Practical Experience with SFRA Technique

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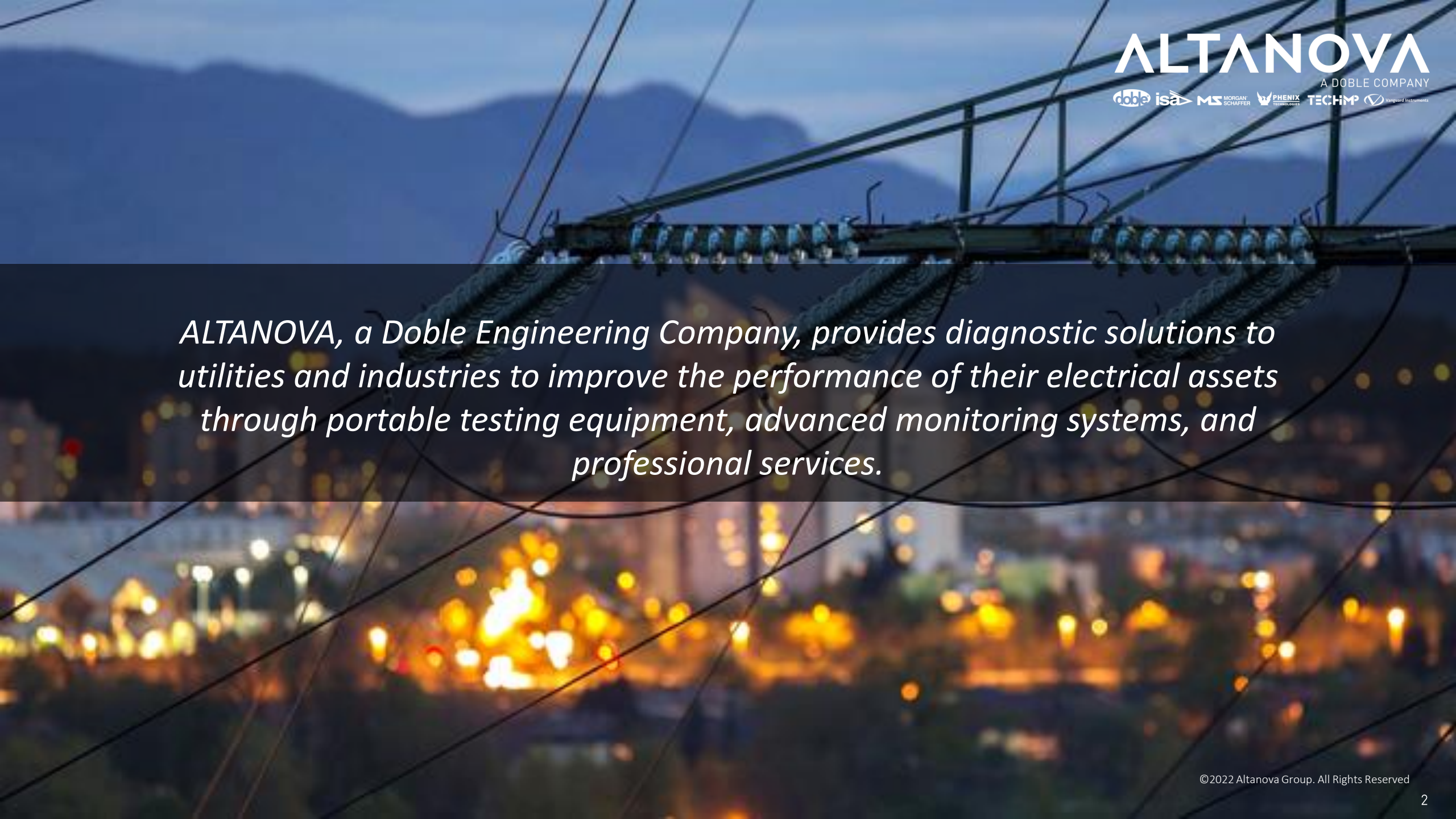

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A DOBLE COMPANY

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

1938 I.S.A. Istrumentazioni Sistemi Automatici S.r.l. is established in Taino ITALY

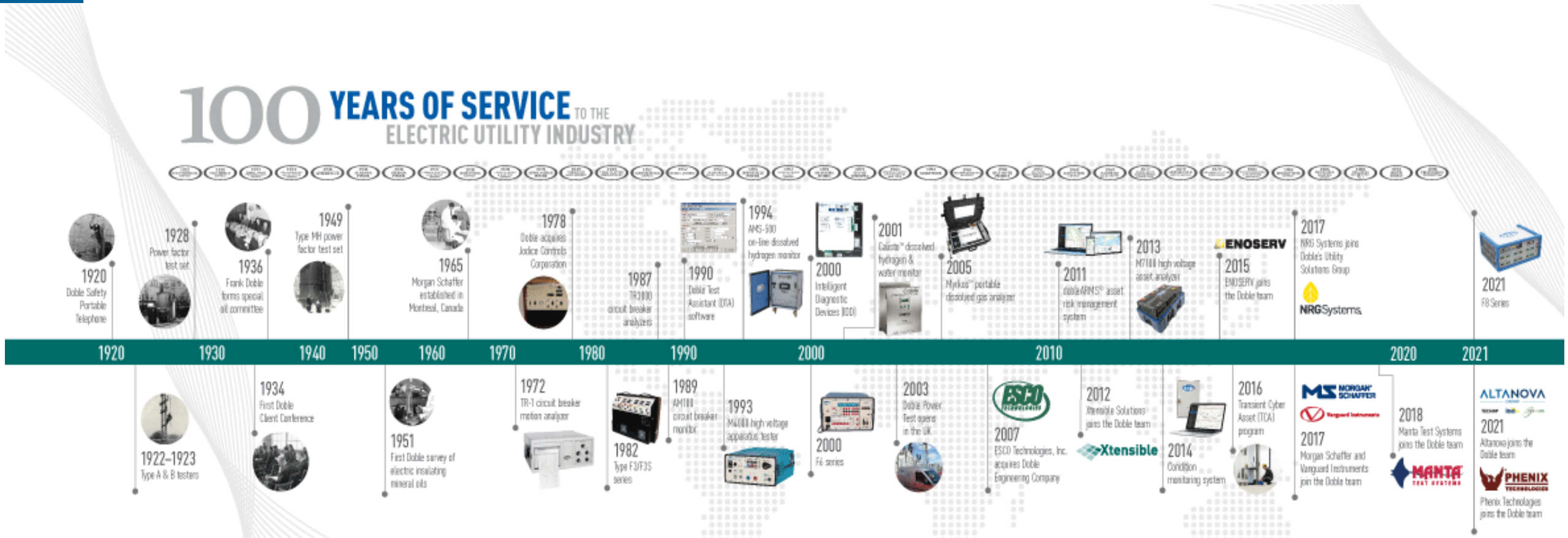
1999 TECHIMP was born as a spin-off from the University of Bologna ITALY.

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:

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- 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






SFRA Technique

1. Introduction
2. Influencing Factors
3. Importance of Reference Results
4. Case Study

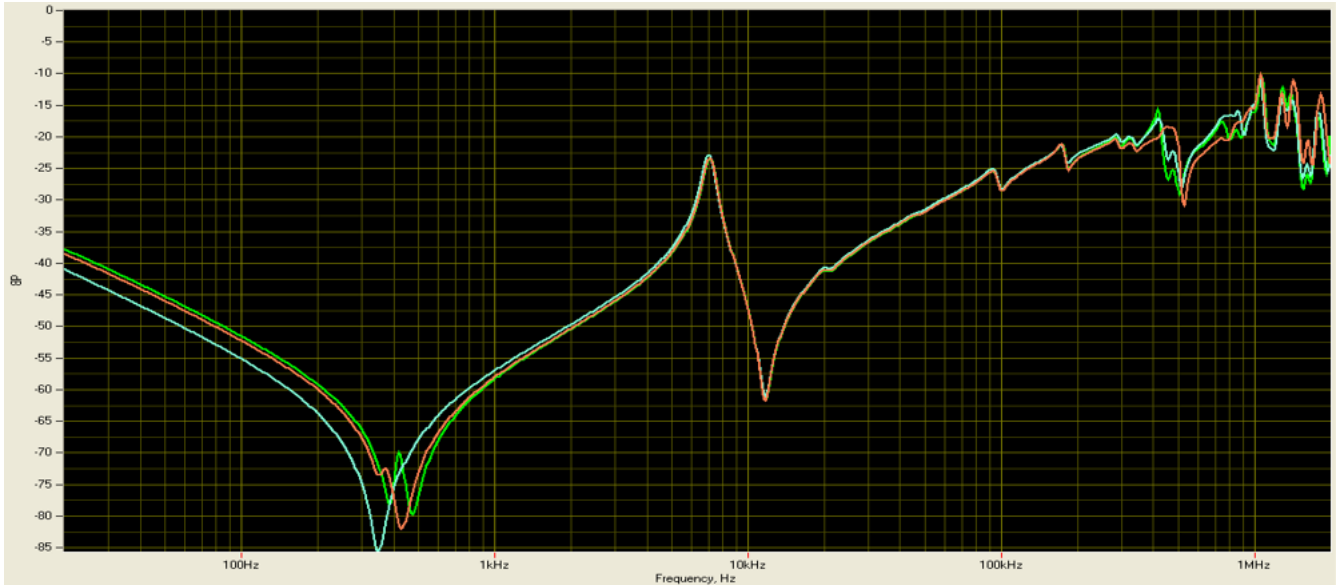
Introduction

Frequency Response Analysis (FRA) is commonly used to assess the mechanical integrity of transformer active part

Normally performed during the following:

- Factory fingerprint before transport to site
- Short circuit test
- Site fingerprint/diagnostic after transportation prior to commissioning
- Relocation and installation
- Routine diagnostic protocol
- After transformer alarm or trip
- After through fault, lightning, seismic event

Comparative test – relies on compared responses being **measured in the same way** and in the **same transformer condition.**



International Collaborations (2008 – 2020)

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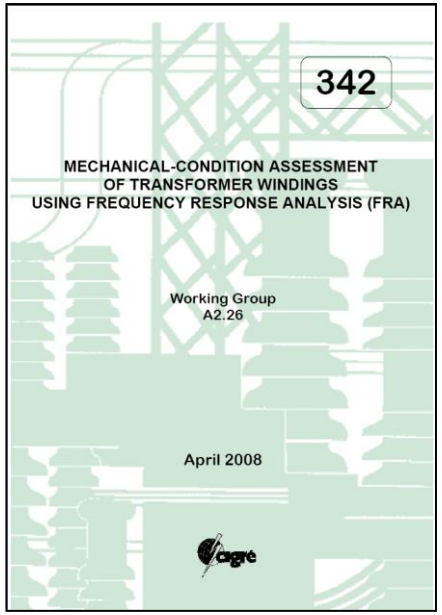
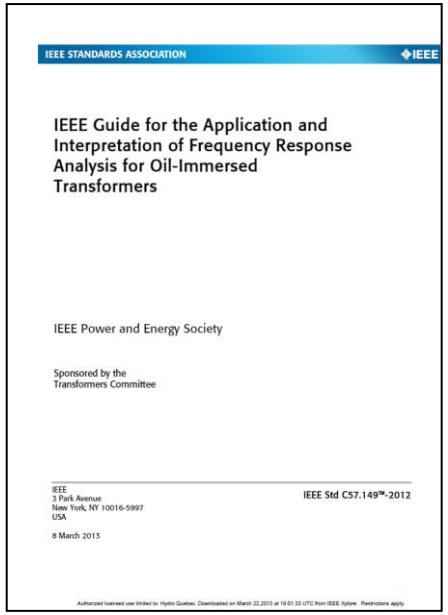
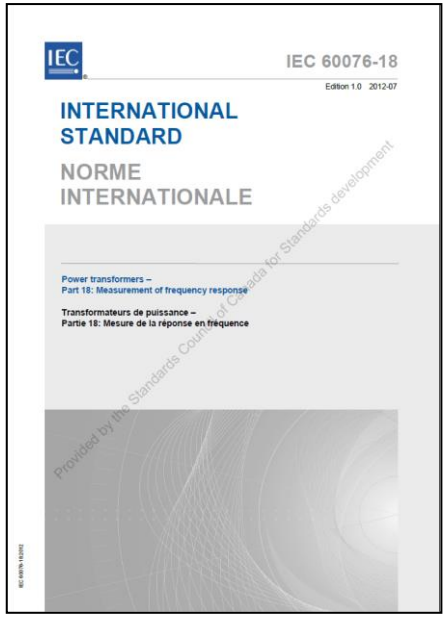
Cigre WG A2.26



