

# Transformer Design Using Advanced Tools

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## Introduction:

Design of a transformer is a critical step for the longer life of the transformers. The program used must have been proven over 40 years. Designers should consider multiple parameters during design such as manufacturing tolerance, material tolerance, material source, stresses during different tests and temperature limits of the components inside. Engineers at Virginia Transformer consider all parameters described above in design process to ensure the perfect transformer is delivered to the customer.

Insulation is heart of the transformer and quality of insulation decides the life, only thermally upgraded cellulose insulation material from Europe with 2% Nitrogen content are use used in our transformers. Life depends on the operating stresses and over voltages occurring inside the transformer. Design of transformers based on the **Basic Insulation Level (BIL)** is a classical method of designing. Design of transformers based on a voltage which is representative of all the design tests makes the designs fool proof and increases life of the transformer. This approach is followed by Virginia Transformer with the introduction of numerical tools in design process.

Insulation materials will withstand 120 °C continuously and hot spot temperature occurring inside the transformer is controlled for maximum insulation life; this is done with winding eddy loss calculation and leakage flux analysis using finite element tool. This article outlines the overall design process followed by Virginia Transformer.

## Design Insulation Level (DIL):

**DIL** is defined as one minute rms power frequency (short duration) equivalent of all the dielectric tests which are lightning impulse, switching impulse, applied voltage and partial discharge tests carried out on a transformer per IEEE/ANSI standard. Factor to calculate the DIL varies with stress duration or the frequency of the applied voltage; this is shown in figure1 for combined oil-press board insulation system.

For example, impulse to power frequency voltage withstand ratio of pressboard is around 3.3 and for mineral oil the ratio is between 2 to 3. This variation in the breakdown values at different frequencies makes the transformer design complex when you deal with different types of fluids and material. DIL based design simplifies these difficulties. After calculating the voltage level during different test conditions, DIL is estimated to finalize the dielectric design. At any location inside the transformer there is only one DIL which it is designed for. Stresses in oil ducts are limited to weidmann partial discharge inception field strengths (rms).

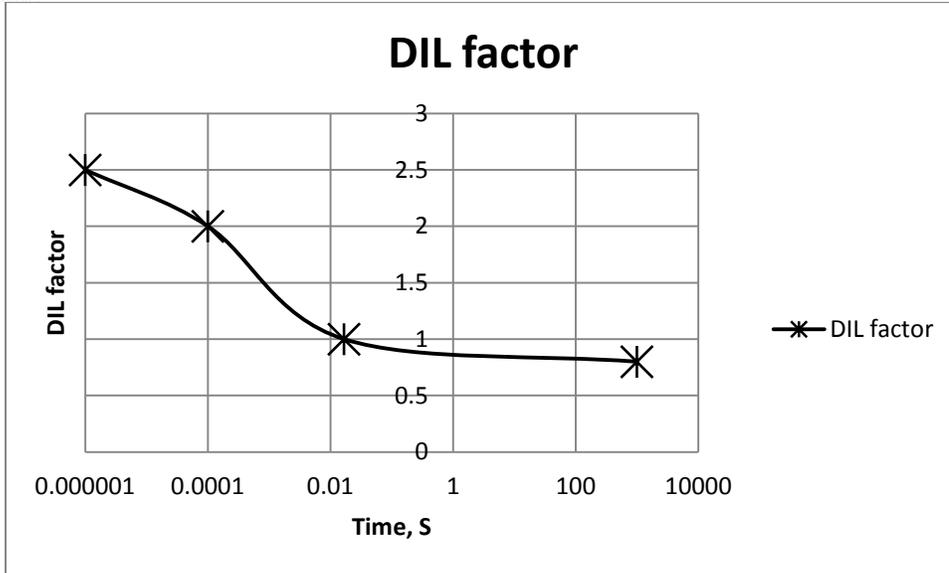


Figure1. Dependence of design values on duration of applied voltage expressed as multiplication factor (DIL factor)

**Transient Voltage Calculation:**

Transformer winding has to be designed for impulse and switching test over voltages as per ANSI IEEE Std C57.12.00. As the voltage rating of the transformer increases, calculation of impulse voltages appearing across turns/discs and between turns are complex and manual estimation is nearly impossible. VTC use VLN 4.5 for estimating transient voltage stresses as part of the design process for a robust winding design. This calculation includes resistance, inductance and capacitance of the coil to model the winding to calculate the over voltage stress. Typical results from the program are shown below.

