

October, 2013

Wye/Wye Transformers & Tertiary Windings

Although care must be exercised when using a wye-wye connected transformer, it has important advantages over other three-phase transformer connections.

- The primary and secondary circuits are in phase (no phase angle displacements). This is an important advantage where transformers are used to interconnect systems of different voltages in a cascading manner.

As an example, suppose there are four systems operating at 500, 230, 138, and 69 kV that need to be interconnected. Substations can be constructed using wye-wye transformer connections to interconnect any two of these voltages. The 500 kV system can be tied with the 69 kV system through a single 500 to 69 kV transformation or through a series of cascading transformations at 230, 138, and 69 kV.

- If the neutral end of a Y-connected winding is grounded, reduced levels of insulation are required at the neutral end of the winding. A winding that is connected across the phases (delta) requires full insulation throughout the winding.

The first advantage is the major reason that wye-wye connected transformers are frequently found in substation installations. They may be appropriate when one is confident that the secondary load is sinusoidal and not comprised of non-linear loads such as variable speed drives and rectifier feeds. When providing power to non-sinusoidal loads however, serious consideration must be made to address and manage the following:

- Triplen harmonics can pass through the transformer. Triplen harmonics are comprised of the odd multiples of the 3rd harmonic (ex. 3rd, 9th, 15th, 21st etc.).

A harmonic is a component of a wave at a frequency that is a multiple of the fundamental (usually 60 Hz) power line frequency. Harmonics are attributed to loading from large amounts of electronic devices, using solid state power switching supplies for converting incoming AC to DC and/or industrial loads for rectifier feeds and induction heating. These non linear loads create harmonics by drawing current in abrupt short pulses, rather than in a smooth sinusoidal manner.

- Ground faults on the transformer secondary are seen as ground faults on the primary since the zero sequence (neutral) current passes directly through the transformer, making relay protection difficult. With a delta-wye transformer, the secondary ground faults do not cause zero sequence current to flow in the primary circuit.

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On three-phase power systems, neutral current is the sum of the three line-to neutral currents. With balanced three-phase linear currents consisting of sine waves spaced 120 electrical degrees apart, the sum at any instant in time is zero, and so there is no neutral current. In most three-phase power systems supplying single-phase loads however, there will be some phase current imbalance and some neutral current. Small neutral current resulting from slightly unbalanced loads does cause problems for typical power distribution systems. Nonlinear loads however, such as rectifiers and power supplies, have phase currents which are not sinusoidal. The sum of balanced, non-sinusoidal, three-phase currents can be substantially above zero. These non-sinusoidal components are referred to as harmonics.

Harmonics loading can result in waveform distortion. The triplen harmonics are of primary concern since their effect on the fundamental waveform are additive.

