Sweep Frequency Response Analyzer

PFRS-25

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Agenda

- Introduction to Transformer Diagnostics
- FRA diagnostic methods
- Basic FRA theory
- Test Specifications
- Hardware
- Test Cases
- Summary

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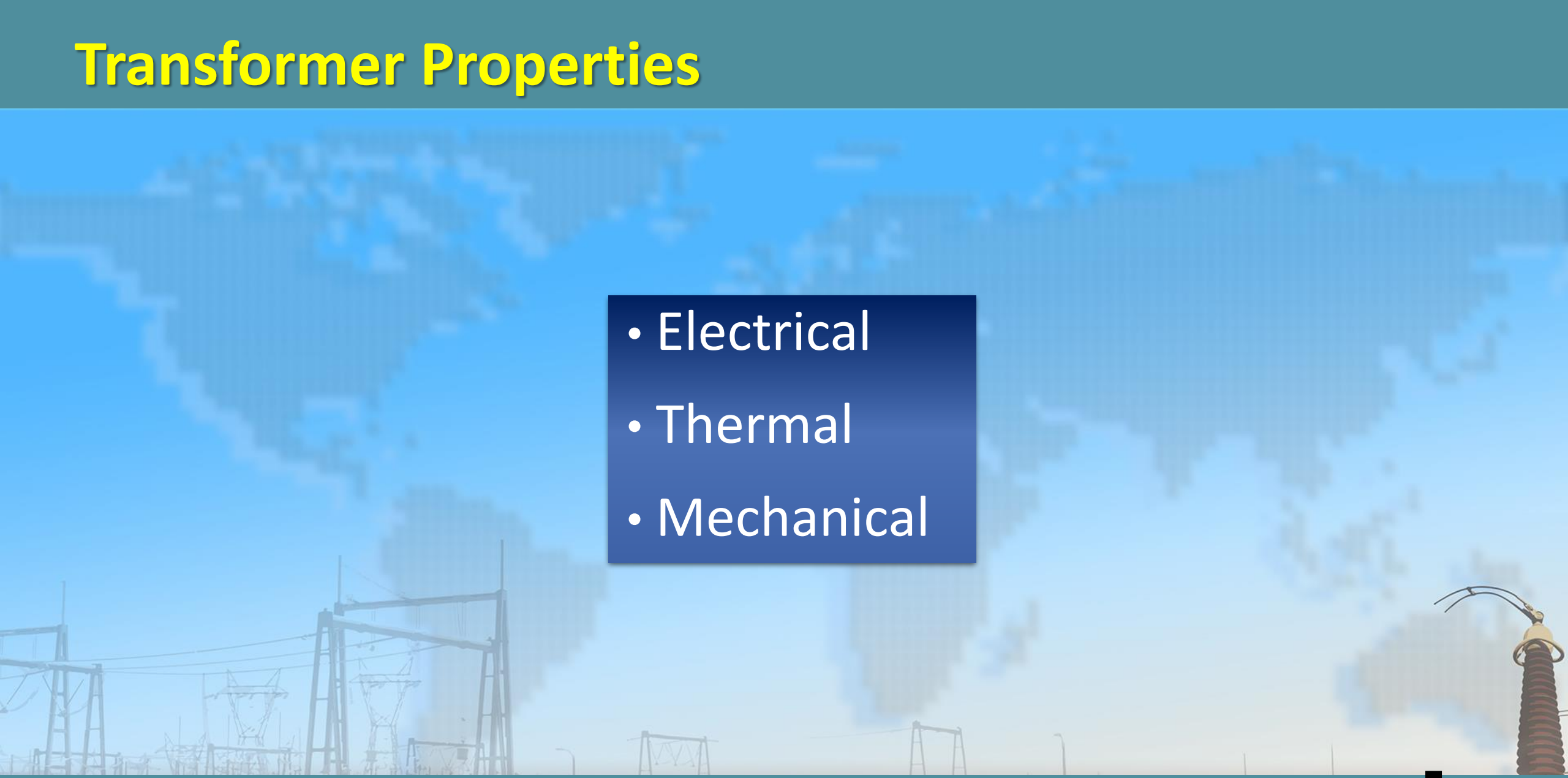
Transformer Properties

- Electrical
- Thermal
- Mechanical



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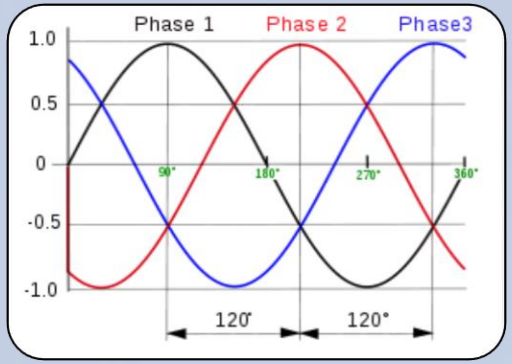
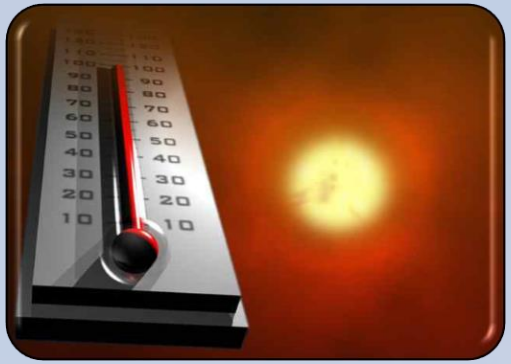
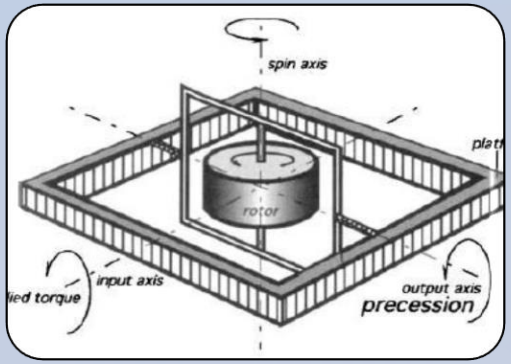
Transformer Diagnostics







Electrical

Insulation resistance

TTR

Exciting Current

Capacitance

Power Factor

DGA

Thermal

Winding Resistance

Thermal Imaging

DGA

Mechanical

SFRA

Leakage Reactance

Capacitance

Exciting Current

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Mechanical Tests

- Frequency Response Analysis (FRA)
- Leakage Reactance
- Capacitance
- Excitation Current (Core Integrity)

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FRA: What is it?

FRA (Frequency Response Analyzer)	• Tool to investigate the mechanical integrity of the transformer.
Useful Tool	• Acceptance, Commissioning, Relocation, Post Fault, or as a Asset Management tool
Quality Control Tool	• For the transformer manufacturer • Large amount of manual labor in building transformer

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FRA Basics

1. FRA of a winding is a function of the RLC network of the windings related to the physical geometry

2. Mechanical changes within the test specimen alter the RLC network, and in turn can alter the frequency response

3. The major transformer resonances are in the range from a few kHz to a few MHz, depending on the voltage and type of the winding

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What is FRA?

1. A simple measurement
2. Inject a voltage at one end of a winding & See what comes out at the other end
3. Repeat for different frequencies
4. Plot results for analysis, trending & comparison (correlation IEEE C57.149-2012)

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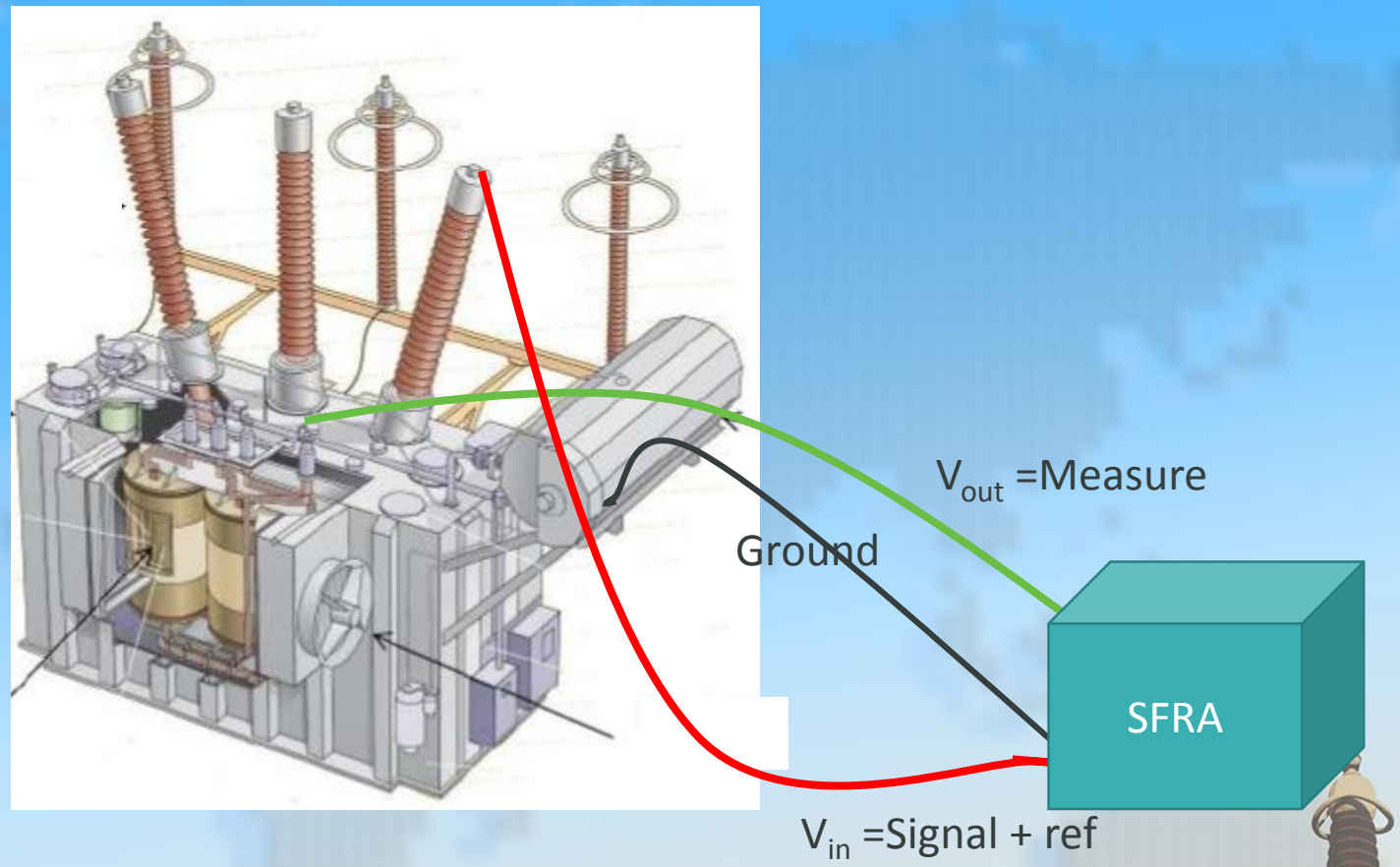
FRA Test

- Injects voltage of different frequencies in to the winding of transformer : Vin
- Measures the voltage at the other end of winding of the transformer : Vout
- Plots the Mag (dB)= $20*\text{Log}_{10}$ Vout/Vin



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Typical FRA Measurements: 10 Hz to 2 MHz

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FRA Trace: Transformer Diagnostics

Transformer elements visible in different parts of the sweep

Low frequencies

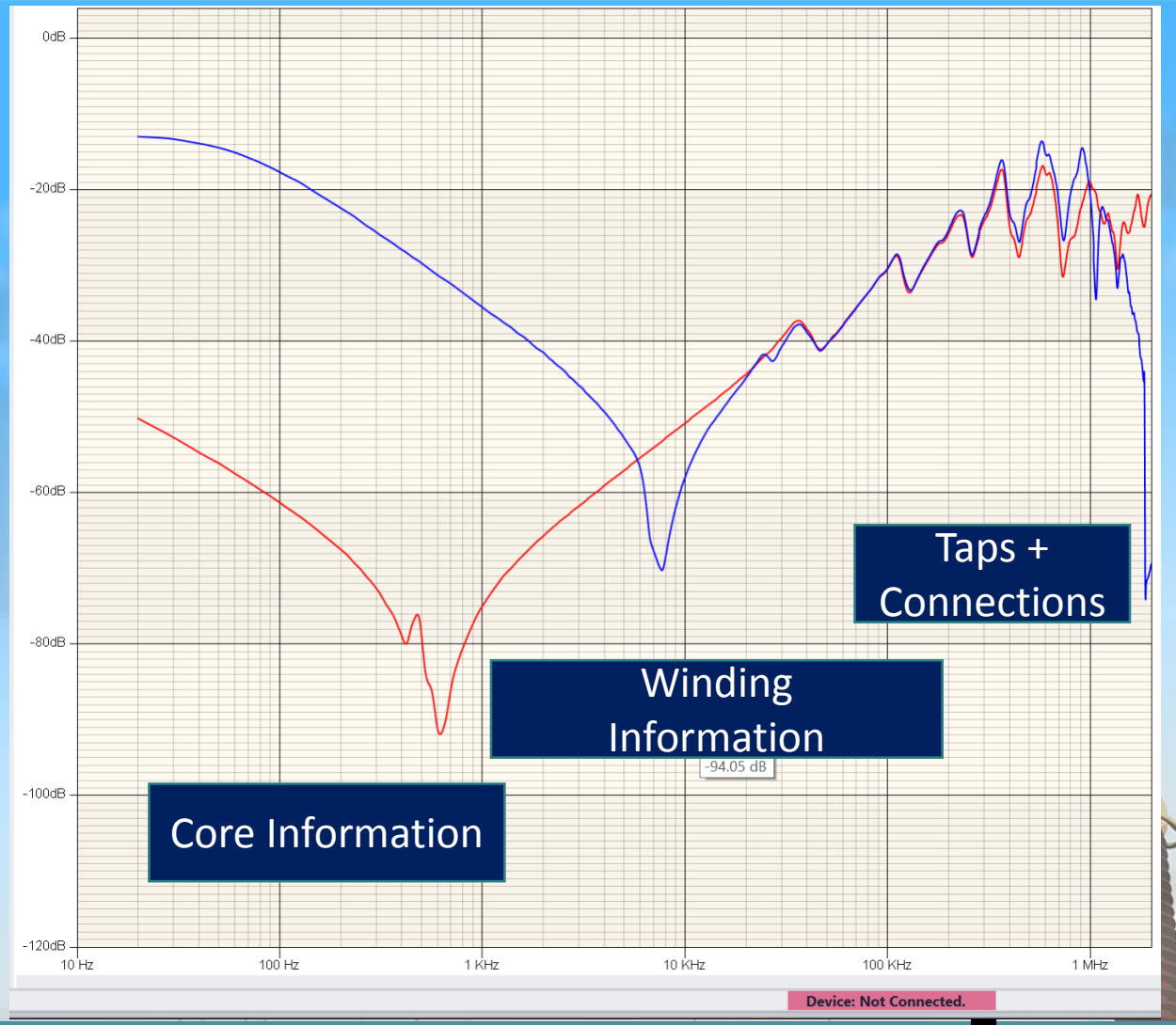
- Core problems
- Shorted or open windings

