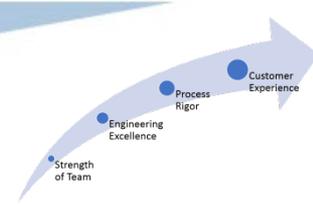


Significance of Tertiary Windings in Y-Y Connected Power Transformers

Introduction



- A “Tertiary” is a third winding added to a two winding transformer.
- Also called “Stabilizing” winding – stabilizes neutral point voltage.
- Stabilizing winding also helps in reduction of third-harmonic voltages in the line, thus reducing harmonic related issues, e.g. telephonic interference or heating.

We will discuss about:

- Application of stabilizing windings in relation to power system performance.
- Application of stabilizing windings in relation to transformer performance.
- Design and construction of stabilizing windings.
- Recommendations – Stabilizing windings required?

Application – Power System Performance

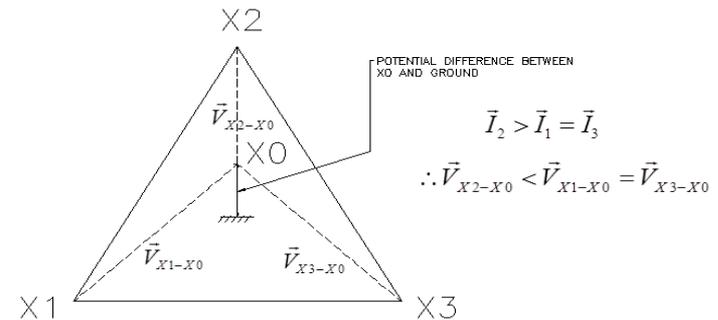


- Y-Y connected transformer can be loaded with continuous or transient unbalanced loads.
- Unbalanced loads involve current flow through the secondary neutral.
- The zero-sequence impedance of the transformer will produce zero-sequence voltage drop when such current flows.
- The zero-sequence voltage drop will rise the neutral voltage with respect to ground from its normal value of zero.
- Also, this raises the voltage of line terminals with respect to ground from its normal value of $V/\sqrt{3}$.

Application – Power System Performance (Continued)



- For an ungrounded neutral, under unbalanced loads, the sum of voltages at the neutral points is no longer zero with respect to ground = neutral shift
- Greater the unbalance, more will be the neutral shift.
- Shingle line to ground faults can create neutral shift to a very high degree.
- Even if the secondary neutral is grounded, a high zero sequence impedance of the system or of the transformer can create neutral shift.



Application – Power System Performance (Continued)

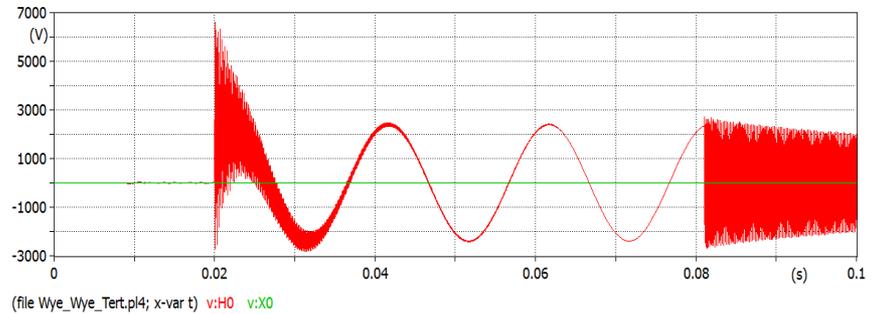
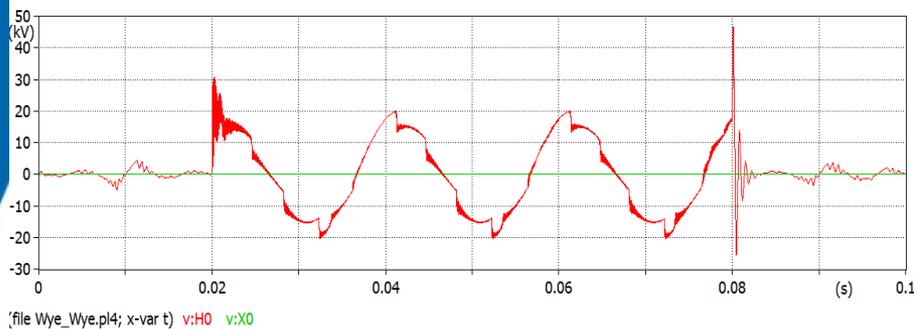


