Easy understanding of 3-phase transformer connections (Delta–Delta, Wye–Wye, Delta–Wye and Wye–Delta)

Three-phase voltage transformations can be accomplished by using **three phase transformers**, which are single devices with all windings constructed on a single iron core.

Three phase voltage transformations also can be accomplished by using three single-phase transformers that are connected externally to form a three-phase bank.

Easy understanding of 3-phase transformer connections - Delta–Delta, Wye–Wye, Delta–Wye and Wye–Delta (on photo: Jefferson Electric transformer)

Three-phase voltage transformations

from a **reliability and maintenance standpoint.** If several identical transformers are needed at one location, the single-phase option can include the purchase of a spare unit to reduce outage time in the event of a failure.

This practice often is seen with critical autotransformer banks and generator step-up transformers because loss of the transformer for an extended period has very significant impacts.

The connections discussed in this article **will be implemented using single-phase units**.

When connecting single-phase transformers to form a three-phase bank, **the winding polarities must be carefully observed.** Polarity is indicated using a dot convention. Current owing into a dot on the primary winding will induce a current owing out of the dot on the corresponding secondary winding.

Depending on how the windings are connected to the bushings, the polarities can be additive or subtractive.

The two most commonly used three-phase winding configurations are delta and wye, named after the Greek and English letter that each resembles. In a delta configuration, the three windings are connected end-to-end to form a closed path. A phase is connected to each corner of the delta.

Although delta windings are often operated ungrounded, a leg of the delta can be center tapped and grounded, or a corner of the delta can be grounded. In a wye configuration, one end of each of the three windings is connected to form a neutral. A phase is connected to the other end of the three windings. The neutral is usually grounded.

The following paragraphs describe three-phase transformers which utilize the delta and wye connections.

Next part of this article will discuss three-phase transformers using the open-delta and open-wye connections, where one of the single-phase transformers making up the three-phase bank is omitted. The leg of the transformer with the missing transformer is referred to as the phantom leg.

1. Delta–Delta

Delta–delta transformers, as shown in Figure 1, often are used **to supply loads that are primarily three phase but may have a small single-phase component**.

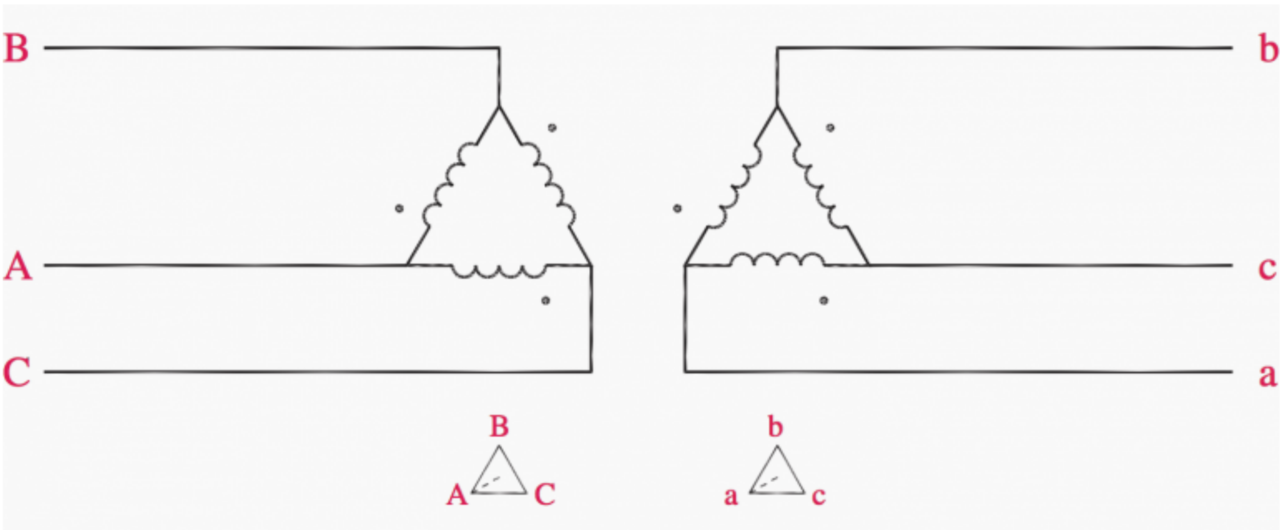

Figure 1 – Delta-Delta Transformer

The three-phase load is typically motor load while the single-phase component is often lighting and low voltage power. The single-phase load can be fed by grounding a center tap on one of the legs of the delta secondary, then connecting the single-phase load between one of the phases on the grounded leg and this grounded neutral.