Medium frequencies

- Winding deformations

High Frequencies

- Connections
- Taps and other connection changes



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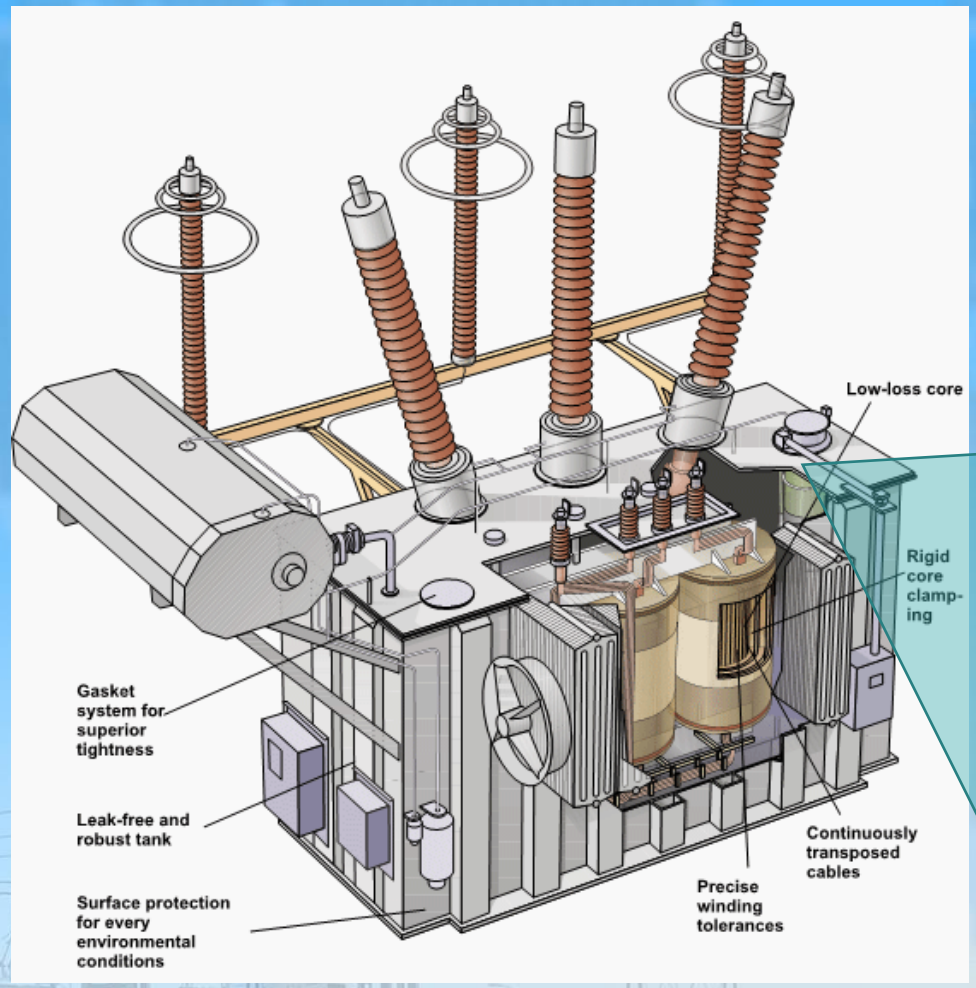
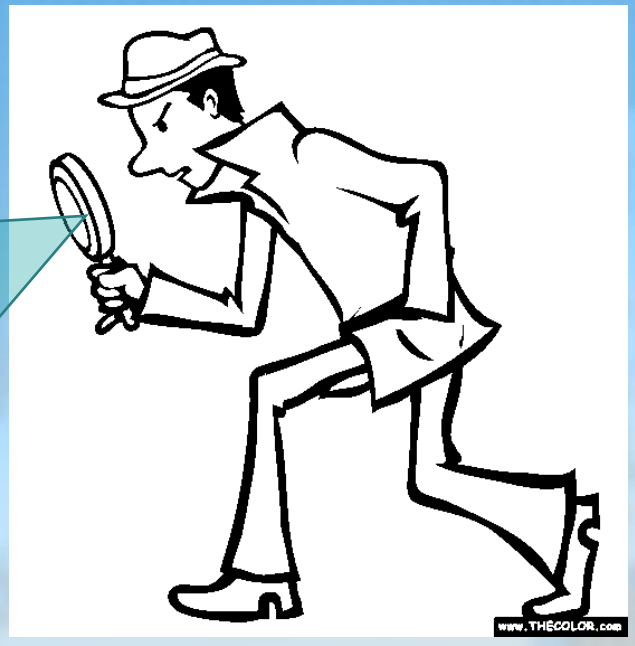
FRA: Examining a Transformer





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FRA: Motivation

- Transformer in the service experiences more through faults & some time internal faults
- Every time transformer during the through fault, its mechanical strength reduces due to forces of short circuit current
- Over a period of time, the mechanical holding system weakens
- Subsequent faults can destroy the transformer

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FRA: Purpose

1. Changes in the frequency response detected, we can diagnose the mechanical changes

2. Electrical fault on the transformer causes winding movement, we can see the changes in the frequency response

3. Comparing the FRA results prior to the fault and after the fault, we can see the differences in the test results.

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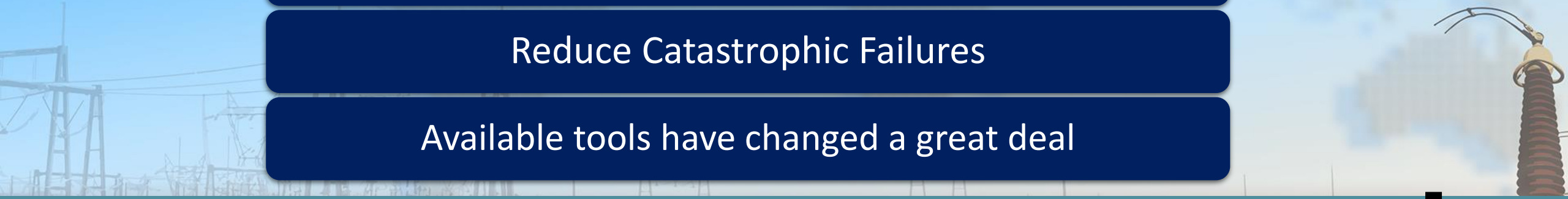
FRA Tests: When and Why

- Acceptance and Commissioning
- Establish a Baseline
- Assess Condition after Electrical Disturbance
- Assess Condition after a Relocation
- Asset Management - Ranking and Prioritizing
- Reduce Catastrophic Failures
- Available tools have changed a great deal



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Rules for Acquiring Good FRA Measurements

Cables	• Shielded high-frequency cables terminated in their matching characteristic impedance
Grounding	• Grounding leads to be as short as possible (without coiling the leads) & use flat braid (20 mm width min.) instead of wire.
Connectors	• Use good connectors for attaching the test leads to terminals.
Test Set UP	• Should be the same for the reference & repeat tests
Other Leads	• Disconnect all unused cables from the bushing terminal.

From : CIGRE WG A2.26

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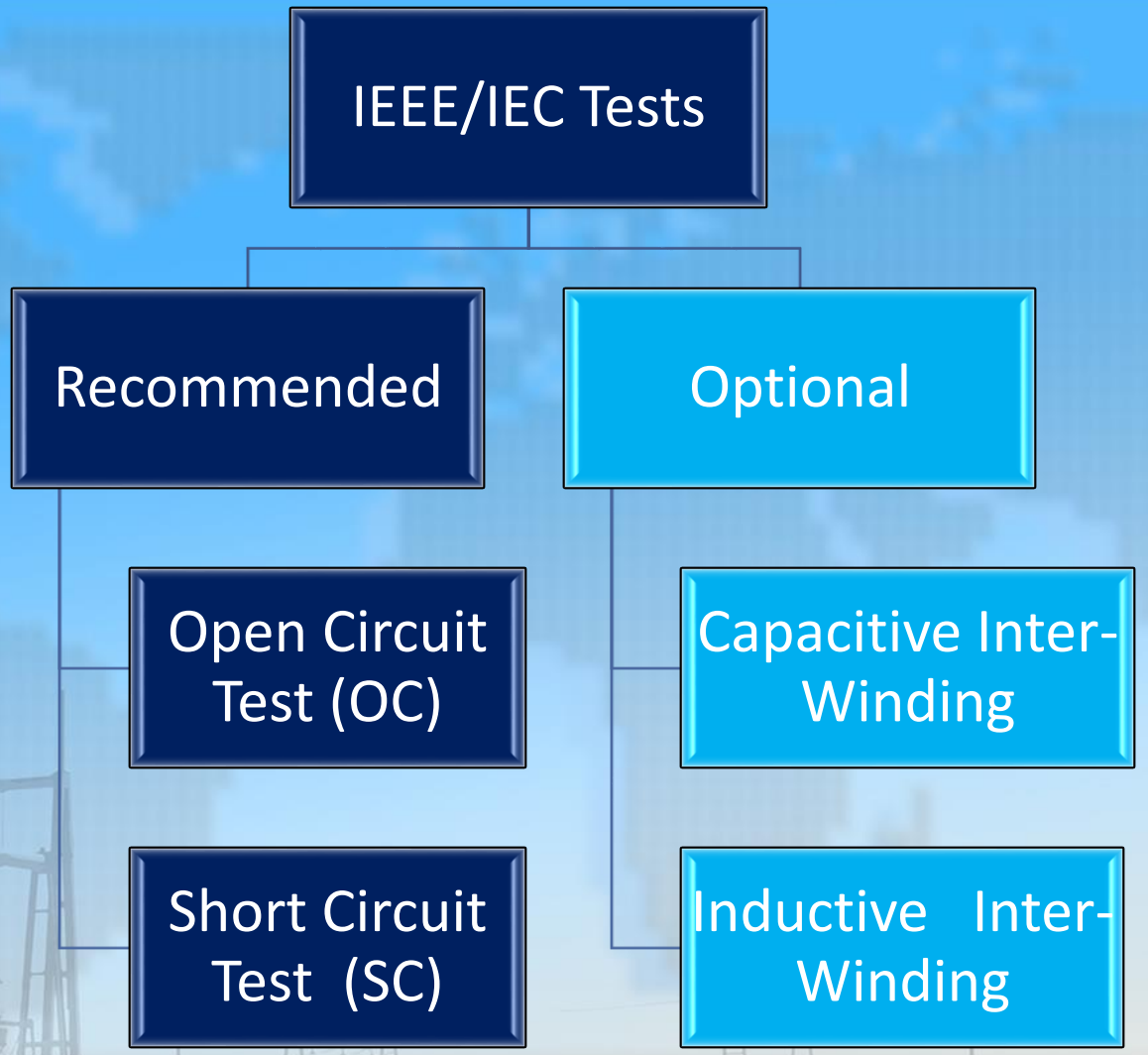
Tests: FRA



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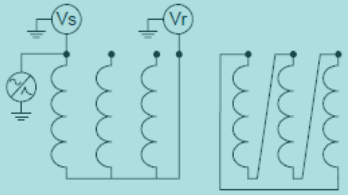
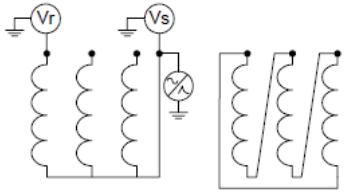
FRA Test: CIGRE Working Group WG A2.26

FRA test types defined by CIGRE WG A2.26

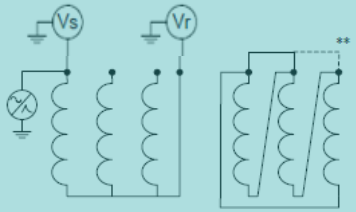
(a) End-to-end (source on phase terminal)



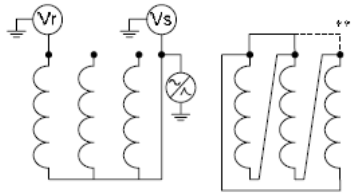
(b) End-to-end (source on neutral terminal)



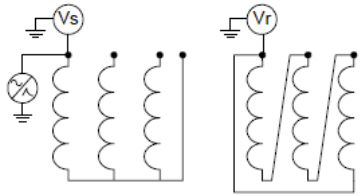
(c) End-to-end short-circuit (source on phase te



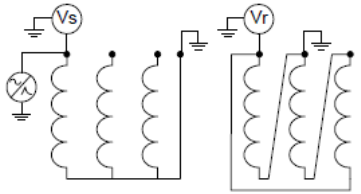
(d) End-to-end short-circuit (source on neutral terminal)



(e) Capacitive inter-winding



(f) Inductive inter-winding



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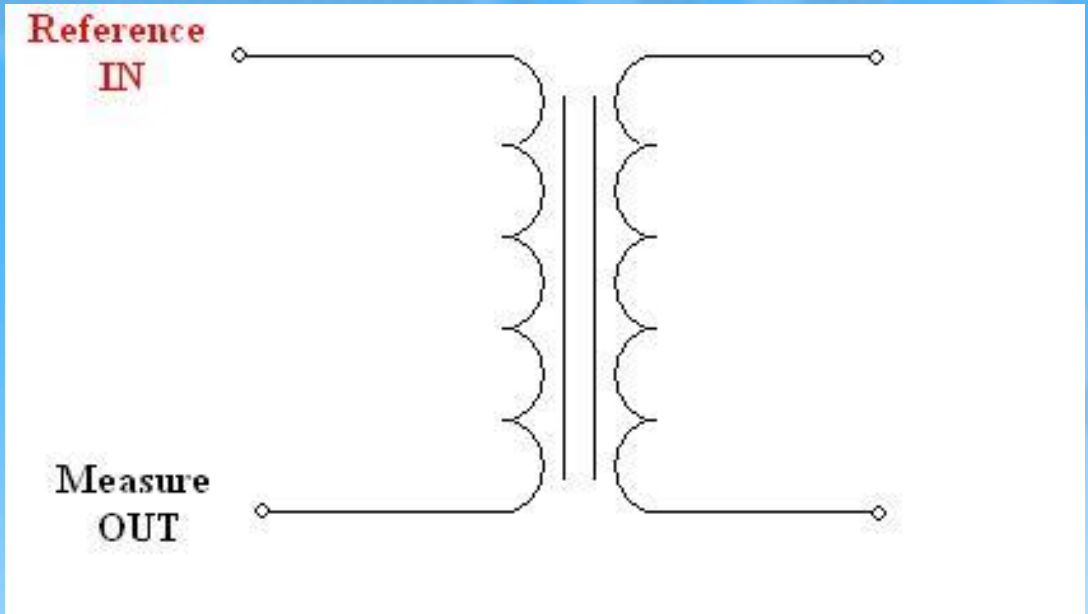
Open Circuit Test



- Open Circuit Test : “Reference IN” at one end of a winding and “Measure Out” at another end with all other terminals floating.
- Open Circuit Self-Admittance tests : Primarily influenced by the core properties at or around the fundamental power frequency

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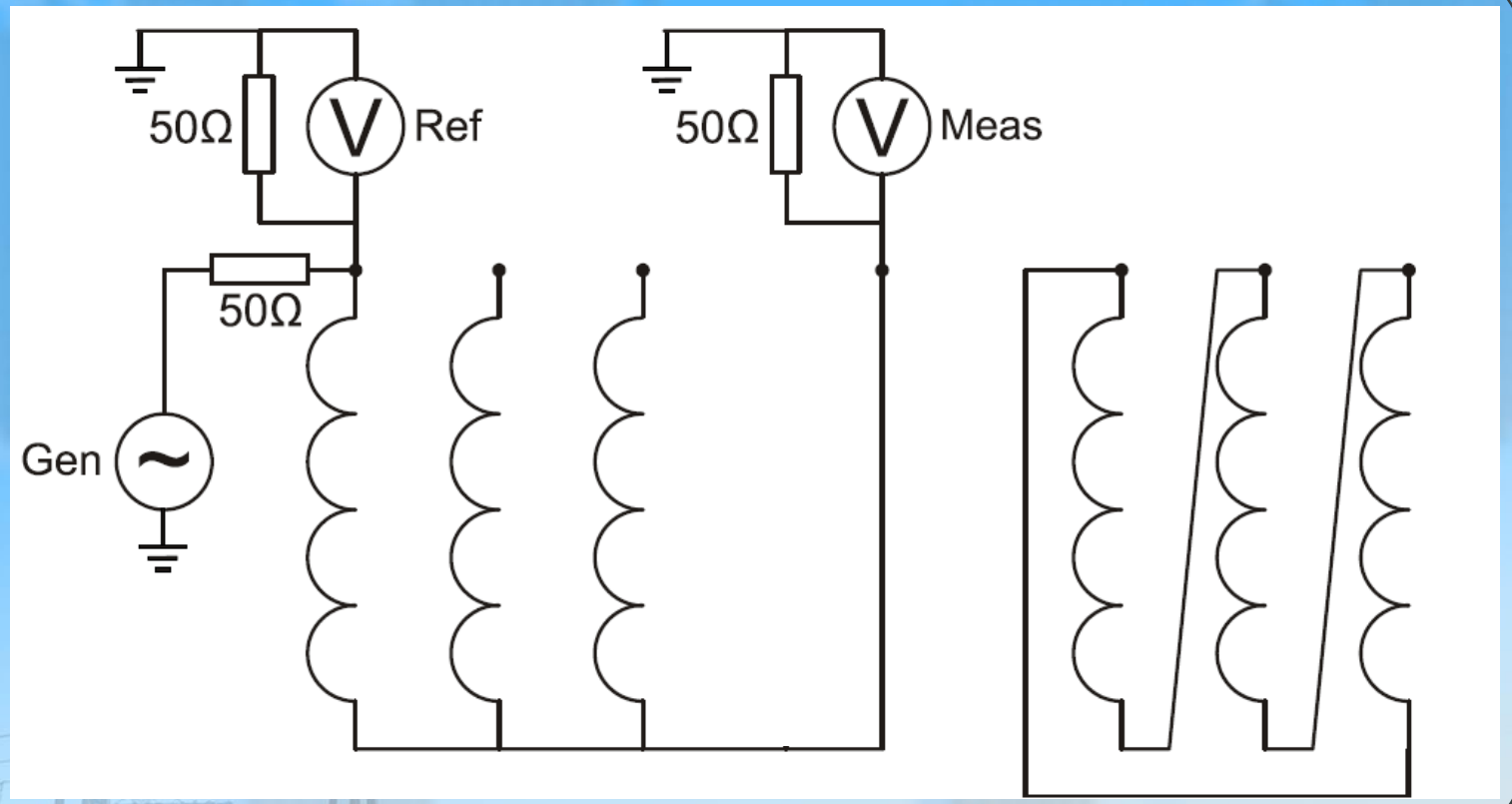
Open Circuit Test Connections



