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ONE SOURCE–ONE COMMITMENT

60 YEARS LIFE TRANSFORMERS

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Introduction: Transformers are vital links within the power transmission and distribution systems. The reliability of the power supply rests heavily on the reliability of the transformers. Thus, it is necessary to design and manufacture transformers which would provide years of reliable service without interruption. In earlier days, the life of a transformer was estimated to be in the range of 20 to 40 years. However, as the system voltages and power levels went up, the required reliability level also went up. To meet this challenge, all aspects of design and manufacturing of transformers were re-examined using modern techniques and tools, which revealed that life expectancy of transformers could go as high as 60 years, if proper care is taken. In this article, we shall discuss some of these points and understand their roles in contributing towards the 60 years life transformers.

(a) Designing with low electrical stress using FEA tools: In high voltage transformers the insulation design is critical. The service conditions, including transients and other disturbances, produce electrical stresses at various parts of the insulation structure. However, these stresses are not uniform throughout the insulation system. The shapes, sizes, thicknesses, orientation and the location all play an important part in determining how much electrical stress is present in those various spots. The higher the electrical stress, more is the probability of partial discharge (PD) occurring at those spots. It is well documented that PD directly affects the life of the insulation. Thus, a good insulation design would have to ensure that the stress level is sufficiently low so as to ensure a long life of the transformer.

The geometry of the insulation system is anything but regular. For detailed analysis of such structure, it requires a Finite Element Analysis (FEA) tool. We at VTC employ some of the very modern FEA tools, into which the details of the winding and insulation are inputted for computation of the electrical stresses, under both power frequency and transient conditions. The stresses are kept within safe limits by taking various measures according to high voltage design practices.

(i) Stresses during a transient condition are verified using tool which considers capacitive and inductive effect in the calculation. Shields are provided to reduce the voltage distribution along the winding height to improve the series capacitance.

(ii) Stresses during operating conditions and at power frequency test condition are performed using finite element tools to limit the stress levels below the oil duct strength curves (published by Weidmann).

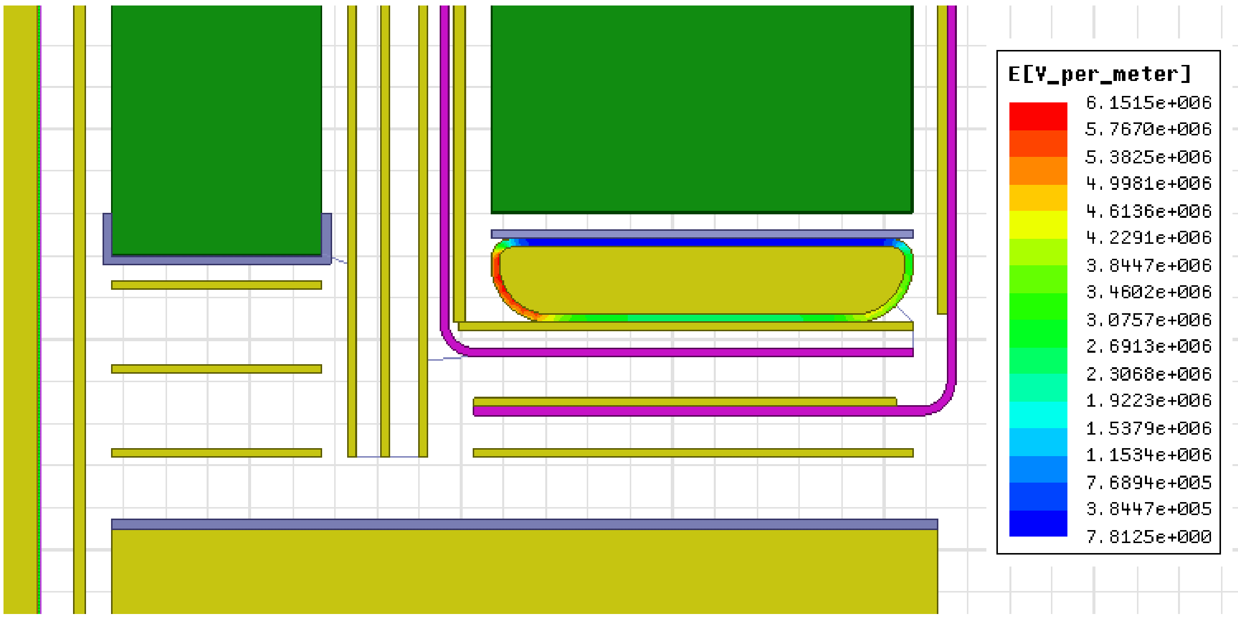

Fig. 1 Electric Field Plot of Insulation Structure of a High Voltage Transformer.

