Introduction to Power Transformer Testing

Andrej Sepcic
RSM
asepcic@doble.com

ALTANOVA
A DOBLE COMPANY

ALTANOVA, a Doble Engineering Company, provides diagnostic solutions to utilities and industries to improve the performance of their electrical assets through portable testing equipment, advanced monitoring systems, and professional services.

Altanova History

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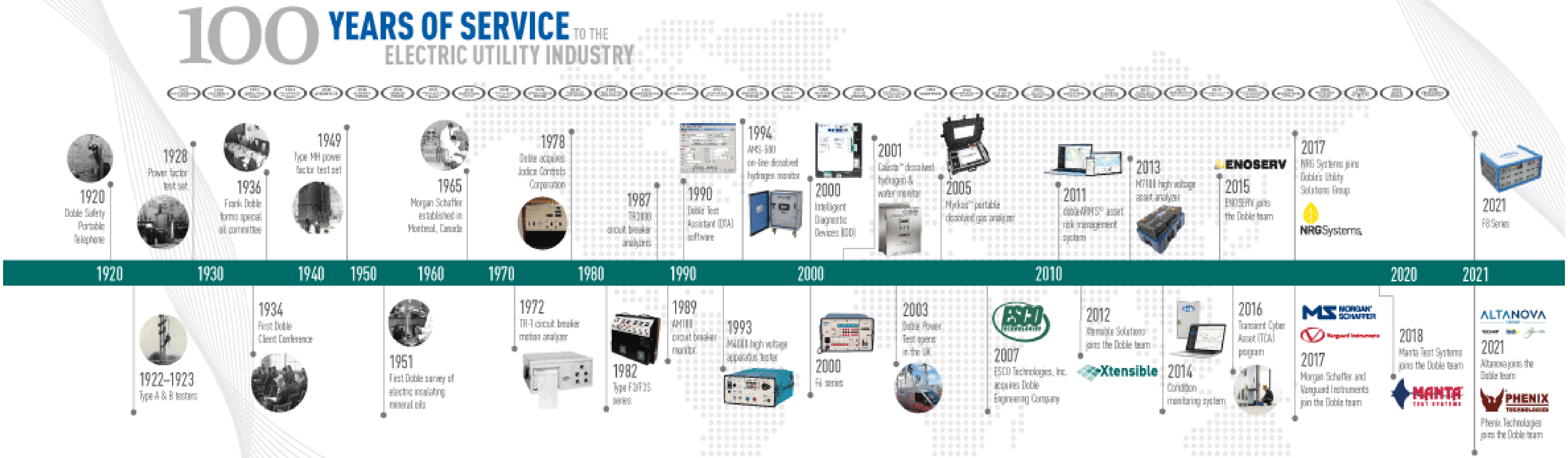
1938	I.S.A. Istrumentazioni Sistemi Automatici S.r.l. is established in Taino ITALY
1999	TECHIMP was born as a spin-off from the University of Bologna ITALY.
2017	I.S.A. and TECHIMP merge giving birth to the ALTANOVA GROUP
2019	INTELLISAW joins ALTANOVA GROUP
2021	ALTANOVA GROUP becomes part of ESCO Technology Group and joins the Doble Engineering Company, as part of the USG division.

Doble History



Altanova Today

ALTANOVA
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100
COUNTRIES

12 GLOBAL FACILITY LOCATIONS

150+
EMPLOYEES

150+
SALES PARTNERS

5550+
CUSTOMERS GLOBALLY

Part of ESCO Technologies' Utility Solutions Group

PRODUCT BRANDS

doble · isa · MORGAN SCHAFFER · PHENIX TECHNOLOGIES · TECHIMP · Vanguard Instruments

Our Solutions

Electrical Test Equipment

Essential for day-to-day maintenance tests of electrical assets. Useful in specific phases of the asset lifecycle:

- Procure
- Operate
- Maintain
- Decommission.

Professional Services

Diversified offer according to the electrical asset lifecycle:

- Installation and commissioning
- Diagnostic test
- Data analysis
- Consultancy
- Training.

Monitoring Systems

Shift from a time-based maintenance to a condition-based maintenance.

Focus on predictive maintenance and shift in focus from electric asset value cost to network outage costs.

Strong evolution of digitalization trend in the power industry.

Testing And Monitoring Solutions For:

- Power transformers
- Circuit breakers
- HV gas insulated switchgears
- MV/HV/EHV cables
- MV/LV switchgears
- Batteries
- Current & voltage transformers
- Protective relays
- Meters and transducers
- Rotating machines
- Variable speed drives
- Overhead lines

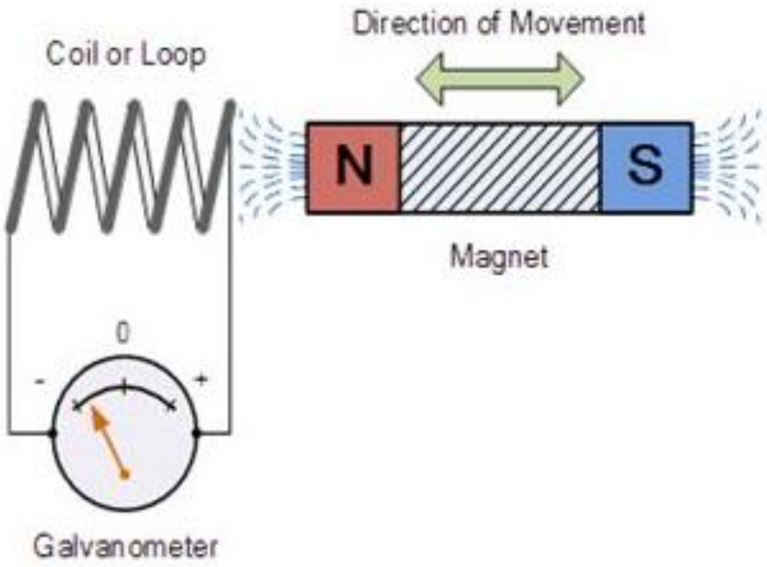





TRANSFORMER

Transformer

1830s - Joseph Henry and Michael Faraday works with electromagnets and discover the property of induction independently on separate continents.

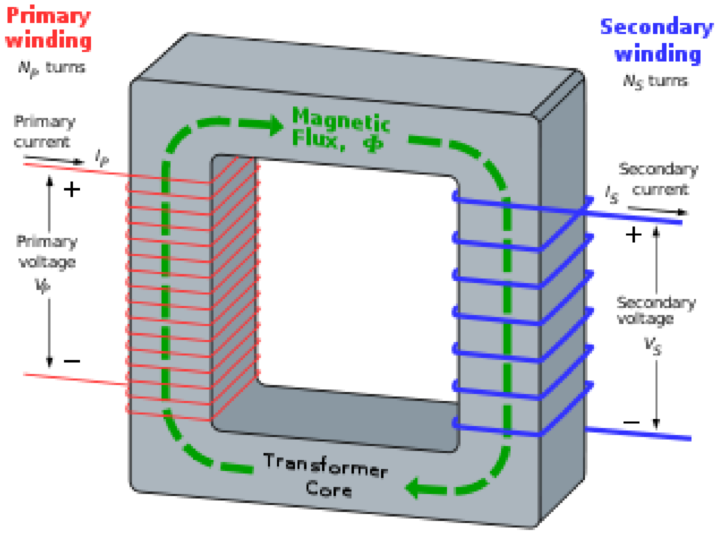


Faraday's Experiment - RELATIONSHIP BETWEEN INDUCED EMF AND FLUX

Transformer

What is a Transformer ?

A transformer is a device that transfers electrical energy from one circuit to another through inductively coupled conductors, the transformer's coils/



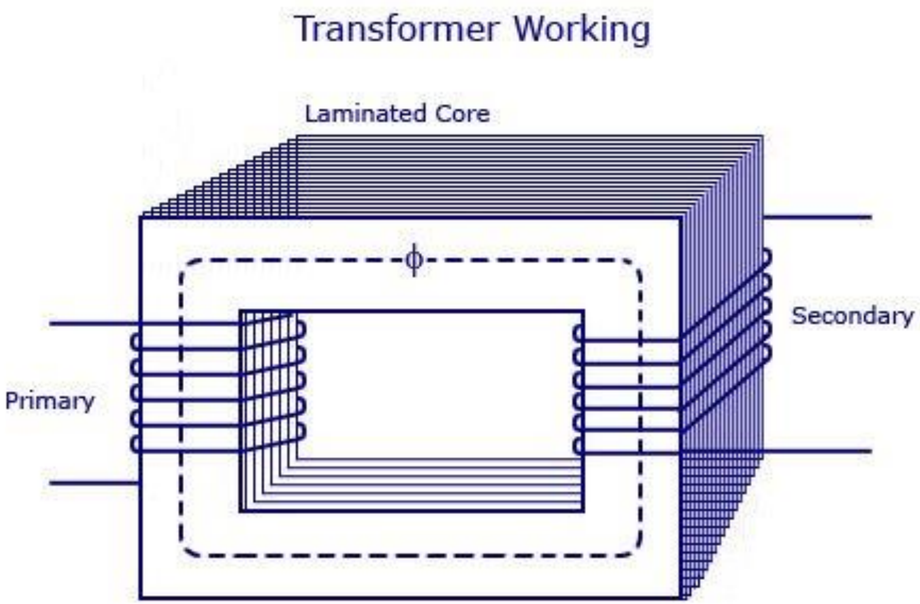
Working of Transformer

- Transfer of electric power
  from one circuit to another.

- Transfer of electric power
  without any change in frequency.

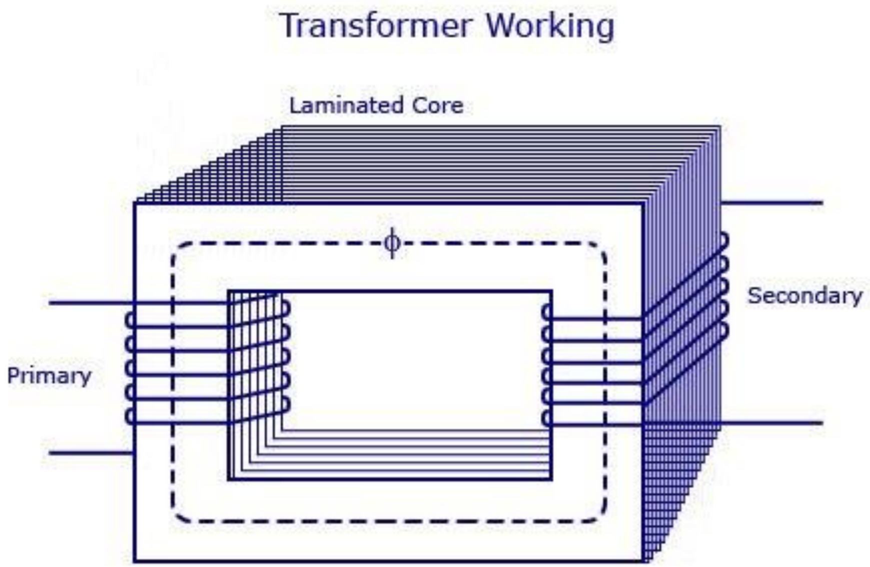
- Transfer with the
  principle of electromagnetic induction.

- The two electrical circuits
  are linked by mutual induction



Why do we need Transformer

- To step-up and – step down the voltage.
- Need for transmitting power from one place to another.
- For isolating and Protection of the circuit.

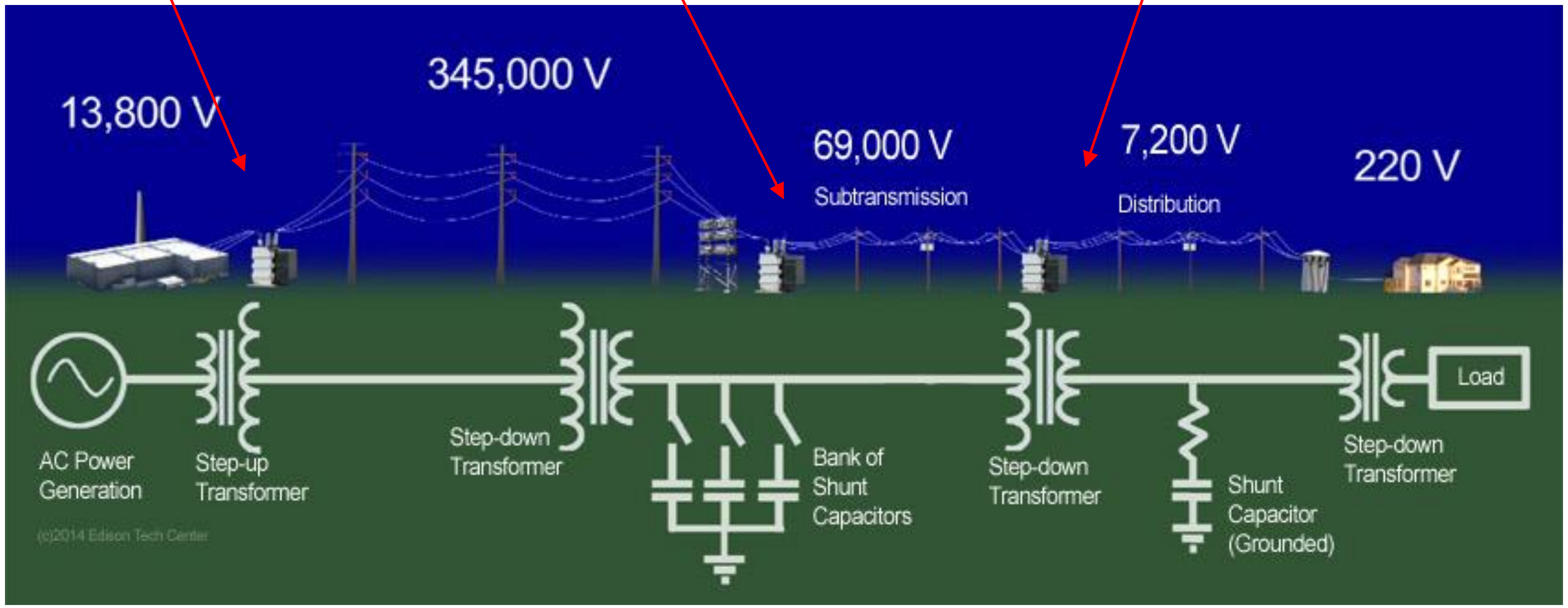


Where do we need Transformer

Generation

Transmission

Distribution

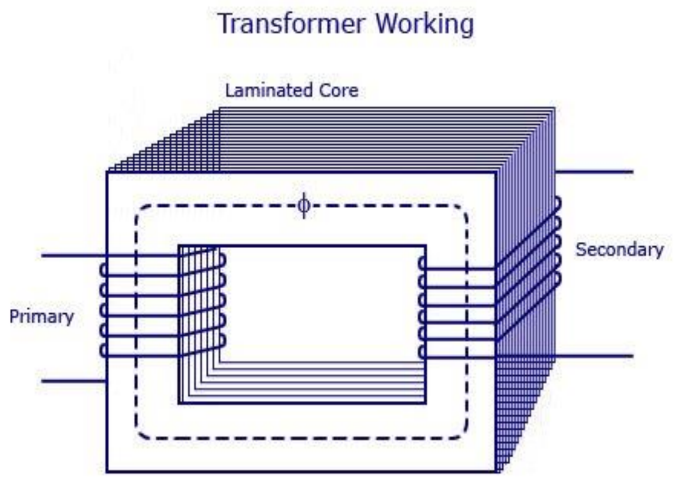


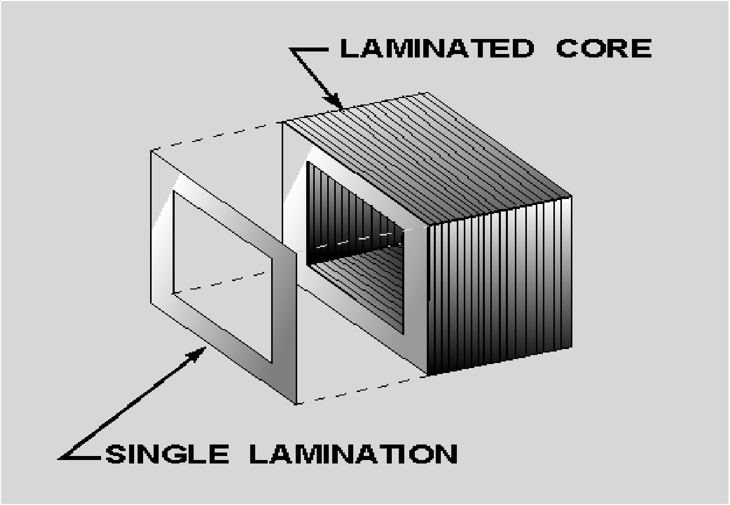
Transformer Main Parts

- Core
- Winding & Insulation System
- Tap Changer – OLTC
- Tank
- Bushings
- Radiator
- PRV – Pressure Relief Valves
- Conservator
- Breather
- Marshalling Box
- BUCHHOLZ Relay
- OSR – Oil Surge Relay
- Temperature indicator

Transformer - Core

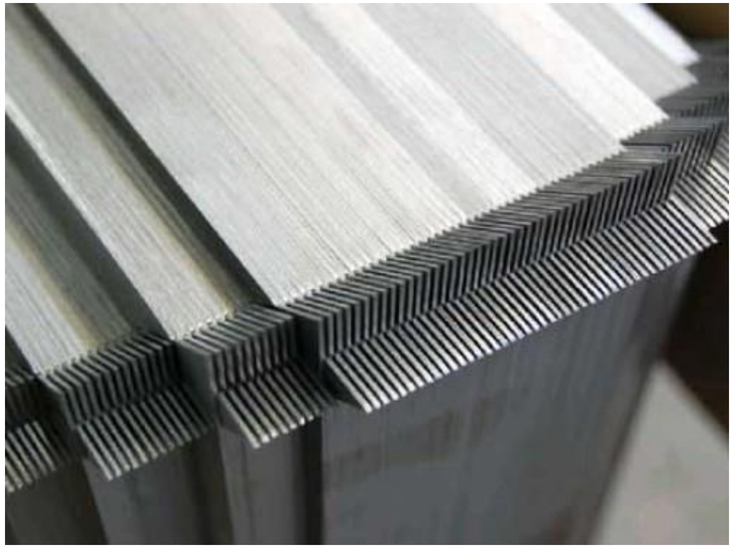
- The role of the magnetic core is to increase and concentrate the magnetic flux that links the primary and secondary coils.
- It is made up of thin laminations of CRGO of thickness 0.28 mm to 0.35 mm.
- Laminations are insulated from each other by oxide coating.
- Magnetostriction in the core produces a vibration that causes audible noise called as Humming (due to contract and expansion of core material)





Transformer - Core

- It is the backbone of the transformer from magnetic and mechanical aspect.
- It provides a path for Magnetic flux.
- It supports windings.
- Low losses, better heat dissipation, low vibrations.
- Higher working flux, specific core losses W/Kg at peak flux density 1.7 Tesla at 50 Hz, ageing withstand capability.



Transformer – Windings & Insulation System

- Windings are made up of Copper material.
- Wound concentrically around the core limbs.
- LV winding with thick cross sectional area is placed near the core on the press board cylinder.
- HV winding is placed above LV winding and is separated by press board cylinder and by oil ducts, hence HV winding is away from the core.

Transformer – Windings & Insulation System

- Superior Craft Paper Insulation is wrapped over conductor.
- Most sensitive part subjected to Thermal, Mechanical and di-electric Stresses.
- Major Insulations used in Windings are Thermally upgraded Craft Paper Cylinders, Synthetic Resins bonded press board cylinder and press board sheets.
- Minor Insulations used in windings are Press Board spacers, Cellulose tape and synthetic enamel wire.

Transformer – Windings & Insulation System

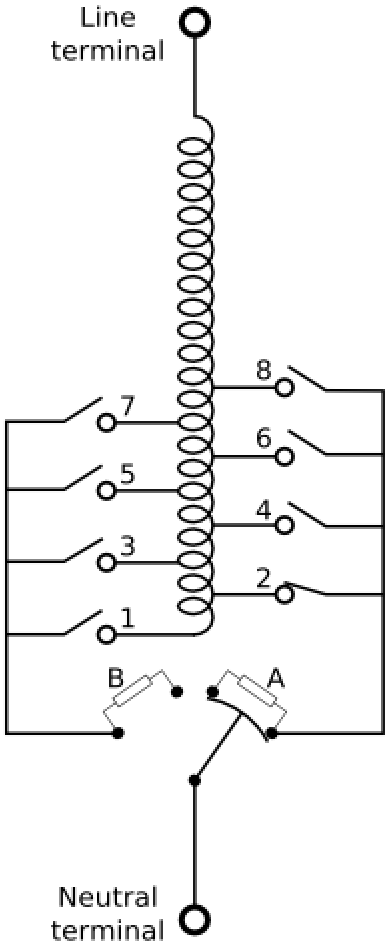
Transformer – Tap Changer

- Responsible of Tap Changer is :
  1. To supply a desired voltage to the load
  2. To counter the voltage drops due to loads
  3. To counter the input supply voltage changes on load

- There are Two types of Tap Changer

  No load (De-energized) Tap Changer – NLTC/DETC

  On Load Tap Changer - OLTC

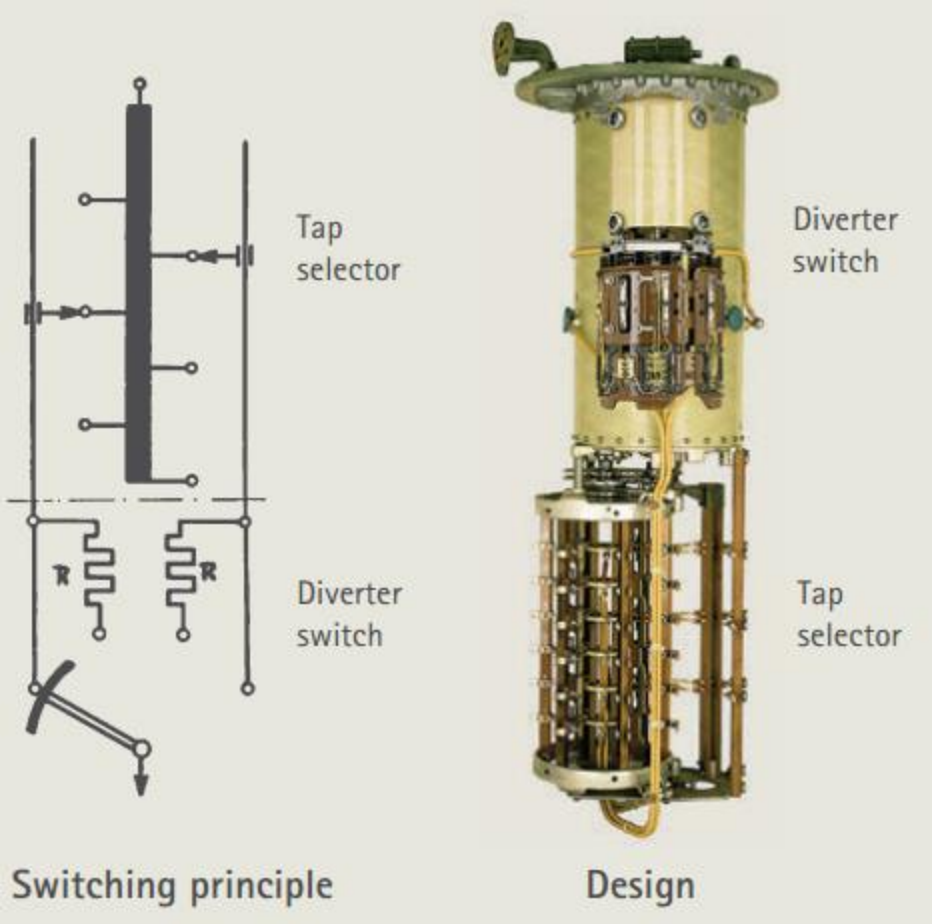


Transformer – Tap Changer

- On Load Tap Changer
  is mounted vertically
  within the Transformer Tank.

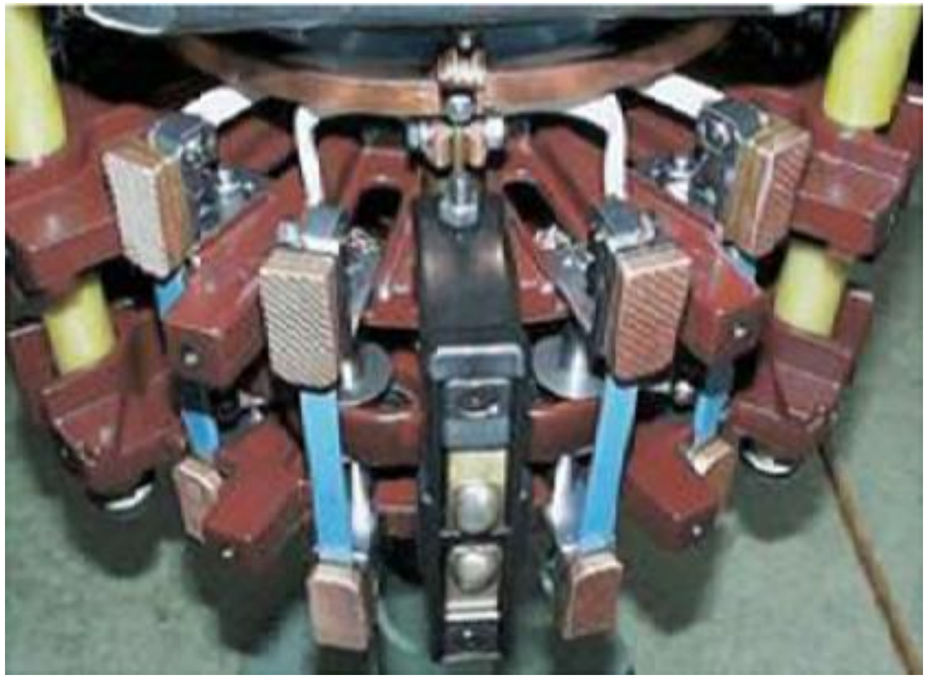
- It consists of diverter switch
  and Tap selector
  and separate Driving Mechanism Box.

- Driving Mechanism Box is fitted
  on the side of the Transformer Tank.



Transformer – On Load Tap Changer

Selector Switch Contact with Roller Contact



Diverter Switch Contact

Transformer – Tap Changer

Tap Changer

Transformer - Tank

- It is made from Steel material.
- Fabricated welded construction to obtain a box type construction.
- Supports and encloses various parts.
- Should be strong sturdy, free from vibrations.

Transformer - Tank

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- Should withstand mechanical load during handling, lifting and transport
- Should withstand Vacuum test and Pressure test
- Tank cover supports, tap changers and other fitments.
- It's accessories includes lifting legs, manhole for inspection, valves for filling and draining oils, earthing terminals.
- Contains filling pipes (to fill in the oil)
- Also lifting bolts to position it into place

Transformer - Bushing

- Bushing is designed to withstand the electrical field strength produced in the insulation
- Provides insulated support to conductor connecting the external terminal to the Transformer winding
- The leads of HV and LV windings are brought out and connected to the terminals of the Bushings.

Transformer - Bushing

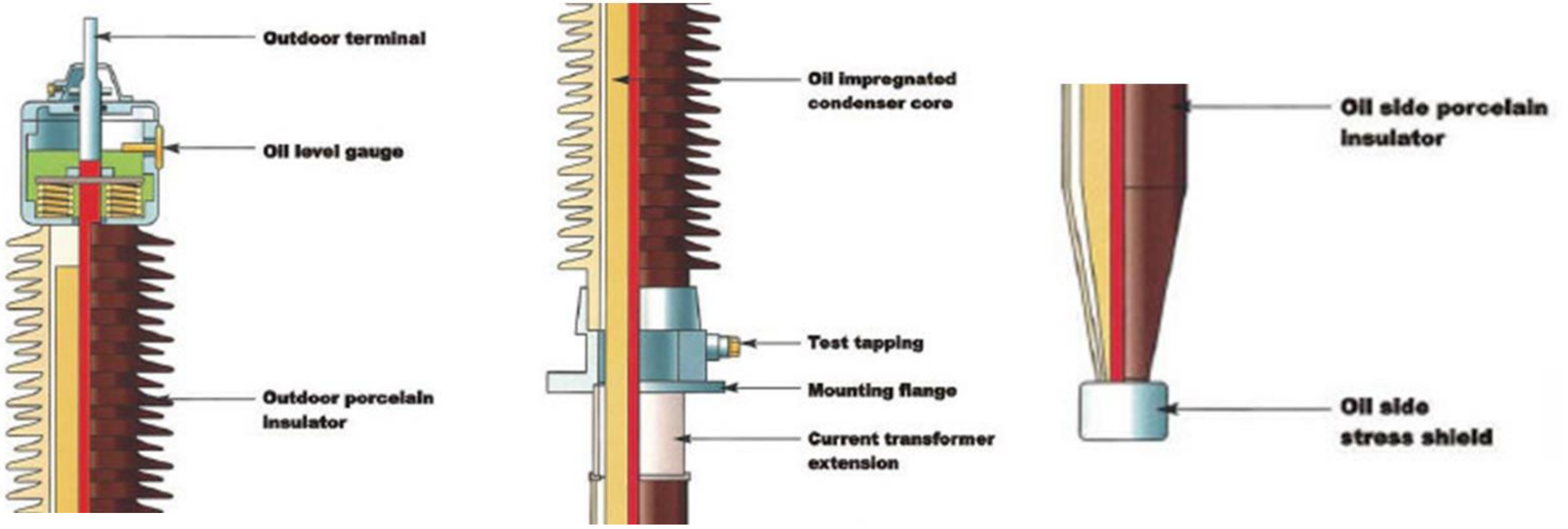
- How to recognize the HV from LV bushings – HV are longer and have more ribs (due to higher voltage) – also in most of the cases has tap adapter – a measurement point for TD (PF,DF) and PD measurement

- LV bushings are shorter but the conductor there is thicker due to the higher current

Transformer - Bushing

- Bushing mounted vertically or inclined on tank over on turrets.
- Two most common type of bushing are
  - solid porcelain bushings onsmaller transformers
  - oil-filled condenser bushings on larger transformers
- From the physical and electrical point of view, bushing appears to be the weakest part of the transformer.

Transformer - Bushing



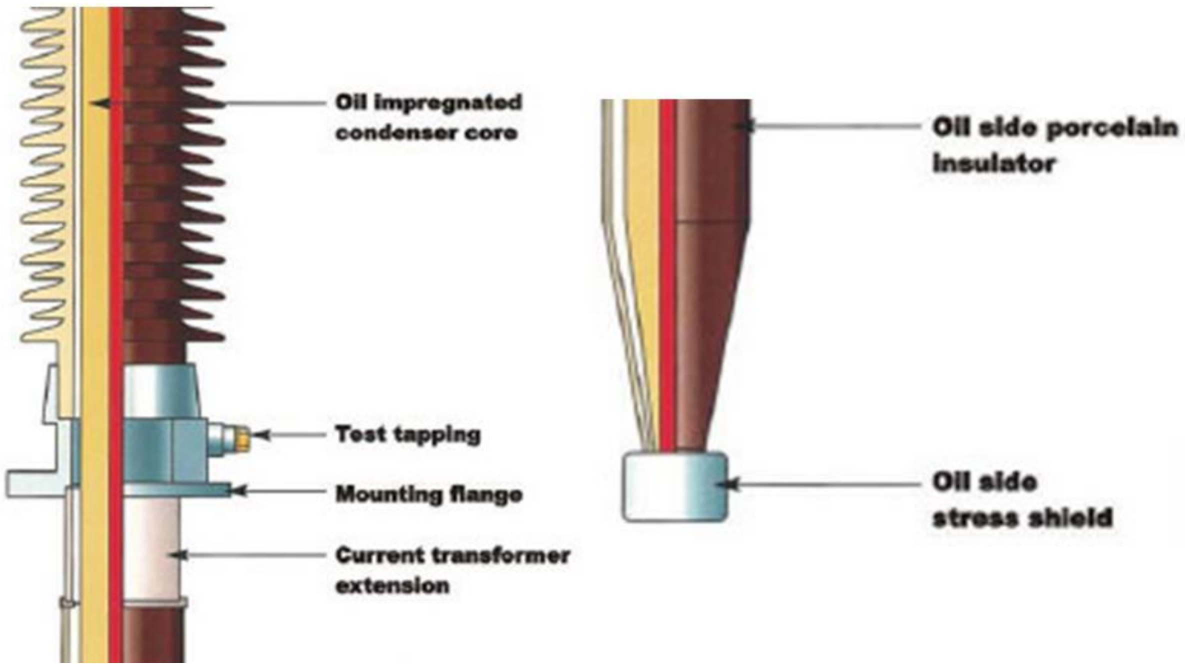
Transformer - Bushing

Current creates big electrical field – which in turn ionizes the insulators and produces a leakage current.

Big Leakage current – Could cause flashover

We want a small leakage current that is why we make the path of a leakage current longer with «ribs» on the bushing.

Also the ribs allow the bushing to keep some parts of the bushing dry when it is raining – to have lover leakage current



Transformer - Radiator

- The **radiator of transformer** accelerates the cooling rate of transformer.
- Oil immersed transformer is always provided with radiator.
- Plays a vital role in increasing loading capacity of an electrical transformer.
- Increases the surface area for dissipating heat of the oil.
- Oil immersed power transformer is generally provided with detachable pressed sheet radiator with isolating valves.

Transformer - Radiator

In case of Small size distributing transformer, the radiators are generally integrated parts of transformer body
and projected from the main tank.

Transformer - Radiator

Operation:

- Under loaded condition, warm oil increases in volume and comes to the upper portion of the main tank
- Then this oil enters in the radiator through top valve and cools down by dissipating heat through the thin radiator wall.
- This cold oil comes back to the main tank through the bottom radiator valve.
- This cycle is repeated continuously
  till the load is connected to the transformer.
- Dissipation of heat in the transformer radiator can be accelerated further
  by force air provided by means of fans.

Transformer – Pressure Relief Valve(PRV)

- Pressure Relief Valve is a safety element of the transformer
- PRV prevent heavy damages of the tank in the case of sudden rise of the internal pressure
- Designed in order to remove the excess pressure in a very short time as soon as pressure limit exceed
- During fault this PRV operate and trip the transformer, so it can be protected from further damage




Transformer - Conservator

- Conservator is a cylindrical tank mounted on supporting structure on the roof of the transformer main tank
- Provides adequate space to the expanded transformer oil
- Acts as a reservoir for transformer insulating oil
- In normal conditions filled up to about 50 %

Transformer - Breather

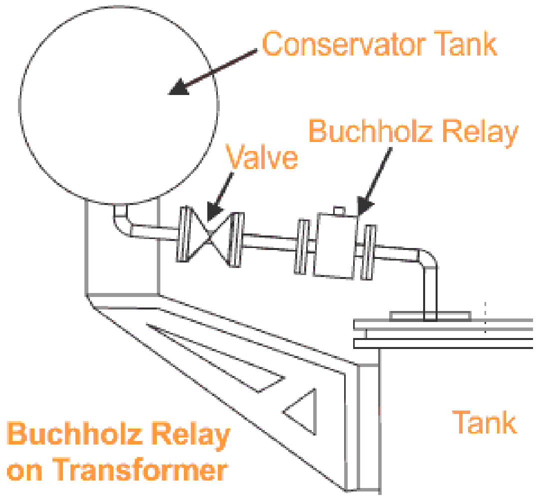
- Breather is used to absorb moisture in air while breathing
- A silica gel breather is the most commonly used way of filtering air from moisture
- **Silica gel breather for transformer** is connected with conservator tank by means of breathing pipe
- As silica gel becomes more affected by moisture, its colour changes
- There are few approaches here – blue to white and vice versa

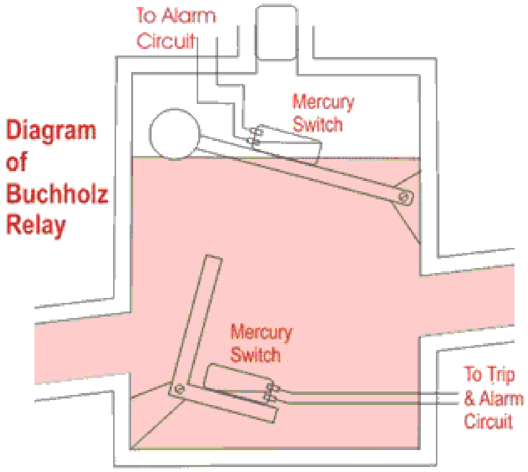
Transformer - Marshalling Box

- Marshalling Box is the master control panel for the protection devices.
- Marshalling box shall be provided with terminals for:
  - oil temperature indicator,
  - winding temperature indicator,
  - magnetic oil gauge
  - and buchholz relay.
- Marshalling box shall be weather proof type and shall be provided on the front side of transformer tank
- All the secondary wiring of the transformer from current transformers are terminated at the Marshalling Box .

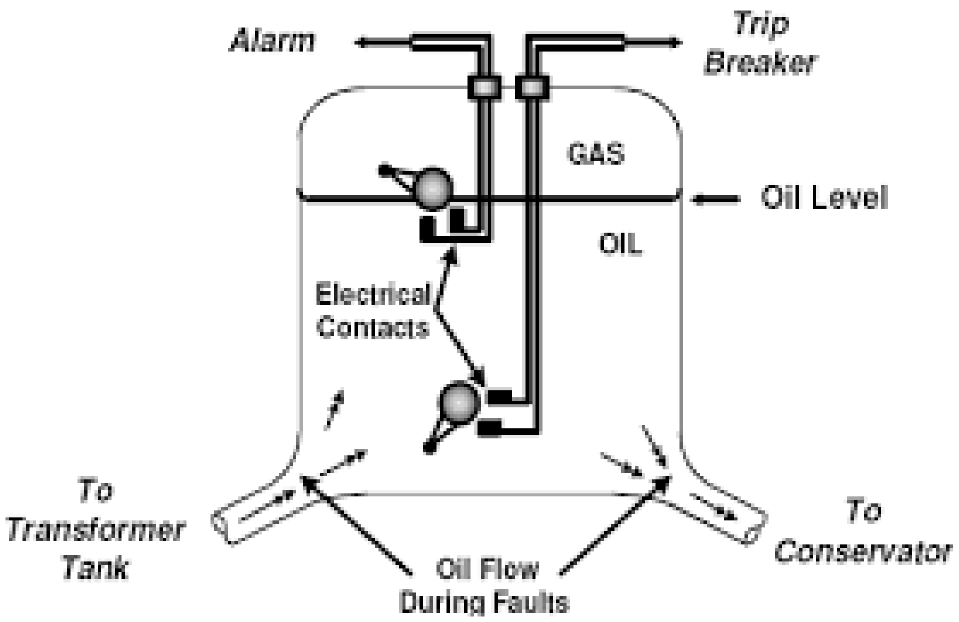
Transformer – Buchholz relay

- **Buchholz relay in transformer** is an oil container housed on the connecting pipe from main tank to conservator tank.
- It is mechanically Actuated.
- Gasses produced, due to internal faults, are the cause of actuating the upper switch of the relay.
- Surge of oil, due to severe faults (phases short circuit), strikes the baffle plate and close the mercury switch of the lower element.





