Study Committee A2

Power Transformers and Reactors

Paper ID_436_2022

Complexities in Design and Manufacturing of Transformers with Low MVA, High Voltage Class

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Motivation

- The paper is focused on difference in winding design of same voltage class based on different kVA ratings of Transformers.
- Difficulties while manufacturing low MVA high voltage class.
- No specified relationship between MVA and Voltage class of Transformer.

Method/Approach

- Transformers are subjected to very high frequency voltage surges because of lightning strikes and switching operations. These surges can rise up to 8-12 times of nominal voltage rating of transformer.
- Basic insulation levels (BIL) have been defined in International standards like IEEE and IEC for different voltage classes. For example as per IEC 60076 for Nominal system voltage of 132kV winding line end BIL is 450, 550 or 650kVp.
- Transformer windings are designed based on response of windings related to the specified impulse test levels. However, winding response to impulse voltages is complicated and is based on capacitances of windings during initial application of impulse.
- Response is dependent on Distribution Constant,
- $$\alpha = \sqrt{\frac{C_g}{C_{se}}} \qquad (1)$$
  Where,
- Cg = Capacitance of winding with respect to ground parts
- Cse = Capacitance from one terminal of winding to other.
- The response of same voltage class windings with same test levels are different in low kVA (< 20,000 kVA) transformers as compared to high kVA (> 60,000 kVA) transformers based on distribution constant, α.

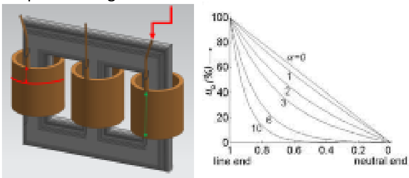
Objects of Investigation

- Following Transformer's design have taken as reference.
- 10 MVA 220/132/33 kV Transformer
- 20 MVA 220/132/33 kV Transformer
- 60 MVA 220/132/33 kV Transformer
- 100 MVA 220/132/33 kV Transformer

Challenges

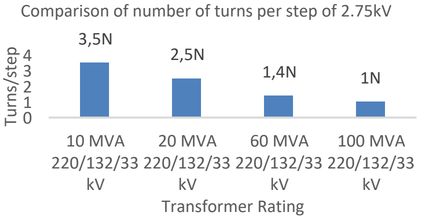
Impulse voltage distribution across windings

- The value of α should be as low as possible (close to zero) for linear distribution of voltage across winding.
- Higher values of α means, more concentration of voltage stress at line end terminal of winding.
- For example for α =10, 80% of voltage stress is across only 20% part of winding. Lower values of α means, uniform distribution of voltage stress across winding.
- For example for α =1 the voltage distribution is almost linear across winding. For a particular voltage class winding α is high if kVA rating of transformer is low.
- For example, same 132kV winding will have poor response to impulse in 10,000 kVA transformer as compared to 60,000 kVA transformer for same impulse voltage.



Regulating Winding Design

- Another challenge in low MVA transformers is to design regulating winding.
- Its design is complex from perspective of manufacturing in certain cases of low MVA, high voltage transformers.
- The number of turns required to achieve the step voltage are very high in low MVA transformers. So, even most commonly used tapping ranges will have quite high number of turns in regulating winding for low MVA transformers. With high voltage variation of +/- 10% in steps of 1.25% of 220 kV i.e. 2.75 kV, the comparative turns per step of 2.75 kV are given in Table I



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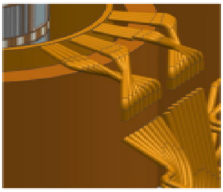
Challenges

- So, the 10 MVA transformer is having 3.5 times number of turns than the 100 MVA transformer for achieving same step voltage of 2.75 kV. This limits the available options for designing regulating winding.
- When regulating winding is inside the other windings, it can only be manufactured as layer winding because leads for each step can only be taken axially out at top or bottom of regulating winding due to presence of other winding over it.
- So, accommodating high number of turns in layer winding under geometrical constraints of winding height is a complex task. Sometimes multi- layer winding construction need to be adopted which would certainly increase the complexity of winding construction due to accommodation of more turns in multiple layer geometry and moreover, handling huge number of leads from multi-layer regulating winding becomes very complicated for manufacturers.



Formulation

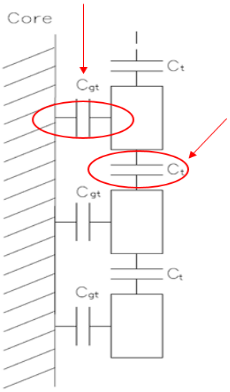
- As per transformer emf equation, Voltage per turn V/T = 4.44 *f*B*A Where, f= frequency in Hz, B= flux density in Tesla
- A= Area of core in sq.m. So, V/T is directly proportional to Core area.