VLN4.5

Impulse voltages and strength of insulation gaps. Calculation diagram HVMAX, Mode 1, Test voltage 450.0 kV , LI(FW) 1.20/ 50.00							
Gap number	Gap designation	Oil duct height, mm	Turn insulation thickness per two sides, mm	Maximum of applied voltage, %	Duration of applied voltage, us	Permissible voltage, kV	Safety factor
11	IHV (3) _RK_1	4.83	12.35	14.86	16.16	182.84	18.36
12	IHV (3) _RK_2	4.83	10.61	10.13	16.24	197.51	12.14
13	IHV (3) _RK_3	4.83	10.61	10.72	16.3	197.41	12.02
14	IHV (3) _RK_4	4.83	10.61	12.14	15.36	199.12	11.81
15	IHV (3) _RK_5	4.83	10.61	12.72	15.2	199.43	11.74
16	IHV (3) _RK_6	4.83	10.61	12.92	14.86	100.19	11.72
17	IHV (3) _RK_7	4.83	10.61	12.76	15.26	199.32	11.73
18	IHV (3) _RK_8	4.83	10.61	12.68	15.64	198.58	11.73
19	IHV (3) _RK_9	4.83	10.61	13.7	15.7	198.47	11.6
110	IHV (3) _RK_10	4.83	10.61	13.54	16.02	197.86	11.61
111	IHV (3) _RK_11	4.83	10.61	12.69	16.48	197.12	11.7
112	IHV (3) _RK_12	4.83	10.61	11.68	16.86	196.52	11.84
113	IHV (3) _RK_13	4.83	10.61	11	17.18	196.07	11.94
114	IHV (3) _RK_14	4.83	10.61	10.34	17.74	195.36	12.05
115	IHV (3) _RK_15	4.83	10.61	9.97	18.32	194.71	12.11
116	IHV (3) _RK_16	4.83	10.61	9.45	18.68	194.35	12.22

Figure2. Transient voltage stresses and strengths

Figure 2 show that the transformer winding has safety factor of 2.14 near the line end with the high voltage winding shields. Difference between initial and final voltage distribution is depicted in figure

3. As the difference increases, there is more oscillation created due to the energy movement between inductance and capacitance.