Transformer – Buchholz relay



Transformer – Oil surge Relay

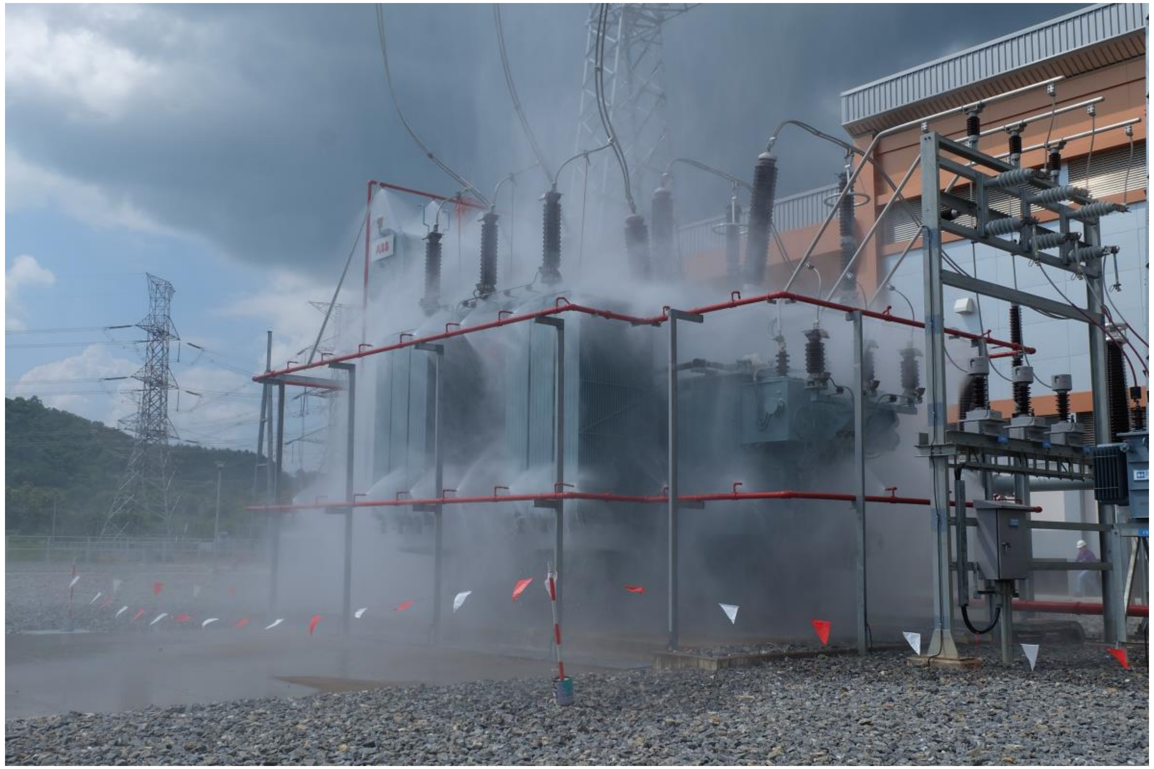
- The OSR (Oil Surge relay) is located on the OLTC (On load tap changer) chamber
- Principal of OSR relay is similar to the Buchholz relay
- As we know, OLTC has Moving parts and here more sparking come in picture due to which gas pressure builds up in OLTC chamber, this pressure is sensed by the OSR and the OSR trips the circuit

TRANSFORMER FAILURE

Transformer Failure

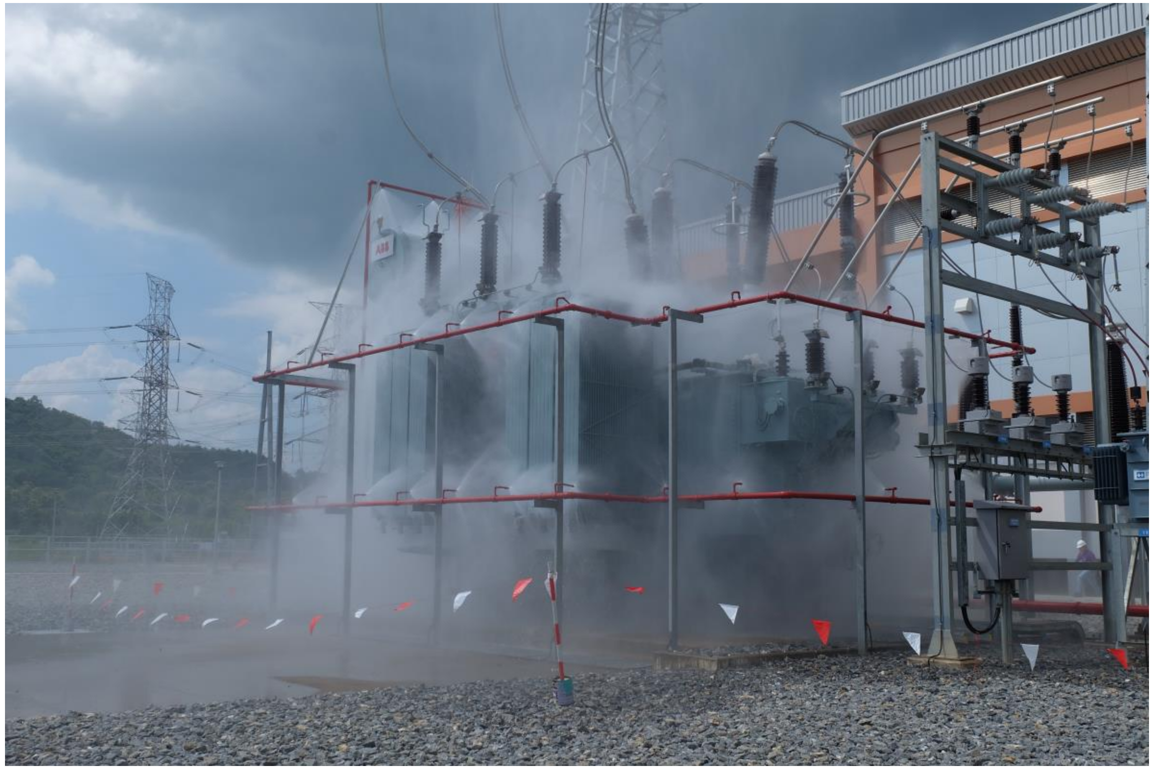
- Is inevitable if transformer is not taken care of

- Is exactly what we would like to avoid by properly maintaing the PT in good health



Important questions to ask ourselves

- **Why** test ?
- **When** to test ?
- **Who** should test ?
- **What** tests ?



Important questions to ask ourselves

Why test ?

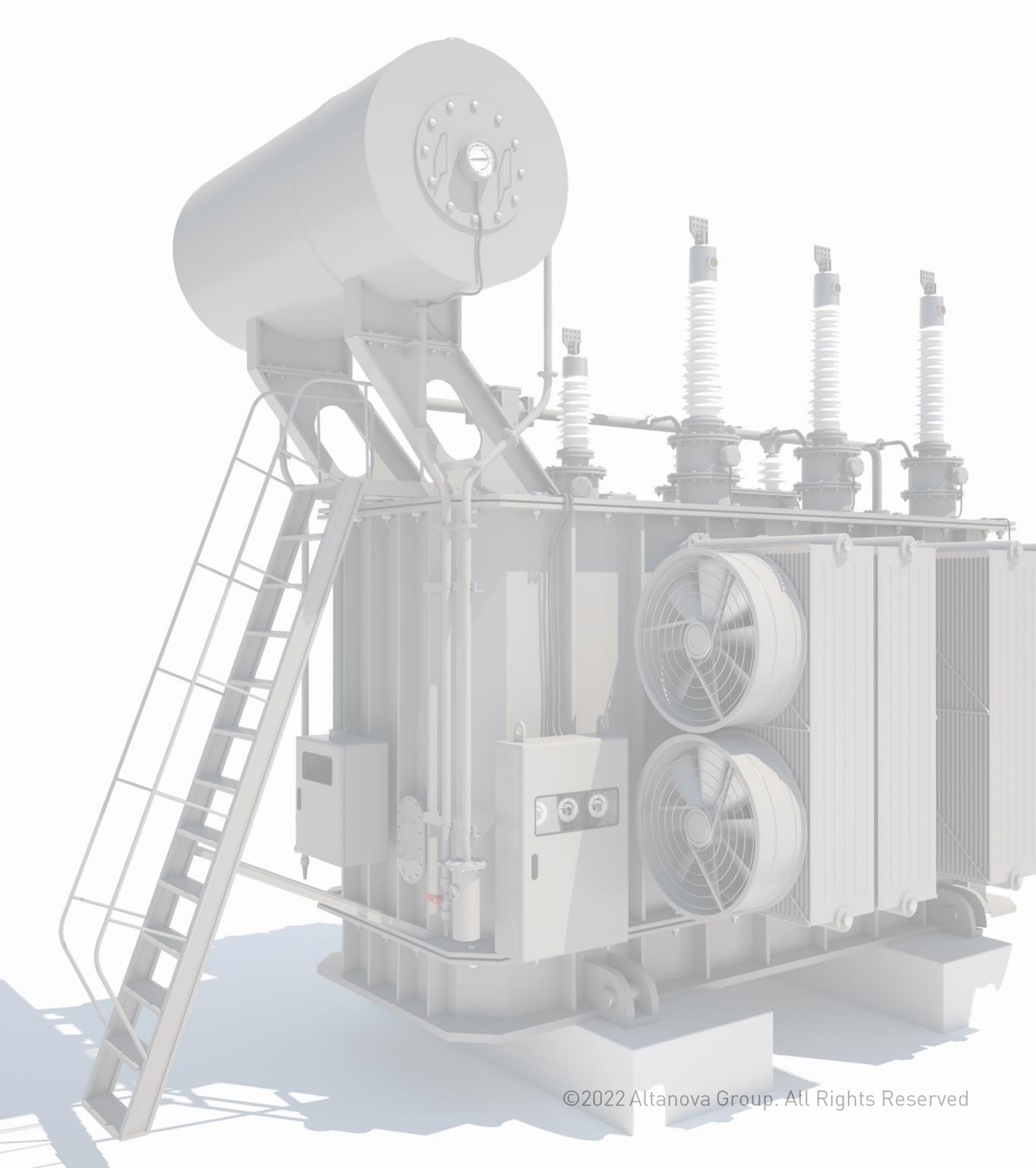
Because transformers are:

- **Expensive**
- Usually **reliable** and **durable**
- **Faults** can and do sometimes occur
- **Difficult** to **diagnose**
- Maintenance and visual inspections **limited value**
- Often **uneconomic** to **repair**
- Failures can be **catastrophic**
- **Appropriate** monitoring and management policies

Views on testing

‘We don’t have any problems,
So we don’t do any testing’

‘When we get a failure,
The first question the boss asks is
“WHEN WAS IT LAST TESTED ?”

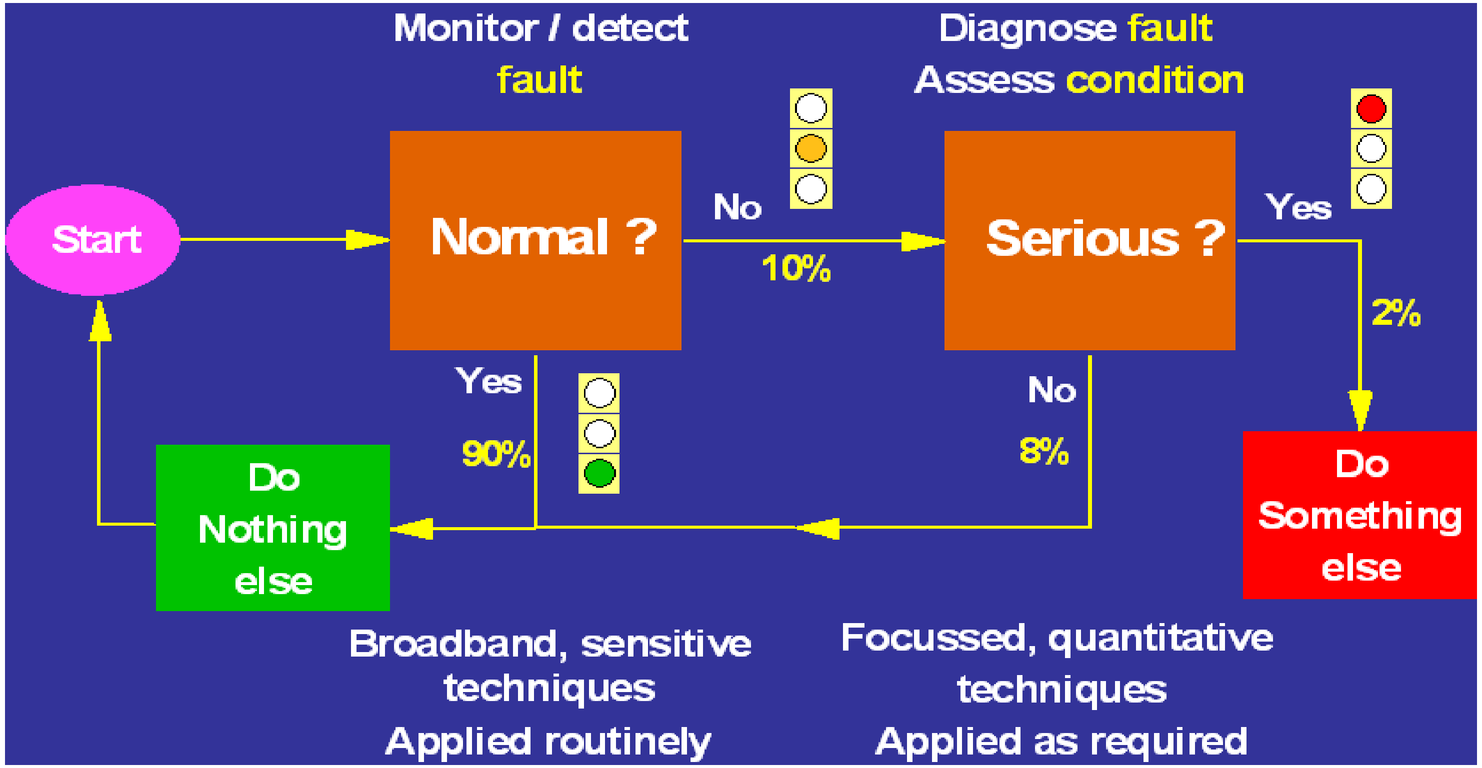


An Appropriate Policy ?

‘If it ain’t broke,
Don’t fix it’

Condition based methodology

When to test ?



Every 3 to 5 years if there are no issues with PT

Visual Inspection

Important questions to ask ourselves

Who should do the testing ?

- University researchers
- Test equipment manufacturers
- Transformer manufacturers
- Utility maintenance personnel
- Service companies

RECOMMENDED TESTS ON POWER TRANSFORMER

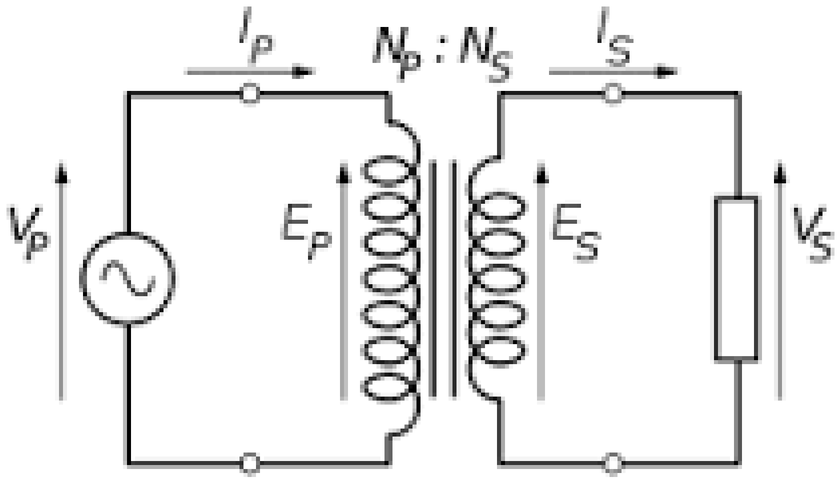
Recommended Tests on Power Transformer

- Ratio / Vector Group
- Winding Resistance and Dynamic Resistance Measurement
- No Load Test/Exciting Current
- Short Circuit Impedance (Leakage reactance) and Frequency Response to Stray Losses
- Insulation Resistance (DC method)
- Tangens Delta (Power Factor, C&DF Dissipation Factor) (AC method)/ Tip up and Tip down Tan Delta/Variable frequency Tan Delta
- SFRA – Sweep Frequency Response Analysis
- Partial Discharge Test
- Oil tests (DGA, breakdown voltage)

TRANSFORMER TURNS RATIO (TTR) TEST

Transformer Turns Ratio (TTR)

The **turns ratio** is defined as the ratio of the number of turns of wire in the primary winding (NP) to the number of turns of wire in the secondary winding (NS)



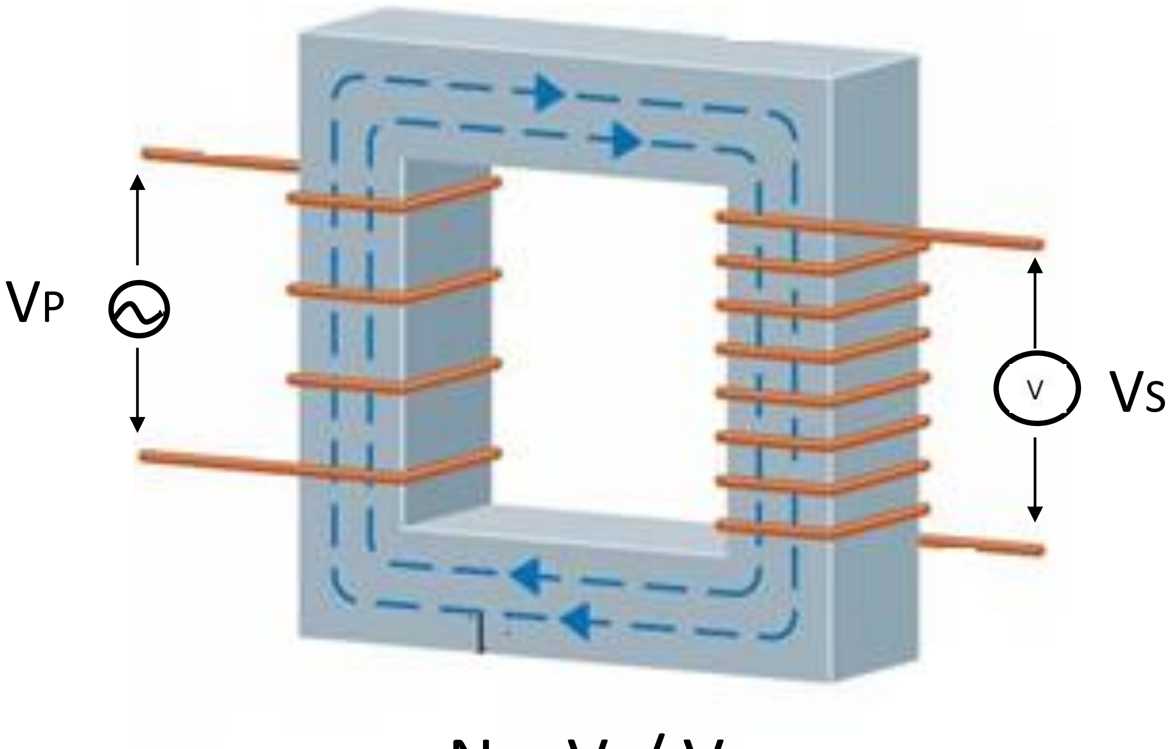
$$\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S}$$

Transformer Turns Ratio (TTR)

Also the turn ratio (N) can be defined as the no-load voltage ratio between two windings of a transformer.

This test can be done on lower voltage levels – for example up to 200 V or Higher voltage levels – for example 10 kV – LV and HV TTR

The HV TTR requires more advanced test sets, but can uncover more issues as it stresses more the insulation



$N = V_P / V_S$

Transformer Turns Ratio (TTR)

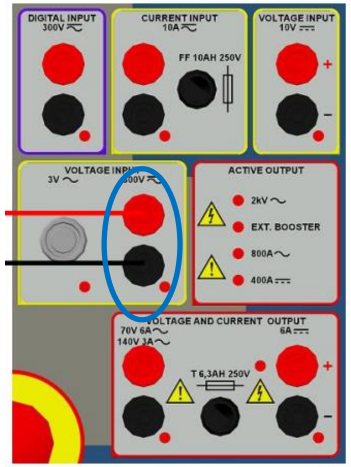
Purpose of Turns Ratio Test:

- Identify if there is:
  - any shorted Turns,
  - any Open turns in HV winding.
- Provides Information on insulation failure between turns.
- Helps in Identifying the Vector Group of the Transformer.

Transformer Turns Ratio (TTR)

Example - Instruments Required to Test :

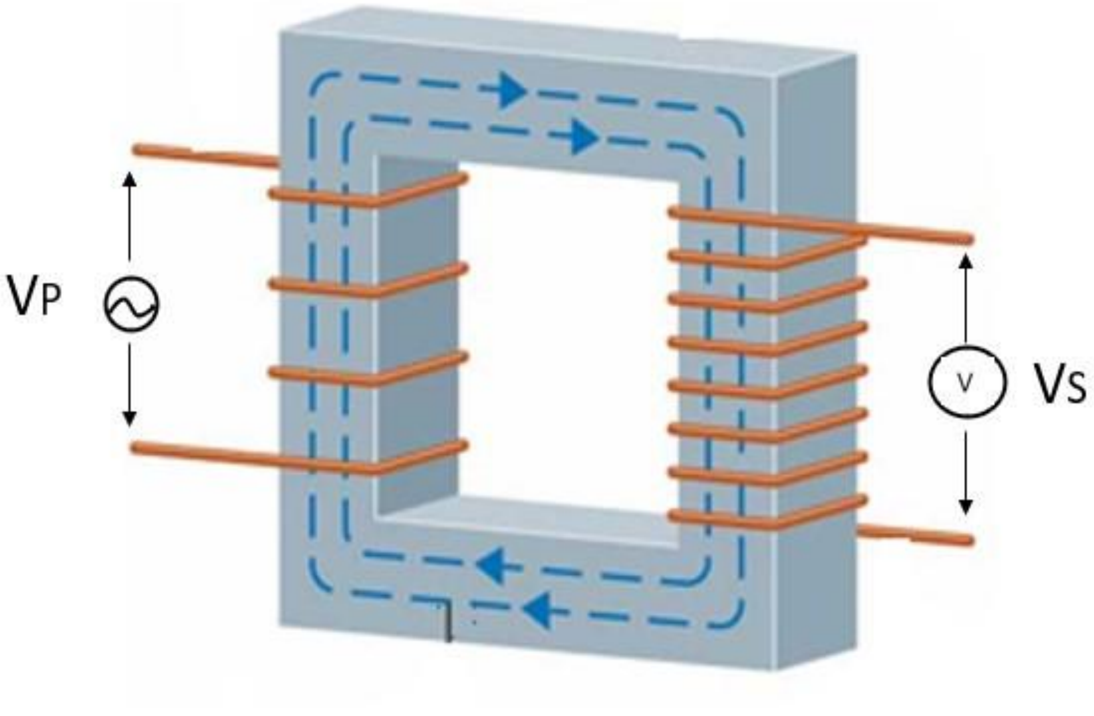
AC voltage Source and Voltage Measurement input, like STS 5000.



Transformer Turns Ratio (TTR)

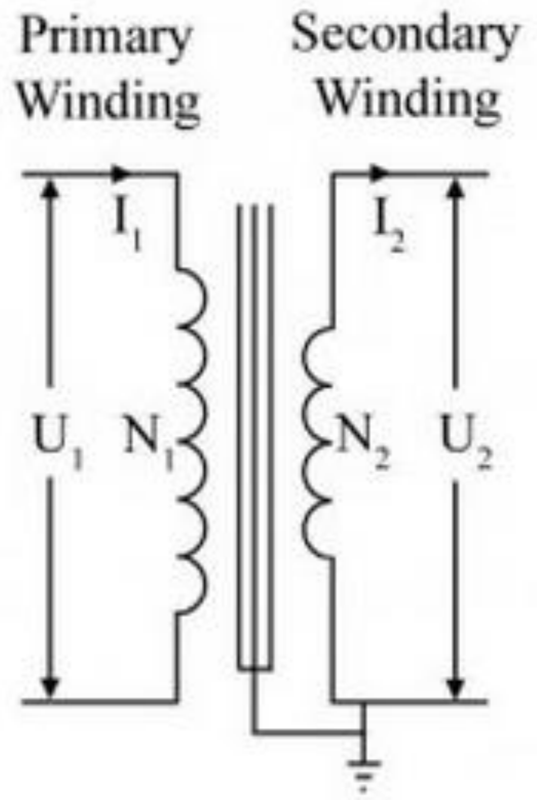
Before Test:

- *Need to know:*
  - Type of Transformer
  - Number of winding
  - Phases
- *Voltage Applied:*
  - Must not exceed the Rated Voltage of Transformer
  - Always to the HV side of the Transformer
- *Voltage Measured:*
  - Must not exceed the measurement input of the Voltmeter.
- *Turns Ratio*
  - Must be measured on all Taps.



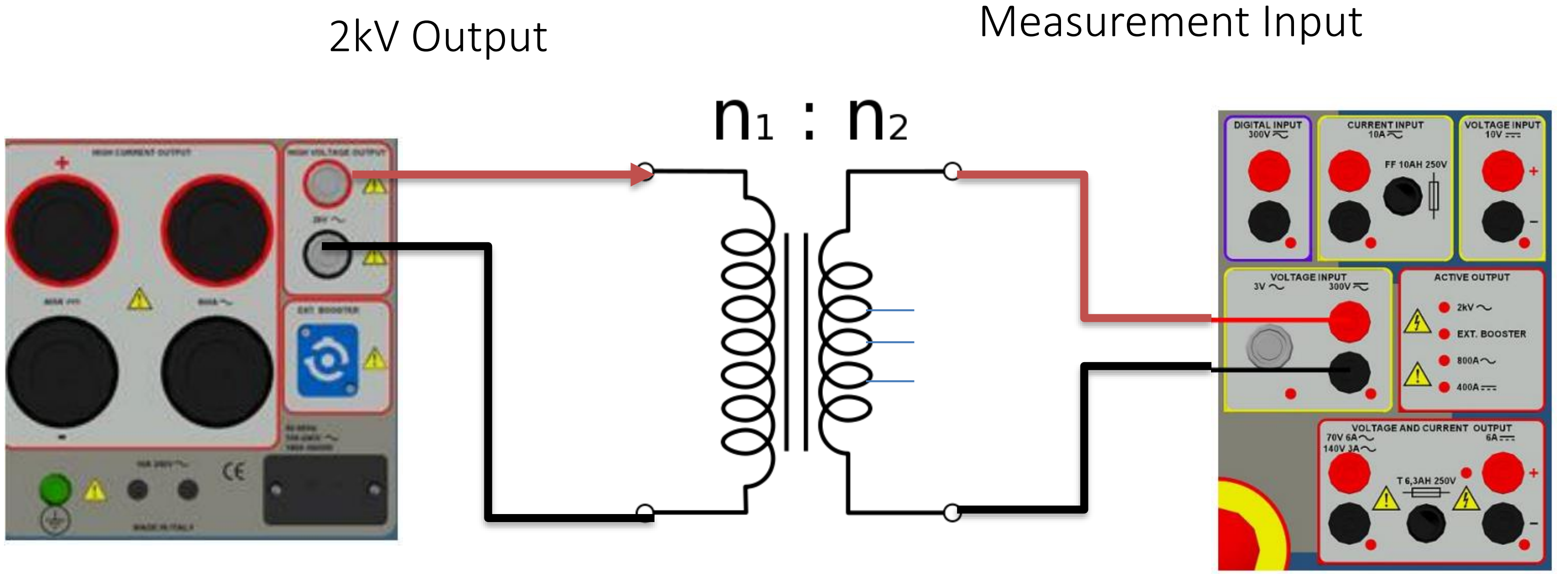
Transformer Turns Ratio (TTR)

Testing on a single Phase Transformer



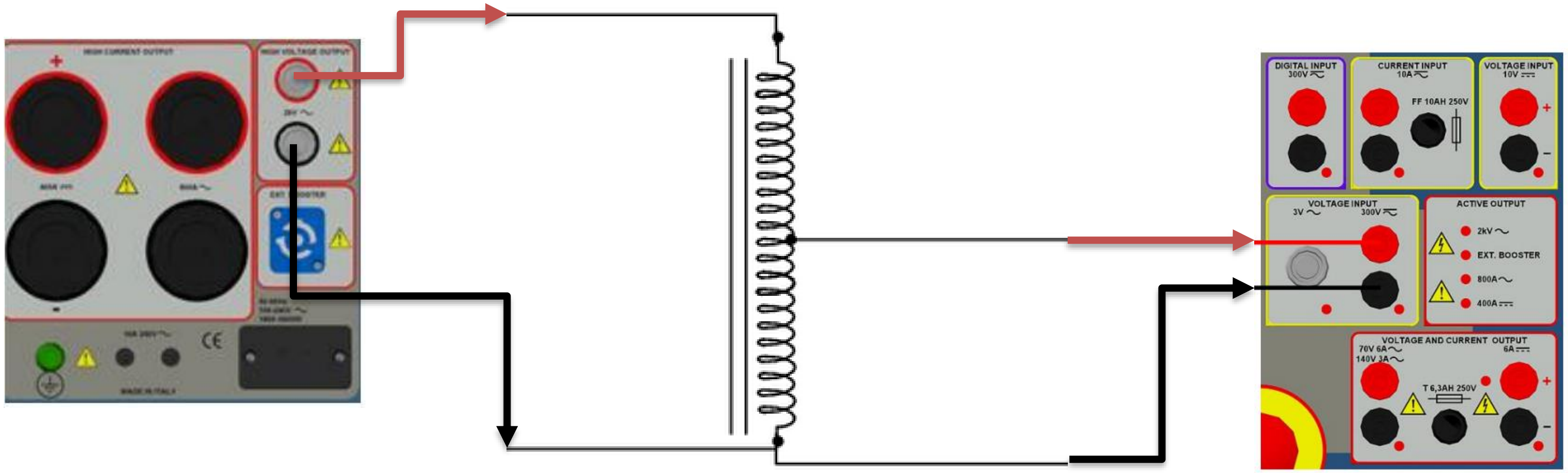
Transformer Turns Ratio (TTR)

Ratio Measurement on a Single Phase Transformer



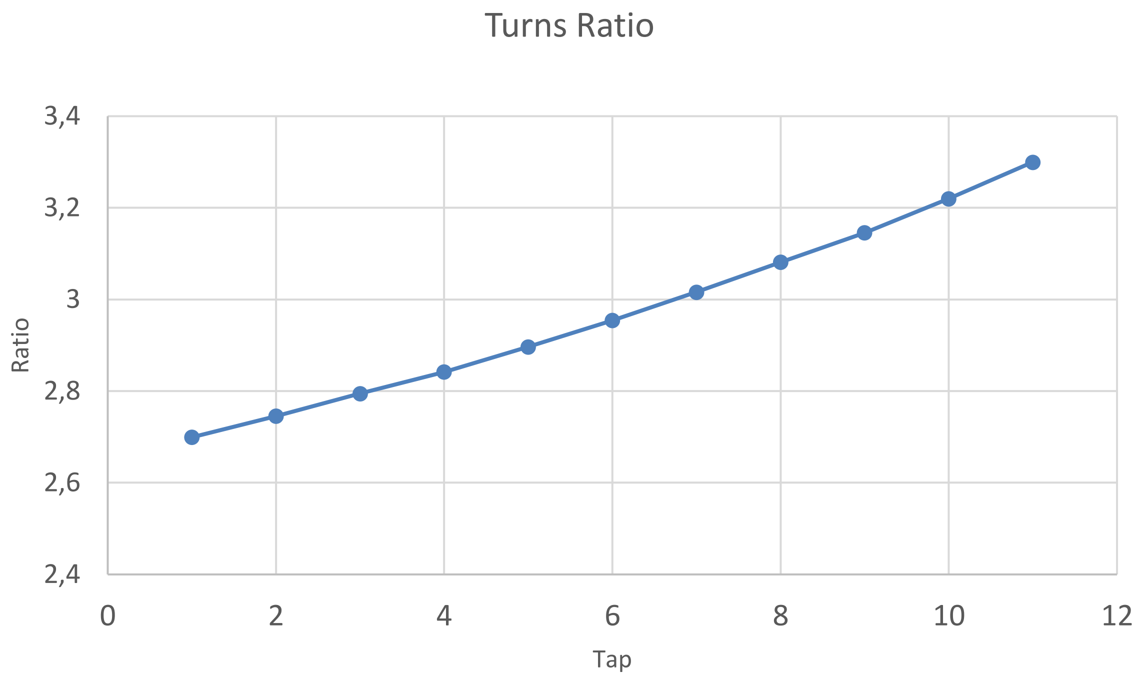
Transformer Turns Ratio (TTR)

Ratio Measurement on a Single phase Auto Transformer



Transformer Turns Ratio (TTR)

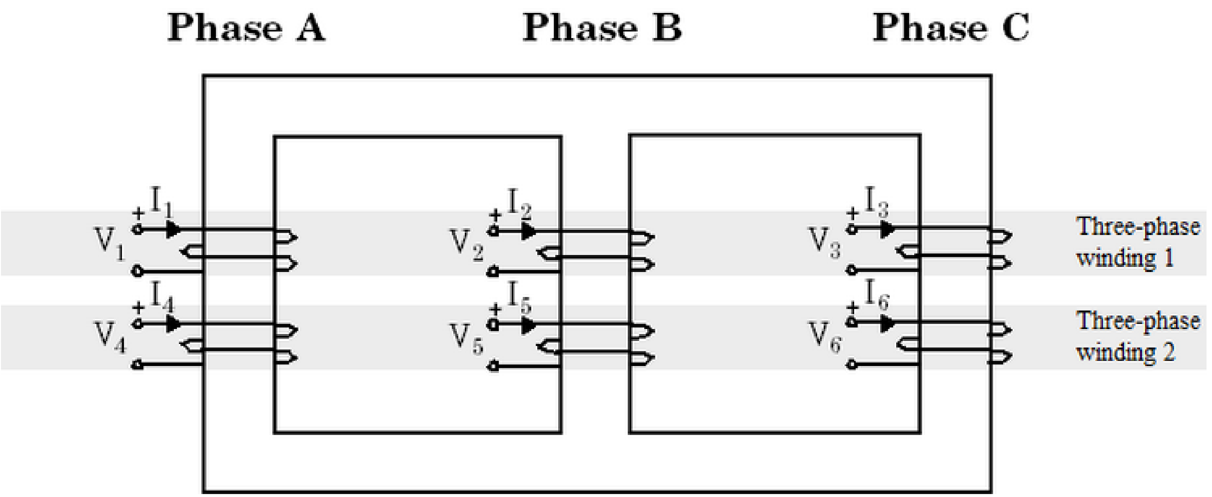
Transformer Turns Ratio Plot wrt Tap



Transformer Turns Ratio (TTR)

Ratio of Three Phase Transformer

- Three phase transformer consists of three sets of primary windings, one for each phase.
- Three sets of secondary windings wound on the same iron core.

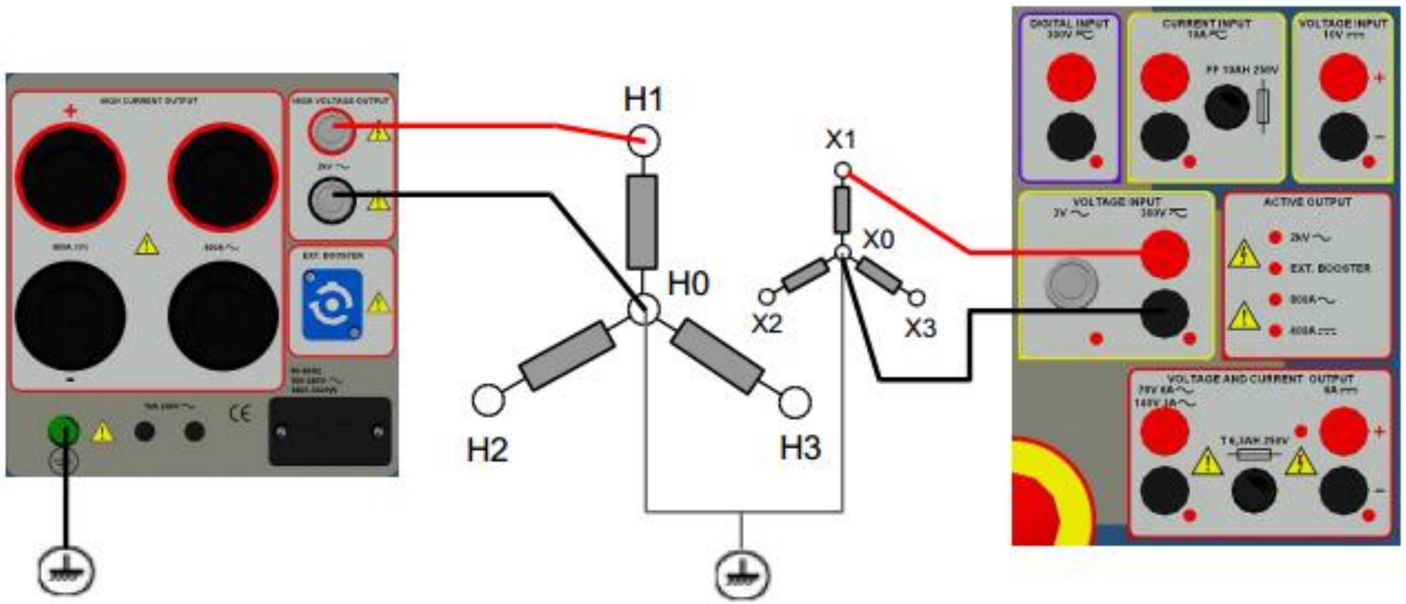


Transformer Turns Ratio (TTR)

220kV Three Phase Transformer

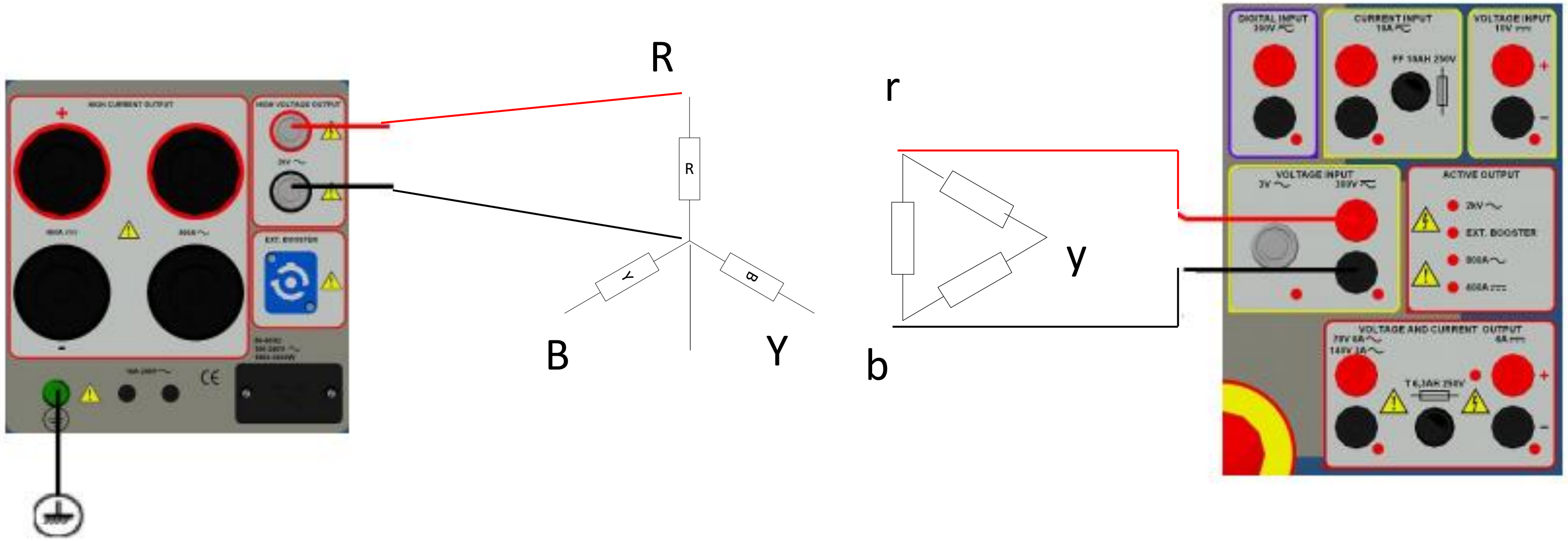
Transformer Turns Ratio (TTR)

Transformer Ratio test on a YNyn0 Vector Group



Transformer Turns Ratio (TTR)

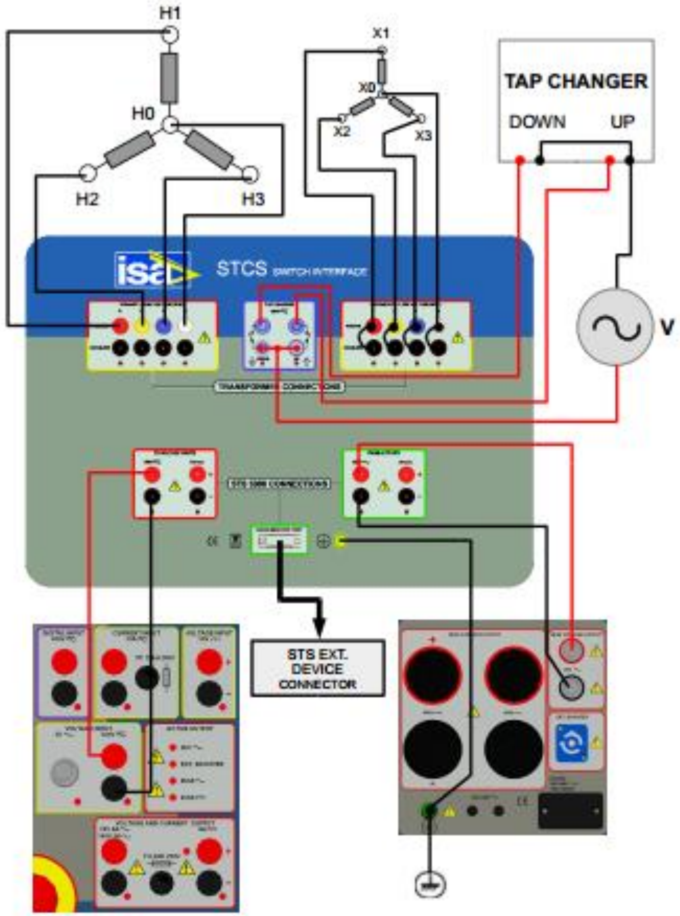
Transformer Ratio test on a YNd11 Vector Group



