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Is it relevant to realize GIC capability tests? Could white-box or black-box models be applied to evaluate the GIC capability of transformer electrically, mechanically and thermically?

The answer to both questions is yes. The electrically behavior of a power transformer under GIC is design-dependent. The harmonics in the currents or the reactive power consumption for a certain DC level are influenced by the core type and the winding design (air core induction). E.g. 3-phase, 3-limb core form transformers need a certain DC magnitude in the range of several dozen Ampere in the grounded neutral of a winding to reach the saturation level of the core. Furthermore, the exact DC level where a 3-phase, 3-limb transformer reaches the saturation level can also vary a lot, depending on some parameters like the nominal AC induction of the core or the number of turns. This is in contrast to single-phase or 5-limb core transformers, where the saturation effects start always already with a very low DC level in the range of several hundred milli-Ampere. However, not only the electrically behavior depends on the transformer design, also the behavior of the hotspot temperatures during GIC are affected by the design. During core saturation an additional stray flux spills out of the core which can cause an additional heating of the metallic components. Consequently this heating depends on the geometry and the material of the affected steel parts in the active part. In the windings the used conductor type (CTC vs. flat conductor) influences the loss increase in case of core saturation [1]. These examples demonstrate that some design details must be always known to evaluate the behavior of a transformer under GIC or DC.

White-box and black-box models are available to simulate different effects of GIC in a transformer. To study the electrically behavior, electro-magnetic network models are sufficient. In such models, relevant areas are modelled with different magnetic resistances. For the thermically behavior, of-course FEM3D models can be used, but the disadvantages of such FEM3D techniques are that such simulations are very time-consuming and always associated with a special software. Therefore, for components with a simple magnetic field orientation under GIC (e.g. tie bars near the core) also simplified layer models are applicable for the loss determination. They are easy to implement and can also be combined with the electro-magnetic network simulation during the design process. Also simplified thermal models are available to determine the hotspot temperature of a tie bar [2].

To verify and improve simulation models for GIC, GIC capability tests are essential [3]. By the help of a DC source and 2 transformer back-to-back connection, different DC levels can be injected into the high-voltage winding of a transformer in addition to the nominal AC voltage excitation. In that way the effects of an additional DC current in the transformer winding together with an AC voltage excitation can be measured under no-load. This includes e.g. the measurement of the additional current harmonics or the rising temperatures measured in metallic parts fitted with thermocouples. When such tests are done in a high-voltage laboratories, costly and difficult tests in the grid can be avoided. However, important is a suitable laboratory equipment, meaning that the generator must be capable to deal with the harmonics in the current and to deliver the reactive power demand of the test circuit. Furthermore it is obvious that the occurred test conditions (e.g. the voltage wave form) must be considered when the test is re-simulated with the calculation model [3].

References:

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[2] J. Raith and U. Schichler: “Risk Assessment of Electrical Equipment under the Influence of GIC”, CMD conference, Xi’An, 2016.

[3] J. Raith: “Risk Assessment of Power Transformers under the Influence of GIC”, Doctoral thesis at Graz University of Technology, Graz, 2019.