PDHonline Course E413 (4 PDH)

Wye-Delta Motor Starters

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Introduction

Most induction-type AC motors in industrial applications in the United States are three-lead, three-phase, wired in delta, and have an inrush, starting, or locked-rotor current of approximately 600% of the motor's full-load current. Depending on the capacity of the electrical system and the horsepower value of the motor, it might be necessary to reduce the starting current of certain motors. In addition to three-lead, three-phase motors, there are six-lead and twelve-lead three-phase motors available that can be started in wye and run in delta. Motors with nine leads, however, can only be started and run in delta or started and run in wye, they cannot switch from wye to delta or vice-versa during operation. Wye-delta motor starting reduces the inrush current to one-third of the delta value, or approximately 200% of the motor's full-load current, when the motor is started in wye. The starting torque will also be reduced to one-third of its delta configuration value because of the wye configuration voltage, as will be discussed later.

Topics that are not covered in this course:

Other electro-mechanical reduced voltage motor starting techniques, such as autotransformer, part-winding, primary-resistor, and wound-rotor.

Multi-speed motor starters.

Nine-lead motors.

Synchronous motors.

Medium-voltage motors.

Since the starting torque of a wye-start, delta-run motor is only one-third of the 'normal' starting torque, this type of starting method is most suitable for loads or processes that can be started without load or with a partial load. Some examples of typical wye-delta starter loads with larger motors include air compressors, chillers, elevators, fire pumps, large air conditioning units, and centrifuges.

Unless otherwise indicated, the motors discussed in this course are 480 VAC, three-phase, induction type. Motor voltages of 240 V and 480 V are stated in this course, but motors for distribution systems at those voltages are actually rated 230 V and 460 V, respectively. Phase rotation is assumed to be A-B-C, in the counter-clockwise direction (in vector space, not the physical rotation of the motor).

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There are many links in the PDF version of this document that will take you to other locations in this document (most of these links are not underlined). For example, if you click on Abbreviations in the Table of Contents above, it will take you to the Abbreviations section toward the end of this document. In order to return to the Table of Contents, or wherever you were when you clicked on the link, use the Previous View button on Adobe Reader. You can use this function repeatedly to go back to multiple previous views in sequential order. If this button is not presently shown on your PDF viewer toolbar, you can add it by clicking on View, Show/Hide, Toolbar Items, Page Navigation, and then enabling Previous View under the Page Navigation Toolbar section. On older versions, click on Tools, Customize Toolbars, and then enable Previous View under the Page Navigation Toolbar section.

It may not be obvious, since the full 480 V is still applied to the motor power terminals when starting in the wye configuration, but wye-delta motor starting is a type of reduced-voltage motor starting. With 480 V, three-phase power applied to the three power terminals of a wye-connected motor, the voltage across each of the three windings is only 277 V. This is easier to see by looking at the wye-delta voltage relationship in Figure 6 on page 11 and the discussion before and after that figure.

Here is a table of the key illustrations in this course write-up:

Motor Type	Delta Currents & Voltages	Wye Currents & Voltages
Three-Lead	Figure 1 on page 6	Not Applicable
Six-Lead	Figure 4 on page 9 Figure 12 on page 17 Figure 13 on page 17	Figure 5 on page 10 Figure 18 on page 22 Figure 19 on page 23
Twelve-Lead at 480 V	Figure 8 on page 13 Figure 14 on page 18	Figure 10 on page 15 Figure 21 on page 24
Twelve-Lead at 240 V	Figure 9 on page 14 Figure 16 on page 20	Figure 11 on page 16 Figure 22 on page 25
Starter Type	**NEMA**	**IEC (European)**
Open-Transition, Non-Reversing	Figure 27 on page 31 Figure 28 on page 34	Figure 29 on page 36 Figure 30 on page 38
Closed-Transition, Non-Reversing	Figure 34 on page 42	No Figure
Open-Transition, Reversing	No Figure	Figure 35 on page 45 Figure 36 on page 47 Figure 37 on page 48

Table 1 – Quick Guide to Key Illustrations

Table 1 provides a quick reference to the key figures that illustrate the main differences and similarities between the motor and starter types and concepts discussed in this course. Let's begin by examining what is meant by delta and wye connections.