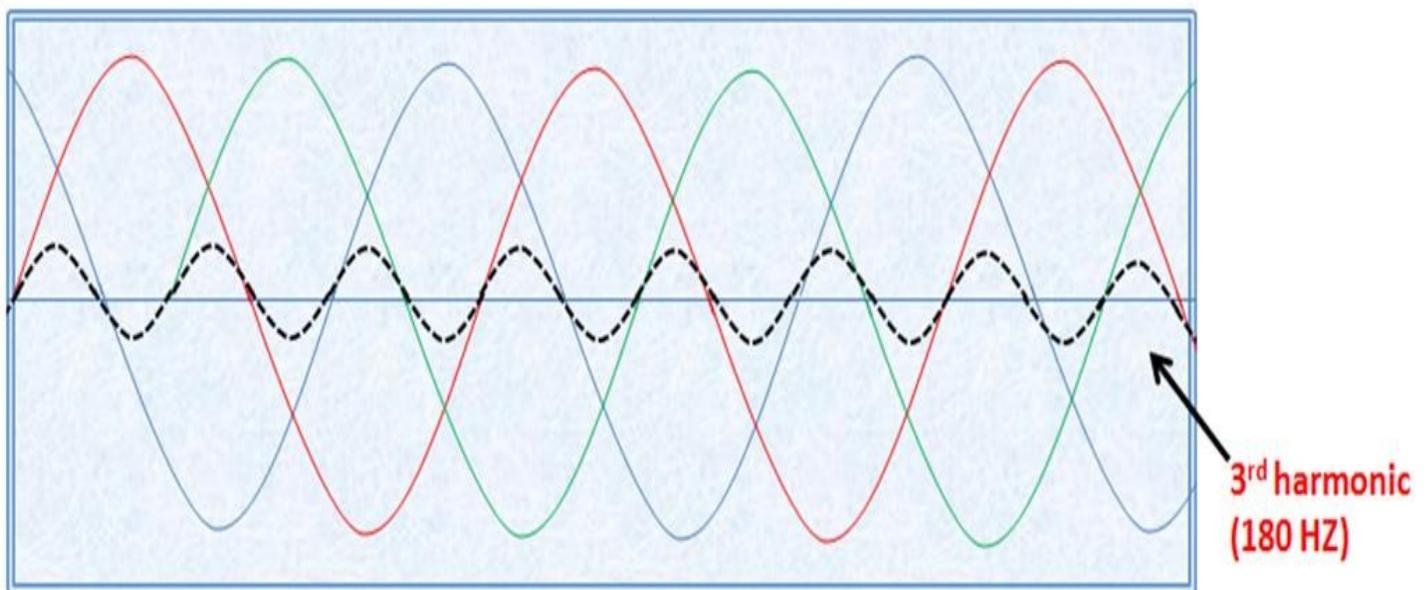


Figure 1

Figure1 depicts three-phase fundamental waveforms space 120 degrees. It also shows the third harmonic waveform. Note that the harmonic waveform is in phase with all three fundamental waveforms and has the same phase relationship to the 2nd and 3rd fundamental waveforms as it does with the 1st. With each positive half-cycle of the fundamental waveforms, there are two positive half-cycles and one negative half-cycle of the harmonic waveform. The 3rd-harmonic waveforms of three 120 degree phase-shifted fundamental frequency waveforms are therefore in phase with one other. Further, since the angular displacement is at 120 degrees and the triplen harmonics are comprised of the odd multiples of 3 (3, 9, 15, 21, etc.) all triplens would precisely overlap and appear as a single, unified waveform.