Transformer Turns Ratio (TTR)

Transformer Ratio Test using Switch Box

- One time connection
- Automatic control of OLTC
- Perform the test as per the Vector Group mentioned
- Also possible to use an integral solution – test set with integrated switchbox



Transformer Turns Ratio (TTR)

Test Result of Ratio Test on 400kV Transformer

Nominal values

	Tap #	Ratings	Vector Group		Phases
HV		400,000 kV	yn		3-phase
LV	1	143,100 kV	a	0	
Turn ratio		2,795			

Test values

Test Voltage 200,0 V

Test Frequency 50,0 Hz

STCS

Auto-tap OLTC

Pulse time 1,0 s

Auto-phase ABC

current 11

from 1

to 11

Results

Vn HV [V]	V HV [V]	I HV [A]	φI HV [°]	V LV [V]	φV LV [°]	Ratio	Err %
200,0	201,7	2,136m	69,5	74,722	-31,0	2,6993	0,21
200,0	201,7	1,554m	69,4	74,633	-31,0	2,7023	0,32
200,0	201,7	2,006m	68,8	74,555	-40,0	2,7051	0,43

Transformer Turns Ratio (TTR)

Tap 1

	Vn HV [V]	V HV [V]	I HV [A]	φI HV [°]	V LV [V]	φV LV [°]	Ratio	Err %
A	200,0	201,7	2,136m	69,5	74,722	-31,0	2,6993	0,21
B	200,0	201,7	1,554m	69,4	74,633	-31,0	2,7023	0,32
C	200,0	201,7	2,006m	68,8	74,555	-40,0	2,7051	0,43

Tap2

	Vn HV [V]	V HV [V]	I HV [A]	φI HV [°]	V LV [V]	φV LV [°]	Ratio	Err %
A	200,0	201,6	2,124m	68,6	73,445	-30,0	2,7455	74,64m
B	200,0	201,6	1,544m	68,4	73,357	-30,0	2,7487	0,19
C	200,0	201,6	2,024m	68,6	73,269	-31,0	2,7517	0,30

Tap17

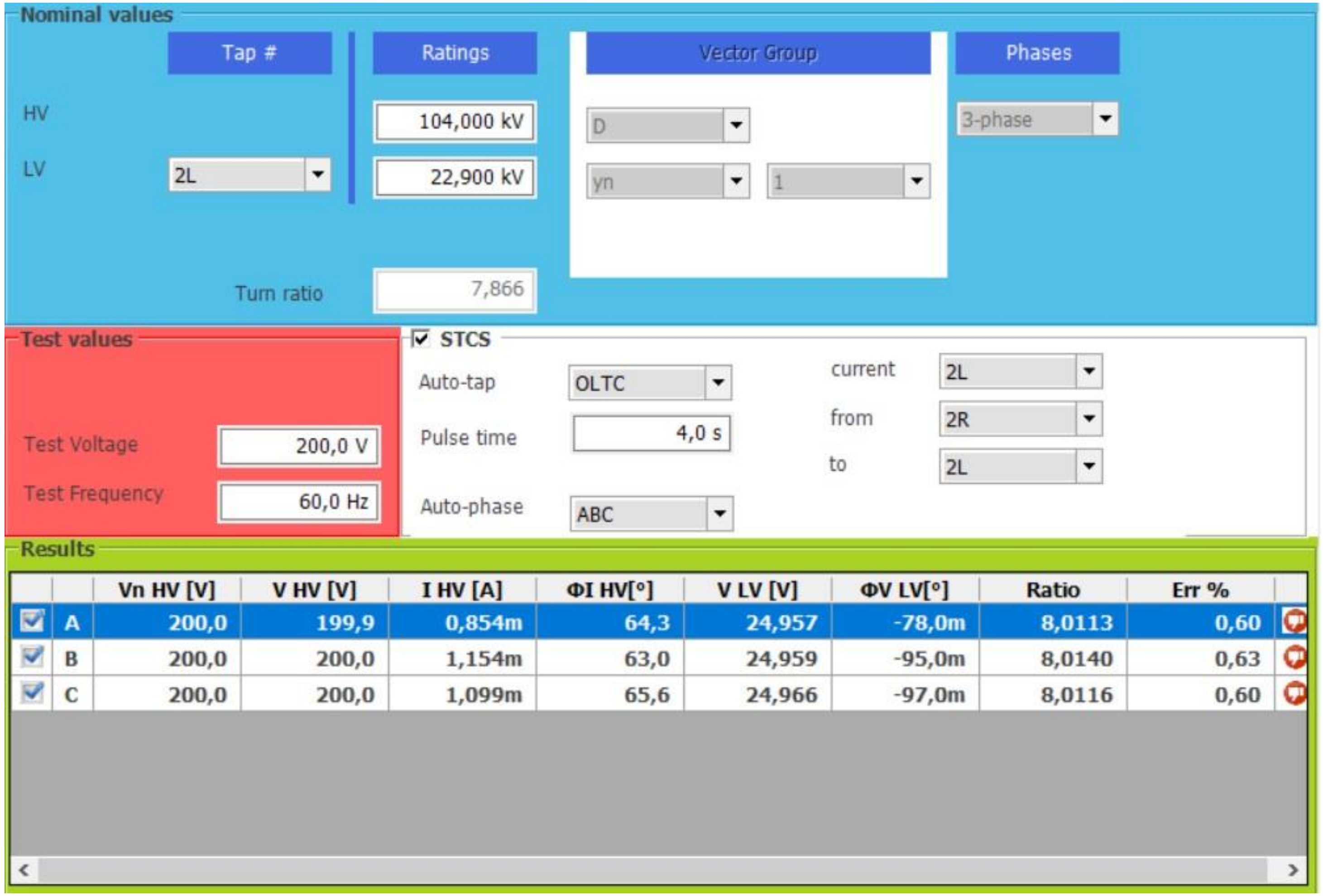
	Vn HV [V]	V HV [V]	I HV [A]	φI HV [°]	V LV [V]	φV LV [°]	Ratio	Err %
A	200,0	201,5	2,360m	68,5	61,077	-26,0	3,2995	0,22
B	200,0	201,5	1,761m	68,8	60,989	-26,0	3,3043	0,37
C	200,0	201,5	2,277m	68,2	60,892	-25,0	3,3094	0,52

For the ones who want to know more – current measured is actually No Load current

Result evaluation – ratio error < 0.5 %

Transformer Turns Ratio (TTR)

Test Result of Ratio Test on 104 kV Transformer



	Vn HV [V]	V HV [V]	I HV [A]	ΦI HV[°]	V LV [V]	ΦV LV[°]	Ratio	Err %
A	200,0	199,9	0,854m	64,3	24,957	-78,0m	8,0113	0,60
B	200,0	200,0	1,154m	63,0	24,959	-95,0m	8,0140	0,63
C	200,0	200,0	1,099m	65,6	24,966	-97,0m	8,0116	0,60

Transformer Turns Ratio (TTR)

Tap 1

		Vn HV [V]	V HV [V]	I HV [A]	ΦI HV[°]	V LV [V]	ΦV LV[°]	Ratio	Err %
☑	A	200,0	199,9	0,854m	64,3	24,957	-78,0m	8,0113	0,60
☑	B	200,0	200,0	1,154m	63,0	24,959	-95,0m	8,0140	0,63
☑	C	200,0	200,0	1,099m	65,6	24,966	-97,0m	8,0116	0,60

Tap2

		Vn HV [V]	V HV [V]	I HV [A]	ΦI HV[°]	V LV [V]	ΦV LV[°]	Ratio	Err %
☑	A	200,0	200,0	0,993m	71,9	25,117	-88,0m	7,9632	0,62
☑	B	200,0	200,0	1,303m	69,3	25,107	-84,0m	7,9659	0,65
☑	C	200,0	200,0	1,239m	69,5	25,111	-91,0m	7,9639	0,63

Tap 3

		Vn HV [V]	V HV [V]	I HV [A]	ΦI HV[°]	V LV [V]	ΦV LV[°]	Ratio	Err %
☑	A	200,0	200,0	0,884m	65,0	25,325	-0,1	7,8990	0,42
☑	B	200,0	200,0	1,141m	62,1	25,318	-0,1	7,9010	0,44
☑	C	200,0	200,0	1,049m	62,0	25,324	-77,0m	7,8981	0,41

Tap 4

		Vn HV [V]	V HV [V]	I HV [A]	ΦI HV[°]	V LV [V]	ΦV LV[°]	Ratio	Err %
☑	A	200,0	200,0	1,095m	70,1	25,486	-0,1	7,8486	0,39
☑	B	200,0	199,9	1,394m	67,8	25,470	-87,0m	7,8504	0,41
☑	C	200,0	200,0	1,334m	67,7	25,486	-0,1	7,8487	0,39

Even thou we see error > 0.5%, it does not mean that we autmatically need to replace the PT. It means we need to investigate further more

Result evaluation – ratio error < 0.5 %

VECTOR GROUP TEST

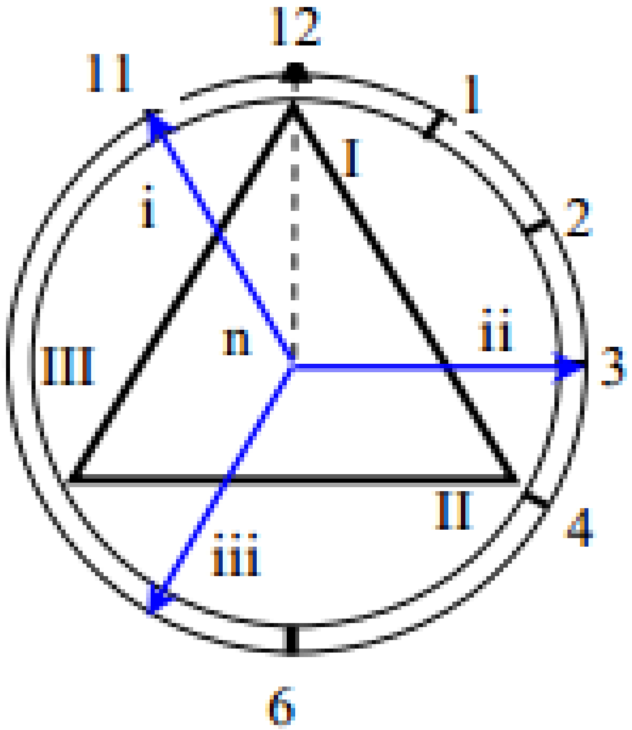
Vector Group Test

Connection of a 3 Phase Transformer

The vector group of transformer is an essential property for successful parallel operation of transformers.

Eg : Dyn11

- “D” indicates delta 1ry winding.
- “yn” indicates Star with Neutral 2ry winding
- “11” indicate the difference in phase angle between the windings, with HV winding is taken as a reference. The number is in units of 30 degrees.



Selection of Phase in case of phase by phase measurement is very critical.

Vector Group Test

Two tests need to be executed in order to verify if the Vector Group is correct.

In both cases we need to short circuit phases B and C on the primary side and generate voltage between phases A and B on the primary side.

Test 1:

We measure on secodary side between phases A and B

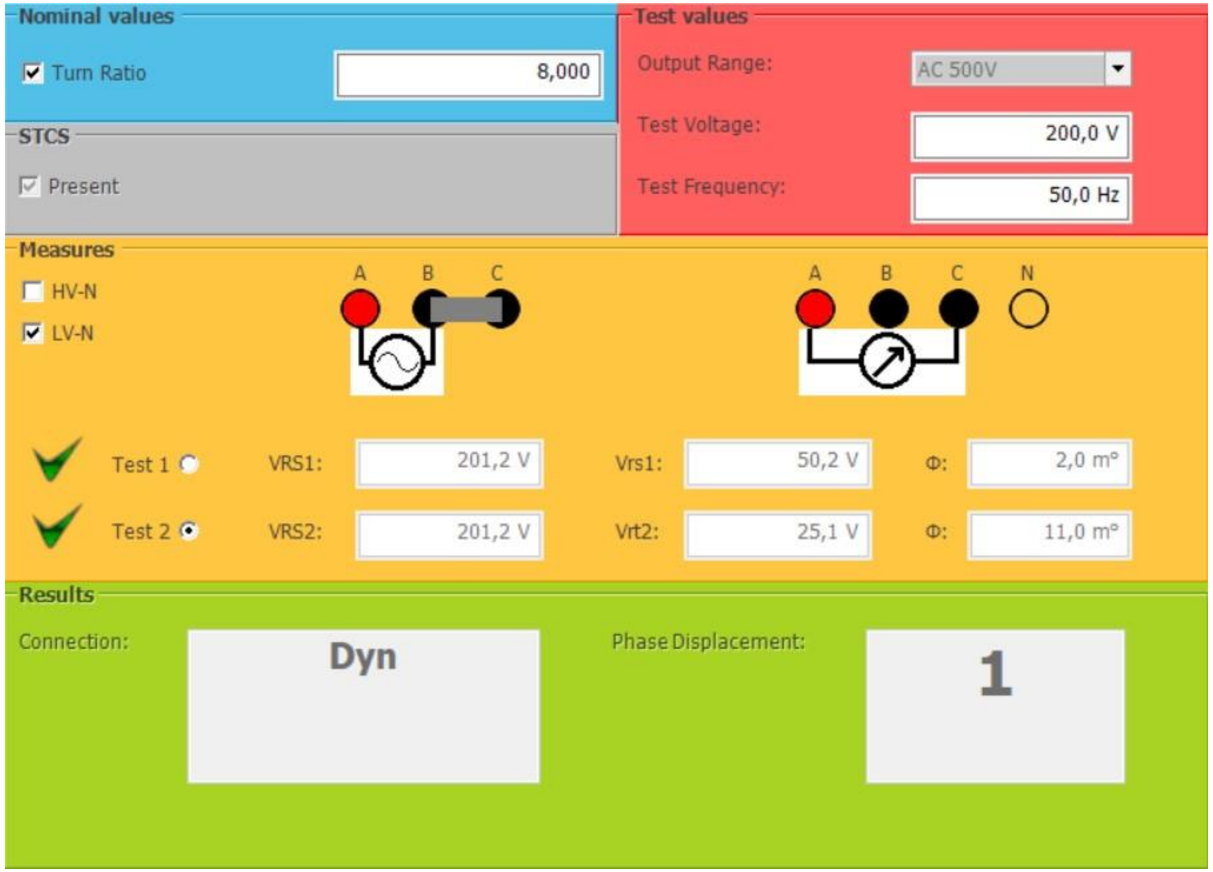
Vector Group Test

Test 2:

We measure on secodary side between phases A and C

Automatically we get the result

Obtained vector group needs to be the same as the nominal vector group.



WINDING RESISTANCE TEST

Winding resistance test

Winding resistance measurements in transformers are of fundamental importance for the following purposes :

- Calculations of the I^2R component of conductor losses.
- Calculation of winding temperature at the end of a temperature test cycle.
- As a Bench mark for assessing possible damage
- Last test to be executed (due to magnetisation of the core the same should be demagnetized before doing No Load and SFRA test)
- It is done at site in order to check for abnormalities due to
    - broken strands of conductor,
    - high contact resistance in tap changers,
    - high voltage leads and bushings in the field.
    - loose connections.

Winding resistance test

- Transformer winding contains inductance and Resistance
- The DC current source must be extremely stable.

$$V_{dc} = I \cdot R + L \frac{di}{dt}$$

I	= DC current through transformer winding
R	= resistance of the transformer winding
L	= inductance of the transformer winding
di/dt	= changing value of current (ripple)

- The inductor current must not be allowed to jump instantaneously from one value to another.
- Note : Open-circuit a physical inductor through which a finite current is flowing, an arc will appear across the switch.
- The fact that we use DC current means that we measure Resistance – not Impedance

Winding resistance test

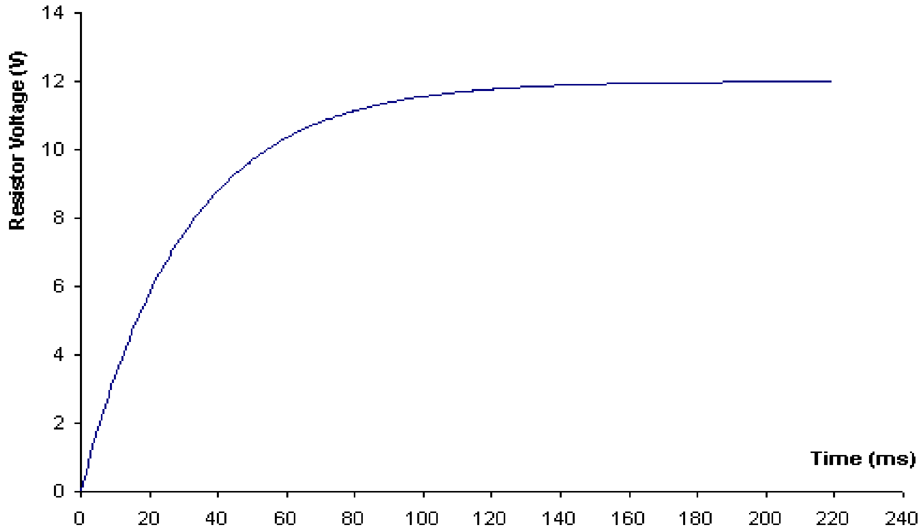
Procedure

- For star connected winding, the resistance measured between the line and neutral terminal.
- For star connected auto-transformers, the resistance of the HV side is measured between HV and LV terminal, then between LV terminal – neutral
- If OLTC Present, Resistance shall be taken at each Tap continuously without Discharging the Transformer
- If DETC Present, Resistance measured at each tap and before changing the Tap Transformer must be denergized
- For delta connected windings, between pairs of line terminals (A-B, B-C, C-A)
- Use Temperature Compensation ("recalculate" the measured values to the temperature at which the initial resistance measurement was done (usually around 70˚C)

Winding resistance test

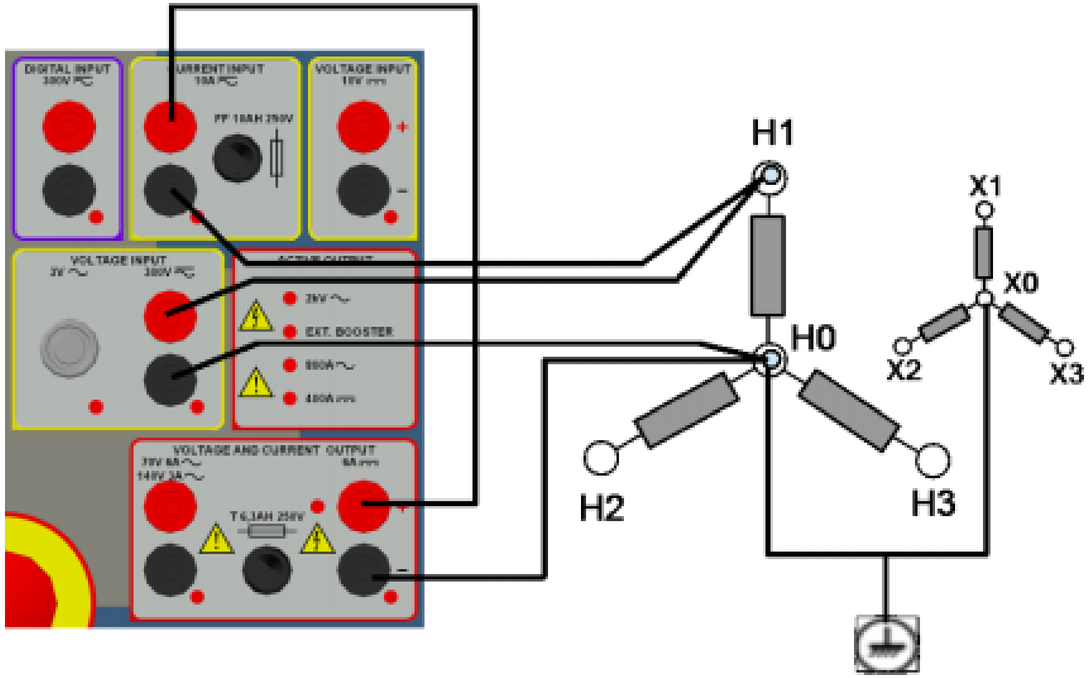
Test Requirement

- Stable DC current Source
- Voltmeter
- Algorithm for stable reading of the Resistance
- Discharging after Measurement
- It would be good if the testing current is not smaller than 1% of nominal current and not bigger than 10 %
- It can take time (few min) to initially charge the transformer core **– so that $\frac{di}{dt}$ change of current becomes 0**
- Time (s)



Winding resistance test

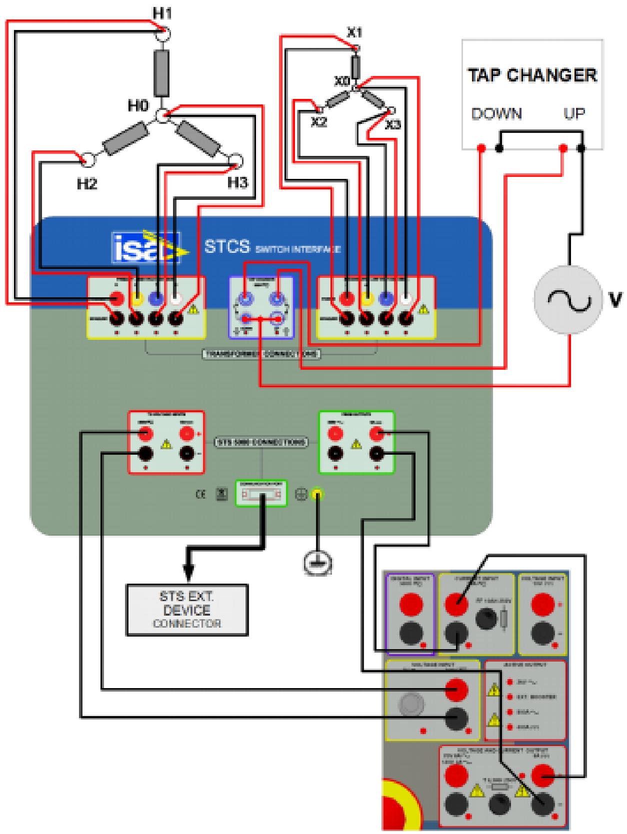
Winding resistance test with STS 5000



Winding resistance test

Winding Resistance with Switch Box :

- Automatic Winding Resistance test on 3 Phase Transformer.
- Measurement is performed both at Primary and Secondary.
- Automatic Control of OLTC of the Transformer for testing of transformer at all Taps.
- It reduces the measurement time a lot (by 70 %) because each Ph is only once energised and de-energised – so 3 time all together



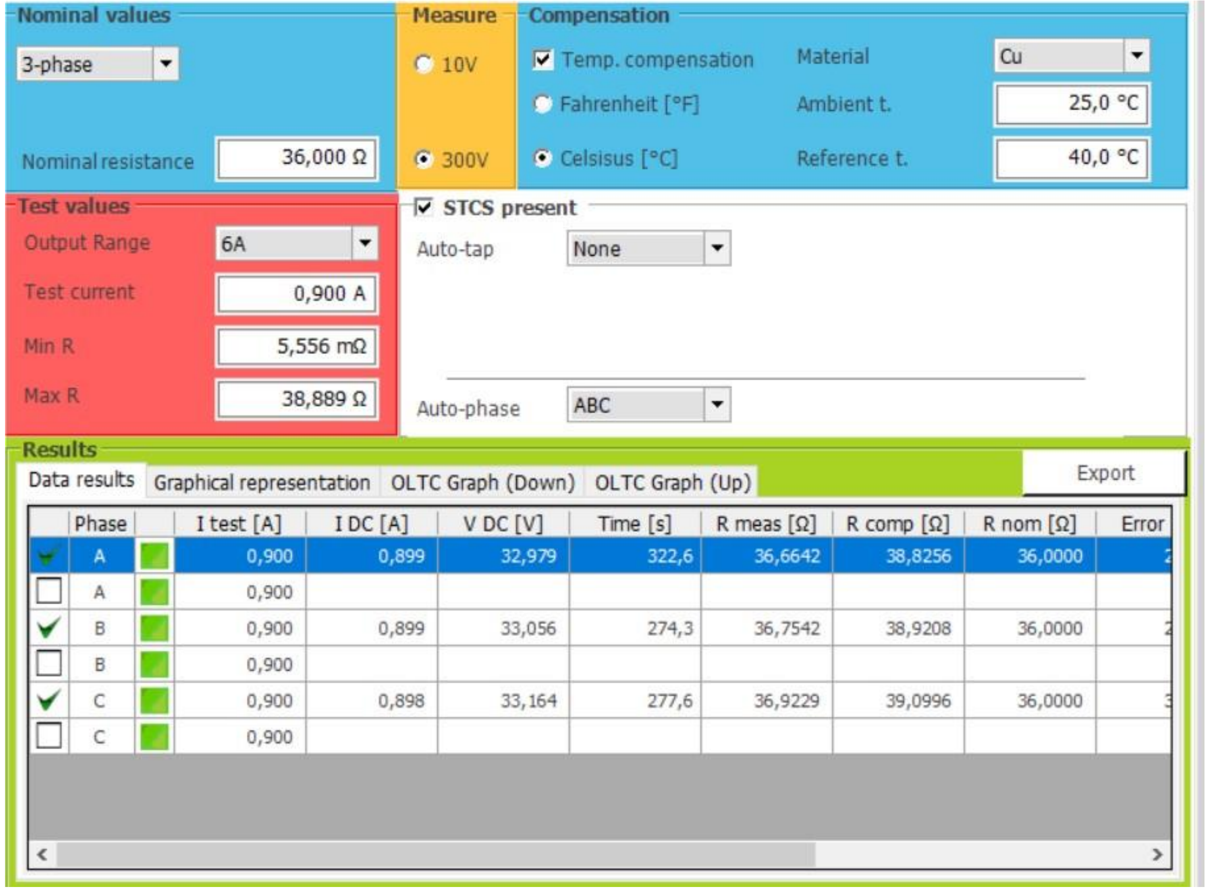
Solution with Integrated Switchbox

Winding resistance test

Result evaluation – result needs to be within 2% of referece value (3% in some cases)

If reference values are not available – Phases are compared – again - 2 % difference between phases is max tolerance

Example 1 – Primary side resistance – usually higher resistance if we talk about step down Transformer (36.7 Ω)



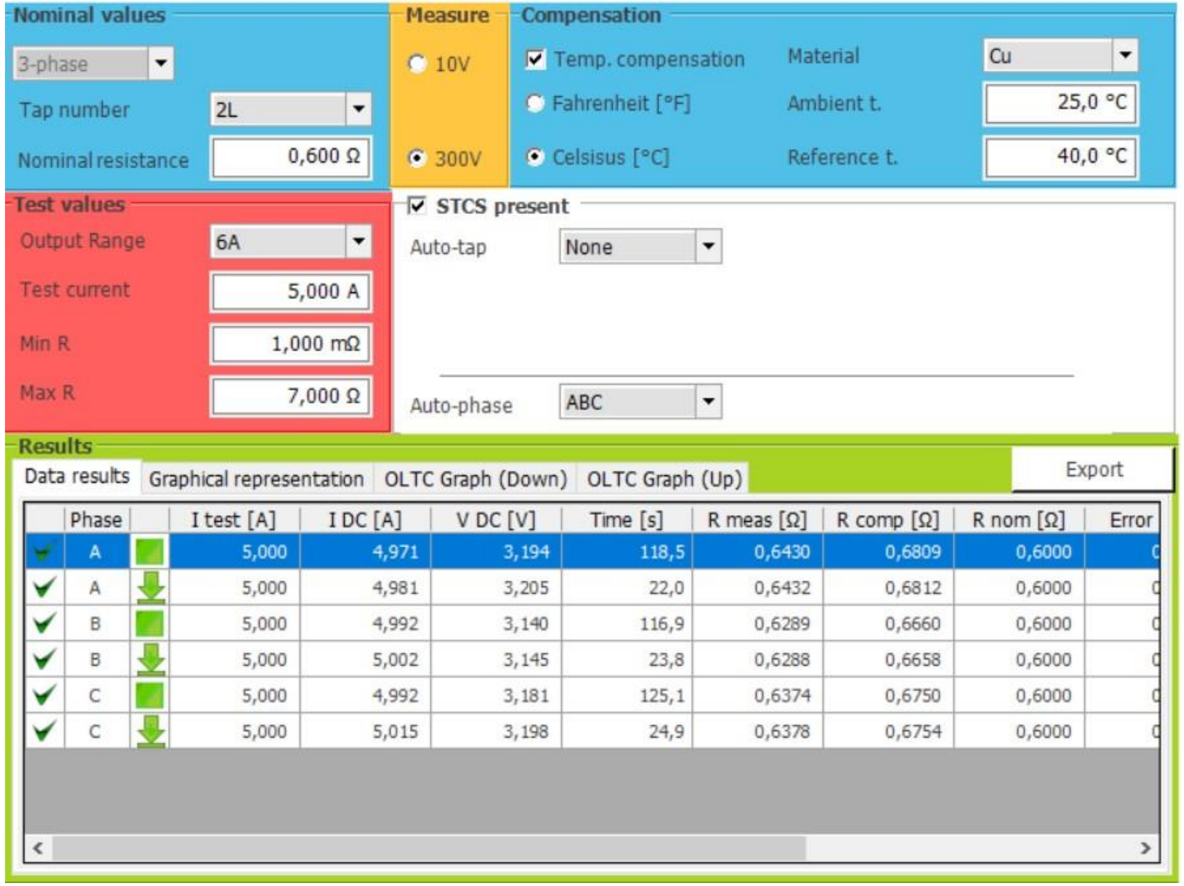
Phase	I test [A]	I DC [A]	V DC [V]	Time [s]	R meas [Ω]	R comp [Ω]	R nom [Ω]	Error
A	0,900	0,899	32,979	322,6	36,6642	38,8256	36,0000	
A	0,900							
B	0,900	0,899	33,056	274,3	36,7542	38,9208	36,0000	
B	0,900							
C	0,900	0,898	33,164	277,6	36,9229	39,0996	36,0000	
C	0,900							

Winding resistance test

Example 2 – Secondary side resistance – usually
lower resistance if we talk about step down
Transformer (0.63 Ω) because lower voltage on the trafo means higher current and for higher current we want lower resistance to reduce the losses.

Observe R_{meas} and R_{comp} colums (compensation)

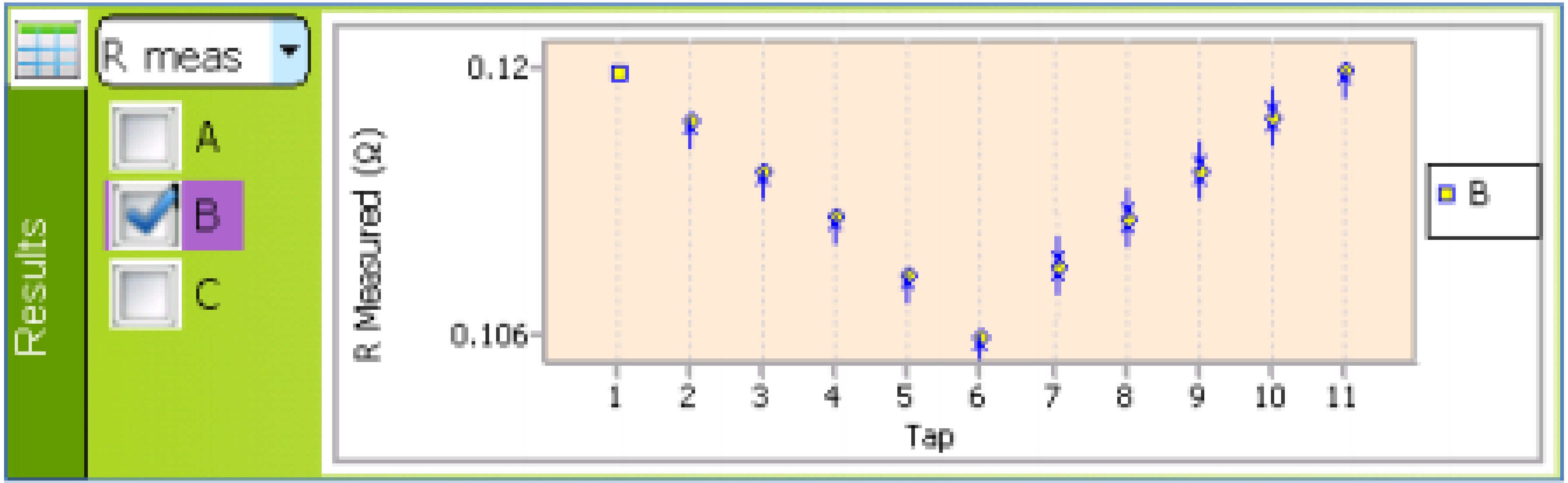
Also see the difference in time needed to execute the measurement (Ph A 118 s vs. 22 s)



	Phase		I test [A]	I DC [A]	V DC [V]	Time [s]	R meas [Ω]	R comp [Ω]	R nom [Ω]	Error
	A		5,000	4,971	3,194	118,5	0,6430	0,6809	0,6000	0
	A		5,000	4,981	3,205	22,0	0,6432	0,6812	0,6000	0
	B		5,000	4,992	3,140	116,9	0,6289	0,6660	0,6000	0
	B		5,000	5,002	3,145	23,8	0,6288	0,6658	0,6000	0
	C		5,000	4,992	3,181	125,1	0,6374	0,6750	0,6000	0
	C		5,000	5,015	3,198	24,9	0,6378	0,6754	0,6000	0

Winding resistance test

Graphical presentation of Winding Resistance on each Tap

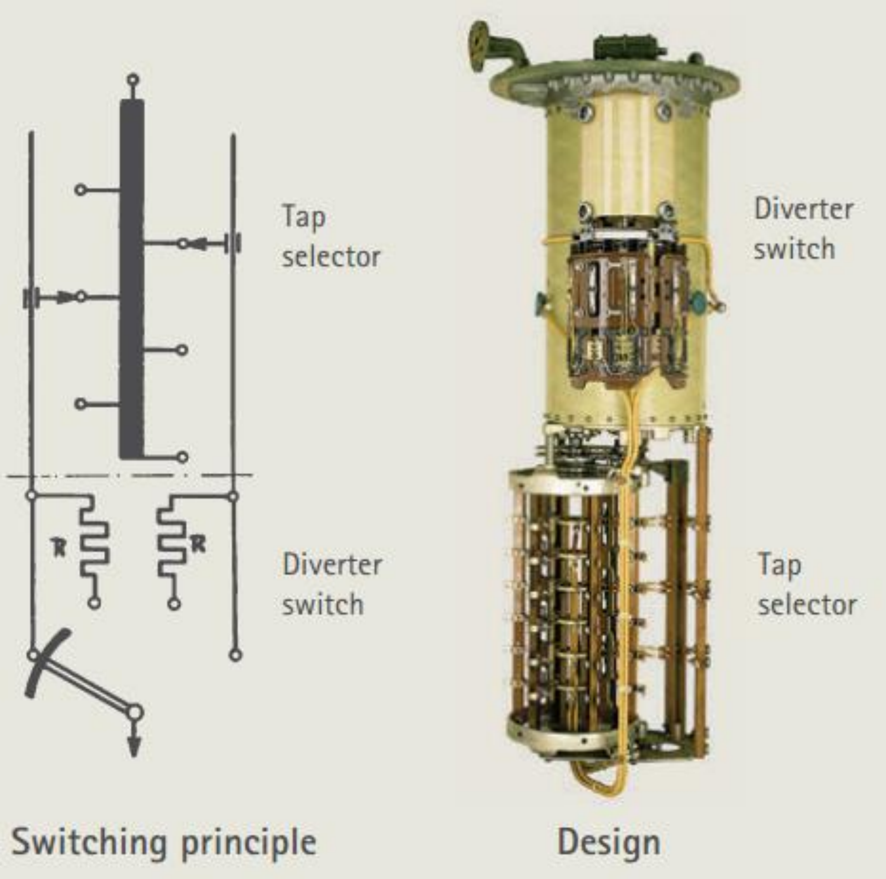


DYNAMIC RESISTANCE OF OLTC (Ripple & Slope of OLTC)

Dynamic Resistance of OLTC

OLTC Contains :