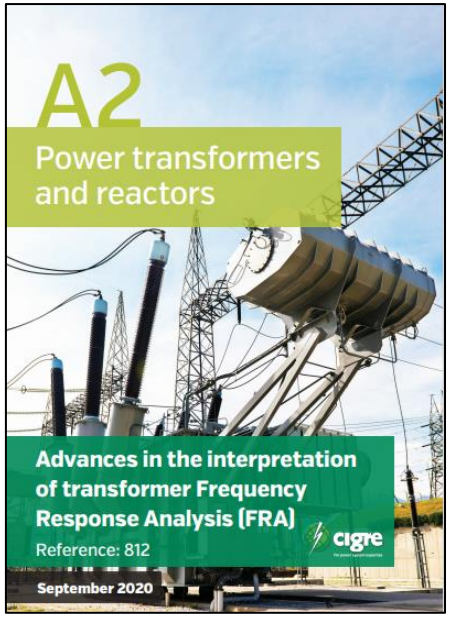
IEEE WG C57.149



IEC PT 60076-18

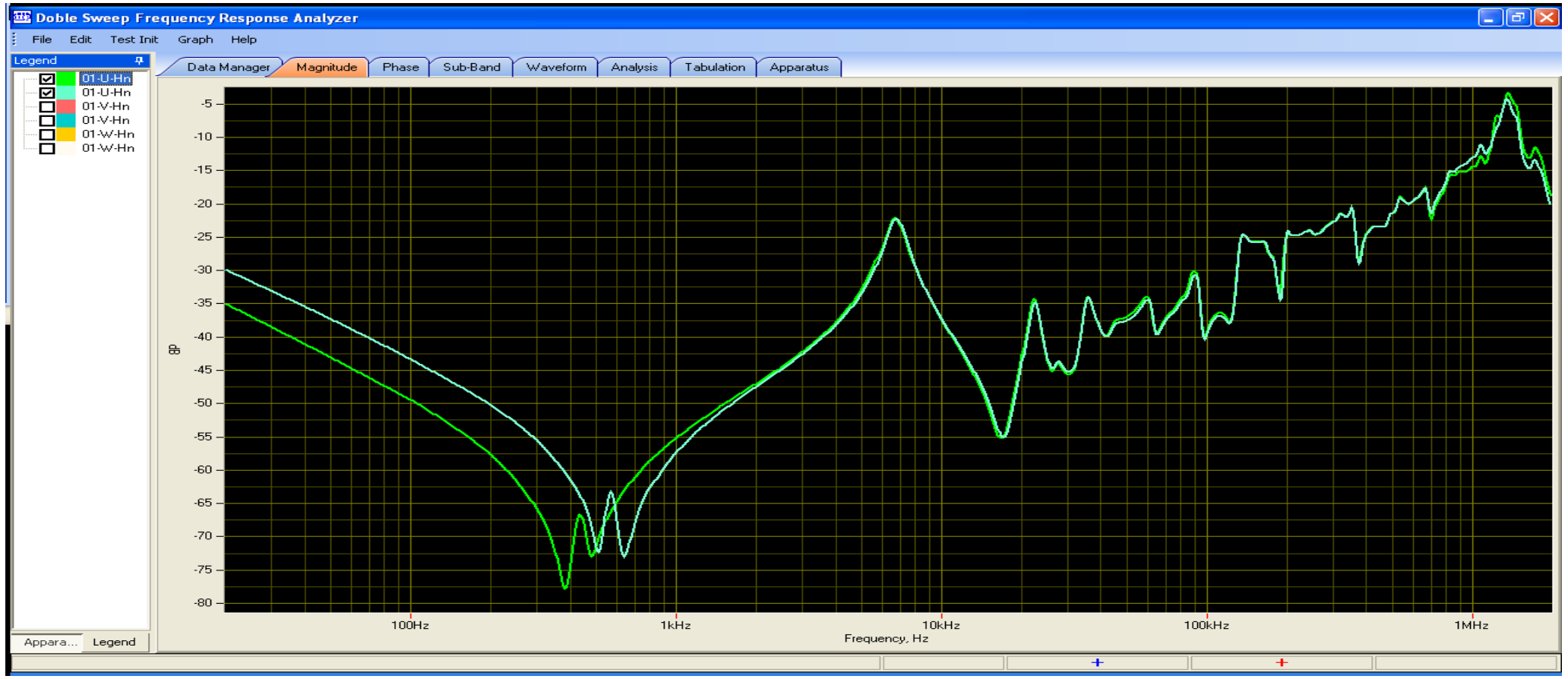


Cigre A2.53



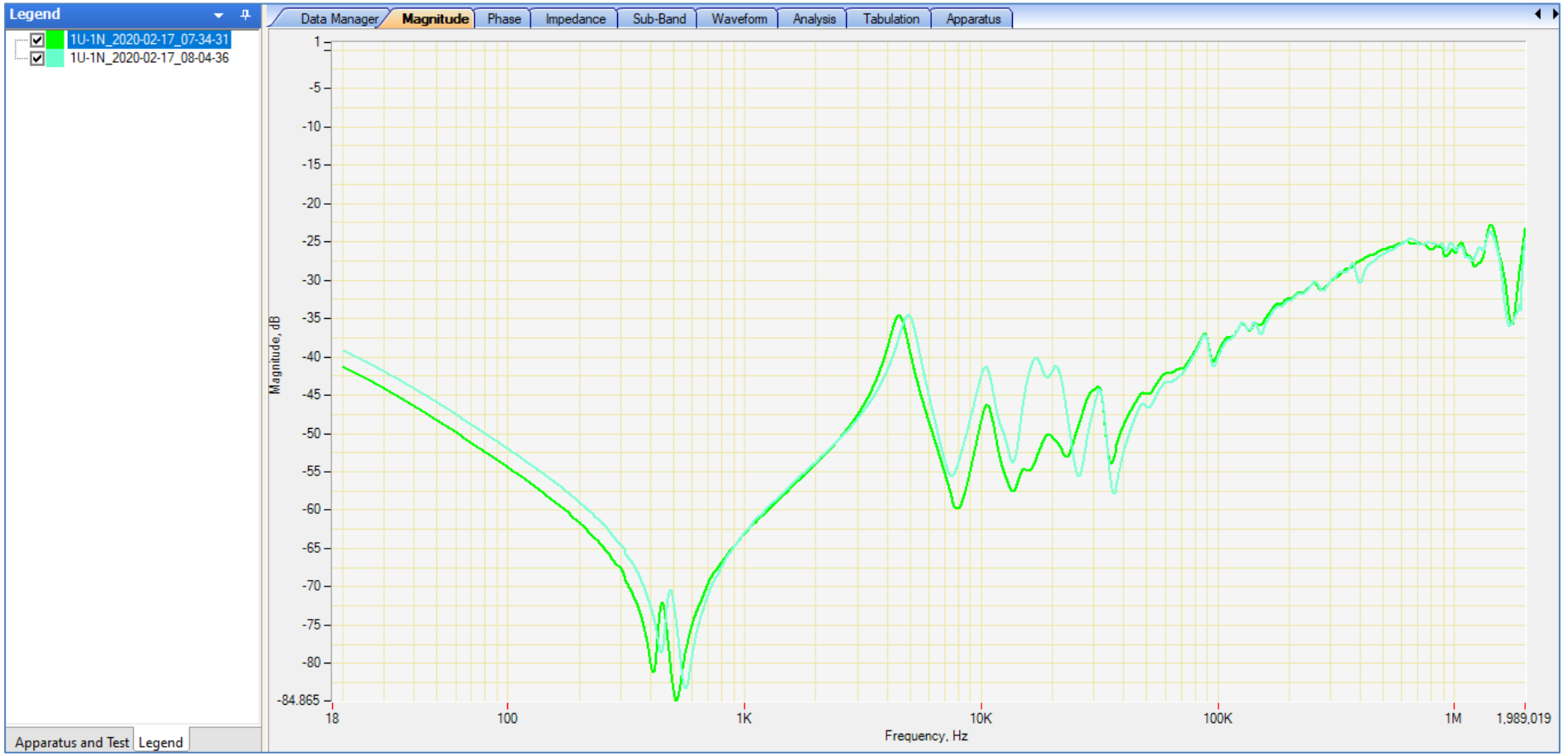
Influencing Factors

Effect of core magnetization



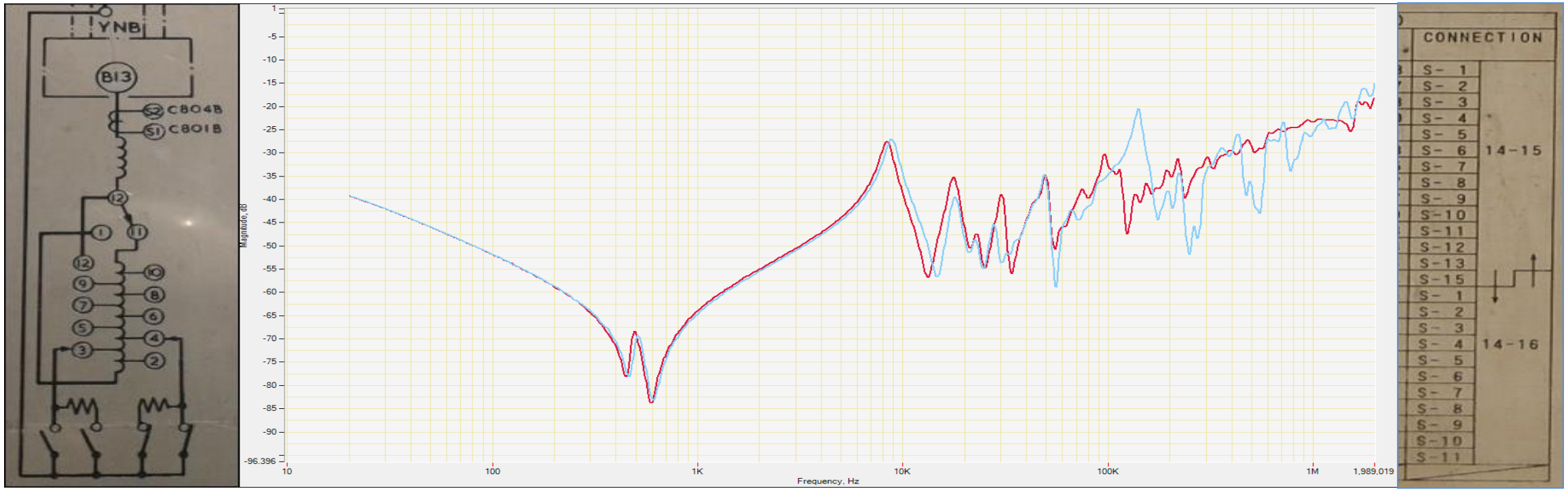
Low frequency variation is severe - but identifiable

Effect of tap position



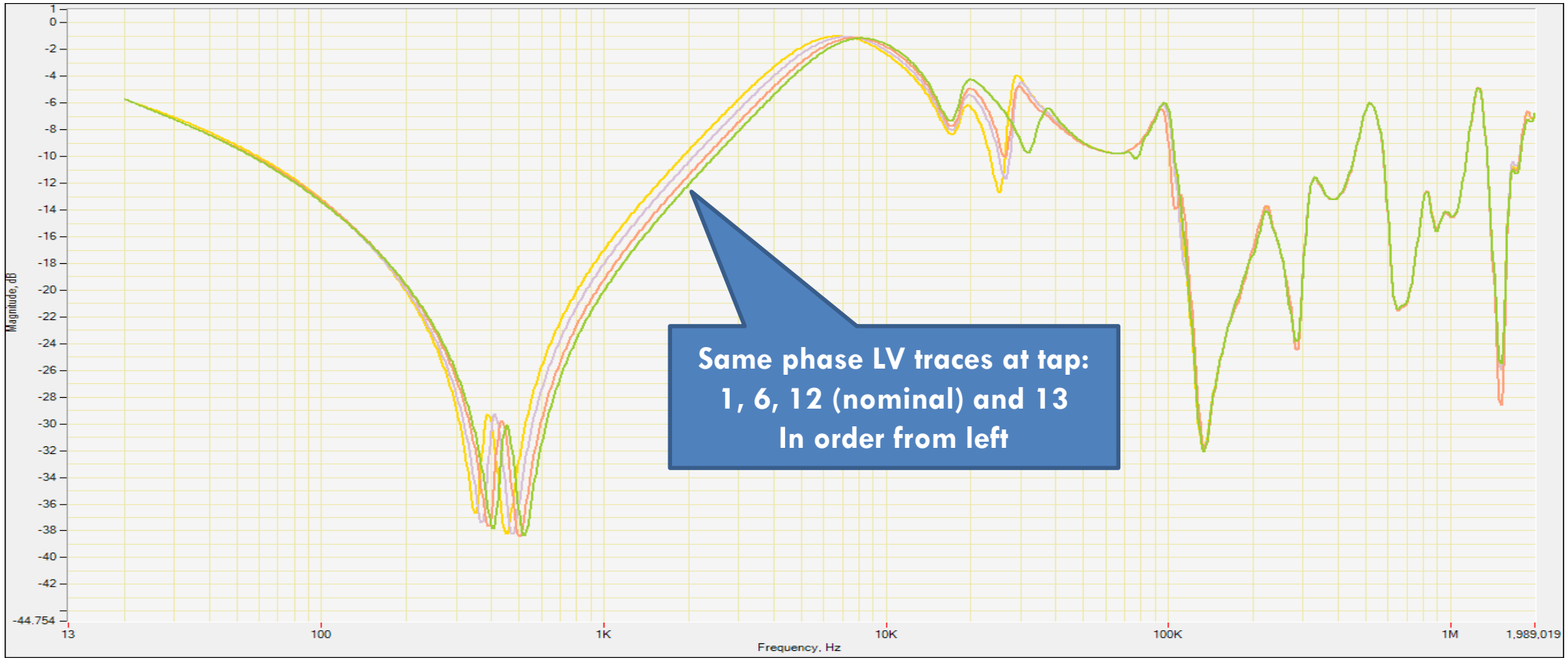
Tap position is one of the most obvious factors influencing result

Nominal tap position (N)



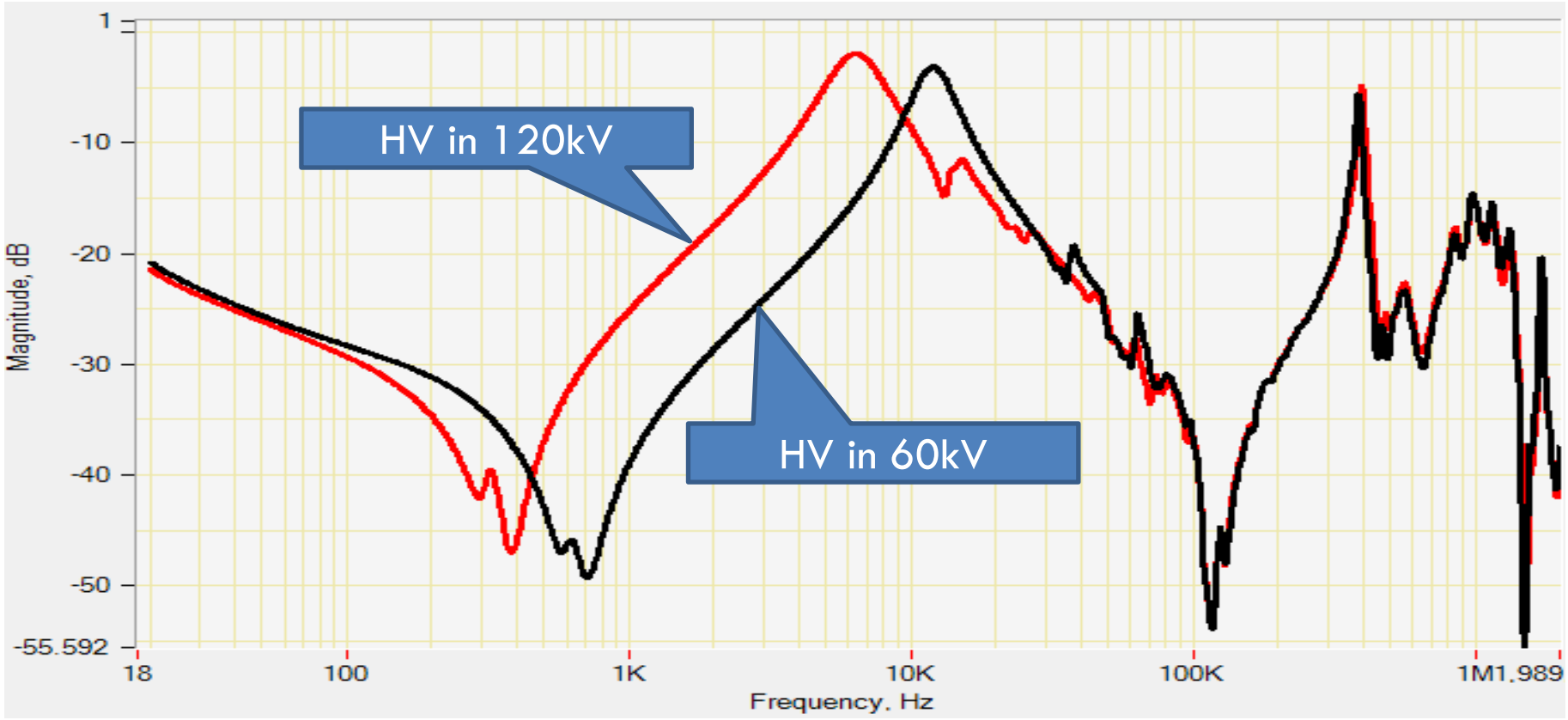
(N) from (N-1) is not the same as (N) from (N+1)

