EDF/R&D
Department THEMIS

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Energization of a 40 MVA 110kV/20kV transformer in a distribution Network and appearance of ferroresonance phenomena.

1. Context

The energization of power transformers may create saturation of the magnetic core and lead to high overvoltages and inrush currents.
This study has been performed for a 40 MVA 110kV/20kV wye/wye/D, 3 limbs, transformer; which has led to the apparition of overvoltages on the secondary winding (MT-side), with a feeding system having a total short circuit power of 4.5 GVA. The time constant is set to 100 ms, with a ratio Z0/Zd equal to 1.5. The network considered is described in figure 1 below:

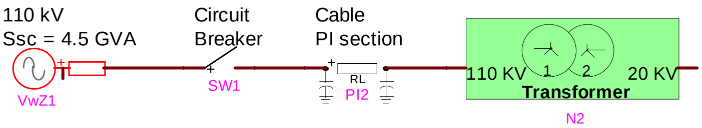

Fig. 1: Simplified drawing of the considered network configuration.

A detailed representation of the Network has been modeled as the following:

-a) The HV-lines, modeled by a propagation line model, adapted to transient phenomena, with constant parameters.
-b) The HV and MV cables modeled by three phased PI devices, having a capacitance of 0,13 F/km.
-c) The circuit breaker, connecting the target transformer to its busbar branch, is modeled by an ideal three phased switch with unbalanced switching times, closing after 0 ms, but with phase B remaining open.
-d) The power transformers (electric and magnetic data), and especially the target transformer, derived from the electro-magnetic duality in a three phase three winding core type transformer [2], [4] and described with a detailed representation of the iron core/Hopkinson analogies and also its saturation characteristics. The target transformer has a magnetic equivalent circuit as shown in figure 2:

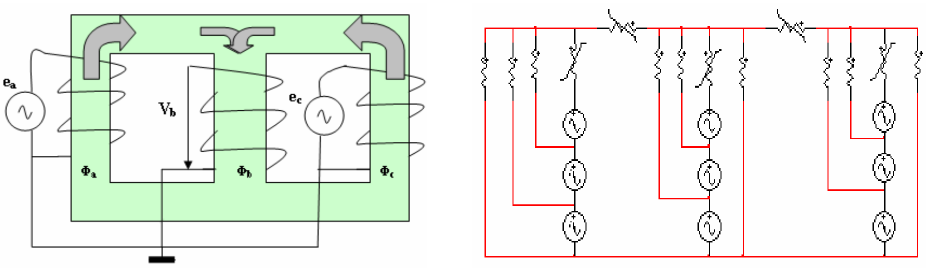

Fig. 2.a: transformer magnetic core *Fig. 2.b: EMTP equivalent circuit*

Fig. 2: Magnetic equivalent circuit of the transformer.

For the target transformer, the non linear transformer characteristic, calculated from manufacturers' data, was inserted in the non linear inductance model. It has the following shape, shown in Fig. 3.

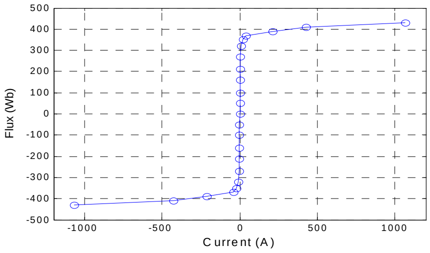

Fig. 3: Non linear characteristics of the target transformer.

The overvoltages are been determined by simulations using the EMTP-RV software, and then compared by on site tests, considering the real closing conditions of the circuit-breakers.

2. Determination of the electrical stresses on the energized power transformer.

2.1 Description of phenomena involved, in the case of residual fluxes set to zero.

When both phases A and C close at the same time (t_A=t_C=18 ms) and phase B remains open, assuming residual fluxes equal to zero, overvoltages appear at the secondary side of the transformer, as shown in figure 4 below.

The overvoltages reach a value of -3.1 p.u. at t = 24 ms on phase B, and show a wave-shape after 30 ms which reproduces the same pattern without any damping, for a long time, which characterizes ferroresonance phenomena.

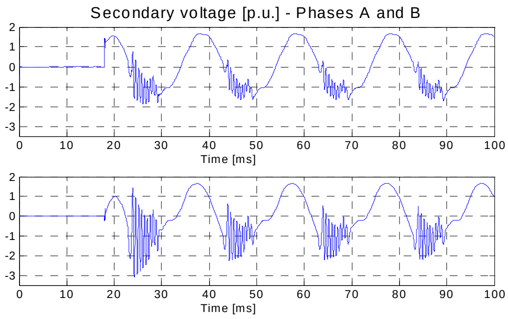

Fig. 4: Overvoltages at the secondary windings of the target transformer- Phases A and B.

The inrush currents are low (up to 0.8 In), because we consider zero residual fluxes for the initial conditions. Fluxes and currents of phases A and B are described in figure 5 below:

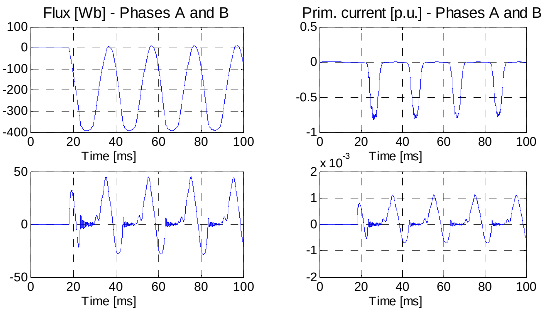

Fig. 5: Fluxes and primary inrush currents - Phases A and B

2.2 Description of the phenomena in case of introducing residual fluxes.

Initially, in the first parts, residual fluxes have been set to zero; however, the initial conditions are a main issue for those studies.
Studies have been performed for average values of residual fluxes in the possible range of 0 to 0.8 pu. Maximum overvoltages have been obtained considering the following sequence for the residual fluxes (-0.4 / 0.4 / 0 pu). In that case, the overvoltages may reach a value of -4.56 pu, which is rather high.

3. Ferroresonance phenomena involves with phase B open; Discussion.

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The figure 6 below illustrates the phenomena developed on phase B, in the case of the representation of the flux through the iron core versus the secondary voltage (state variable representation).

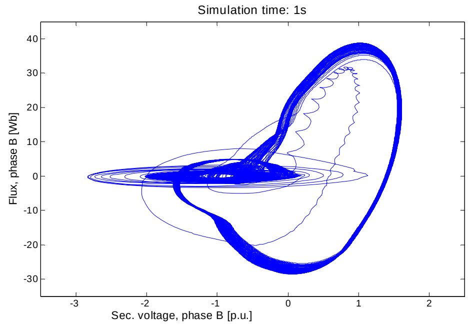

Figure 6 : Flux over secondary voltage, phase B; simulation time of 1 s

The total flux flowing in the circuit is a very important variable, involved in the state variable representation, as decribed in fig. 6; ferroresonance phenomena are involved in that case.
The closing of the pole B of the circuit-breaker, 17 ms after phases A and C, stops the development of the phenomena, but may not prevent the fact that high overvoltages may occur before 10 ms on the transformer N2.

4. Conclusion

This document presents the energization of a transformer in a 110 kV Distribution Network. From a detailed representation of the network, and especially the target transformer, it shows that high discrepancies in the circuit-breaker poles closing times may lead to high overvoltages of up to 4.56 pu, which bas been confirmed by on site tests. Phenomena involved, when phase B remains open, are ferroresonance ones.
Recommendations on the closing of the circuit-breaker poles, in order to avoid those overvoltages are also given.

References

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