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Diagnostic of power transformers and their insulation materials

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I. IMPORTANCE OF THE DIAGNOSTICS

- In order to prevent the fault condition of transformers – different types of diagnostic measurements.

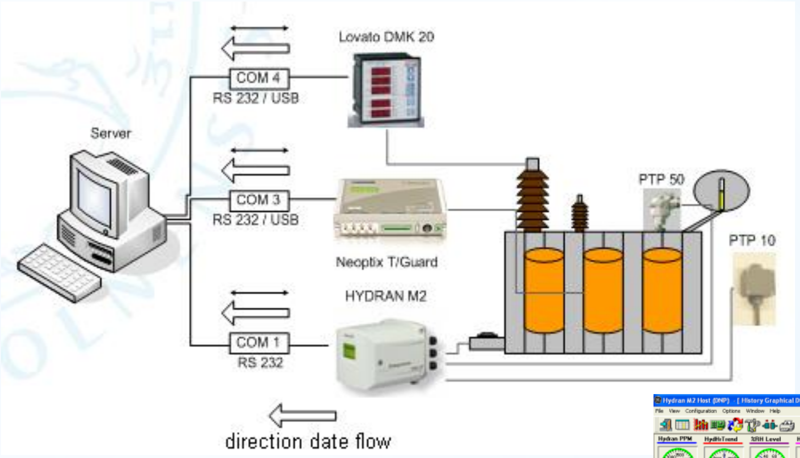
Diagnostic measurement:

- illustrate a momentary condition of the measured equipment,
- early to warn in change of parameters,
- early to warn in possible failures.

- Principle about diagnostics – to detect weak points in insulating and construction system of transformer.

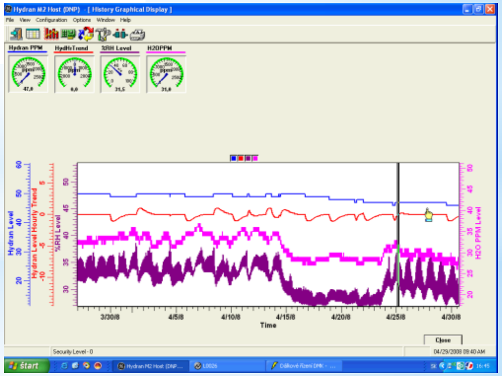
II. The Diagnostic Methods of Transformer

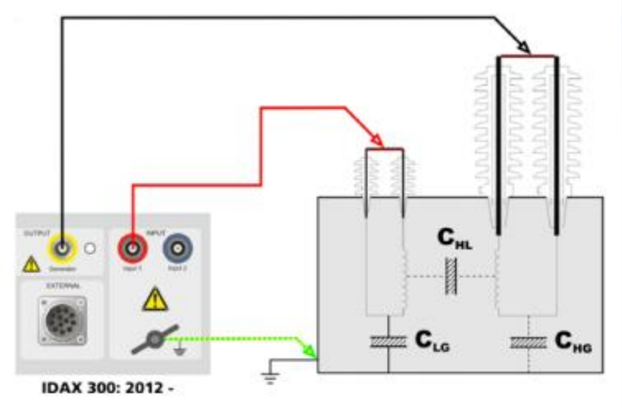
Laboratory of diagnostics of electric machines in University of Zilina

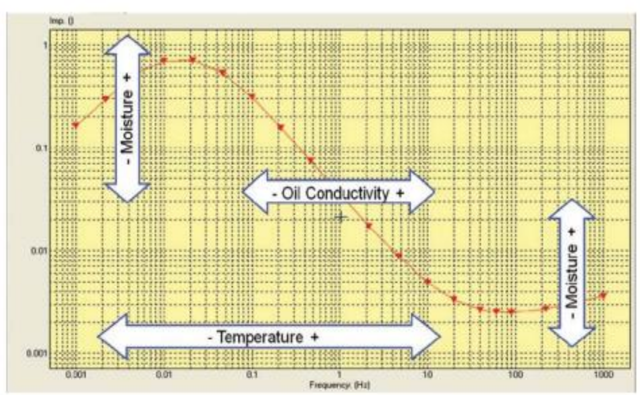


On-line system for diagnostics of insulating transformers properties

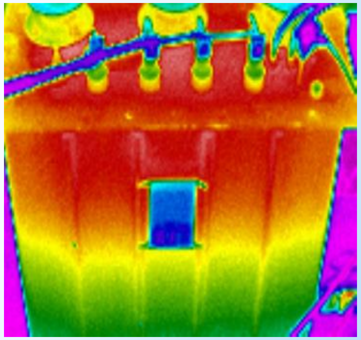
- Gas.
- Aqua.
- Moisture.
- Temperature.