Some of the common techniques require rounding off the edges of metals and insulation items. This avoids the discharge around the sharp points. This also requires suitable manufacturing care for rounding the sharp points. Suitable shaping and profiling of the various insulation items are very important so as to avoid surface discharges in areas of high field concentration. This is often achieved by specially shaped and molded insulation components. These measures result in very long life of transformers, typically in the range of 60 years, when coupled with the measures listed out below.

Minimum Safety factor of 1.3 is recommended to achieve 60 yr life.

(b) Low PD Levels: As mentioned above, an important key to long life of a transformer is low PD levels. PD is by far the number-one killer of transformers. Several precautions are adopted in VTC to ensure that the PD levels are low.

Rounding of the sharp points is of great importance in keeping the PD low. Techniques such as Metallization are very effective in achieving this.

Within the solid insulation, there are a large number of micro pockets, or voids. During operation, the electric field causes tiny arcing which reduce electrical distances, higher stress levels, and progressively ‘eat’ into the insulation. These voids enlarge with time, eventually lead to failure of the transformer. Removal of all these air voids within the insulation is an important aspect of keeping the PD low. This is achieved by applying a high degree of vacuum, by which all such voids get later filled and impregnated by the oil.

Avoiding sharp points in and around the windings, like connections and other structures will help reduce the electric stress levels, which in turn will result in lower PD and eliminate generation of Hydrogen and other combustible gases.

Typical PD values should be 50 to 150 pC. Lower PD level is preferable to achieve 60 yrs life.

(c) Optimum moisture for long insulation life obtained through excellent dry-out processing (VPD):

Another key to long life of transformer is removal of moisture from within the insulation. The research carried out by the industry and academia has established that the life of insulation is directly linked with the amount of moisture present in the insulation, and this effect is very significant. Moisture reduces the voltage withstand capability of oil and insulation, accelerating the rate of additional moisture generation, leading to premature failure.

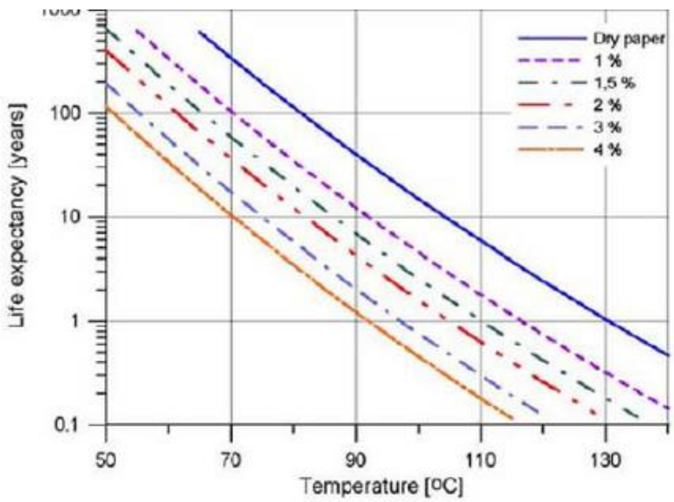

Fig 2. Moisture directly Affects Life of the Insulation

Thus, we at VTC lay great importance to the process of moisture removal from insulation. We understand the physics of inter-relation of the temperature, the degree of vacuum, the thickness of the insulating material and the time of moisture migration. Our process of transformer dry-out is based on this physics.

We have installed Vapor Phase Drying (VPD) systems in all our plants to achieve a very high degree of dryness of the insulation. As a result, we get low levels of PD during the testing of the transformer. Thus, our transformers have a very long life.

Insulation moisture level of .5% is close to ideal. This corresponds to -40 to -50 Deg C dew point.