Delta-Connected versus Wye-Connected Motors

Wye is defined as something Y-shaped, or the letter Y itself. Delta is defined as something delta- or triangle-shaped, as is the Greek letter delta (Δ). A wye-delta (Y-Δ or Y-D) motor starter is designed to start the motor with its windings in a wye configuration, with reduced starting current and torque, then switch the motor windings to a delta configuration so that it can run like a 'normal' motor, with regular full-load current and torque. Wye-delta motor starters are also known as star-delta (*-D or *-Δ) motor starters, since the wye shape can sort of resemble a star or a half-hearted asterisk.

As previously stated, in order for a motor to be able to be change from a wye to a delta configuration while running, it must have six or twelve leads. Before we look at wye-start/delta-run motors, let's start by considering a 'normal' motor with only three leads.

Delta-Connected Three-Lead, Three-Phase Motors

Figure 1 shows an ordinary, everyday, three-lead, three-phase motor, connected as a delta load. This particular motor cannot be connected in a wye configuration because its internal wiring is already connected in a delta configuration, with terminals T1, T2, and T3 being available for connection to the three-phase power source.

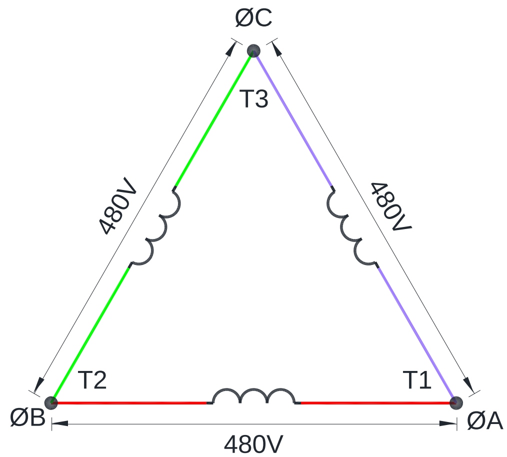


Figure 1 – Delta-Connected Three-Lead, Three-Phase Motor

The relationships between line currents in the power conductors going to a delta-connected motor and the winding (phase) currents within a delta-connected motor, whether three-lead, six-lead, or twelve-lead, are illustrated in Figure 12 on page 17, with current vectors and values for a 200 Hp example being given in Figure 13 on page 17, Figure 14 on page 18, and Figure 15 on page 19. If a six-lead or twelve-lead motor is connected in delta, it will act just like a three-lead motor connected in delta from the perspective of the power source.

Let's look at typical motor wiring diagrams, such as those provided by a motor manufacturer, for three-lead, six-lead, and twelve-lead motors, examples of which are shown in Figure 2. Notice for six-lead and twelve-lead motors that the numbering for the two ends of each winding is based on adding three to the lower number. For example, a six-lead motor has three windings, which are numbered T1-T4, T2-T5, and T3-T6. Twelve-lead motors, which have six windings (described as six half-windings in this course), continue this numbering scheme with three more winding designations numbered T7-T10, T8-T11, and T9-T12 in addition to the three winding designations present in six-lead motors. See also Table 2 and Figure 3 on the upcoming pages.