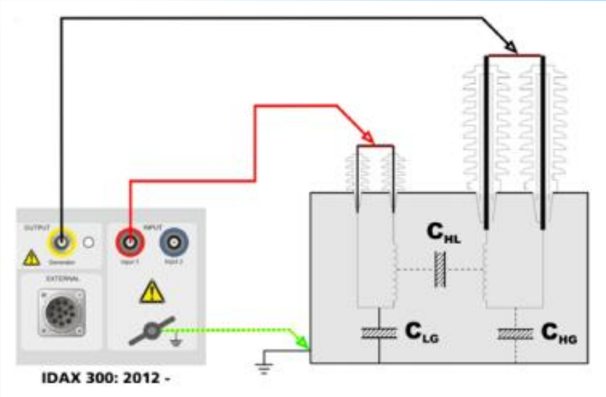
Off-line system for diagnostics of insulating transformers properties – frequency method

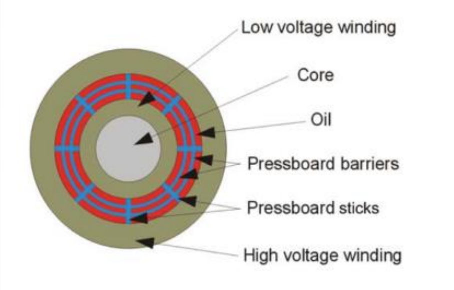


III. Diagnostics of the Transformer Insulation Properties

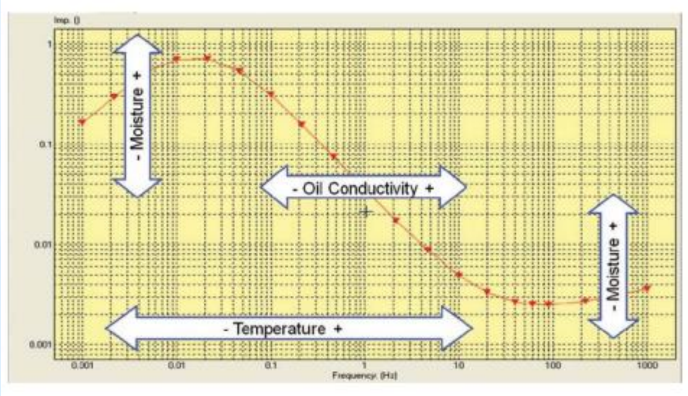
III.A Diagnostics of the Transformer Insulation Properties

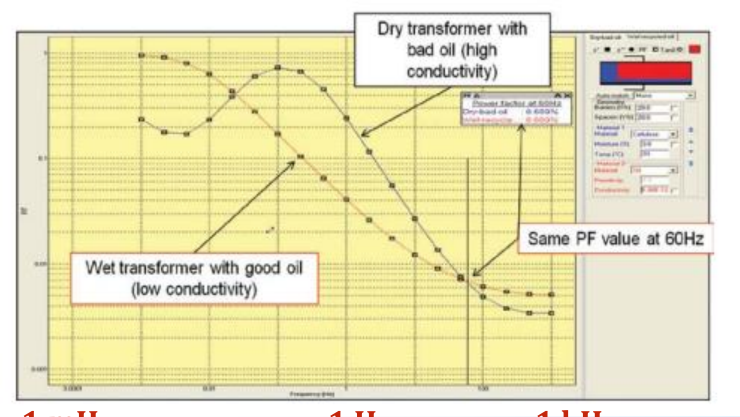
- **Monitoring by means of probe HYDRAN M2** – trend monitoring of gases, moisture and water in transformer oil,
- **Dielectric spectroscopy (FDS) –** measurement of dissipation factor, capacitance and permittivity depending of frequency,
- **Return voltage measurement (RVM) –** time method,
- **Chromatography –** detection of resulting gases in transformer oil.





Analysis: deformation and moisture in insulating paper and conductivity in oil.





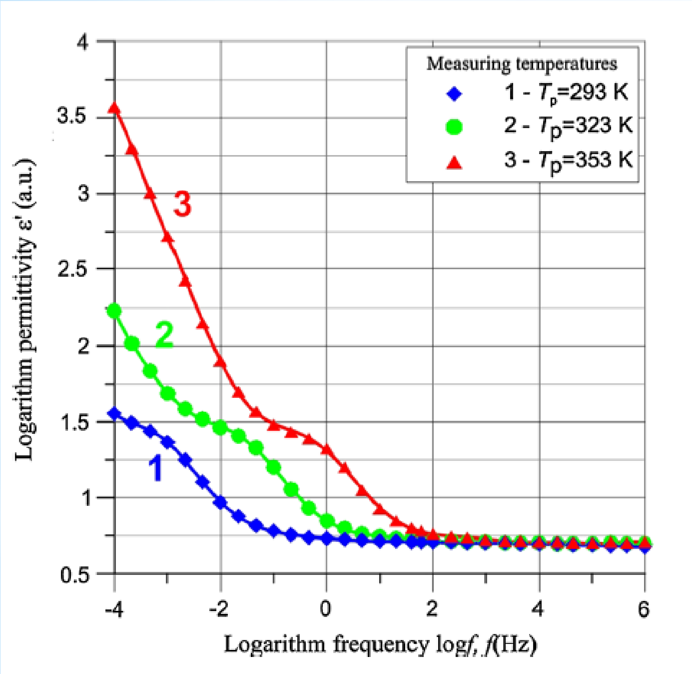
1 mHz 1 Hz 1 kHz

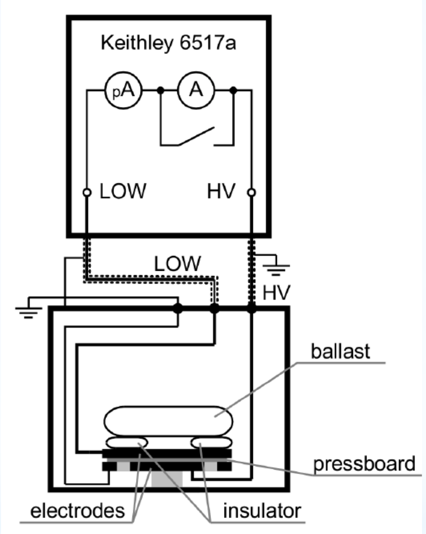
International cooperation with Gdansk university and Lublin university, Poland