- Diverter Switch
- Selector Switch

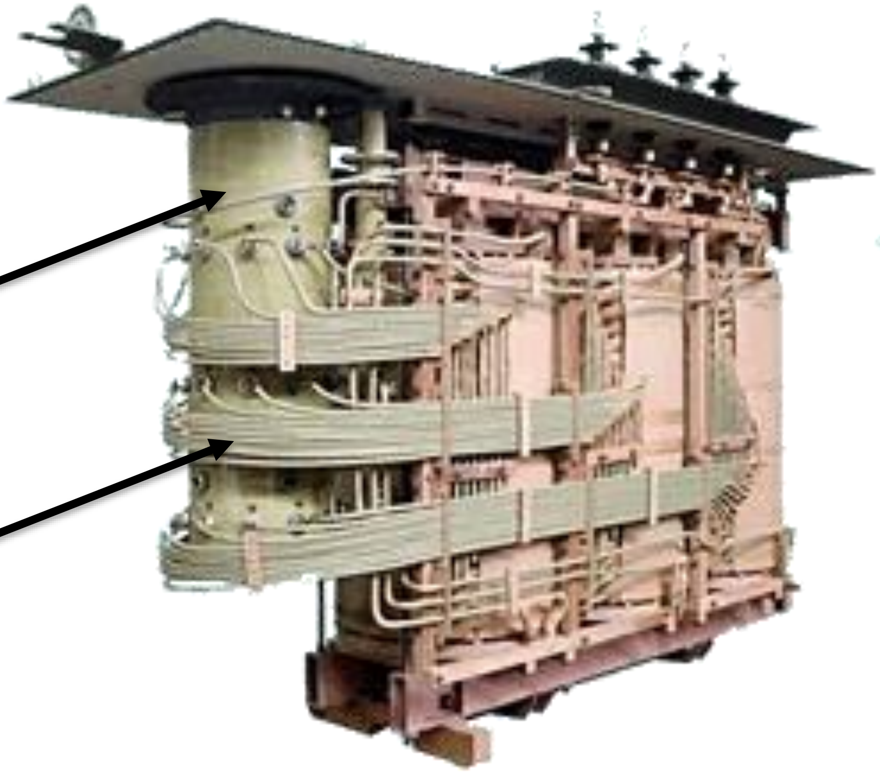


Dynamic Resistance of OLTC

OLTC inside the Transformer Tank

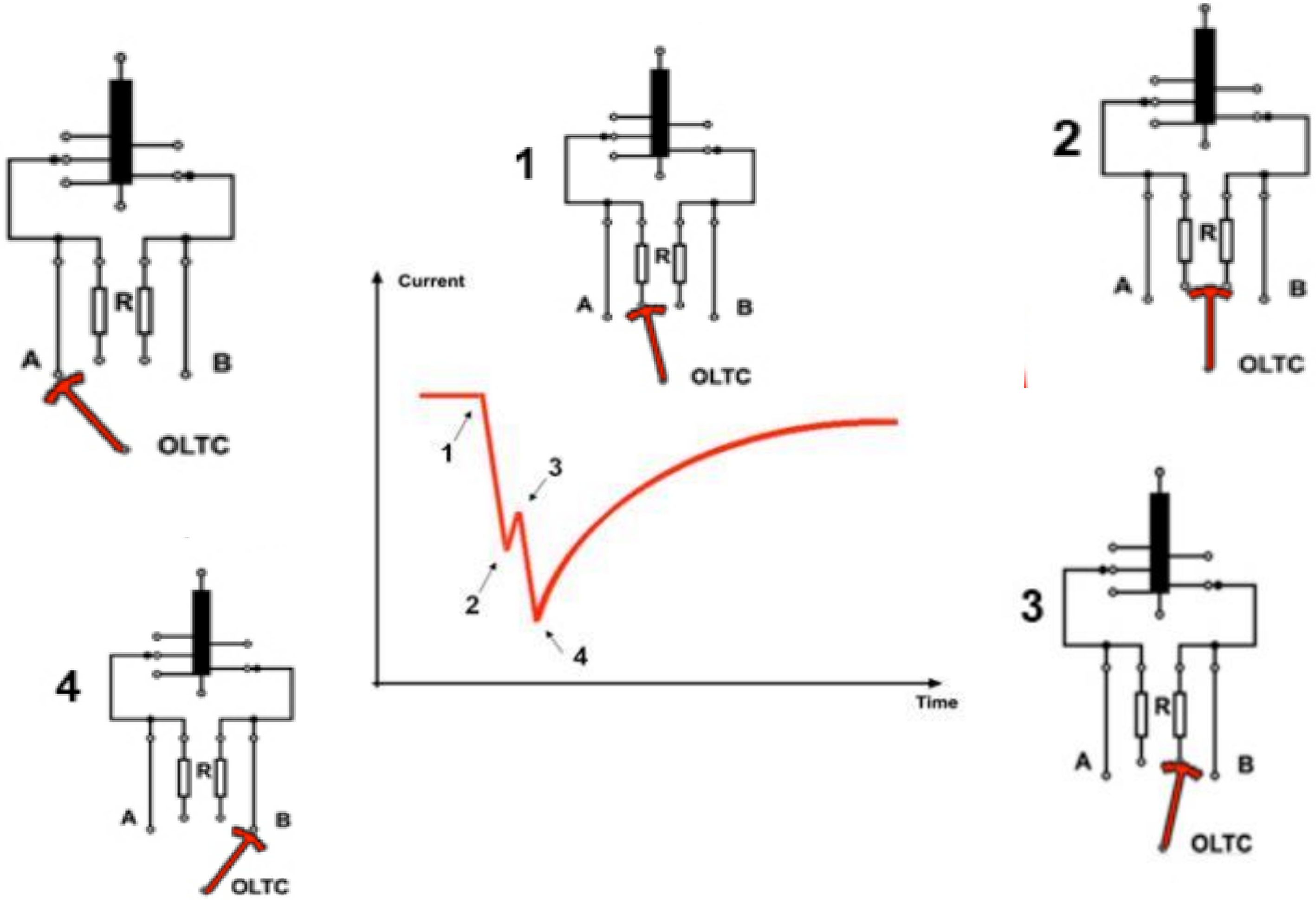
OLTC Chamber

Tapped Winding



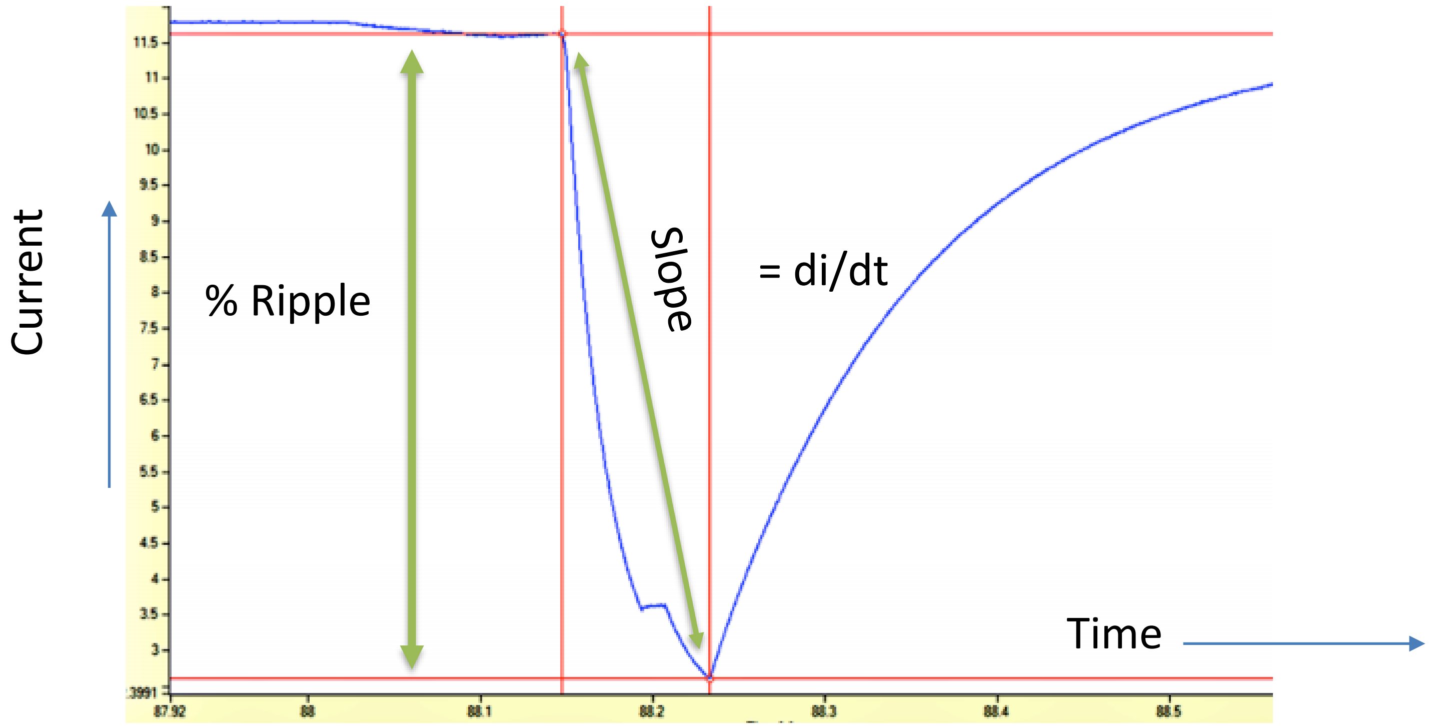
Dynamic Resistance of OLTC

Movement of Diverter Switch



Dynamic Resistance of OLTC

Flow of current with time with change in time



Dynamic Resistance of OLTC

Static resistance Provides values of:

All internal contacts (gives information of Selector Switch of OLTC)

+

Winding Resistance

All Internal Contacts contain :

- diverter switch contacts
- tap selector switch
- Internal Contacts

Dynamic Resistanceof OLTC

Static resistance with Ripple and Slope Provides values of:

All internal contacts

+

Winding Resistance

+

Information on Dynamic movement of Diverter Switch

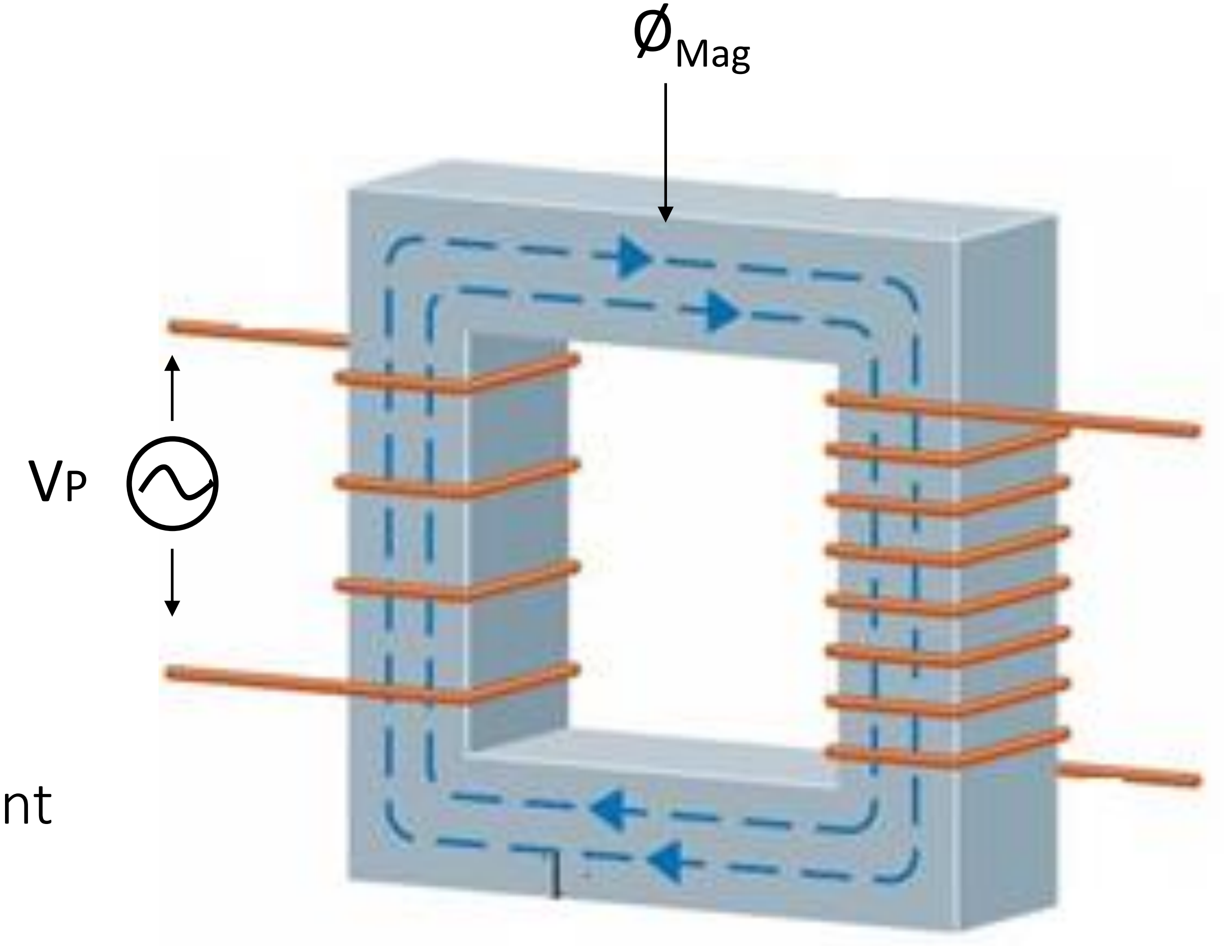
Note : Test is always performed for both up ward movement and downward movement of tap position.

NO LOAD CURRENT
(Excitation Current Test)

No Load Current

No-Load Current Test indicates :

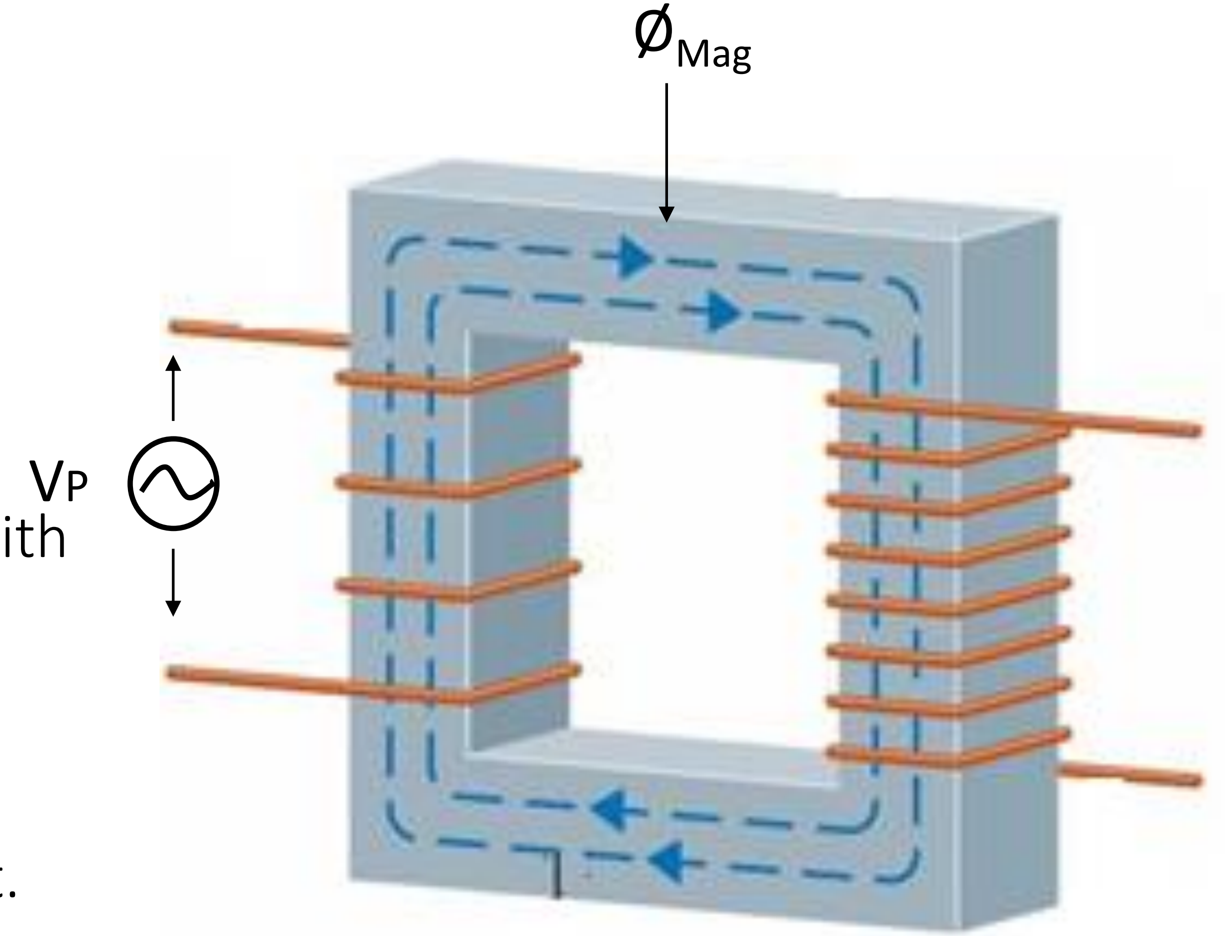
- Abnormal core grounds
- Winding faults: shorts, open circuits
- On Load Tap Changer problems
- Manufacturing defects
- Determines losses in the core (eddy current and hysteresis)



No Load Current

Execution of the test:

- Voltage applied on Primary side with Secondary side open circuit (in some countries vice versa)
- Current required to magnetize the core with Magnetic flux **Ømag.**
- This Magnetic flux induces the voltage V_2
- Current Required is the Excitation Current.



No Load Current

Significance of No Load Current Test:

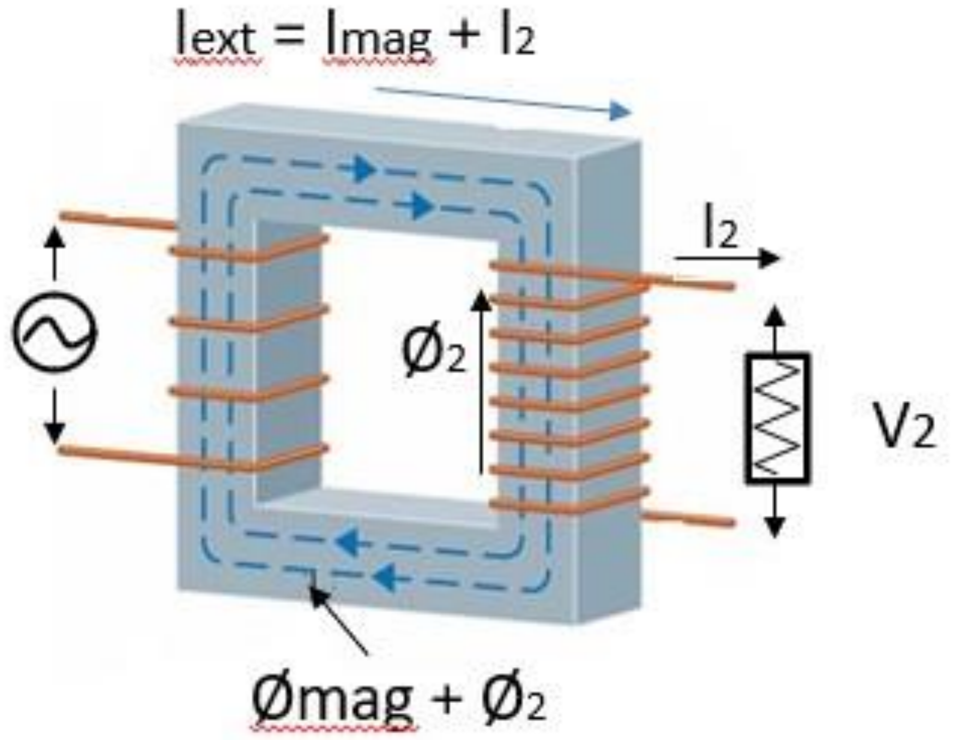
- When a Load is placed on 2ry winding, a current will flow

$$I_2 = \frac{V2}{R2}$$

- The current I2 will in-turn create an Opposing Magnetic Flux $\emptyset_2$

- Considering the V_2 Voltage constant, the voltage generator V_1 will provide more current I_1 to maintain the core magnetized equal to the opposing flux

$$I_1 = I_{excitation} = I_{mag} + I_2$$



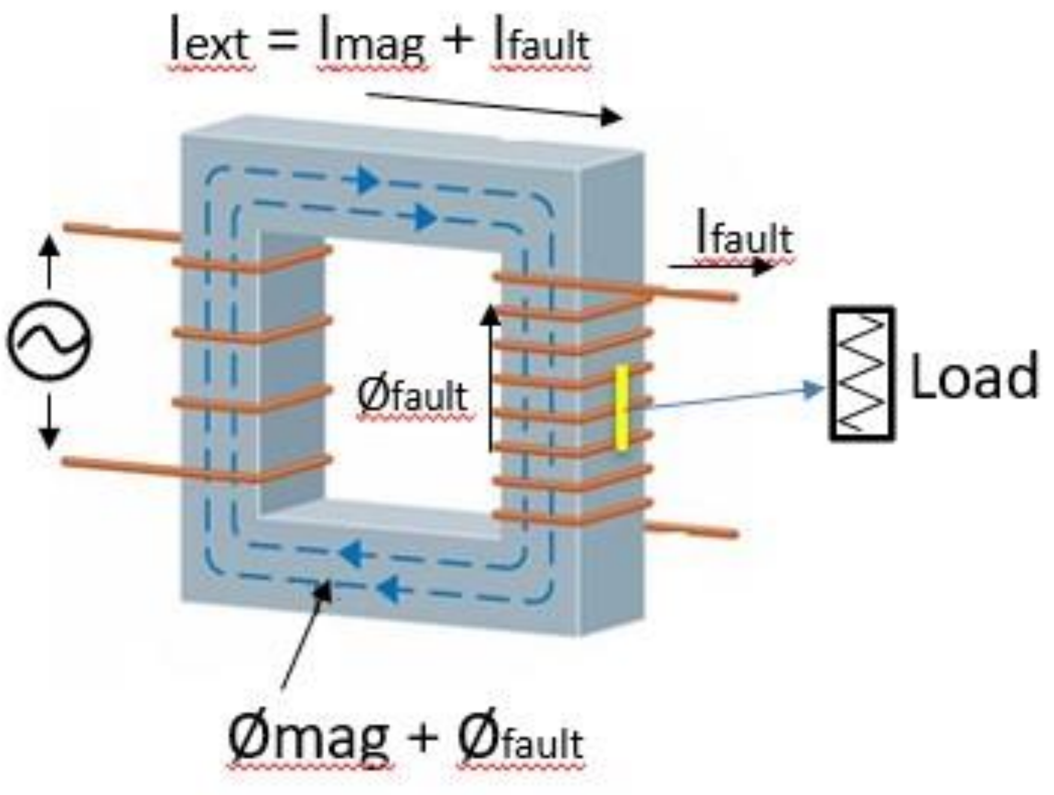
No Load Current

Significance of No Load Current Test:

Turn-to- Turn Short circuit fault

- Any Shorted turns at Secondary side, will acts as a load across the fault winding which will leads to draw a fault current.
- The Excitation Current will increase in due to opposing flux created by the fault Øfault.

✓ **Any short at Secondary Will result in increase Excitation Current.**



No Load Current

Test to be performed :

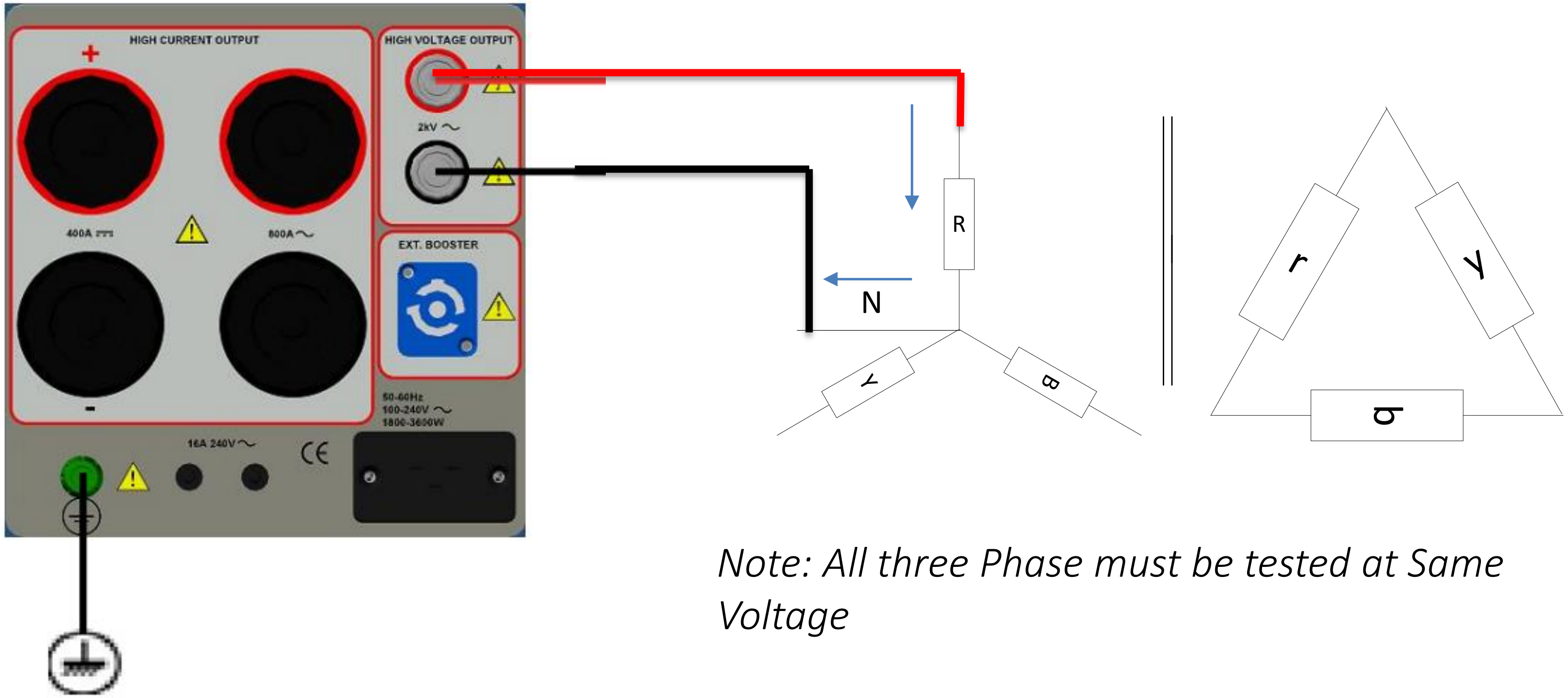
- Each phase must be tested with the same voltage
- Test must be performed with highest Voltage possible
- Test Voltage must not exceed the Rated voltage
- **Compare with Previous Results.**

Up to 12kV @ 300mA

Up to 2kV @ 1.5A

No Load Current

Test Performed with 2kV voltage Source



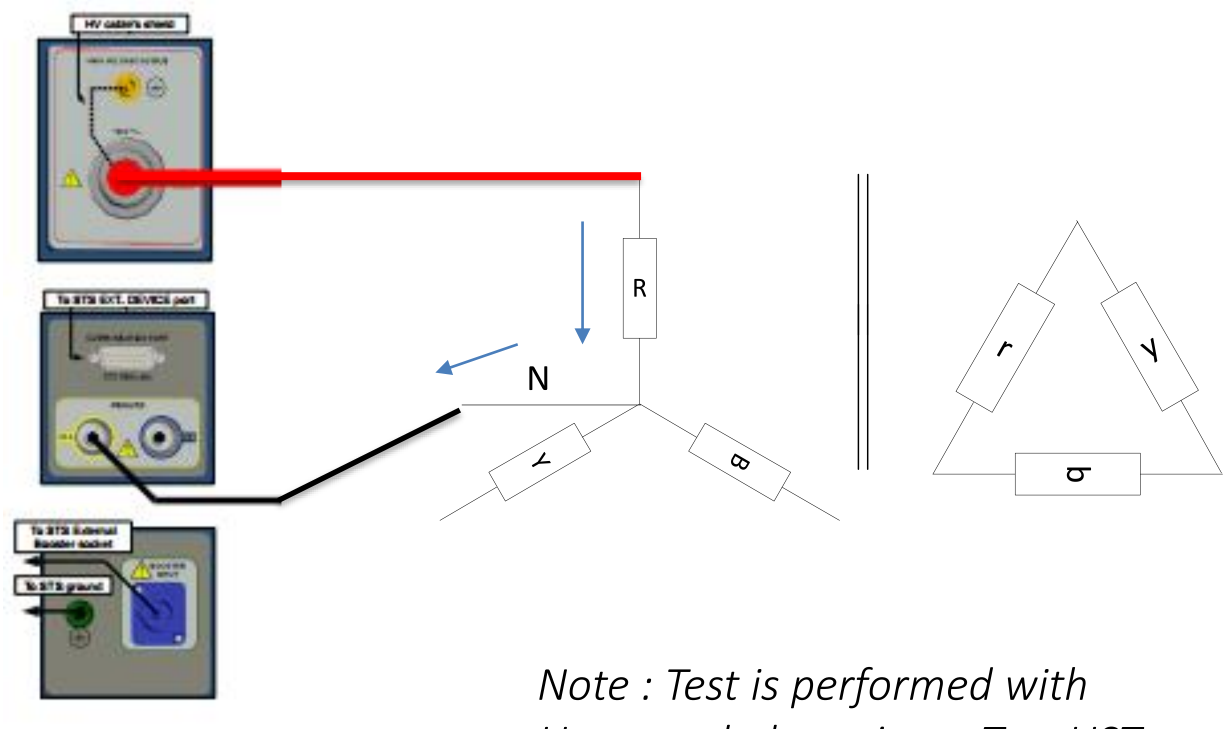
Note: All three Phase must be tested at Same Voltage

SW recalculates to 10 kV

No Load Current

Test performed with accessory for Capacitance & Tandelta on a Star Winding Trafo

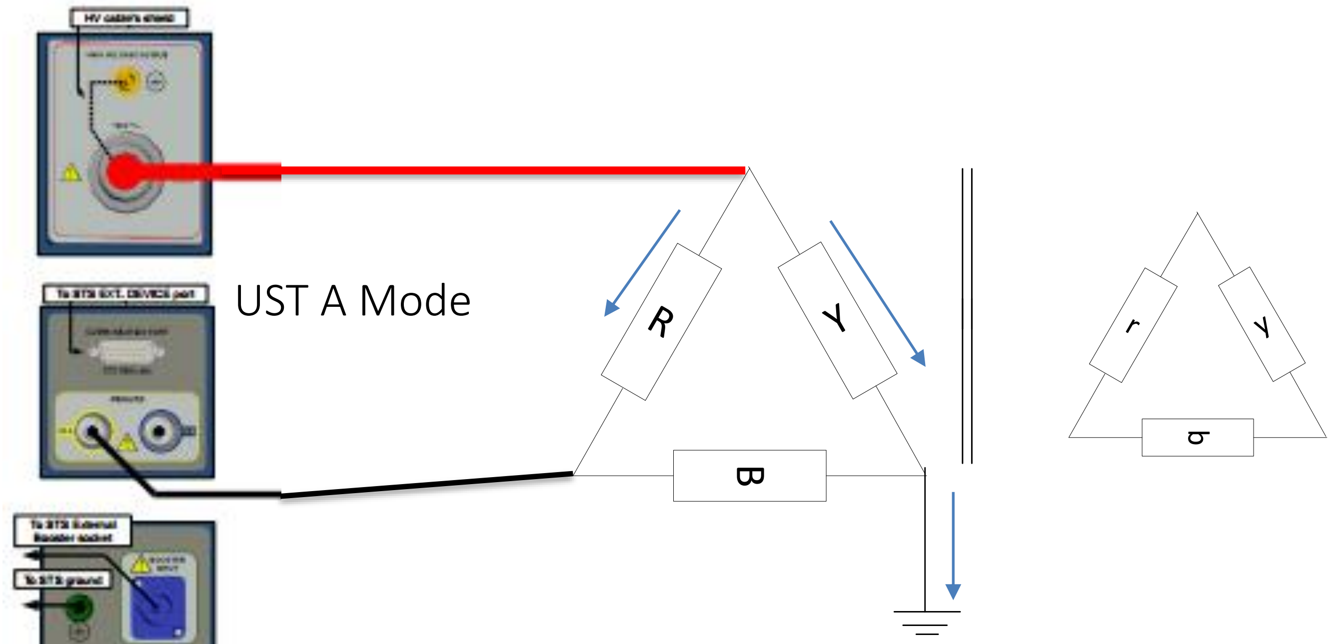
UST A Mode



Note : Test is performed with Ungrounded specimen Test UST

No Load Current

Test performed with accessory for Capacitance & Tandelta on a Delta Winding Trafo

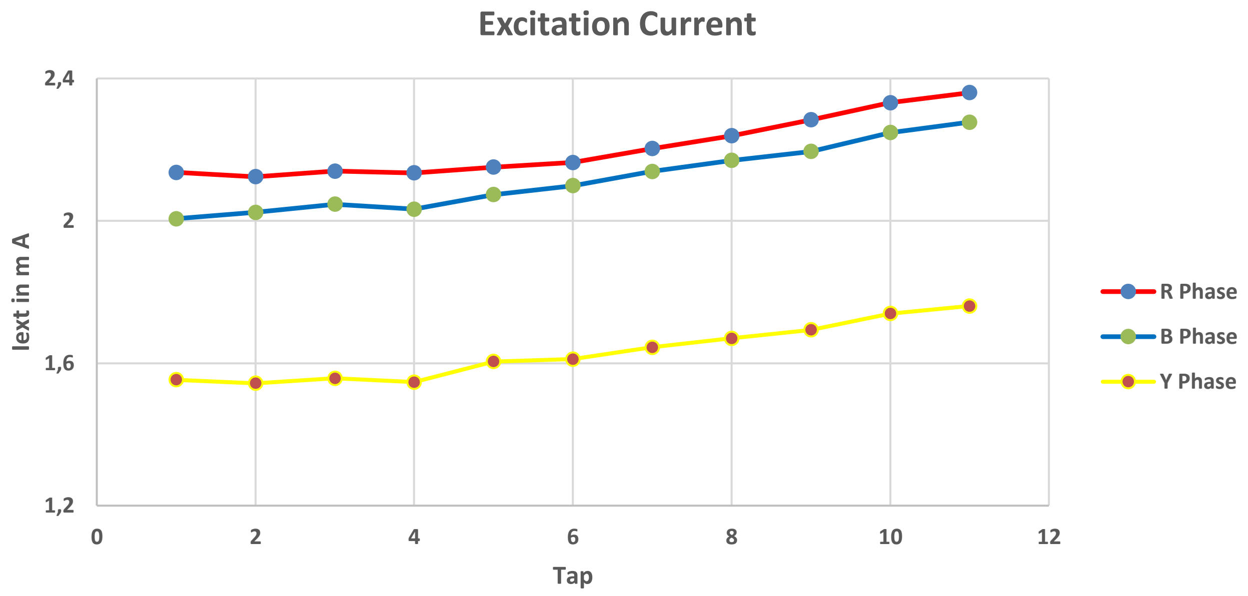


Note : Test is performed with Ungrounded specimen Test UST, Ground Current is bypassed.

No Load Current

Test Performed

- 400 kV / 132 kV Transformer
- Phase-Phase Comparison
- Shows two similar High Readings and one Low reading, it is common with 3 phase transformer



No Load Current

Test Result Analysis

- Check the Phase to Phase : two similar high readings and one low reading is normal (though there are exceptions).
- When Tap Changers are present, consider the pattern within the phase.

In for this test, comparison of the results with the ones obtained in the factory is not suggested since the ones in factory were done with 3 ph source and usually a much higher voltage

SHORT CIRCUIT IMPEDANCE (Leakage Reactance)

Short Circuit Impedance Test

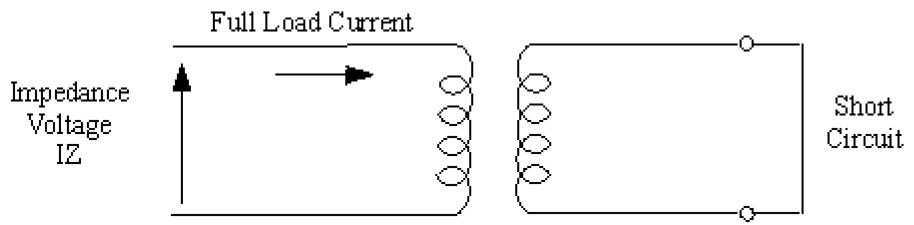
"It the percentage of the nominal primary side voltage required to circulate full-load current under short circuit conditions on the secondary other side.“

(Or)

The percentage impedance of a transformer is the voltage drop on full load due to the winding resistance and leakage reactance expressed as a percentage of the rated voltage.

Losses in Copper due to Ohm resistance of conductors (losses on a car due to its weight)

$$Z\% = \frac{\text{Impedance Voltage}}{\text{Rated Voltage}} \times 100$$

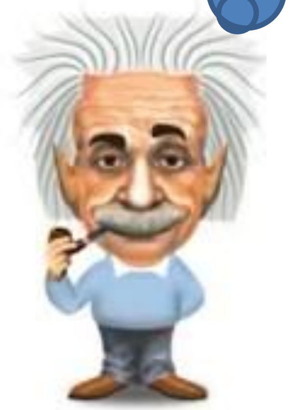


Short Circuit Impedance Test

Why Short Circuit Impedance Test :

- To determines the maximum value of fault current that will flow under fault conditions
- It can show us possible winding movement caused by the heavy Fault Current that passed through the Transformer
- It can also show is possible Winding Deformation Caused during the transportation.

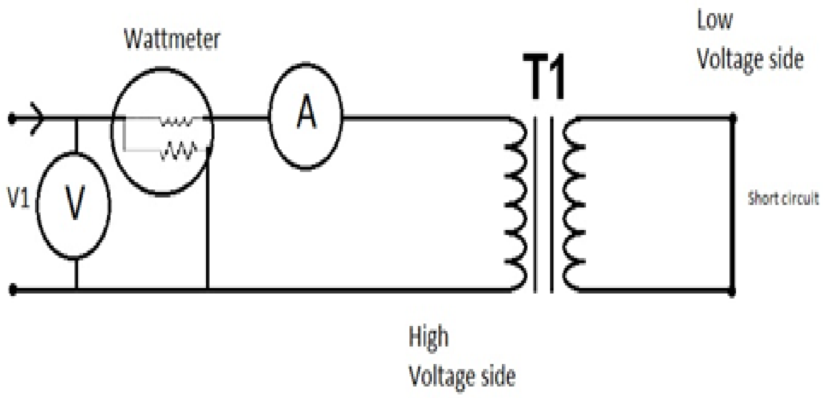
If we were to compare Transformer with a car, the car needs to «loose» some power to move its own mass. The same here, Trafo needs to loose some of the power to overcome its own ohmic resistance of the copper windings



Short Circuit Impedance Test

How to Perform the Test :

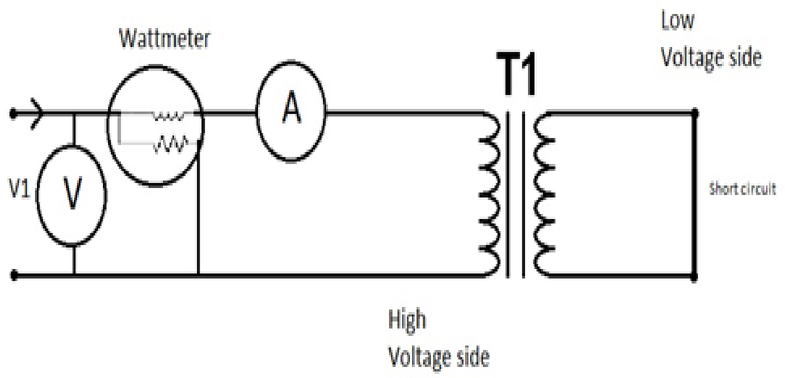
- The test is conducted on the high-voltage (HV) side of the transformer.
- Low-voltage (LV) side or the secondary is short circuited (in some countries it is vice versa).
- Since Voltage Applied is Very low (e.g. 100 V) compared to the Rated Voltage, Core Losses are Neglected



Short Circuit Impedance Test

How to Perform the Test :

- Watt Meter Reading Provides Watt Loss or Copper Loss.
- Result is compared With the Name plate Value – **Z%** (e.g. 7.8 %, 10 %).
- Error Limit allowed maximum is 3% from Name Plate Value
- Use **Thick** cables to SC the secondary side



Short Circuit Impedance Test

Testing on a 3 Phase Tansformer:

A three-phase transformer can be tested using a single-phase power source using one of these two Methods :

- 3 Phase Equivalent method (often used at the producer)
- Per Phase Method (if Primary is star winding, with neutral point accessible)
- In both case we will execute 3 measurements after which test set automatically shows us the result

Short Circuit Impedance Test

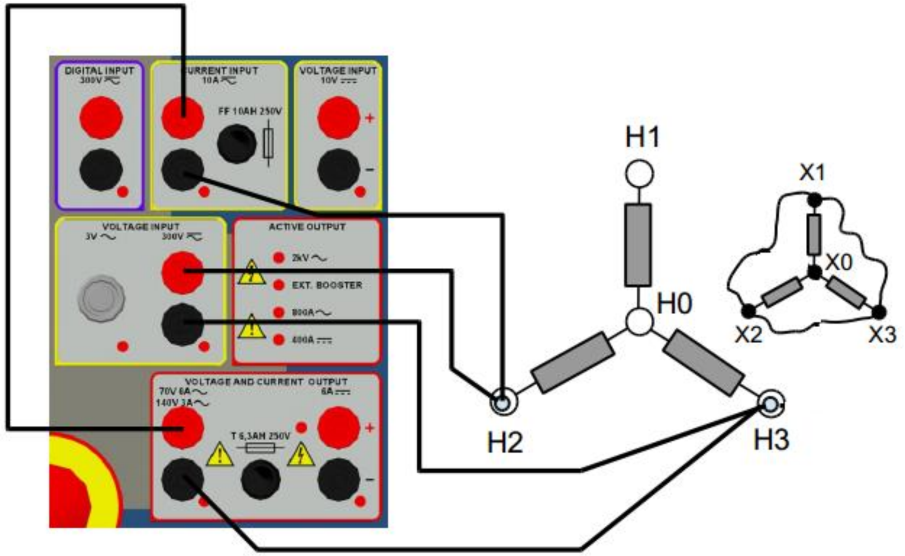
Testing on a 3 Phase Transformer – 3 Phase equivalent method

Perform Test for :

H1-H2

H2-H3

H3-H1



Calculation for % Zk will be as below :

3-phase equivalent:

$$Zk\,\%\,meas = \frac{(Zk_{AB} + Zk_{BC} + Zk_{CA})[\Omega]}{60} \cdot \frac{P\,nominal\,[kVA]}{V_{LL}nominal\,[kV]}$$

Short Circuit Impedance Test

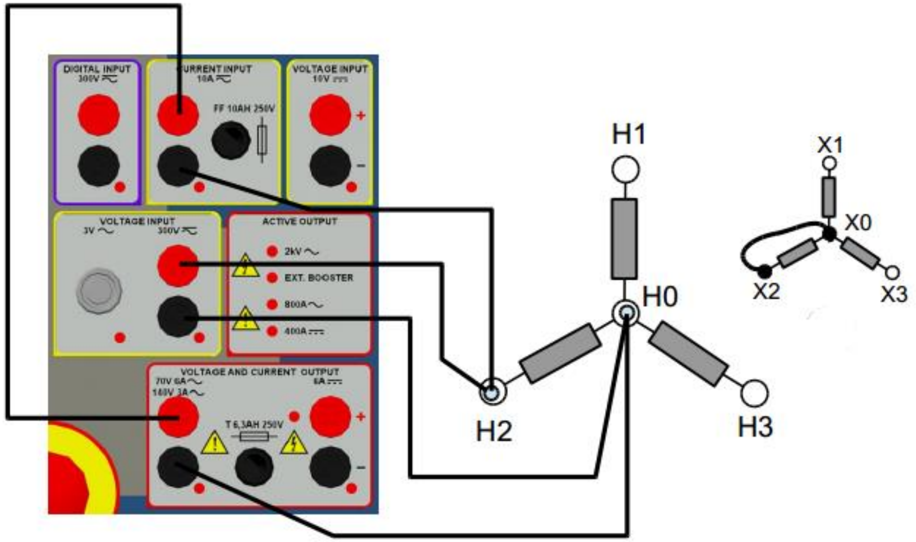
Testing on a 3 Phase Transformer – Per Phase

Perform Test for :

H1-H0

H2-H0

H3-H0



Calculation for % Zk will be as below :

Per-phase:

$$Zk\,\%\,meas = \frac{Zk\ [\Omega]}{10} \cdot \frac{P\ nominal\ [kVA]}{V_{LL} nominal\ [kV]}$$

Short Circuit Impedance Test

Data results | Graphical representation

Per-phase C | 3-phase equivalent A-B | 3-phase equivalent B-C | 3-phase equivalent C-A