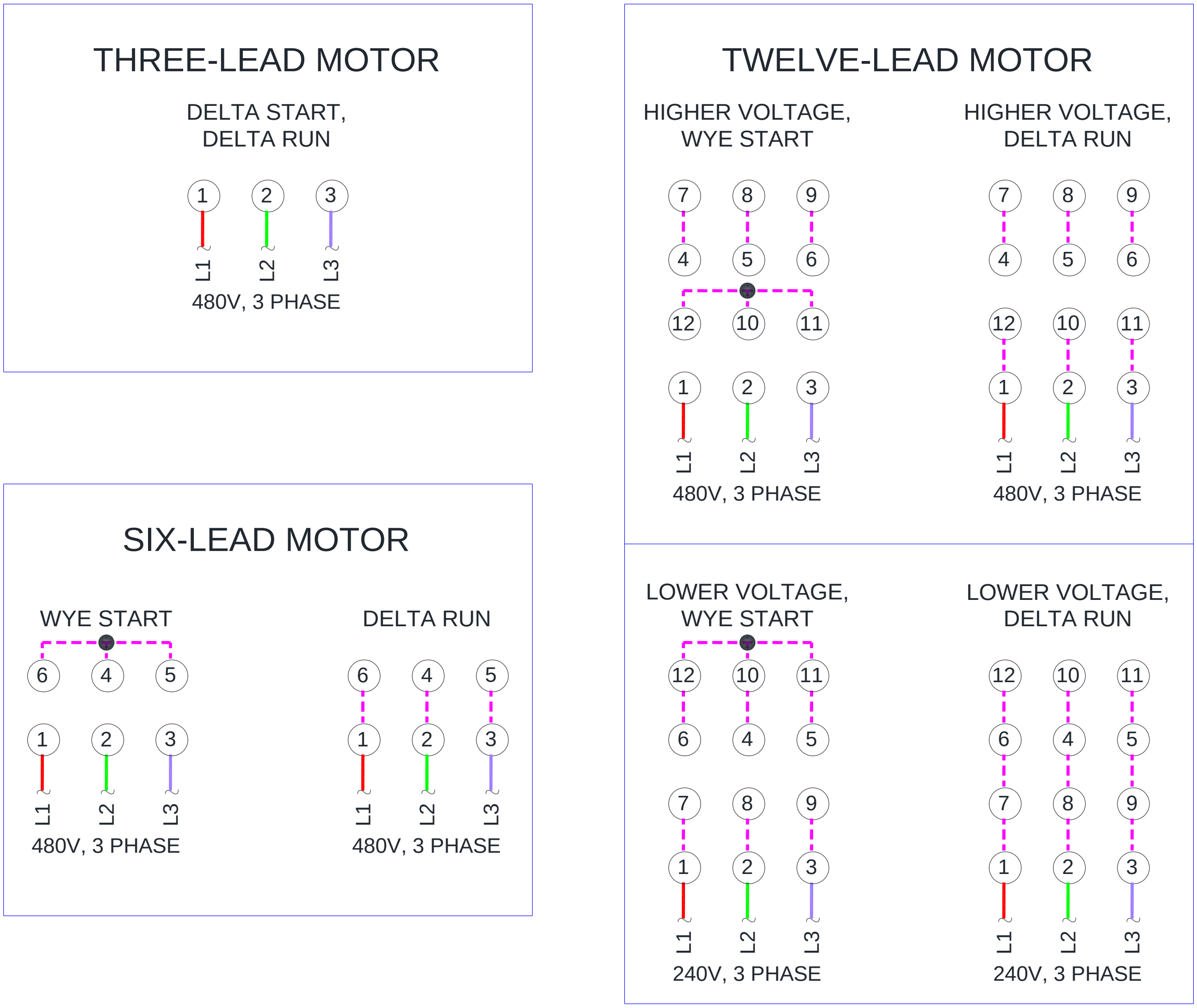


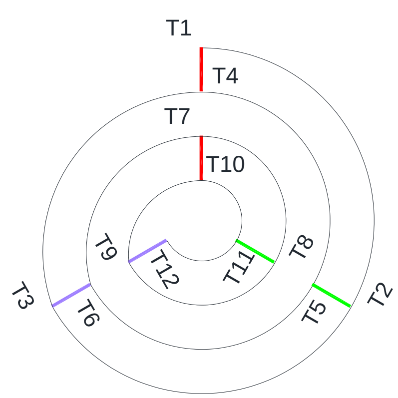
Figure 2 – Three-Lead, Six-Lead, and Twelve-Lead Motor Wiring Diagrams

The terminals in Figure 2 are labeled, 1, 2, 3, et cetera, to represent the actual markings of T1, T2, T3, et cetera. The three-lead motor wiring diagram in Figure 2 is quite straightforward: L1 is wired to motor terminal T1, L2 is wired to motor terminal T2, and L3 is wired to motor terminal T3. This power connection is also true for six-lead and twelve-lead motors, whether they are connected in wye or delta, but there are additional connections to make for six-lead and twelve-lead motors.

