Dielectric Breakdown Simulations of an On-Load Tap-Changer in a Transformer Considering the Influence of Tap Leads and Windings

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Summary. This paper reports on the simulation of an on-load tap-changer in a power transformer. The electric fields are computed and resulting breakdown voltages are estimated by using the streamer criterion. The environment of the on-load tap changer its taken into account by modeling tap leads in detail as well as transformer windings. The goal of the investigations is to justify standard design and test-procedures which assume a low dependency of the interior dielectric properties of the on-load tap-changer on the surrounding.

1 Introduction

On-Load Tap-Changers (OLTCs) are devices which permit the change of the turn ratios of transformers, allowing voltage regulation or phase shifting under load without interruption.

Power transformers equipped with OLTCs have been main components of electrical networks and industrial applications for nearly 80 years [2,4].

One crucial criterion for the selection of an adequate OLTC for a certain transformer or application is its insulation level. Generally, the dielectric strength depends on the whole system, i.e. the transformer, as well as the connection-leads and the OLTC. However, usual test-procedures by OLTC manufacturers are not done within a transformer but on a separate OLTC. Also during design the influence of leads and windings on the internal OLTC insulation is usually neglected. This gives rise to further investigations justifying this approach. Therefore, a typical system is simulated by computing the electric field and breakdown voltages with and without windings and tap-leads.

2 Finite Element Simulation

For simulation half of the core and the tap windings of the transformer phase nearest to the OLTC are modeled. The OLTC itself is represented by its lower part—the tap selector. After several simplifications the CAD-data of the tap selector are directly imported into the simulation software [1]. The leads are created manually. Finally the transformer tank is built as a surrounding box.

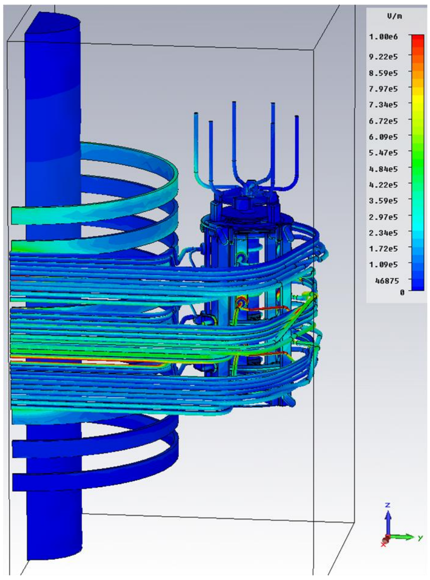

Fig. 1. Magnitude of the electric field of the total arrangement. Red colored parts of the plot are above 1 kV/mm.

Here, we consider AC stresses. Hence, the electric field is computed for the electrostatic case, i.e. we solve

$$\nabla \cdot (\varepsilon \nabla \phi) = 0 \quad \text{in } \Omega\,, \tag{1}$$

where Ω is the non-conductive domain, applying constant potentials $\phi = \phi_0$ on Dirichlet boundaries representing grounded and stressed electrodes and the transformer tank.

For the calculation 2nd order, isoparametric finite elements are used. The result of a computation with 22.6 million unknowns is shown in Fig.1.

3 Dielectric Breakdown Calculation

Breakdown in oil cannot be described by one coherent theory as in gas. To explain the main mechanisms two basic approaches are used: one is an extension of gaseous breakdown, the other one assumes that breakdown is caused by bridges of fibrous impurities.

To calculate the breakdown voltage in inhomogeneous electric fields different methods can be used, see e.g. [3,5]. The calculation method we use is based on the streamer criterion along a critical path C

$$\int_C \alpha(|\mathbf{E}(\mathbf{x})|)\, dl_x \geq k\,, \tag{2}$$

where α is the effective ionization coefficient, $\mathbf{E}$ the electric field and k defines the number of electrons necessary for breakdown. With an exponential equation for α and the introduction of a normalized electric field $e(x) := |\mathbf{E}(\mathbf{x})|/U$, (2) can be solved as in [3] for the breakdown voltage

$$U_b = (1\mathrm{mm})^{1/z} \cdot \left(\int_C \left(\frac{e(x)}{E_0} \right)^z dl_x \right)^{-1/z} \tag{3}$$

with constants $E_0 = 15\,\mathrm{kV/mm}$ and $z = 4.2$. These constants are derived from measured breakdown data of uniform fields.

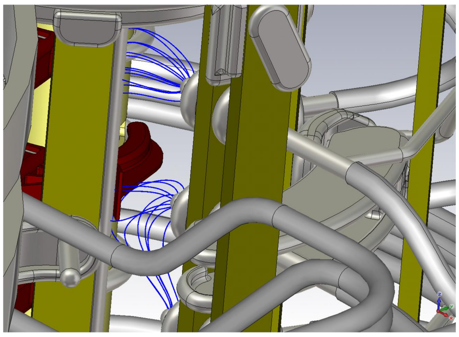

Fig. 2. A subset of evaluated critical lines in the tap selector

The streamer criterion (2) has to be evaluated along critical paths, which for breakdown in oil gaps are fieldlines starting at electrodes with high electric field stresses. Since the most critical fieldline does not necessarily start at a local field maximum many fieldlines have to be evaluated, some of them are shown in Fig. 2. The most critical path and the associated U_b is determined by finding the minimum over all calculated voltages.

4 Influence of the Tap Leads and Windings

To investigate the influence of the transformer and the leads on the dielectric strength of the OLTC three different systems are simulated, see Fig. 3. Field values along several lines parallel to the tap selector axis are compared. In Fig. 4 field values along two of these lines are shown. One line represents a region with low, the other one a region with high electric stresses.

In regions with low fields there is a significant influence of the transformer and the leads, but in regions with high field stresses, which are critical concerning dielectric strength, the differences are maximum 10%. Regarding the calculated breakdown voltages the deviation is even less than 1%.

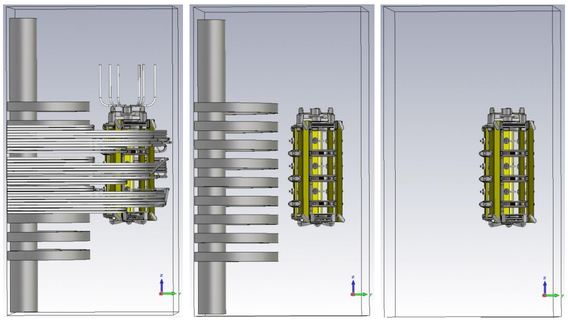

Fig. 3. Different geometries. Left: Tap selector with leads and transformer windings. Middle: Tap selector and windings. Right: Only tap selector

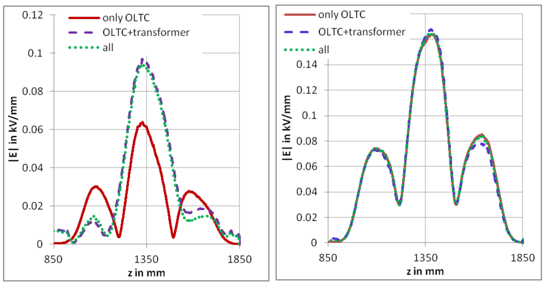

Fig. 4. $|\mathbf{E}|$ comparing all geometric arrangements, region with low fields (left), region with high fields (right)

5 Conclusion

It has been shown that for the investigated typical example the influence of the transformer and the tap leads on the internal OLTC insulation is small enough to neglect them during design optimization and test-procedures.

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