Figure 2 shows a delta–delta transformer connection.

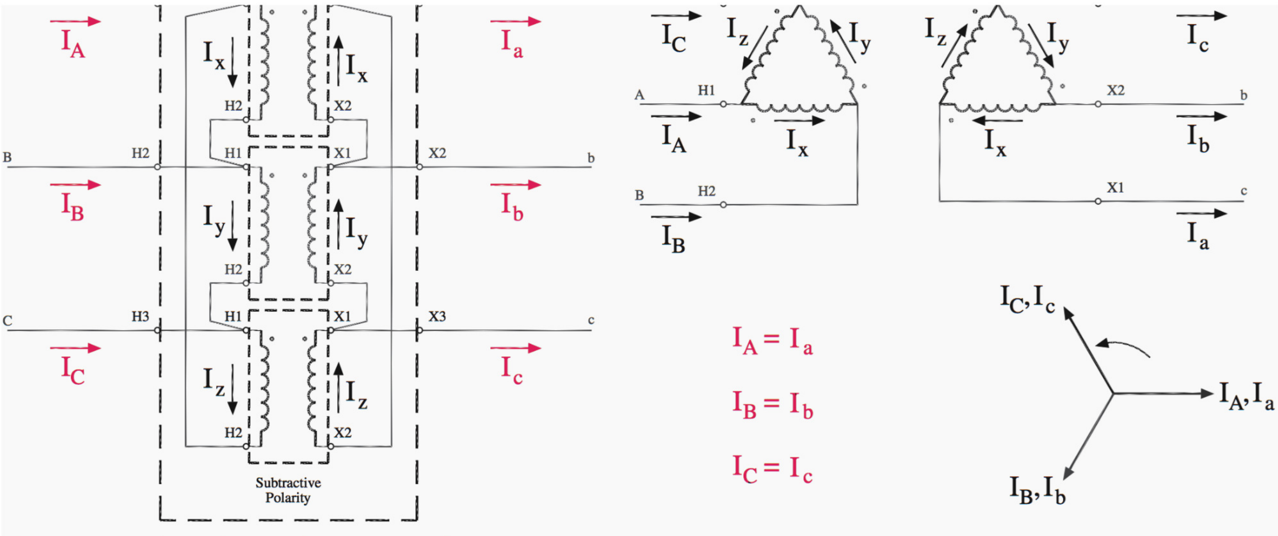

Figure 2 – Delta–Delta Transformer Connections (click to expand diagram)

The connection diagram on the left shows how a delta–delta connection can be made, **either with three single-phase transformers or with one three-phase transformer**.

The dashed lines indicate the transformer outlines. The three single-phase transformer implementation can be seen by disregarding the outer dashed outline and the bushing labels shown at that outline, and concentrating on the three smaller (single-phase transformer) outlines.

> The bushings of the single-phase transformers are connected by external jumpers as shown to accomplish the delta–delta connection. In the case of the one three-phase transformer implementation, the three inner outlines are disregarded, and the jumpers between the windings are made inside the transformer tank. The six bushings on the three-phase transformer outline are available for connection.

The schematic diagram at the upper right is perhaps easier to analyze, as the delta connections can clearly be seen.

currents, and the equations at the bottom center show those relationships mathematically.

> *As the loading on a delta–delta transformer becomes unbalanced, high currents can circulate in the delta windings leading to a voltage imbalance. Balanced loading requires the* ***selection of three transformers with equal voltage ratios and identical impedances.***

Also, the amount of single-phase load should be kept low because the center-tapped transformer must supply most of the single-phase load. As the single-phase load is increased, the center-tapped transformer will increase its loading more than the other two transformers and will eventually overload.

If one of the single-phase transformers in the delta–delta bank fails, the bank can be operated with only two transformers forming an open delta configuration. The kVA rating of the bank is reduced, but three-phase power is still supplied to the load.

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2. Wye–Wye

Wye–wye transformers, as shown in Figure 3, can serve **both three-phase and single-phase loads.** The single-phase load should be distributed as evenly as possible between each of the three phases and neutral.