(d) Proper Handling of Insulation:

It is very important to treat and handle the insulation with 'respect'. Any improper handling of insulation, such as creasing, scratches and other damage would result in severe reduction in the electrical and mechanical strength of the insulation. A compromised insulation would directly impair the life of the transformer. Proper storage of insulation is also important, so that insulation does not collect impurities like dirt, dust, moisture and metallic impurities. All of these would directly lead to reduced life of insulation and hence the life of the transformer.

(e) High Short Circuit Strength:

(i) Tight Windings are one of the most vital requirements of high short circuit strength of a transformer. Any looseness within the winding will allow movements of the conductors when forces work on them. Such movements are the beginning of the failure of the windings, and hence must be avoided for long life of transformers.

(ii) **Coil Sizing**: After winding the coils, they need to be sized by application of a specified pressure, by using special fixtures. This process eliminates any tiny gaps between turns, and also presses the spacers to their required thickness. This makes the coil a compact one, enabling its ability to withstand high short circuit forces.

(iii) **Proper Mechanical strength of conductors**: The winding conductors experience large forces during sort circuit events. These forces cause tensile and compressive stresses in the conductors in various parts of the windings. Depending on the level of the stress, the designer chooses conductors of higher tensile strength.

(iv) **Proper Mechanical strength of insulating materials**: The insulating materials such as spacers, cylinders, blocks, rings etc. are subject to very large forces and consequent stresses. It is necessary to employ insulating materials with proper mechanical strength, so that coil assembly can withstand the large forces of short circuit.

(f) Good balancing of electromagnetic forces: When the transformer carries load current, and particularly during the short circuit events, large forces are produced by interaction of the current carrying conductors and the leakage magnetic field. These forces have both axial and radial components, which act on the windings. Due to various reasons, such as different insulations, number of turns, taps, etc., the forces are not uniform throughout. This results in unbalance of forces. Any unbalanced force acts axially which, unless properly restrained, can results in movement of parts of the winding, which is not at all desirable. Therefore, it is necessary to properly balance the electromagnetic forces through proper balancing of the Ampere-turns. Matching of the coil phase center lines in height and diameter help reduce the short circuit forces. These factors contribute towards long life of a transformer.

The strength of copper and free span between the spacers should be such as to keep the 1.2 to 1.5 mechanical strength safety factors.

(g) Advanced computation of magnetic fields and stray losses by FEA programs:

Stray losses are generated due to leakage flux emanating from the winding. Stray flux or leakage flux impinging on the windings as wells as steel parts of transformer lead to localized over-heating during operation. Stray losses are huge under the following conditions:--

(i) When the transformer is of high impedance (greater the ANSI STD impedance) or operates at second stage fan rating for which the ratio of losses are approximately 3.5 times (1.86^2) the base MVA losses.

(ii) When the transformer is of large size and surface area of the structural parts are huge.

(iii) When the loss evaluation rates are high, leading to high mass of active parts and hence leading to higher eddy losses in winding and steel parts.

Under these conditions, localized hot-spot temperatures on the structural parts such as Tie-plate, clamps and tank wall are accurately estimated to limit the temperature below the limit of the insulation material in contact with the steel parts.

Magnetic wall shunts attract the magnetic flux lines coming out of the core and coil assembly there by reduces restricts the flux lines going to tank wall. In addition to limiting tank wall losses, magnetic wall shunts are used to contain the localized over-heating on the tank wall.

Stray losses should be limited to 10 to 20 % of the I^2R, copper losses.

