PDHonline Course E427 (1 PDH)

Standard AC System Voltages (600 V and Less)

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Introduction

There are many different voltage standards for AC systems throughout the world as listed at this link: http://en.wikipedia.org/wiki/Mains_electricity_by_country. This course discusses standard AC system voltages that are available in the United States of America, as described in Table 1 of ANSI C84.1-2011. An additional voltage, 600Y/347V, is included because is it listed in 220.5(A) of the NEC.

When you ask, 'What is considered low voltage and what is considered high voltage?' you will probably get different answers, depending on whom you ask. Some people might consider 24 V to be low voltage while 120 V as high voltage, based on their perspective. Table 1 below is based on Section 3 System voltage classes, from ANSI C84.1:

Voltage	Class	Examples
1,000 V or less	Low Voltage (LV)	120V; 208V; 240V; 277V; 480V; 600V
Greater than 1,000 V and Less than 100 kV	Medium Voltage (MV)	2,400V; 4,160V; 12,470V; 13,800V; 69,000V
Greater than or Equal to 100 kV and Less than or Equal to 230 kV	High Voltage (HV)	115KV; 138KV; 230KV
Greater than 230 kV and Less than 1,000 kV	Extra-High Voltage (EHV)	345KV; 500KV; 765KV
Equal to or Greater than 1,000 kV	Ultra-High Voltage (UHV)	1,000KV; 1,500KV

Table 1 – Voltage Classes

The voltages in this course are 600 V and less, which are considered to be low voltage.

Standard AC System Voltages

The voltages listed in Table 2 below are based on the Nominal System Voltage column of Table 1 in ANSI C84.1:

Voltage	Description	Secondary Connections
120 V	1Φ, 2-wire	Figure 4(a) on page 8
120/208Y	1Φ, 3-wire	Figure 6(c) on page 12
120/240 V	1Φ, 3-wire	Figure 4(b) on page 8; Figure 6(a) & (b) on page 12
208Y/120V	3Φ, 4-wire	Figure 4(f) on page 8; Figure 6(c) on page 12
208 V	3Φ, 3-wire	Figure 4(c) on page 8
240/120 V	3Φ, 4-wire	Figure 4(g) & (h) on page 8; Figure 6(b) on page 12
240 V	3Φ, 3-wire	Figure 4(d) & (e) on page 8
480Y/277V	3Φ, 4-wire	Figure 4(f) on page 8
480 V	3Φ, 3-wire	Figure 4(c), (d), & (e) on page 8
600 V	3Φ, 3-wire	Figure 4(c), (d), & (e) on page 8
600Y/347V	3Φ, 4-wire	Figure 4(f) on page 8

Table 2 – Standard AC System Voltages

Table 2 above provides a quick reference to the figures in this course that illustrate the transformer secondary connections for standard AC voltages. The last row in Table 2 above is not listed in Table 1 in ANSI C84.1, but it is listed in 220.5(A) of the National Electrical Code (NEC). Table 3 below is a rearrangement of the information in Table 2 above, in case this arrangement is preferred by the Reader.

The number of wires in the description of a voltage system, whether 2-wire, 3-wire, or 4-wire, includes only the phase (hot) and neutral conductors, not the grounding conductors. A grounding conductor is not always brought from the transformer secondary to the panel board, and it would have no bearing on the description of the voltage, whether it is present or not. If a neutral conductor is brought from the transformer secondary to the panel board, however, it is counted and determines the description of the voltage.

Single-Phase Systems		
Two-Wire	120 V	Figure 4(a) on page 8
Three-Wire	120/208Y	Figure 6(c) on page 12
Three-Wire	120/240 V	Figure 4(b) on page 8; Figure 6(a) & (b) on page 12
Three-Phase, Three-Wire Systems		
Wye	208 V; 480 V; 600 V	Figure 4(c) on page 8
Delta	240 V; 480 V; 600 V	Figure 4(d) on page 8
Open Delta	240 V; 480 ; 600 V	Figure 4(e) on page 8
Three-Phase, Four-Wire Systems		
Wye	208Y/120V; 480Y/277V; 600Y/347V	Figure 4(f) on page 8
Delta	240/120 V	Figure 4(g) on page 8; Figure 6(b) on page 12
Open Delta	240/120 V	Figure 4(h) on page 8

Table 3 – Standard Single-Phase and Three-Phase Systems

The single-phase, three-wire system known as 120/208Y is sort of an oddball in that it does not appear in its true form in Figure 4 on page 8 of this course, nor in Figure A1 of ANSI C84.1, but it does appear as a note to Table 1 of that ANSI standard and is illustrated in Figure 6(c) on page 12 of this course.

