QUESTION 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 thermically?

Black-box models and white-box models can be combined at the design stage to assess the effect of GIC events on a power transformer.

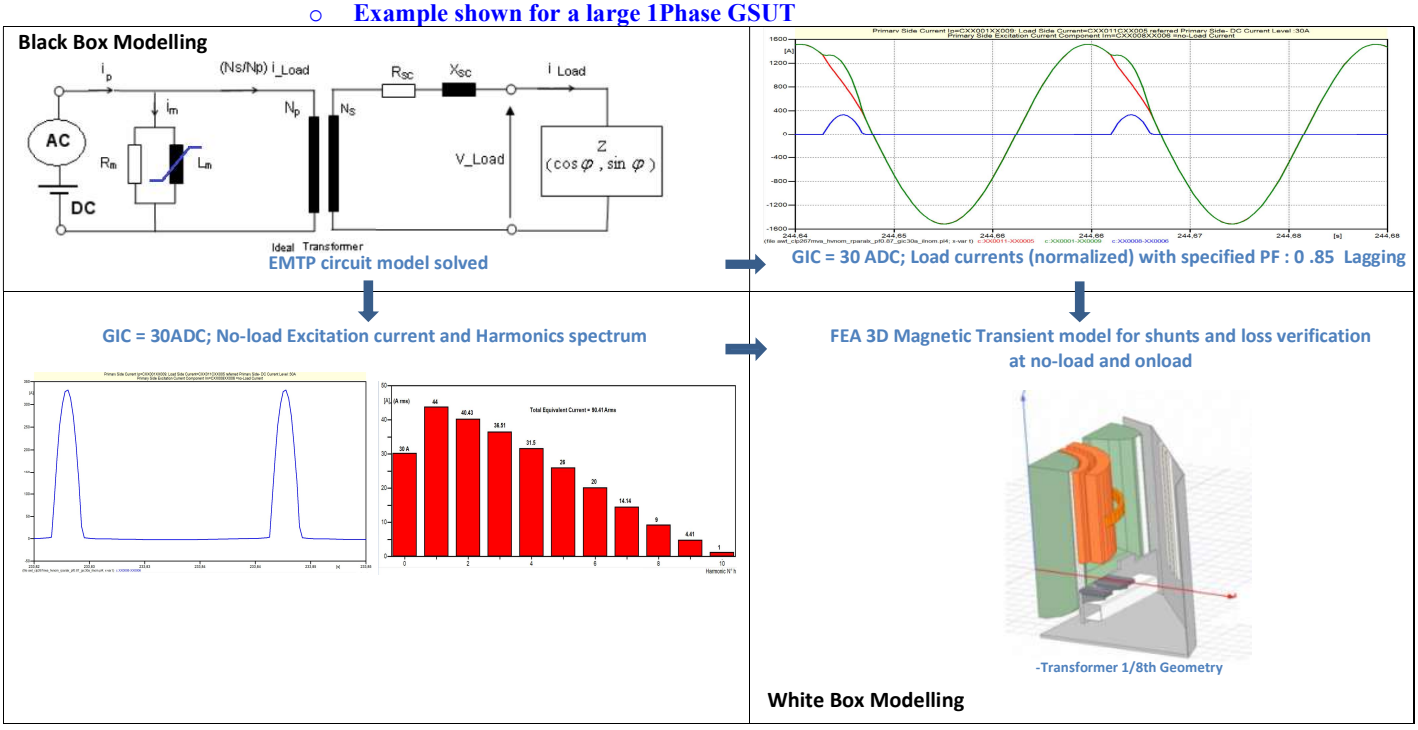
1. **Specifications related to GIC, or manmade DC bias capability of transformers usually comprise:**

   - Peak excitation current vs DC current level
   - Harmonics of the excitation current
   - Reactive power consumption
   - Transformer vs GIC/DC current level withstand duration curve