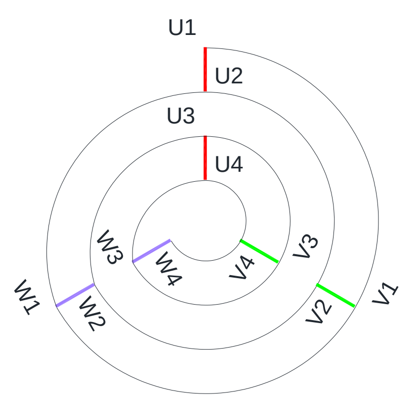
Three-Lead NEMA	Three-Lead IEC		Six-Lead NEMA	Six-Lead IEC		Twelve-Lead NEMA	Twelve-Lead IEC
T1	U1		T1	U1		T1	U1
T2	V1		T2	V1		T2	V1
T3	W1		T3	W1		T3	W1
N.A.	N.A.		T4	U2		T4	U2
N.A.	N.A.		T5	V2		T5	V2
N.A.	N.A.		T6	W2		T6	W2
N.A.	N.A.		N.A.	N.A.		T7	U3
N.A.	N.A.		N.A.	N.A.		T8	V3
N.A.	N.A.		N.A.	N.A.		T9	W3
N.A.	N.A.		N.A.	N.A.		T10	U4
N.A.	N.A.		N.A.	N.A.		T11	V4
N.A.	N.A.		N.A.	N.A.		T12	W4

Table 2 – NEMA and IEC Motor Terminal Designations

Three types of motors are shown in Table 2. The three-lead motor designations in the first group of columns in Table 2 are for 'regular' three-phase motors, the six-lead motor designations in the middle group of columns are for single-voltage wye-start/delta-run motors, and the twelve-lead motor designations in the last group of columns are for dual-voltage wye-start/delta-run motors. Let's look at this topic from another viewpoint. Figure 3(a) and (b) below show the standard motor terminal marking requirements from NEMA publication *MG 1* Figures 2-48A and 2-48B respectively, (see Additional Reading section, which begins on page 60).



Using "T"
(a)



Using U, V, W
(b)

Figure 3 – Three-Phase Motor Terminal Markings

Starting at T1 in Figure 3(a) or U1 in Figure 3(b), follow the spiral in a clockwise direction to determine the three-phase motor terminal numbers or markings. For a three-lead motor with "T" lead numbers, the terminals would be marked T1, T2, T3, as shown in Figure 3(a). If the motor has six leads, the numbering continues T4, T5, T6, with T1 and T4 being at opposite ends of the same winding, as indicated. For a twelve-lead motor, the numbering continues T7 through T12, with T12 being at the opposite end of the winding from T9.

Figure 3(b) is for European types of applications and the motor terminal markings are in accordance with IEC 60034-8 (see Additional Reading, which starts on page 60). So, for a six-lead motor using this convention, the terminals would be marked U1, V1, W1, U2, V2, and W2, with U1 and U2 being at opposite ends of the same winding. For a twelve-lead motor, the numbering would continue U3, V3, W3, U4, V4, and W4. Let's continue our discussion with the simpler of the two types of wye-start/delta-run motors – the six-lead motor.

Delta-Connected Six-Lead, Three-Phase Motors

Just because a motor has six leads does not mean it is a wye-start/delta-run motor, it might be a two-speed motor or some other special type of motor. The motor's nameplate should give the pertinent information, operating characteristics, and wiring diagram.

The six-lead motor in Figure 4 is connected in a delta configuration, just like the three-lead motor in Figure 1 on page 6, but we can also rearrange the electrical connections in Figure 4 to wire the six-lead motor in a wye configuration, as will be shown later in Figure 5.