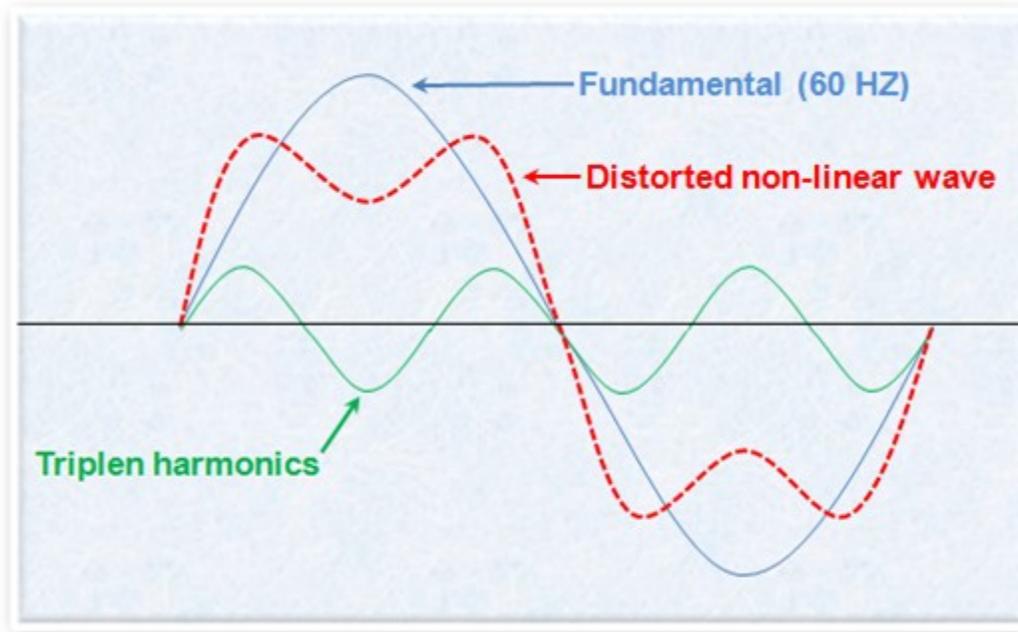


Figure 2

Although the triplen harmonics waveform is “uniform”, the values of each are additive. Heavy harmonic loading therefore can result in significant fundamental waveform distortion. Figure 2 depicts a single phase fundamental waveform with compound triplen harmonic loading. The resultant distortion of the fundamental is significant.

Depending on the method of operation, load side equipment can be affected in a variety of ways by the distortion of the fundamental waveform. Significant harmonic content can lead to overheating in motors which may result in the degradation of insulation and loss of life. Other equipment may be dependent on accurate waveshapes and may malfunction when harmonics are present. Harmonics due to multiple single phase distorting loads can result in neutral currents that exceed rated line current which in turn may result in a reduction in electrical distribution system wiring life and the possibility of fire. For the transformer itself, unmanaged harmonics may result in increased winding and core losses which may lead to overheating and loss of service life due to gassing and degradation of the insulation system.

Transformers that are connected delta-delta, delta-wye, and wye-delta have balanced voltages due to the absence of a floating neutral. A floating neutral is however the case with a wye-wye connected transformer. The primary and secondary windings are connected in a wye configuration with the neutral and phase winding terminated at the bushings. To accommodate and mitigate the propagation of harmonics, a third winding connected in a delta configuration can be “buried” as a tertiary (stabilizing) winding. The tertiary winding provides a circulating path for the harmonics that are produced with the power frequency.

The addition of a delta connected tertiary winding within a wye-wye transformer provides a path for the balancing current to flow when the secondary must supply an unbalanced load and the neutral point on the primary winding cannot be connected to the system neutral. Without the tertiary winding, an unbalanced load would result in a voltage shift on the secondary neutral and nonsymmetrical voltages.