Motors for use on 480 V systems are rated at 460 V. In other words, the utilization voltage is less than the system voltage. Table 4 below is based on the Nominal Utilization column of Table 1 in ANSI C84.1.

Utilization : System	Ratio
115 V : 120 V =	95.83%
200 V : 208 V =	96.15%
230 V : 240 V =	95.83%
266 V : 277 V =	96.03%
460 V : 480 V =	95.83%
575 V : 600 V =	95.83%

Table 4 – Ratio of Standard Utilization Voltages to System Voltages

The ratio of 200 V to 208 V (96.15%) in Table 4 might seem like an aberration, but this utilization voltage is called 200 V instead of calling it 199.333 V for convenience, so it still fits the nominal ratio of 95.83%. Likewise, the utilization voltage of 266 V is a rounding-up of 265.5 V.

An important thing to remember about three-phase transformers is that they are composed of three single-phase transformers, or two, in the case of open-delta or open-wye arrangements.

This concept is easy to recognize in pole-mounted transformer banks, where the quantity of single-phase transformers is self-evident, but is not so obvious in pad-mounted or enclosed three-phase transformers.

What is the relationship between the two voltages in a 480Y/277V system? The line-to-line voltage is 480 V and the line-to-neutral voltage is 277 V. Why is that? Likewise, how are the three-phase voltages related in a 208Y/120V system and in a 600Y/347V system?

√3 Relationship of Three-Phase Voltages in Four-Wire Systems

The square root of three (√3) is the ratio of the line-to-line (phase-to-phase) voltage (480 V) to the line-to-neutral (phase-to-neutral) voltage (277 V) in three-phase power systems. Figure 1 below illustrates that this relationship is based on simple geometry. This figure is drawn to scale and the Reader is encouraged to confirm the voltages by measuring them.