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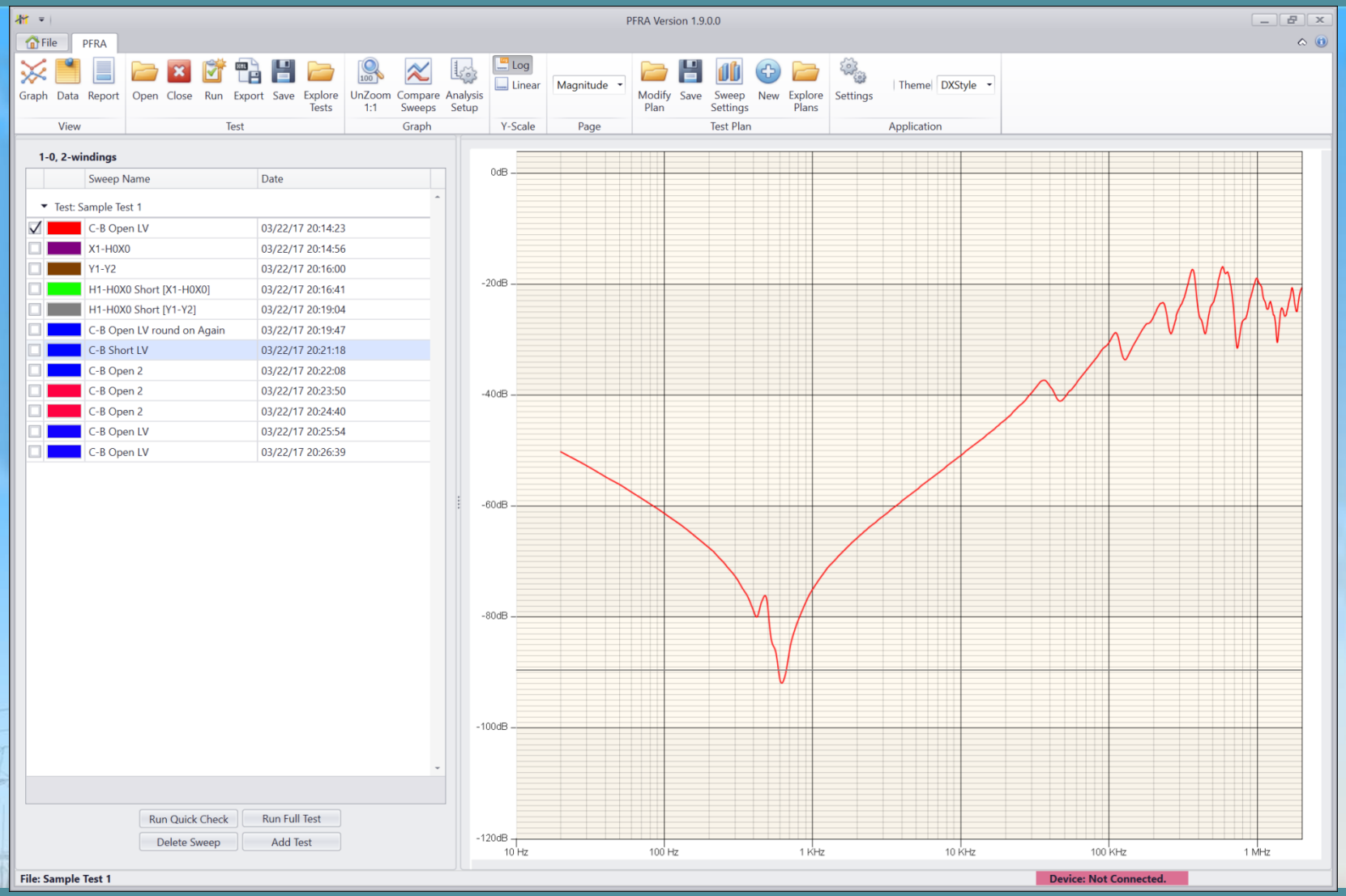
Open Circuit Test (OC): HV Winding



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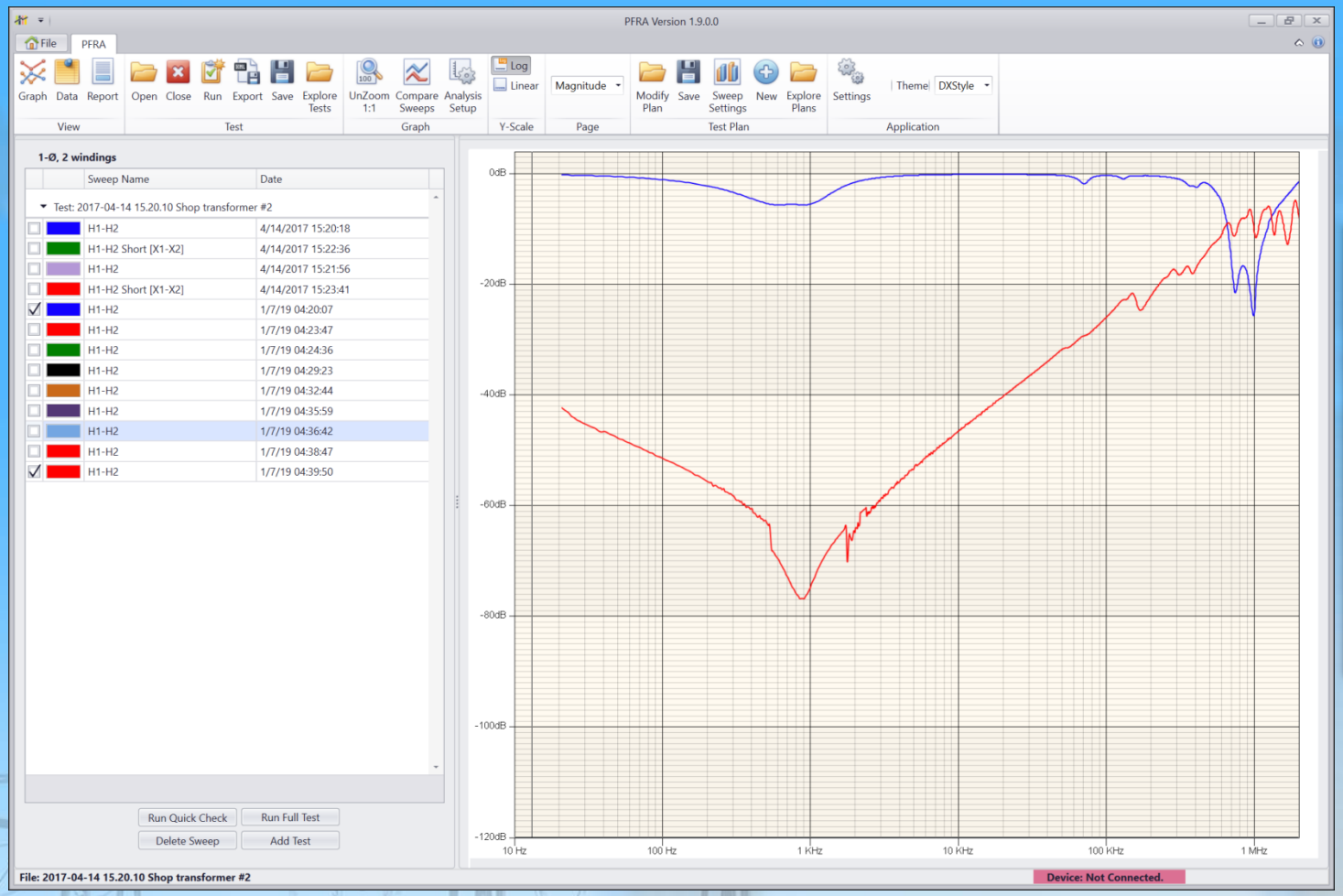
Transformer Fingerprint



- End to End (OC) tests characterizes magnetizing impendence in the low frequency region
- Each winding separately can be examined
- Common test due to simplicity

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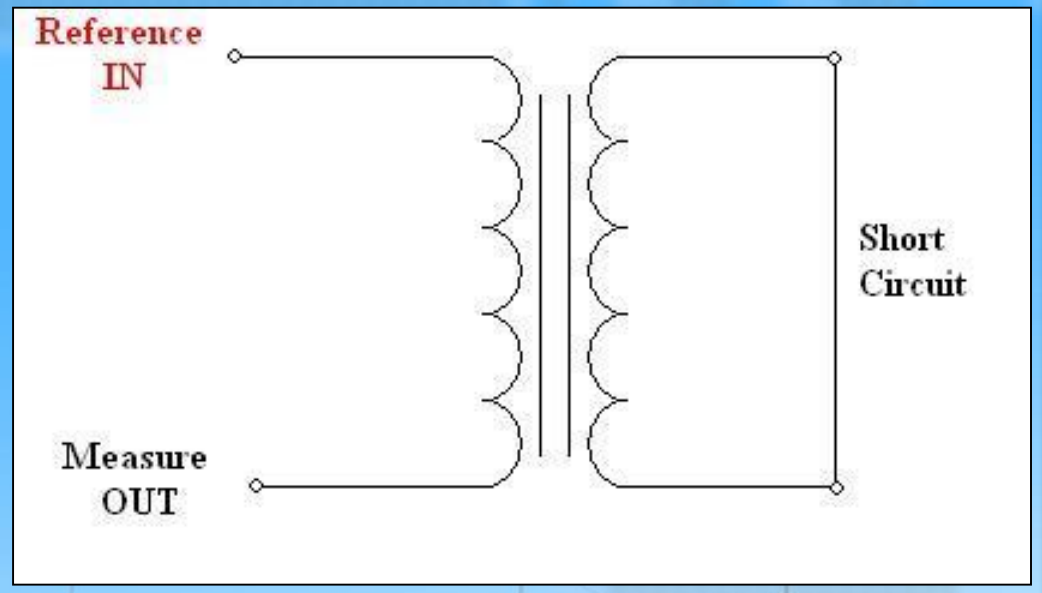
Short Circuit Test (SC)



- A Short Circuit Self-Admittance measurement: ”Reference In” at one end of a high voltage winding to “Measure OUT” at the other end with low voltage winding shorted.
- The Short Circuit Self-Admittance test isolates the winding impedance from the core effects properties at or around the fundamental power frequency.

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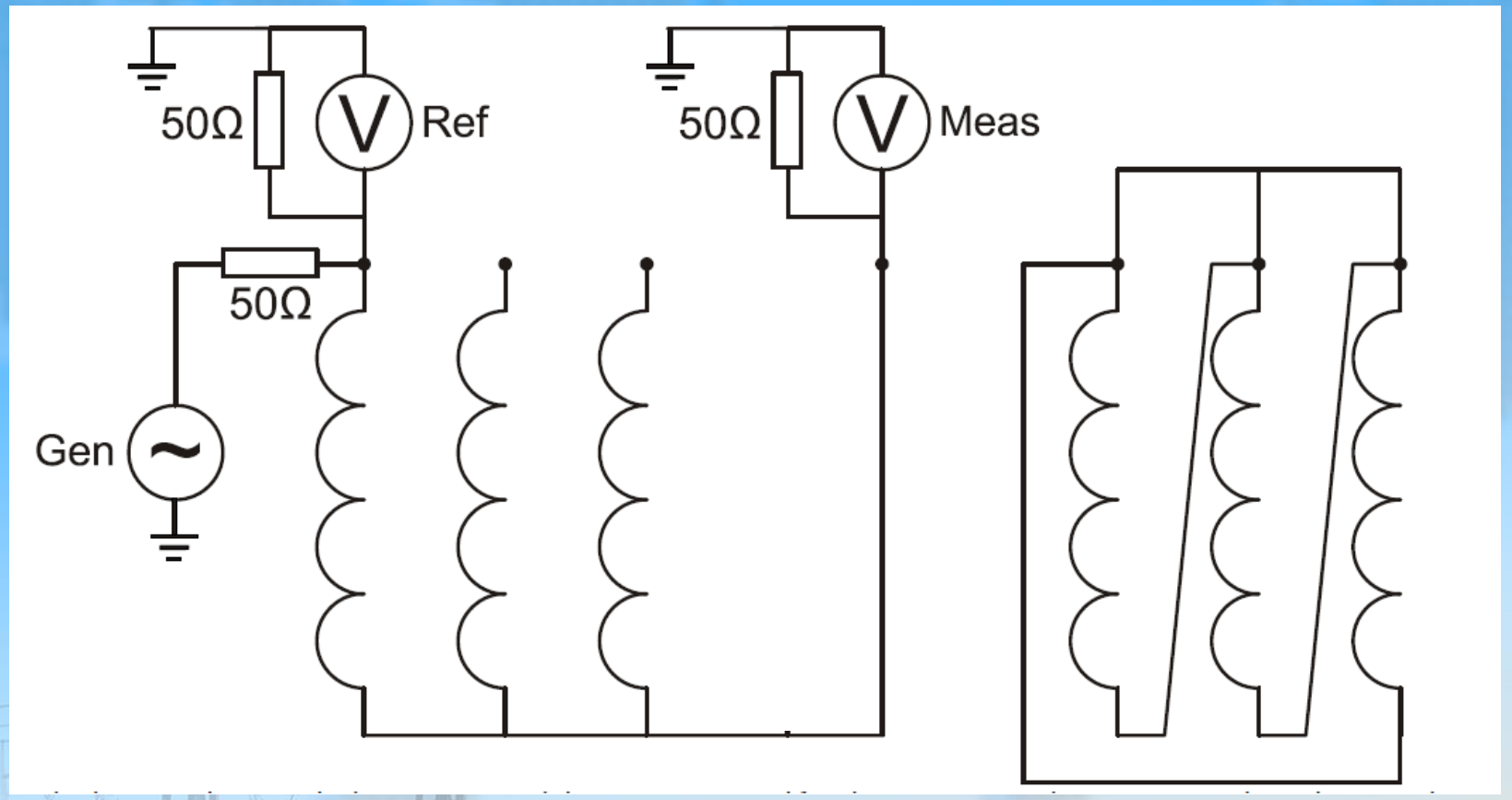
Short Circuit Test (SC) Connections



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Short Circuit Sweep Vs. Open Circuit Sweep

- Blue Trace Open circuit test
- Red Trace Short Circuit test
- Higher freq. identical response
- SC Test : Isolates effect of core

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Test Cases: FRA Diagnostics

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Diagnostics

Winding deformation	• Presence of an additional peak • Loss of resonance peak • Shift in frequency for the existing resonance peak
Winding looseness	• Increase in magnitude compared to original trace • Significant Increase in phase angle trace
Magnetized core	• Residual magnetization lowers inductance hence shift of resonance to right at lower freq
Second core ground	• Absence of resonance at lower frequency