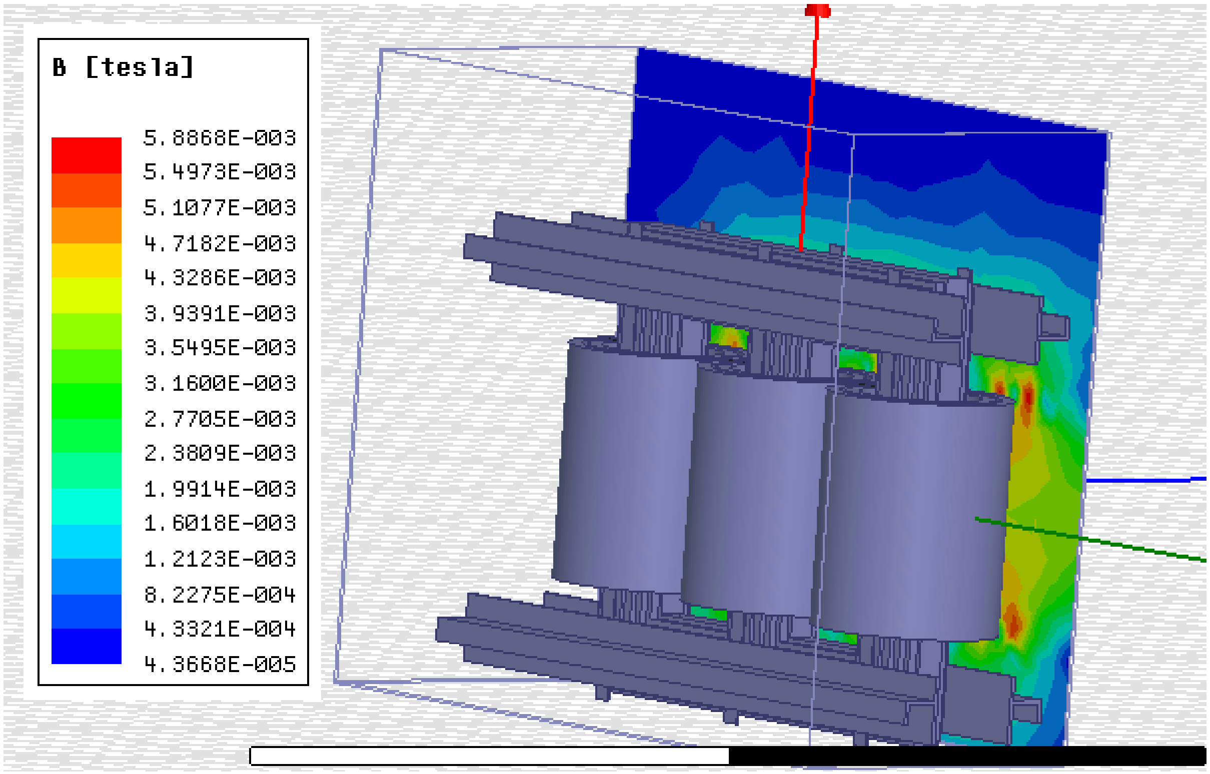

Fig. 3 Magnetic Field Mapping of Stray Losses occurring in Tank Walls

(h) Proper Thermal Design and Controlling Hot Spots:

The life of the transformer is only as good as the life of the insulation, which in turn highly affected by the temperatures to which it is subjected to. The operating temperatures are a balance between the heat generated and the heat dissipated. Heat generated by the core and the windings are dissipated internally by conduction and convection and externally by convection and radiation to the outside environment. This is a subject of great importance and of great details to ensure that no part of the transformer reaches a temperature that will lead to premature loss of life of the insulation. The design of the cooling system plays a very important role in the thermal design of the transformer.

Avoiding hot spots in core will eliminate gassing of the oil. Avoiding hot spots within the winding is very crucial, as hot spots will weaken the insulation leading to drastic reduction of life of the transformer.

Hot spot factor should be kept at 1.1 to 1. 18 in order to achieve long life.

(i) Low sound level = low vibration and longer mechanical insulation life:

During its operation, vibrations are produced by the Core and the Windings of the transformer. Core vibration is produced by the magnetostriction of the core steel. Also, loose core and large core cutting burrs can contribute towards higher vibration and sound. The winding vibration is produced by the forces due to electromagnetic attractions and repulsions between the conductors of the windings. One of manifestations of these vibrations is sound. Low sound level means lower amounts of vibration. Such vibrations also produce rubbing and friction between adjacent conductors within the winding. Such frictions slowly eat away the insulation, and the mechanical insulation life. Thus, for long life of a transformer it is essential to keep the sound level low.

Typical sound level should be kept 6 to 8 dB below the NEMA TR1 values.

(j) Monitoring with devices like VCM and Correcting issues before damage occurs:

In a companion paper on VCM produced by VTC, we have described VTC's patented transformer monitoring device VCM. This device gives the user advance warning of any incipient problems. Taking corrective measures based on such advance warnings is like routine preventive maintenance and thus the life of the transformer can be prolonged substantially. The VCM provides data which can be charted to look at the history in time domain and magnitude, which can be a powerful tool for prolonging the life of the transformers.

Conclusion:

Keeping the design and performance parameters listed above within the limits will yield the max life of insulation based on the temp and dryness.

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