Effect of state of other winding



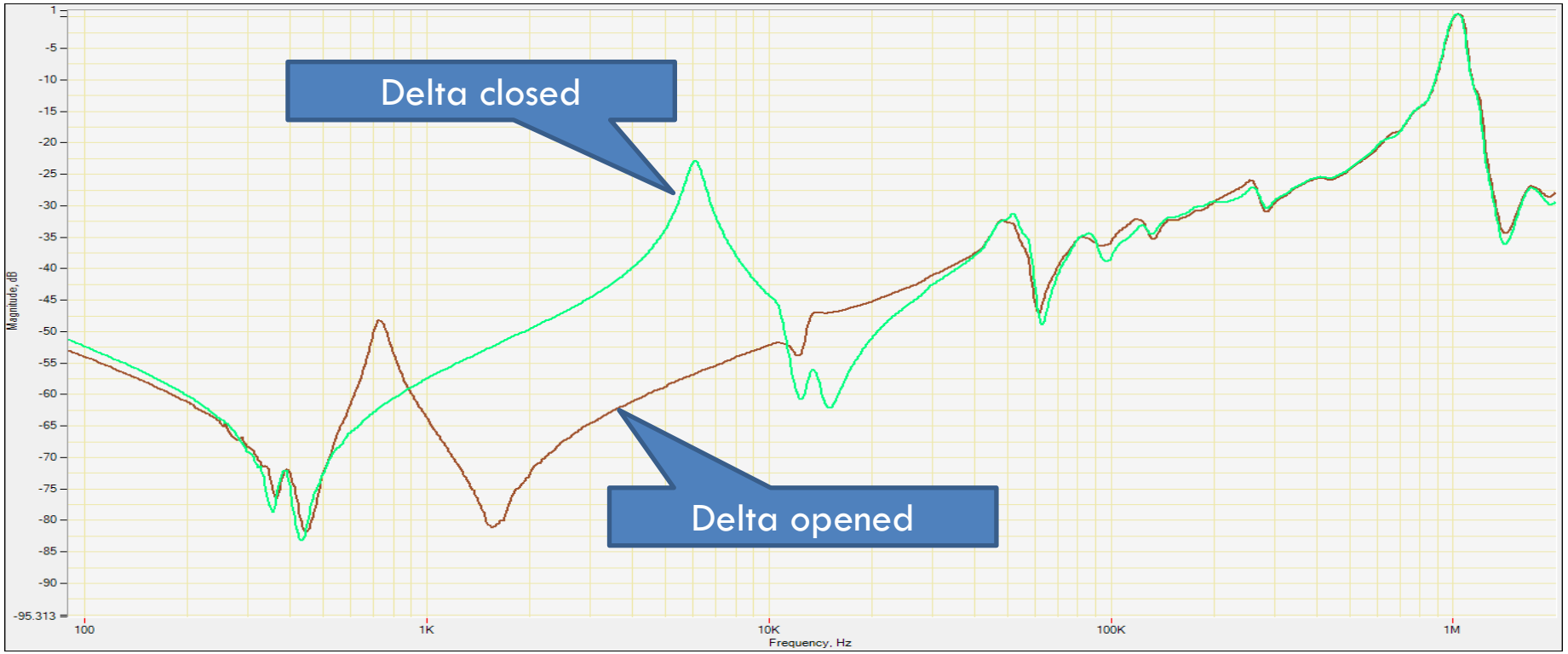
Impact of HV tap position on LV test

Effect of state of other winding



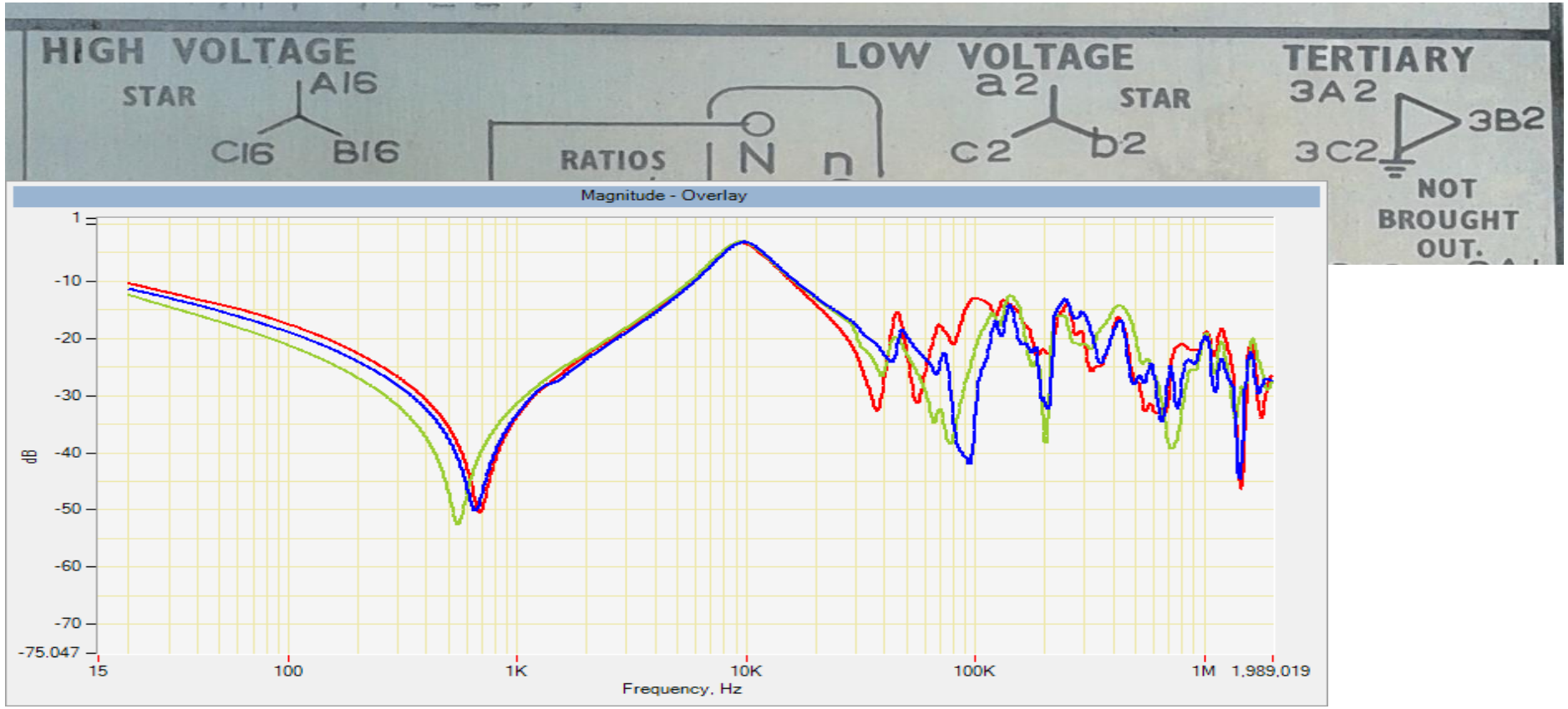
Impact of HV series/parallel switch on LV test

