to determine whether or not the "abnormally-high" CH and CL Power Factor values are due to "bad bushings"
4. **The load-tap-changer (LTC) insulation system**, assuming that there exists a load-tap-changer on either the High-Voltage (H) side or the Low-Voltage (X) side? Always test in an off-neutral tap-position
5. **The main-tank insulation system?** If the Power Factor measurements are valid, and both the CH and CL Power Factor values are "higher than normal", then in addition to one or more of the issues stated above, there may exist compromised insulation inside the main-tank of the transformer

Thank you!