III.B FDS METHOD – ACCURACY IS AFFECTED BY TEMPERATURE
– ELIMINATION BY MATHEMATICAL AND PHYSICAL MODEL

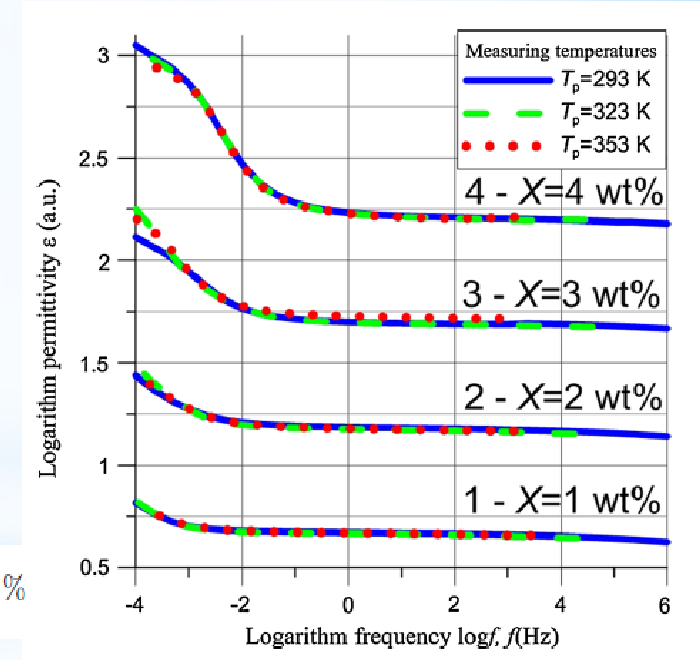
International cooperation: Permittivity of a composite of cellulose, mineral oil, and water nanopractícles: theoretical assumptions, In: **Cellulose.** ISSN 0969-0239. - Vol. 23, no. 1 (2016), p. 175-183. **IF=3.42**

Frequency method FDS is very temperature-sensitive for determination right value of moisture of paper and conductivity in oil.
Therefore in cooperation with the Polish Universities, we decided to create a physical isolation model of transformer, where it was designed the frequency curves for different temperature ranges at the given moisture and temperature 20 °C.





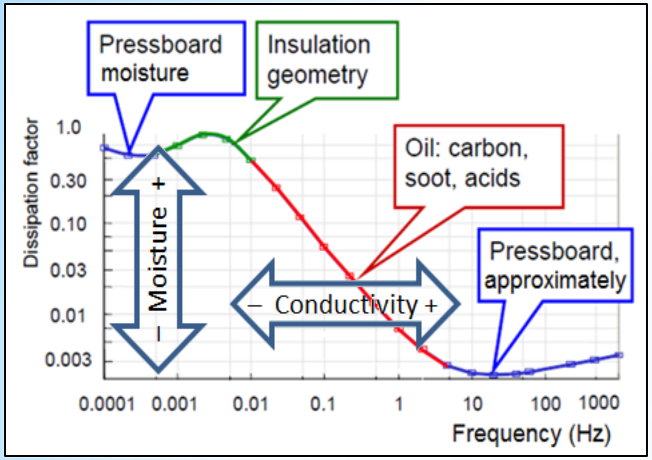
$$Y(\log f) = \frac{\varepsilon_{apr}(293\,\mathrm{K}) - \varepsilon_{apr}(T_i)}{\varepsilon_{apr}(293\,\mathrm{K})} \times 100\,\%$$