- The increase in voltage of terminals with respect to ground implies higher degree of insulation level required for transformer and associated equipment connected to terminals.
- A Y-Y connected transformer with primary neutral disconnected from the source or ground exhibits high zero-sequence impedance at its secondary side.
- A stabilizing winding, in the above case, effectively reduces the zero sequence impedance of the transformer by providing a path for zero sequence current to flow, thus reducing the neutral shift.

Application – Power System Performance (Continued)



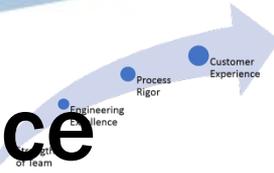
- Effect of adding stabilizing winding on a Wye-Wye transformer under SLG fault conditions.



- A 25 kV (rms) Wye-Wye transformer without a stabilizing winding, the neutral voltage (H0) peaks in the range of 20kV.

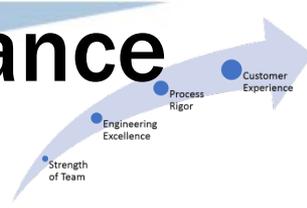
- A 25kV (rms) Wye-Wye Tertiary transformer, the neutral voltages (H0) peaks in the range of 3kV only.

Application – Transformer Performance

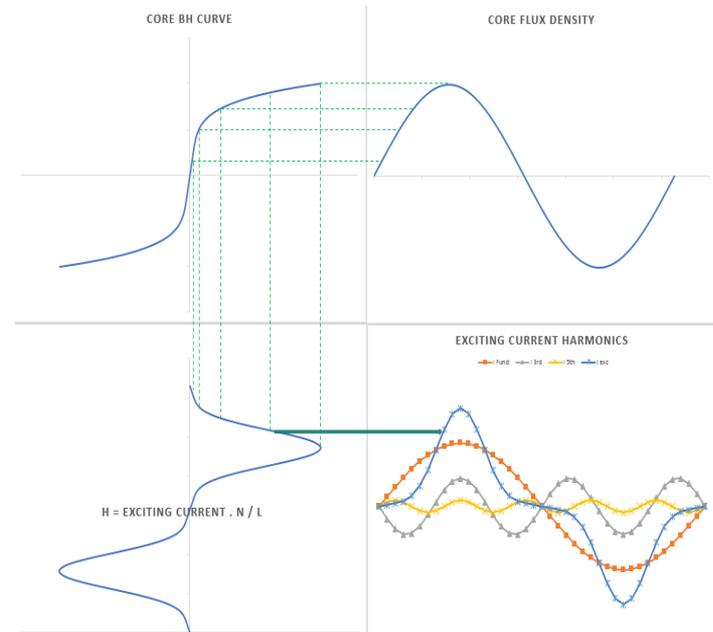


- **Stabilizing windings provide path for circulation zero sequence currents – comes from third-harmonic component of magnetization current, or neutral current drawn by unbalanced load.**
- **For temporary or continuous unbalanced loading the zero sequence current magnitudes may be lower, however for unbalanced faults, like single-line-to-ground (SLG) faults. The magnitudes may be high enough to cause heating effects in the transformer.**
- **Therefore, transformers without a stabilizing winding cannot supply significant unbalanced loads for longer duration or high short circuit currents for shorter duration.**

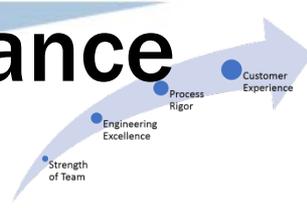
Application – Transformer Performance (Continued)



- Third harmonics currents
- B/H curve of the magnetic material of the core is not linear.
- Thus exciting current will have harmonics.
- Third harmonic component being the highest of the harmonics.
- Third harmonic component of different core legs will be in same phase.
- Thus they behave like zero-sequence currents. And hence cannot vectorially sum to zero at the neutral