Effect of state of other winding



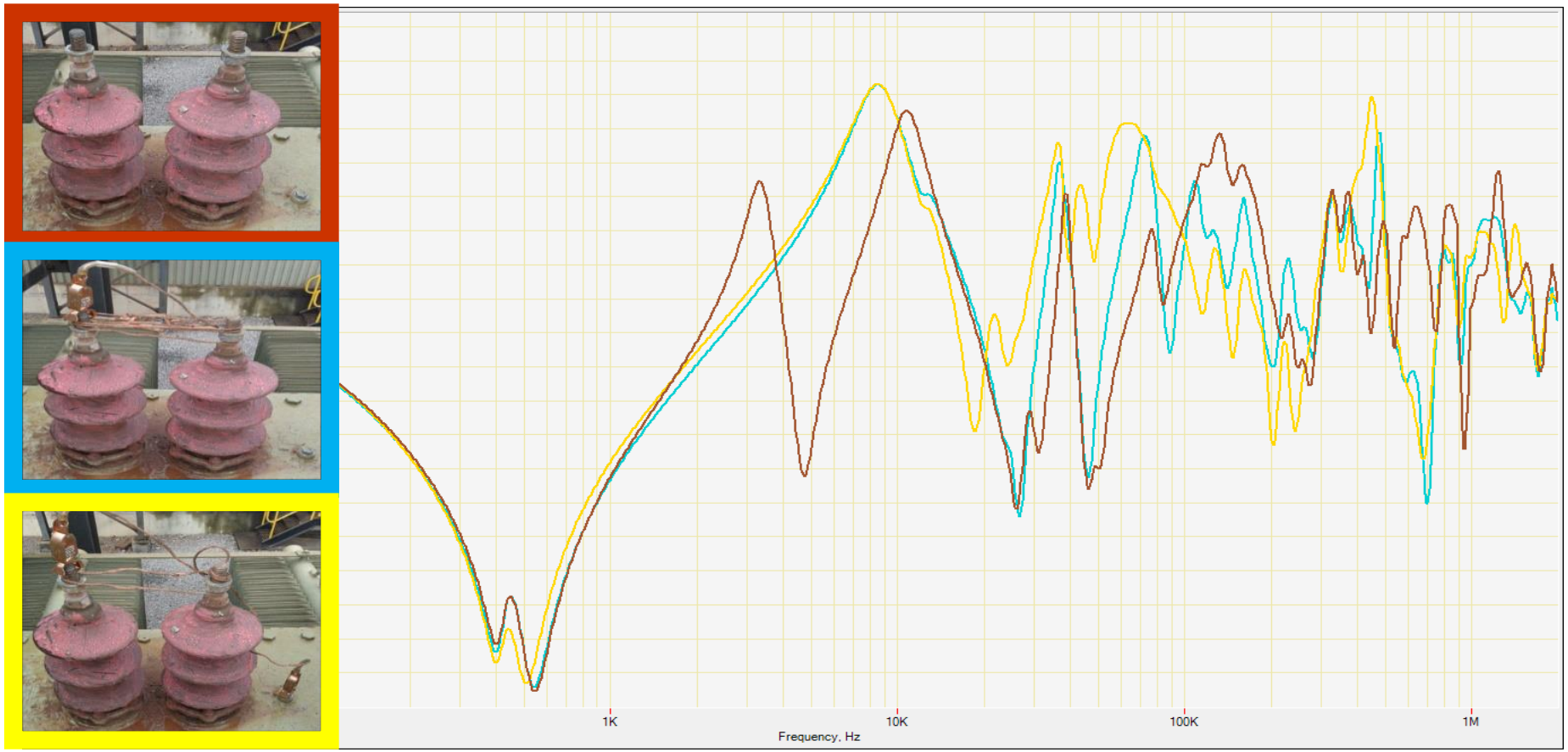
Impact of LV delta state on HV test

Effect of internally grounded delta winding



Impact of internally earthed delta winding on responses of other windings

Experiment with delta winding

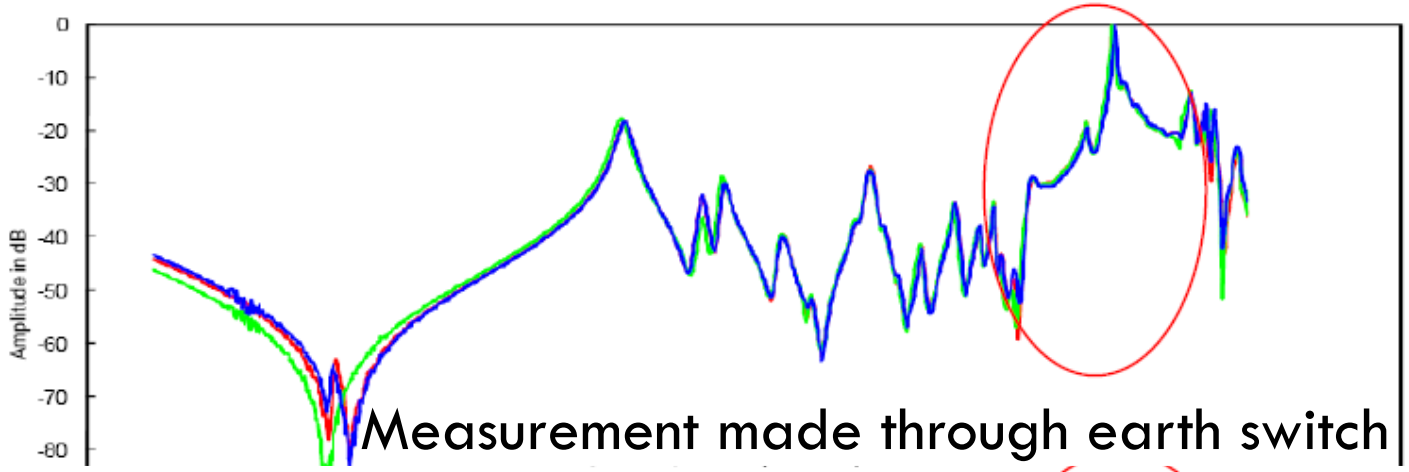


Impact of state of delta winding on responses of other windings

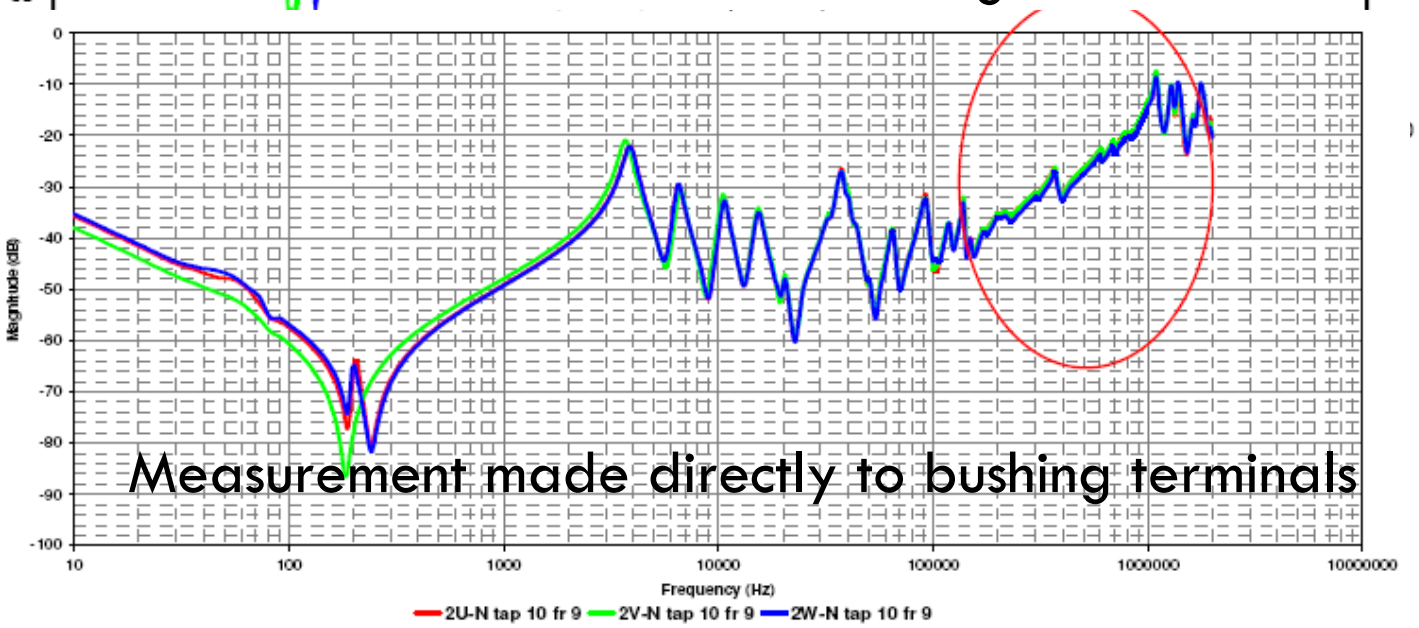
Effect of insulating liquid

Measurement in fully assembled condition and in transportation condition

Effect of long GIS busbar

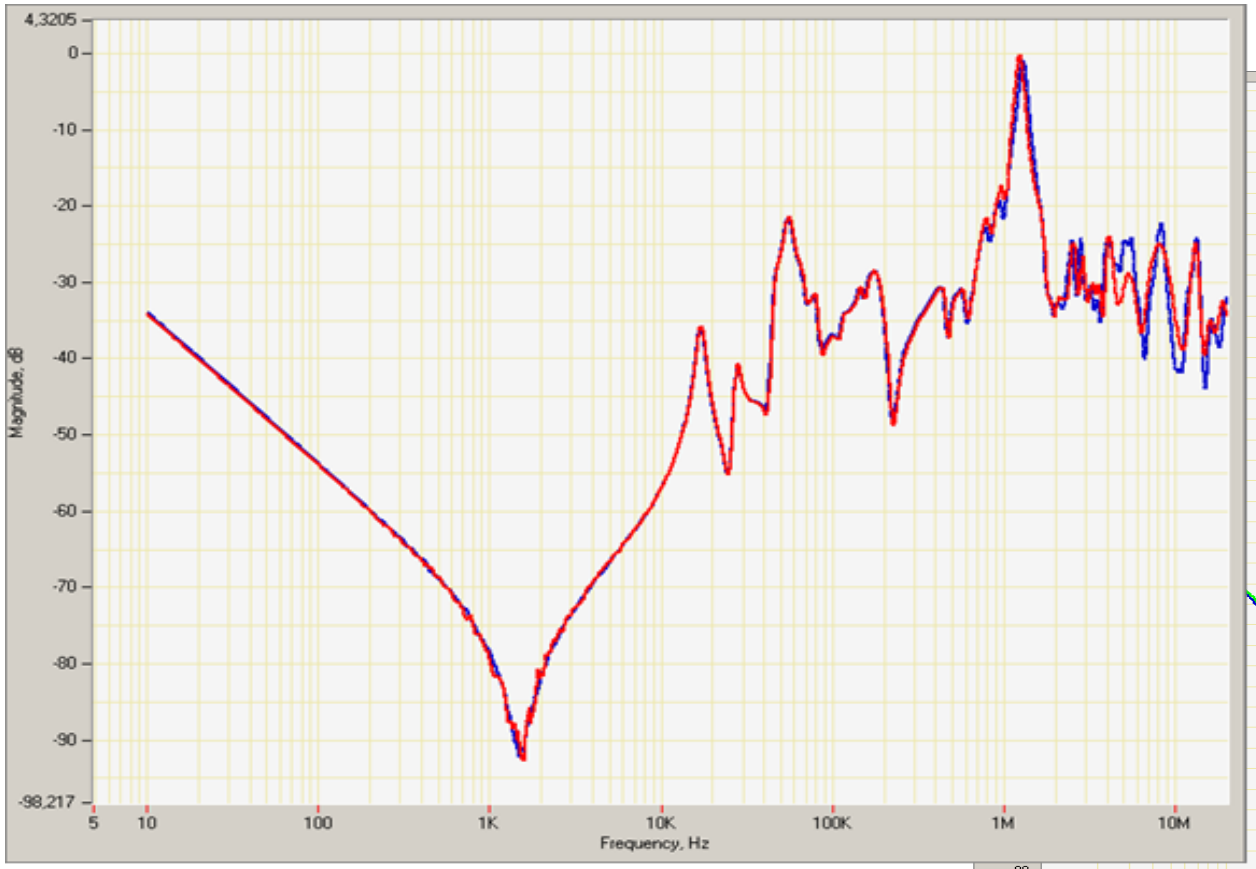


Measurement made through earth switch

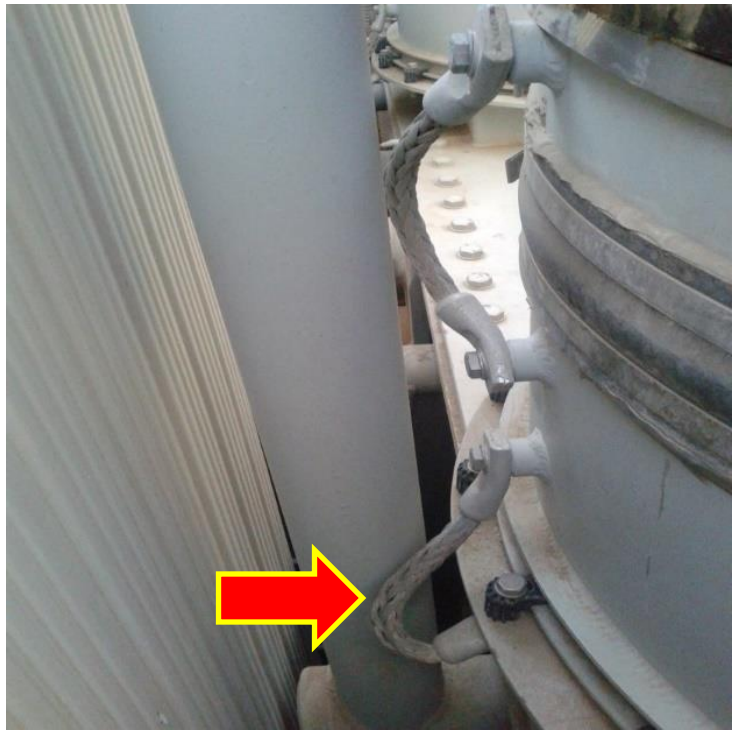


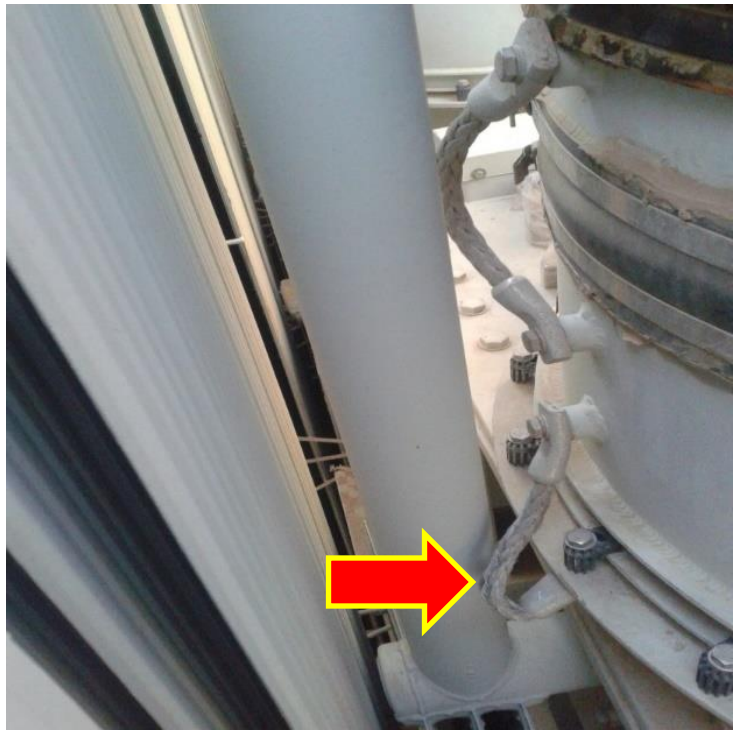
Measurement made directly to bushing terminals

Effect of missing core earth



Effect of poor grounding





Can you spot difference between the two grounding braids?

Effect of poor grounding

…one was not correctly earthed

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Importance of Good Reference Results

Importance of good reference results

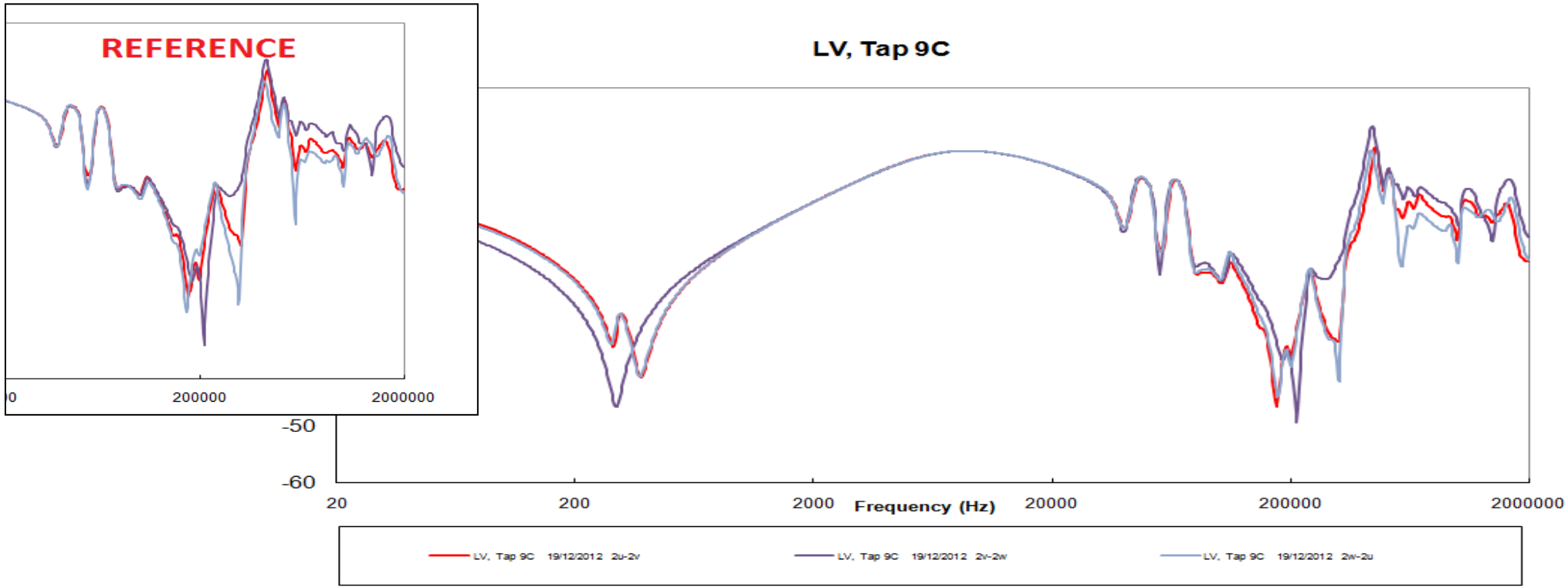
The SFRA results not always give easy to interpret results eg. completely aligned responses of three phases. Although in some cases experience plays important role and allows to recognize certain situations, sometimes additional reference results are extremely helpful in interpretation.

Such reference can be usually taken from:

- Previous results
- Sister unit

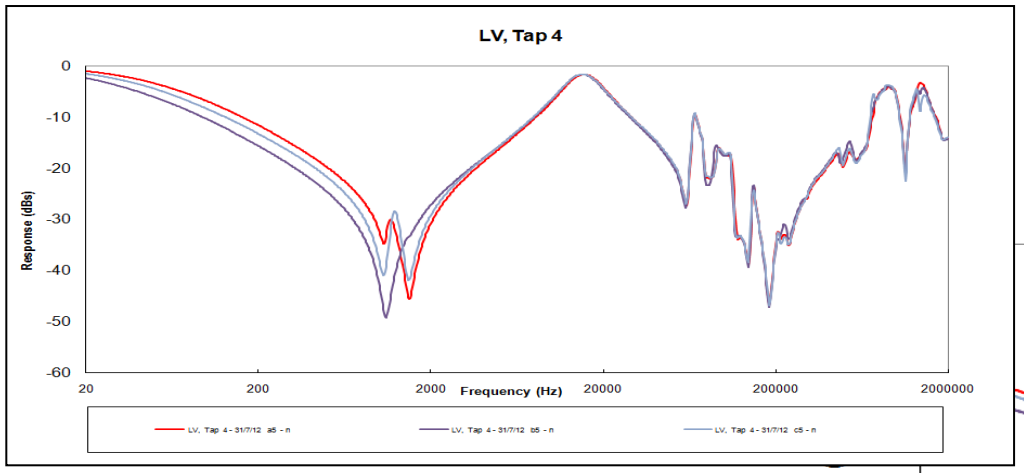
It is important to obtain the same test setup as was used for reference results in order to use them.

Importance of good reference results

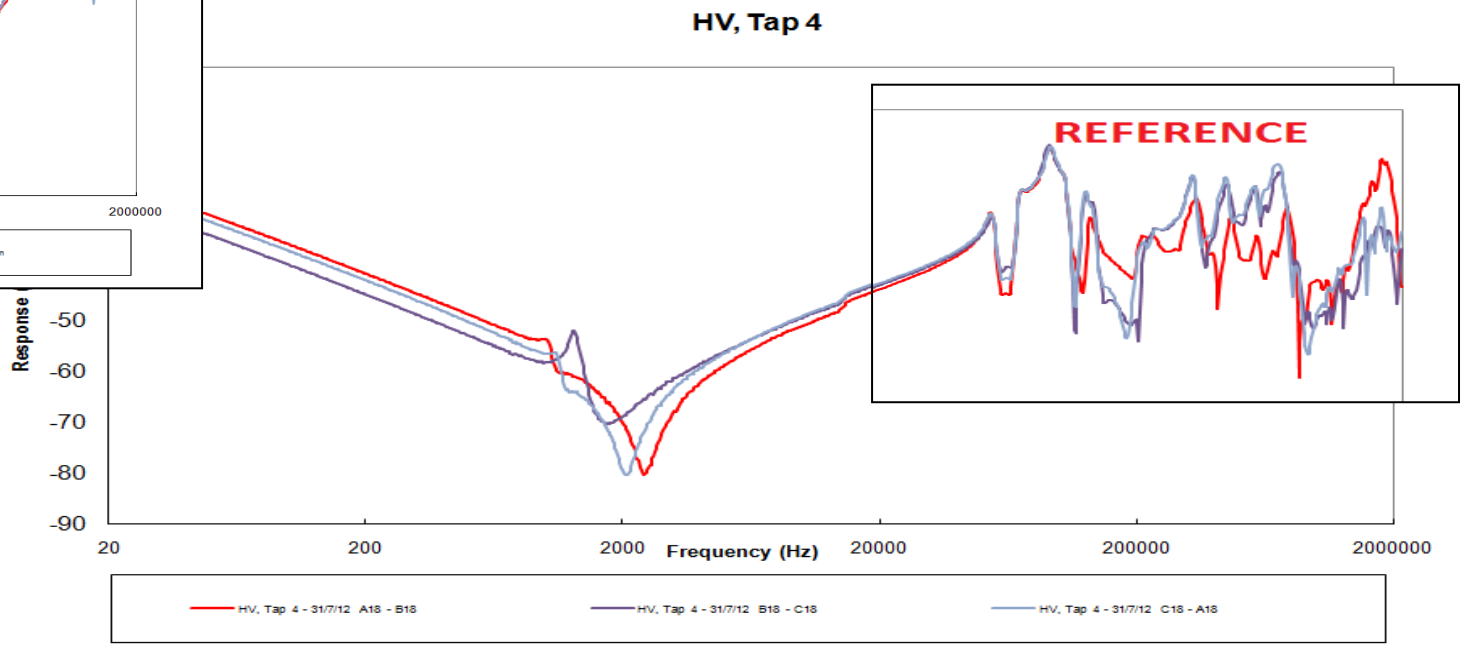


Suspicious difference was measured at LV side. Sister transformer was available to obtain reference but it was connected to HV cables.