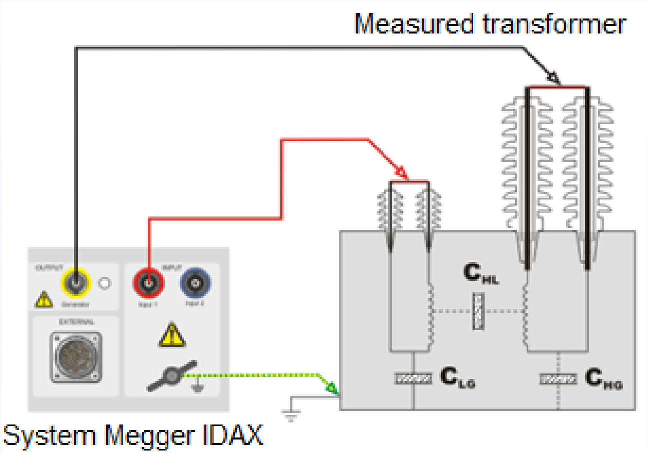


Permittivity with frequency – different temperature at the given moisture

Elimination for 20°C
by mathematical and physical model

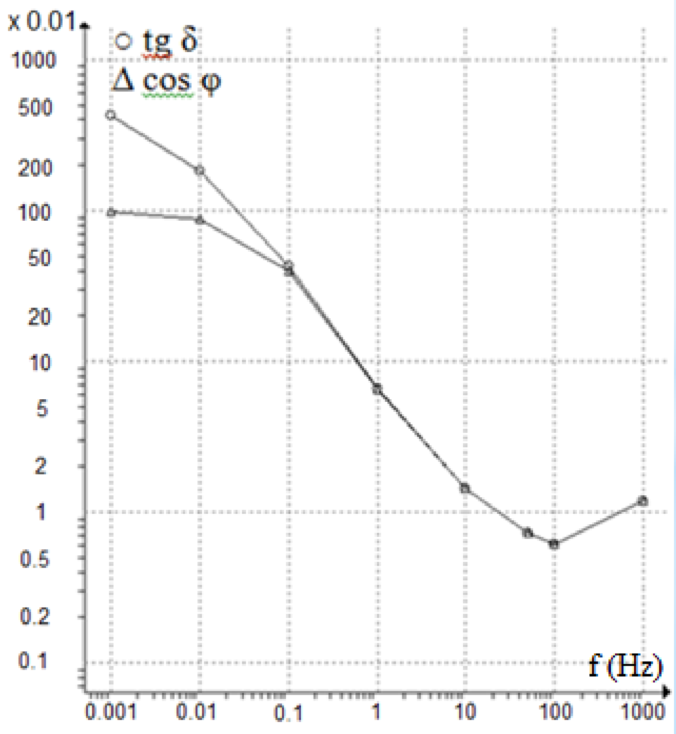
III.C EXPERIMENTAL MEASUREMENT BY FDS METHOD





In the paper it is described experimental measurement of three-phase oil transformer 22 kV by methods FDS and RVM method.
Here it was analyzed deformation and moisture in the paper insulation and conductivity in oil.

Measurement of the frequency response of the isolation system or measurement by the frequency domain spectroscopy (FDS) method was performed by the MEGGER IDAX instrument.
In this method it was measured parameters - the percentage loss factor, capacities and permittivity depending on the frequency of 10 kHz up to 1 mHz.



The processes in Figure show the measured characteristics of the loss factor (tgδ) and the power factor (cosφ) between the windings, depending on the frequency of the harmonic supply.
From the entered values of temperature, moisture and transformer parameters, the modelling curves are calculated by the IDAX program. Moisture of paper had value 3.5%.

III.D Experimental Measurement by RVM Method

Our task was to compare the sensitivity of the two methods – time RVM method and FDS method by frequency response.

The evaluation of the measurement of the moisture content in the insulating paper - it was determined from the analysis of the charging time and the maximum voltage.

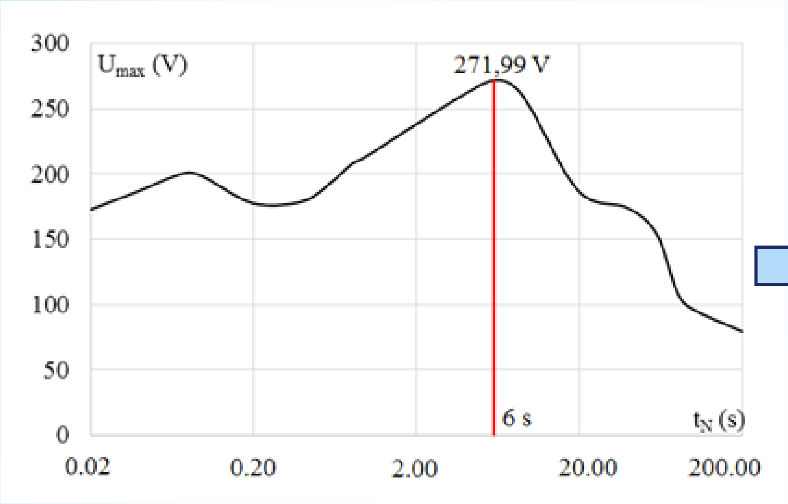


Fig. 1 The time behaviour of voltage response of the insulation system

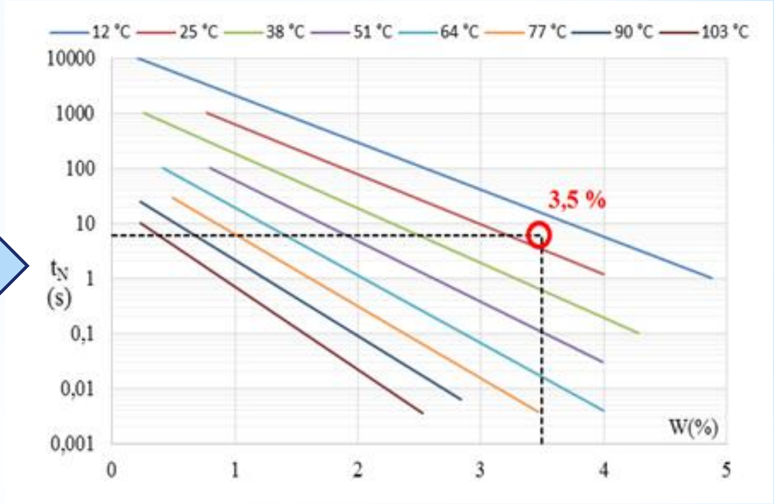


Fig. 2 Evaluation curves for the voltage response measurement method

According to Fig.2:

- value of moisture content in the transformer **paper was 3.5 %,** which means very wet transformer and unsuitable to operation.

III.E Conclusion

- The both measuring methods are unique in terms of analysis of insulating system of oil power transformers.
- In comparison with other methods, the RVM and FDS methods can evaluate the moisture condition of the insulation paper of the power transformer with high accurate.
- Their reliability in determining moisture in paper was shown by determining the same result (3.5%) on the same measured distribution transformer.
- The advantage of the FDS method compared to the RVM method is in determining the conductivity value of the oil and the loss factor (including the total transformer insulation system).
- The disadvantage of the FDS method is the need to measure very small currents. It is necessary to use shaded measuring cables.