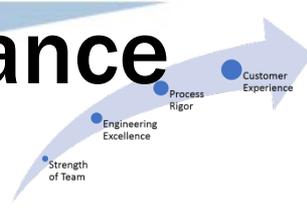


Application – Transformer Performance (Continued)

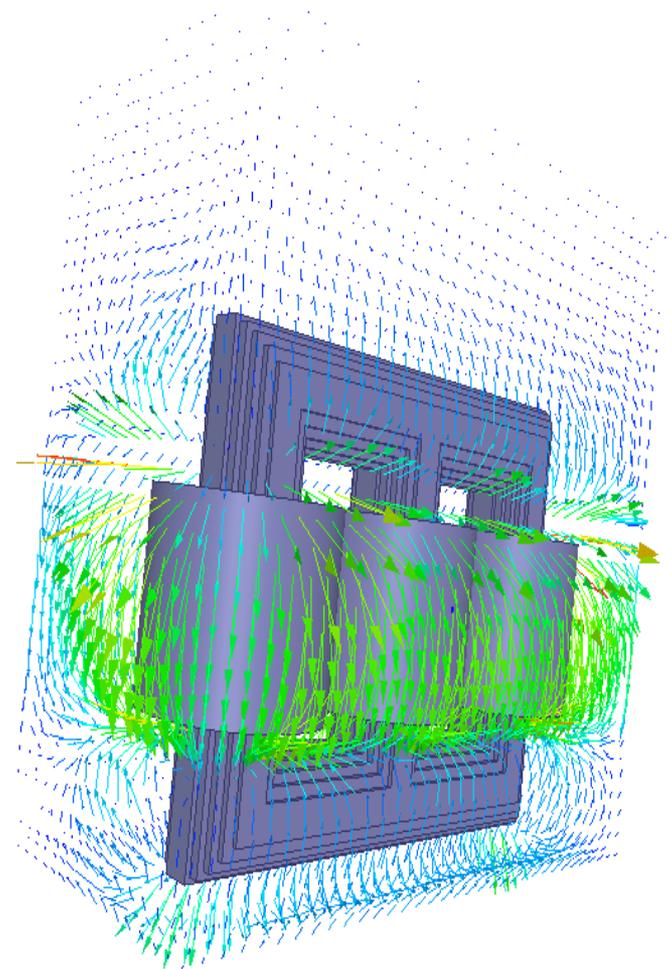


- If there is no path for zero sequence current to flow, the generated flux in the core will be non-sinusoidal. Thus output voltage will be distorted with harmonics.
- A delta connected stabilizing (tertiary) winding provides a path for circulation the third harmonic current by electromagnetic induction.
- If the primary neutral is grounded, that cfan still provide a path for third harmonic currents to flow even if the delta tertiary is not available.

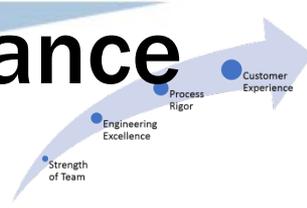
Application – Transformer Performance (Continued)



- Three phase transformer with three-legged core, without delta connected windings, can supply high line-to-ground short circuit current – if appropriately designed.
- This is because of the high reluctance path to zero-sequence flux of their magnetic circuit that reduces its magnitude significantly.
- However, the remaining zero-sequence flux has to pass through the tank cover, walls, bottom including core frames, which can produce severe overheating of these components.

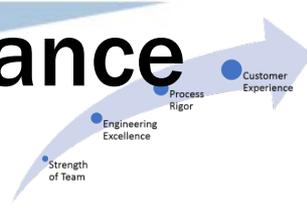


Application – Transformer Performance (Continued)

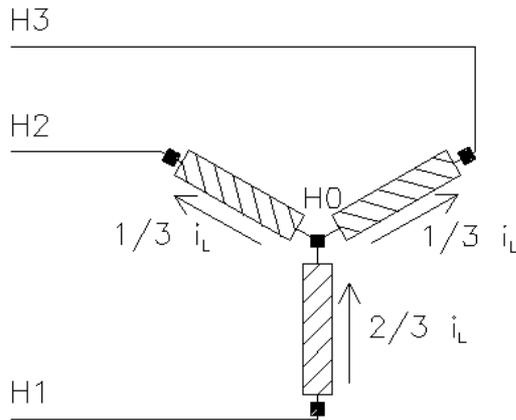


- This close loop forms like a virtual tertiary single turn winding.
- The overheating is caused by the eddy currents produced by these zero sequence fluxes.
- To manage these hot-spots, the tank can be magnetically shielded for carrying these zero sequence fluxes.
- The core frames can be isolated in such a way as to prevent building of closed loops.