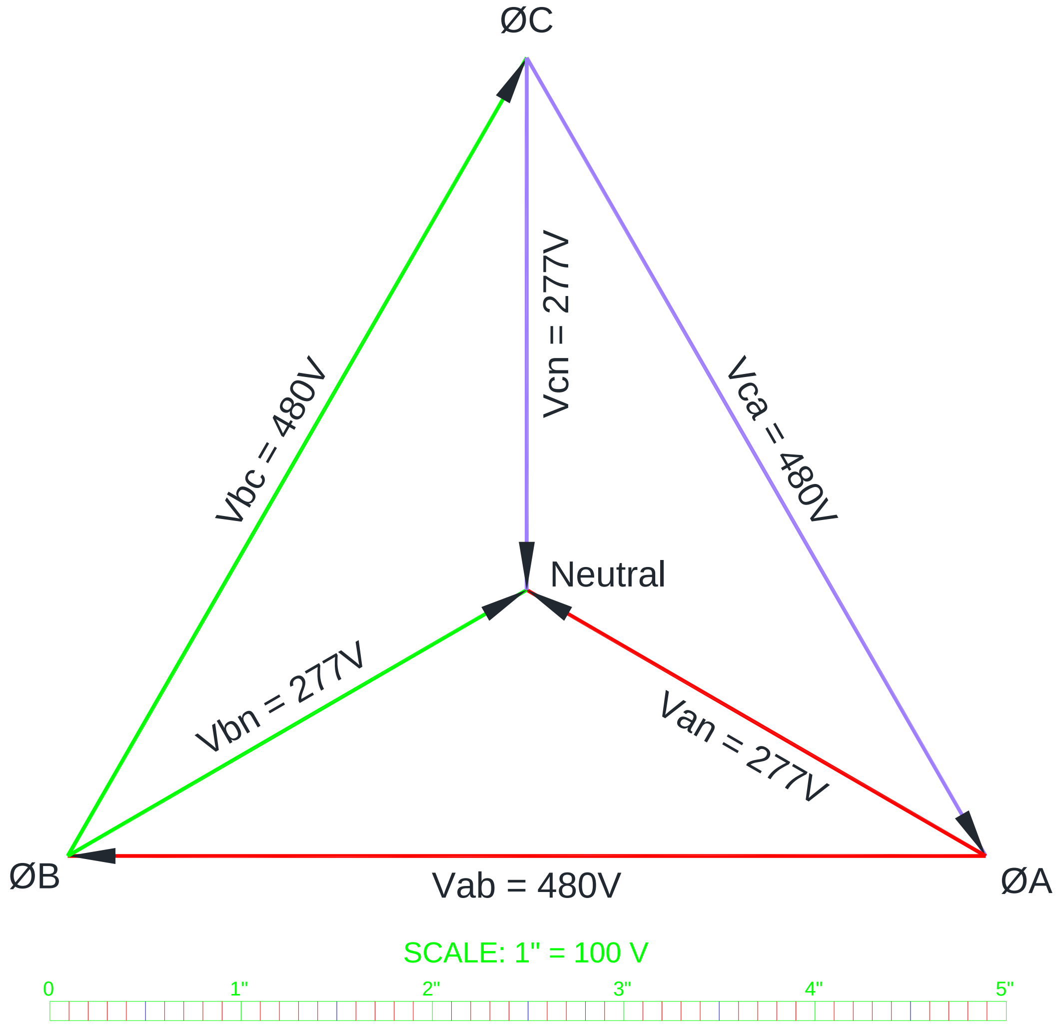

Figure 1 – 480Y/277V Wye-Delta Voltage Relationship

The voltage relationship between 277 V wye and 480 V delta from Figure 1 can be thought of as simple right-triangle geometry, where the hypotenuse is 277 V and the adjacent side to the 30° angle is half of 480 V, or 240 V. Figure 2 below is the bottom portion of Figure 1. The length of the short vertical side opposite the 30° angle is of no concern for this exercise.

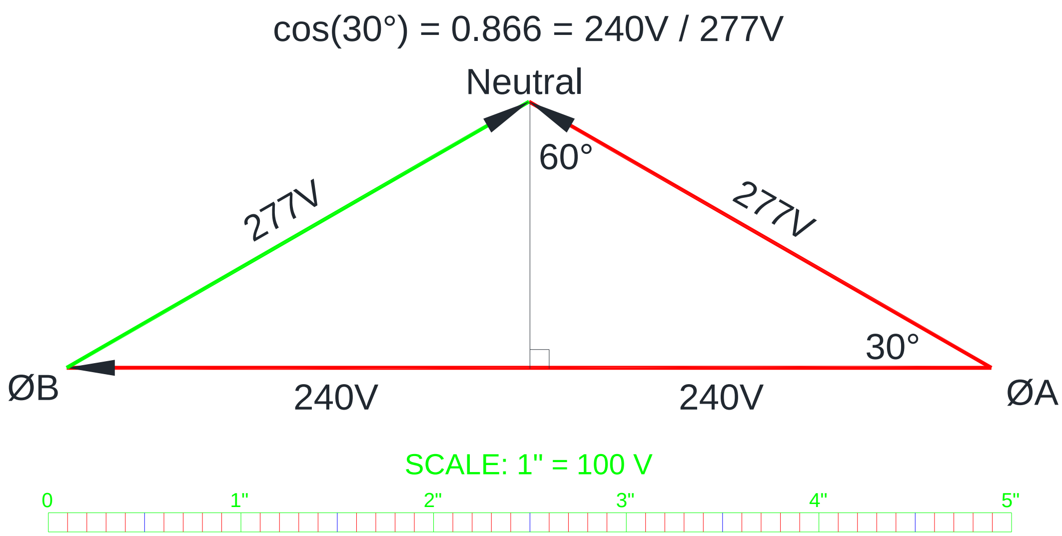

Figure 2 – Wye-Delta Voltage Relationship – Right Triangle Geometry

As shown in Figure 2, the length of the 240 V side of the right triangle is related to the length of the 277 V side by the cosine of 30° or 0.866. Alternatively, we could have used the 60° corner for reference in Figure 2 and stated that the relationship between 240 V and 277 V was defined by: sin(60°) = 0.866 = 240 V / 277 V to get the same result. The value of 0.866 is more exactly equal to √3 / 2, as one might expect from the voltages shown in Figure 2.

The square root of three also comes into play for the voltage applied to a wye-start/delta-run motor. Interested Readers should see PDH Online Course *E413 Wye-Delta Motor Starters*, listed in the Additional Reading section beginning on page 13.

The wye-delta geometry shown for the 480Y/277V system in Figure 1 also applies to all other wye-delta, three-phase voltages, as well. Figure 3 shows a 208Y/120V system, also drawn to scale.