IV. Diagnostics of the Transformer Mechanical Properties

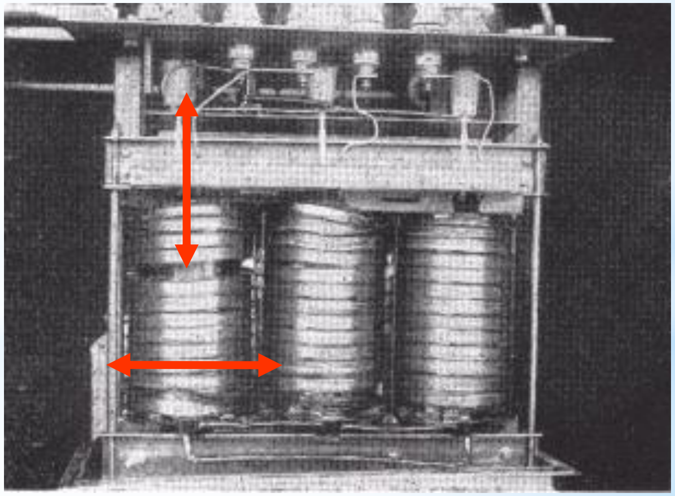
IV.a The theory of the causes of short circuit forces

- The effect of mechanical forces on the windings during short circuit.
- The direct cause of origin the forces acting the windings.

- The normal operating - forces at the windings generally small.
- At the short-circuit - forces can become dangerous of windings and fixing design.

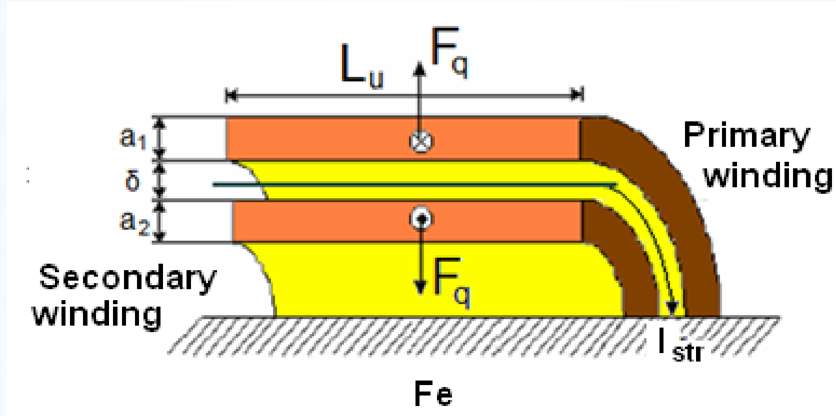
Short-circuit forces on the windings:

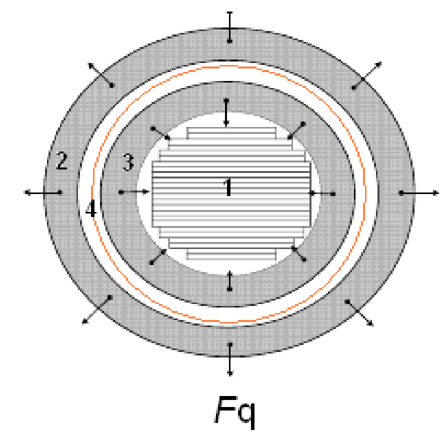
- **radial (transverse),**
- **axial (lengthwise).**

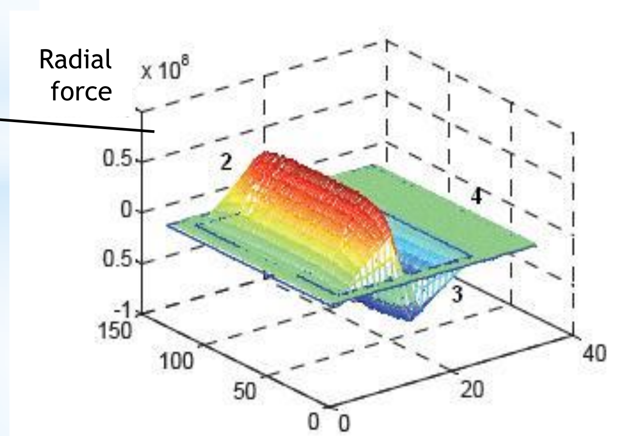


Effect of radial forces on the windings

- Radial forces are a result of effect of the longitudinal field.
- These forces stretched the outdoor windings and compresses the internal winding.
- The sum of the radial forces is active to additional space between the windings.