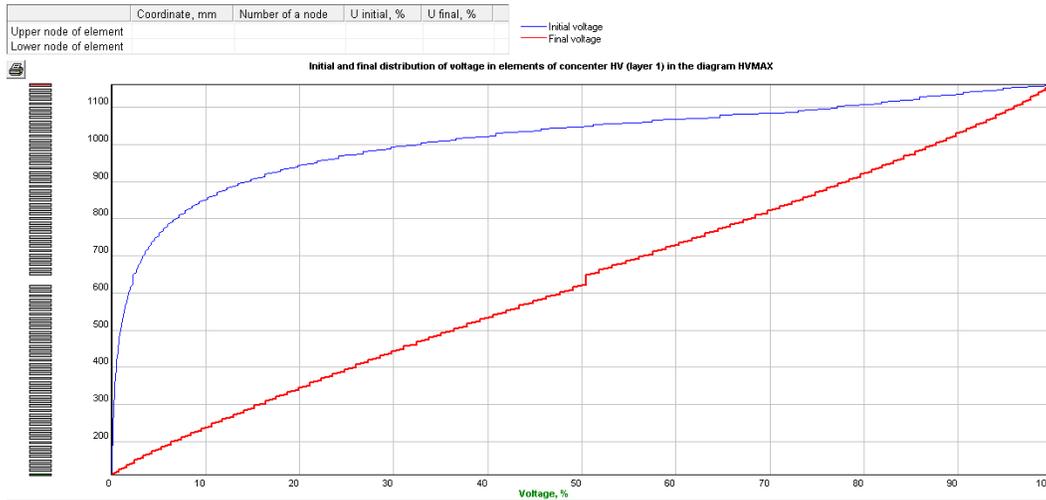


Figure3. Initial and Final voltage distribution along the winding

VLN 4.5 can compute turn to turn insulation stresses, layer to layer voltages, step voltages for regulating winding, stresses on the shield insulation, de-energized tap changer voltages and voltage on the series parallel switches. Transferred surge between the windings and winding end oscillations are also verified for special cases.

**Power frequency voltage stresses:**

**Virginia Transformer** use finite element tool to estimate the stresses inside the transformer. Regions analyzed are gap between windings, winding to yoke and lead stresses for ensuring the design is adequate and has 20 to 30% margin over the weidmann published degassed oil curves. Tangential stresses are also estimated using finite element tool; and further verified with weidmann partial discharge inception curves for partial discharge free operation. Typical stress plot and equi-potential plots are shown below.

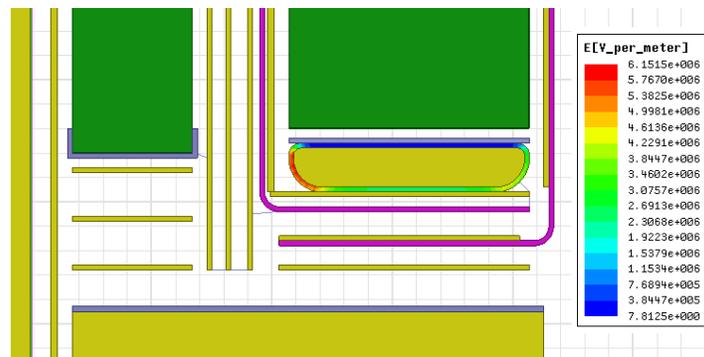


Figure4. Corner stress in High voltage unit

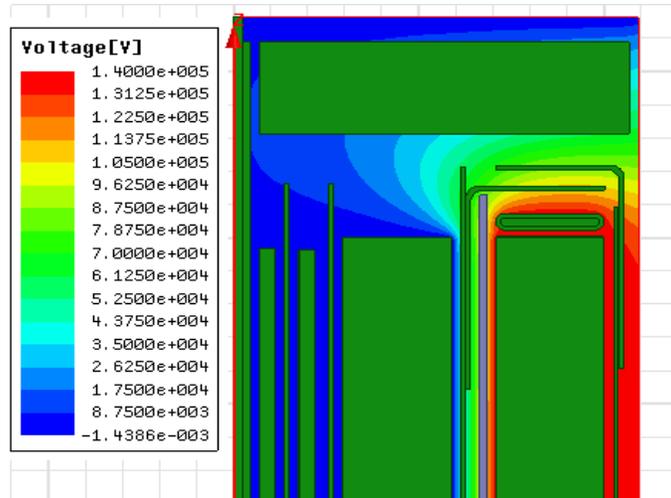


Figure5. Equi-potential plot of active part

**Leakage flux:**

ANSYS finite element tool is used to estimate the leakage flux density on the clamps, tank wall, tank wall magnetic shunts and tie bars. Temperature on the structural part is designed to be lower than 130 °C at any daily average operating condition. Peak flux density on the tank wall shunt is limited such that saturation of the wall shunt is prevented during the operation of the transformer.