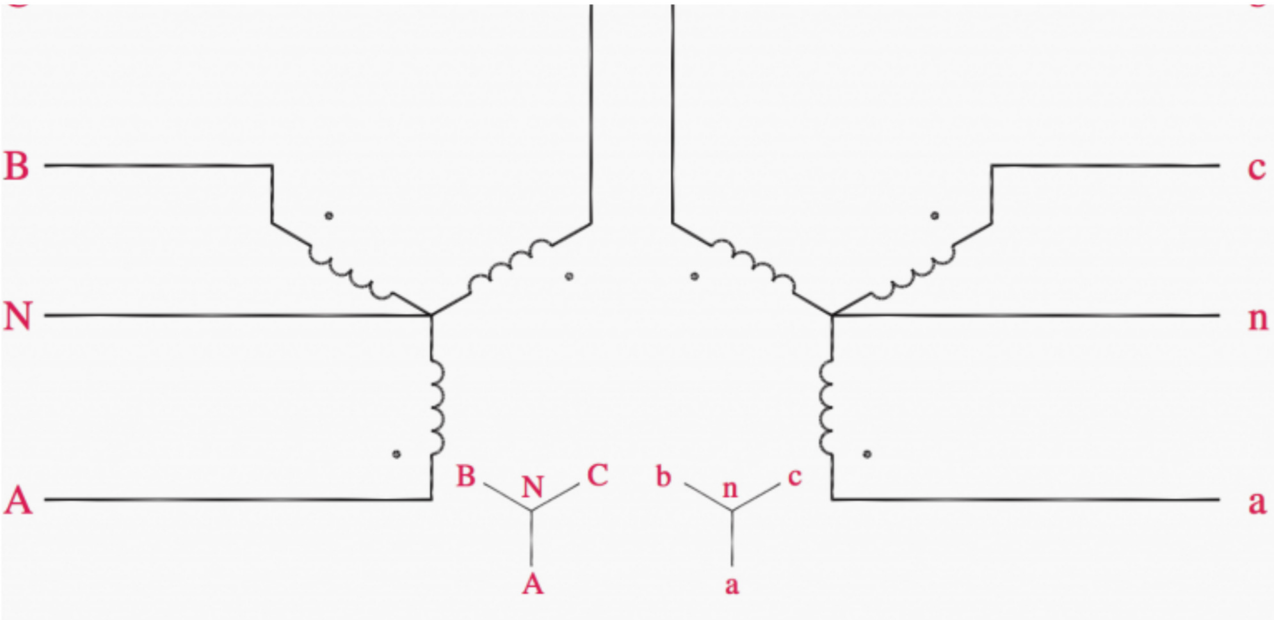

Figure 3 – Wye–Wye Transformer

Figure 4 illustrates the wye–wye connection, either as three single-phase transformers or as a single three-phase unit. Both bushing labels and polarity dots are shown.