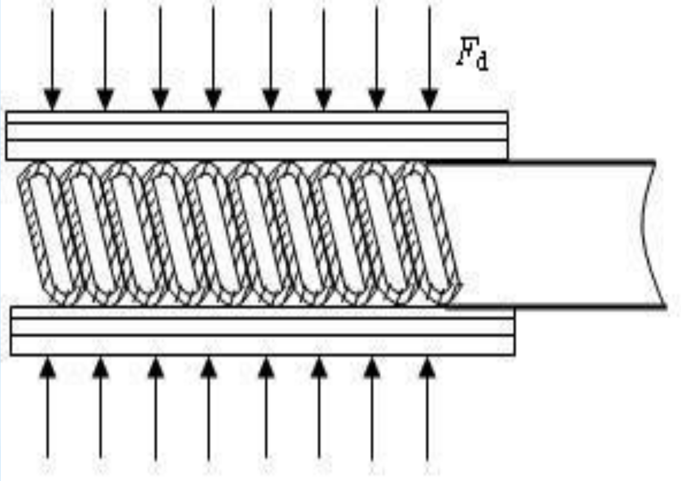




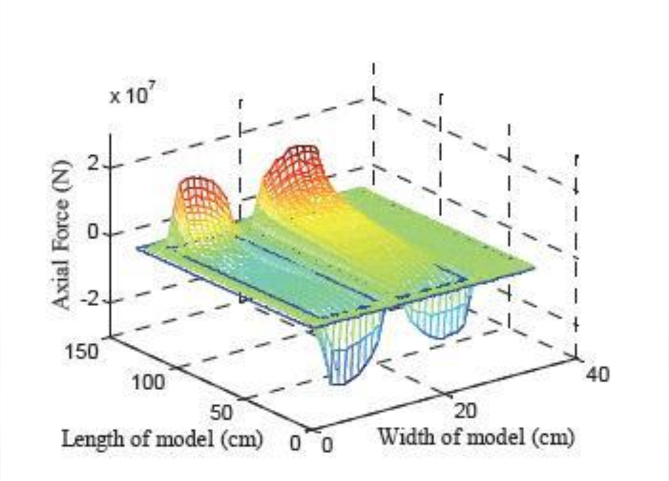


Effect of axial forces on the windings

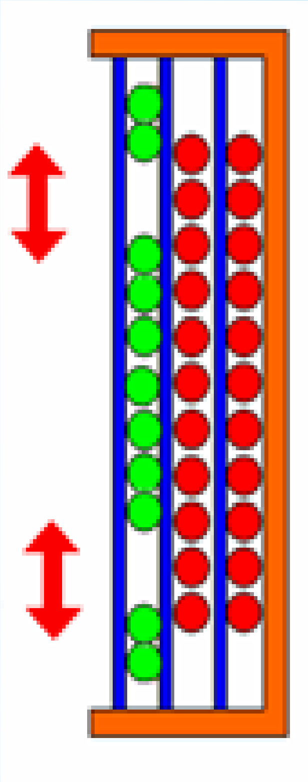
- Axial forces are dangerous in the case of winding asymmetry.
- These forces compress the winding in one another and remove the small air or oil space between the turns and coils.