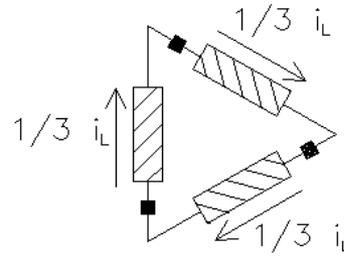
Application – Transformer Performance (Continued)



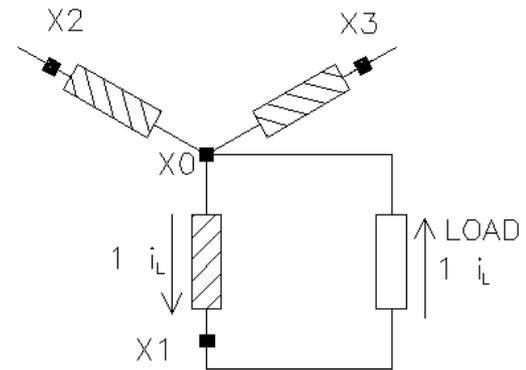
- A delta connected stabilizing winding acts as a “bridge” that “converts” line-to-neutral currents at the secondary into line-to-line currents in the primary.
- The ratio of current division between primary and tertiary is based on the inter-winding impedances, in most cases.



PRIMARY

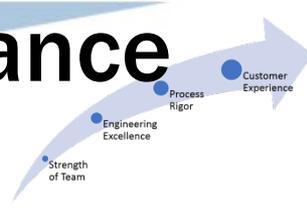


TERTIARY

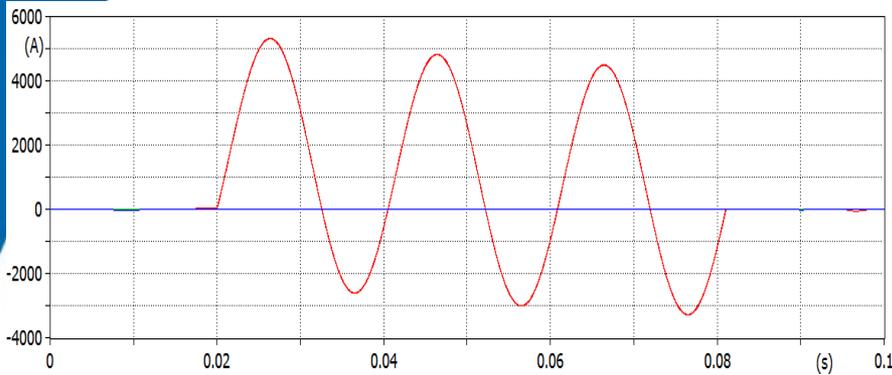


SECONDARY

Application – Transformer Performance (Continued)

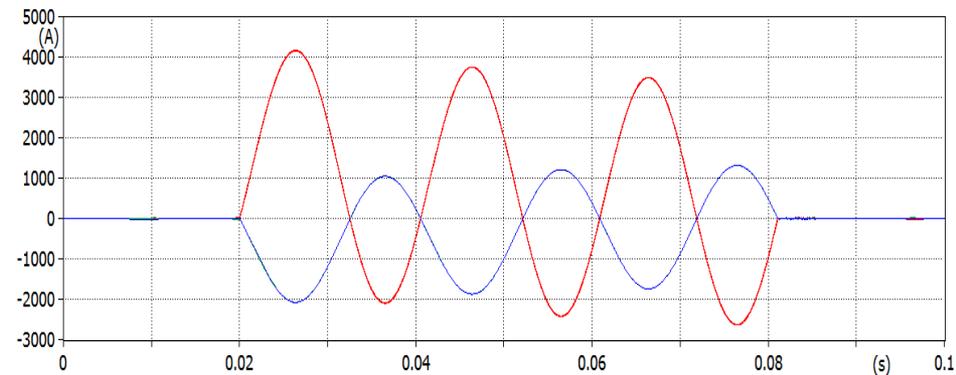


Effect of adding stabilizing winding on a Wye-Wye transformer under SLG fault conditions.