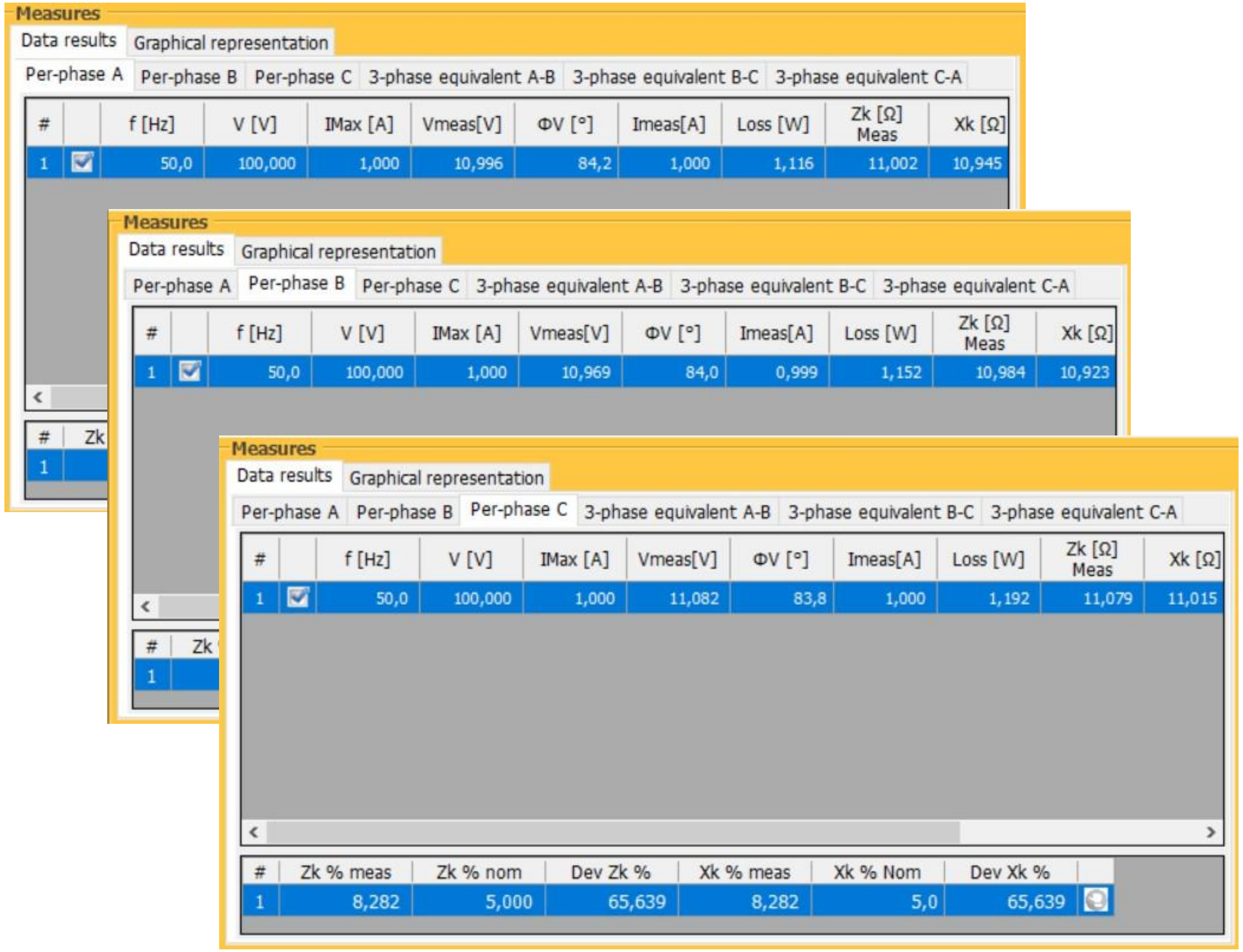
#		f [Hz]	V [V]	Imax [A]	V meas [V]	φV [°]	I meas [V]	Loss [W]
1	☑	15,0	56,000	1,000	28,686	83,8	1,003	3,105
2	☑	30,0	100,000	1,000	59,332	86,5	1,043	3,777
3	☑	50,0	100,000	1,000	94,655	86,6	1,001	5,604
4	☑	75,0	100,000	1,000	120,471	87,6	0,852	4,210
5	☑	135,0	100,000	1,000	99,929	87,6	0,395	1,638
6	☑	200,0	100,000	1,000	99,946	87,5	0,268	1,185
7	☑	300,0	100,000	1,000	115,581	87,3	0,208	1,139

ent B-C | 3-phase equivalent C-A

				k [Ω]	Rk [Ω] calc	Lk [mH]
				,447	3,673	0,302
				,792	4,129	0,301
				,431	6,653	0,301
				1,282	6,895	0,300
				2,580	12,457	0,298
87,5	0,268	1,185	372,538	372,024	19,554	0,296
87,3	0,208	1,139	556,414	555,531	31,337	0,295

#	Zk % meas	Zk % nom	Dev Zk %	Xk % meas	Xk % Nom	Dev Xk %
1	17,112	16,430	4,150	17,112	16,4	4,150

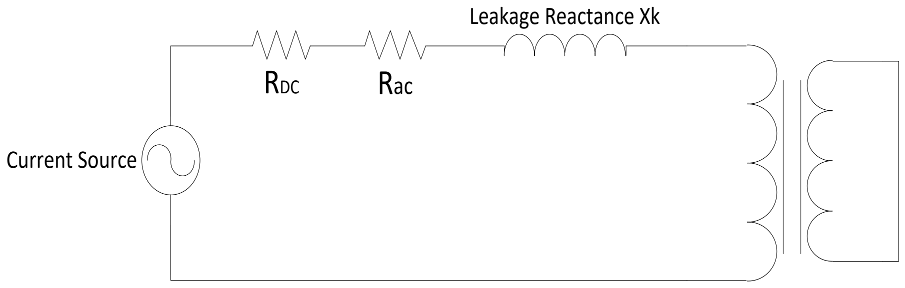
Short Circuit Impedance Test

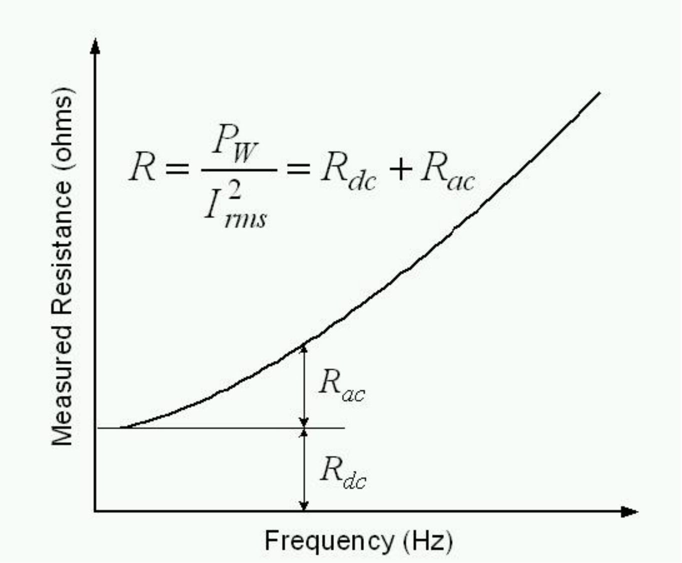


FREQUENCY RESPONSE OF STRAY LOSSES (FRSL)

Frequency Response of Stray Losses

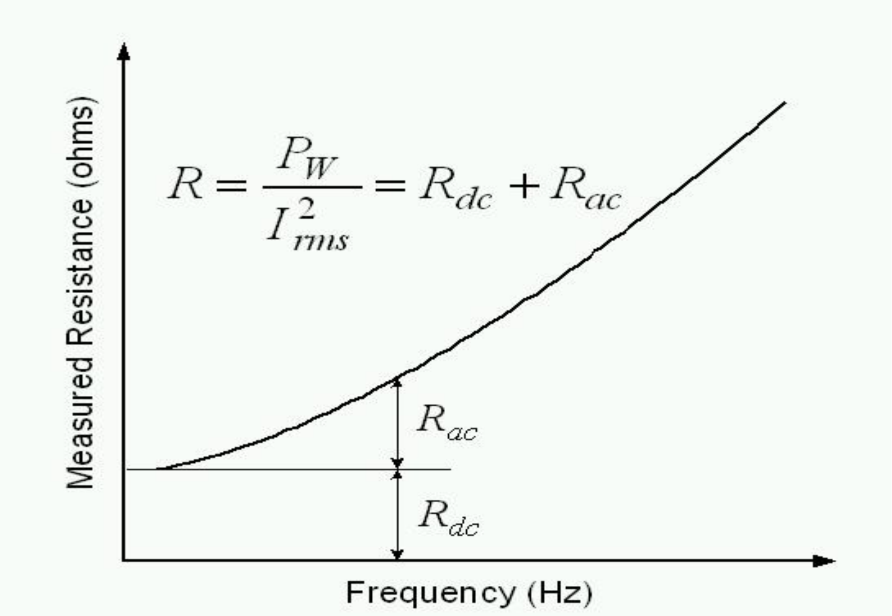
- **FRSL** is a Short Circuit Impedance Test , but the test at Variable Frequency i.e. 15Hz to 500Hz.
- It is the only electrical method to tell us about short-circuits between parallel strands and local overheating due to excessive eddy current losses.





Frequency Response of Stray Losses

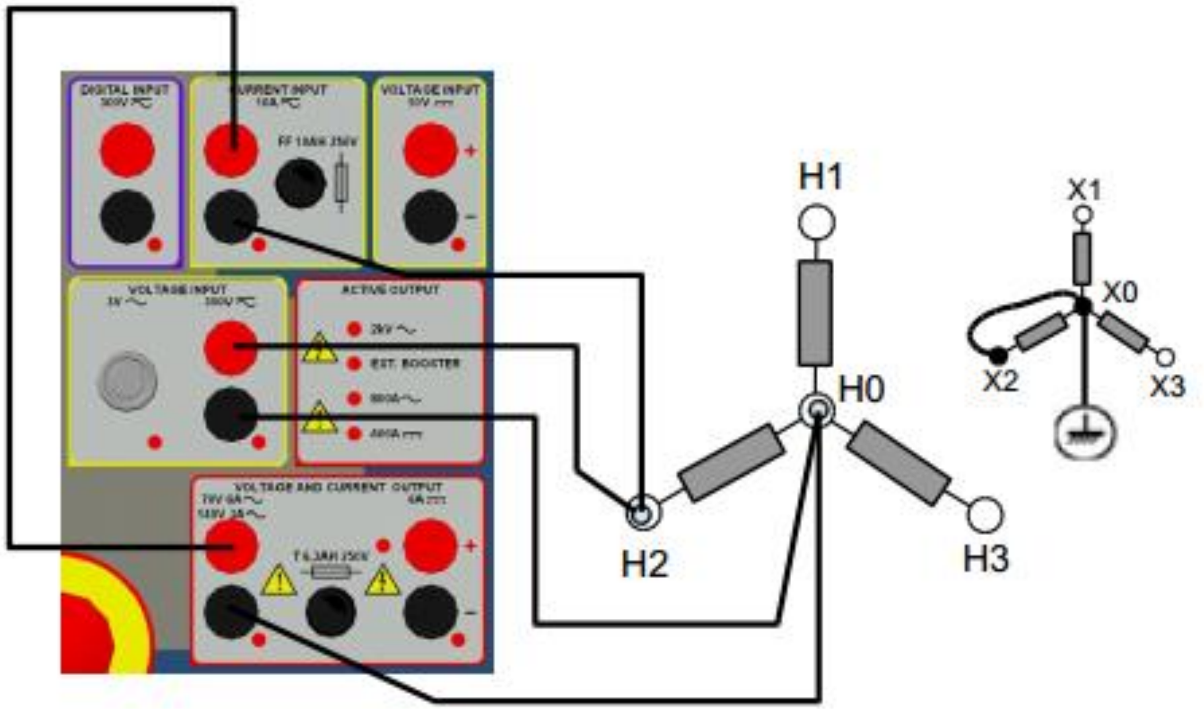
- Short in Parallel Stands influence skin effect.
- The AC resistance Increases with the Increase in Frequency.



Frequency Response of Stray Losses

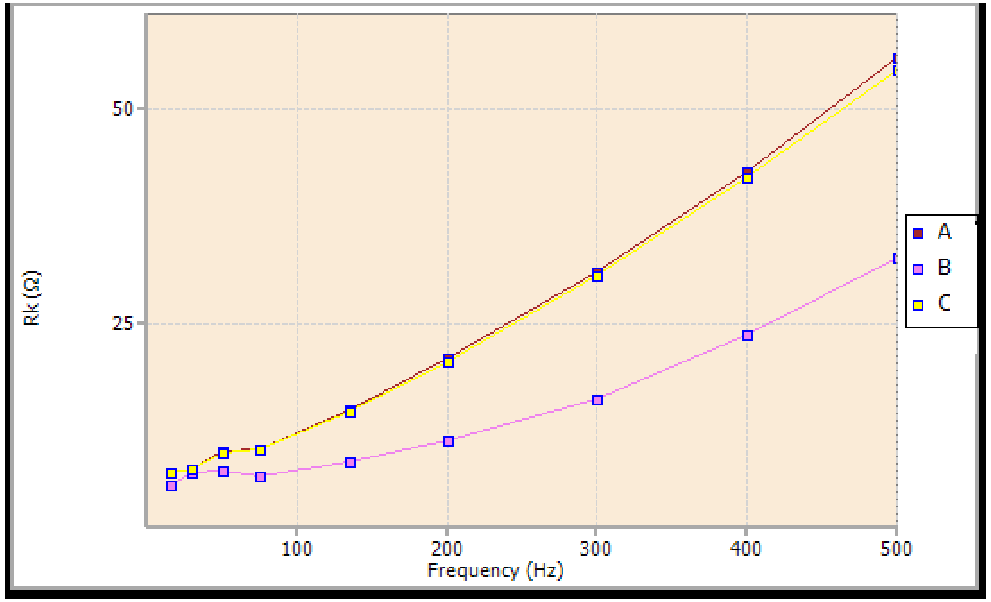
How to perform the Test :

- Test is similar to short circuit impedance test, but test is done at variable frequency.
- Results are interpreted by comparing phases



Frequency Response of Stray Losses

- Phase to Phase Comparison Showed that there is a problem with the transformer.
- Increase in Eddy current Loss increased in Ph A and Ph C resistance with Frequency., which indicates some local heating or short of copper laminations
- FRSL Test Advance which provides more information than short circuit impedance Test.



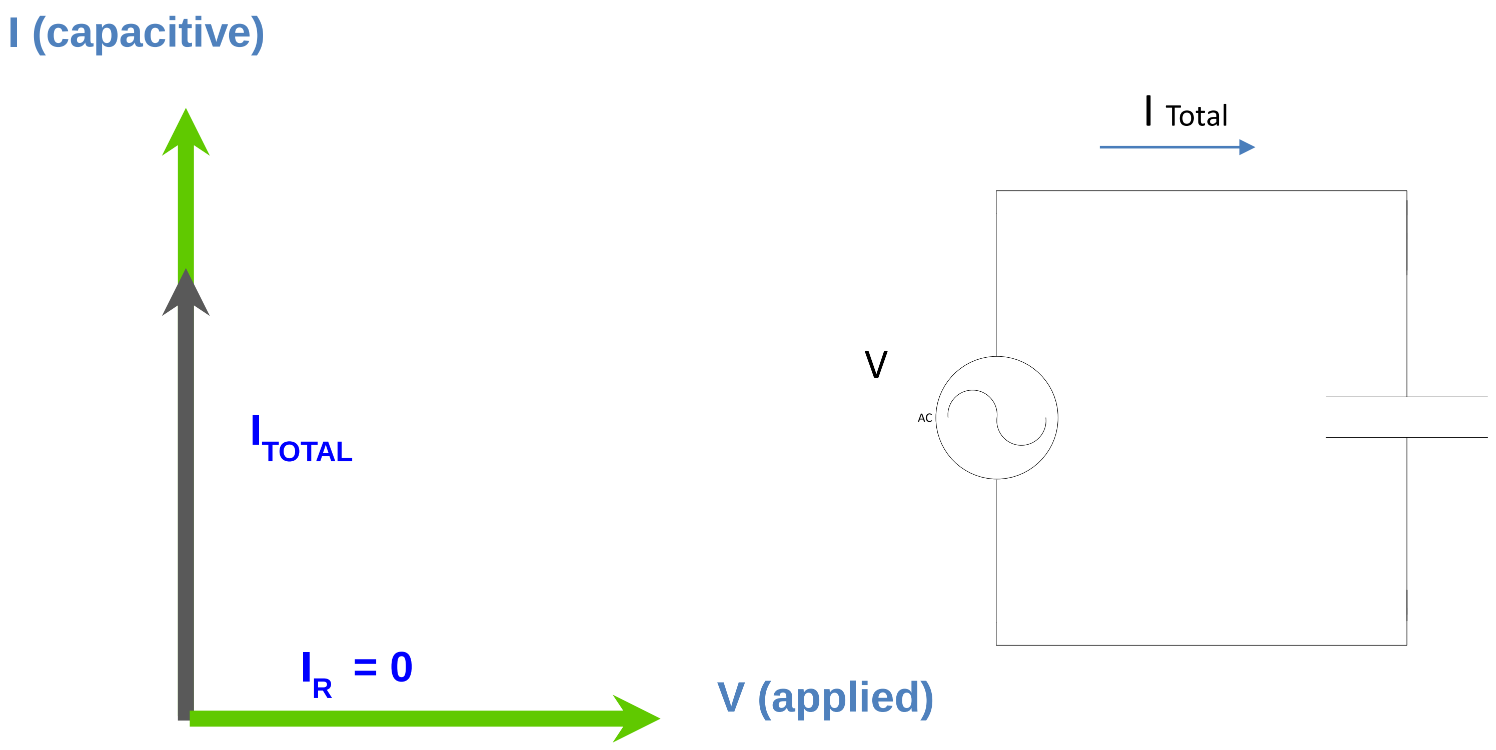
CAPACITANCE and TAN δ

Capacitance and Tan Delta

- **C & TD test** is the most common technique used to asses the insulation of the Transformer.
- It is an AC test
- Test is used to check :
  - Mechanical Deformation.
  - Aging of the Insulation.
- Reference for wide range of insulation is always available for comparision.
- Test is performed always between two different Potentials.

Capacitance and Tan Delta

Ideal (perfect) Insulation

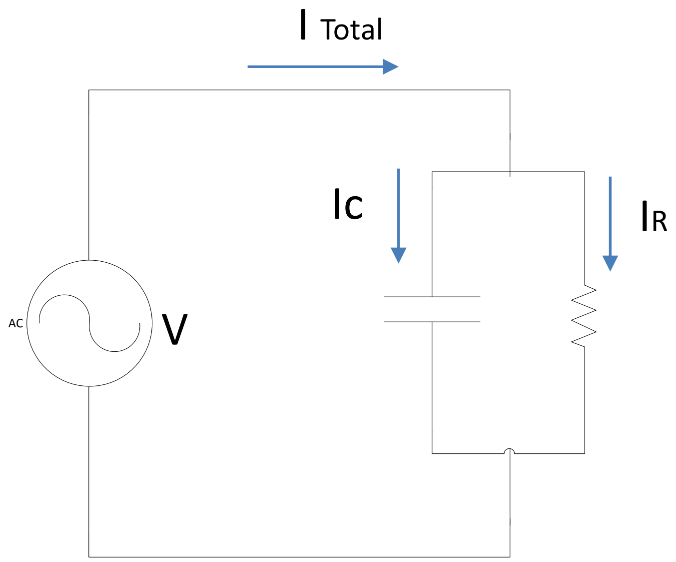


Capacitance and Tan Delta

Actual Insulation

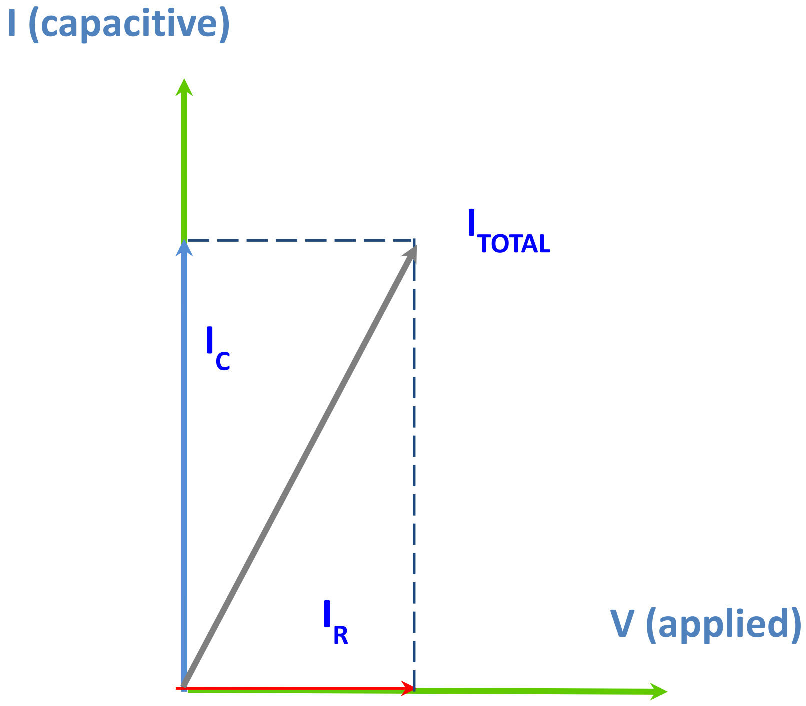
In a Real Insulation System there is also a loss current I_R flowing in-phase with the voltage.

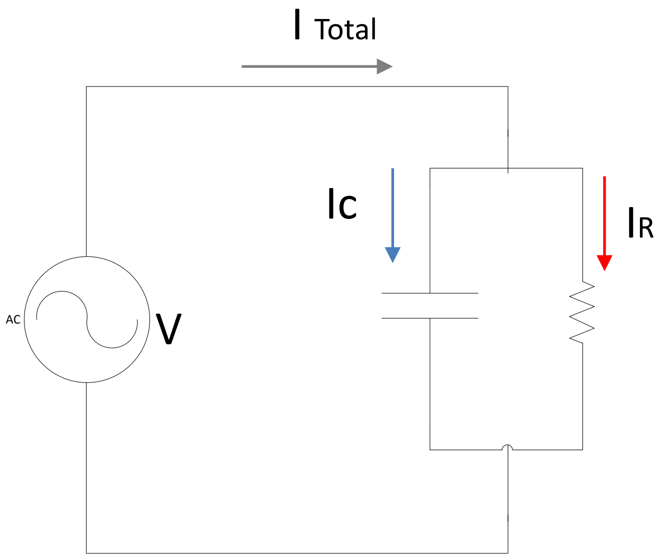
$$I_{Total} = I_C + I_R$$



Capacitance and Tan Delta

Actual Insulation





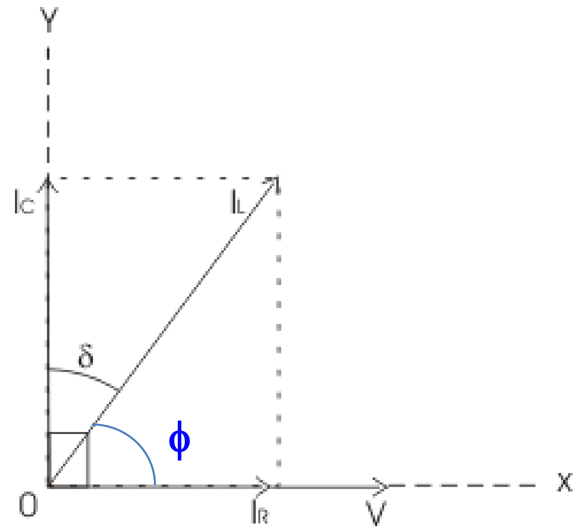
Capacitance and Tan Delta

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

$$\text{Tan } \delta = I_R / I_C$$

Since Power dissipates due to I_R

Tan Delta equals Dissipation Factor



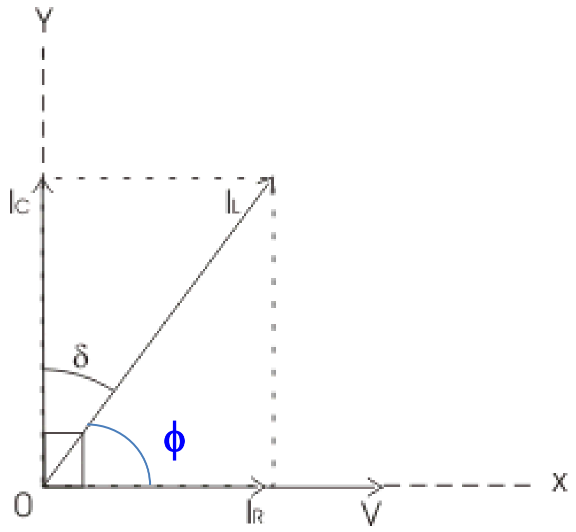
Capacitance and Tan Delta

Power factor (PF) is the ratio of resistive current to the total current.

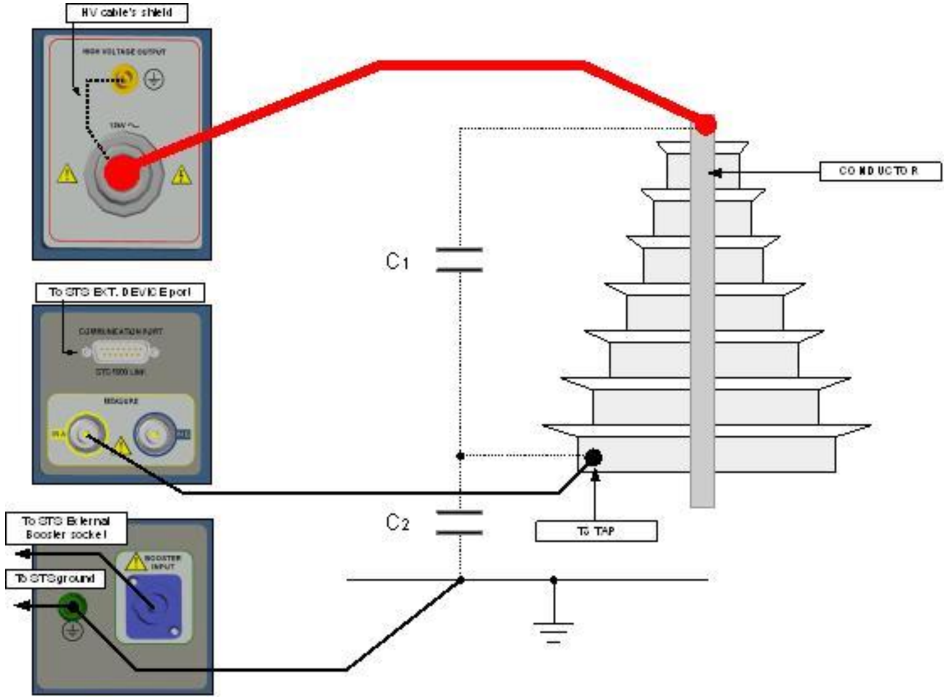
For the δ value up to 10 °, PF and Tan Delta can be considered the same in value

$\text{Cos}\,\phi = I_R / I_{Total} = I_R / I_C = \text{Tan}\,\delta$

$I_{Total} = I_R + I_C = I_C$ (if δ is very small)



Capacitance and Tan Delta



Capacitance and Tan Delta

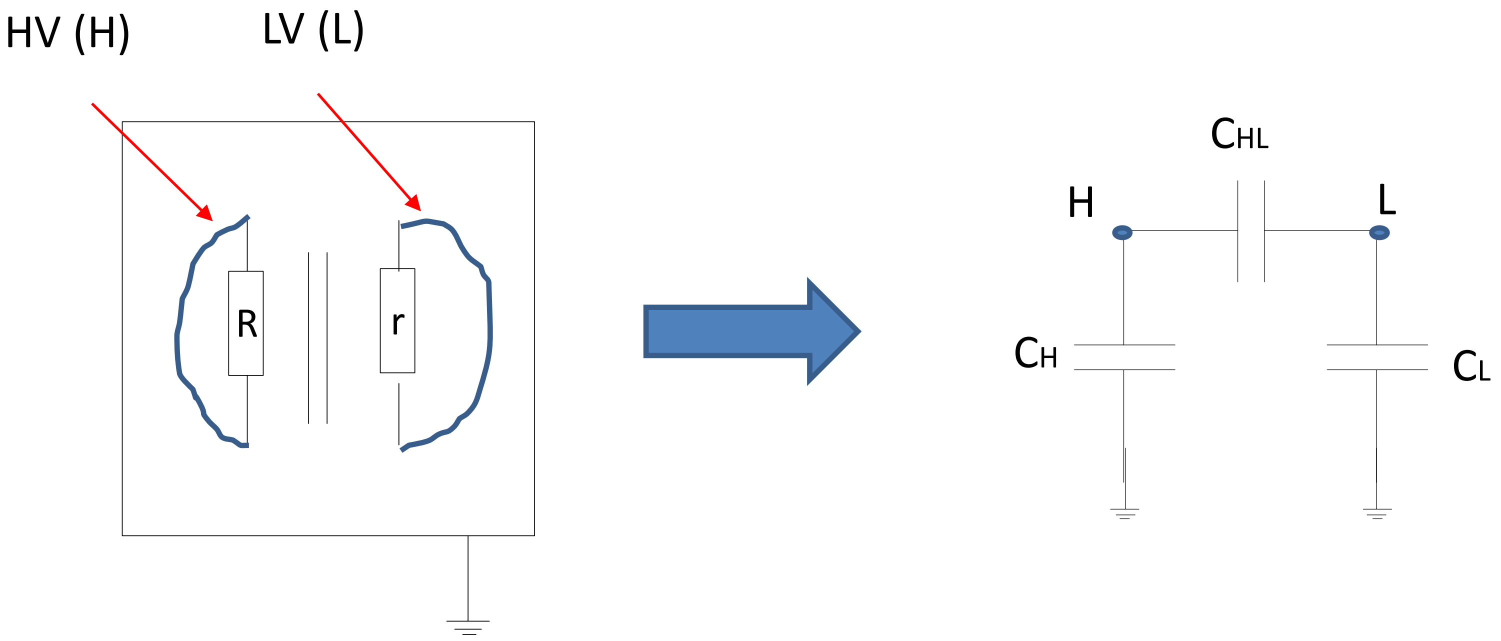
Can be tested on all types of Transformers:

- Single Phase.
- Three Phase.
- Two Winding.
- Three Winding.
- Auto Transformers with Tertiary.
- Auto Transformer without Tertiary.
- Delta Winding.
- Star Winding.

Capacitance and Tan Delta

Single Phase two winding Transformer

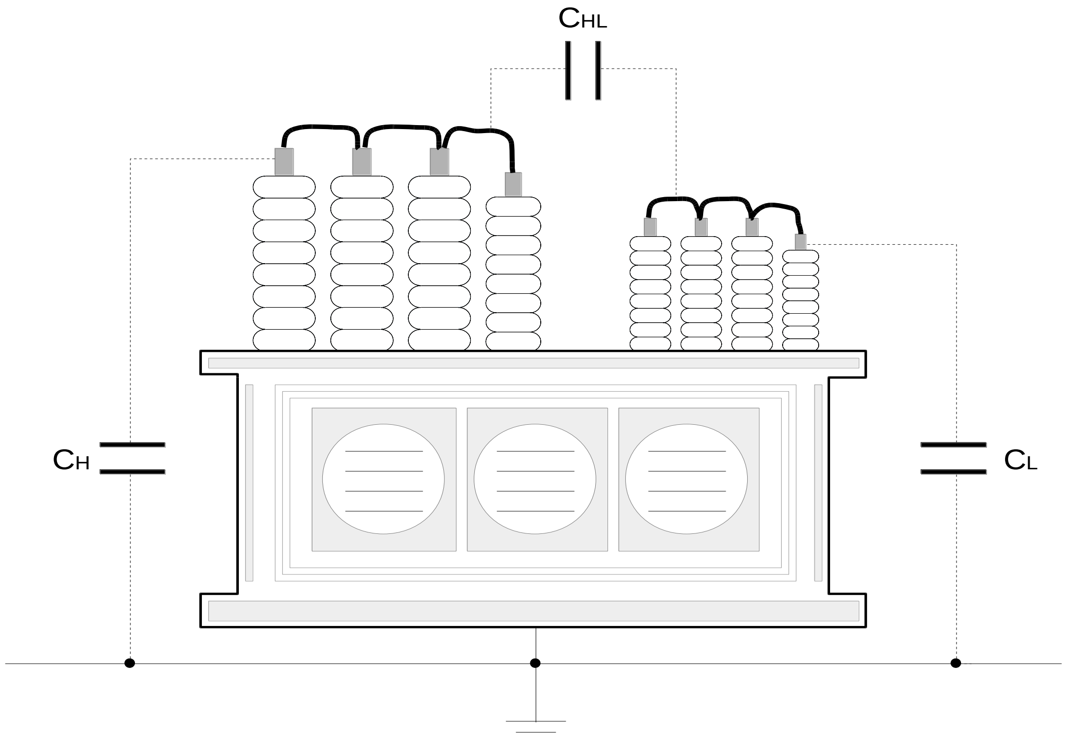
- All terminals of same Winding must be shorted.



Capacitance and Tan Delta

Three Phase two winding Transformer

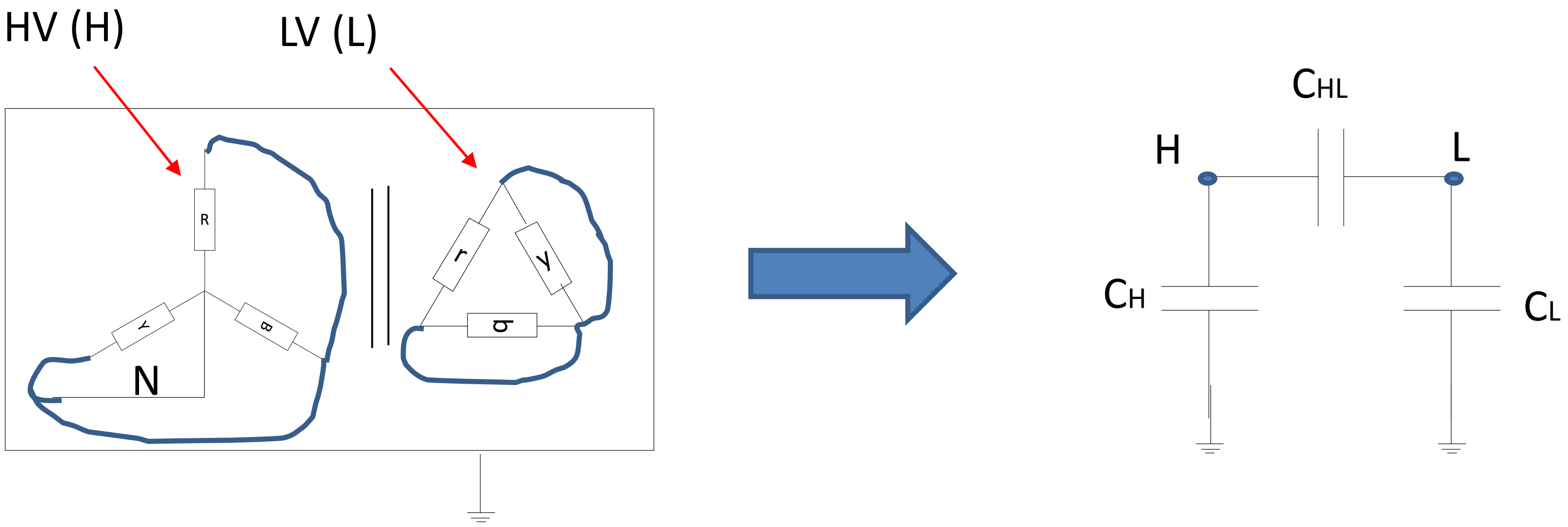
- All terminals of same Winding must be shorted.



Capacitance and Tan Delta

Three Phase two winding Transformer

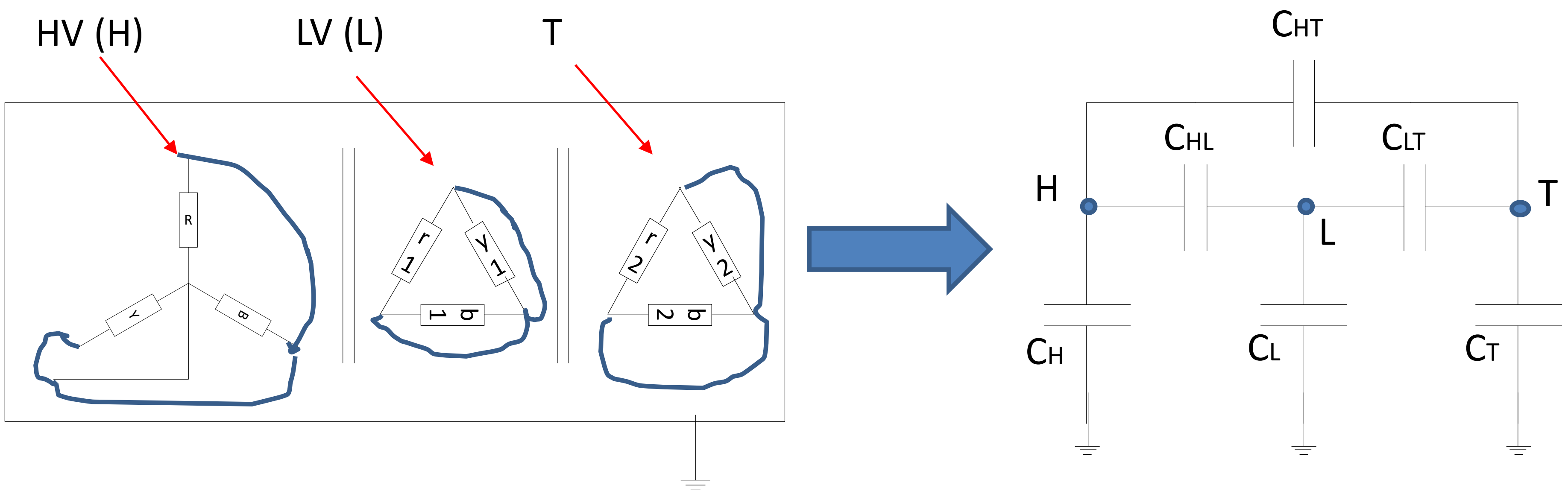
- All terminals of same Winding must be shorted.



Capacitance and Tan Delta

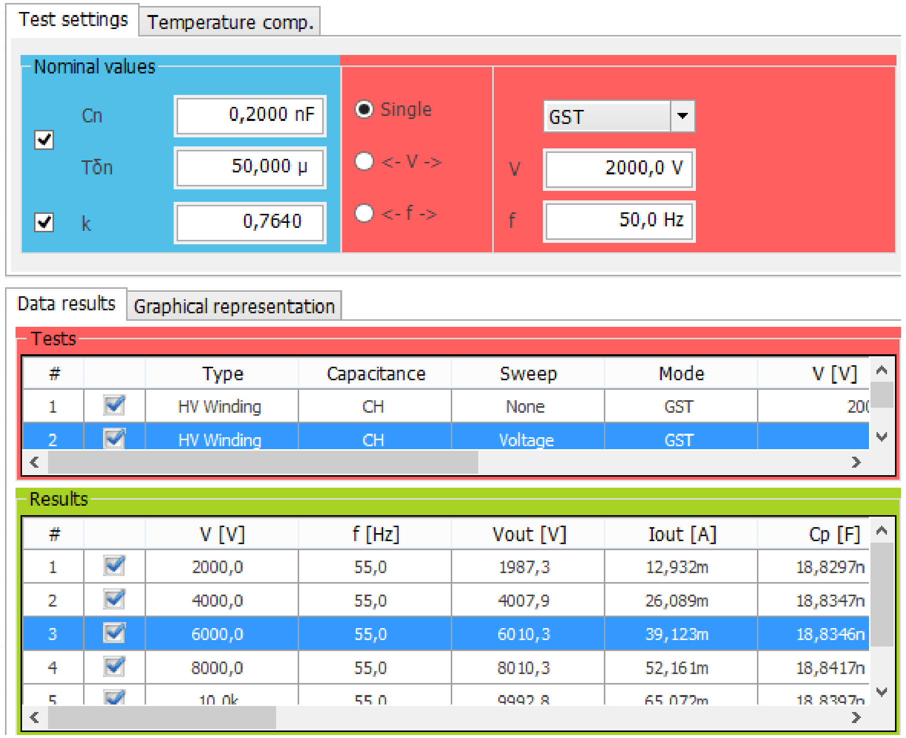
Three Phase Three winding Transformer

- All terminals of same Winding must be shorted.