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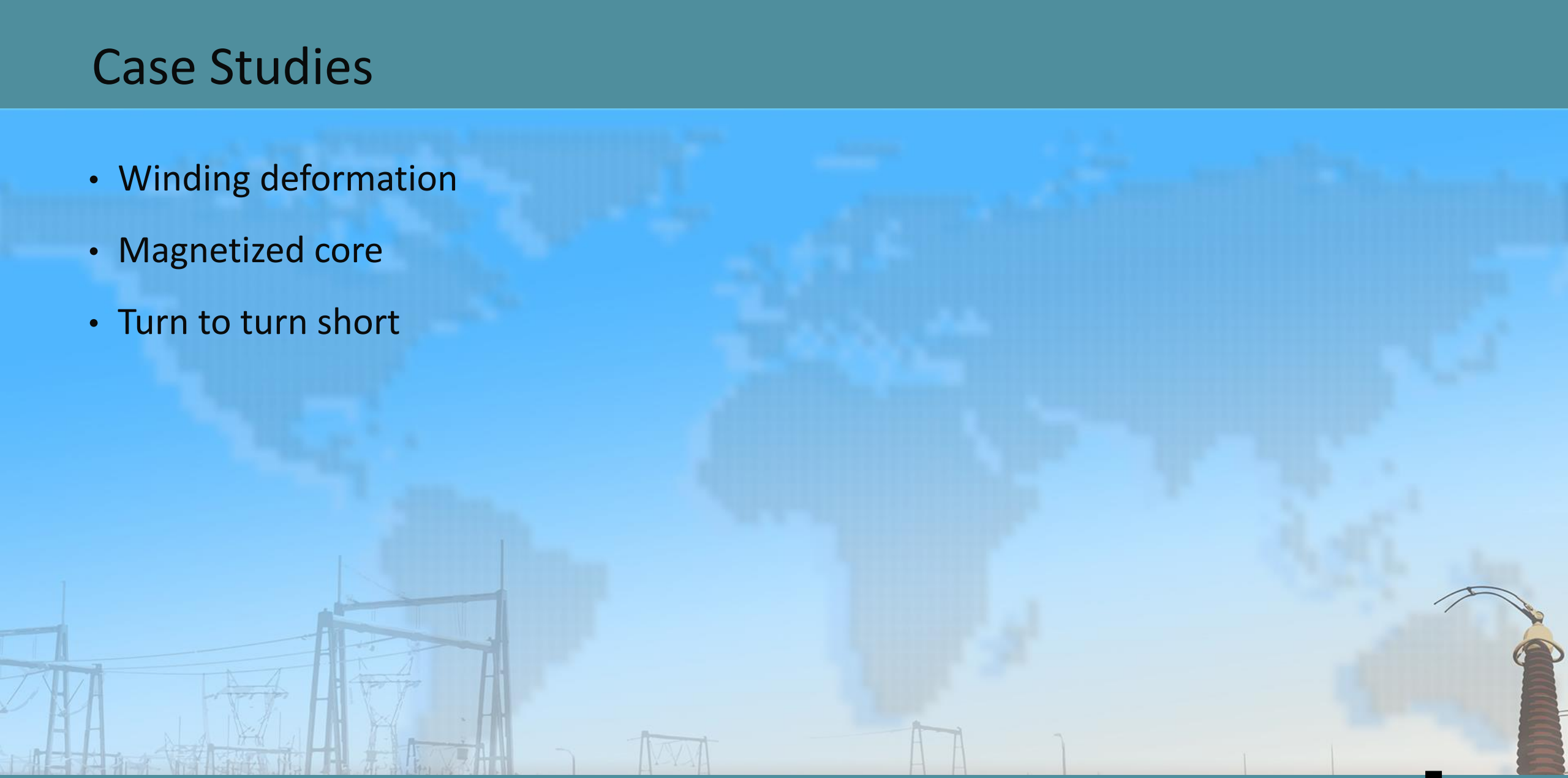
Case Studies

- Winding deformation
- Magnetized core
- Turn to turn short



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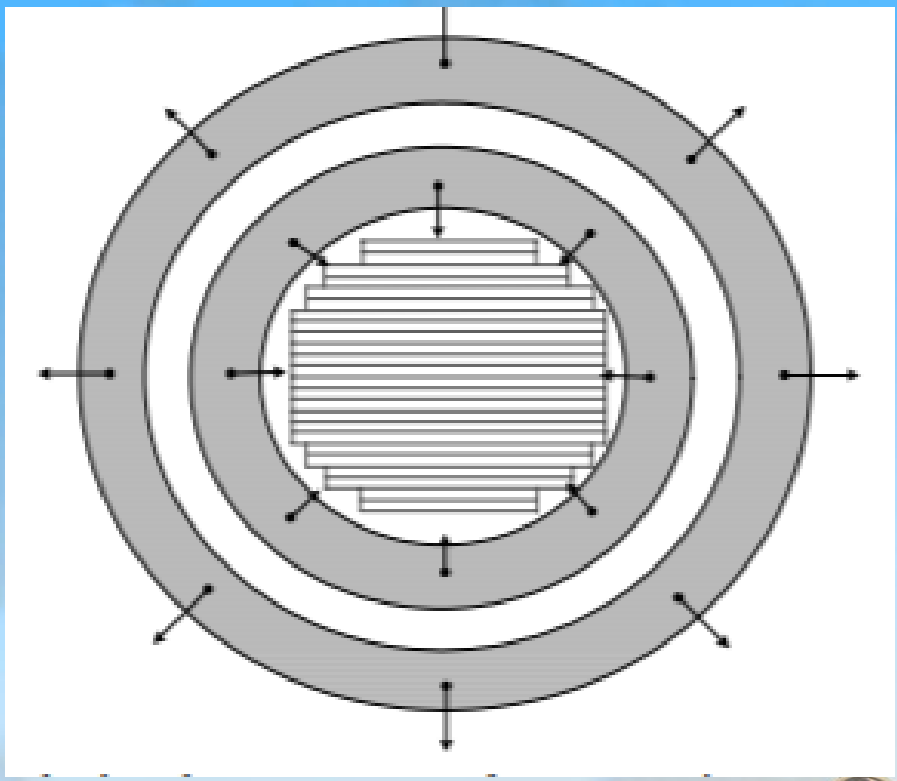
Winding Deformation : Hoop Buckling

- Short circuit current in the transformer produces hoop stresses on the windings.
- Inner windings (LV) produces compressive forces while outer winding (HV) produces hoop stress
- The force is proportional to $(NI)^2$
- Short circuit current also produces axial forces trying to expand winding axially
- These stresses deforms the windings and weakens the holding structure
- RLC components changes once the windings are deformed



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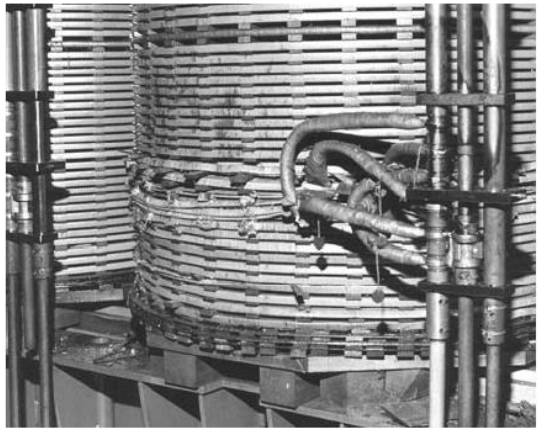
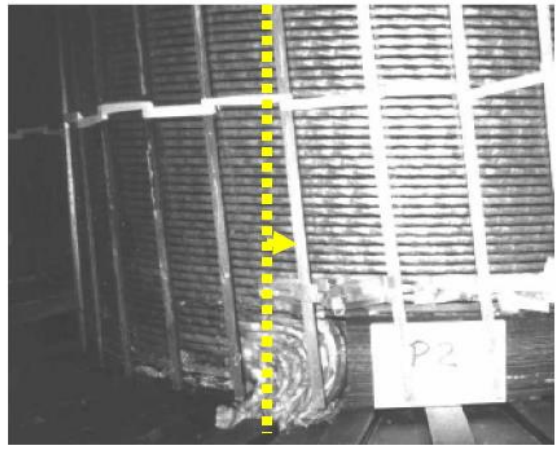
Winding Deformations

- Through fault current some time 20 times the load current, creates axial and radial forces which can deform the windings
- The typical results of these forces :

Radial Buckling



Conductor tilting



Axial Shifting

End winding support collapse

FRA : Tool to diagnose these conditions with repeatability of results and good sensitivity
Easy to analyze the results in frequency domain

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Case study : 1998, 3 Ph. 33kV/.6.9 kV , 4.5 MVA

- Background
  - Tfr was in normal operation
  - Routine test carried out indicated presence of hot spot in the transformer
  - Sister unit has a failure history
- SFRA, C & PF and winding resistance test performed
  - All other test did not indicate any major problem
  - SFRA test was performed

Perticular	ppm
Methane CH4	341
Ethylene C2H4	1409
Ethane C2H6	120
Acetylene C2H2	43
Hydrogen H2	5
Carbon Monoxide CO	4
Carbon-di-oxide CO2	1175

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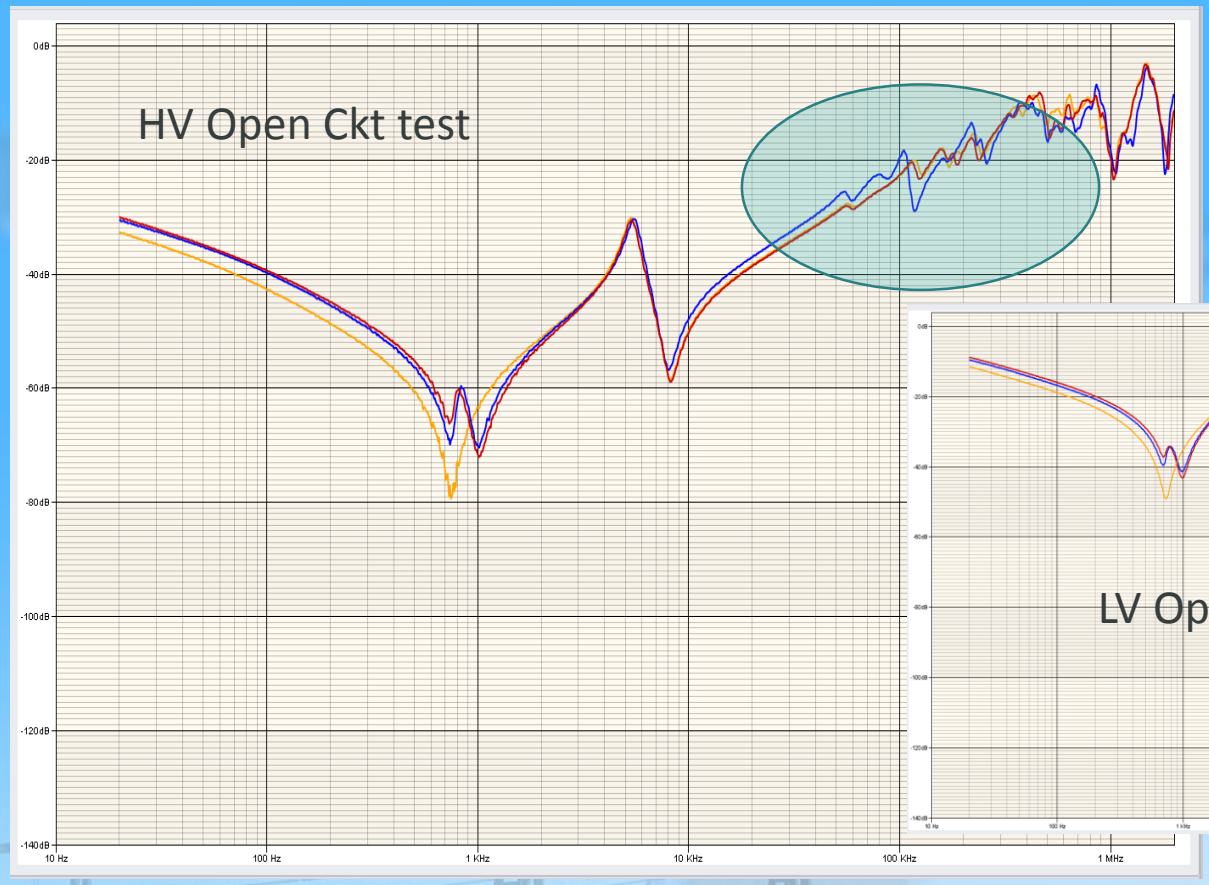
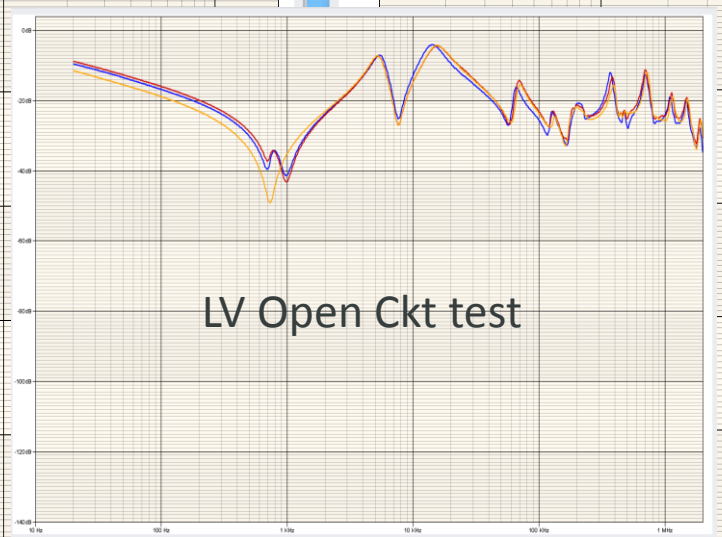
Winding Deformation Case





Open Circuit Test shows winding shift left (Blue trace)
Leakage reactance results showed a problem in the phase

Short Circuit Test shows increased impedance in one phase

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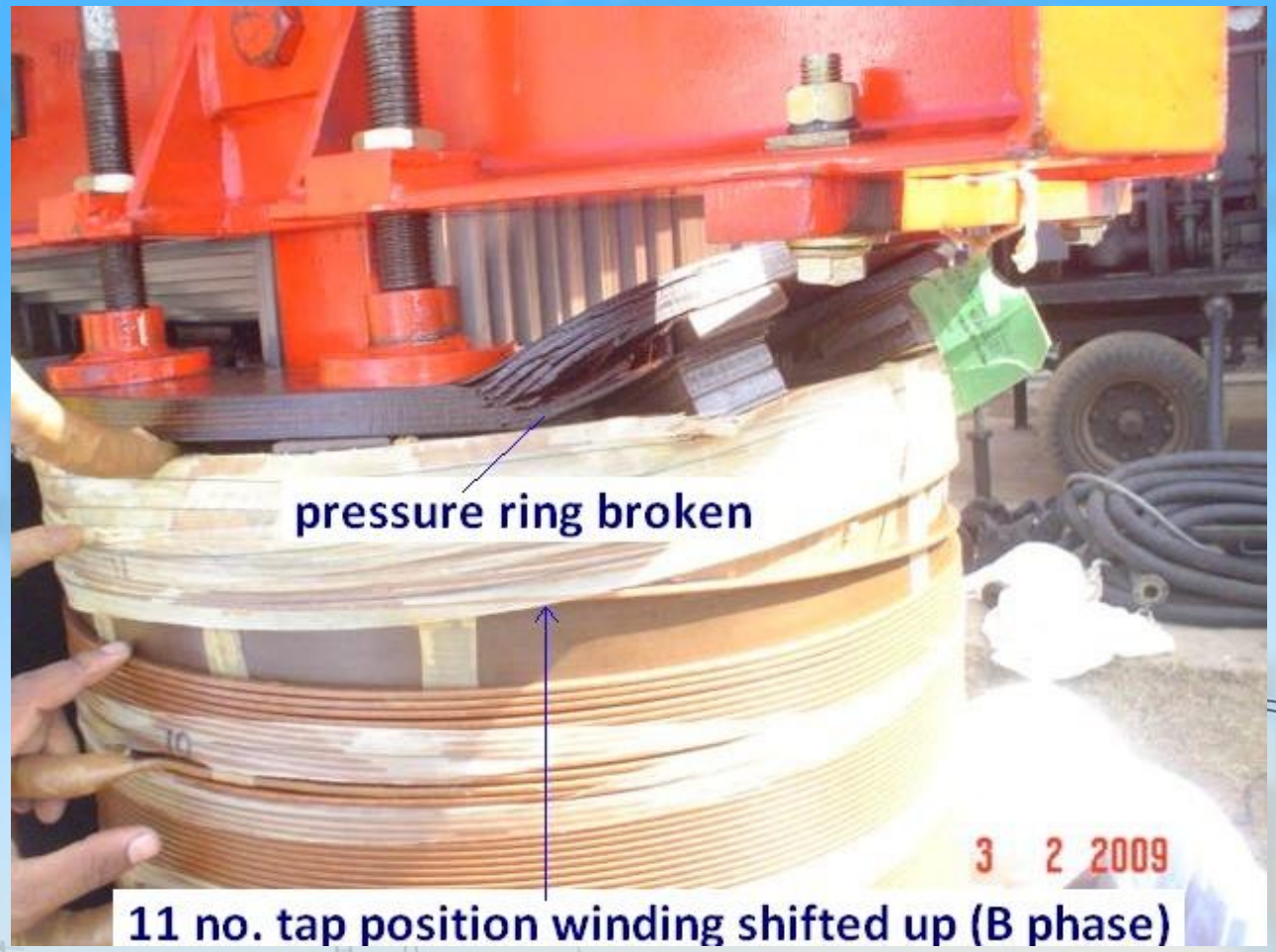
Winding Deformations

- HV phase is showing variations at 100KHz
- LV phase is moving towards lower frequency
- Increased LC components indicating minor winding deformation and/or hoop buckling
- Recommended that the transformer be internally inspected