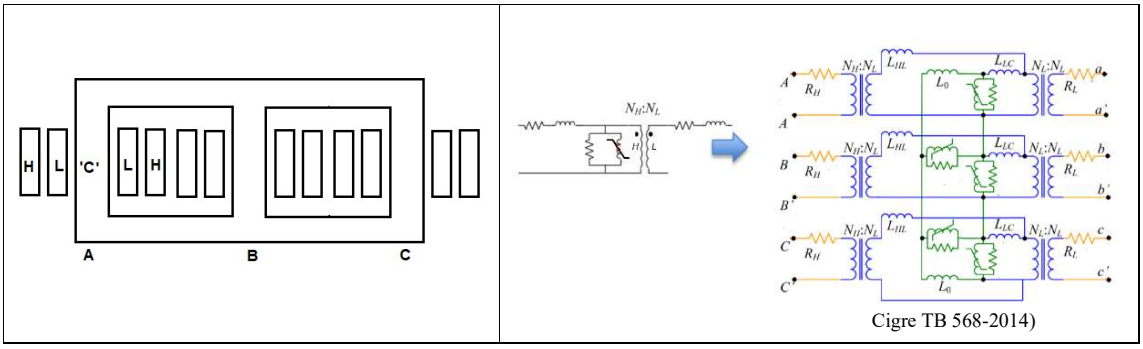
2. **Application of Black-box models**

   System studies tools like the EMTPs can be used to determine the currents waves driven by the transformers for varying levels of GIC and hence the harmonic content and reactive power consumption.

   - **Example shown for a large 1Phase GSUT**



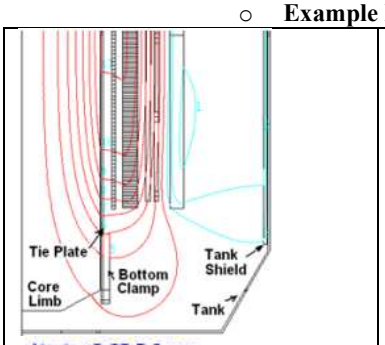
   - Sensitivity to GIC is dependent on the core structure, with 3Phase 3limbs being less sensitive.
   - Topologically correct representation of the cores is available in some EMTPs as ATP (Hybrid transformer model) to consider the core type for same analysis.
     - Example 3 limbs core with hybrid transformer model in ATP



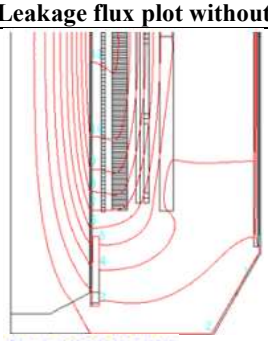
3. Application of White-box models

The currents derived from system(black box models) studies can be injected in transformer white-box model to determine losses and temperature rise, hence time withstand curves.

- Application to windings, which are the more critical part of the transformer
  - **Example Leakage flux plot without and with GIC to verify shunts sizing windings losses**

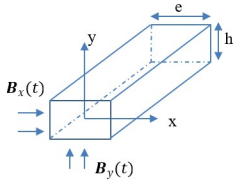


Leakage Flux Plot on Tank Bottom side
GIC = 0 ADC



Leakage Flux Plot on Tank Bottom side
GIC = 50 ADC

Windings eddy loss at the frequency *f*

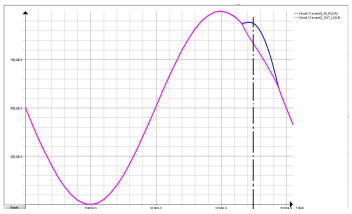


$$W_{eddy}(f) = \frac{\sigma.e.h}{6}.\pi^2.f^2.[\,e^2.B_y{}^2 + h^2.B_x{}^2] \quad \text{(W/m)}$$

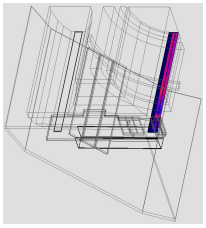
σ: Electrical conductivity of the conductor strand.
After harmonic decomposition of local flux density,
Bx, By: Local leakage flux harmonic components of frequency f.

- Example further verification of shunts and clamps (flitch plate)

White-Box models for clamps will require 3D transient solution with eddy current considered. Latest development in established commercial software tools enable transient FEA3D determination of loss density distribution in different types of materials (stainless steel, mild steel). Due to hardware resources and solving time required, it may be difficult considering performing such studies at design stage, for each commercial project.


HV and LV currents normalized. IDC=30A


Verification of the wall shunt, IDC = 30A


Loss density in the flitch plate, IDC =30A

4. CONCLUSION:

Black-box transformer models to derive the transformer terminal characteristics can be combined with white-box transformer models to derive local hot spot temperatures inside the transformer, to give an assessment of the effect of GIC events on the power transformer. The white box model may presently require significant hardware resources and solving time, but as a library of model output results and benchmark experimental tests is built-up the need to perform detailed studies on every design may be alleviated.