Importance of good reference results

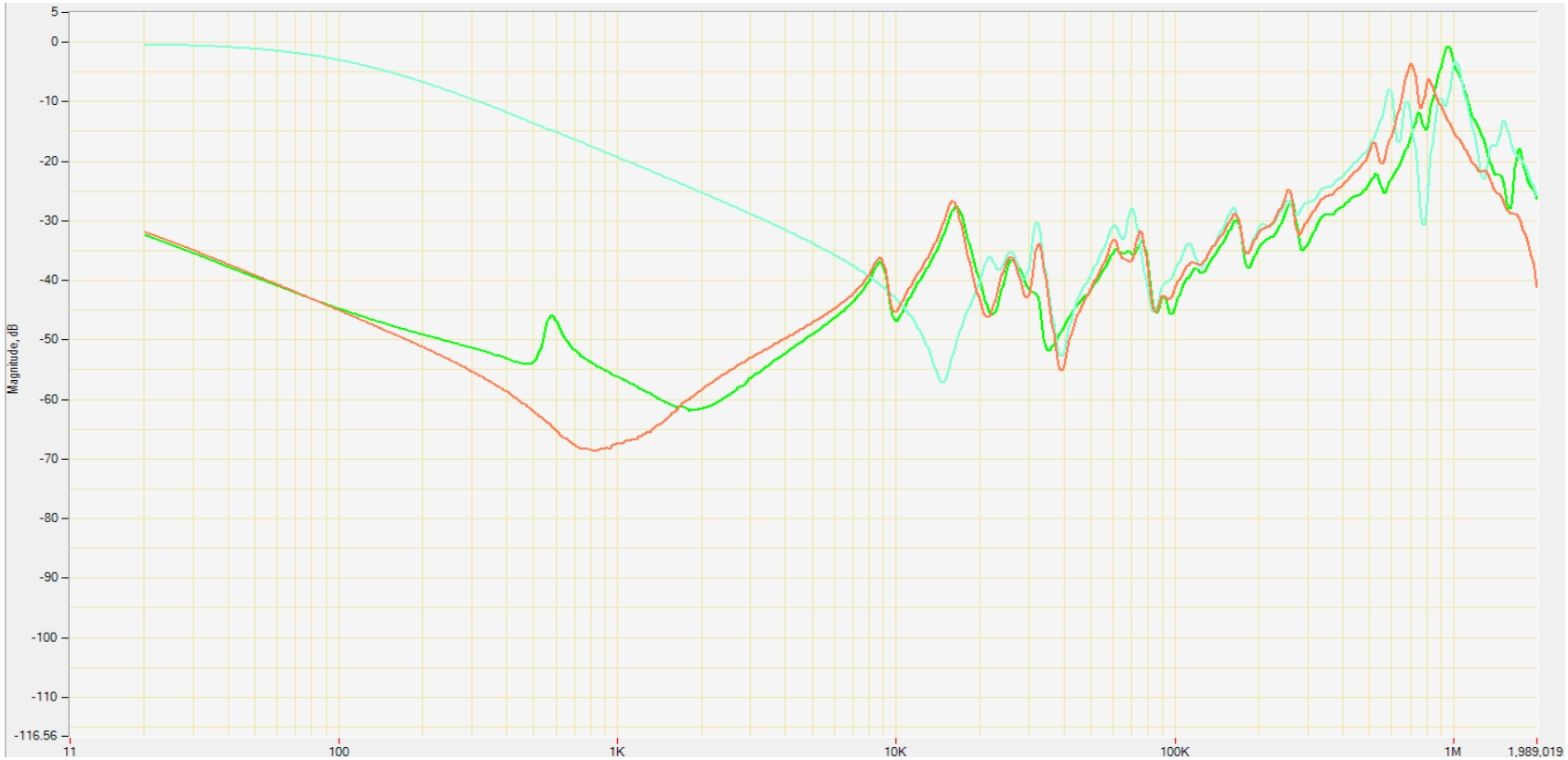


Small distribution transformer



SFRA Examples

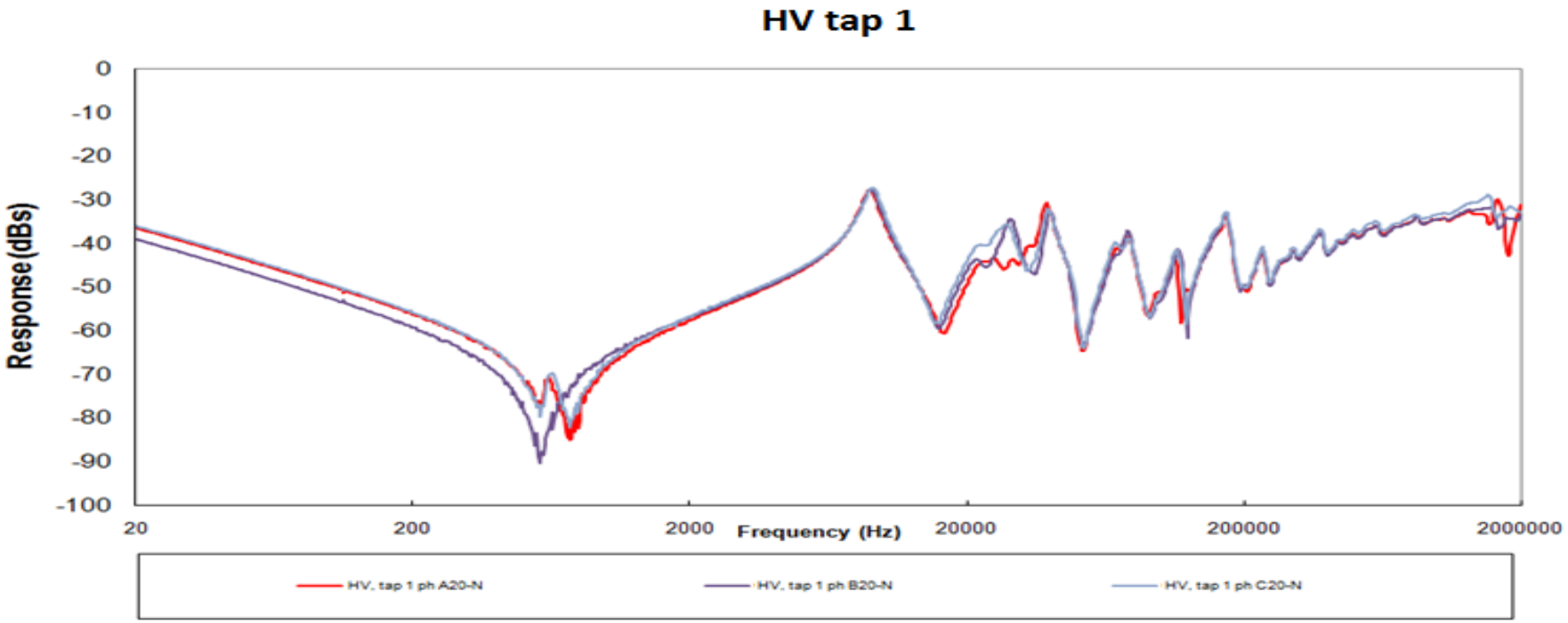
Shorted turns



Let’s start with something easy.

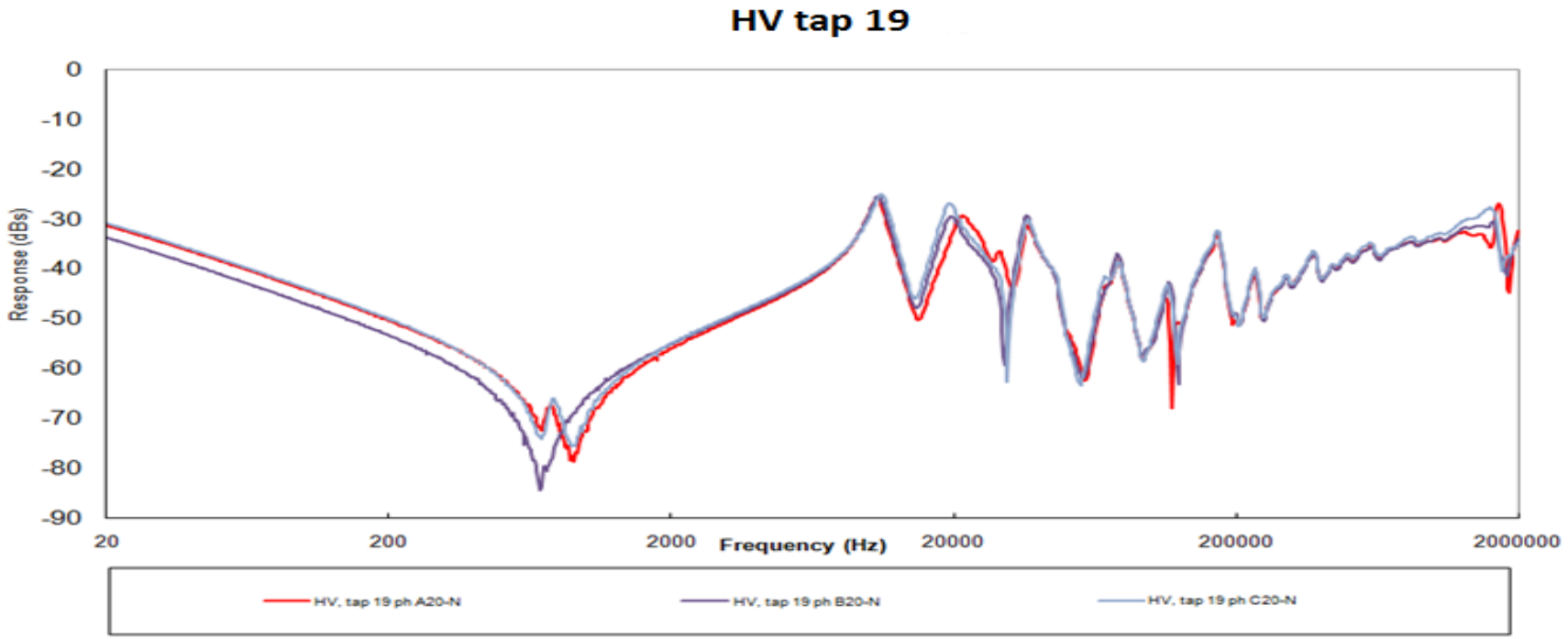
750MVA, 380/230/13.8kV autotransformer YNay0d11, failed in service

Movement of Single Turns



So is this a good transformer? It tripped from service due to flashover across contacts of A phase OLTC selector.

Movement of Single Turns



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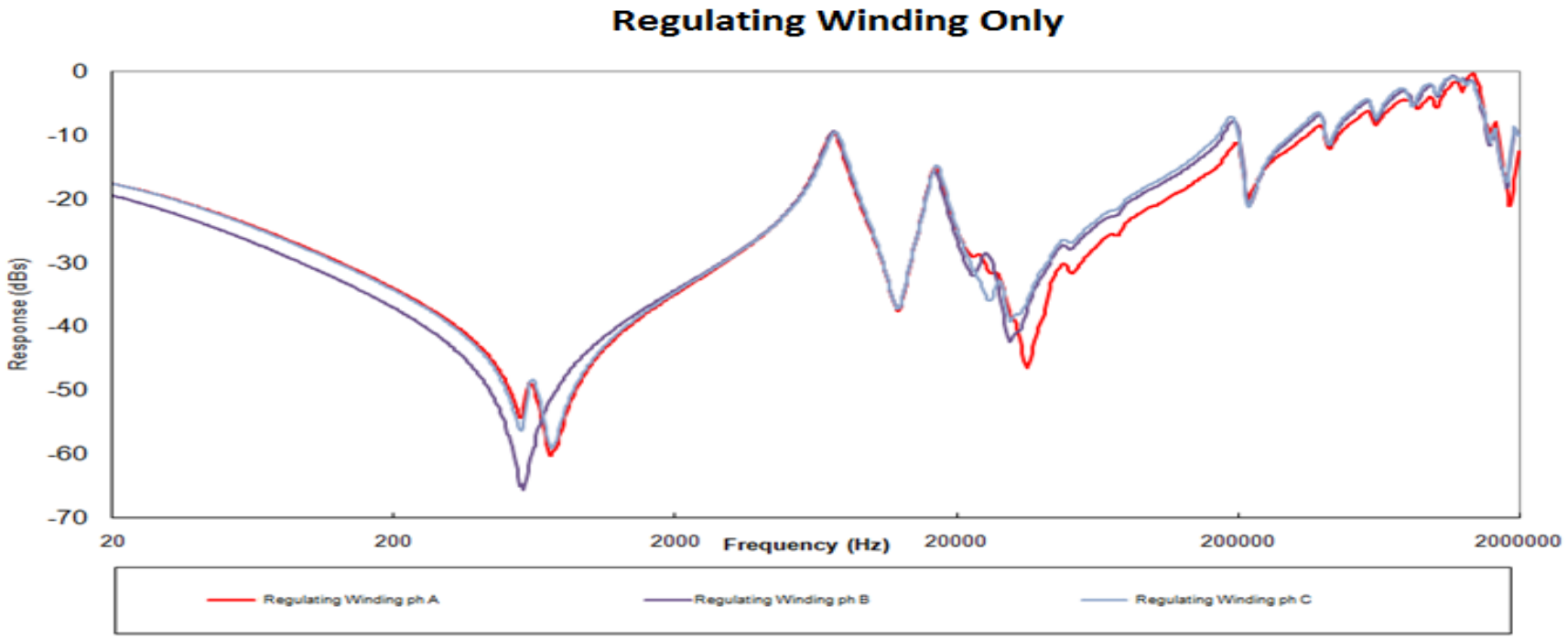
Movement of Single Turns