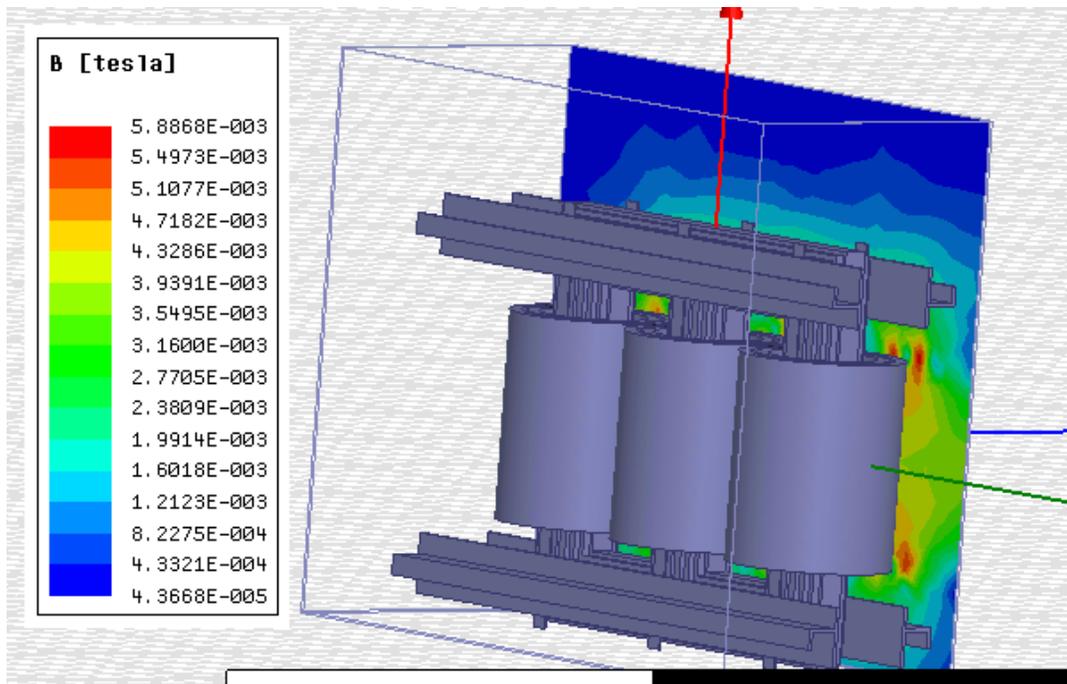


Figure6. Flux density on tank wall due to leakage flux

Flux density on the tank wall is shown above for a typical case. In addition to that, surface loss density is plotted to further estimate the hot spot on the structural part. This process ensures that there is

no localized hot spot developed due to the leakage flux impinging on the structure. This exercise is done with offset in winding magnetic centers with highest leakage flux out of the core and coil assembly to ensure the simulation carried out at worst possible scenario.

### Short circuit stability:

**Virginia Transformer** use **FLD12** Andersen program for studying the short circuit stability of the transformer. FLD12 is a two dimensional finite element program to calculate reactance, losses and forces in core type transformer. Three winding transformers are verified for single line to ground fault for the stability of unloaded tertiary winding. IEC 60076-5 is used as guide for allowable stresses during short circuit event.

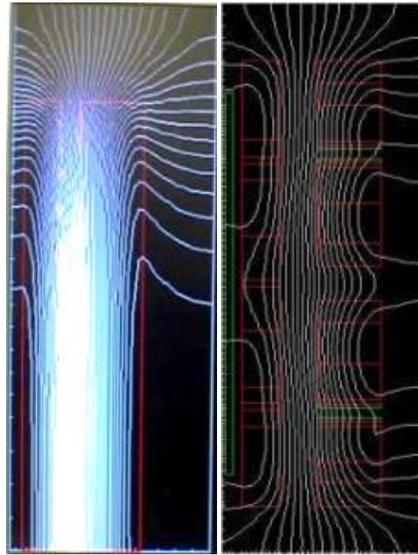


Figure7. Leakage flux pattern from FLD12

### Conclusion:

**Virginia Transformer** custom designs as per the specification of the customer and also verifies the necessary parameters with numerical tool for medium and large power transformers. **Virginia Transformer** improves the quality of designs with latest software and programs available in the market. SAPR TON program is used for assessing thermal performance of the transformers. Virginia also utilizes these tools for product development studies and other new configuration studies.