Pitching wires of coils from excessive axial forces

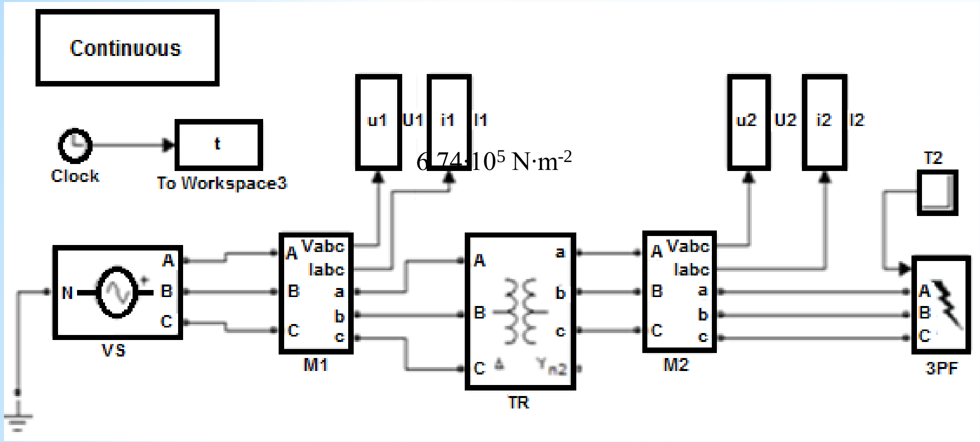


The effect of axial forces at the outer turns in coil

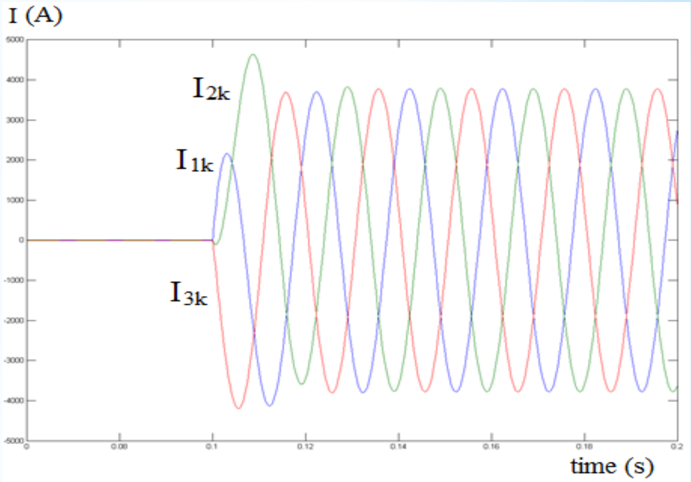


A shift in the primary winding of the vertical sides

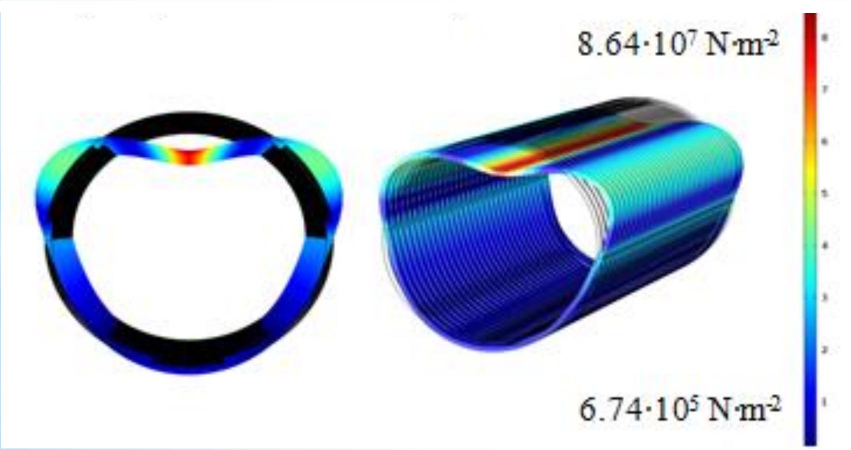
DETERMINATION OF THE SHORT-CIRCUIT CURRENTS



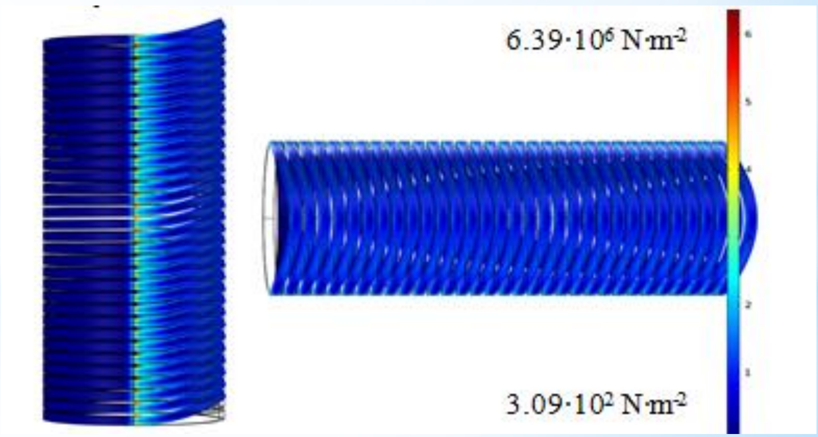
Short circuit directly behind the transformer



Wave-shape of the short-circuit behind transformer



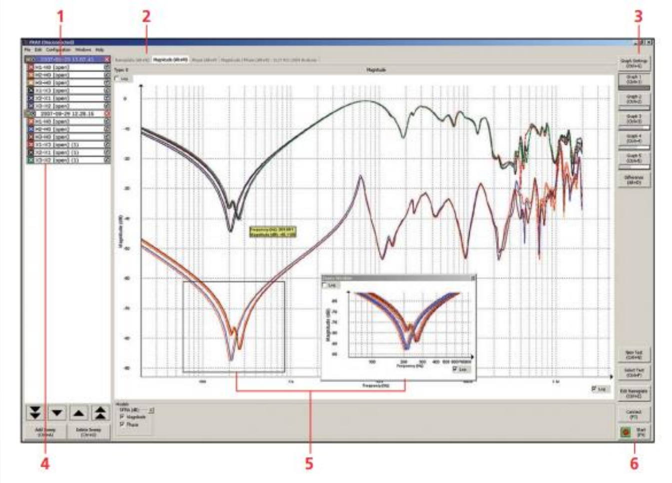
Permanent deformation and distribution of the pressure stress due to radial force.



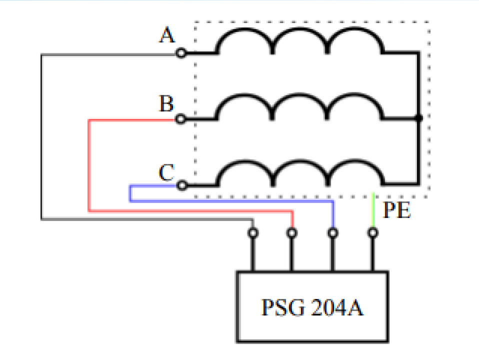
Permanent deformation and distribution of the pressure stress due to axial force (a=5%).

IV.B Diagnostics of the Transformer Construction Condition

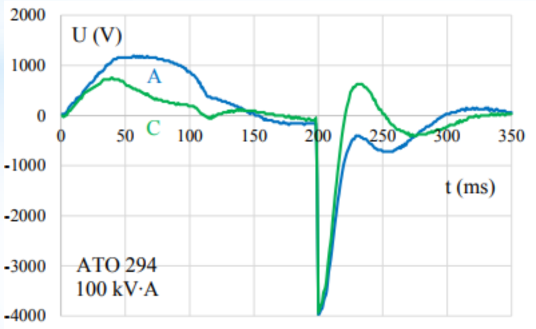
- **Diagnostic measurement of the power transformers by SFRA method (Sweep Frequency Response Analysis):**
  - deformation of winding and its movements,
  - short-circuited turn or opened winding,
  - loose or damaged switching system,
  - core movement or connection problem,
  - partial breakdown of winding or its wrong grounding.