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Winding Deformations

- Core clamping bolt and nut got welded to the core created hot spot
- Indicated by DGA

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Bulk Winding Deformation

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Case Study : Core Magnetization

- Single phase GSU : 630 MVA 420 kV/21 kV
- Unit Tripped on flash over on C phase
  - Differential protection operated and fault current recorded was 36KA
- SFRA test performed
  - 3 other sister transformers were also tested (3 ph & I spare)

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Flash Over

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SFRA : 4 identical Units

- Core resonances are shifted to right
- Reason : core magnetization
- All other windings matches well
- No damage to the transformer
- Confirmed by SFRA
- Demagnetize the transformer to put it back in service

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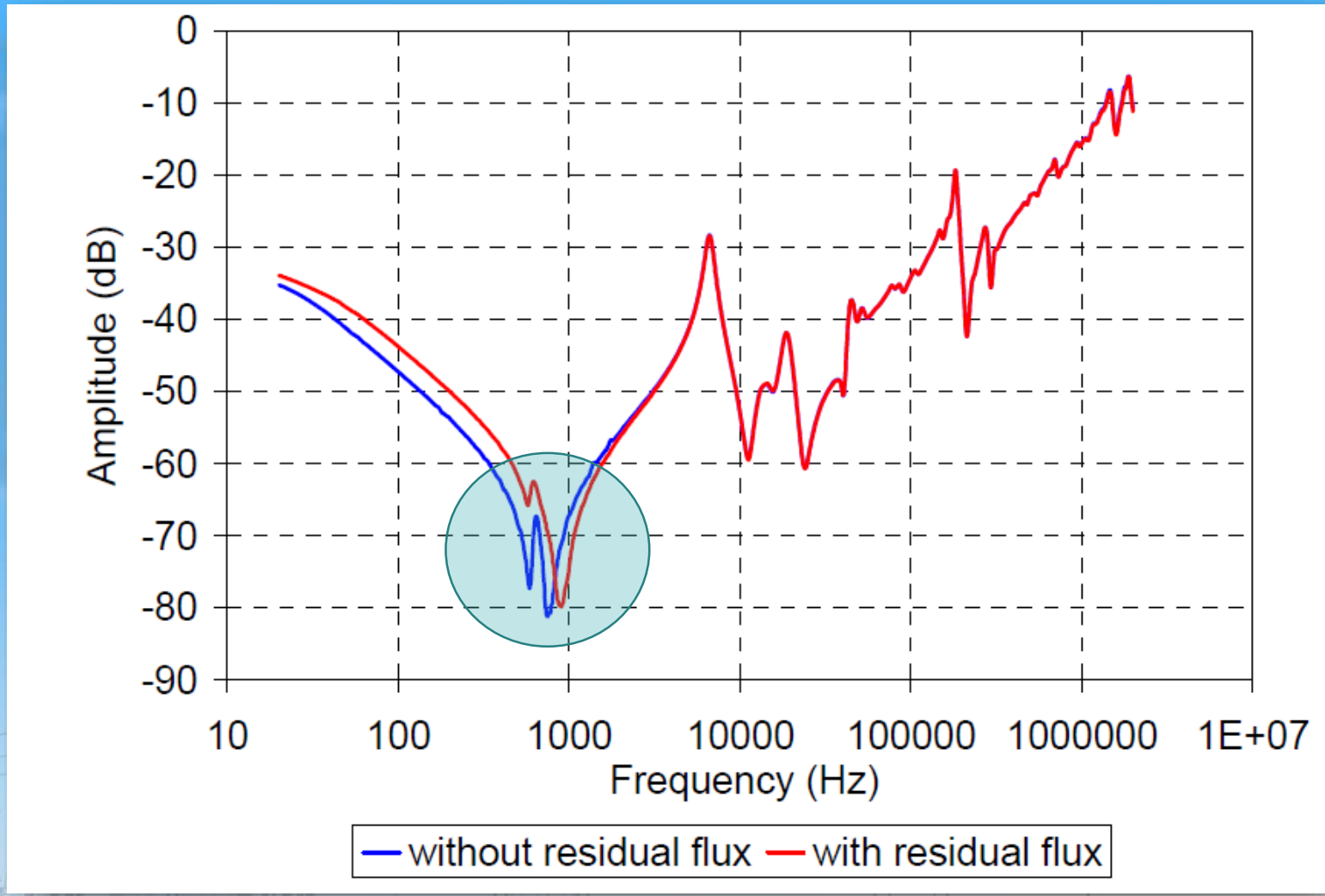
Core Residual Magnetization



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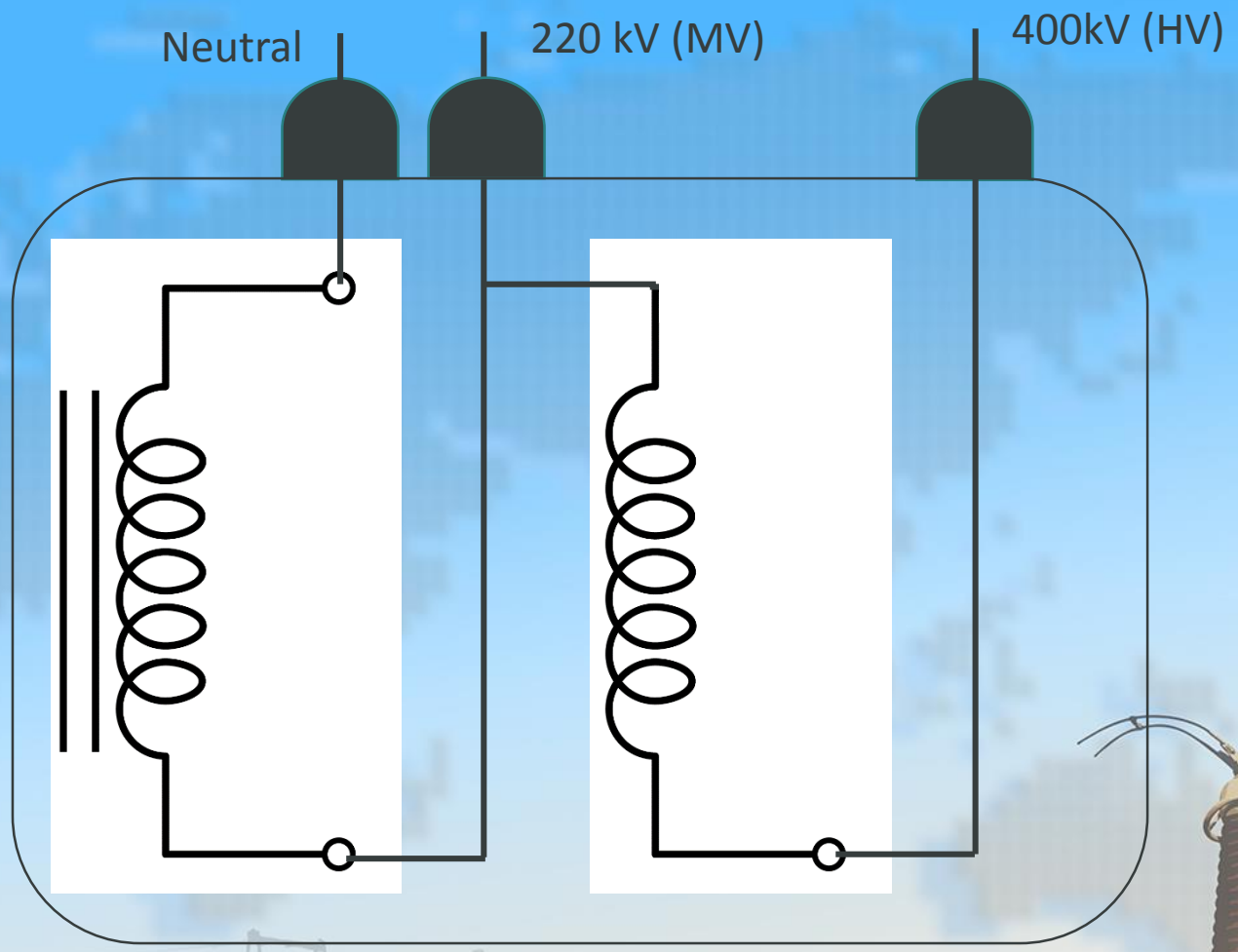
Case Study : Turn to Turn Short

- 1997 400/220/33 kV auto transformer
- 167 MVA single phase auto transformer
- Protection operated
  - Pressure Relief Valve & Buchholz relay
  - Over current relay
- Test Performed

  -SFRA, Capacitance & PF, Winding Resistance, DGA, Excitation Current, Ratio

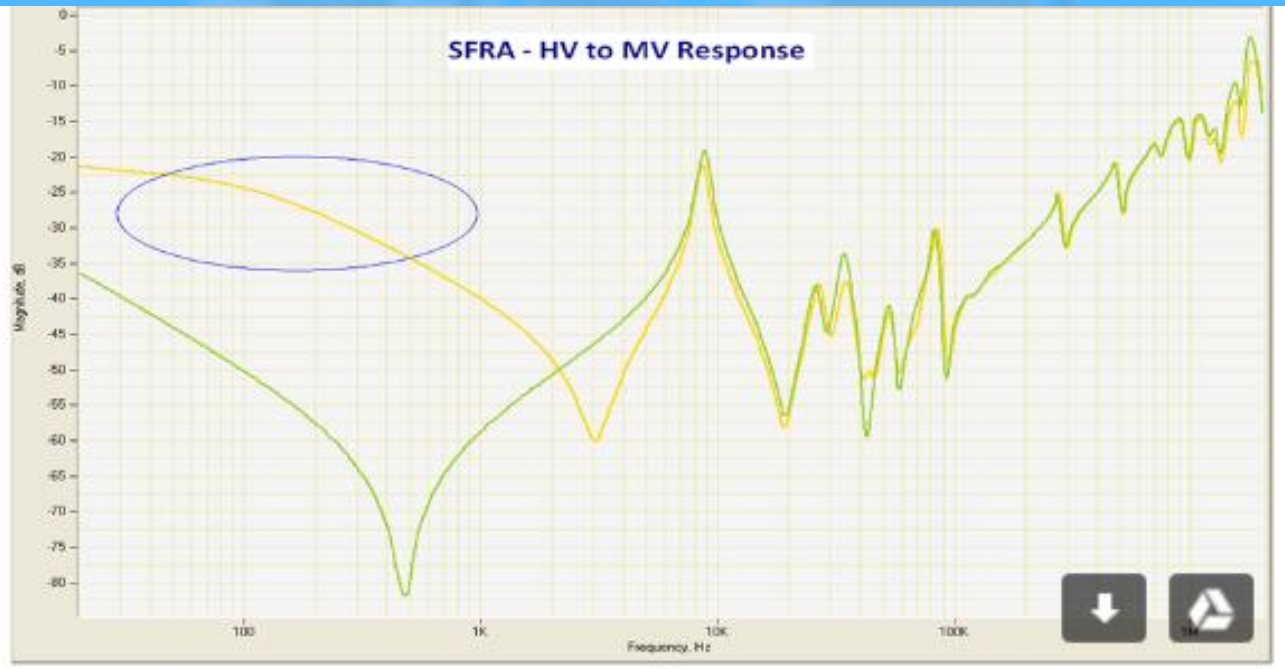


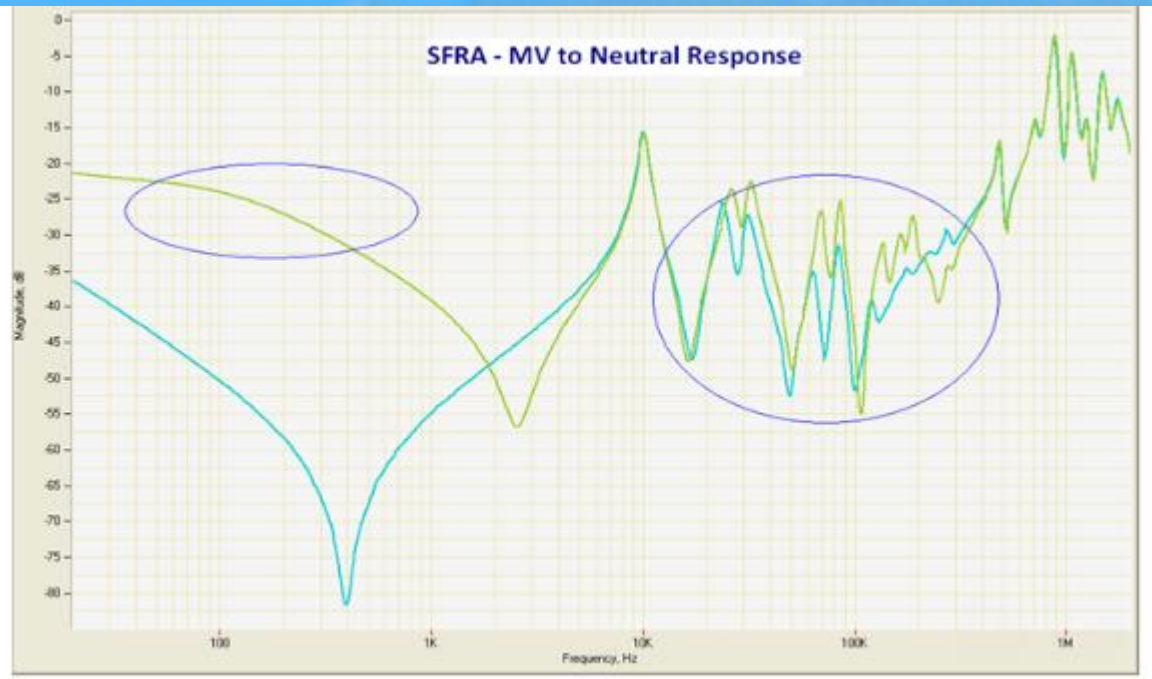
DGA Data

Perticular	ppm
Methane CH4	46
Ethylene C2H4	94
Ethane C2H6	10
Acetylene C2H2	68
Hydrogen H2	131
Carbon Monoxide CO	315
Carbon-di-oxide CO2	4265
Oxygen O2	6105
Nitrogen N2	25020

Presence of Acetylene & Hydrogen gas indicative of a problem

Turn to Turn Fault : Open Circuit Test





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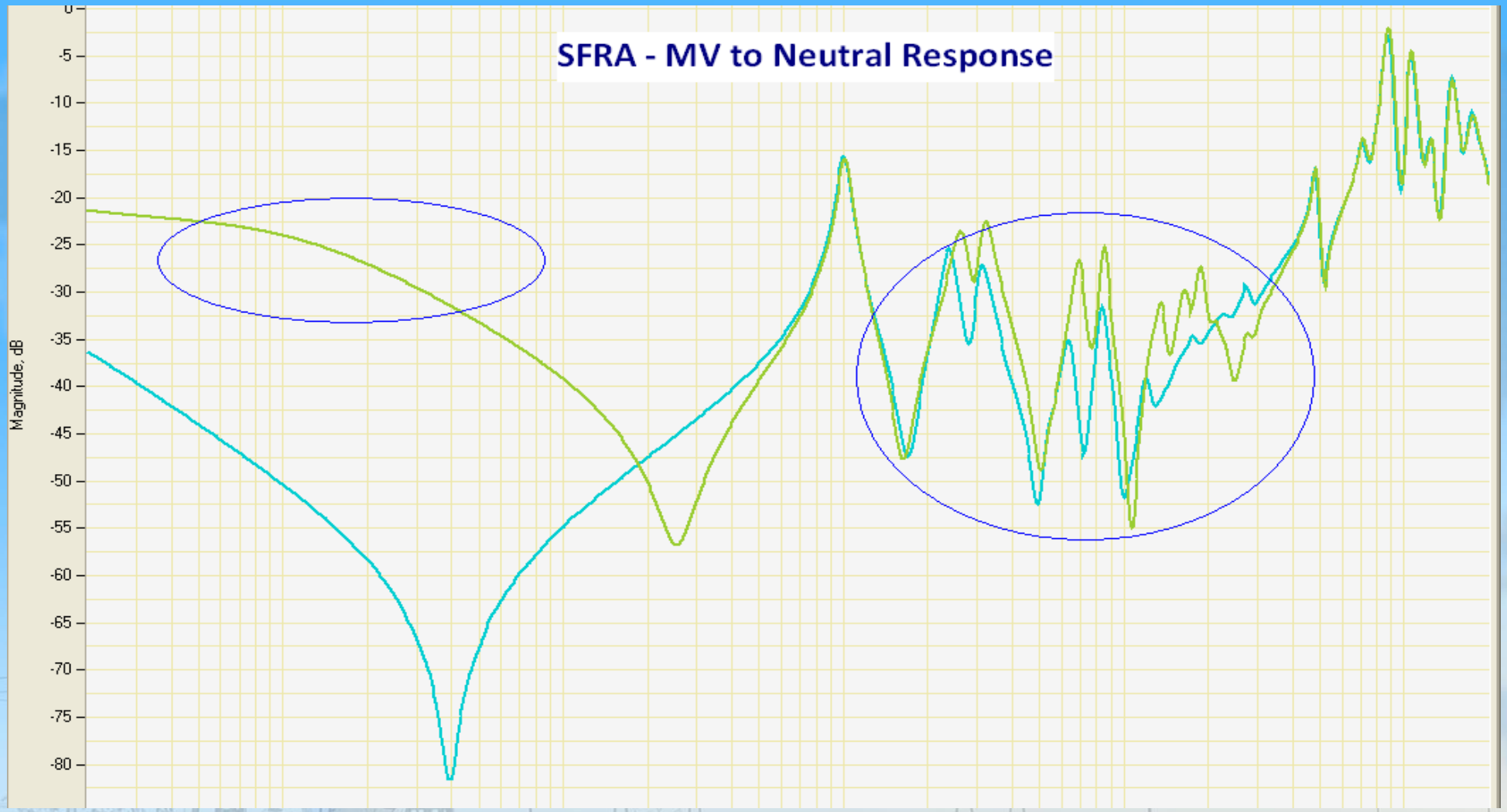
Comparison with sister unit