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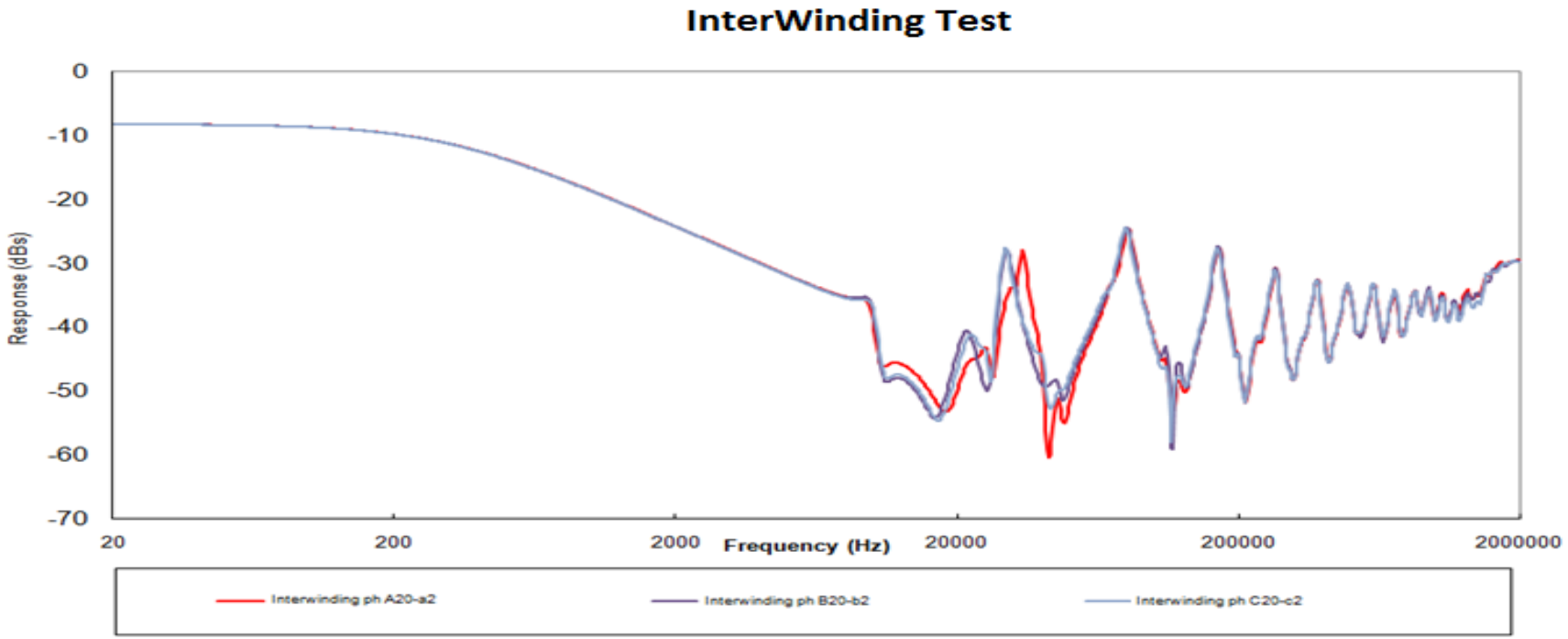
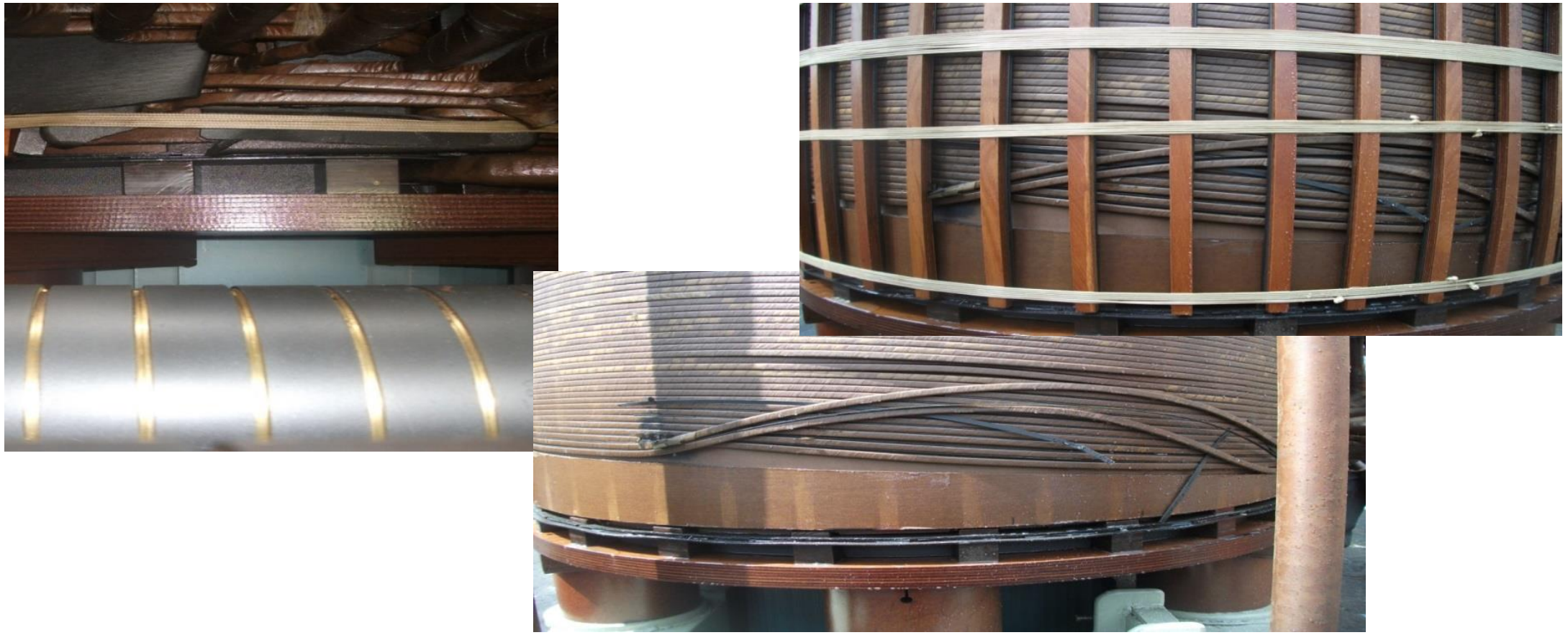


So is this a good transformer? It tripped from service due to flashover across contacts of A phase OLTC selector.

Movement of Single Turns



Luckily it was possible to see damage through inspection hole.

Scrapping confirmed slight winding deformation on A phase

Axial Collapse

Initial symptoms

35 year old 400/132 kV 240 MVA auto-transformer

10:53 a.m. Monday 5th November 2001

Buchholz alarm

Transformer **switched out for investigation**

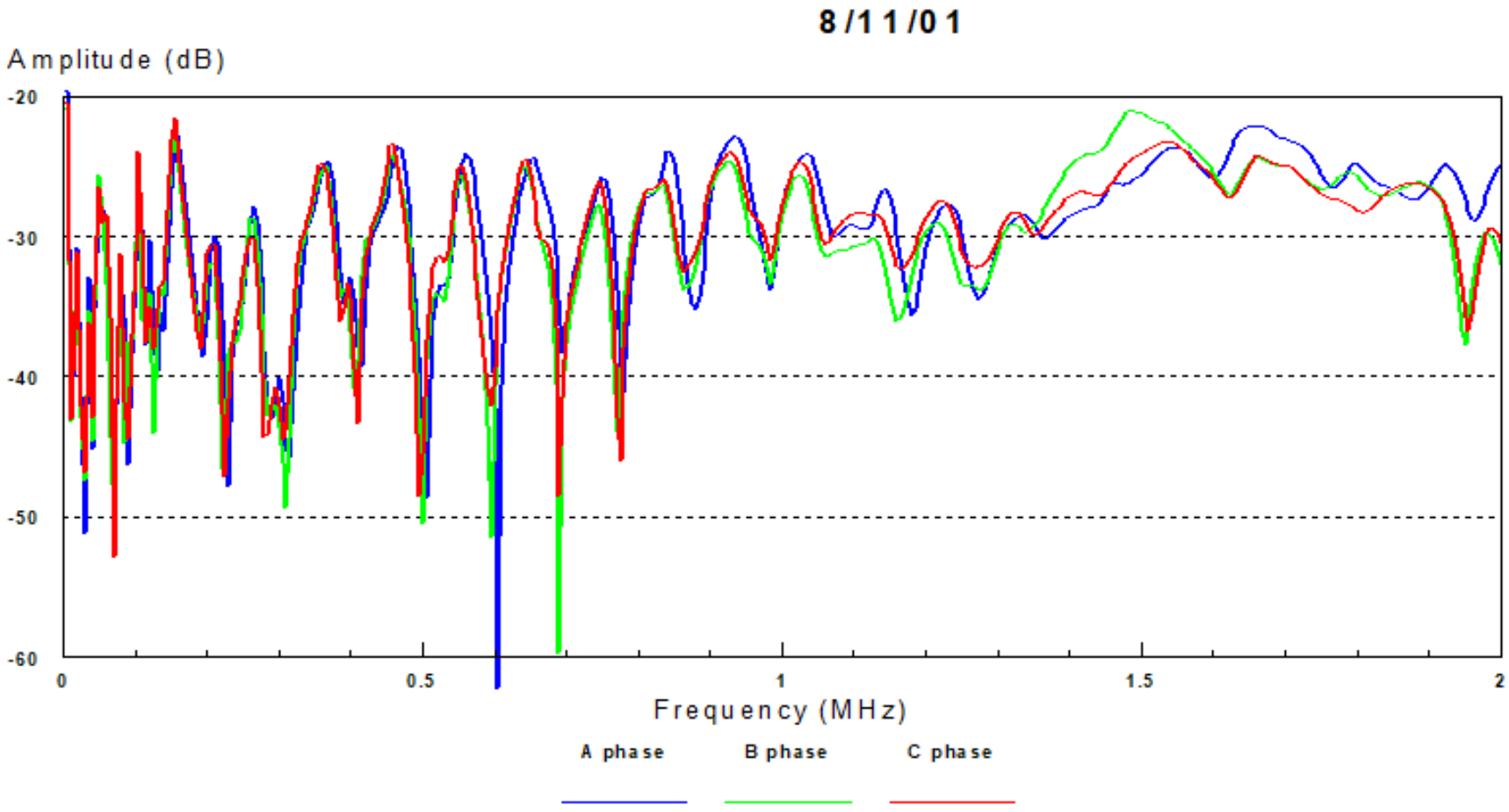
Analysis of Buchholz gas and main tank oil indicated **serious fault**

No abnormal system events

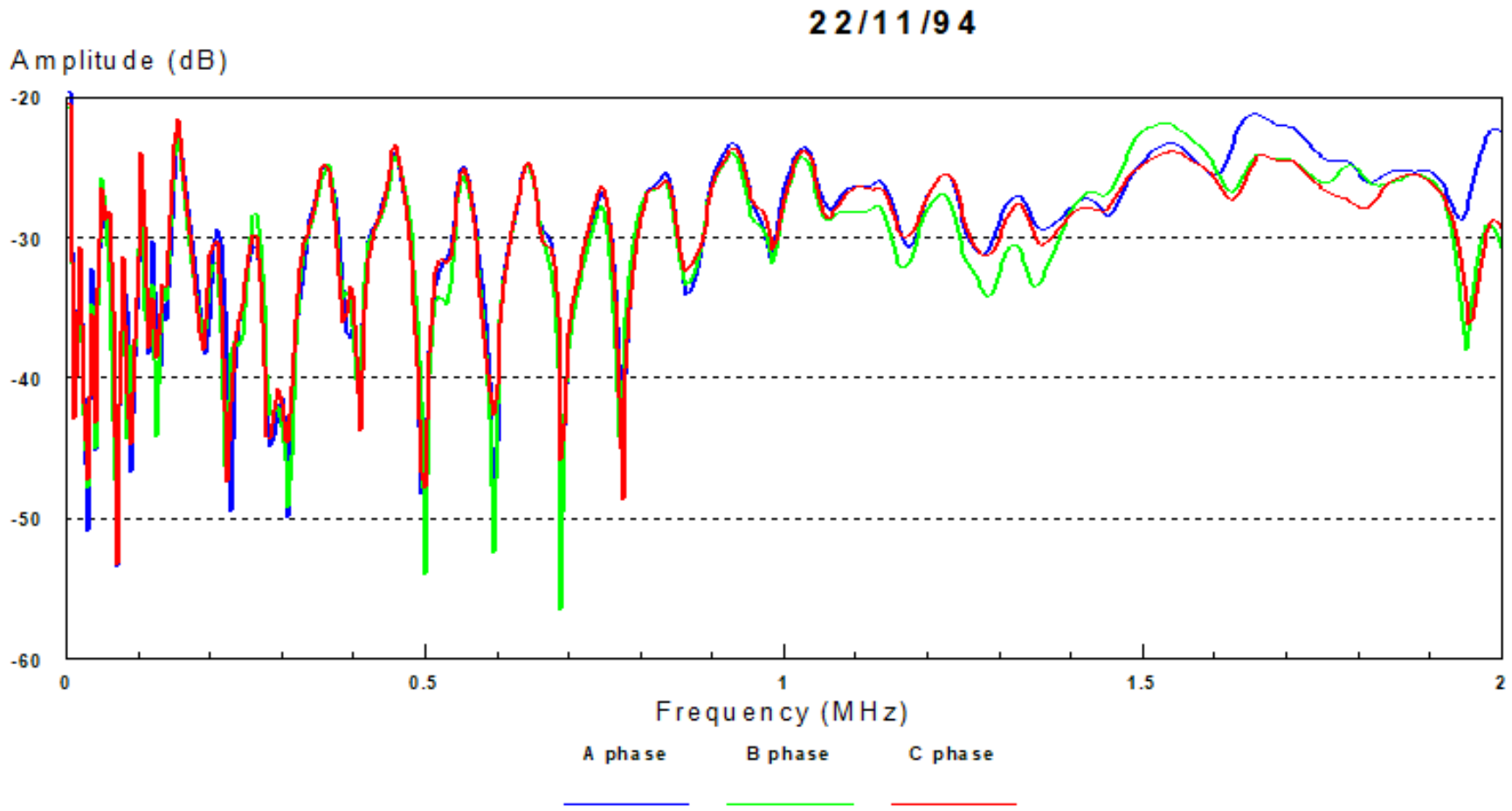
Transformer was operating at 80% loading