(file Wye_Wye.pl4; x-var t) c:49SA -82PA c:49SB -82PB c:49SC -82PC

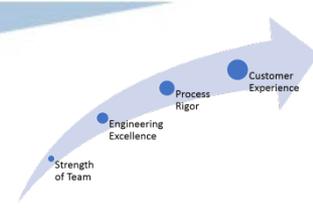
25 kV Wye-Wye transformer without stabilizing winding; the corresponding primary terminal (or phase) carries the full short circuit current.



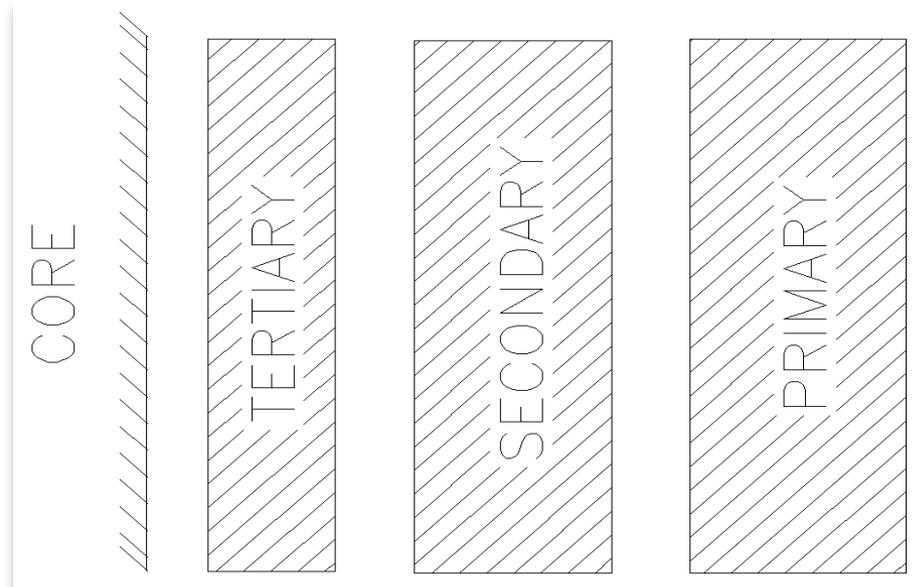
(file Wye_Wye_Tert.pl4; x-var t) c:49SA -82PA c:49SB -82PB c:49SC -82PC

25 kV (rms) Wye-Wye-Tertiary transformer, the short circuit current gets shared by tertiary winding (not shown above) based on interwinding impedances, subsequently shared by other phases (shown above).

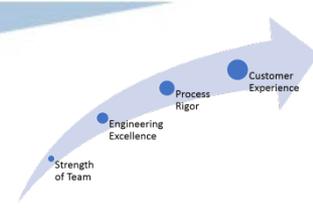
Design & Construction of Stabilizing Winding



- As stabilizing windings do not need to supply power, they can be designed for any voltages as long as it provides the required ampere-turns under SLG fault.
- For this reason, they are designed a lower voltage and kept next core.
- This increases the overall cost of transformer as secondary and primary windings are wound on top of it.

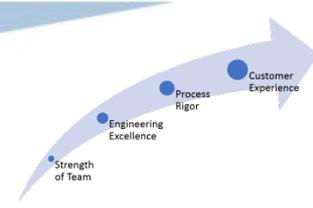


Design & Construction of Stabilizing Winding



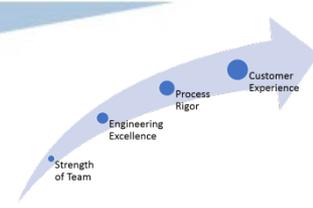
- Stabilizing winding needs to be designed for mechanical stresses due to the single-line-to-ground short circuit.
- Also, thermal stresses due to the short circuit current flowing through it. Allowable hot-spot temperature would be chosen depending on duration of loading and cumulative effects from reclosing cycles during short circuit.
- The short circuit current magnitude can vary between 1% to 50% of the total short circuit ampere-turns, which depends on interwinding impedances.

