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?
• 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 $V/\sqrt{3}$. 
• For and 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.
• 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.
• 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 (HO) peaks in the range of 20kV.

A 25kV (rms) Wye-Wye Tertiary transformer, the neutral voltages (HO) peaks in the range of 3kV only.
• 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.
• 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
• 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.
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.
• 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.
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.
Effect of adding stabilizing winding on a Wye-Wye transformer under SLG fault conditions.

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

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.
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 if 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


Questions

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