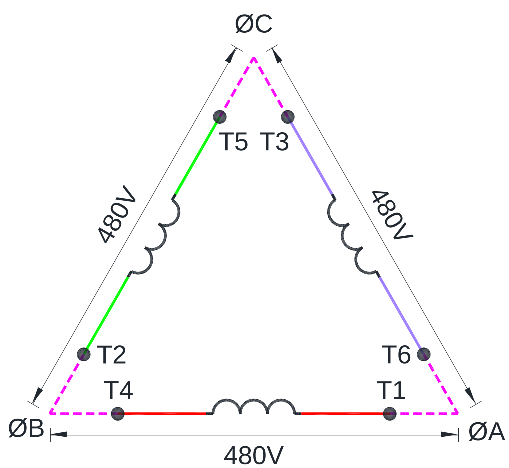


Figure 4 – Delta-Connected Six-Lead, Three-Phase Motor

The delta-connected six-lead motor in Figure 4 will behave the same as a delta-connected three-lead motor and will have the same torque and the same line and phase currents. This delta configuration is the ultimate objective of all wye-delta starters.

Wye-Connected Six-Lead, Three-Phase Motors

The six-lead, three-phase motor connected in a delta configuration in Figure 4 can also be connected in a wye configuration, as shown in Figure 5.

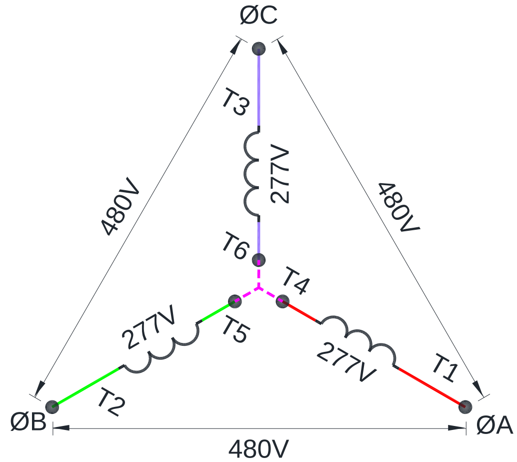


Figure 5 – Wye-Connected Six-Lead, Three-Phase Motor

When a motor is connected in wye as shown in Figure 5 and 480 V, three-phase is applied to terminals T1, T2, and T3, the resulting voltage across the windings in each of the three legs is only 277 VAC. This can be seen more readily in Figure 6. The Reader will see various technical documents that state that the voltage applied to the motor windings is reduced to 58% of the normal voltage when the motor is started in the wye configuration. This is true, since $1 / \sqrt{3} = 0.58$, which is the ratio of 277 V / 480 V. The Reader might also see documents that erroneously state that the current in a wye connection is also 58% of the full-load current (FLC) value, but the actual ratio is 33%, as will be demonstrated later. The center of the wye-connected motors in this course is not connected to ground nor to a neutral conductor, it is left floating.

120° Between Phases:

In this course, it is stated that there is an angle of 120° between each of the three voltage phases, but the equilateral triangles used to represent the three phase voltages in delta configuration such as in Figure 6 might give the impression that there is only an angle of 60° separating each phase from its neighbor. The angular difference between the phases is determined by the direction of the vectors, not the angle between them when they intersect head-to-tail in the corners of the equilateral triangle.