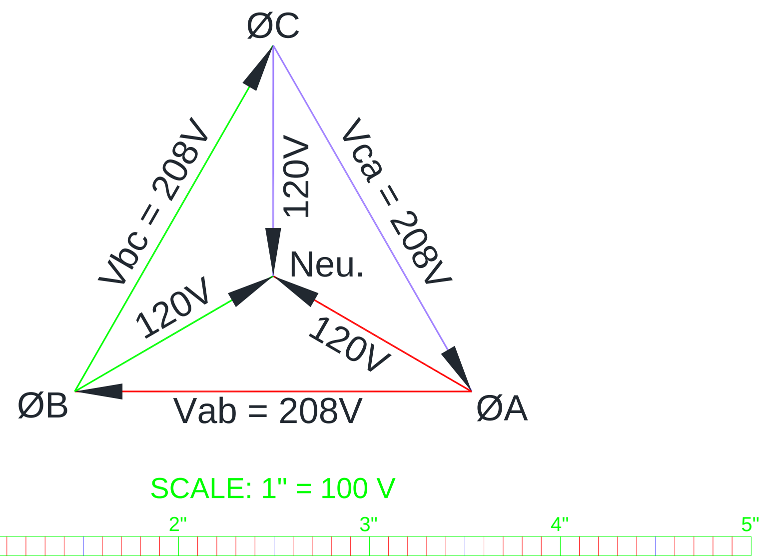

Figure 3 – 208Y/120V Wye-Delta Voltage Relationship

The square root of three (√3) relationship is an immutable characteristic for all three-phase power systems, including 400Y/230V and 600Y/347V. Let's look at the standard transformer secondary connections that are used to achieve three-phase and single-phase voltages.

Standard Transformer Secondary Connections

Figure 4 below presents most of the transformer secondary connections listed in Figure A1 of ANSI C84.1. The applicable system voltages are listed beneath each type of connection. The primary windings are not shown in Figure 4.

Topics that are not covered in this course:

- *24 VAC and 48 VAC.*
- *Direct-current (DC) system voltages.*
- *Grounding.*
- *Scott T or tee transformer connections.*
- *Sensitive electronic equipment from NEC 647.*
- *Two-phase AC systems.*
- *Zig-zag transformers.*