Design & Construction of Stabilizing Winding



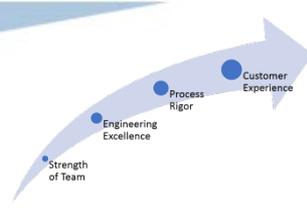
- Also, the insulation system needs to be designed for the transferred surge voltages from another winding.
- The voltage rating of stabilizing winding is irrelevant as the purpose is to provide required zero sequence ampere-turns, however the voltage rating shall be lesser than the adjacent LV winding to keep the transferred voltage surges lower.
- Sometimes, to limit the short circuit current circulating inside the stabilizing winding, reactors are used in series with stabilizing winding before the delta formation.

Design & Construction of Stabilizing Winding



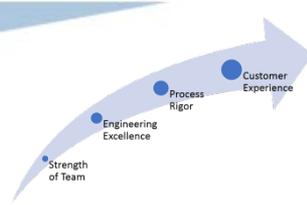
- Typically one corner of the stabilizing winding is brought out through suitable bushing – this allows grounding of any transferred voltages, and measurement of insulation resistance, power factor.
- Sometimes, all corners of stabilizing winding are brought out for exciting the transformer during testing, as it provides low enough voltage when LV and HV are both high voltages.

Recommendations – Is a Stabilizing Winding Required?



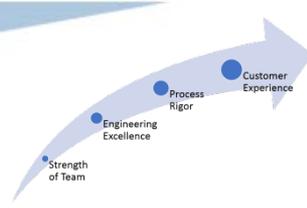
- The main effect of stabilizing winding in a Y-Y connected transformer are to reduce the zero-sequence impedance and to control the generation and flow of third harmonic voltage and currents.
- A design with stabilizing winding would be safe side of all possible considerations.
- There is a potentially unnecessary extra cost to it.
- On the other hand, eliminating the stabilizing winding can include, not only the cost, but also may reduce the number of components exposed to short circuit currents.

Recommendations – Is a Stabilizing Winding Required?



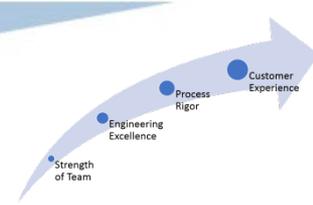
- From technical performance, whether or not the stabilizing winding can be omitted entirely depends upon the following:
 - Whether the resulting zero-sequence and third-harmonic characteristics are compatible with the system into which the transformer is to be installed (steady state operation, relaying practice, grounding).
 - Whether the transformer will be capable of performing reliably under expected transient and emergency conditions.
- This has to be discussed and agreed upon between transformer manufacturer and the specifying engineer (customer).

Recommendations – Is a Stabilizing Winding Required?



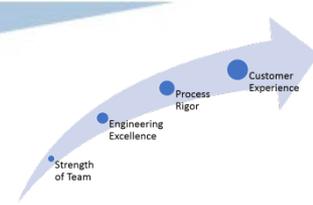
- In some applications, there would be no trouble is the stabilizing windings were omitted from transformers because of the following:
 - Today the loads on transmission lines are much closer to being balanced.
 - Telephone ground return circuits have been replaced with metallic return or cables. Also,, migration from cable to fiber optics communications eliminates all interference possibilities.
 - Modern relaying equipment can calculate the various components of voltages and currents.
 - Modern transformers' cores have better saturation characteristics which produce third-harmonic components.

References



- [1] PC57.158/D7A, July 2017, “Draft Guide for the Application of Tertiary and Stabilizing Windings in Power Transformers”.
- [2] Kulkarni, S.V., Khaparde, S.A, “Transformer Engineering – Design and Practice”, Marcel Dekker, New York, 2004.
- [3] Blume, L.F et al, “Transformer Engineering – A Treatise on the Theory, Operation, and Application of Transformers”, 2nd Edition, John Wiley and Sons, 1951, New York.

Questions



I will be glad to answer any questions you may have.