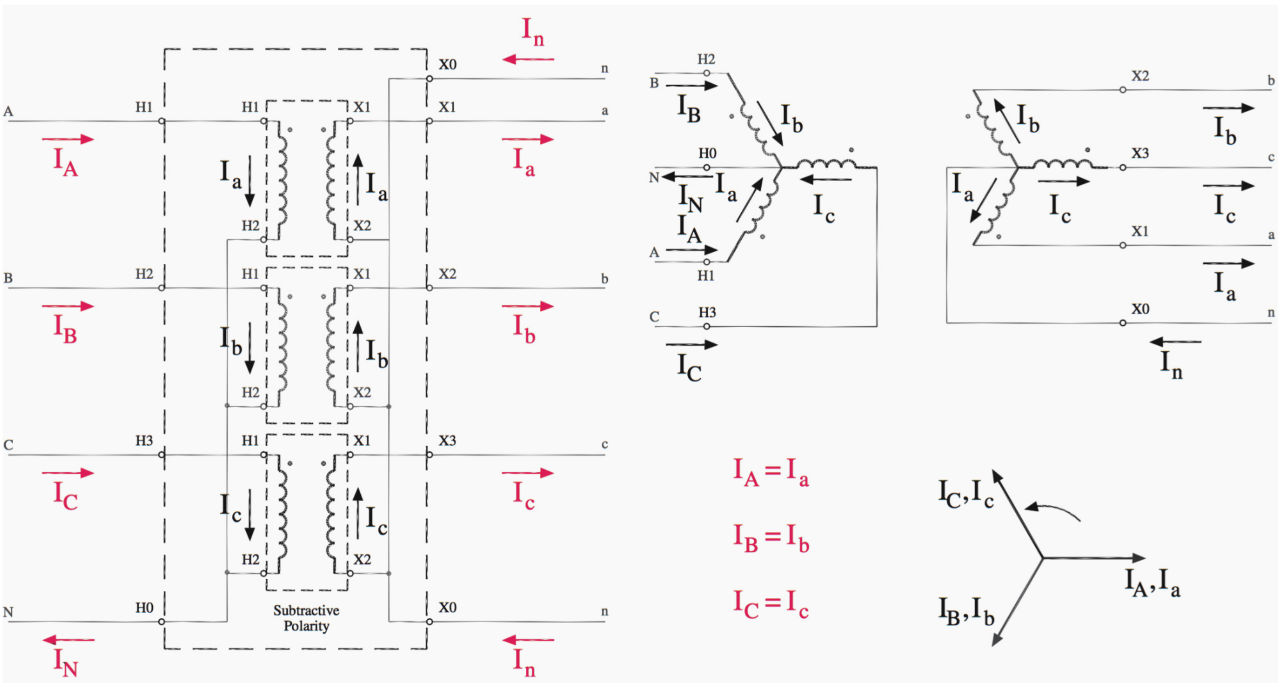

Figure 4 – Wye–Wye Transformer Connections Diagram (click to expand diagram)

interference in nearby communication circuits as well as other assorted power quality problems.

> Another problem is that the possibility exists for **resonance to occur** between the shunt capacitance of the circuits connected to the transformer and the magnetizing susceptance of the transformer, especially if the circuits include insulated cable. Because of these problems, wye–wye transformers must be specified and implemented carefully.

Adding a third (tertiary) winding connected in delta alleviates many of the concerns mentioned.

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3. Delta–Wye

The delta–wye connection is the most commonly used **three-phase transformer connection**. The wye-connected secondary allows single-phase load to be distributed among the three phases to neutral instead of being placed all on one winding as with a four-wire delta secondary.

> This helps keep the phase loading on the transformer balanced and is **especially important when the amount of single-phase load becomes large**. The stable neutral point also provides a good ground location to allow critical damping of the system to prevent voltage oscillations.

If one of the single-phase transformers in the delta–wye bank fails, the entire bank becomes inoperative.

Figure 5, it cannot be paralleled with delta–delta and wye–wye transformers that produce no phase shift.

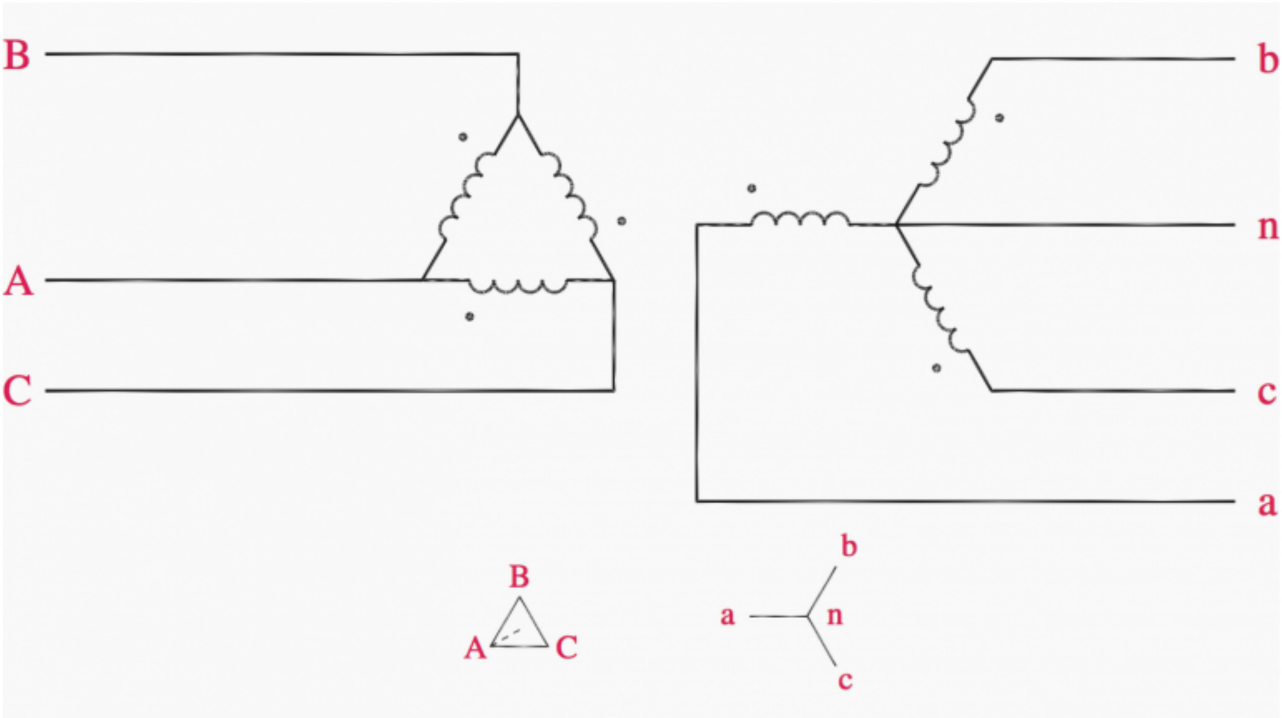


Figure 5 – Delta–Wye Transformer

Figure 6 illustrates the delta–wye connection, either as three single-phase transformers or as a single three-phase unit. Both bushing labels and polarity dots are shown.