Capacitance and Tan Delta

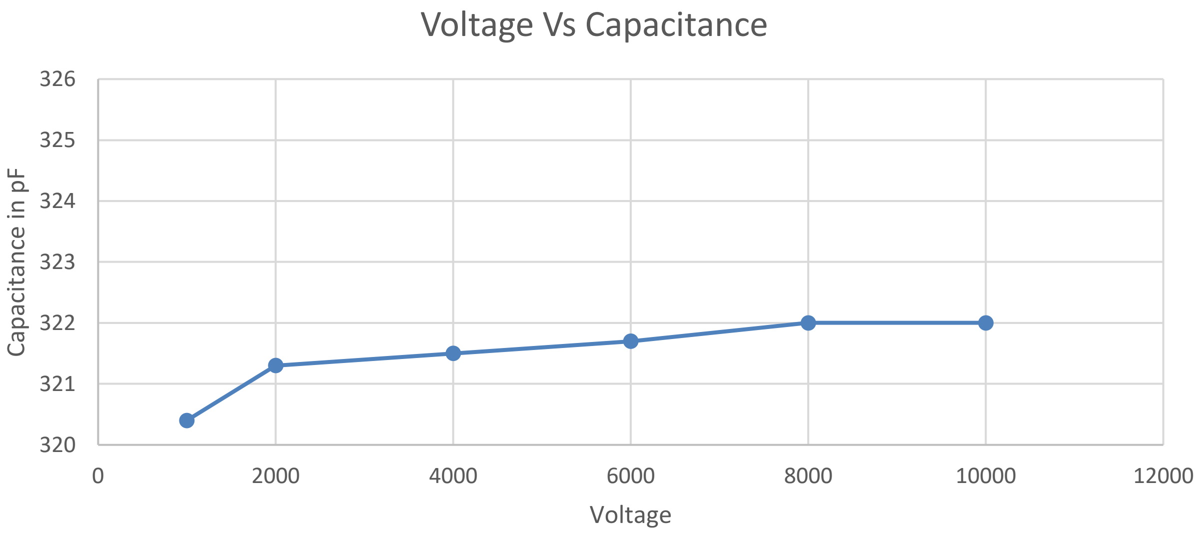
Test Results Tested by STS 5000 +TD5000.



Capacitance and Tan Delta

400 kV Transformer Bushing

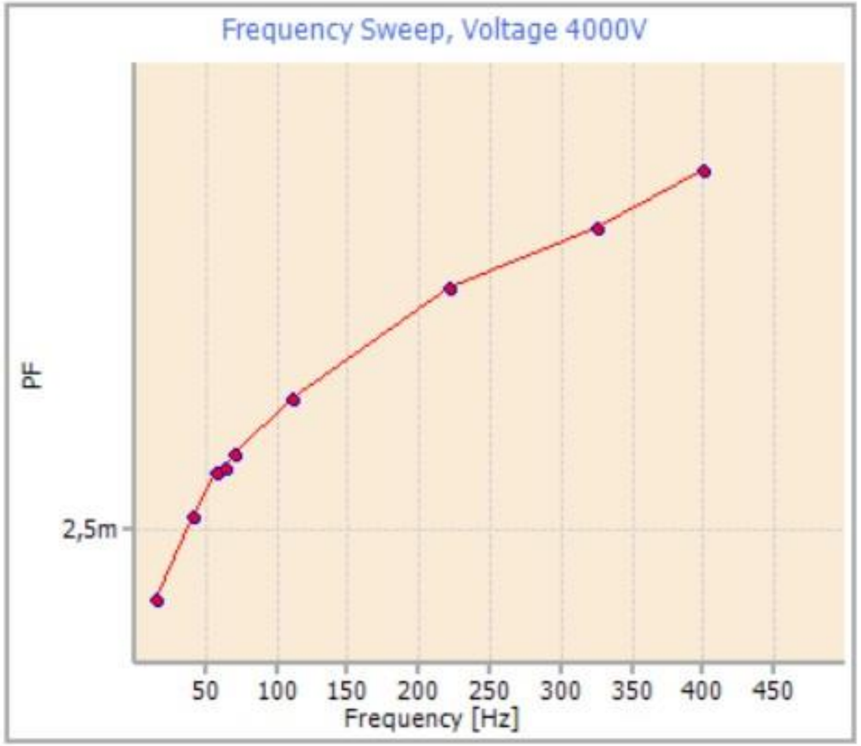
Capacitance Vs Voltage



Capacitance and Tan Delta

Transformer Bushing

Frequency Vs Tandelta



Capacitance and Tan Delta

Comparison Tan Delta (AC) vs. PI (DC) Test:

Tan Delta is:

A) Less Destructive (DC leaves the free electrons that can cause PD if there were voids)

B) Time Independent (Result of DC testing changes if the test duration changes)

C) Faster

D) Giving us more similar conditions (AC) than PI test since we are using the said equipment with AC voltage

E) More repeatable

F) Better because if we have a good and a bad layer, PI will show us accetable result, while Tan Delta will show us the real state of insulation

Capacitance and Tan Delta

Capacitance tell us :

Capacitance provides the information of Deformation of the winding or partial breakdown with the bushing.

Tan δ tells about:

Ageing of insulation, contamination, moisture increase in the insulation.

DFR tan delta at low freq

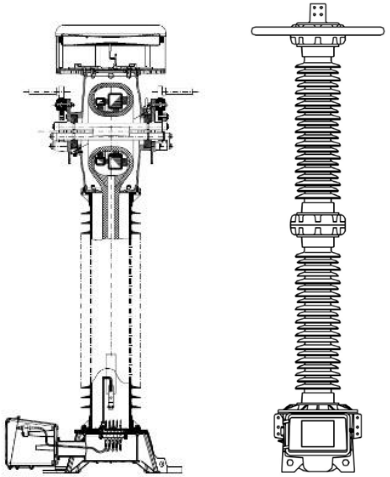
Provides the information on the amount of water in the insulating material
Frequencies go from mHz to kHz

SWEEP FREQUENCY RESPONSE ANALYSIS

SFRA

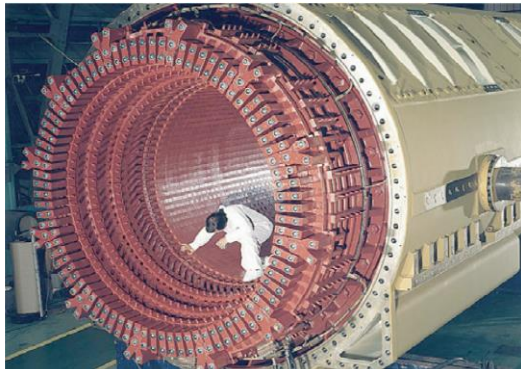

Power transformer

Passive filter



Measurement transformer

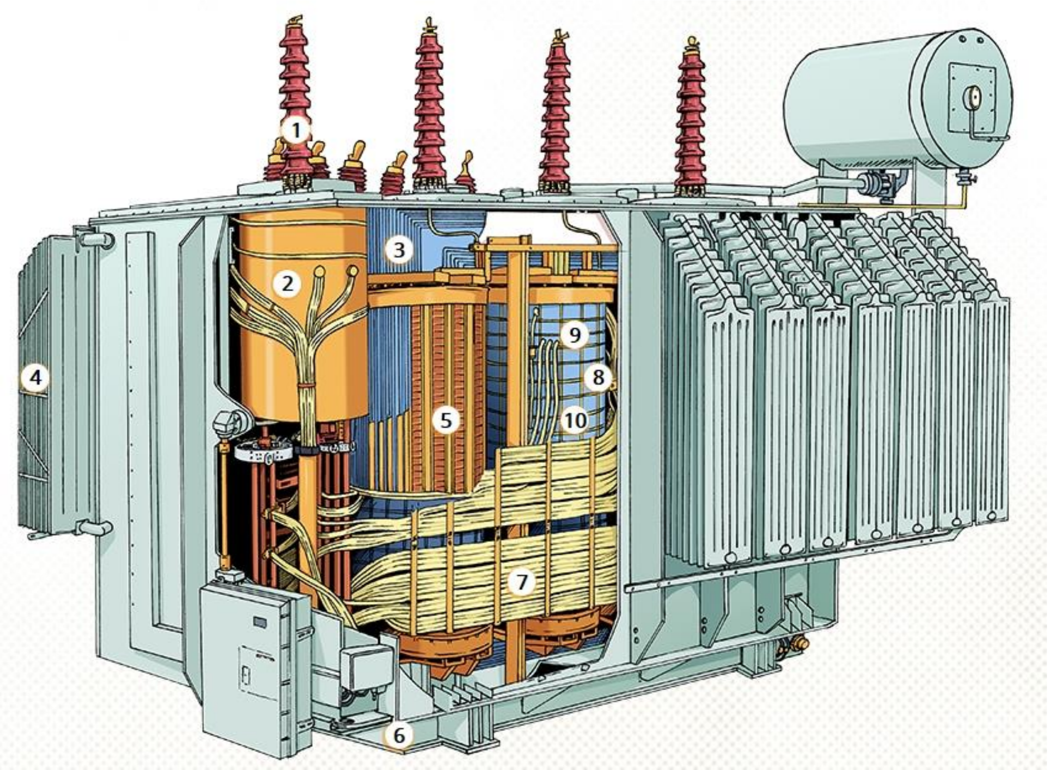


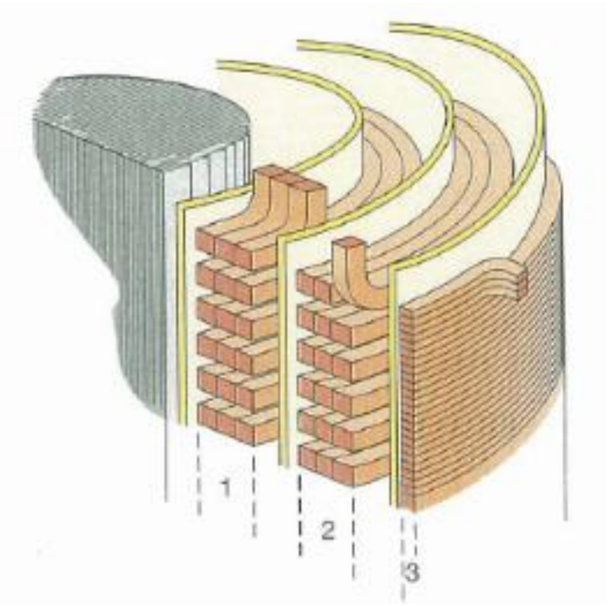


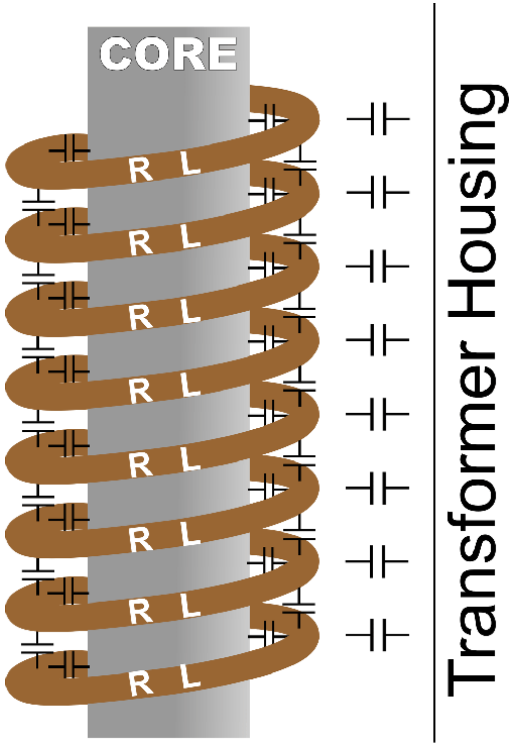

Coil, motor, generator

SFRA

Transformer is a combination of R, L and C

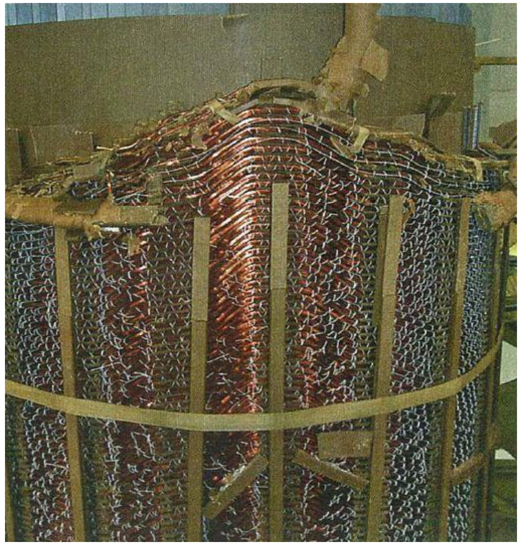






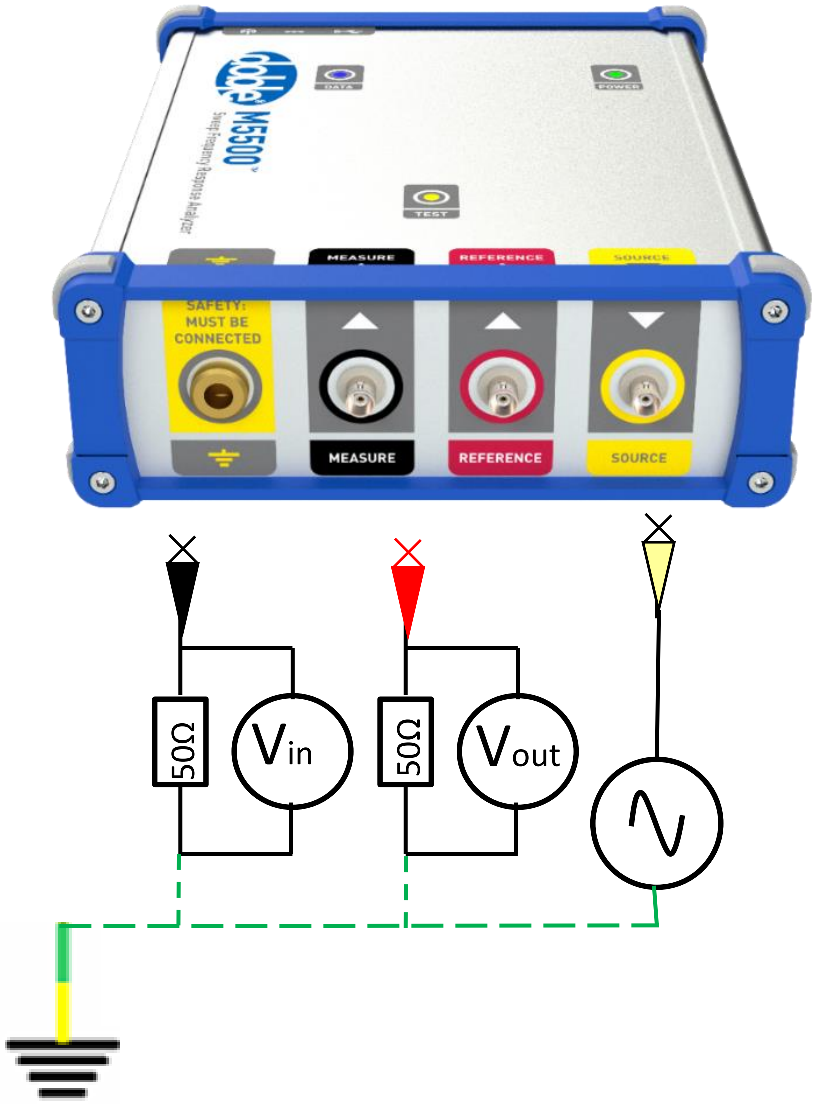
SFRA

- Detectable defects – with this test
  we will discover if something geometrically moved within the transformer as an effect of a hit to the transformer or as an effect of a very high current passing through the transformer



- Axial deformation of the winding
- Radial deformation of the winding
- Partial and localized deformation of a coil
- Short-circuit between turns
- Breaking a winding
- Connection problem (resistance, grounding, …)
- Problem on the magnetic circuit

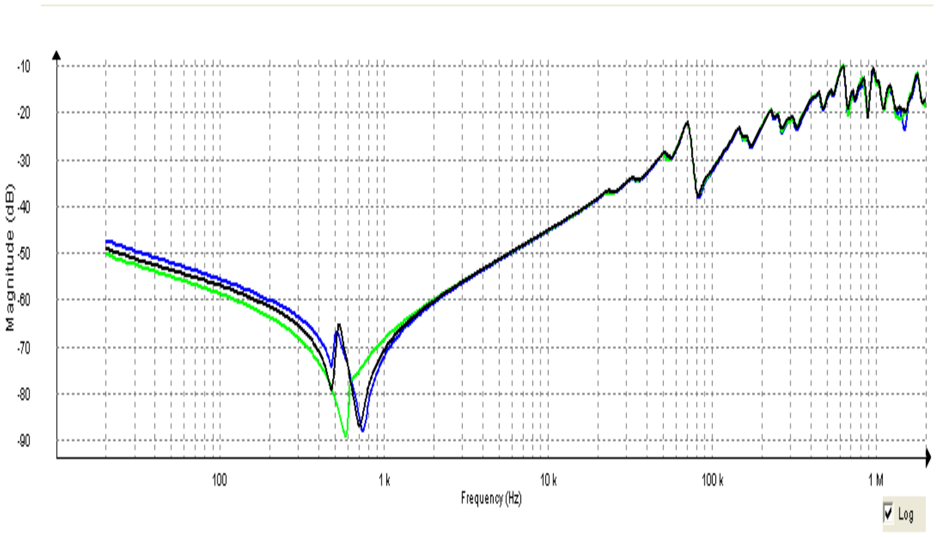
SFRA

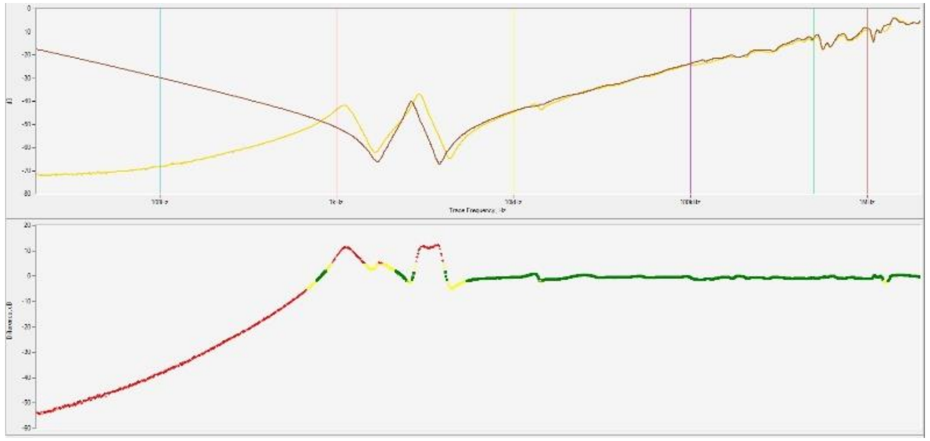


$$G(dB) = 20\log_{10}\left(\frac{V_{out}}{V_{in}}\right)$$

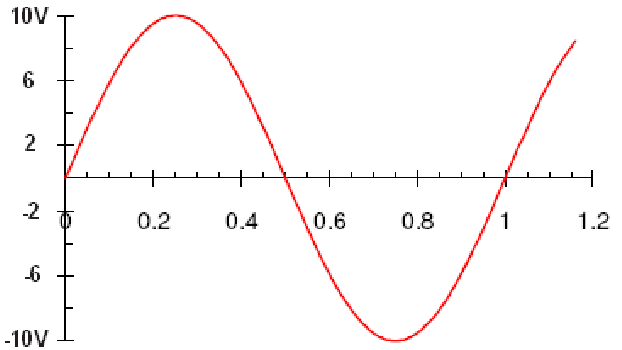
We generate low voltage (10 V_{pp}) on one side of the PT and measure from the other.

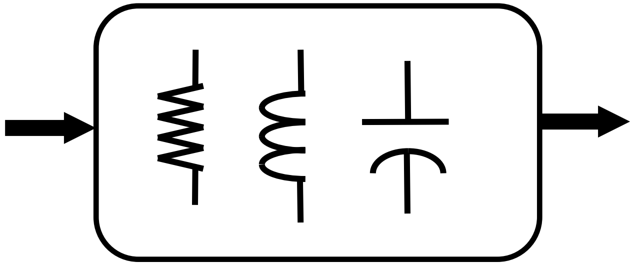
While doing so frequency of generated voltage changes form few Hz to few MHz in order to obtain the transfer function

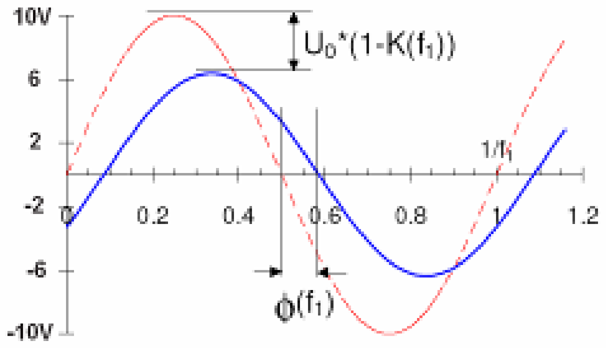




SFRA







$x = A \sin \omega t$

$y = B \sin(\omega t + \varphi)$

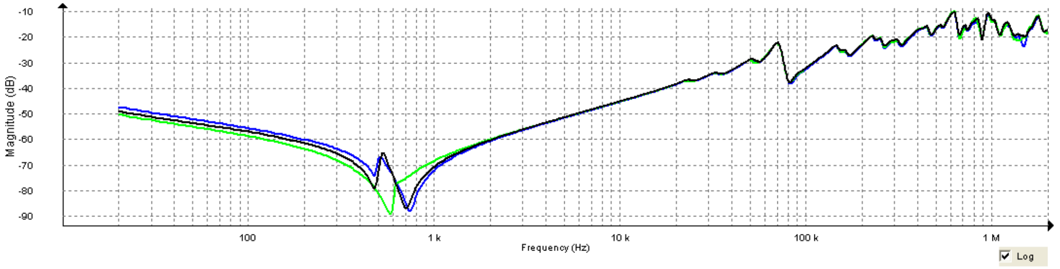
V sinwaves with variable frequency

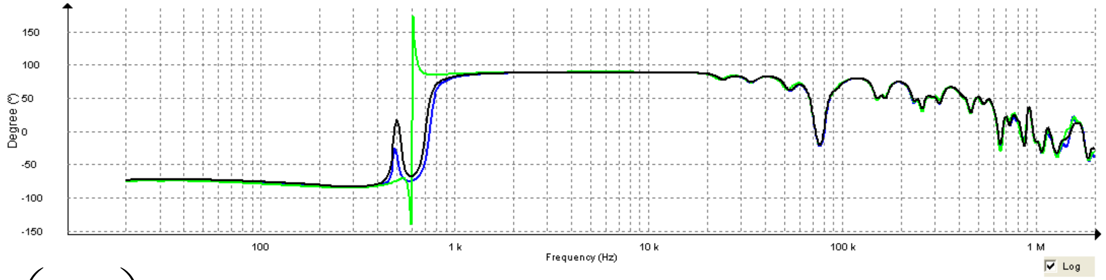
V mesured

Provides us with the fingerprint of the trafo

Gain in dB

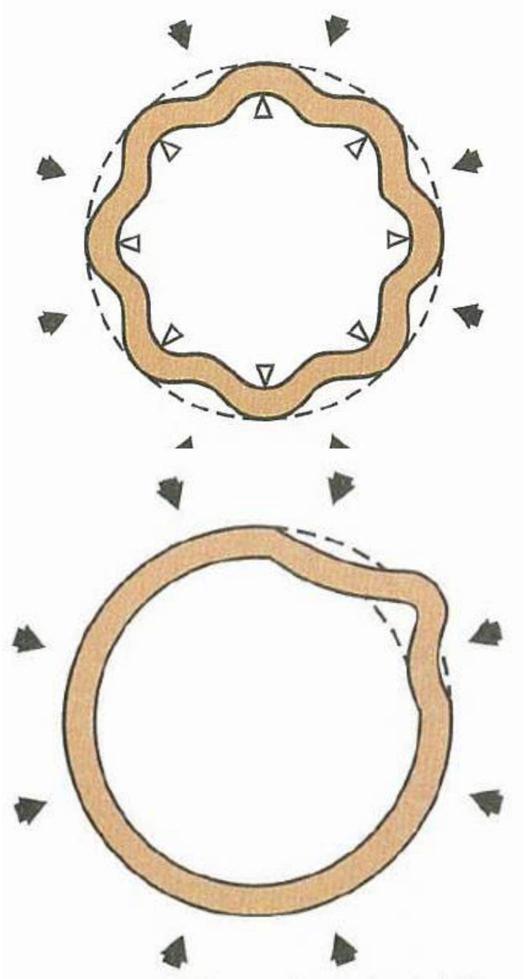
Phase in °



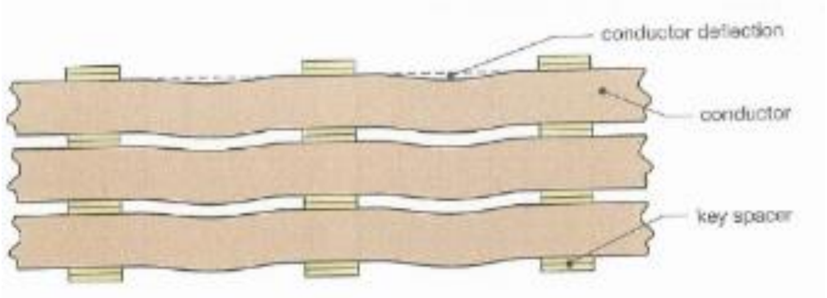


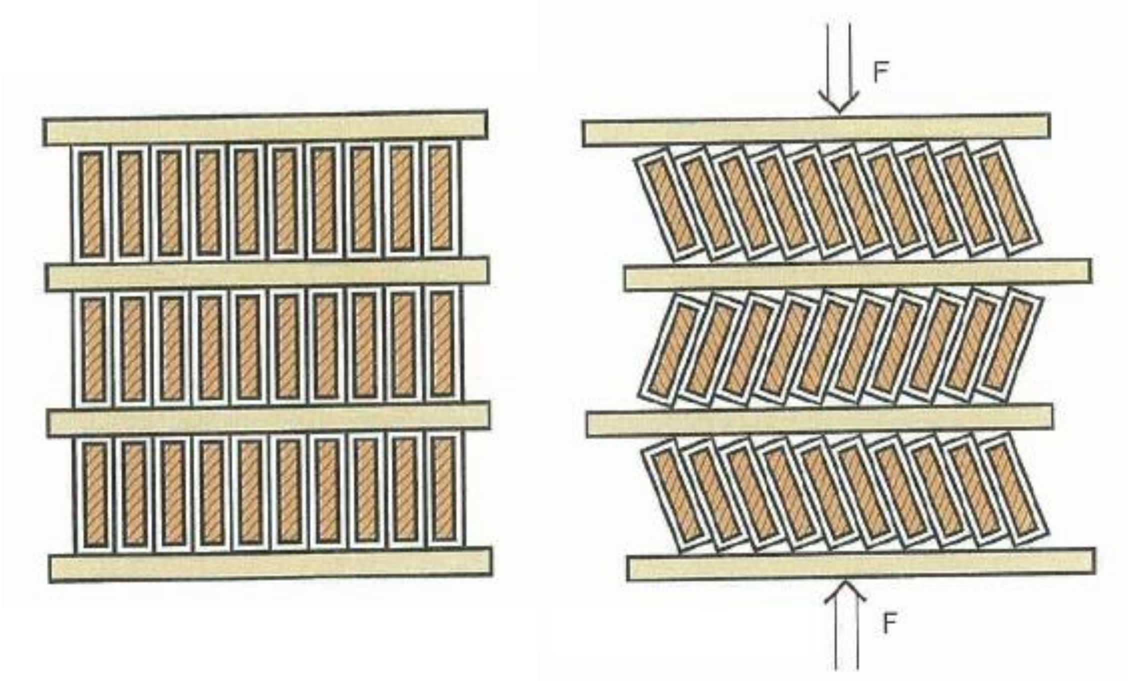
$$G(dB) = 20\log_{10}\left(\frac{V_{out}}{V_{in}}\right)$$

SFRA



Radial deformation of the winding





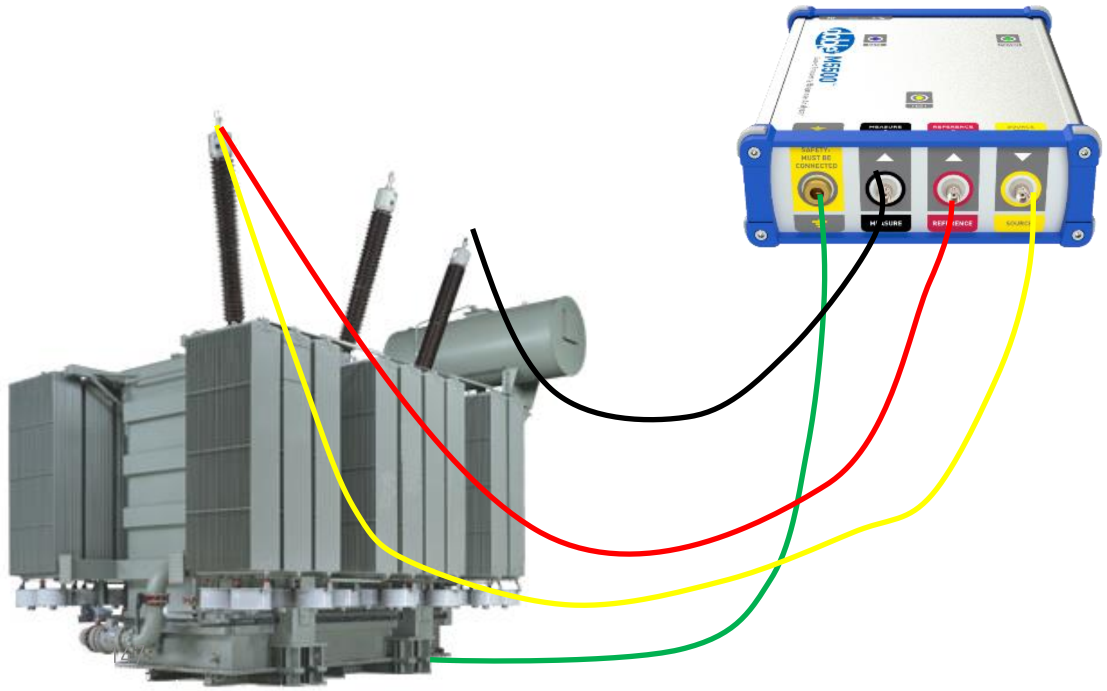
Axial deformation of the winding

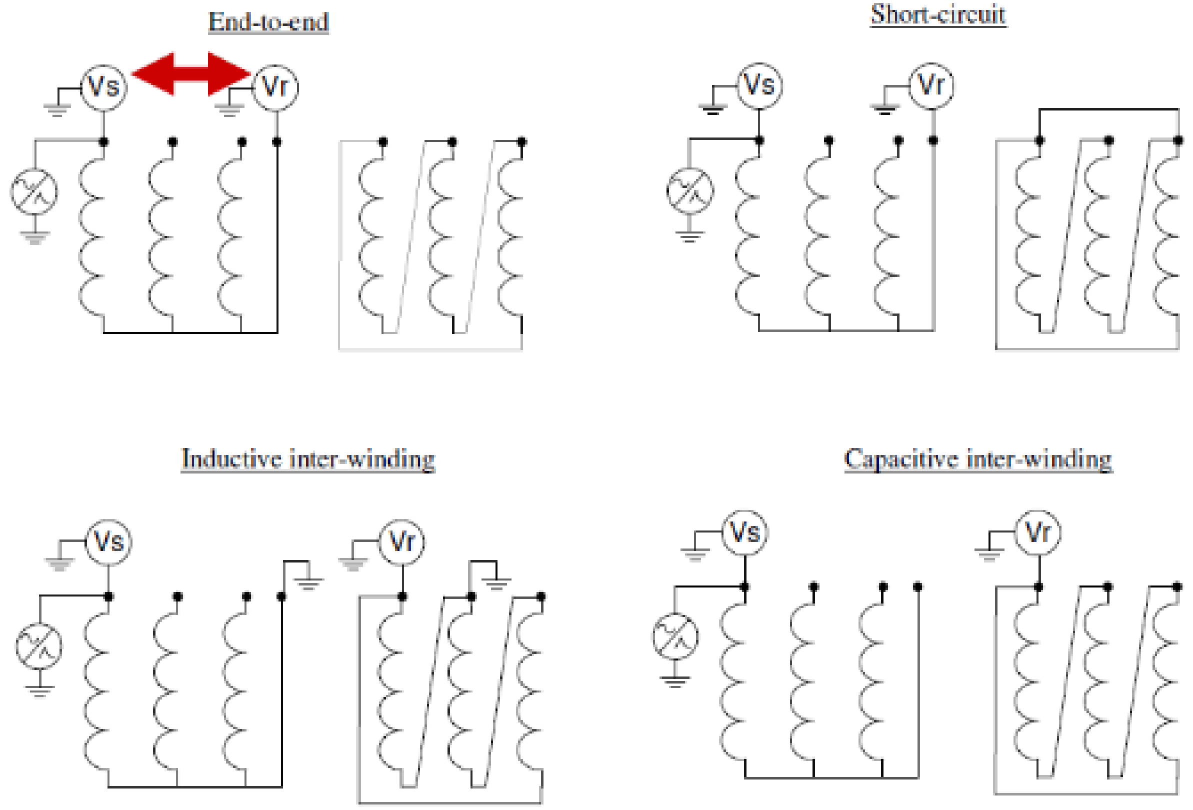
SFRA

- IEC 60076-18
- IEEE PC57.149/D8
- DLT911 / 2004
- CIGRE WGA2.26 & 342

CIGRE
1) End-to-End Open
2) End-to-End Short-Circuit
3) Capacitive Inter-Winding (CIW)
4) Inductive Inter-Winding (IIW)

IEEE
Open Circuit Self Admittance (OC)
Short Circuit Self Admittance (SC)
Inter-Winding (IW)
Transfer Admittance (TA)





SFRA

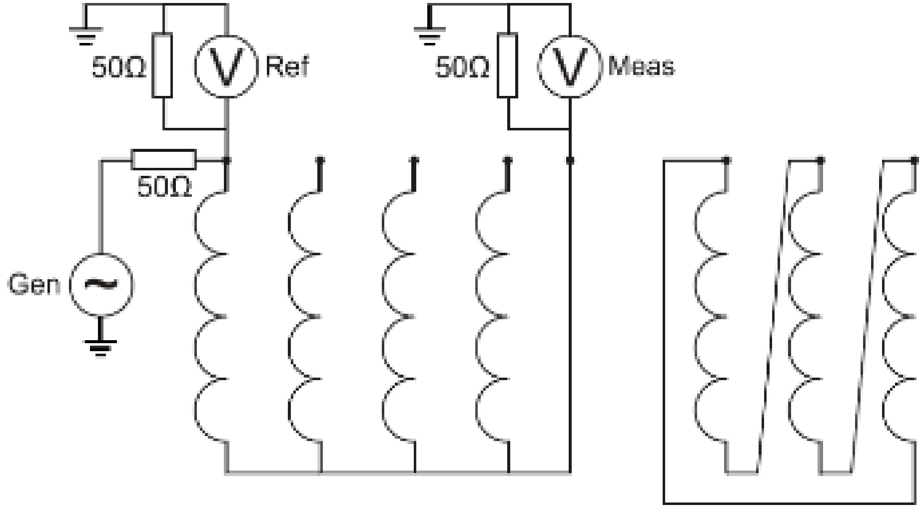
ALTANOVA
A DOBLE COMPANY

- IEC 60076-18
  - Measurement on max coil turn (winding + adjustment coil)
  - Measurement on nominal position of OLTC

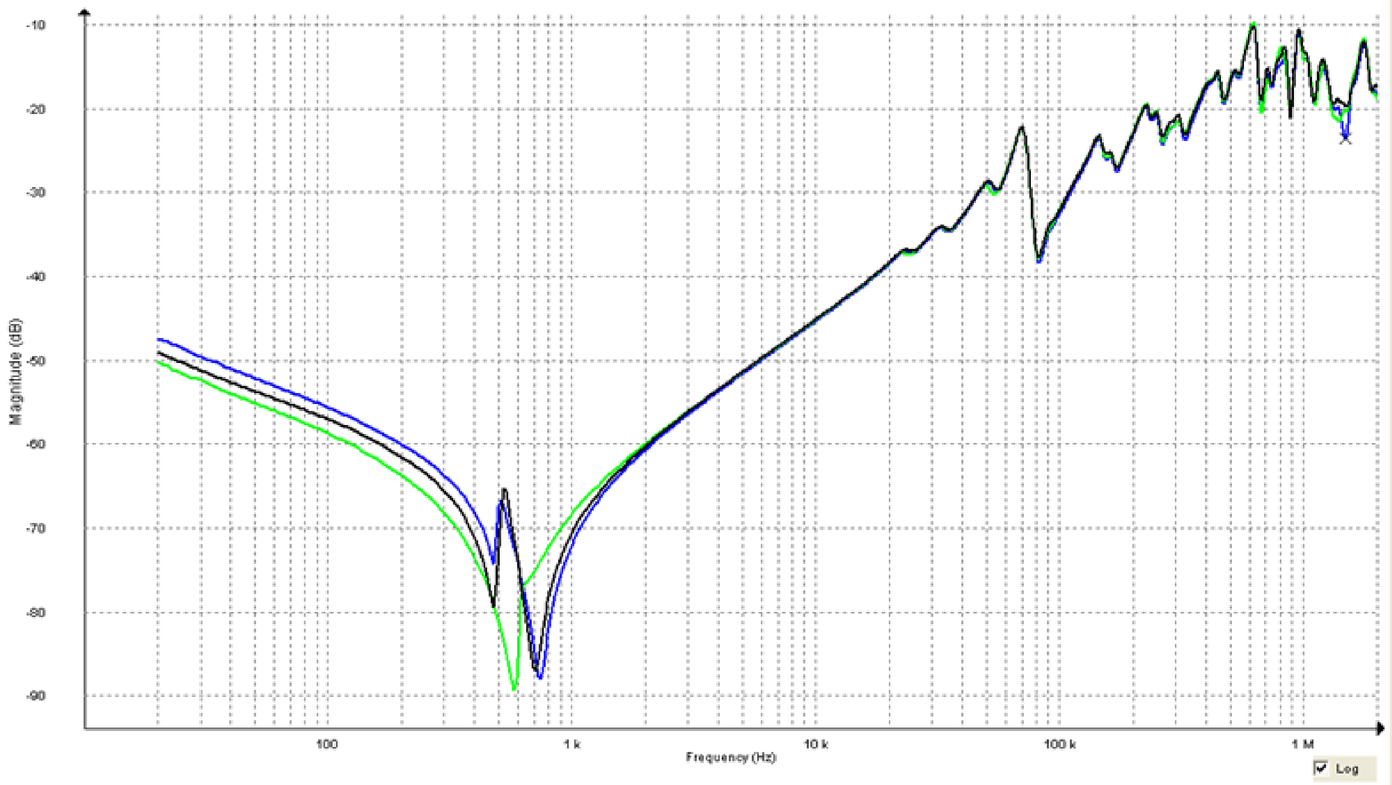
Test type	Test #	3φ Δ-Y Group 2 θ ⇒ 30° LAG	3φ Y-Δ Group 2 θ ⇒ 30° LAG	3φ Δ-Δ Group 1 θ ⇒ 0°	3φ Y-Y Group 1 θ ⇒ 0°	1ϕ
HV Open Circuit (OC) All Other Terminals Floating	1	H1-H3	H1-H0	H1-H3	H1-H0	H1-H2 (H1-H0)
	2	H2-H1	H2-H0	H2-H1	H2-H0	
	3	H3-H2	H3-H0	H3-H2	H3-H0	
LV Open Circuit (OC) All Other Terminals Floating	4	X1-X0	X1-X2	X1-X3	X1-X0	X1-X2 (X1-X0)
	5	X2-X0	X2-X3	X2-X1	X2-X0	
	6	X3-X0	X3-X1	X3-X2	X3-X0	
Short Circuit (SC) Short [X1-X2-X3][a]	7	H1-H3	H1-H0	H1-H3	H1-H0	H1-H2 Short [X1-X2][a]
	8	H2-H1	H2-H0	H2-H1	H2-H0	
	9	H3-H2	H3-H0	H3-H2	H3-H0	
Capacitive Inter-Winding All Other Terminals Floating	10	H1-X1	H1-X1	H1-X1	H1-X1	H1-X1
	11	H2-X2	H2-X2	H2-X2	H2-X2	
	12	H3-X3	H3-X3	H3-X3	H3-X3	
Inductive Inter-Winding High (H) to Low (L) Ground (H- and X-)[b]	13	H1-X1	H1-X1	H1-X1	H1-X1	H1-X1 Ground [H2, X2]
	14	H2-X2	H2-X2	H2-X2	H2-X2	
	15	H3-X3	H3-X3	H3-X3	H3-X3	