Hardly non-conclusive electrical test results, but…

Axial Collapse

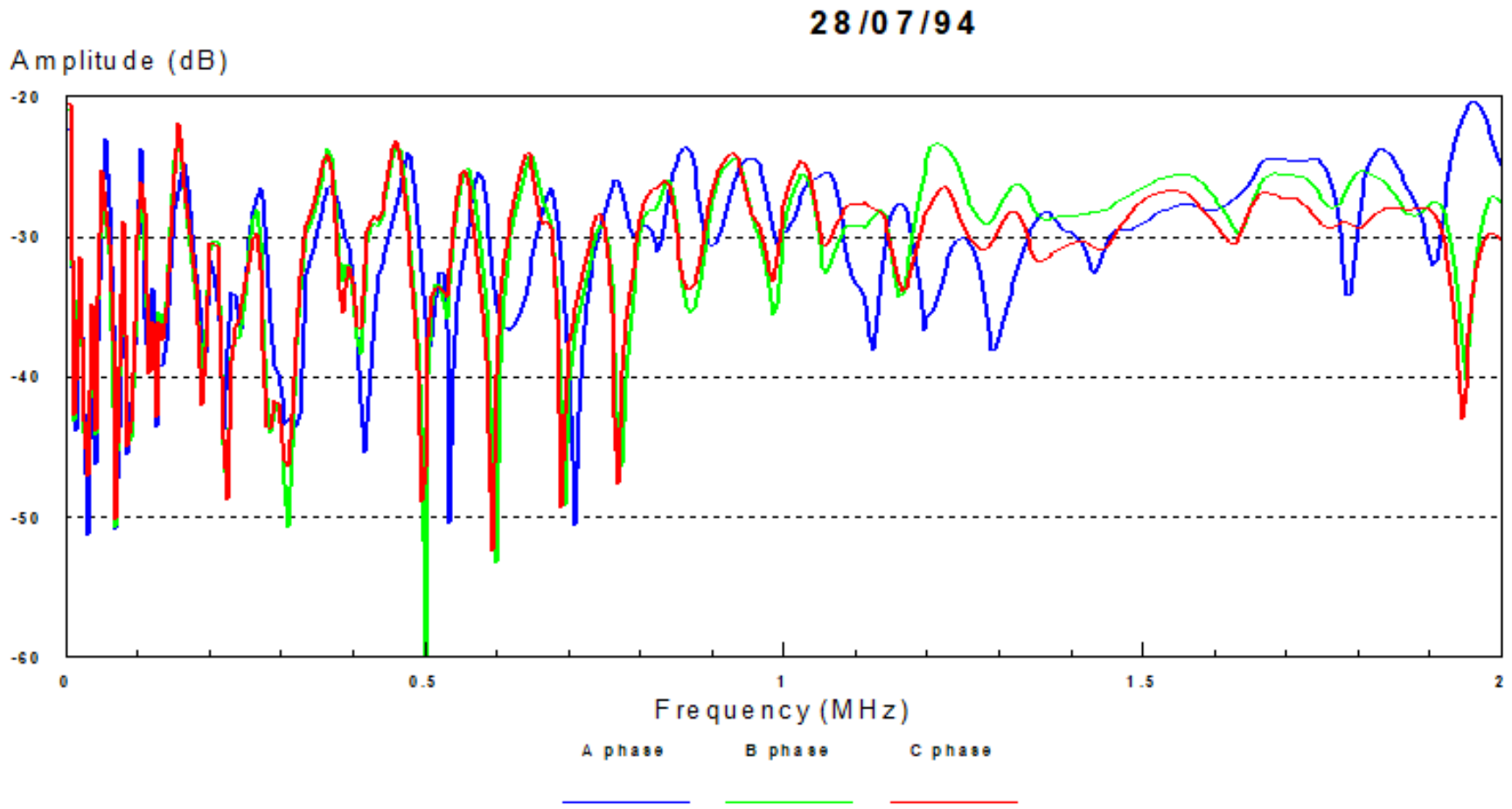


Axial Collapse



Previous results

Axial Collapse



Sister unit failed in service

Axial Collapse

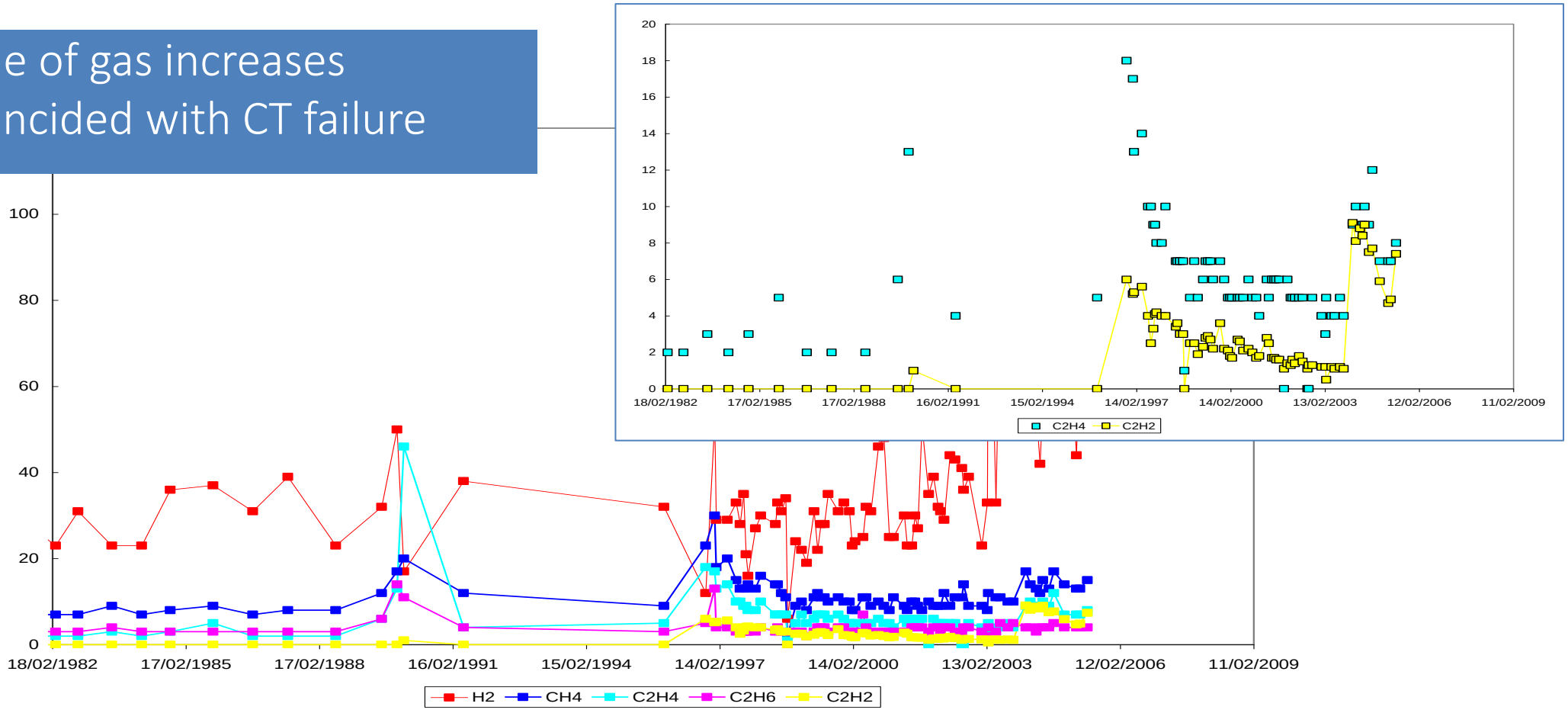
Buckling Deformation

Transformer details:

- 375/750MVA ONAN/ODAF
- 400/275/13kV autotransformer
- No taps
- Built 1966
- Deterioration in DGA results
- Removed from service for investigation

Buckling Deformation

One of gas increases coincided with CT failure



DGA showed three potentially damaging events

Buckling Deformation

Sister transformer

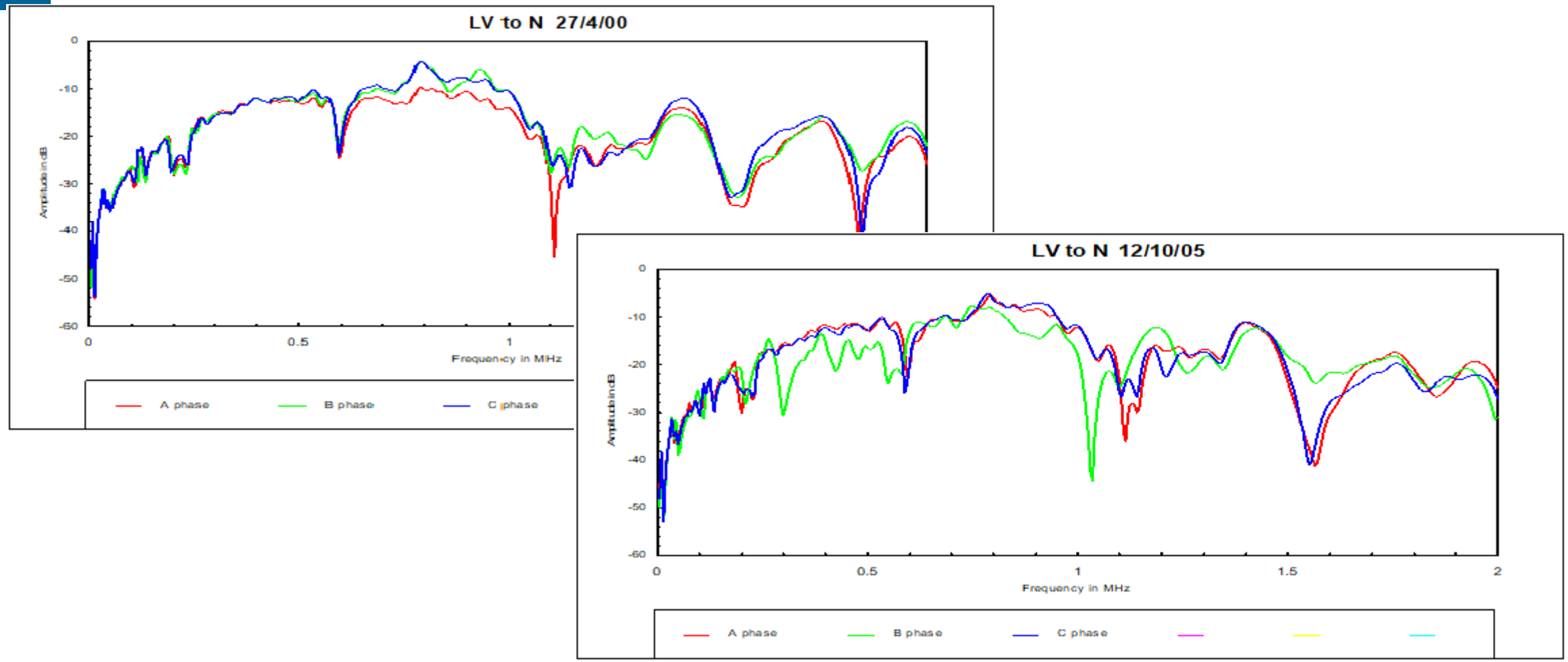
T4673			
	A phase	B phase	C phase
Main windings to earth, CH	4,405 pF 0.51 %	3,634 pF 0.56 %	4,294 pF 0.52 %
Main windings to tertiary, CHT	8,786 pF 0.55 %	8,711 pF 0.56 %	8,525 pF 0.56 %
Tertiary winding to earth, CT	17,924 pF 0.52 %		

Suspect transformer

T4971			
	A phase	B phase	C phase
Main windings to earth, CH	4,246 pF 0.75 %	3,368 pF 0.51 %	4,273 pF 0.62 %
Main windings to tertiary, CHT	8,277 pF 0.42 %	**5,775** pF **1.91** %	9,030 pF 0.54 %
Tertiary winding to earth, CT	**20,668** pF 0.46 %		

Significant difference in capacitance and power factor were noted for phase B

Buckling Deformation



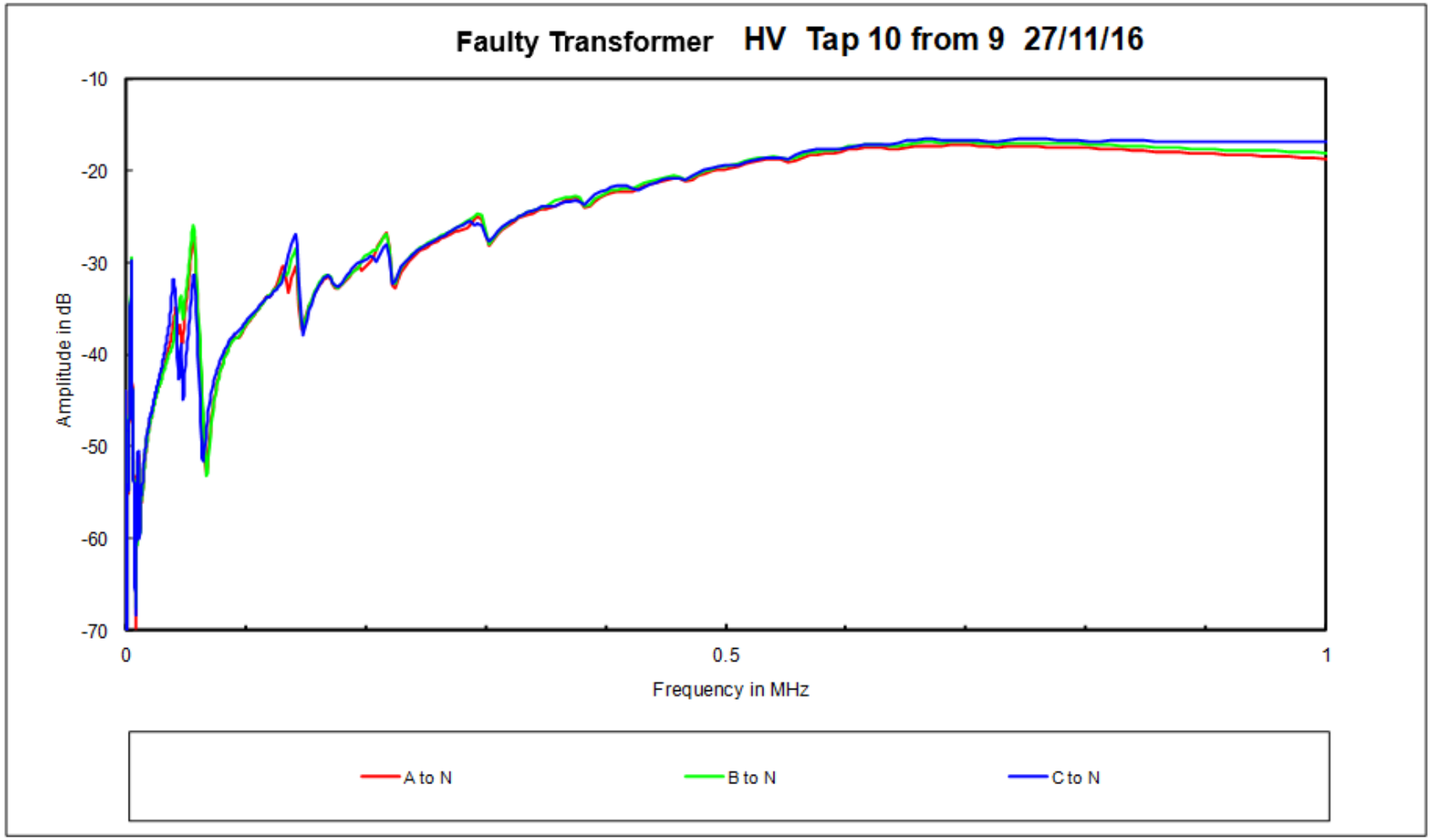
Also a significant difference in frequency response was noted for phase B