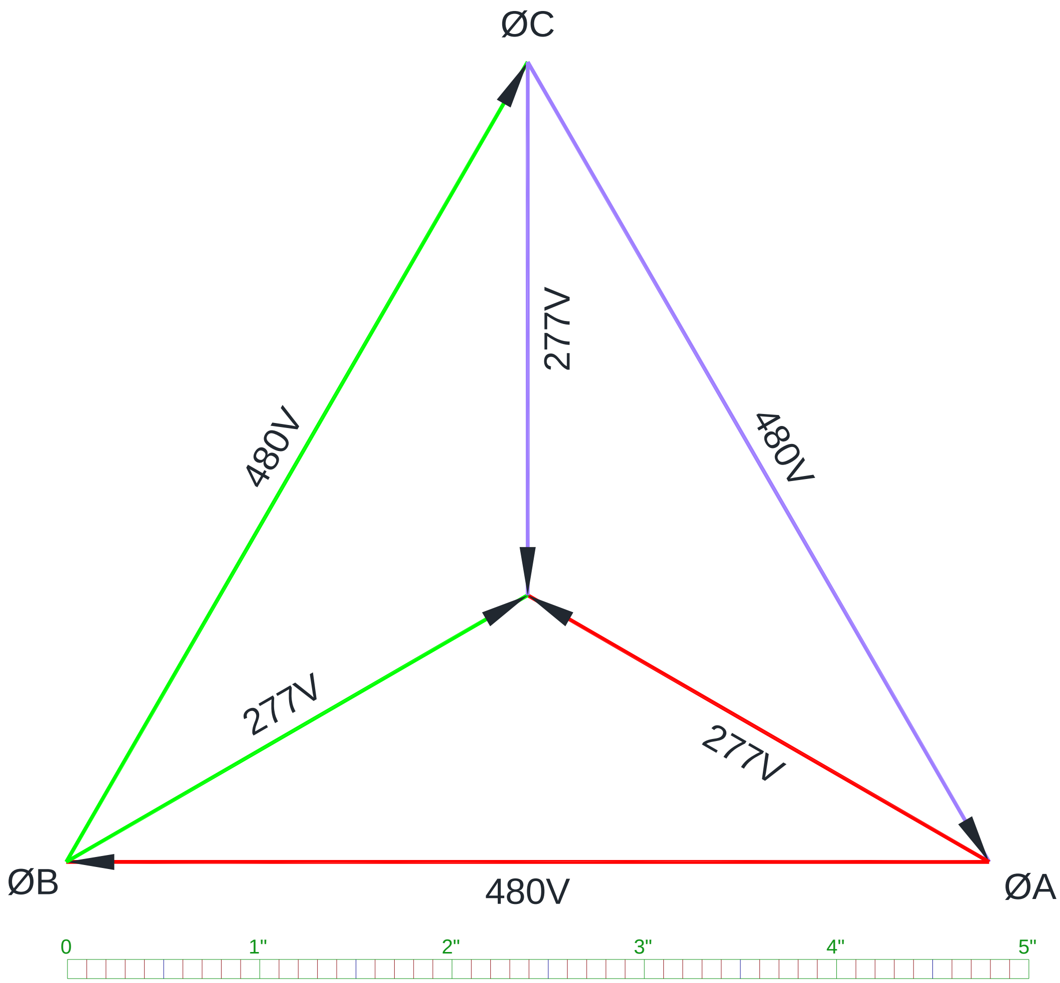


Figure 6 – Wye-Delta Voltage Relationship

When this page of the PDF version of this course is printed out without being scaled to fit the paper (when printing, set Page Scaling to None, or Actual Size, or 100%, depending on your version), a ruler, scale, or tape measure can be used to confirm the lengths of the lines in Figure 6. The lengths of the 277 V and 480 V vectors correspond to the voltages, such that the 277 V vectors are 2.77" long and the 480 V vectors are 4.80" long (approximately). This wye-delta voltage relationship is based on the fact that the 480 V vectors are 120° apart from each other and the 277 V vectors are 120° apart from each other and the tails of the 277 V vectors align with the tails of the corresponding 480 V vectors, so simple right-triangle geometry can be used to obtain these results, as illustrated in Figure 7. The red 480 V vector from Phase A to Phase B in Figure 6 is pointed in the 180° direction, the green 480 V vector from Phase B to Phase C is pointed in the 60° direction, and the purple or blue (depending on your printer) 480 V vector from Phase C to Phase A is pointed in the 300° direction. The related 277 V vectors are lagging 30° behind the 480 V vectors, with the red 277 V vector from Phase A pointed in the 150° direction, the green 277 V vector from Phase B pointed in the 30° direction, and the purple or blue 277 V vector from Phase C pointed in the 270° direction.

