Interpretation of Results of Diagnostics of Power Transformers by Using the Frequency Response Analysis Method

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Insufficient short-circuit strength of transformer windings, leading to their mechanical deformations, is one of the main reasons for the emergency withdrawal of transformers out of operation. This problem has been particularly aggravated in recent years due to the increase in the proportion of the depreciated equipment with its rated lifetime already expired. The technical staff is periodically facing a question whether it is necessary to repair the transformer or its operation could be continued.

After the transformer came from factory, the mechanical condition of its windings can change only to the worst; the most important action at this stage is to monitor this condition. The trustworthy information on the current state of the transformer is especially important for transformers being a long time in service, as it allows bringing the transformer timely out of service before its mechanical condition becomes dangerous. On the other hand, confidence in the absence of dangerous changes in the condition of the transformer can serve as a basis for extending the timeframes between repairs or even for canceling the scheduled repair work.

Electrodynamic forces resulting from the short circuits can cause residual deformations and therefore can change the sizes of insulation gaps in windings, reducing thereby the dielectric strength and overall transformer reliability. The electrical breakdown of insulation may occur much later – at the next overvoltage or overload of the transformer. Unfortunately, the true assessment of the mechanical condition of the transformer windings in operation is fairly complicated and not always possible even by visual inspection of the active part. The ambiguity of test results interpretation is dangerous, but even more dangerous is the peremptory conclusion about the satisfactory condition of the transformer based on the wrong interpretation.

Numerous studies have shown that Frequency Response Analysis (FRA) method is highly sensitive to various changes in a mechanical condition of transformer windings. The main reason preventing the widespread usage of FRA technique is the lack of clear criteria to interpret diagnostic results, to identify the nature of the damage, its size and the danger for the further operation of the transformer.

Application of FRA method in Russia has a long history: it has its roots in the low-voltage impulse (LVI) method which was used in the former USSR since 1975. Diagnostic measurements were carried out on more than 200 power transformers from 25 kVA to 400 MVA under short-circuit tests in test laboratories and on hundreds of transformers up to 1000 MVA in operation.

On the basis of experience gained from the application of the LVI method several generations of devices for FRA diagnostics were developed since 2005 and extensive database of measurement results was created. These diagnostic devices based on FRA method are now applied in test laboratories (at shirt-circuit tests of power transformers) as well as in electric power systems.

In accordance with recommendations of CIGRE Publication №342 both approaches are used: an impulse method – with application of the rectangular impulse voltage source, and a sweep frequency method – with the source voltage as a function of frequency. This made it possible to take advantages of both approaches and to use previously accumulated experience gained through application of LVI and FRA diagnostics to improve the criteria for transformer condition assessment.

These criteria make it possible to qualify a condition of FRA-diagnosed transformer as follows:

– State 1: the mechanical condition of the transformer windings has not changed; transformer operation is possible without any restrictions;

– State 2: there are some initial changes in the mechanical condition of the transformer windings, but they are not harmful to the transformer; it is strongly recommended to repeat FRA measurements after a certain time or after the next close short circuit;

– State 3: there is a high probability of transformer damage; more detailed examination of the transformer is required in accordance with operating and maintenance guide.

In this report the experience in FRA-analysis of power transformers at short-circuit tests and in operation is presented. The approach to numerical modeling of the windings of power transformers and reactors for analysis of their frequency characteristics in the high-frequency range with the help of software developed by the authors is given. The report presents the results of theoretical and experimental studies carried out on mathematical and physical winding models and aimed at developing the criteria for assessing the mechanical condition of transformer windings and interpretation of the results of FRA measurements.