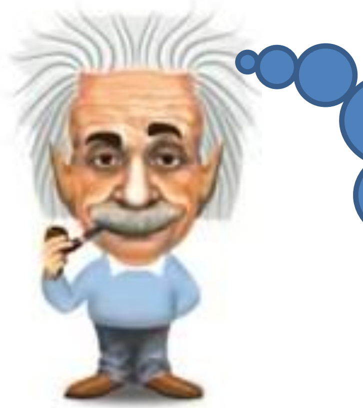
SFRA

- HV injection, LV open



The low frequencies are influenced by the magnetisation current

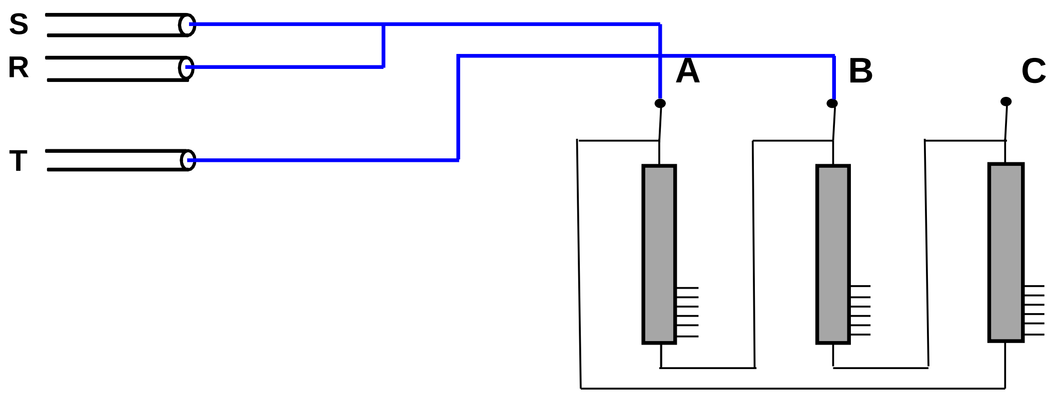


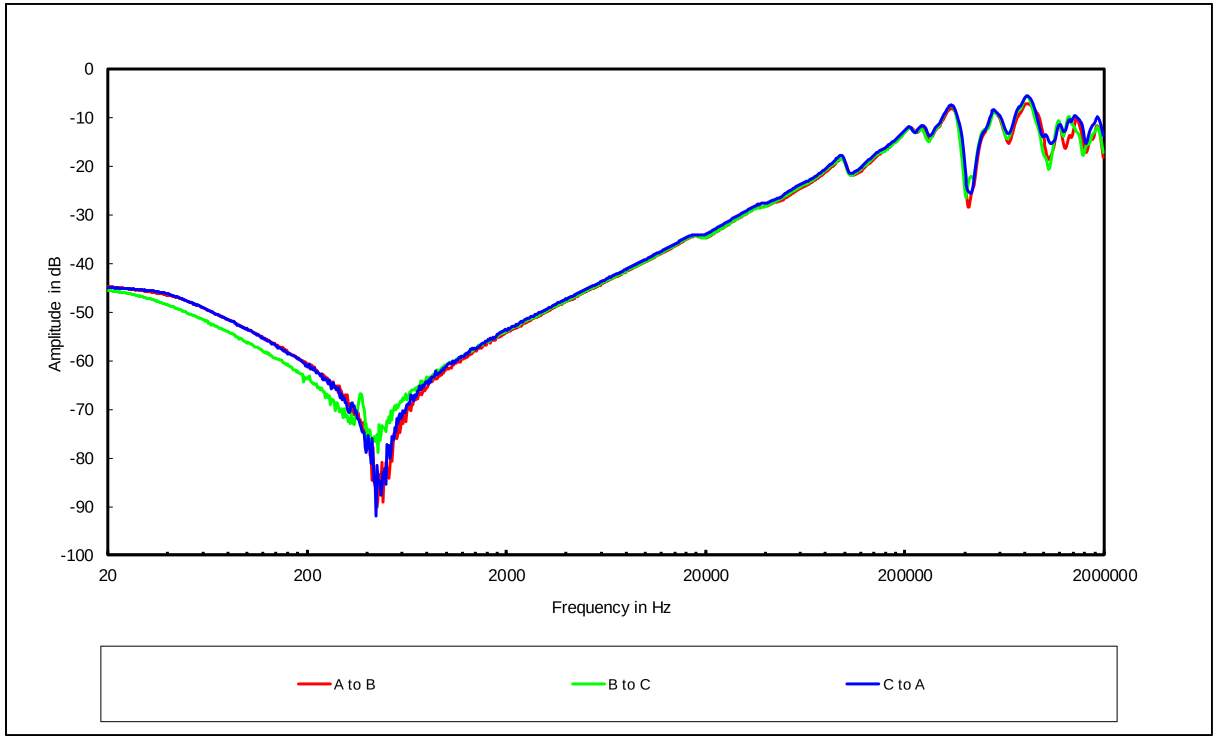


It is of the utmost importance that before this test transformer is demgetized

SFRA - Standard test dry transformer

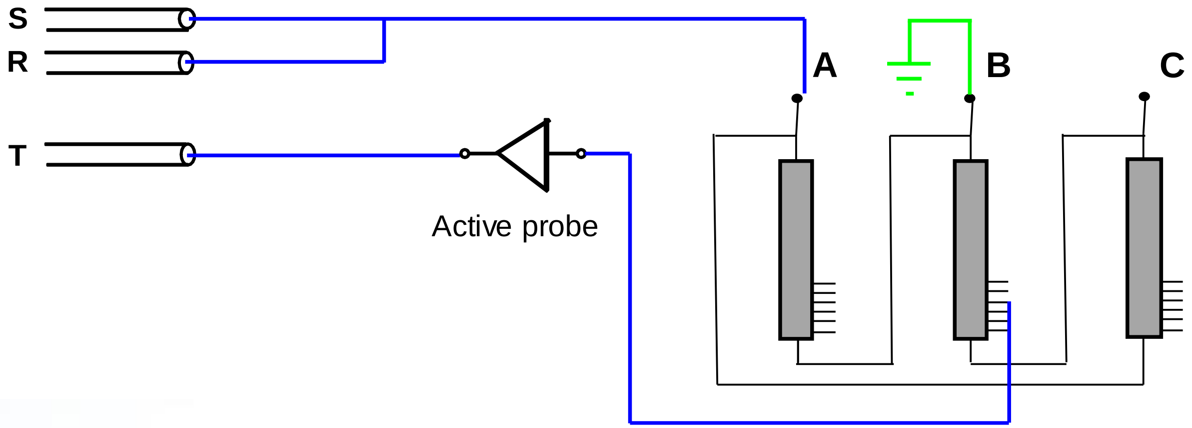
- HV injection, LV open

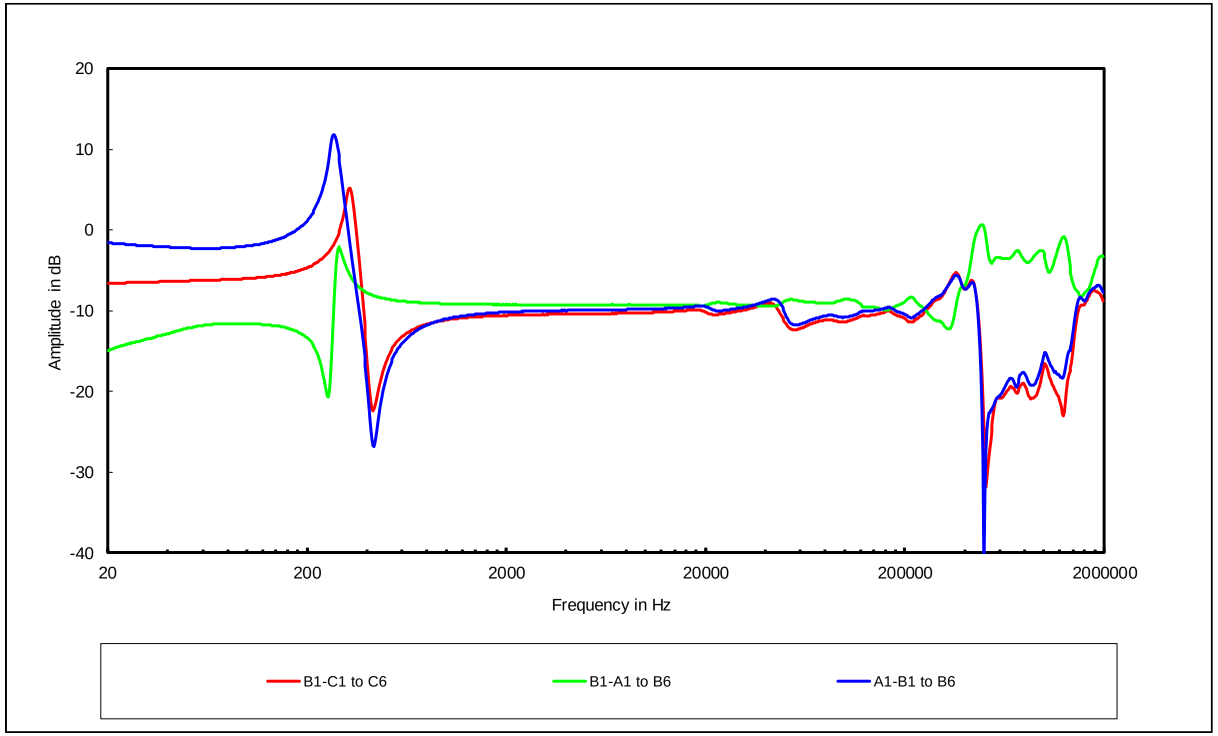




SFRA - Frequecy resonnance test

- Dry Transformer

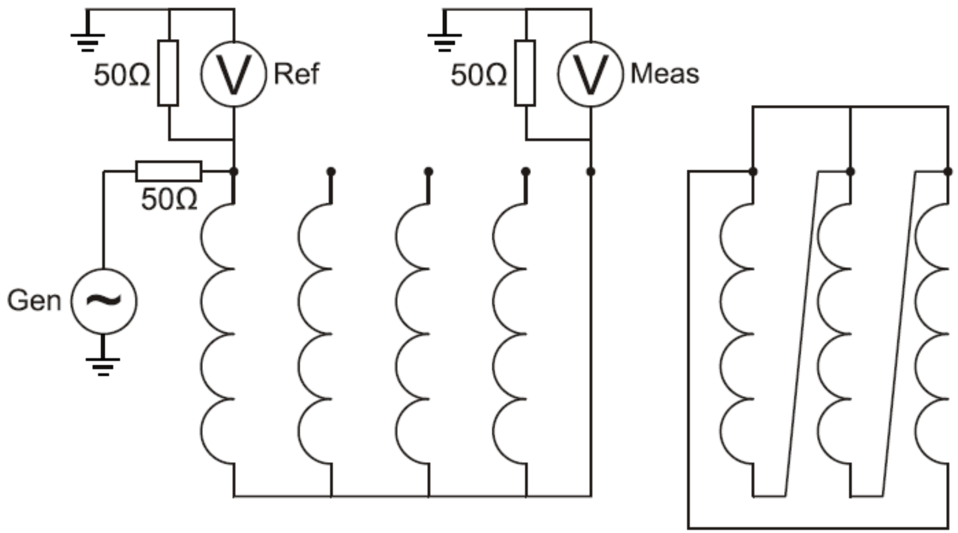


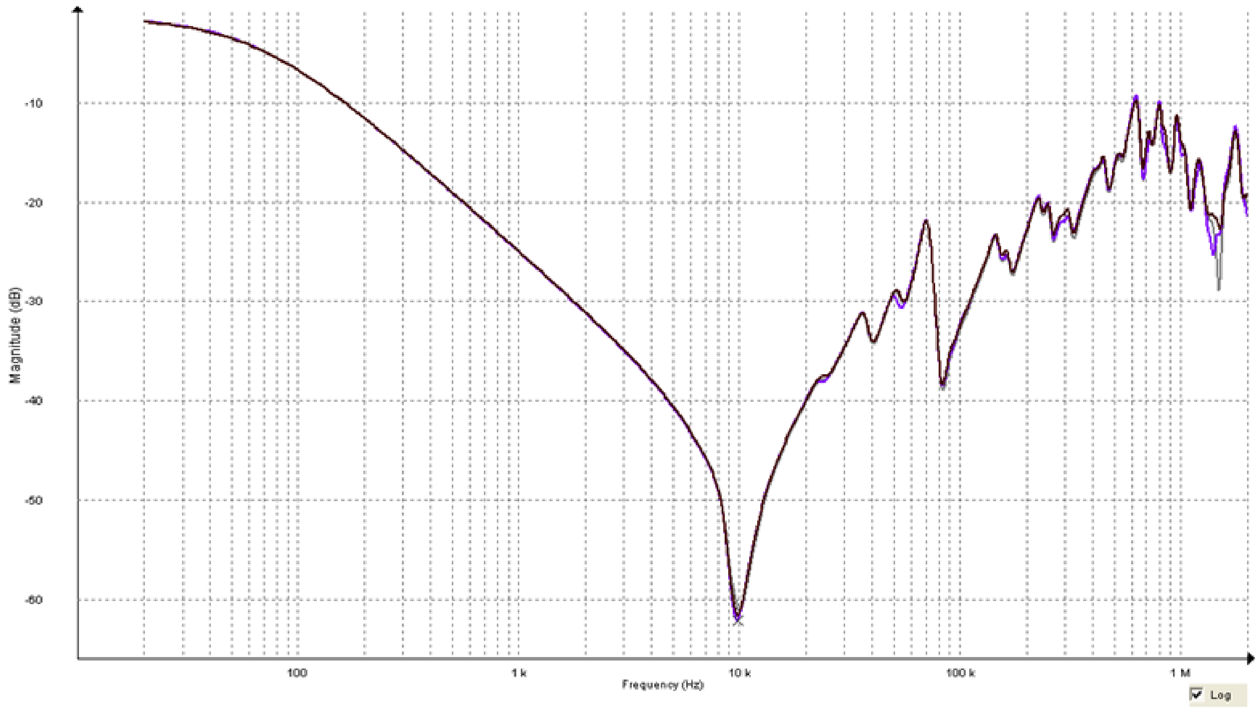


SFRA - Standard & test plan

- HV injection, LV Short

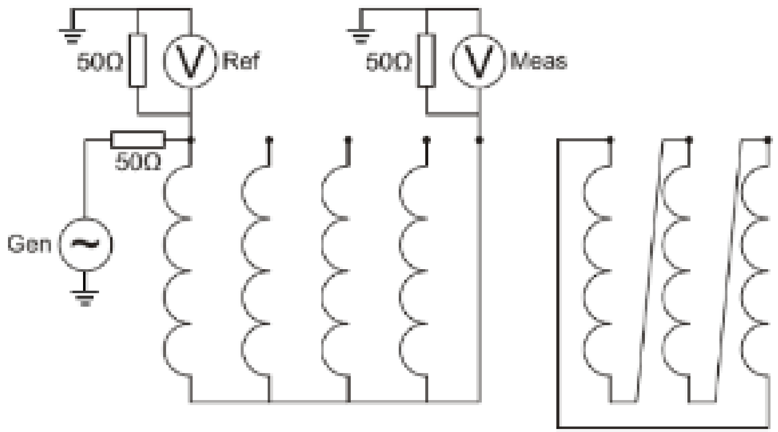
Short circuit, no magnetisation current
Measure the short circuit impedance
The transfer function is the same for the 3 phases

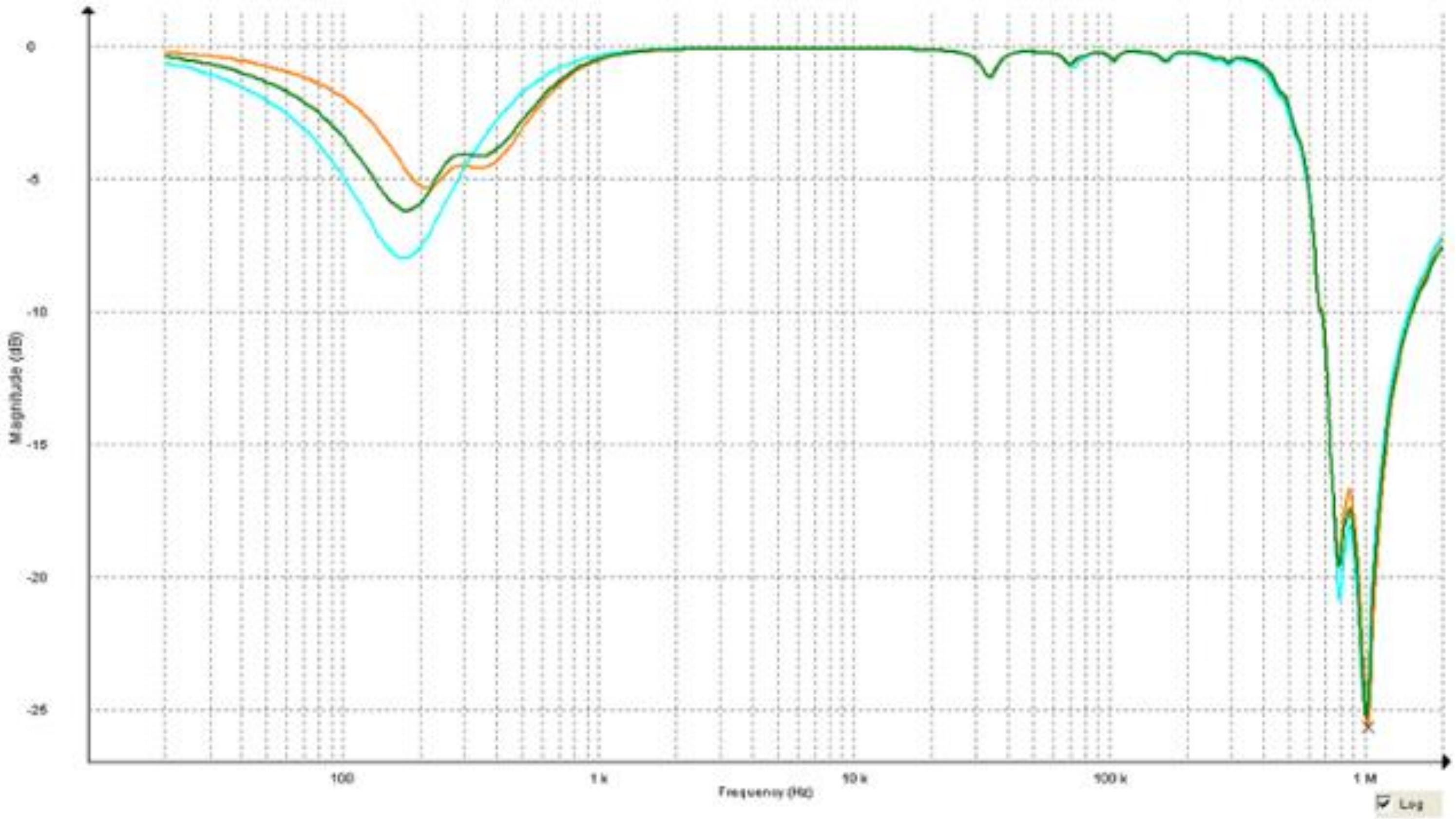




SFRA - Standard & test plan

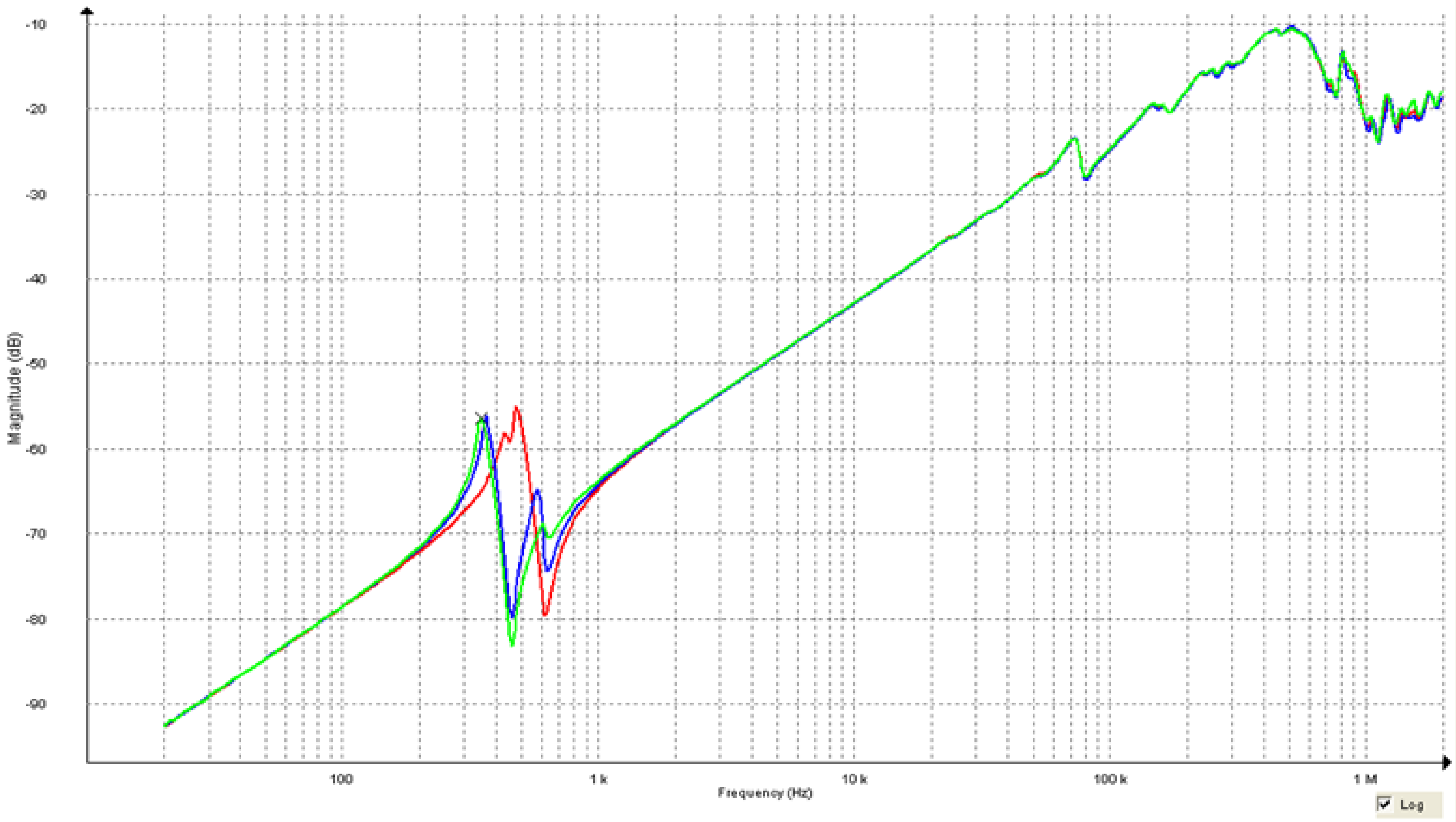
- LV injection, HV open

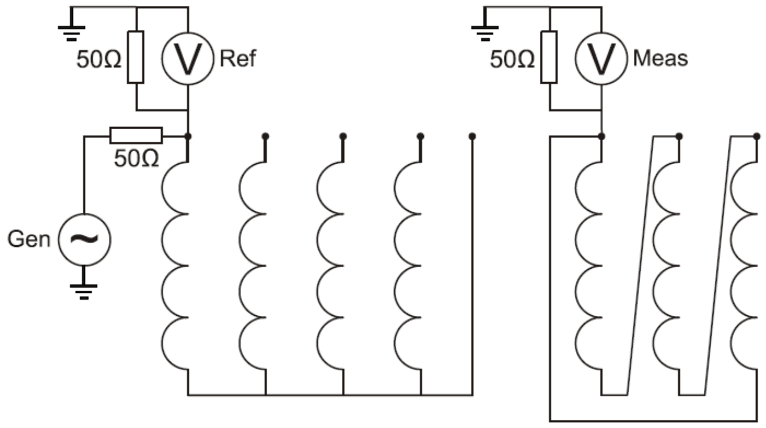




SFRA - Standard & test plan

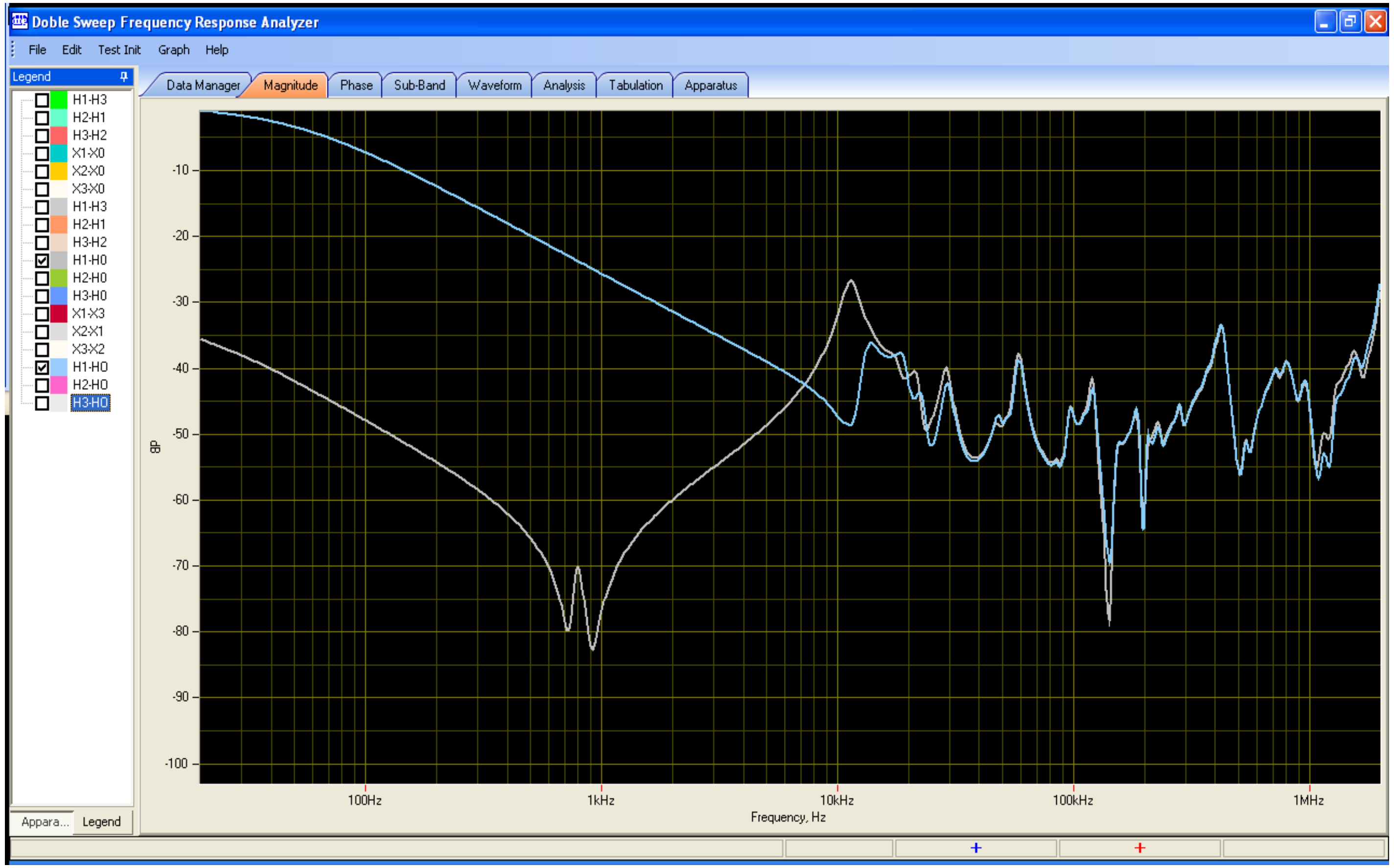
- HV injection, LV measurement (CHL)





SFRA - Standard & test plan

- Comparison open and short measurement



Interpretation – We need to have the previous result (from the factory if we do this test for first time)

Software compares the new curve – transfer function - and the old one

If they match all is fine – focus is on extremes (maximums and minimums)

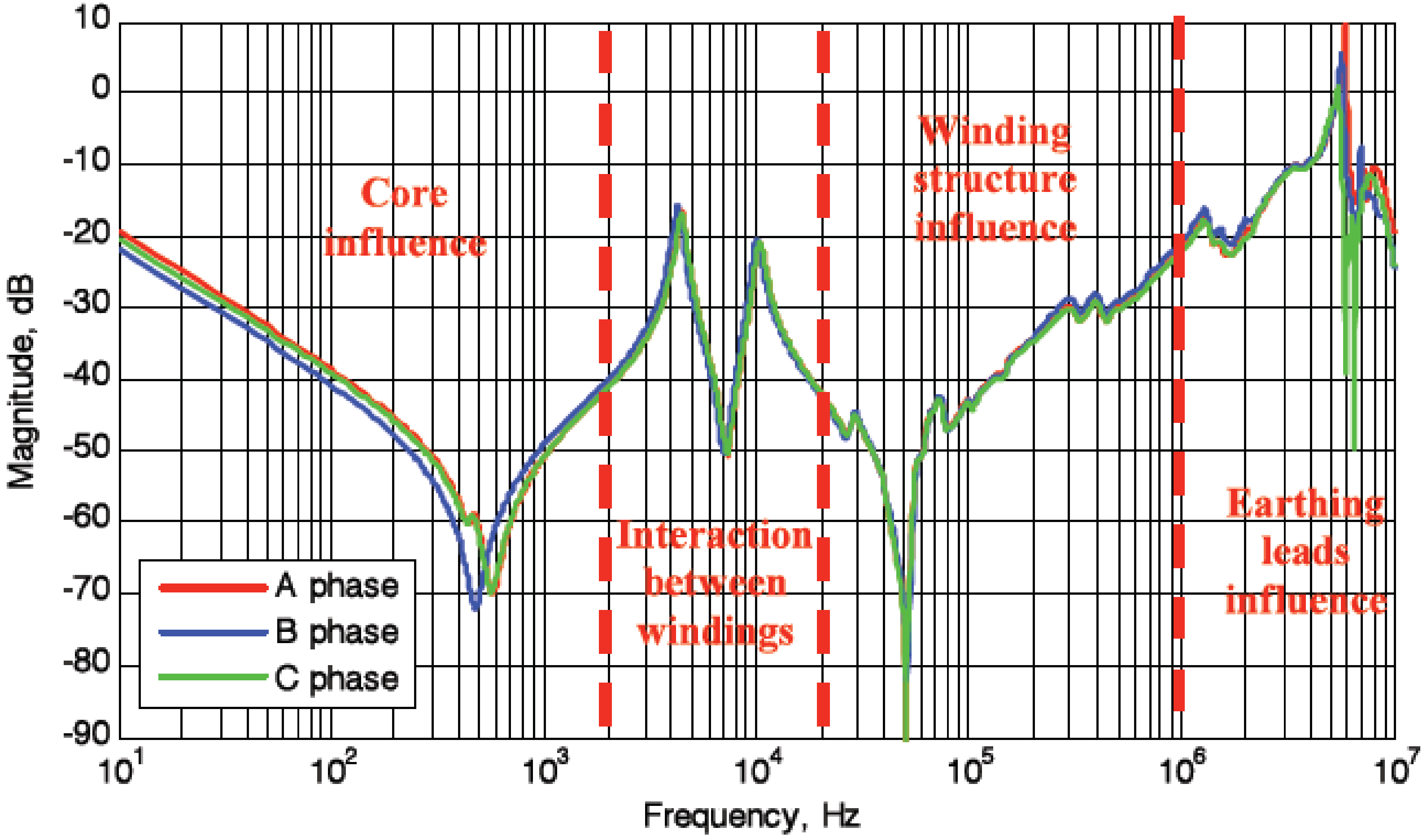
If they do not – something moved inside the PT

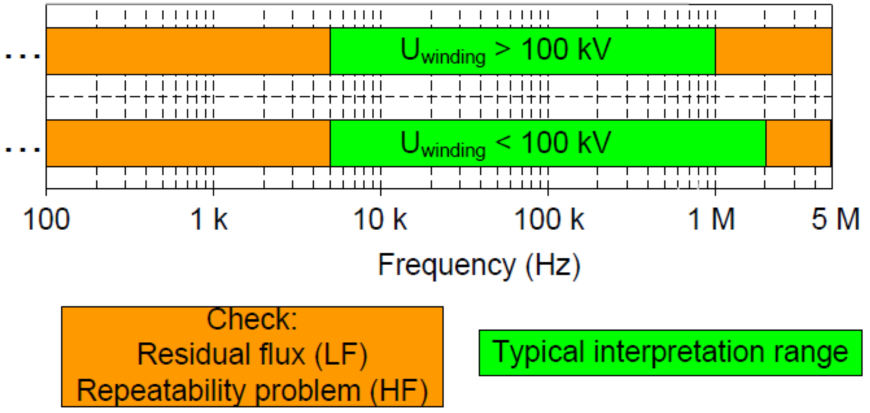
SFRA - When to perform this test

- **Factory**
  - Validation (quality, before and after short circuit test)
  - Before transformer transportation
- **Commissioning**
  - After transportation
  - After bushing and accessories assembled
- **Exploitation**
  - Insulation fault (Phase to ground, Phase to Phase)
  - Short-circuit (Phase to ground, Phase to Phase)
- **Another**
  - Earthquake
  - Lighting impulse

SFRA - When to perform this test

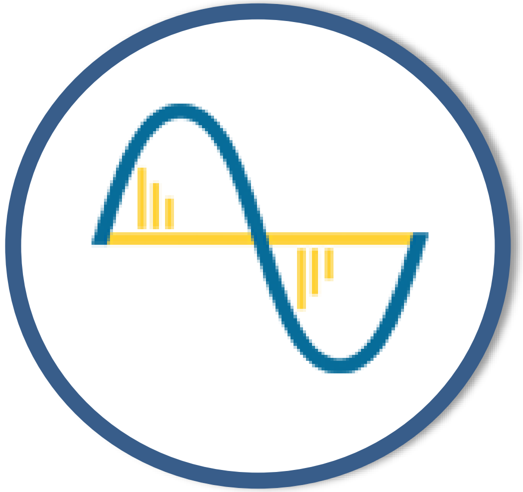
SFRA - Measurement analyze





PARTIAL DISCHARGE ON THE TRANSFORMER

What is PD?



PD are micro sparks inside (Internal PD) or on the borders of different insulating materials (Surface PD) that show us that insulation start to degrade

What is PD?

- Local overheating of the transformer oil → hot spots → gasses → low density region → PD
- Insulation (paper) damage caused by over voltages, lightning strikes
- Manufacturing defects (sharp edges, bad impregnation,...)
- Natural aging processes, humidity increase, ...
- Contact wear in tap changers
- Deposition of “conductive species” on transformer board
- Faulty bushing taps
- Selector problems (tap changer)

Partial Discharge

APPLICATIONS :

- Permanent Monitoring
    - *Sensors*
    - *Acquisition Box*
    - *Communication & Alarms*
- Quality Control in factory
- Spot PD measurements in the field
    - *On-line service*
    - *Off-line service*
    - *Instruments*

Sensors units used in PD measurment

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Sensors units used in PD measurment

BUSHING MODELS CURRENTLY EQUIPPED	
ABB	GOB
ABB *formerly HSP*	EKTG
ABB *formerly ASEA*	GOA
PASSONI & VILLA	PNO
PASSONI & VILLA	POBO
PASSONI & VILLA	PCTO
TRENCH	ETG
TRENCH	COT

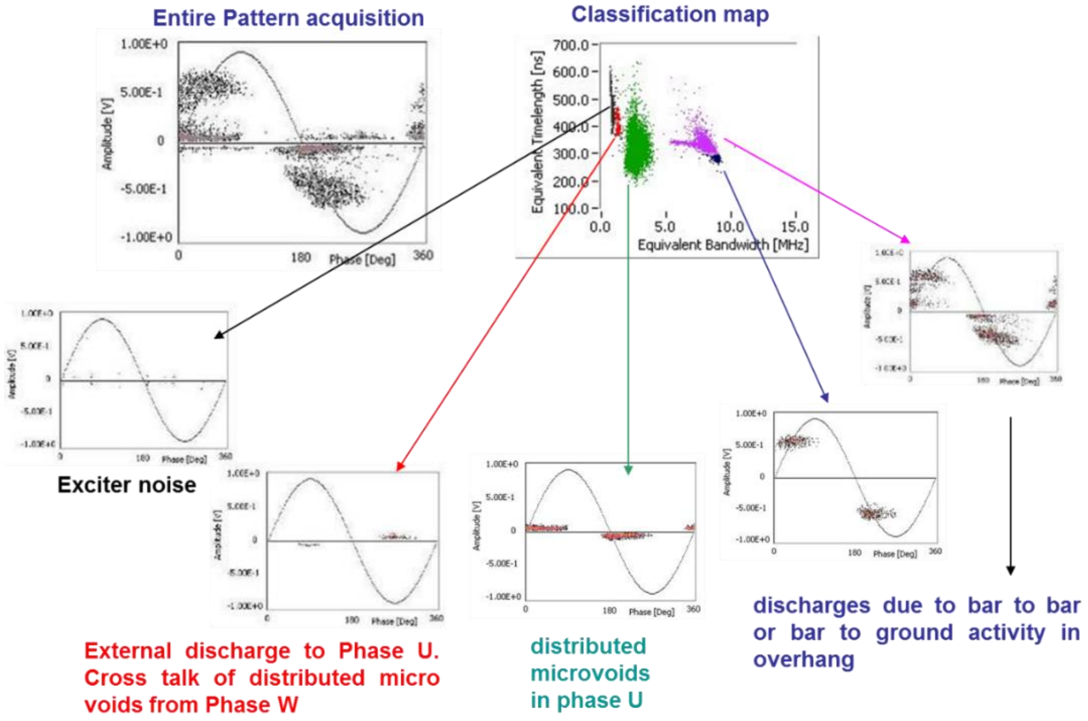
SPECIFICATIONS	
Voltage output @ 50Hz or 60Hz	1 ÷ 10Vrms
Max output transient voltage	$90V_{peak}$
V_{out} vs V_{in} phase shift	90°
Operating temperature	-25°C ÷ +65°C
Output connector	BNC
Protection degree	IP66
Current to ground @ 50Hz or 60Hz	Below 10mA

Acquisition units used in PD measurment

Very advanced oscilloscopes with even more advanced software

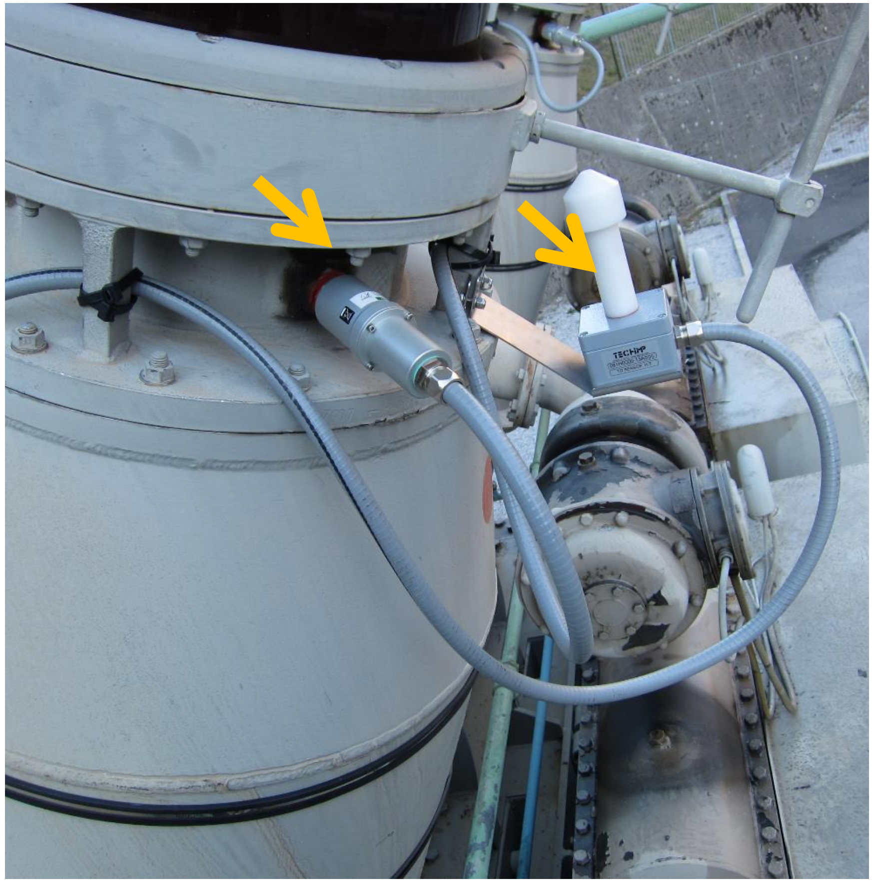
Acquisition units used in PD measurment

Software needs to have ability to filter our the noise (since we measure very low values) and to separate the sources (corona, internal and surface PD)



Sensors used in PD

Sensors used in PD



Sensors used in PD

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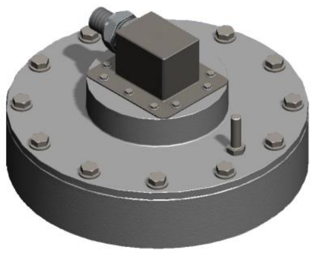
UHF External Sensor:
500MHz – 3GHz bandwidth



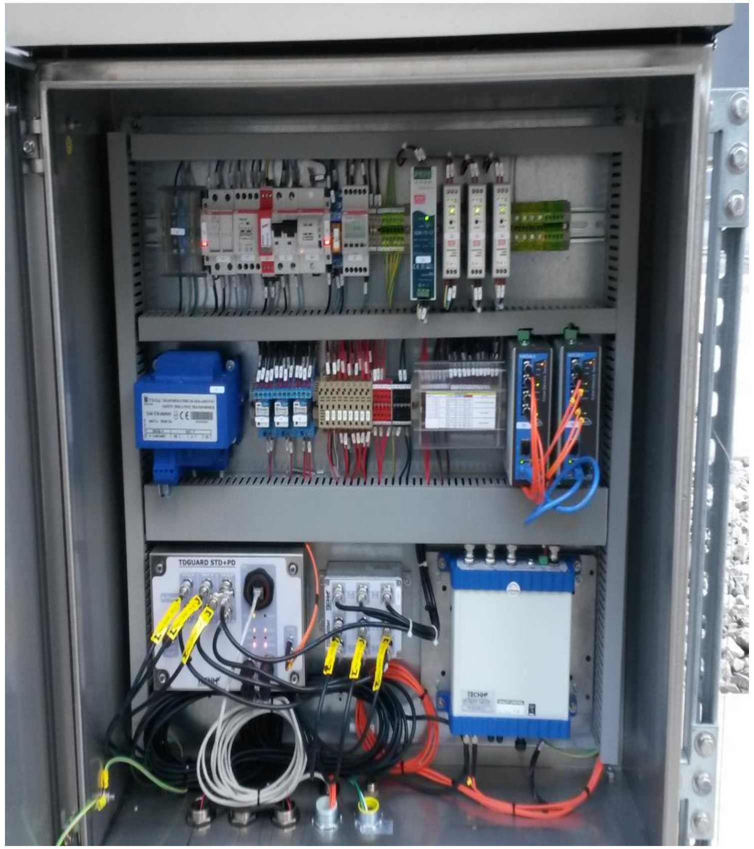
- UHF Spiral antenna is a sensor designed to receive electromagnetic (EM) emissions from a PD.
- It is a broadband antenna with a flat response. .
- It has been optimized to operate in a frequency range typical for PD activity and it was designed to provide maximum sensitivity and high gain.
- Its compact and robust design makes Spiral antenna the optimal sensor for direct installation on high voltage Transformers.
- It can be virtually applied in any electrical equipment provided that it has apertures or EM transparent surfaces.