- In other words, for a particular voltage, turns are inversely proportional to area of transformer core.
- Lower kVA transformers have smaller core diameters (less cross-sectional area) as compared to higher kVA transformers. Thus, it means more turns for same voltage levels.
- For example, for same voltage class 220/132/33kV
- 10,000 kVA transformer as compared to 60,000kVA transformer will have:
- Smaller core diameter
- Lesser value of V/T
- Thus, for same voltage windings more number of turns.
- Therefore, windings in 10,000kVA transformer will have more turns than 60,000kVA transformer for same voltage levels.

- As per Equation (1) For lesser α, designers are focused on achieving low value of Cg and a high value of Cse.

- Consider Layer winding, Ct is the turn to turn capacitance. Then for Nt turns there will be Nt-1 capacitances in series.
- Net Series capacitance,

  $$Cse = \frac{Ct}{Nt-1} \qquad (2)$$
- Therefore, more number of turns means lesser value of Cse.
- Similarly, Cgt is the turn to ground capacitance
- Then for Nt turns (parallel capacitances), net ground capacitance,
- $Cg= Nt\, Cgt \qquad (3)$
- Therefore, more number of turns means more value of Cgt .
- Conclusively, more turns in winding in low kVA transformers will lead to higher values of α.
- In simple terms, layer or disc windings are more stressed at line terminals under impulse voltage application for low kVA transformers as compared to high kVA transformers.



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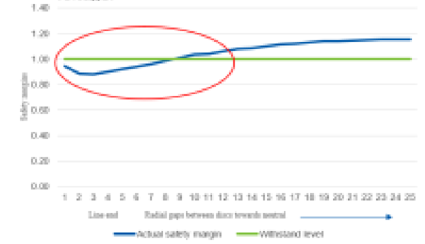
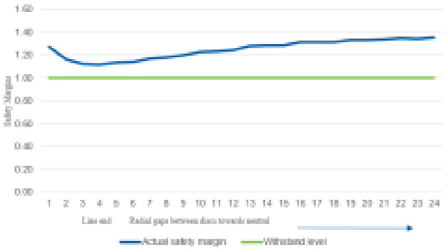
Results

- Simulation has been done (using VLN, Ukraine) for impulse voltage distribution in 132kV winding for 10,000kVA and 60,000kVA transformer. Winding type-Disc winding Lightning Impulse test level= 650kVp
- $\text{Safety Margin} = \frac{\text{Withstand voltage level}}{\text{Actual appeared voltage}}$
- Actual voltage distribution across winding is based on distribution constant, α,
- While withstand level is based on insulation design and time duration of appeared voltage across discs.
- For 10,000kVA, 132kV disc winding
- Safety Margins are less than 1
- Which means actual voltage appearing > Withstand voltage
- Disc winding not able to withstand given impulse voltage.

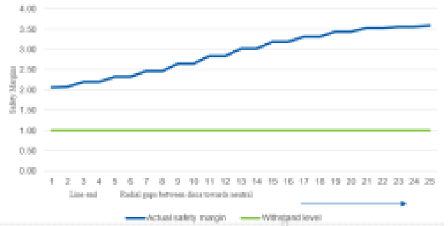


For 60,000kVA, 132kV disc winding

- Safety Margins are more than 1
- Which means actual voltage appearing < Withstand voltage.Disc winding is able to withstand given impulse voltage.
- Therefore, various techniques are adopted by designers for better stability under impulse conditions in low kVA transformers.
- The most preferred method is making interleaving windings.
- This method is more effective in low kVA transformers as two physical adjacent turns are more electrically apart because of more turns per disc.



- More turns per disc, which was earlier a disadvantage for disc winding is now an advantage in interleaving winding for improving Cse in low kVA transformers.
- However, interleaving windings are highly time consuming and very complex with respect to design and manufacturing.
- For 10,000kVA, 132kV interleaving winding
- Safety Margins are more than 2
- Which means actual voltage appearing is less than half of withstand voltage.



Conclusion

- Disc windings have more concentration of stress at line end terminal in low kVA high voltage class transformers, as compared to high kVA transformer of same voltage class.
- Various methods such as interleaving are required for improving series capacitances in winding of low kVA transformers but such methods are relatively difficult and time consuming from manufacturing perspective.
- These challenges are based on real experiences as CGPISL have rich experience in designing low kVA, high voltage transformers. To conclude, kVA rating of transformer must be in correspondence with voltage class.
- Therefore, the transformer specification framing committees need to consider this phenomenon in low kVA transformers and focus should be laid on standard rating of transformers which will relatively minimize the complexities in manufacturing along with resulting in more stable and reliable products.
- Apart from impulse distribution there are other challenges in low kVA transformers such as:
- Design and placement of regulating winding in low kVA transformers pertaining to more turns per step.
- Limitations for placing stabilizing winding to improve inter winding impedance.
- Routing of high voltage leads because of smaller tank dimensions, etc….
- Therefore, these challenges need to be addressed properly during low kVA, high voltage transformer design.