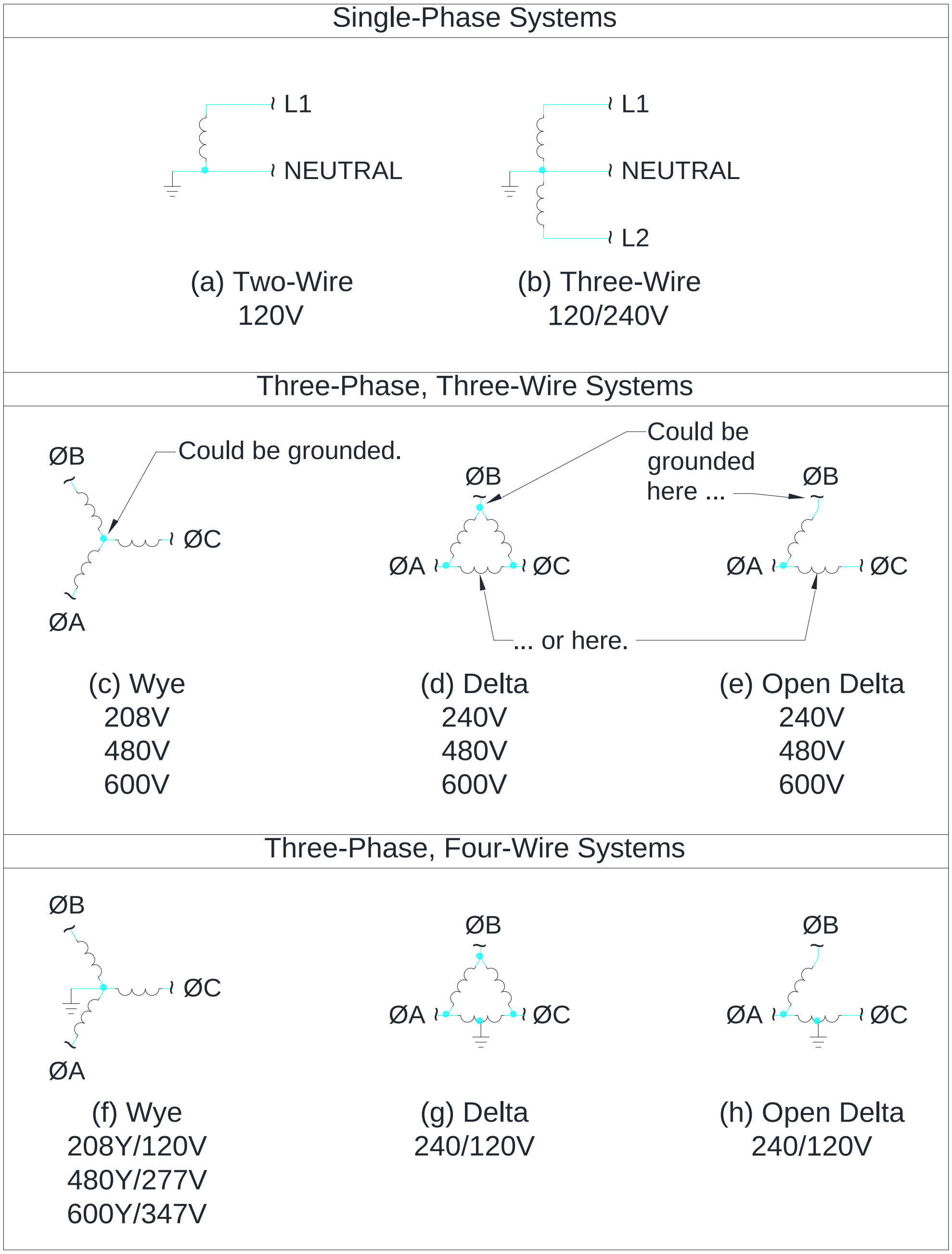

Figure 4 – Transformer Secondary Connections to Supply the System Voltages

It doesn't matter that the A, B, and C phases in Figure 4 are in different clock positions than in previous figures in this course. The three phases are constantly rotating, and diagrams like Figure 4 and others in this course simply freeze this rotation in order to show how the three phases are related to each other at that instant in time.

The connections in Figure 4 are discussed in more detail in the sections below.

Figure 4(a) – Single-Phase, Two-Wire

The connections in Figure 4(a) are typical for a control circuit transformer in a motor control center bucket or in a control panel. In that installation, L1 is usually fused and the neutral is typically labeled as X2.

Figure 4(b) – Single-Phase, Three-Wire

The connections in Figure 4(b) are typical for the service to our homes. There is 120 VAC from L1 to neutral and from L2 to neutral, which adds up to 240 VAC between L1 and L2. See Figure 6(a) on page 12.

Figure 4(c) – Three-Phase, Three-Wire

The connections in Figure 4(c) are not that common, since most wye systems are typically grounded. If this figure is grounded, it becomes Figure 4(f). Since this is a three-wire system, there is no neutral conductor, even if there is a connection to ground. The following paragraph is a paraphrased excerpt from Note (a) to Table 1 in ANSI C84.1:

Three-phase, three-wire systems are systems in which only the three-phase [hot] conductors are carried out from the source for connection of loads. This source may be derived from any type of three-phase transformer connection, grounded or ungrounded. Three-phase, four-wire systems are systems in which a neutral conductor (which is usually grounded) is also carried out from the source for connection of loads. Four-wire systems are designated by the phase-to-phase voltage, followed by the letter Y (except for the 240/120V delta system), a slant line, and the phase-to-neutral voltage [for example, 480Y/277V]. Single-phase services and loads may be supplied from either single-phase or three-phase systems. [See examples in Figure 6(b) and Figure 6(c) on page 12 in this course.]

Figure 4(d) – Three-Phase, Three-Wire, Closed-Delta

The connections in Figure 4(d) are not that common, since most three-phase systems installed nowadays are typically grounded wye. The ungrounded delta or corner-grounded delta 480V system was popular in the 20th century, and some legacy installations still endure. Since this is a three-wire system, there is no neutral conductor, even if there is a connection to ground. If this figure is center-grounded and has a neutral conductor, it becomes Figure 4(g).

Figure 4(e) – Three-Phase, Three-Wire, Open-Delta

The connections in Figure 4(e) are not that common, since most new three-phase systems nowadays are grounded wye. The open delta type of system is used occasionally on power poles for overhead distribution. Since it does not require the third transformer, it is less expensive than a closed delta three-phase transformer bank. If the center tap of one transformer is grounded, it results in Figure 4(h), which is commonly occurring.

The total KVA of the two-transformer open-delta transformer bank is less than one might expect when removing one of the three transformers to make the open delta. If a transformer is removed from a 30 KVA closed-delta transformer bank that had three 10 KVA transformers, the new rating of the two-transformer bank would be 58% of 30 KVA or 17.3 KVA. This is discussed in more detail in PDH Online Course *E431 The Square Root of Three (√3) in Electrical Calculations*, listed in the Additional Reading section beginning on page 13.