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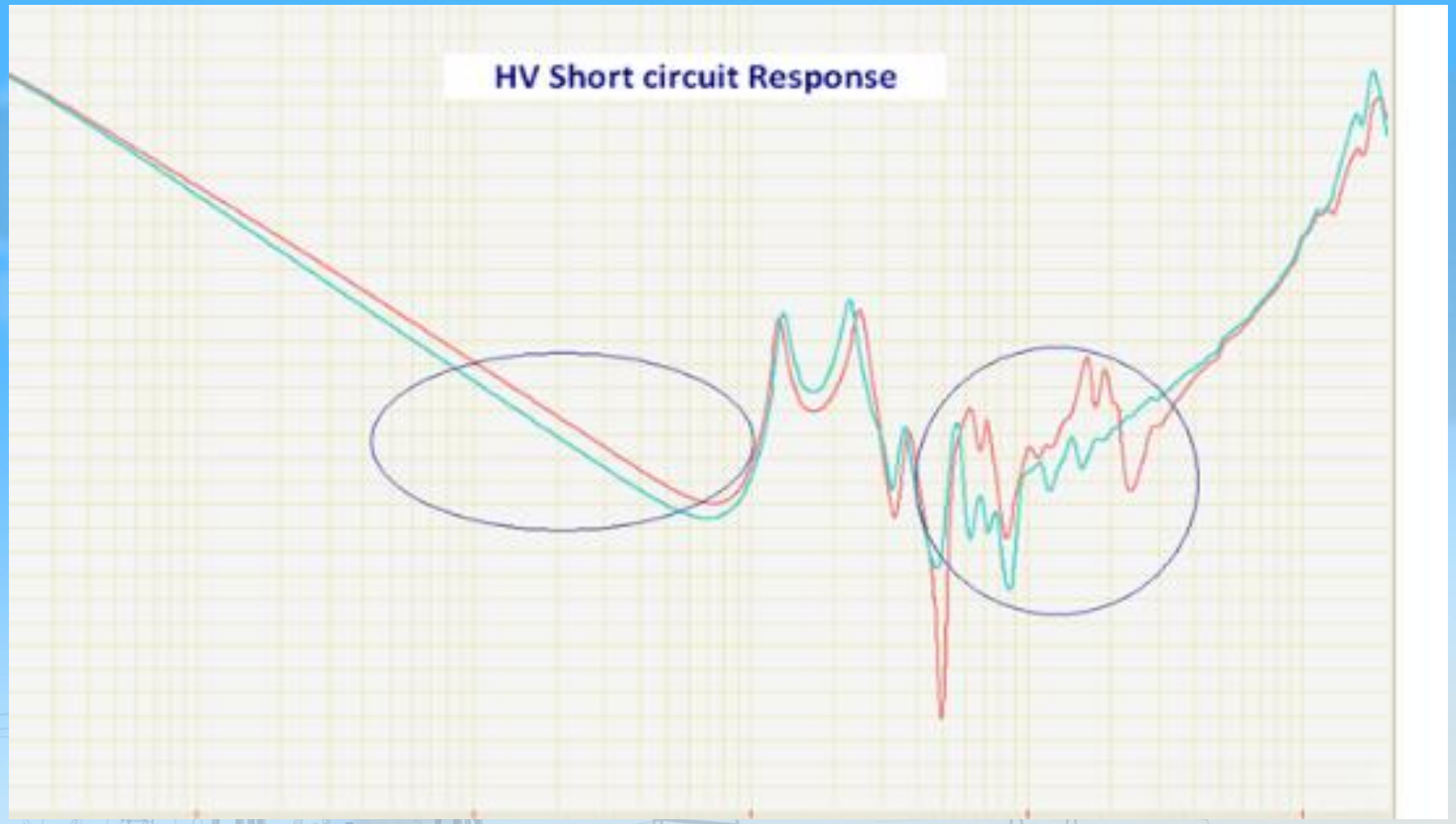
Short Circuit Test : 400/220 kV Auto Tfr



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Winding Deformation & Turn To Turn Fault

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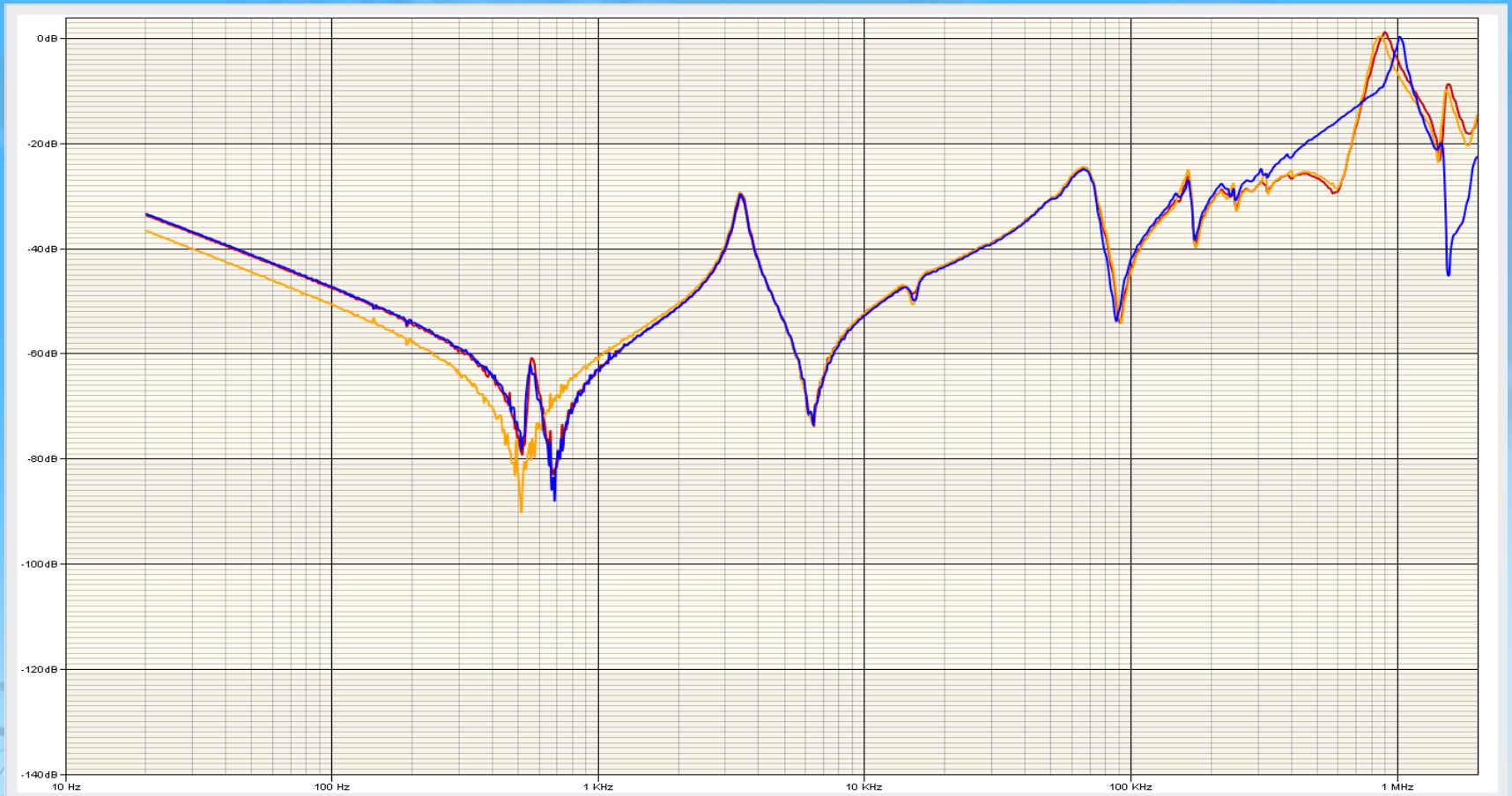
Case Study : Lead and Termination Problem



- 230/33 kV YNYno 125 MVA
- Routine SFRA testing in 2017
- Blue Trace in HF region is not matching with other phases indicates termination problem

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HV short ckt test

- HV short ckt test indicates the same Condition.
- Blue trace is showing changes In the HF region

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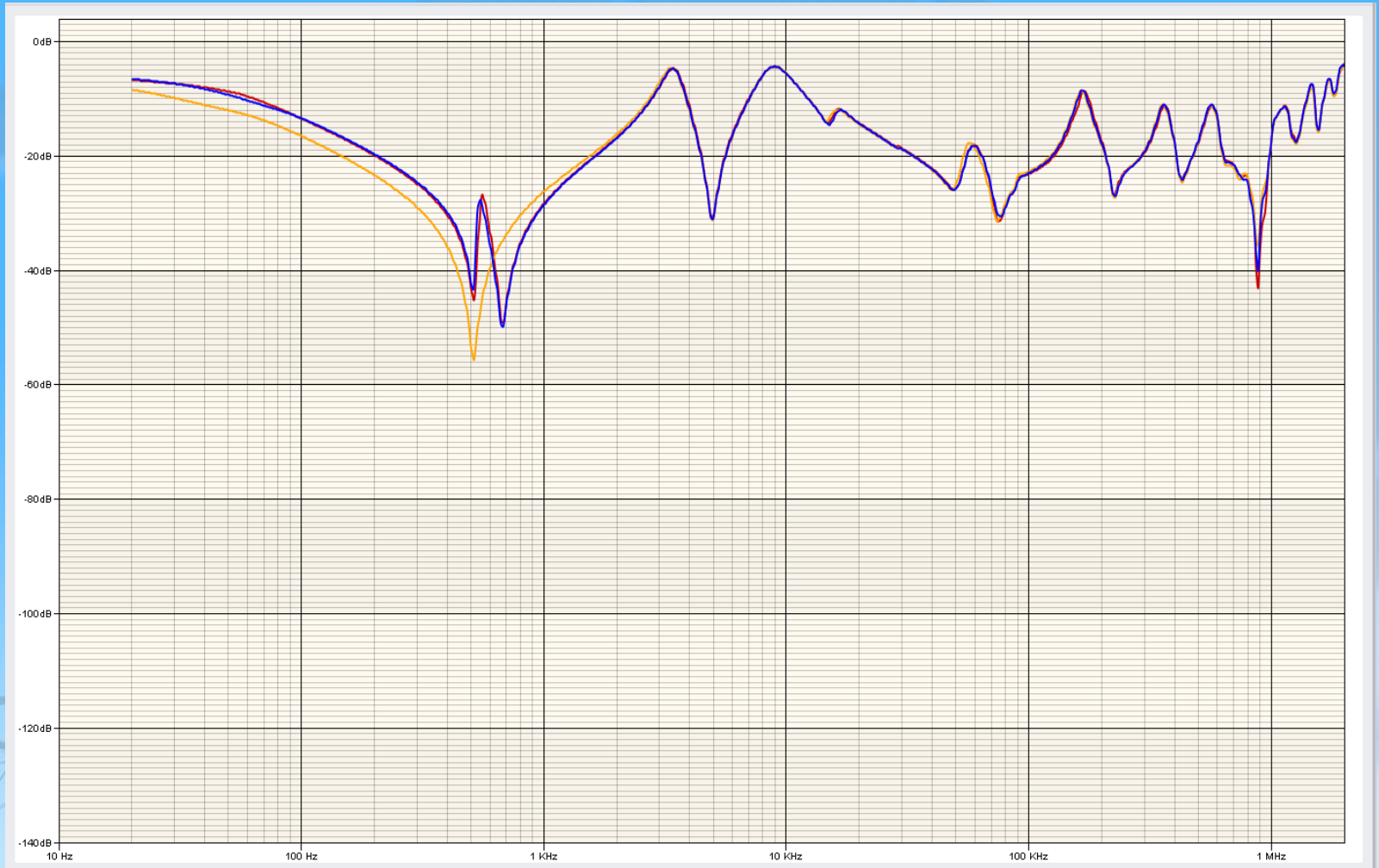
LV Open ckt test



- LV open ckt test indicates no problem on all phases
- LV ckt is ok
- Problem is with high voltage winding termination
- On inspection one of the tap changer lead is dislodged from the support structure

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Case Study : Core Ground

- 1991 132/11.5 KV, 50 MVA, 3Φ Transformer
- Differential protection operated
- Tests performed
  - SFRA
  - Magnetic Balance
  - Insulation resistance
- Magnetic balance test shows inconstant pattern
- Insulation resistance from Core to ground showed 0 Ohms
- SFRA test was performed

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SFRA HV open Ckt Test

- W phase (C phase) indicates the problem
- The shape of the resonance should be like U phase (A phase)
- Resonance peak is missing or reduced in core region
- Problem with the C phase core

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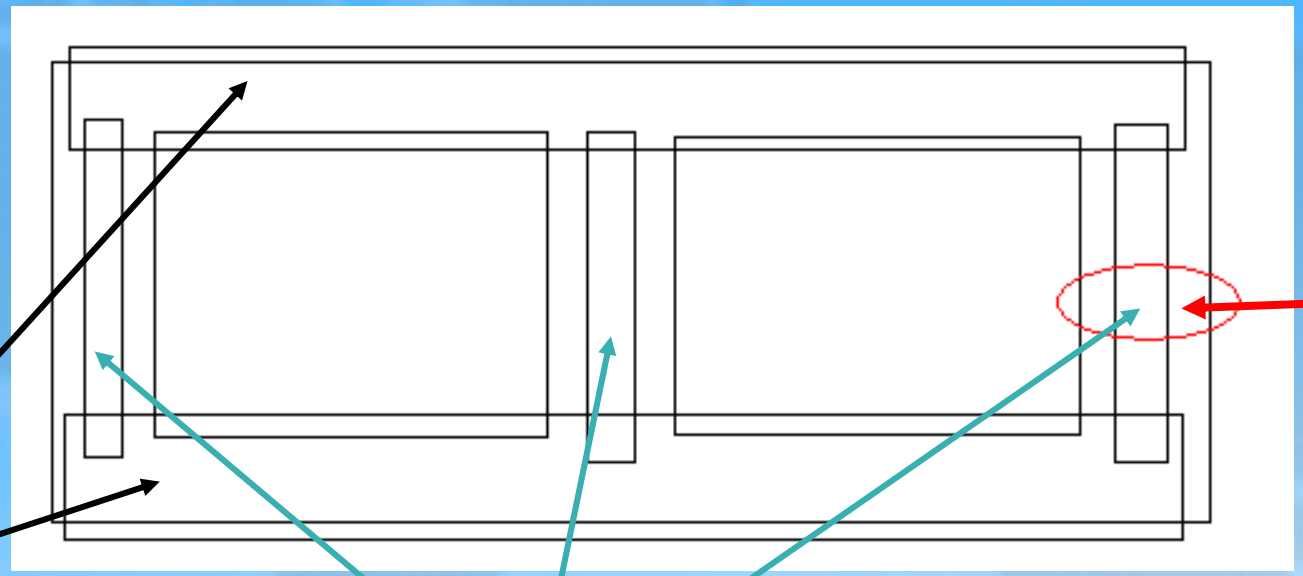
Core Construction