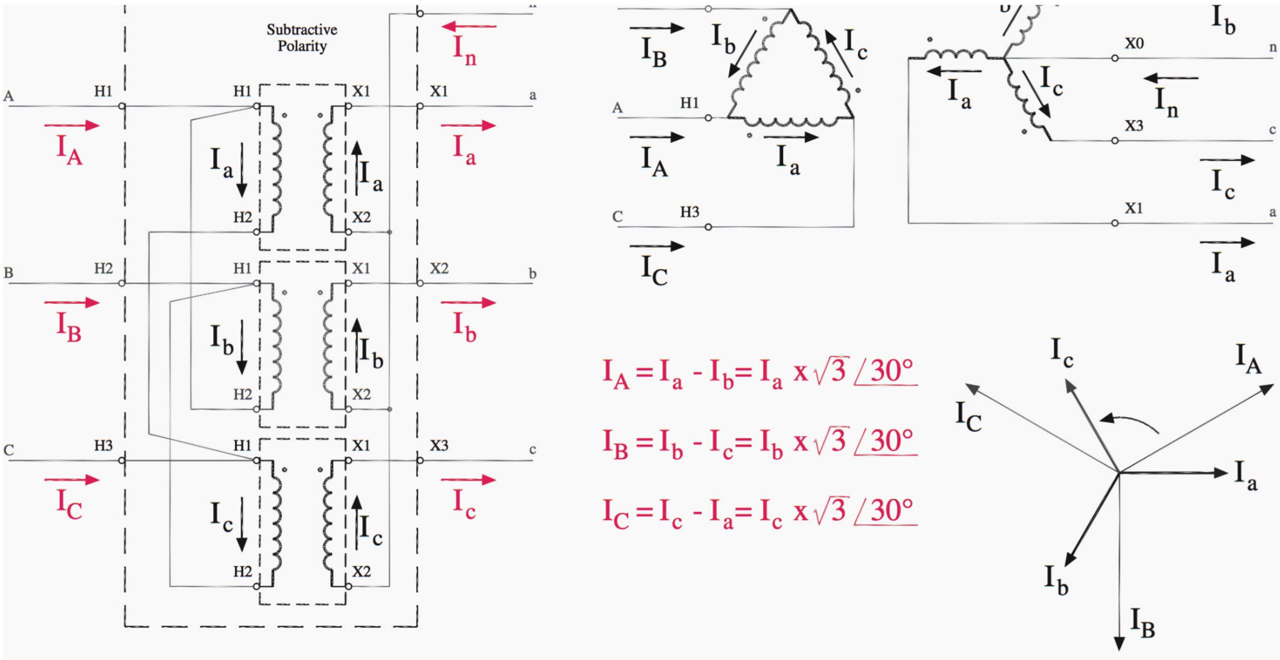


Figure 6 – Delta–Wye Transformer Connections

Analyzing the delta–wye transformer illustrates many important concepts regarding the operation of polyphase transformers. The analysis can be done on either a voltage or a current basis. Since voltage (potential difference or the subtraction of two phasor quantities) is rather abstract and difficult to visualize, current (or the flow of charge) will be used as the basis for analysis, since current is easy to conceptualize.

The currents owing in the windings of a delta–wye transformer are shown in Figure 7. Note that the arrows indicate instantaneous directions of the AC current and are consistent with the dot convention.