Figure 4(f) – Three-Phase, Four-Wire, Grounded Wye

The connections in Figure 4(f) are very popular for commercial and industrial power systems, especially 480Y/277V and 208Y/102V. Those voltages are illustrated in Figure 1 on page 5 and Figure 3 on page 7. This connection provides both three-phase (480 V and 208 V) and single-phase (277 V and 120 V) power.

Figure 4(g) – Three-Phase, Four-Wire, Closed-Delta, Grounded Center Tap

The connections in Figure 4(g) are typical for some commercial applications. When one of the transformers is grounded at its center tap, the opposite phase (B) connection is termed the "red leg," the "high leg," "wild leg," "stinger leg," or, more colorfully, the "bastard leg," since its voltage with respect to ground is different from that of the other two phases (A & C, in this case). Phase B is the phase that is required to be the high leg by NEC 408.3(E)(1) and NEC 409.102(B). This type of connection is represented by the scaled drawing in Figure 5 below.

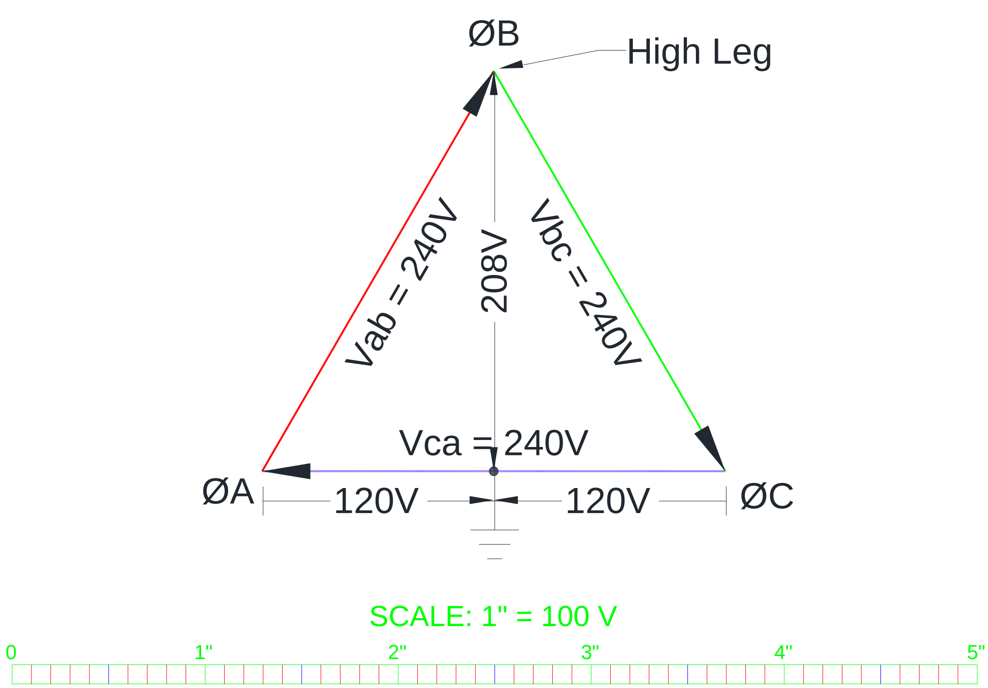

Figure 5 – 240/120V, 3Φ/4W Voltage Relationships

As previously stated, the B phase in this type of connection is called the "high leg" because its potential is higher above the ground reference than the other two phases (A & C). Figure 5 above demonstrates that the voltage from A phase to ground is 120 V, while the voltage from C phase to ground is also 120 V, but 180° out of phase with A phase. The voltage from A to C is 240 V, which is why this is called a 240/120V system.

The voltage from B phase to ground is 208 V, which can be measured readily in Figure 5. That is why this phase is called the "high leg." It is also known as the "red leg" because it is typically required to be an orange conductor or marked with paint or tape as an orange conductor to differentiate it from the other two phase conductors [NEC 110.15]. See, also, the high-leg identification requirements of NEC 408.3(F)(1) for switchboards, switchgear, and panelboards.

This type of transformer is available as an enclosed three-phase transformer, but an important thing to note about this type of transformer secondary connection is that the line-to-neutral voltage (120 VAC) loads is often limited to only 5% of the total KVA rating of the three-phase transformer. In other words, if the enclosed transformer is rated 30 KVA, only 5% or 1.5 KVA can be used for 120 VAC loads. The enclosed transformer cut-sheet should have all pertinent information regarding this rating. This is different from the closed-delta and open-delta arrangement realized with banks of individual transformers, since the utility will sometimes provide a larger transformer (located opposite of the high leg) for the single-phase loads.