C phase Flitch plate shorts the Core

Top and Bottom Frame

Flitch plates

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Case Study : Core Ground

Burnt insulation may be due to PD shorts the Flitch plate to the C phase core

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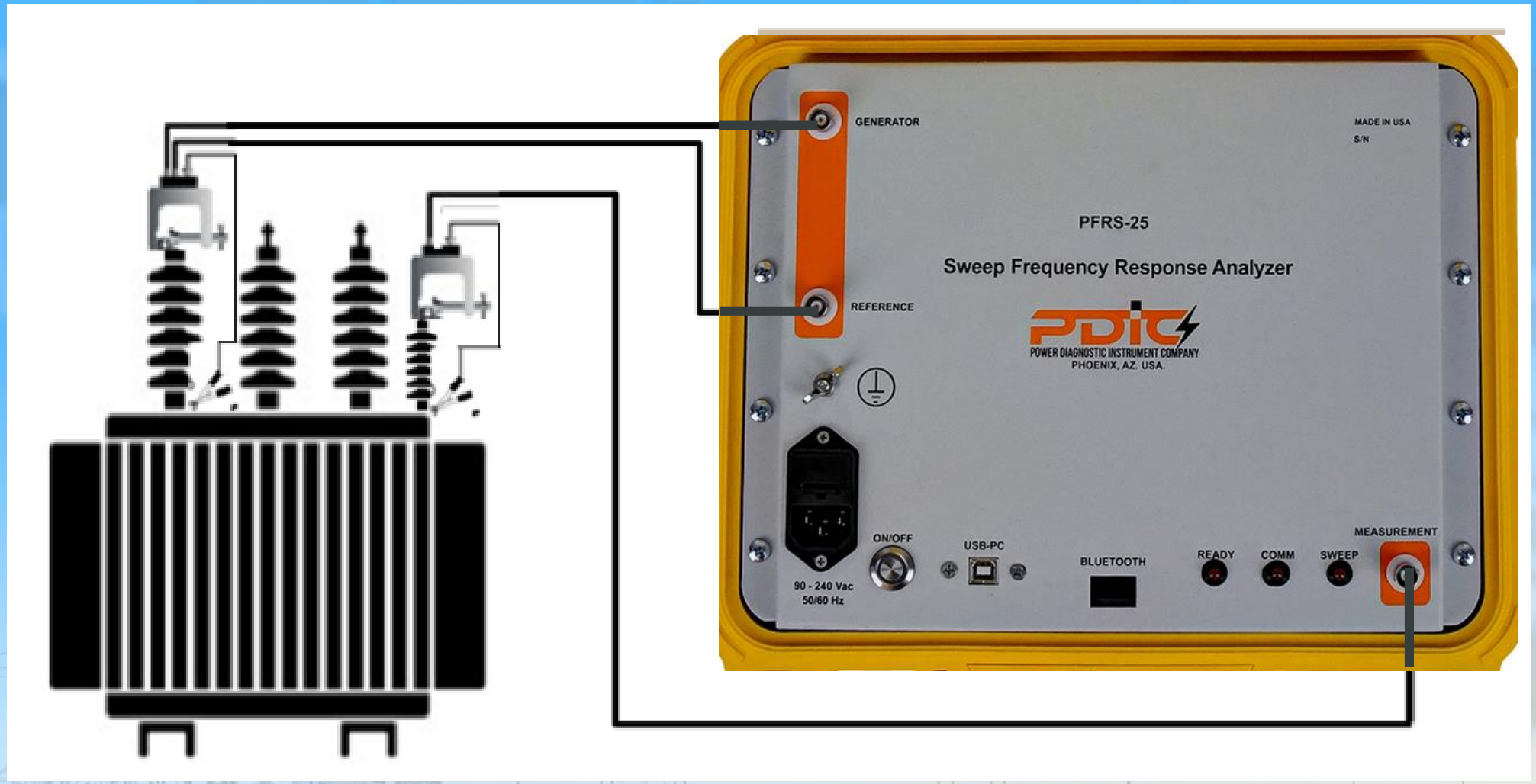
PFRS-25 Connection Diagram



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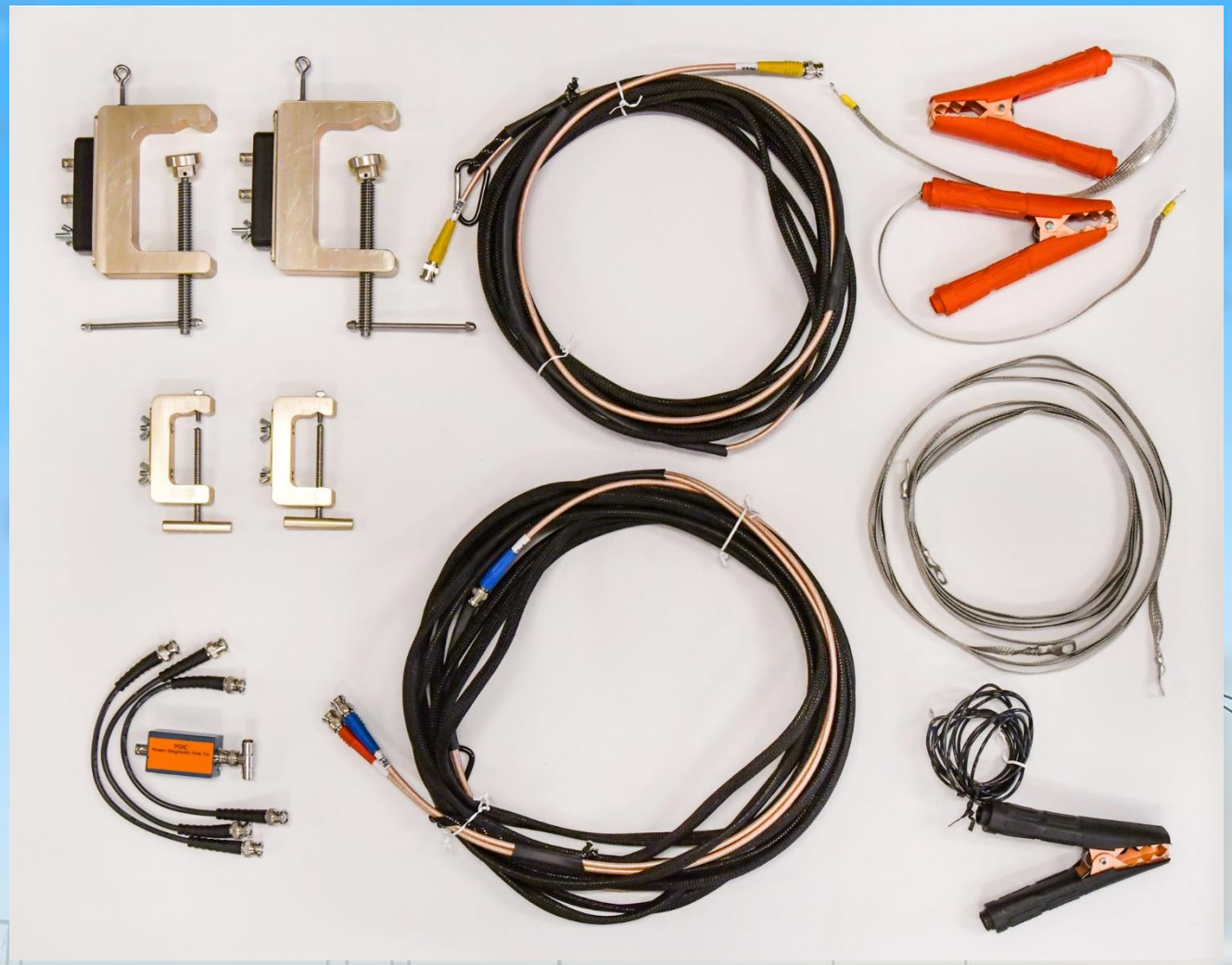
PDIC Instruments PFRS-25 Accesories



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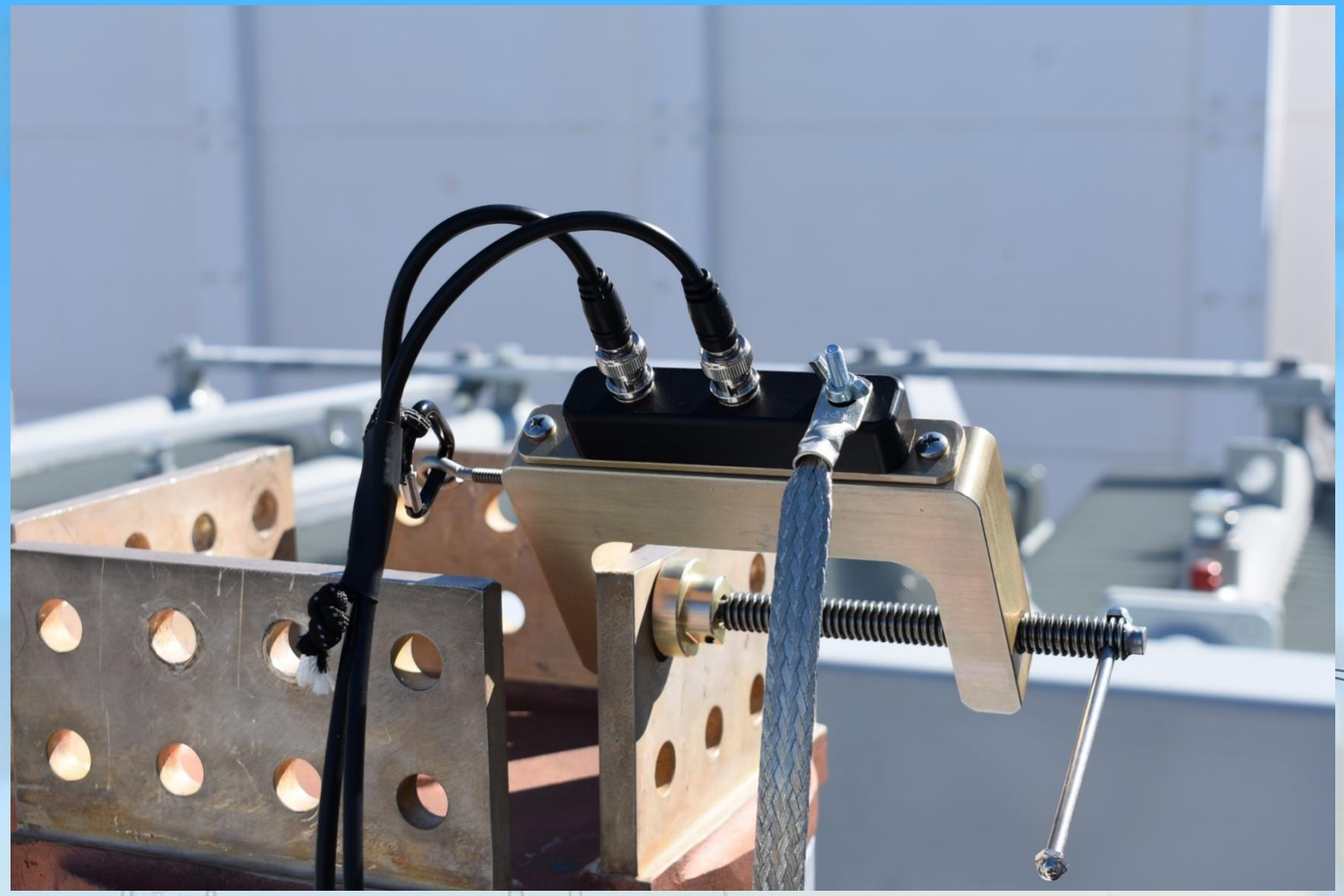
PFRS-25 Test Connections : Source and Ref



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PFRS-25 Test Connections : Measure

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PFRS-25 Test Connections

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PFRS-25 Features

- Support sweep frequency from 0.1Hz to 25MHz
- Bluetooth and USB PC interfaces
- Frequency scan 20Hz-2 MHz : 30 Secs (Bluetooth)
  - Megger, Omicron scan time in 60 secs (Bluetooth)
- Noise floor ≥ -140 dB : standard requires -90 dB
- Superior frequency response in noisy environment
- Test voltage 0.2 Vp-p to 20 Vp-p
- Battery module allowing 6 hours of continuous operation

PDIC
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PFRS-25 Features

- PC based Analysis software
- Comparison graphically
- Correlation Calculation:
  - C57.149-2012 Standard
  - DL/T 911-2004 Standard
- Software will read Frax 101, Doble SFRA files, Omicron files
- Export files into CSV, IEC XML, CIGRE format
- Provide 30ft cable sets with ground straps, 3 signal clamps, 2 ground clamps
- Size: 13” x 11” x 6”, Weight: 7.0 lbs.

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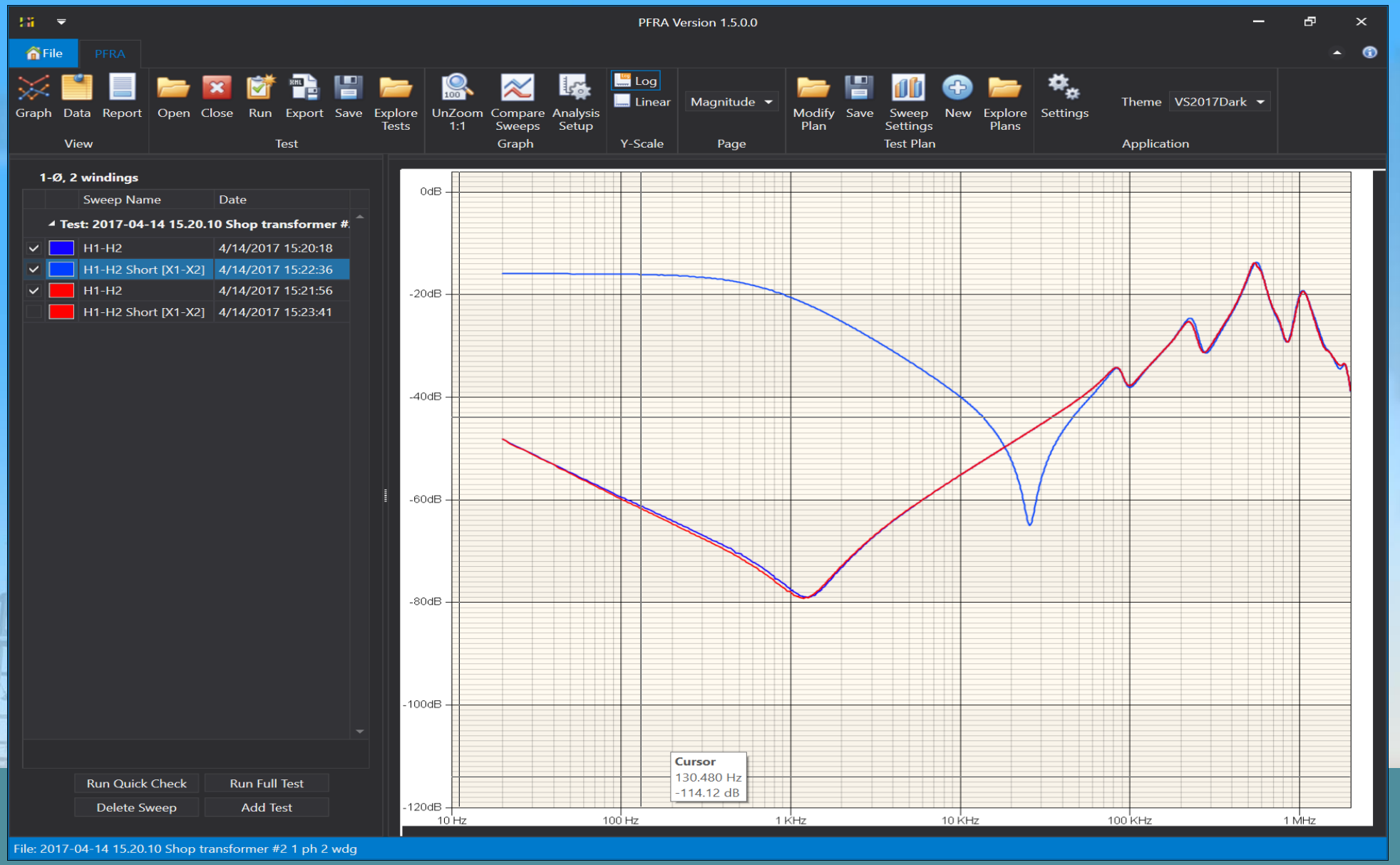
PFRS-25 PC Software Screen



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Sweep Comparison

1-Ø, 2 windings

		Sweep Name	Date
		Test: 2017-04-14 15.20.10 Shop transformer #2 1	
☑		H1-H2	4/14/2017 15:20:18
☐		H1-H2 Short [X1-X2]	4/14/2017 15:22:36
☑		H1-H2	4/14/2017 15:21:56
☐		H1-H2 Short [X1-X2]	4/14/2017 15:23:41

