

Sc A2 - Power transformers & reactors
PS 3 / Improving reliability for transformers

**Resonant overvoltages inside power transformer windings and the measures
improving their ability to withstand high-frequency stresses**

V.S. Larin^{1,2}, D.A. Matveev², B.K. Maximov²

¹VEI, ²NRU MPEI

Russia

vlarin@inbox.ru

Windings of power transformers of high, extra-high and ultra-high voltages are complex oscillatory circuits, the natural frequencies of which are from units to hundreds of kHz. It is well known that if the frequency of voltage oscillations at the input terminals of the transformer is close to one of the winding natural frequencies, such oscillations can initiate the development of resonant overvoltages inside the windings, which poses a potential danger to the internal insulation of the transformer.

The most common reason for the appearance of voltage oscillations at the transformer terminals with frequencies from tens to hundreds of kHz is the multiple reflections of electromagnetic waves at the ends of the supply cable lines having a length from tens to hundreds of meters. With the increase of the cable lines rated voltages and with their growing application in recent years, there have been more and more cases of damages of the transformer internal insulation due to high-frequency resonant overvoltages inside the windings.

There are several combinations of typical electrical schemes and switching operations, causing high-frequency voltage oscillations in the "cable – transformer" system with frequencies comparable to the natural frequencies of the transformer windings, including the energization of "cable-transformer" system and the earth fault of one of the phases at the beginning of the supply line.

In the case of energization of "cable-transformer" system the oscillation frequency can be determined at the network design stage and taken into account during design of transformer and transformer overvoltage protection. The situation is different in the case of earth fault, since the place of earth fault is not known apriory, and it is not easy to determine the most likely frequency of voltage oscillation.

A set of measures can be used to protect the insulation of transformer windings from resonant overvoltages:

1) network technical and organizational measures [the exclusion of schemes, where the switching of power transformers is performed together with the feeding cable or gas-insulated lines having the length of several hundred meters; the installation of protective RC-circuits (in case of medium voltage classes); the use of circuit breaker with pre-inserted resistors, etc.];

2) design of new transformers considering the possible frequency of voltage oscillations at the manufacturing stage (selection of the type and design of the windings for tuning the natural frequencies of the transformer windings with respect to network voltage oscillation frequencies, which can be possible in operation; the use of built-in surge arresters connected to winding parts, etc.).

In the report the influence of the winding type on the development of high-frequency resonant overvoltages in the transformer windings is considered, and the types of windings most and least susceptible to resonant overvoltages are noted.

In general, the winding connection schemes (star, delta etc.) and neutral earthing mode (isolated or earthed neutral) both influence on development of resonant processes inside the transformer winding. The features of the development of resonant overvoltages in the windings of distribution transformers operating in networks with isolated or high-resistance grounded neutral are considered. The report shows that in case of delta-connected primary windings significant increase of resonant overvoltage inside the windings can be due to imposition of high-frequency oscillations of different phases. The design features of distribution transformers and the effect of amplification of oscillations in their windings should be considered when developing measures to protect these transformers from resonant overvoltages.

To ensure the ability of transformers to withstand high-frequency stresses, it is important to evaluate the voltages affecting their internal insulation.

Recently, the high-frequency models of transformers (so-called white-box models) have received great development. Their use allows to estimate resonant frequencies of transformers and to get qualitative figures of development of resonant phenomena in transformer windings. However, the limitations of these models, namely the absence of frequency-dependent losses, do not allow them to provide a reliable assessment of the resonant-overvoltage amplitudes inside the windings. For a more accurate determination of the voltages at the sections of the winding insulation, it is most preferable to use direct measurements of voltages in the windings and transfer functions in a wide range of frequencies. In practice, however, such measurements are often difficult to conduct. The article discusses the application and the accuracy improvement of computational and experimental evaluation of voltages affecting the winding internal insulation by combination of results of modelling and available measurements.

Another important issue of ensuring the ability of transformers to withstand high-frequency stresses is the testing of power transformers. The report discusses the issues of choosing the shape of test voltage which is equivalent to the operational high-frequency stresses.