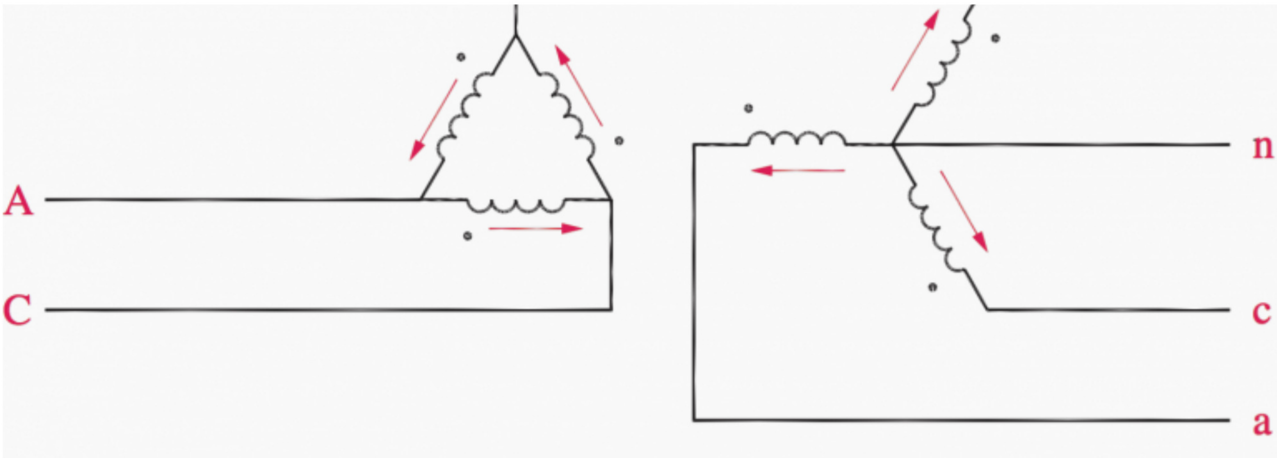
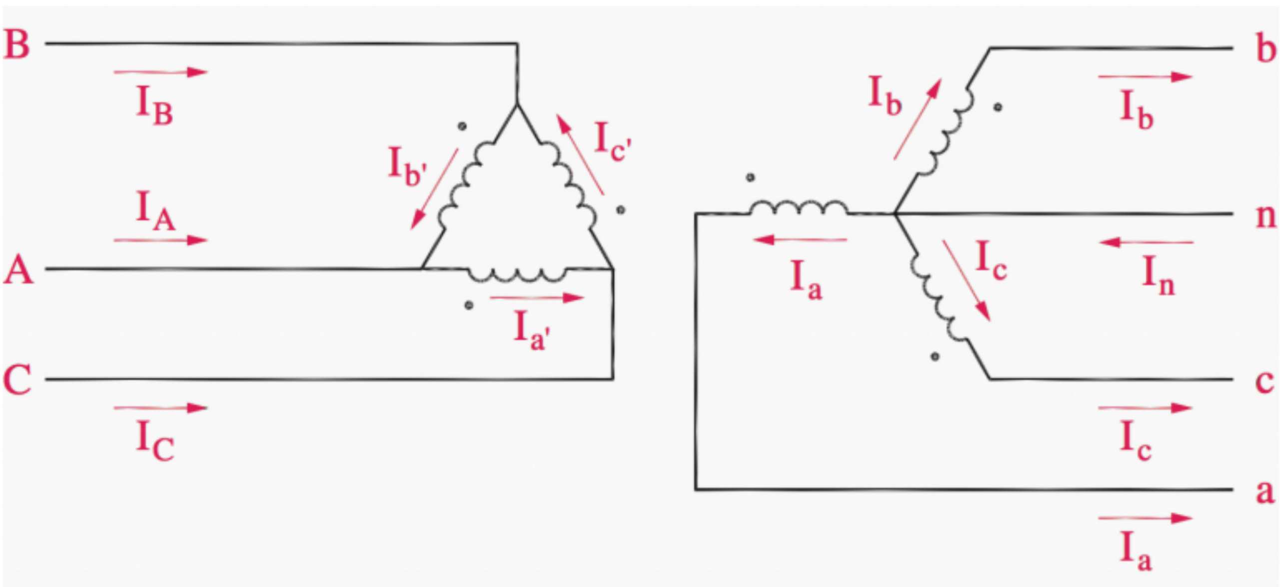


Figure 7 – Delta and Wye Windings

The analysis must begin in one of the two electric circuits, either the delta- connected high voltage circuit or the wye-connected low voltage circuit.

Since current is being used as the basis for analysis, the wye-connected circuit is selected as the starting point, since in a wye-connected circuit, the line currents (leaving the transformer) and the phase currents (owing in the transformer windings) are equal. This relationship between line and phase currents simplifies the analysis.

The analysis starts by labeling all line and phase currents. This is shown in Figure 8.



Note that lower-case subscripts indicate line currents in the low voltage circuit, and upper-case subscripts indicate line currents in the high voltage circuit. In the low voltage circuit, the phase currents are identical to the corresponding line currents, so they also are labeled I_a, I_b, **and** I_c. When the transformer windings are drawn, a particular high voltage winding corresponds to the low voltage winding drawn parallel to it.