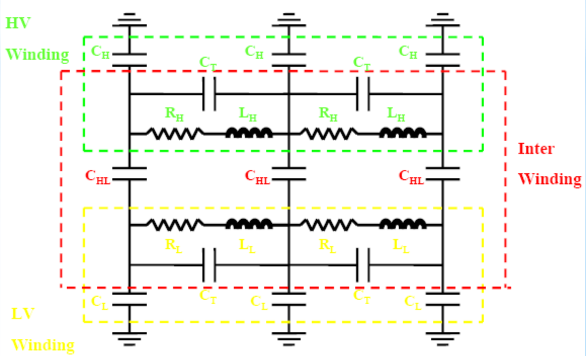
- **Measurement by method of impact test**



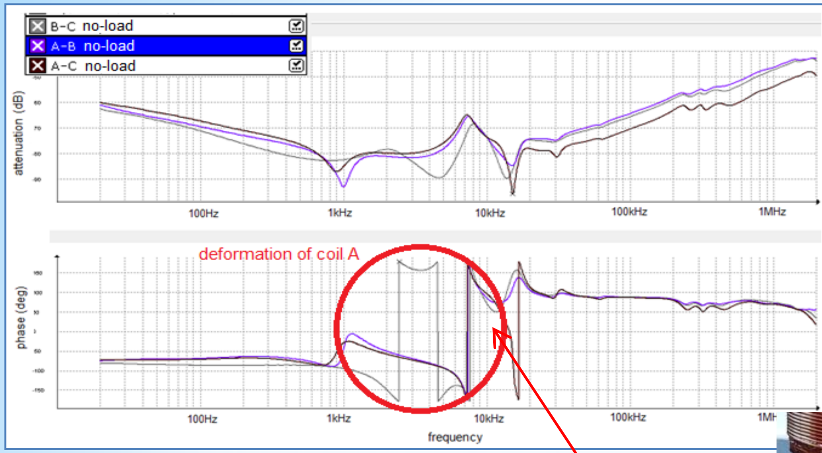
Zapojenie pre meranie rázovým impulzom

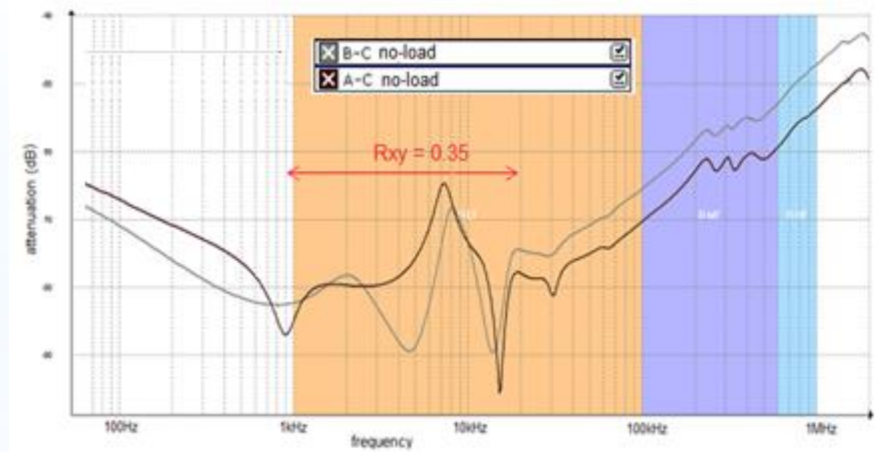


Časové priebehy napäťových impulzov na fázach A-C



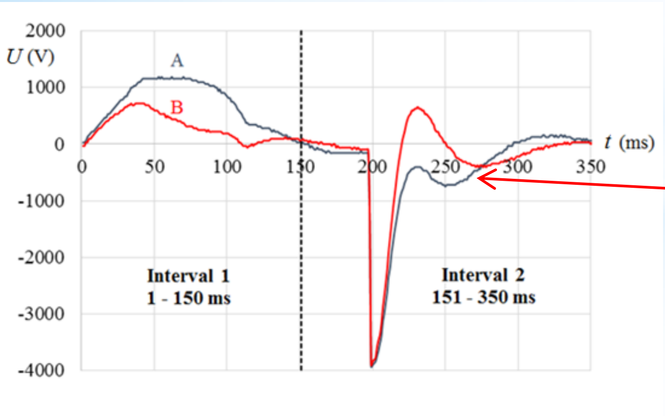
-Example of determination of a defect on the transformer by both methods:



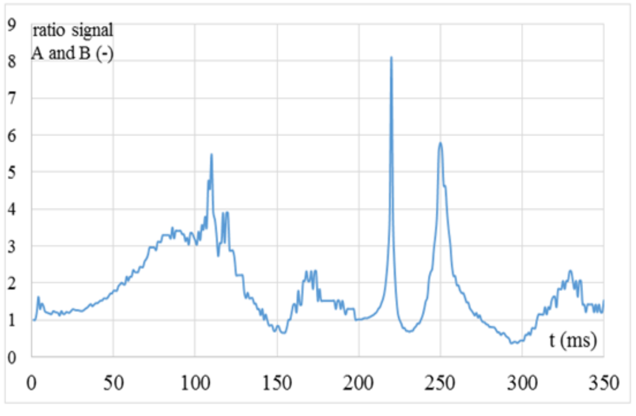


$$LR_{XY} = \frac{C_{XY}}{\sqrt{D_X D_Y}}$$

By SFRA method - differences between the curves (1. a 2.phase) at medium frequencies (between 1kHz and 100kHz), which indicates as fault in the winding of 1. phase.



Effects of short-circuit currents



In the bottom figures, according to the impact method is confirmed a defect by different curves in time domain and we analyze short-circuited turn in the winding.

IV.C CONCLUSION

Good diagnostics = activities:

- design depth analysis of adverse effects on the state of transformers,
- design of modern methodology of measurements and its verification,
- design of new integrated system of diagnostics with the possibility of analysis for classification of possible failures on transformers.

THANK YOU FOR YOUR ATTENTION