One might wonder, if we can ground the center tap of the single-phase transformer between Phase A and Phase C, why couldn't we do the same thing to the single-phase transformer between Phase B and Phase C and the single-phase transformer between Phase B and Phase A, thus providing three sources for 120 VAC from the same three-phase transformer bank? We won't get into any mathematics, but let's picture this in our minds.

If a voltage system is not tied to ground, it is not possible to say what the voltage at any point in that system is with reference to ground. If, on the other hand, one point on the voltage system is permanently tied to ground, such as the center-tap in Figure 4(g), we can be assured that, under normal conditions, the voltage from Phase A to ground will be 120 VAC, the voltage from Phase C to ground will always be 120 VAC, and the voltage from Phase B to ground will always be 208 VAC to ground. It is okay to tie one corner or one center-tap of the secondary of a three-phase transformer or transformer bank to ground at one place only, since the voltage vectors will still be free to rotate around that neutral point. If an attempt is made to ground the voltage system at a second point, it would be the same as installing a short-circuit between those two grounded points, since both points would be at the same potential. This, obviously, is not an acceptable situation.

Figure 4(h) – Three-Phase, Four-Wire, Open-Delta, Grounded Center Tap

The connections in Figure 4(h) are typical for some business and commercial installations and only require two transformers, as discussed for Figure 4(e) above. The transformer that is center-tapped is typically grounded at that point in order to provide 120/240V single-phase, as well as 240V, three-phase. The center-tapped transformer is often larger than the other one, since the center-tapped transformer provides power for lighting, receptacles, and other single-phase loads, in addition to three-phase loads. Whether the center-tapped transformer is larger or not, it is often called the "lighter," since it powers the lights and other single-phase loads. If one of the transformers is smaller, it is sometimes called the "power" or "kicker" transformer. If the three-phase load increases after installing this type of transformer bank, a third transformer can be added later to provide additional capacity, resulting in Figure 4(g).

Three Ways to Provide 120 VAC Power

There is more than one way to provide 120 VAC power for lighting and convenience receptacles; three of them are shown in Figure 6 below.