> In other words, a high voltage winding and a low voltage winding that are drawn parallel to each other constitute **a single-phase transformer or two windings on the same leg of the magnetic core of a three-phase transformer**.

The high voltage phase current corresponding to I_a is labeled $I_{a'}$. The direction of $I_{a'}$ relative to that of I_a must honor the dot convention. The magnitude of $I_{a'}$ relative to I_a is the inverse of the **transformer turns ratio "n"**, or

$$I_{a'} = \frac{1}{n} I_a$$

When analyzing a transformer using per-unit, **n = 1** so it becomes:

$I_{a'} = I_a$

So,

$I_{a'} = I_a$ **(per-unit)**
$I_{b'} = I_b$ **(per-unit)**
$I_{c'} = I_c$ **(per-unit)**
(Eqs. 1)

Next, Kirchhoff's current law can be applied to each node of the delta:

$I_C = I_{c'} - I_{a'} = I_c - I_a$

(Eqs. 2)

Equations above express the **high voltage circuit line currents in terms of the low voltage circuit line currents**. At this point, numerical values can be substituted for I_a, I_b, and I_c. **Keeping in mind that I_a, I_b, and I_c represent a balanced set of phasors**, arbitrary per-unit values are selected to represent **a-b-c phase sequencing**:

$$I_a = 1\angle 0^\circ$$
$$I_b = 1\angle 240^\circ$$
$$I_c = 1\angle 120^\circ$$

Eqs. 3

A positive phase sequencing (a-b-c) must be used, since the IEEE standards for power transformers (the IEEE C57 series) are based on positive phase sequencing.

Substituting Eqs. 3 into Eqs. 2:

$$I_A = 1\angle 0^\circ - 1\angle 240^\circ = \sqrt{3}\angle 30^\circ$$
$$I_B = 1\angle 240^\circ - 1\angle 120^\circ = \sqrt{3}\angle 270^\circ$$
$$I_C = 1\angle 120^\circ - 1\angle 0^\circ = \sqrt{3}\angle 150^\circ$$

Eqs. 4

difference and a 30° angular difference are apparent.

IEEE Std. C57.12.00 defines the direction in which the phasor angles shall change from one electrical circuit to the other. In a standard delta–wye (or wye–delta) transformer, the positive-sequence currents and voltages on the high voltage side lead the positive-sequence currents and voltages on the low voltage side by 30°.

> **When the high voltage phasors lag the low voltage phasors, the connection is considered to be non-standard.** Sometimes nonstandard connections are necessary to match the phasings on two different systems that must be electrically tied, but normally, standard connections are specified.

Note that the convention to determine a standard connection requires that the high voltage phasors lead the low voltage phasors by **30°**. No reference is made to primary or secondary. The primary windings of a transformer are those windings to which voltage is applied. The secondary windings have an induced voltage impressed across them.

Usually, the primary windings are the high voltage windings, but this is not always the case. A good example of an exception is a generator step-up transformer.

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4. Wye–Delta

The wye–delta transformer shown in Figure 9 is sometimes used **to provide a neutral on a three-wire system but also can serve load from its secondary.**