Sensors used in PD

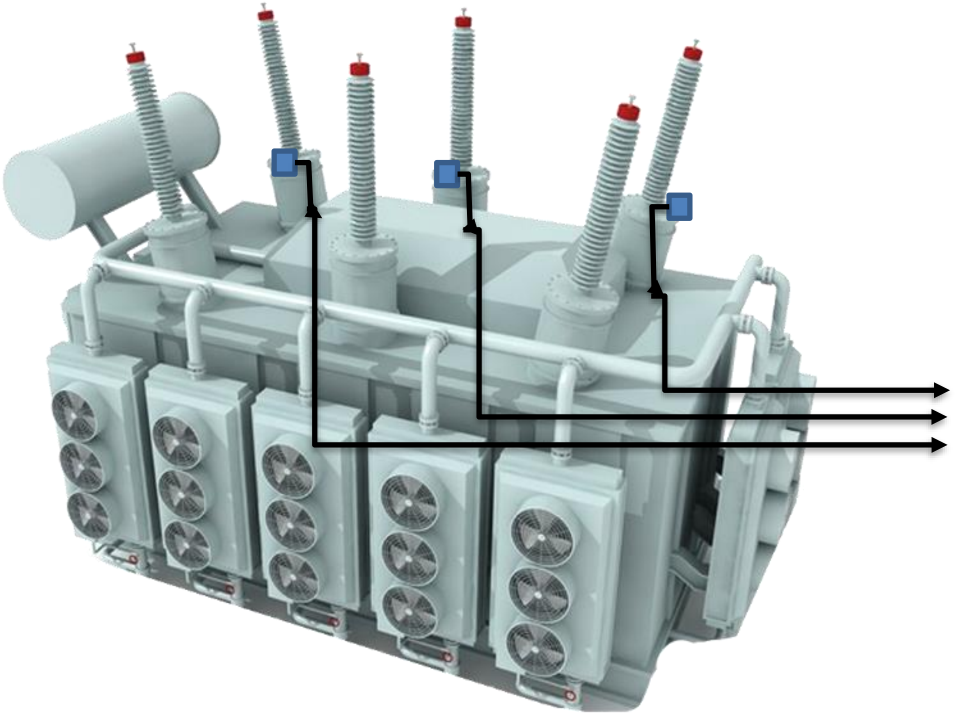
HFCT 30mm / HFCT 50mm

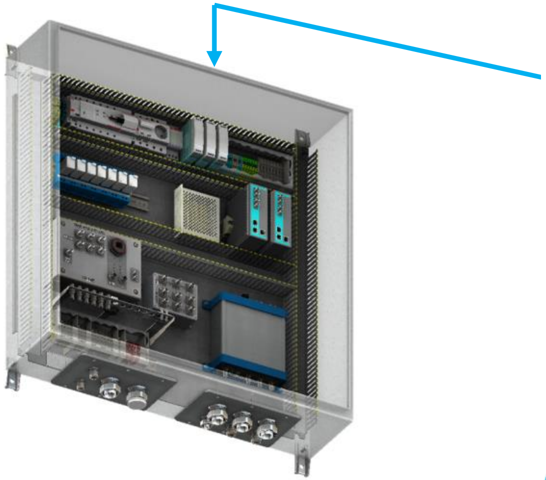
HFCT clamp 39mm / HFCT clamp 140mm

If you decide to go for online monitoring of PD



If you decide to go for online monitoring of PD





PD & TD Acquisition Box

Central Unit
(with TiScada
software inside)

TiScada software
(On Virtual Machine)

PD Instrument

Tap Adapter

FO cable for communication purpose

Coaxial cables inside protective pipe

Power Supply cables

If you decide to go for online monitoring of PD

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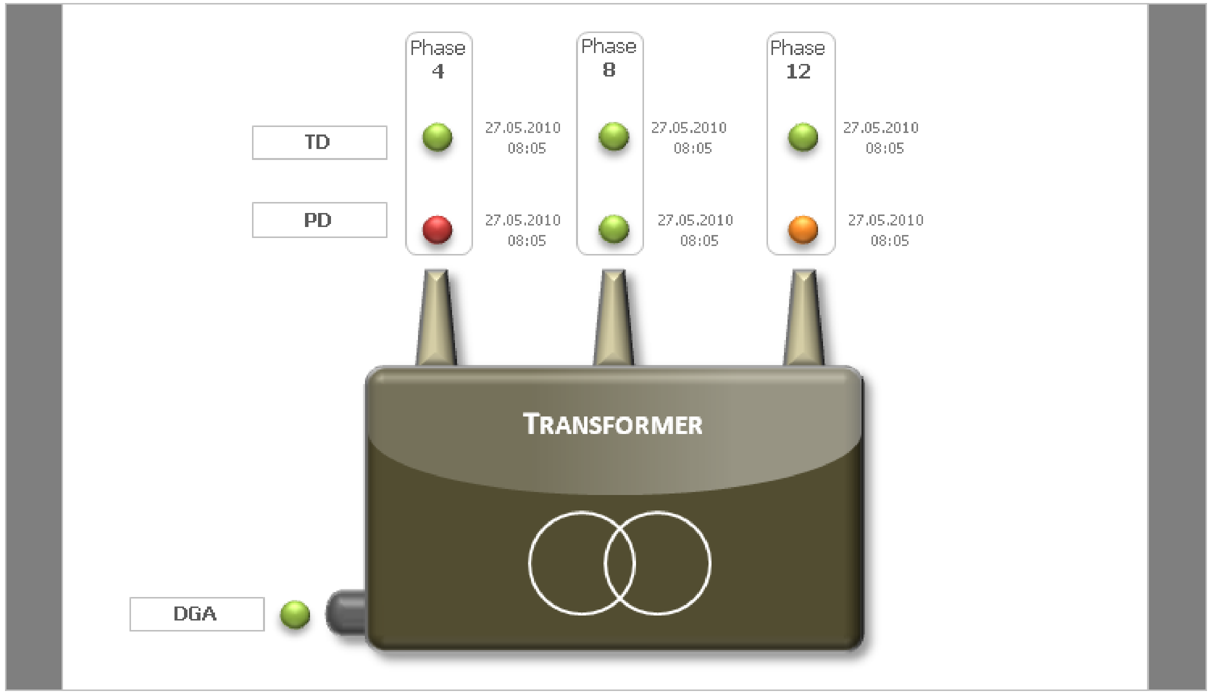
SYNOPTIC VIEW for a 3-phase TRANSFORMER



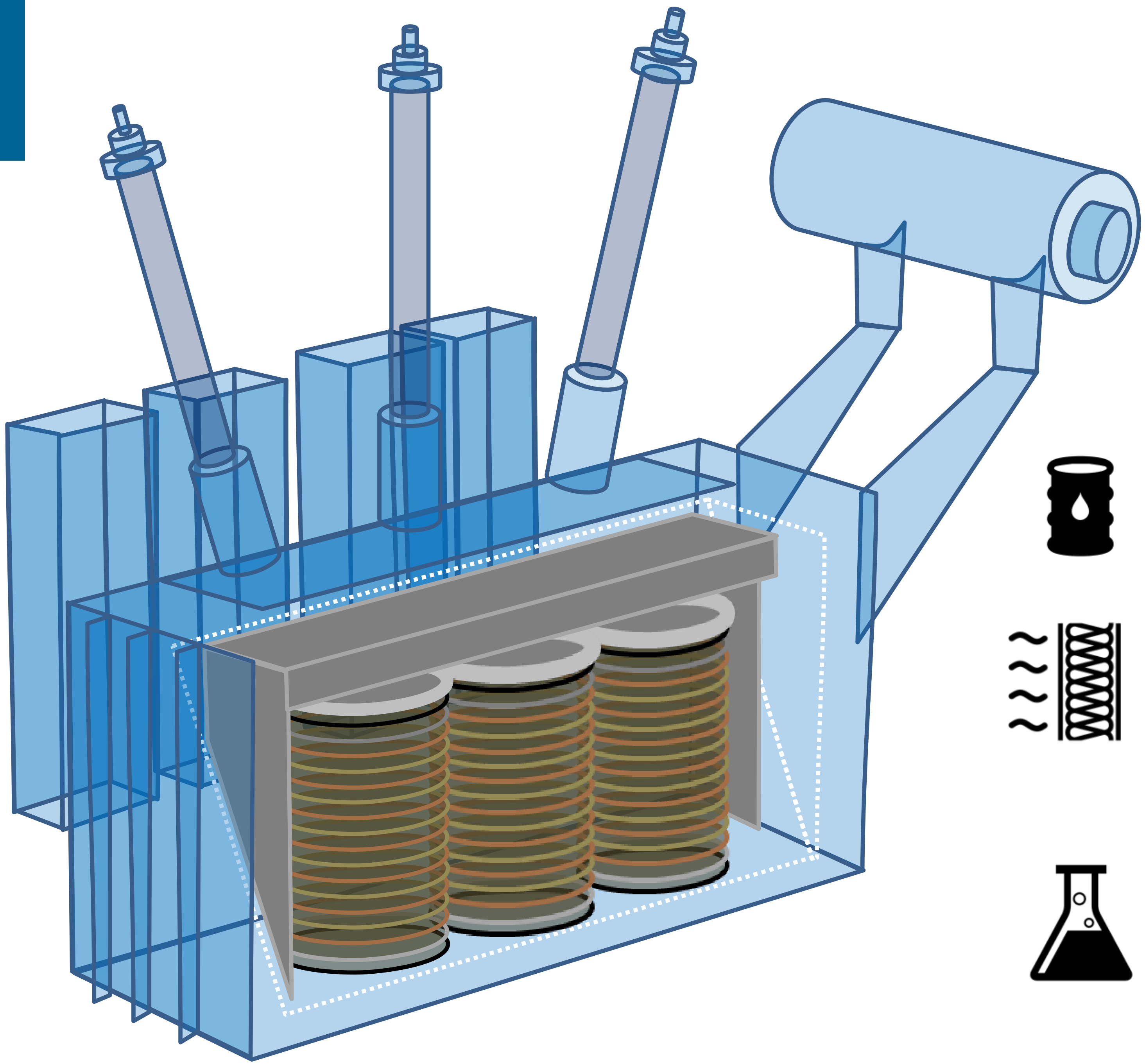
Dissolved gas analysis

Many faults in the transformer lead to gaseous by-products dissolved in the oil. Therefore, a proper and regular dissolved gas analysis (DGA) is required to determine the status of the transformer.

A **DGA** is the first indicator of a problem and can identify:

- Deteriorating insulation and oil
- Overheating
- Hot spots
- Partial discharge
- Arcing

The “health” of the oil is a good indication of the “health” of the transformer.



Transformer Oil
=
'The Blood' of a Transformer

Transformers are filled with oil that cools and insulates its windings.

The insulating oil is in contact with the internal components, so as normal and abnormal events occur within the transformer, "fault gases" are produced and become dissolved in the oil.

Analyzing these gases provides a snapshot of the overall health of the transformer, much as a blood test provides a snapshot of the overall health of a human body.

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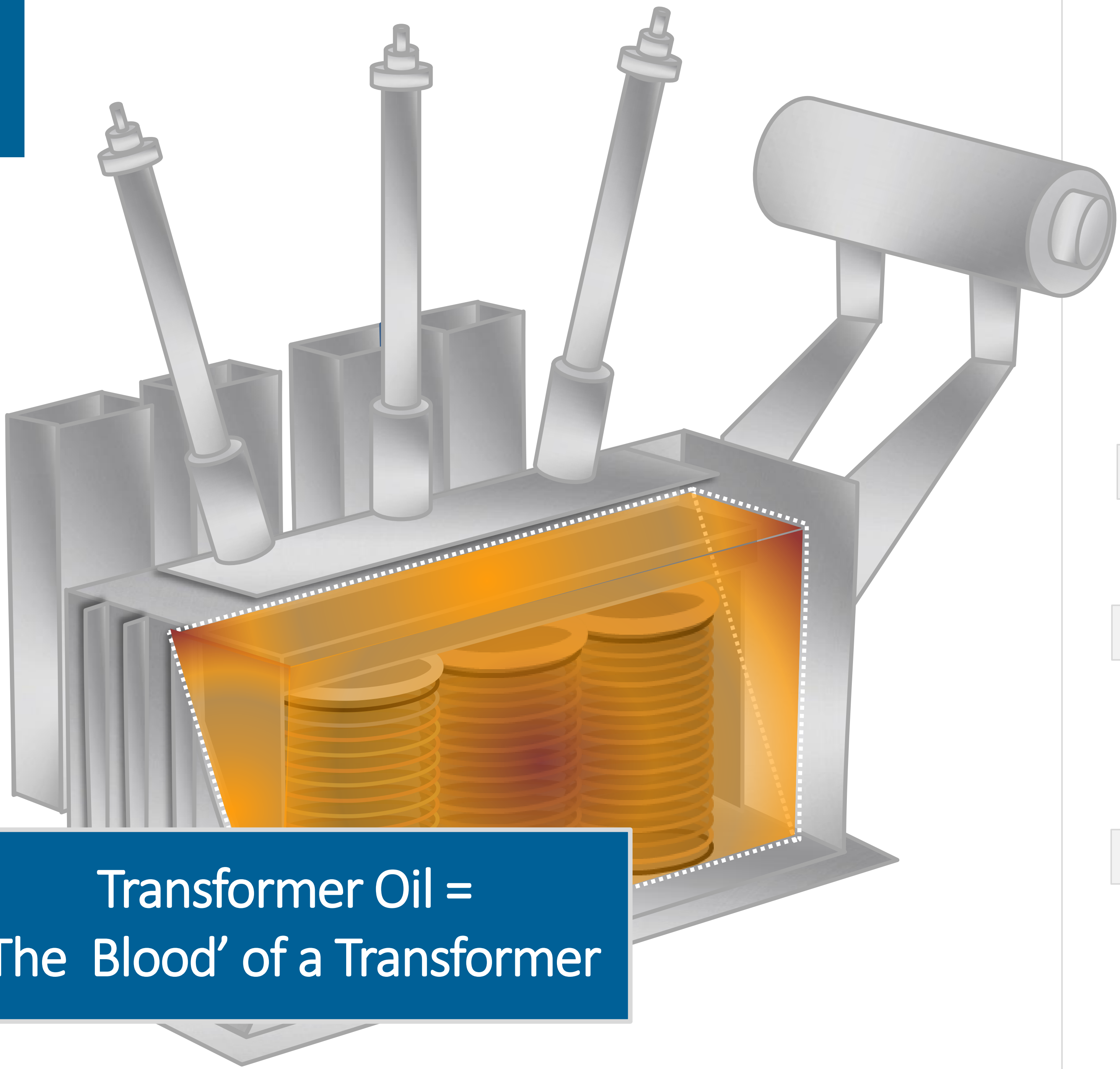

Transformer Oil =
'The Blood' of a Transformer

GASSES DISSOLVED IN THE OIL

H2	CO	CH4
Hydrogen	Carbon Monoxide	Methane
C2H6	**C2H4**	**C2H2**
Ethane	Ethylene	Acethylene
O2	**CO2**	**N2**
Oxygen	Carbon Dioxide	Nitrogen

H2O
Moisture

Dissolved gas analysis

- Different deterioration processes result in different DGA "fingerprints".
- Key gasses are formed by the degradation of oil: hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4) and acetylene (C_2H_2) paper carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), etc.
- Gas type and amount of gas are determined by the severity of the fault and the energy involved

Standards involved with DGA

IEC 60567 ed4.0 (2011-10), Oil-filled electrical equipment – Sampling of gases and analysis of free and dissolved gases

IEC 60599 ed2.0 (1999-03), TC/SC 10, Mineral oil-impregnated electrical equipment in service - Guide to the interpretation of dissolved and free gases analysis

Cigré TB783 – (Oct 2019) DGA Monitoring.
The different types and technologies of on-line gas monitors
Accuracy of the on-line monitors on the market
Procedure for evaluating the accuracy of on-line gas monitors

Dissolved gas analysis

For a DGA test the following condition ranges can be defined based on the severity of the fault (IEC60599, IEEE C57-104, ...):

Gas	Condition ranges				primary cause
	Good	**Fair**	**Poor**	**Action**	
Hydrogen (ppm)	<101	>100 <1000	>1000 <2000	>2000	pd, electrolysis of water
Methane (ppm)	<121	>120 <401	>400 <1001	>1000	overheated oil
Ethane (ppm)	<66	>64 <101	>100 <151	>150	overheated oil
Ethylene (ppm)	<51	>50 <101	>100 <201	>200	very overheated oil
Acetylene (ppm)	<36	>35 <51	>50 <81	>80	arcing in oil
Carbon Monoxide (ppm)	<351	>350 <571	>570 <1401	>1400	overheated paper, air polution
Carbon Dioxide (ppm)	<2501	>2500 <4001	>4000 <10001	>10000	overheated paper, atmosphere
Oxygen (ppm)	<3501	>3500 <7001	>7000 <10001	>10000	atmosphere

Dissolved gas analysis

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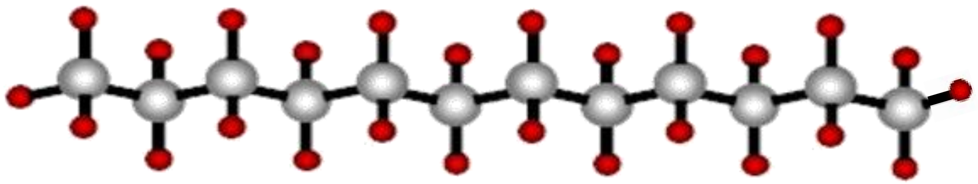
Generic Oil Molecule

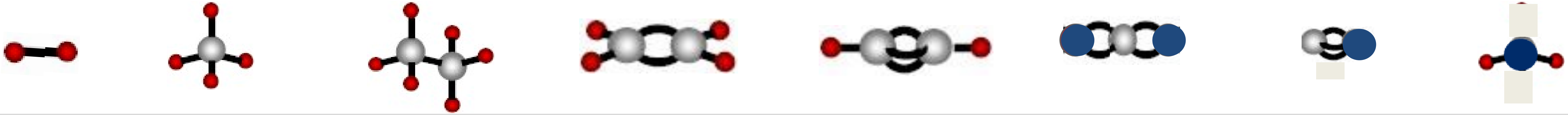
$CH_3 - [CH_2]_n - CH_3$



Thermal stress

Electrical stress

Oxygen exposure



H_2 | CH_4 | C_2H_6 | C_2H_4 | C_2H_2 | CO_2 | CO | H_2O

Fault Gas Formation

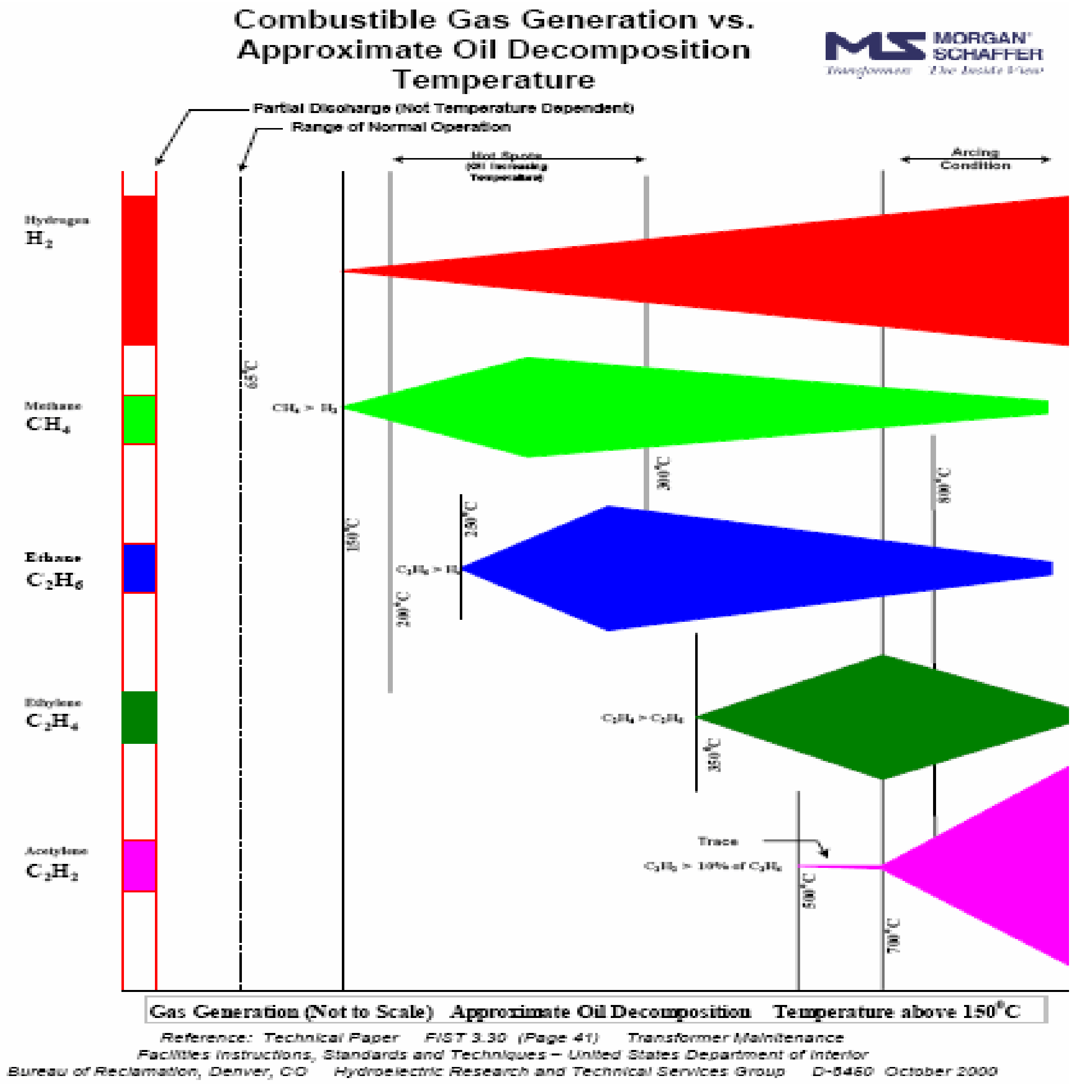
Stray gassing

Oil oxidation

Cellulose degradation

Dissolved gas analysis

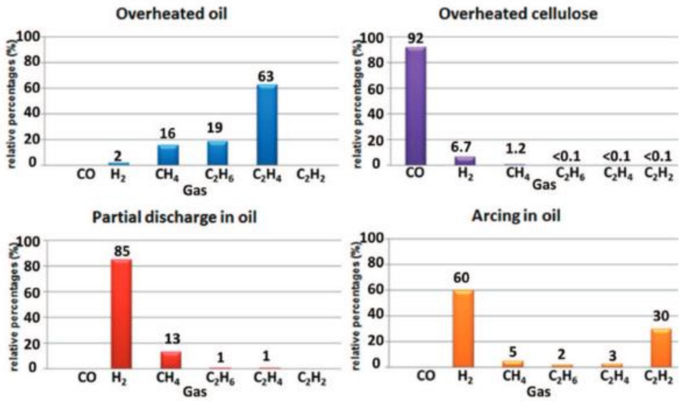
Understanding Fault Gases



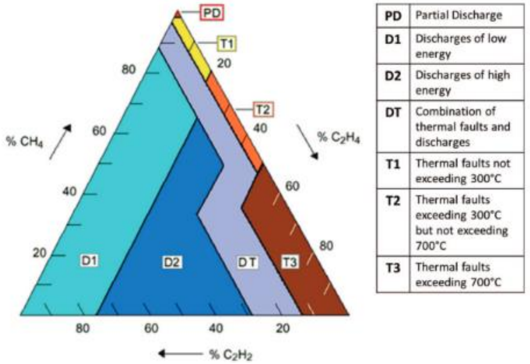
Dissolved gas analysis

Accurate fault identification methods – multiple gases

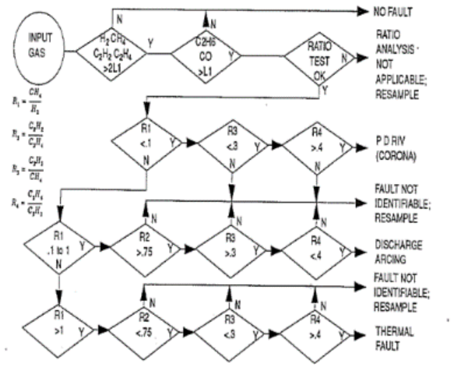
KEY Gas Method



Duval's Triangle



Doernenburg Method



Roger Ratios

Table 6
Rogers Ratios for Key Gases

Case	R2 C_2H_2/ C_2H_4	R1 CH_4/ H_2	R5 C_2H_4/ C_2H_6	Suggested Fault Diagnosis
0	<0.1	>0.1 <1.0	<1.0	Unit normal
1	<0.1	<0.1	<1.0	Low-energy density arcing—PD (See NOTE)
2	0.1–3.0	0.1–1.0	>3.0	Arcing—High-energy discharge
3	<0.1	>0.1 <1.0	1.0 3.0	Low temperature thermal
4	<0.1	>1.0	1.0–3.0	Thermal <700 °C
5	<0.1	>1.0	>3.0	Thermal >700 °C

Dissolved gas analysis

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Basic Fault Types Detectable with DGA

Code	Fault
PD	Partial discharges of corona type
D1	Discharges of low energy, including partial discharges of the sparking type
D2	Discharges of high energy
T1	Thermal fault T < 300 ºC
T2	Thermal fault 300 ºC < T < 700 ºC
T3	Thermal fault T > 700 ºC
DT	Mixed electrical and thermal fault

Oil testing Lab

What we can offer?

Chlorinated Fluid Screen (Askarels, Wecosol, tri- and tetra-chlorobenzenes, perchloroethylene)

Screen, Chlorinated Fluid

Test	Method
Water/RS	D 1533
Neut. No.	D 974
Furanic Compounds	D 5837

Silicones

Screen, 5-Part Silicone

Test	Method
Color/Visual	D 2129, D 1524
Water/RS	D 1533
Dielectric	D 877 or D 1816
Neut. No.	D 974
Spec. Gravity	D 1298

Screen, 6-Part Silicone

Test	Method
Color/Visual	D 2129, D 1524
Water/RS	D 1533
Dielectric	D 877 or D 1816
Neut. No.	D 974
Spec. Gravity	D 1298
Power Factor, 25°C	D 924

Screen, 7-Part Silicone

Test	Method
Color/Visual	D 2129, D 1524
Water/RS	D 1533
Dielectric	D 877 or D 1816
Neut. No.	D 974
Spec. Gravity	D 1298
Power Factor, 25°C	D 924
Power Factor, 100°C	D 924

Natural Esters

Screen, 8-Part Natural Ester

Test	Method
Color/Visual	D 1500, D 1524
Water/RS	D 1533
Dielectric	D 877 or D 1816 or D 1816 (2mm gap)
IFT	D 971
Neut. No.	D 974
Spec. Gravity	D 1298
Viscosity, 40°C	D 445
Power Factor, 25°C	D 924

Oil testing Lab

What we can offer?

Transformer Mineral Oil and High Molecular Weight Hydrocarbons

Screen, Mini

Test	Method
Water/RS	D 1533
IFT	D 971
Inhibitor	D 2668
Neut. No.	D 974

Screen, 4-Part/D 1816/PF at 25°C

Test	Method
Water/RS	D 1533
IFT	D 971
Dielectric	D 1816
Pow. Factor, 25°C	D 924

Screen, 4-Part/D 1816/PF at 100°C

Test	Method
Water/RS	D 1533
IFT	D 971
Dielectric	D 1816
Pow. Factor, 100°C	D 924

Screen, Mini with PCB

Test	Method
Water/RS	D 1533
IFT	D 971
Inhibitor	D 2668
Neut. No.	D 974
PCB	D 4059

Screen, 5-Part/D 1816

Test	Method
Color/Visual	D 1500, D 1524
Water/RS	D 1533
Dielectric	D 1816
Neut. No.	D 974
Spec. Gravity	D 1298

Screen, 5-Part/D 877

Test	Method
Color/Visual	D 1500, D 1524
Water/RS	D 1533
Dielectric	D 877
Neut. No.	D 974
Spec. Gravity	D 1298

Screen, 6-Part/D 877

Test	Method
Color/Visual	D 1500, D 1524
Water/RS	D 1533
Dielectric	D 877
IFT	D 971
Neut. No.	D 974
Spec. Gravity	D 1298

Screen, 6-Part/D 1816

Test	Method
Color/Visual	D 1500, D 1524
Water/RS	D 1533
Dielectric	D 1816
IFT	D 971
Neut. No.	D 974
Spec. Gravity	D 1298

Screen, 7-Part/D 877

Test	Method
Color/Visual	D 1500, D 1524
Water/RS	D 1533
Dielectric	D 877
IFT	D 971
Neut. No.	D 974
Spec. Gravity	D 1298
Pow. Factor, 25°C	D 924

Screen, 7-Part/D 1816

Test	Method
Color/Visual	D 1500, D 1524
Water/RS	D 1533
Dielectric	D 1816
IFT	D 971
Neut. No.	D 974
Spec. Gravity	D 1298
Pow. Factor, 25°C	D 924

Screen, 8-Part/D 1816

Test	Method
Color/Visual	D 1500, D 1524
Water/RS	D 1533
Dielectric	D 1816
IFT	D 971
Neut. No.	D 974
Spec. Gravity	D 1298
Pow. Factor, 25°C	D 924
Inhibitor or PF, 100°C	D 2668 or D 924

Oil testing Lab

What we can offer?

Screen, IEC

Test	Method
Color	ISO 2049, ASTM D 1500
Appearance	IEC 60296
Water/RS	IEC 60814
Dielectric	IEC 60156
IFT	ISO 6295, ASTM D 971
Acidity	IEC 62021
Dissipation Factor, 90°C	IEC 60247

Screen, Comprehensive

Test	Method
Color/Visual	D 1500, D 1524
Water/RS	D 1533
Dielectric	D 877
Dielectric	D 1816
IFT	D 971
Neut. No.	D 974
Pour Point	D 97
Spec. Gravity	D 1298
Inhibitor	D 2668
Viscosity at 40°C	D 445
Pow. Factor, 25°C	D 924
Pow. Factor, 100°C	D 924
PCB	D 4059

Screen, Expanded Comprehensive

Test	Method
Color/Visual	D 1500, D 1524
Water/RS	D 1533
Dielectric	D 877
Dielectric	D 1816
IFT	D 971
Neut. No.	D 974
Pour Point	D 97
Spec. Gravity	D 1298
Inhibitor	D 2668
Viscosity at 40°C	D 445
Pow. Factor, 25°C	D 924
Pow. Factor, 100°C	D 924
PCB	D 4059
Flash Point	D 92
Aniline Point	D 611
Corrosive Sulfur	D 1275B
PFVO	Doble
SFL	Doble

Screen, Doble Condition Assessment

Test	Method
Color/Visual	D 1500, D 1524
Water/RS	D 1533
Dielectric	D 877
Dielectric	D 1816
IFT	D 971
Neut. No.	D 974
Pour Point	D 97
Spec. Gravity	D 1298
Inhibitor	D 2668
Viscosity at 40°C	D 445
Pow. Factor, 25°C	D 924
Pow. Factor, 100°C	D 924
PCB	D 4059
Dissolved Metals	D 5185
Particulate Metals	Doble
Particle Count	D 6786
Corrosive Sulfur	D 1275B
Sulfur, CCD Test	Doble
Furanic Compounds	D 5837

Oil testing Lab

What we can offer?

Specification Testing

Doble TOPS (Mineral Oil)

Test	Method
Aniline Point	D 611
Color	D 1500
Visual	D 1524
Flash Point	D 92
IFT	D 971
Pour Point	D 97
Spec. Gravity	D 1298
Viscosity at 100°C	D 445
Viscosity at 40°C	D 445
Viscosity at 0°C	D 445
Dielectric	D 877
Dielectric	D 1816
Impulse Breakdown	D 3300
Gassing Tendency	D 2300
Power Factor, 25°C	D 924
Power Factor, 100°C	D 924
Oxidation Stability	D 2440
Oxidation Stability	D 2112
Inhibitor	D 2668
Corrosive Sulfur	D 1275B
Water/RS	D 1533
Neut. No.	D 974
PCB Content	D 4059
Furanic Compounds	D 5837
PFVO	Doble
SFL	Doble
Carbon Type	D 2140
Doble CCD Test	Doble
Dibenzyl Disulfide	Doble
Benzotriazole	Doble
Irgamet 39	Doble

ASTM D 3487 (Mineral Oil)

Test	Method
Aniline Point	D 611
Color	D 1500
Visual	D 1524
Flash Point	D 92
IFT	D 971
Pour Point	D 97
Spec. Gravity	D 1298
Viscosity at 100°C	D 445
Viscosity at 40°C	D 445
Viscosity at 0°C	D 445
Dielectric	D 877
Dielectric	D 1816
Impulse Breakdown	D 3300
Gassing Tendency	D 2300
Power Factor, 25°C	D 924
Power Factor, 100°C	D 924
Oxidation Stability	D 2440
Oxidation Stability	D 2112
Inhibitor	D 2668
Corrosive Sulfur	D 1275B
Water/RS	D 1533
Neut. No.	D 974
PCB Content	D 4059

IEC 60296 (Mineral Oils)

Test	Method
Viscosity, 40°C	ISO 3104
Viscosity, -30°C	ISO 3104
Pour Point	ISO 3016
Moisture	IEC 60814
Dielectric, received	IEC 60156
Dielectric, after filtering	IEC 60156
Density, 20°C	ISO 3675, ISO 12185
Dissipation Factor, 90°C	IEC 60247
Appearance	IEC 60296
Acidity	IEC 62021
IFT	ISO 6295
Total Sulfur	ISO 14596
Corrosive Sulfur	DIN 51 353
Antioxidant	IEC 60666, Sec. 5.1
2-Furfural	IEC 61698
Oxidation Stability	IEC 61125C
Gassing Tendency	IEC 60628
Flash Point	ISO 2719
PCA Content	IP 346
PCB Content	IEC 61619
Optional Tests	
ECT Test	CIGRE SC12
Baader Test	DIN 51 554
CCD Test	IEC 62535

Oil testing Lab

What we can offer?

Specialty Tests on Liquids and Solids Related to Corrosive Sulfur

TEST	Method	Amount Required
Copper Content in Insulating Paper or Pressboard	Doble	5 grams
Corrosive Sulfur in Oil (Copper Strip)	ASTM D 1275A or B	250 mL
Corrosive Sulfur in Oil (Silver Strip)	DIN 51 353	150 mL
Corrosive Sulfur in Oil (Copper Strip), discontinued	ISO 5662	250 mL
Covered Conductor Deposition, Doble	Doble	50 mL
Covered Conductor Deposition and Dielectric Strength of Paper	Doble	50 mL
Covered Conductor Deposition	IEC 62535	50 mL
Covered Conductor Deposition, ABB	ABB	50 mL
Dibenzyl Disulfide	Doble	5 mL
Elemental (free) Sulfur	UOP-286/387	80 mL
Inorganic Chlorides and Sulfates	ASTM D 878	100 mL
Mercaptan Sulfur	ASTM D 3227	50 mL
Passivator Determination (BTA/Irgamet 39®)	Doble	10 mL
Pilot Treatment for Removal of Corrosive Sulfur Compounds	Doble	1 to 2 liters
Treatment Experiments to Remove Corrosive Sulfur (other than above)	Doble	1 to 2 liters
SEM/EDX of Copper, Paper or other solids	Doble	Contact lab
Sulfur Content in Insulating Paper or Pressboard	Doble	5 grams
Corrosive Sulfur Presence in Insulating Paper or Pressboard with silver	Modified TAPPI T 444	100 cm^2
Sulfur Speciation	ASTM D 5623	30 mL
Tarnish Level of Copper Strip used in corrosive sulfur tests	ASTM D 130	N/A
Total Sulfur	ASTM D 4294 ISO 14596	10 mL

Oil testing Lab

What we can offer?

<u>TESTS Commonly Requested, Liquid Dielectrics</u>

Individual Tests for Mineral Oil

TEST	ASTM Number	Volume of* Liquid, mL
Dissolved Gas-in-oil analysis (DGA)	D 3612A or C	35
Color	D 1500	50
Dielectric Breakdown	D 877A or B	80
Dielectric Breakdown	D 1816	450
Furanic Compounds in Oil	D 5837	20
Inhibitor Content	D 2668	1
Interfacial Tension	D 971	25
Neutralization Number	D 974	20
Polychlorinated Biphenyls (PCBs) in Oil	D 4059	5
Power Factor @ 25°C	D 924	250 (1 liter**)
Power Factor @ 100°C	D 924	250 (1 liter**)
Power Factor @ 25°C & 100°C	D 924	250 (1 liter**)
Specific Gravity	D 1298	500
Viscosity @ 40°C	D 445	25
Visual Examination	D 1524	300
Water Content – Oil	D 1533	10

Oil Testing – Breakdown voltage

Brakedown voltage – We put oil in a small standardizrd holder – tank – and we apply voltage with fixed distance between electrodes

At one point in time (as we increase the voltage between electrodes) the oil will become conductive – there will be a spark between electrodes

We note that number and see if it is lower than allowed

DC Voltage testing

An older metod

Today we prefer to use TD (DF,PF) which is AC testing
Makes sense on PT with solid insulation while PT with liquid insulation will not have repeatable results (oil moves within the PT)

We generate certain voltage (5 kV) to measure what is called the Polarization Index, or PI, which is a ratio of the megohms after 10 minutes divided by the megohms after 1 minute

Less than 1	Dangerous
10 – 1.1	Poor
1.1 – 1.25	Questionable
1.25 – 2.0	Fair

DC Voltage testing

Dielectric Absorption Ratio (DAR)

Ratio of the megohms at 1 minute divided by the megohms at 30 seconds.
When the measured leakage current stabilizes within 1 minute, operators typically use the DAR Test.

If this happens, the 10 minute PI test is useless because the ratio is 1.
Values for DAR and PI commonly used in the literature and by manufacturers of test equipment for assessing the insulation conditions are:

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Next ALTANOVA **WEBINARS**

19 Apr — Offline testing of underground cables with high level intro - APAC

4 Mag — Las diferentes herramientas de diagnóstico del Análisis de Gases Disueltos (DGA), cuándo / cómo usarlas de manera eficiente

10 Mag — Managing and visualizing transformer oil test data - EMEA

17 Mag — Managing and visualizing transformer oil test data - APAC

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Thank you for your attention ☺

Andrej Sepcic
RSM
asepcic@doble.com