COUNTRY : USA
REGISTRATION NUMBER : DLG5993

GROUP REF. : A2
PREF. SUBJECT : PS3
QUESTION N° : 3.9

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 thermally?

Generally, transformers with return limbs and independent magnetic circuit may be considered for GIC testing. GIC capability tests can be relevant for transformers with high total GIC susceptibility like Category IV & Category III, assessed using section 8.3 of IEEE standard C57.163. Adjustable DC source with AC bypass, Adequate Reactive power supplies, Harmonic isolation from grid and compatible instrumentation need to be considered if a factory test set up is needed. However, few site testing have been reported which were subsequently used to validate white box models.

The following standard test may be performed under both GIC and normal conditions

1. No Load loss & Excitation test
2. Load loss test
3. Heat Run test with DGA

Two approaches to GIC problems in transformers can be

1. Designing conventional transformers to withstand required GIC
2. GIC compensated transformers

In both the cases, GIC capability test can be used to demonstrate the reliability.

Black box models may be sufficient for system level studies (stability, load flow etc.), but detailed white box models are needed if effects on equipments needs to be assessed. For both system and equipment level studies, co-simulation of equipment FEA and system network models can be done. The computation time can be reduced by using High Performance Computing (HPC) tools available in cloud as IaaS.

Some of the existing white-box models for GIC analysis are

1. Topology based equivalent circuit method (UMEC)
2. Harmonic balance FEA
3. Circuit coupled FEA

Most of the existing white box models for GIC analysis are based on using a magnetic equivalent circuit method to solve for winding currents. Once the winding currents are known, losses and temperatures are calculated using a transient FEA. These methods have the following drawbacks.

1. The tank and its non-linear permeability cannot be accurately modeled resulting in partial saturation with much lower GIC Amps.
2. Unequal limb saturation resulting in zero sequence currents that can circulate in tertiary along with third harmonic currents cannot be modeled.
3. Three phase interconnected magnetic circuit effect on saturations currents (Helping effect as described by Price) resulting in AT balance of phases not undergoing saturation at a given time cannot be modeled.
4. GIC transient effects and condition for steady state (Walling) cannot be modeled.
5. DC bias current due to DC voltage input (not DC current input) cannot be modeled.
6. Tank circulating currents due to zero sequence / 3rd harmonic flux cannot be calculated.
7. Loss densities in structural components with the actual 3 phase GIC winding currents (rather than superposition of harmonics) and nonlinear permeability cannot be accurately calculated.

Hence, we can use a 2D non-linear transient circuit coupled FEA technique with actual core, windings, tank, circuit connections, excitations and non-linear material properties. This model is used to quickly obtain the magnetizing current waveforms, core flux density and reactive power.

Once the accuracy of the winding currents pattern and harmonics magnitudes are verified and if the transformer undergoes partial saturation, the following approach can be followed to calculate losses and thermal performance.

1. Capture the steady state winding currents for 3 cycles (50 ms) and perform a 3D transient analysis with current excitation and with all structural components and shunts.
2. Calculate losses and temperature rise using non-linear impedance boundary in transient analysis.
3. These can added to the loss and temperature rise of the load condition prior to GIC or can be calculated simultaneously with both rated load and GIC currents present. (Non-linear impedance boundary under non-sinusoidal excitation is now supported in FEA software)
4. These steps has to be repeated for each GIC values in the GIC profile.
5. Top Oil and hot spot (winding, clamp, flitch plate and tank) temperature can be found from time variation of losses using “n” and “m” exponent
6. De-rating curves can be obtained so that for a given GIC Amps and component temperature, the pre GIC + GIC component temperature is less than the target component temperature.