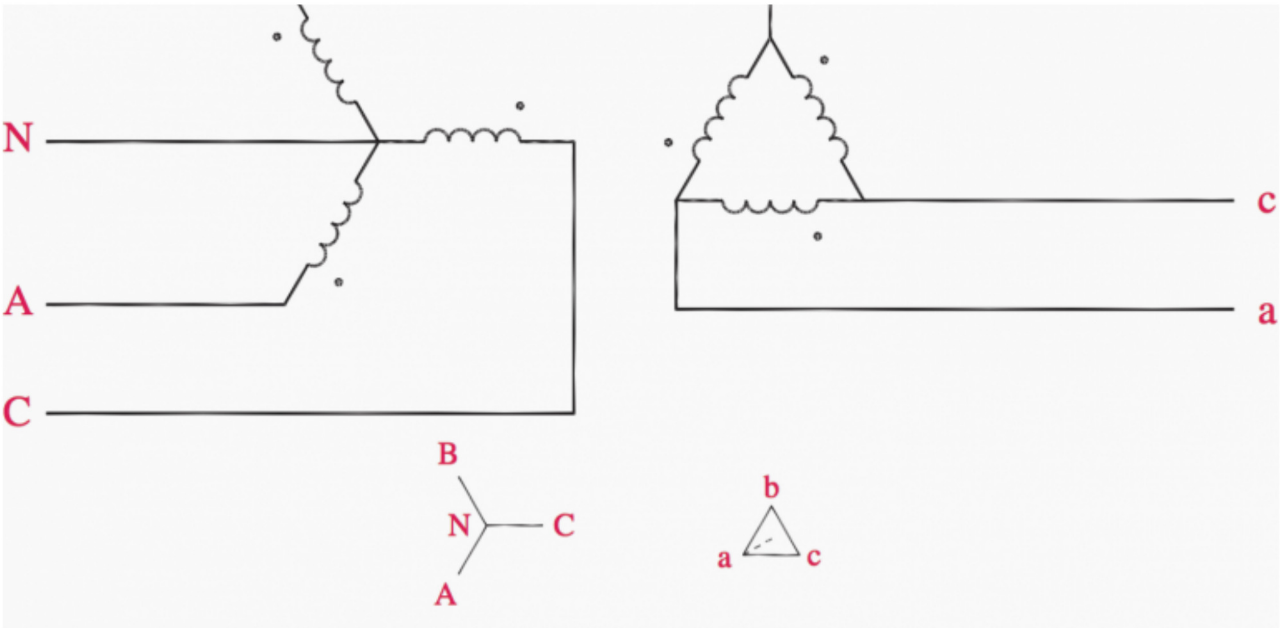

Figure 9 – Wye–Delta Transformer

The primary wye windings are typically grounded. If the secondary is a four-wire delta, the fourth wire originating at a center tap on one of the legs of the delta is grounded.

> *Figure 10 illustrates the wye–delta connection, **either as three single-phase transformers or as a single three-phase unit. Both bushing labels and polarity dots are shown.***

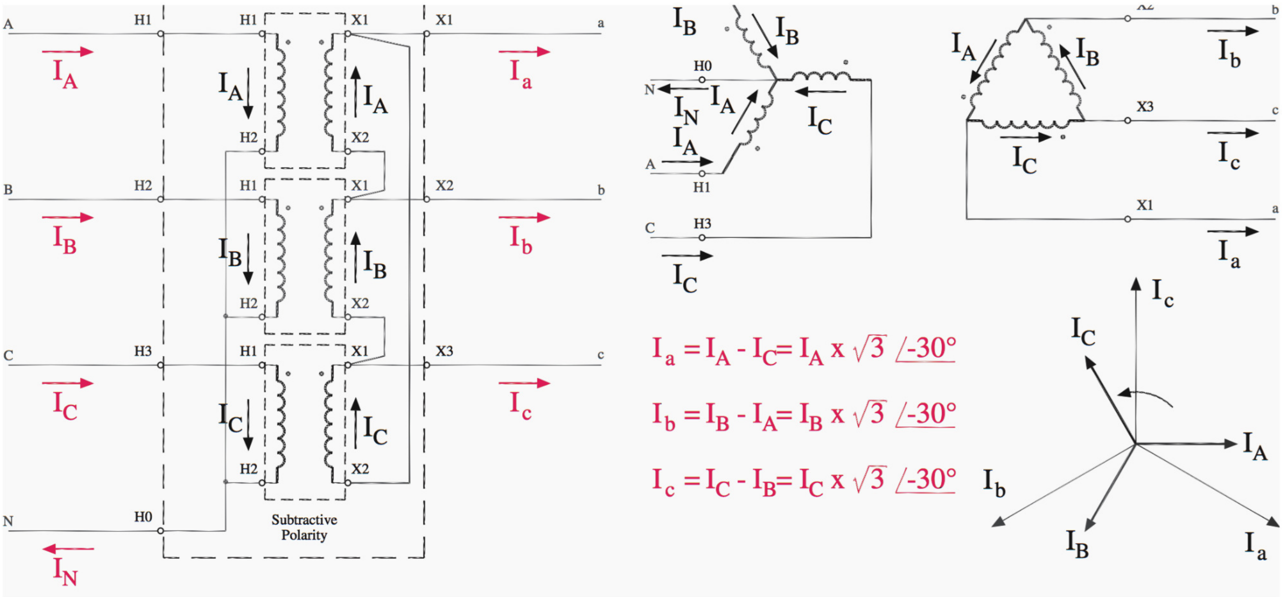

Figure 10 – Wye–Delta Transformer Connections (click to expand diagram)

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Will be continued…

Reference // *Industrial power distribution by Ralph E.Fehr*

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trunking (<6300A) in power substations, commercial buildings and industry fascilities. Professional in AutoCAD programming. Present on Google+