Buckling Deformation

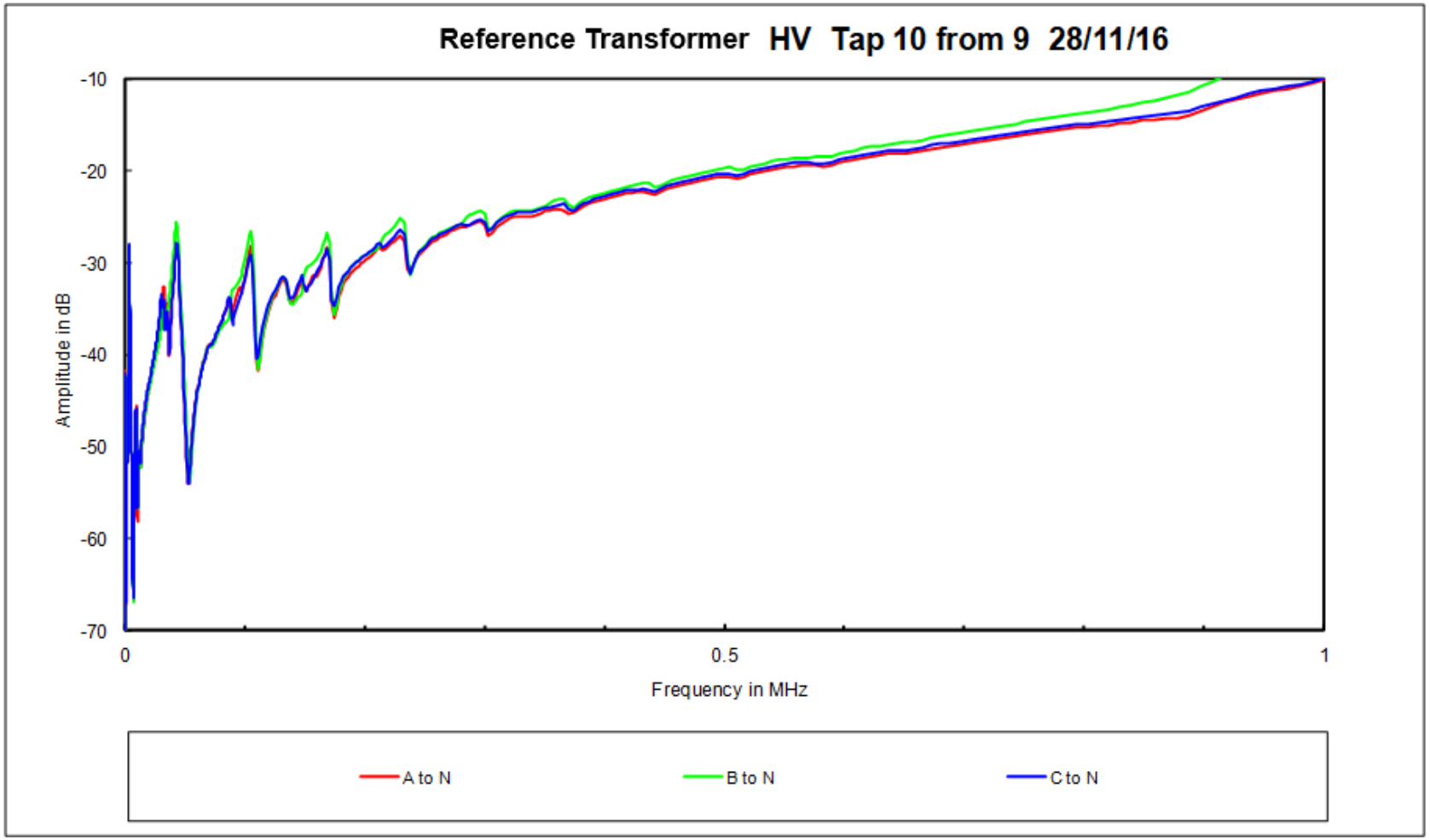
Tap Winding Movement

- 275/33kV 120MVA YNd1 transformer feeding steelworks suffered flashover between taps while on ‘hot standby’
- Barrier board between tap-changer and main tank broken
- SFRA tests indicated movement for tap winding:
  - ✓ **Difference for Blue phase at Tap 1 (taps ‘all-in’), but not at Tap 10 (‘all-out’)**
  - ✓ **Compared responses with sister reference transformer**
  - ✓ **Note faulty transformer was without oil, while reference was oil filled**
- Internal inspection confirmed conductor tilting for Blue phase tap winding
- Special SFRA Tests showed possibility of internal resonant over-voltage between taps involved in flashover for switching surge at HV line terminal

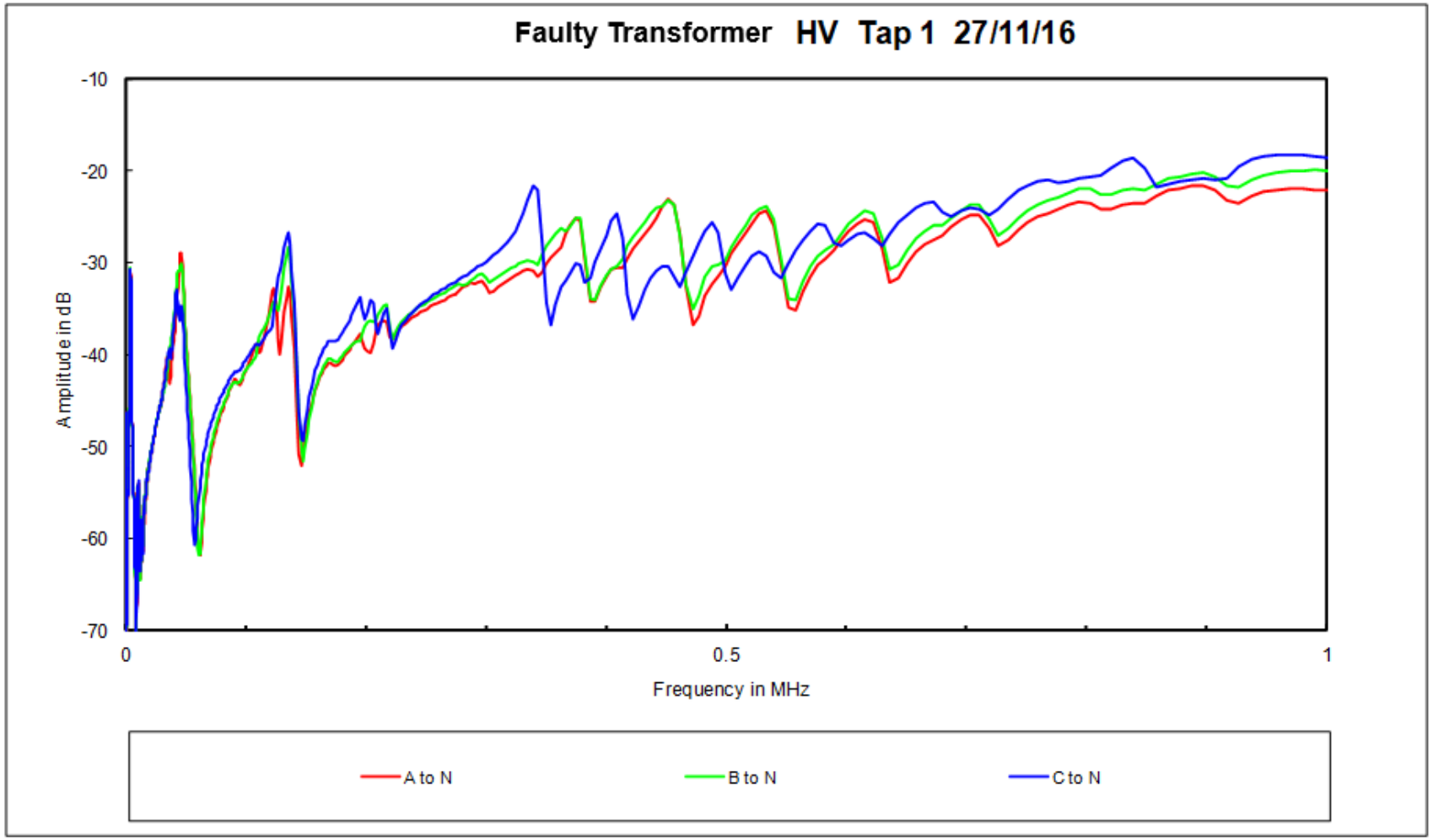
Tap 10 HV SFRA for faulty transformer



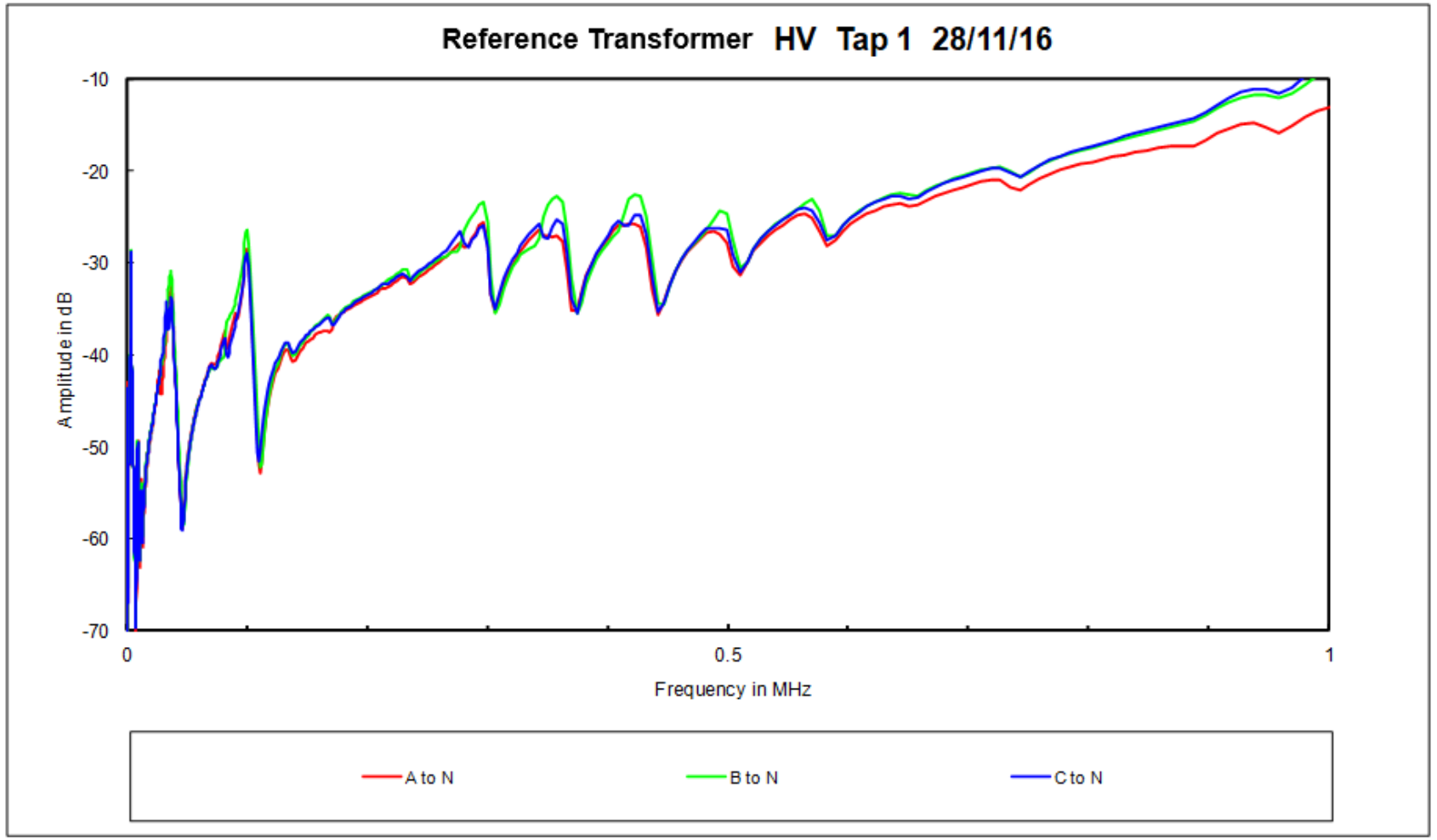
Tap 10 HV SFRA for reference transformer



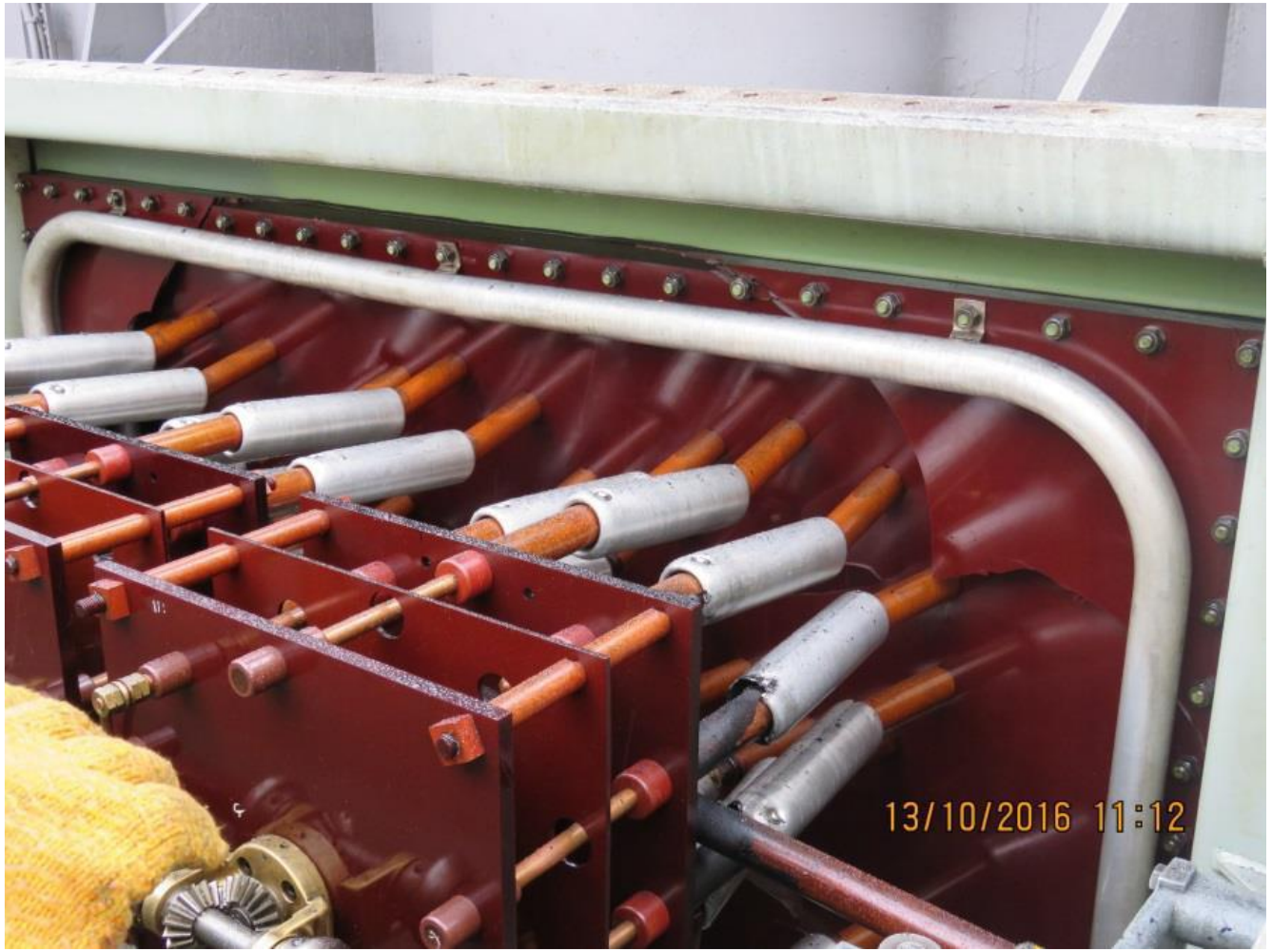
Tap 1 HV SFRA for faulty transformer



Tap 1 HV SFRA for reference transformer



Broken tap-changer barrier board



Flashover damage between Blue phase tap leads

Internal View

Conclusions

- Reference results if available, can greatly support interpretation of results. This can help either to confirm winding damage or to clear doubts regarding suspicious traces
- It is important to be aware of number of different factors which can affect the measurement, eg. tap position, state of stabilizing winding. Results obtained in different conditions may not make good reference.
- Little difference can still mean dangerous deformation but at the same time, large differences can be caused by factors other than winding damage. This makes interpretation more difficult.

Thank you!

Rafal Zaleski
Principal Transformer Engineer
Doble Engineering