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Application of winding natural frequency deviation patterns and high-frequency models for FRA interpretation

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In recent years Frequency response analysis (FRA) is increasingly used to assess the mechanical condition of windings of power transformers and shunt reactors in service condition.

For interpretation of FRA measurement results in practice are widely used a comparison between the measured frequency responses using correlation analysis and indexes showing the differences of frequency responses in a wide frequency range. Despite its simplicity, this approach, being based on the integral indicators, does not allow to take into account the specifics of the object of measurement and explicitly interpret all the variety of possible types of defects.

The frequency response of individual windings, measured with respect to the beginning and the end of the winding, comprises the set of resonant and anti-resonant frequencies of different nature and very often in practice without special measures it is difficult to clearly separate these frequencies in its origin. The individual resonant frequencies correspond to the natural frequencies of the windings, which are their fundamental parameters.

These natural frequencies are primarily dependent on the electrical length of the winding, the physical parameters of longitudinal winding insulation (e.g., dielectric constant of longitudinal insulation), the location and the electromagnetic coupling of the individual parts of the winding, restrictions on the spatial distribution of voltage within the winding (the connection between the parts of the windings, connection of the terminals of the windings with the ground). Changes of natural frequencies of the windings are usually associated with serious damage of windings and have different patterns depending on the type of damage and its location.

The report considers the issues of determining winding natural frequencies from the FRA results and practical recommendations on FRA measurement schemes.

The report shows the new patterns for internal short circuits in the windings. The task of determining the presence of internal winding short-circuit faults can be solved using traditional methods of diagnosis such as measurement of no-load losses, the voltage ratio and winding resistance, but, unfortunately, these methods cannot solve the task of determining the locations of faults inside the windings. This second task is rather optional in service, since the presence of internal short-circuit fault is a significant limitation for further transformer operation. However, this task is demanded in the case of subsequent disassembling and inspection of the transformer to identify the internal faults, to find the causes of failure and to assess the maintainability of the transformer.

Summing up the results of studies on mathematical and physical models the report shows the typical patterns of natural frequencies deviations for different position of turn-to-turn and disc-to-disc internal short-circuit faults. In case of internal short-circuit fault the reduction of the electrical length of the winding occurs, and therefore the natural frequencies of the winding, in general, either increase or remain almost unchanged (in the case when a short circuit occurs near the maximum of the spatial voltage distribution for certain natural frequencies). This important property can be used as one of the main criteria of the internal short-circuit fault inside the winding.

The report presents the approach to the identification and approximate evaluation of internal short-circuit fault location inside the windings using FRA and analysis of the pattern of deviations of the first natural frequencies through its graphic representation. Deviations of first natural frequencies can be determined from the comparison of the frequency characteristics of the same phase before and after damage, as well as between the phases after damage.

White-box models for many years are used in transformer industry for the calculation of the impulse transients in the windings of power transformers and shunt reactors. Recently the white-box models increasingly find their application in problems of transformers and external network interaction: both in the network studies and in the analysis of accidents related to resonance phenomena in the transformer windings. There is a need in tools and interfaces for the transfer of white-box models from manufacturers of transformers to network design companies for the analysis of transients in the external networks.

Another application of white-box models is the calculation of the frequency responses of the transformer windings (in high frequency range) for investigation and qualitative analysis of the influence of internal damages to the frequency responses that can be used in the interpretation of the FRA results.

The report presents a description of the white-box model used by the authors. The problems of model parameters calculation and their adjustments to account for the influence of windings deformations and other damage of the transformer are discussed. The issues associated with the integration and application of models in the EMTP-type program for simulation of FRA-measurement schemes and calculation of frequency characteristics are considered. The report presents the results of modeling of frequency-response deviations caused by the appearance of the shields with floating potential and shows the directions of further work in modeling other defects such as windings radial displacements etc.