Run Quick Check | Run Full Test

Delete Sweep | Add Test

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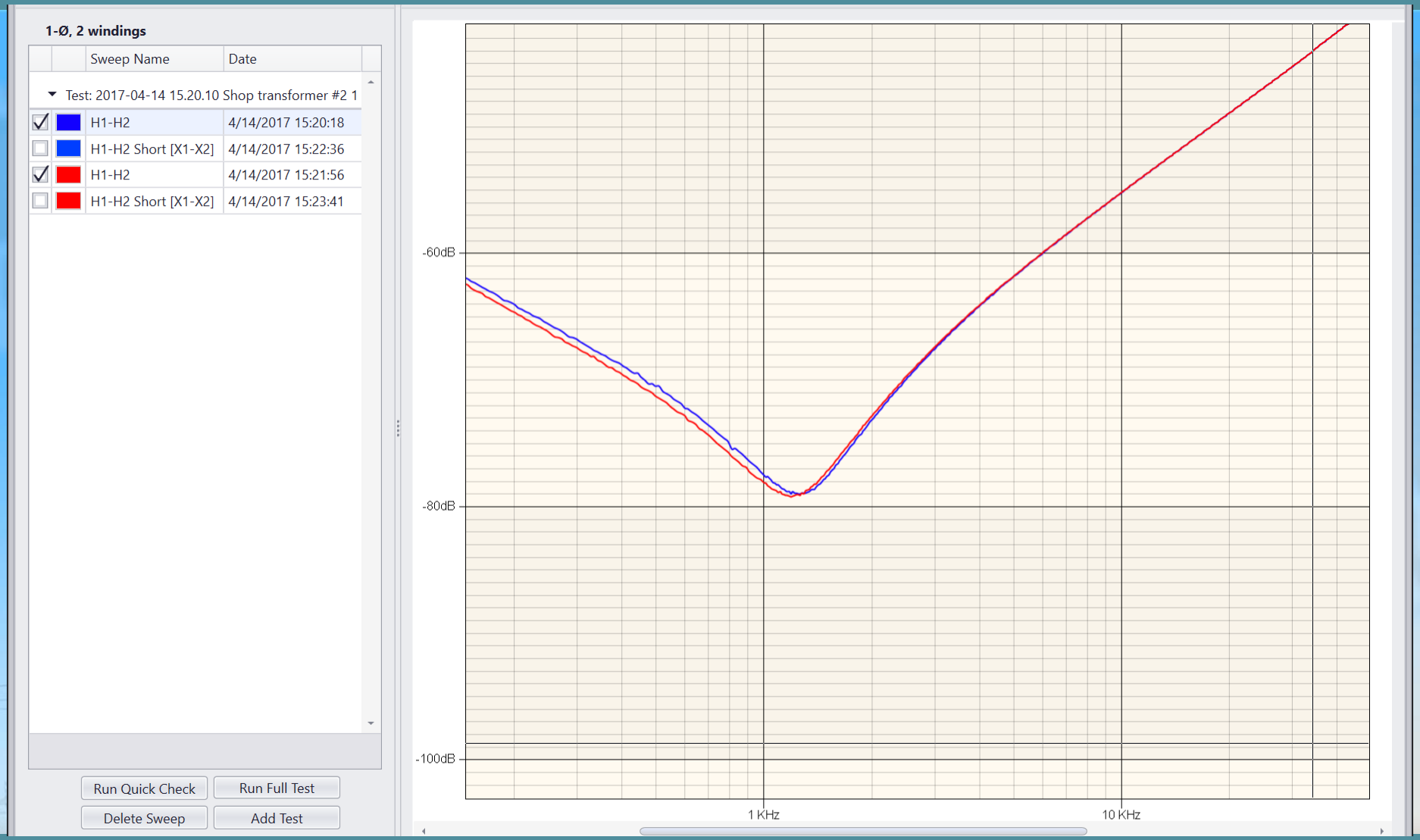
Sweep Comparison : Zoom



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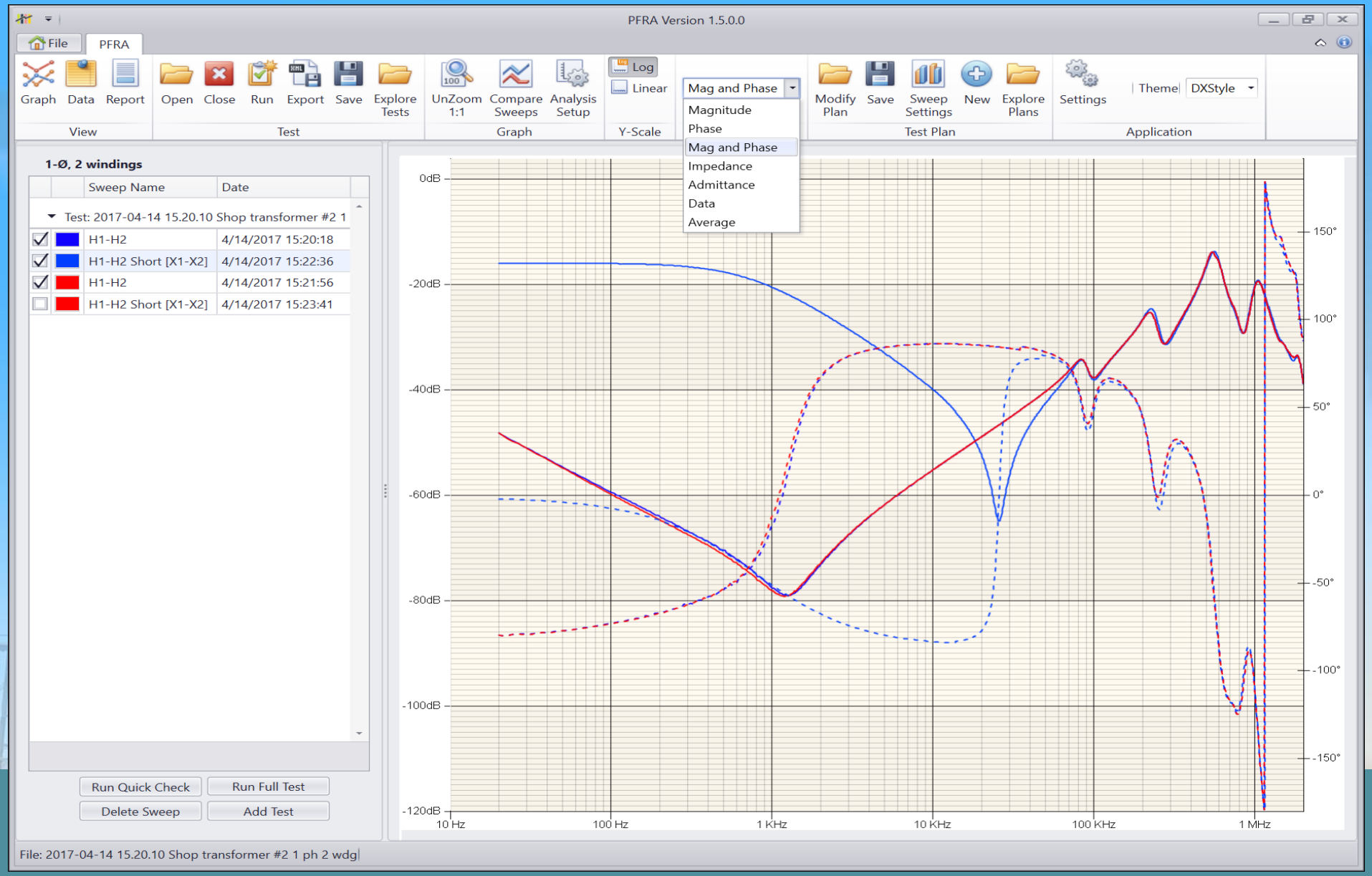
Sweep Display



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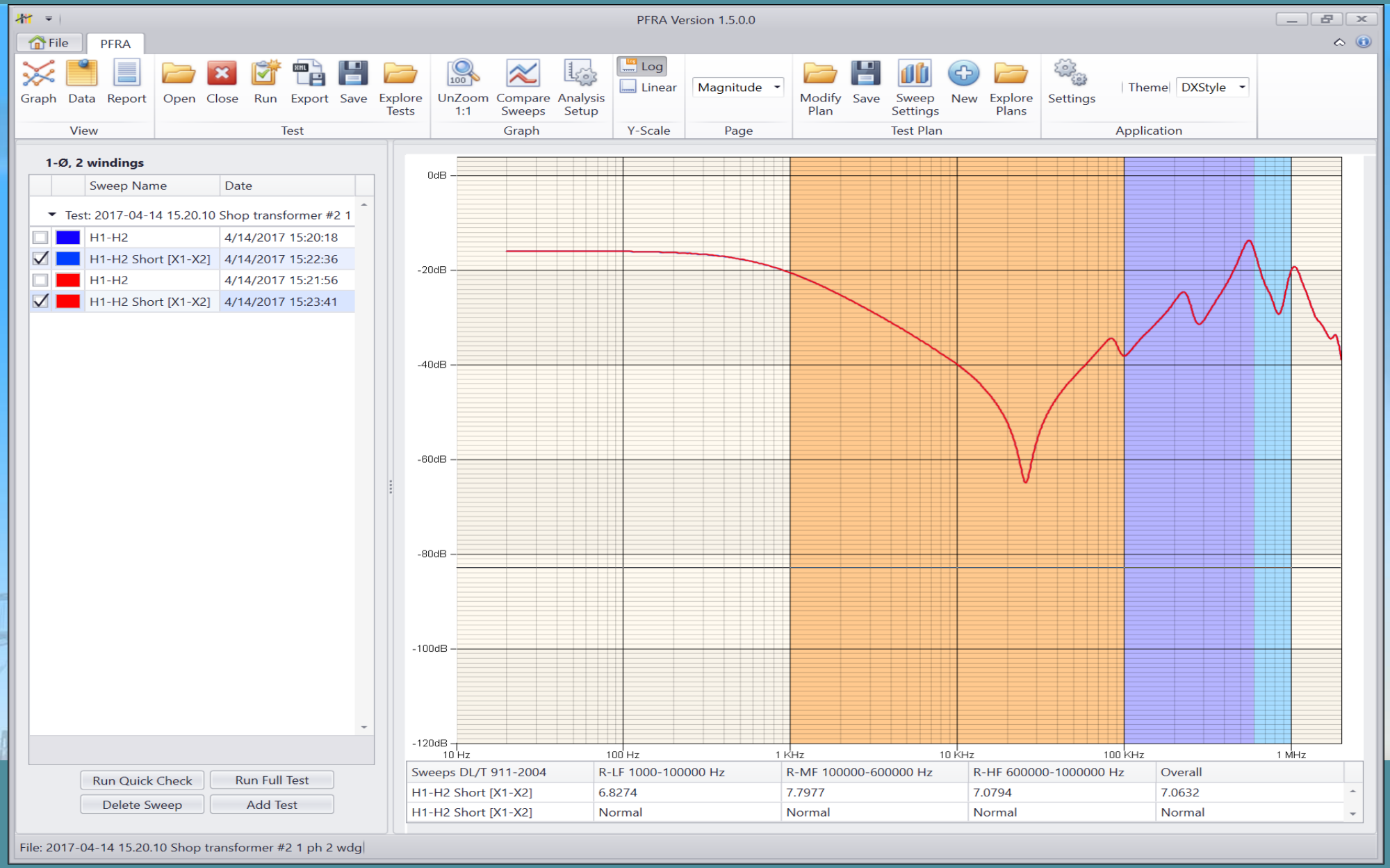
PFRS-25 DL/T 911-2004 Analysis Screen



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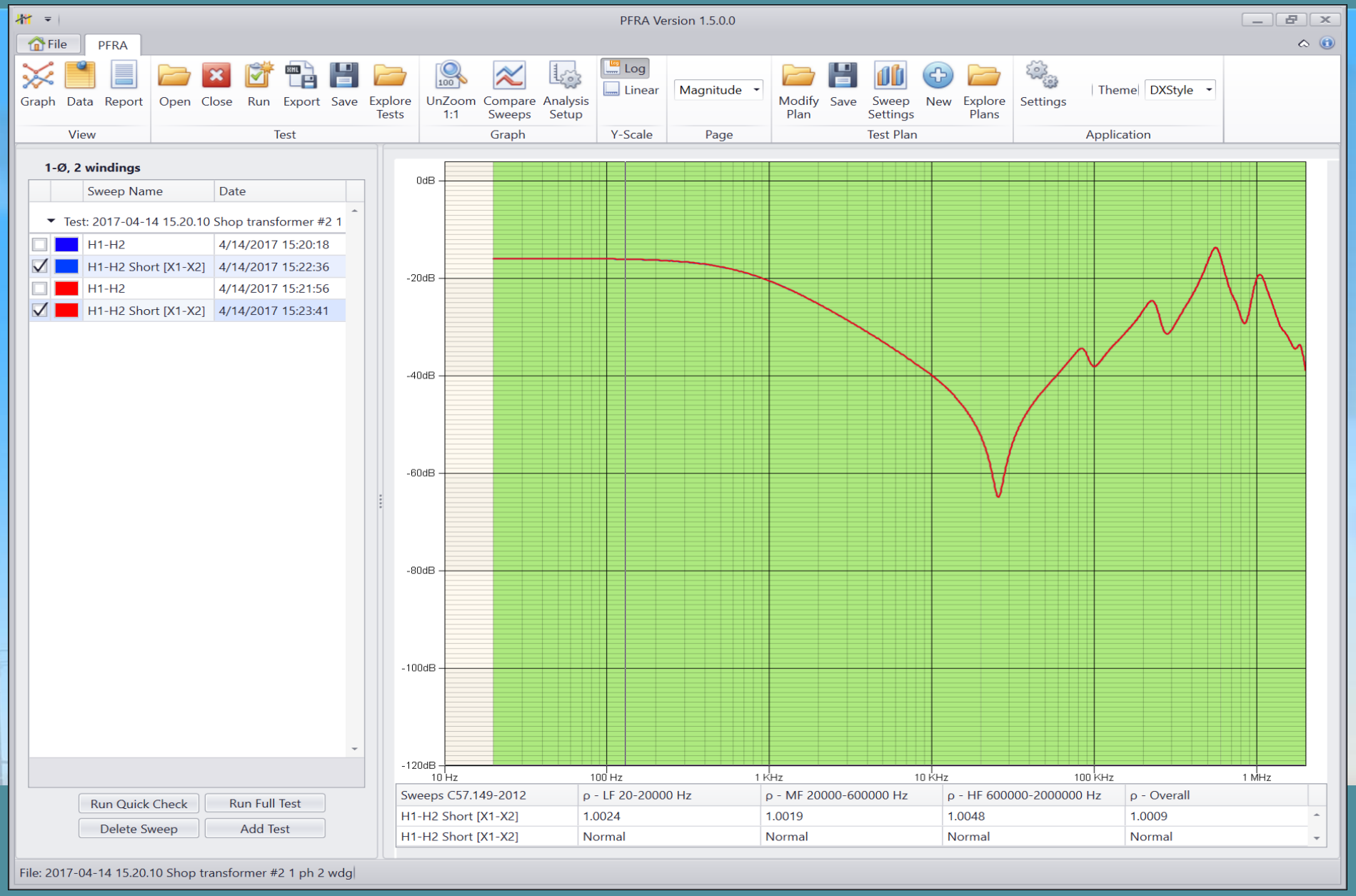
PFRS-25 IEEE C57.149-2012 Analysis Screen



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PFRS-25 Report

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Test: 2017-04-14 15.20.10 Shop transformer #2 1 ph 2 wdg

Type: 1-Ø, 2 windings

Company: Vanguard Instruments Co., Inc
Manufacturer: Howard Industries
Vector Group: Single Phase
Impedance %: 5%
Substation: Shop
Serial Number: 466454

Designation: Lab use
Date of Mfr: 1997
KV: 466454 123 456
MVA: 123 456 789
Type: Pole Mount
Transformer ID: shop sample

DETC pos: N/A
Air Temp: 72F
Top oil temp: 71F
LTC pos: N/A
Tested By: HN
Notes:

Weather: Nice
Cooling: Air
Oil Status: Full
% RH: 20%

Sweep Name	Date / Time
H1-H2	4/14/2017 15:20:18
H1-H2 Short [X1-X2]	4/14/2017 15:22:36
H1-H2	4/14/2017 15:21:56

PFRS-25: Outstanding Features

- Faster sweep time
- Field rugged housing
- Built in Battery Back up
- Superior Dynamic Range
- Export import CIGRE standard format
- User Friendly PC software

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