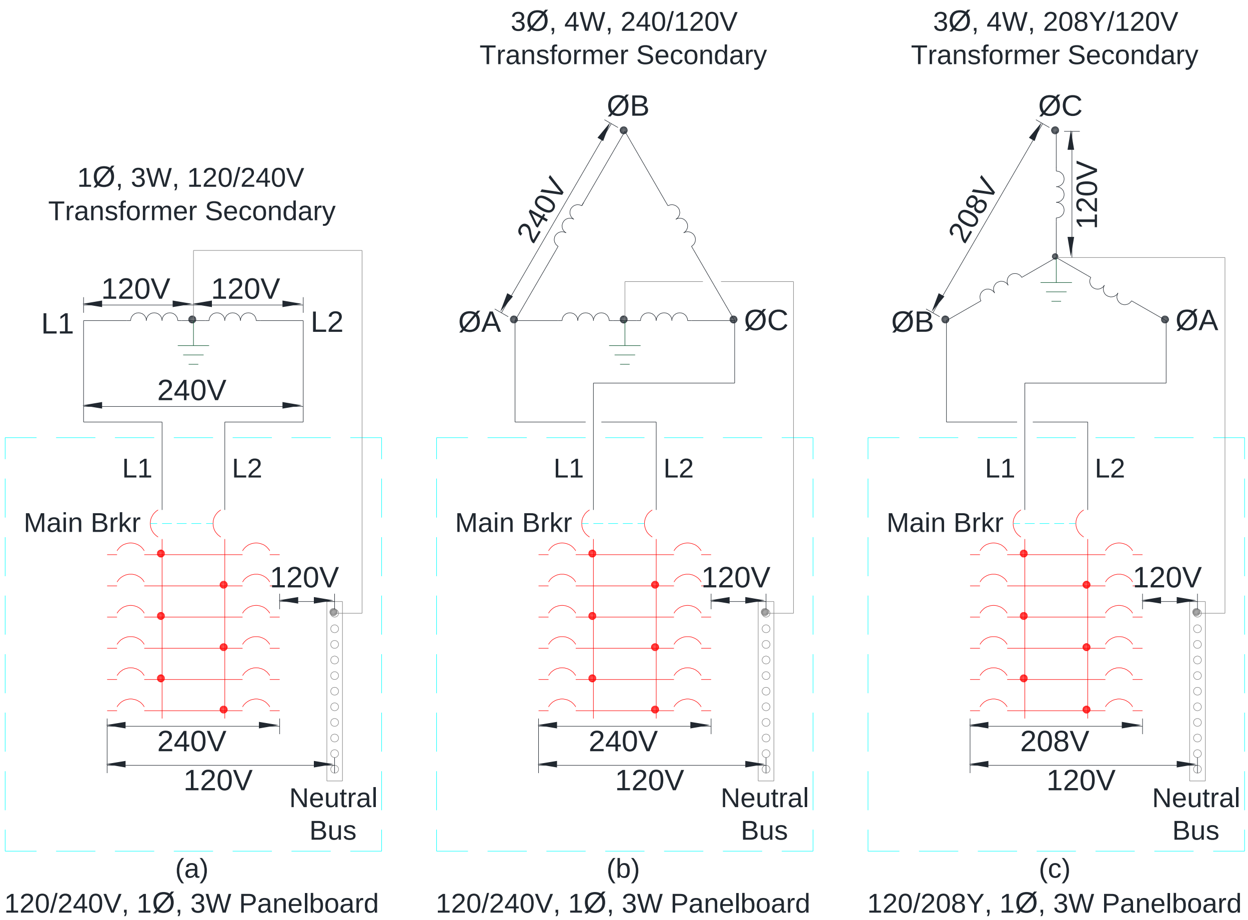

Figure 6 – Three Ways to Provide 120 VAC Power

Figure 6 shows three different ways to provide 120 VAC to a facility. In each of the three examples in this figure, there is 120 VAC from each hot or phase connection to the neutral, but there is 240 VAC between the two phase connections in Figure 6(a) and (b), while there is 208 VAC between the two phase connections in Figure 6(c).

Figure 6(a) is powered from a single-phase, three-wire, 120/240V transformer, such as illustrated in Figure 4(b) on page 8.

Figure 6(b) is powered from the center-tapped portion of a three-phase, four-wire, 240/120V transformer, such as illustrated in Figure 4(g) on page 8, but it could also be accomplished with the open-delta secondary arrangement shown in Figure 4(h).

Figure 6(c) is powered from two secondary phase connections and a neutral connection on a three-phase, four-wire, 208Y/120V transformer, such as illustrated in Figure 4(f) on page 8. No connection is made to Phase C in Figure 6(c). This could be powered by an open-wye transformer bank, which isn't shown in Figure 4, but can easily be pictured as not having a Phase C winding. There is a Note (d) to Table 1 in ANSI C84.1 that addresses this specific voltage system by saying, "*A modification of this three-phase, four-wire system* [Figure 4(f)] *is available as a 120/208Y-volt service for single-phase, three-wire, open-wye applications.*"

In Closing

In this course, we have reviewed the standard AC system voltages that are available in the United States. We have also seen that the phase-to-phase and phase-to-neutral voltages are related to each other by the square root of three ($\sqrt{3}$) in three-phase AC systems. All of the voltage systems, in fact, can be drawn to scale and measured to prove the voltage relationship of various connection points to each other.

Whether or not a three-phase system is three-wire or four-wire depends on whether or not a neutral conductor is brought out from the voltage source to supply other systems or loads. It is possible that a three-phase service could be grounded without installing a neutral conductor.

It is hoped that this course has either served as a refresher or will assist the Reader in easily recognizing the transformer arrangements that are implied when he or she hears the term '480Y/208V' or '120/240V, 3-wire.'

Abbreviations

A	Amp or Amps
AC	Alternating Current
ANSI	American National Standards Institute, Inc.
Hz	Hertz or cycles-per-second
N.A.	Not Applicable
NEC	National Electrical Code, 2014 Edition
NEMA	National Electrical Manufacturers Association
V	Volt or Volts
VAC	Volts Alternating Current

Additional Reading

ANSI C84.1-2011 American National Standard Electric Power Systems and Equipment – Voltage Ratings (60 Hertz) at www.nema.org

Mains electricity by country at http://en.wikipedia.org/wiki/Mains_electricity_by_country

NFPA 70 National Electrical Code, (NEC) 2014 Edition at www.nfpa.org

PDH Online course E413 Wye-Delta Motor Starters at www.pdhonline.org

PDH Online course E431 The Square Root of Three (√3) in Electrical Calculations at www.pdhonline.org

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