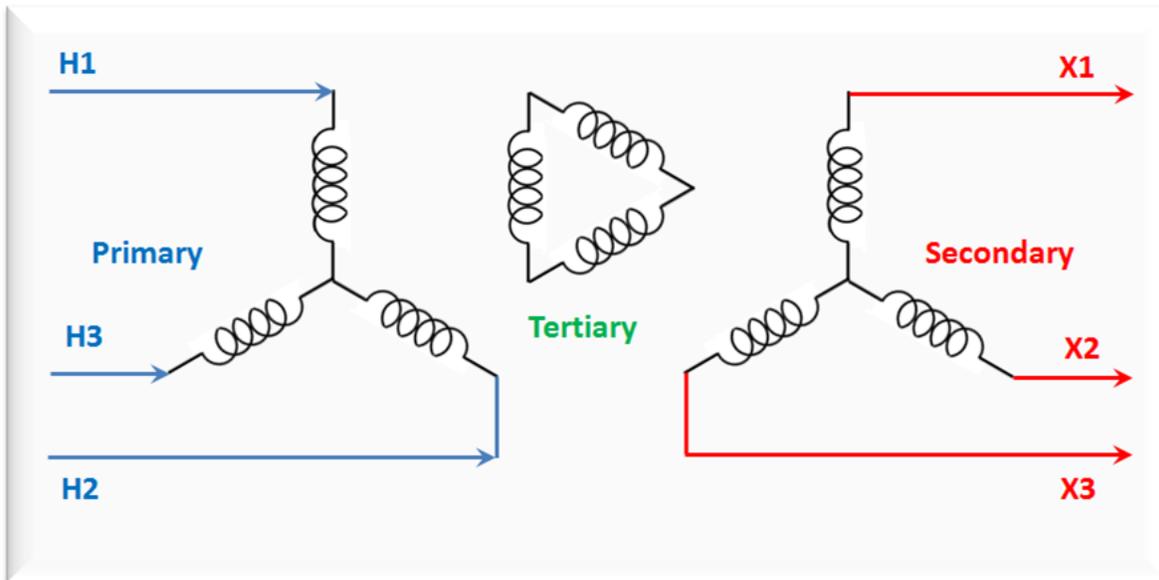


Figure 3

Figure 3 represents a wye-wye connected transformer with a buried tertiary winding. The primary and secondary windings terminate at the transformers HV and LV bushings. It is not necessary to terminate the delta connected tertiary external to the tank when it is used solely to accommodate harmonic loading. The tertiary windings can however, be used to provide supplemental power in which case they can be terminated on their own tank bushings.

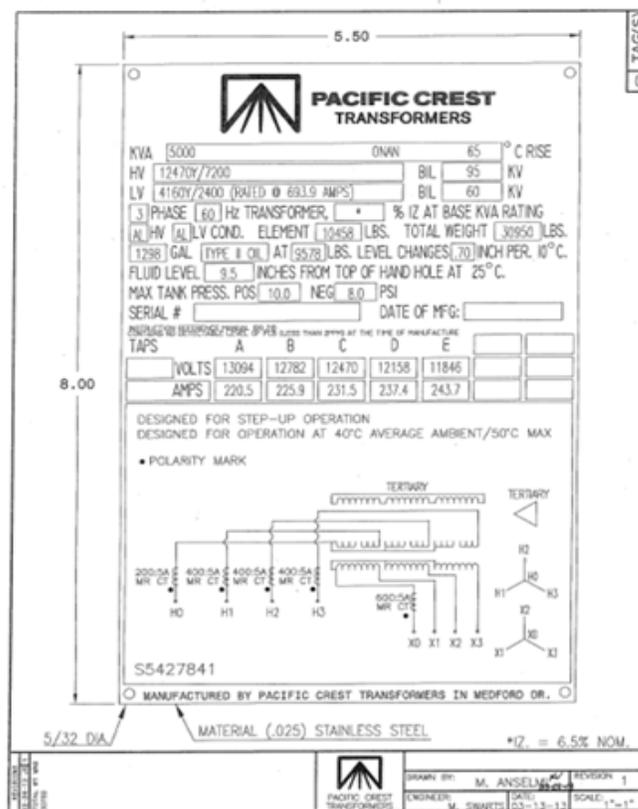
The rating of the tertiary winding until recently has been managed “casually” by specifiers and manufacturers. Recently however, the IEEE Transformers Committee met and approved the following:

“The group has been working for three years to resolve the subject of default kVA rating for stabilizing windings. A new clause was prepared by the group for inclusion in C57.12.00, and the following text was surveyed among the Performance Characteristics and Insulation Life Subcommittees prior to this meeting.

5. 11.1.2 Thermal Rating for Stabilizing Windings (buried tertiary) In addition to the short circuit duty stabilizing windings shall be designed to withstand the transient and continuous thermal duty as specified by the user and in accordance with the allowable temperature limits of 5.11.1. In the event no continuous thermal duty for the stabilizing winding can be established from the user’s specification, the manufacturer shall design the stabilizing winding considering the

circulating current in that winding, resulting from a full single phase load in the largest main secondary winding. The manufacturer shall determine kVA rating for the stabilizing winding based on the transformer's equivalent circuit for single phase loading condition."

In the event of a line to ground fault on primary or secondary, the fault current in the tertiary winding will be 1/3 of that in the main winding. Therefore, to insure sufficient mechanical withstand strength in the total winding, the tertiary winding capacity must be designed to equal or exceed 1/3 of the transformer kVA.



Above is an image of a nameplate drawing for a transformer recently supplied by PCT. Note the buried tertiary. The transformer was designed for generator step-up duty.

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