The torque of a motor is directly proportional to the square of the voltage applied across the motor windings. If the voltage across each leg of the motor is 277 V, then the torque at 277 V compared to the torque at 480 V would be $(277 / 480)^2$ or $(1 / \sqrt{3})^2 = 1/3$ the torque at 480 V. Since a typical NEMA Design B motor will momentarily produce around 150% of its rated torque (depending on horsepower rating and synchronous speed) when started at full voltage, one-third of this value will give a momentary starting torque of 50% of its rated torque value. Likewise, if a motor has a starting torque of 120% of its rated torque, the starting torque will be one-third of this or 40% of its rated torque when started in wye. See Table 12-2 in NEMA standard *MG 1* for locked-rotor (starting) torque values for Design B motors (see Additional Reading section, which begins on page 60). Don't be put off by the 50% or 40% starting torque values, they are still one-third or 33% of the delta starting torque value for the particular motor, based on the square of the voltage impressed across the motor windings.

As mentioned above, the voltage relationship between 277 V wye and 480 V delta from Figure 6 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. The length of the short side opposite the 30° angle is of no concern for this exercise. Figure 7 is the bottom portion of Figure 6.

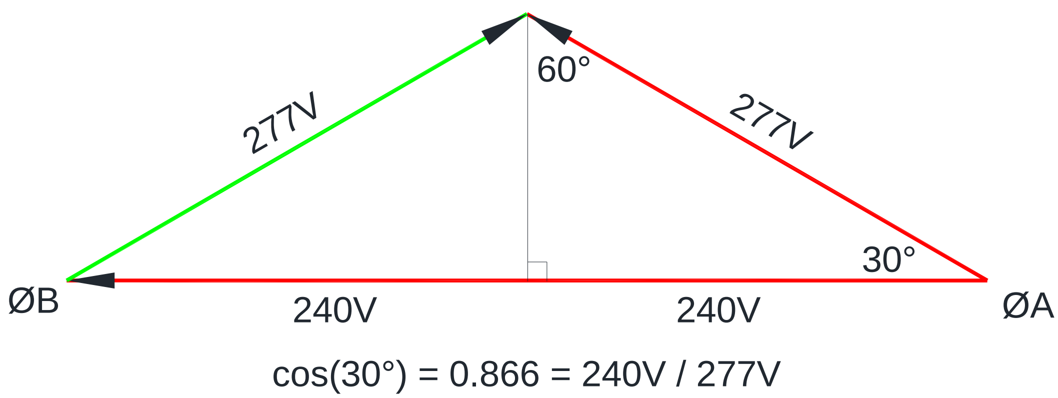


Figure 7 – Wye-Delta Voltage Relationship – Right Triangle Geometry

As shown in Figure 7, 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°. Alternatively, we could have used the 60° corner for reference in Figure 7 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 $\sqrt{3} / 2$, as one might expect from the voltages shown in Figure 7.

Since the wye voltage in Figure 6 is 277 V when 480 V is applied, it stands to reason that the wye voltage would be half of this or 138.5 V when 240 V is applied to the motor. This will be discussed in more detail after Figure 11 on page 16.

Delta-Connected Twelve-Lead, Three-Phase Motors

A twelve-lead motor is the same as a six-lead motor, except that each of the three motor windings is divided in half and both ends of each of the halves are made accessible for wiring. Twelve-lead motors are used for dual-voltage applications with voltage ratios of 1:2, with the two halves of each winding in series for the higher voltage and the two halves in parallel for the lower voltage. Dual-voltage motors with a ratio of 1:2, such as 230/460, are found mainly in the United States. Multi-voltage motors with ratings of 208/240/480 V, three-phase (also known as 200/230/460V, three-phase motors), are actually 240/480 V motors that are a little more robust so they will operate correctly when powered by 208 V, three-phase, but these are not wye-start/delta run motors.

Dual-voltage motors in other countries have a ratio of 1:√3, such as 220/380, and are wired in delta at the lower voltage and in wye at the higher voltage. These dual-voltage motors are not discussed in detail in this course, since they are not wye-start/delta-run motors, but it is clear from the examples in this course that applying 380 V to a wye-connected motor will put 220 V across each winding, the same voltage that would be across each winding when wired in delta with 220 V applied.

Twelve-Lead Motors:

A six-lead wye-start/delta run motor can be described as a Y-Δ motor, but a twelve-lead wye-start/delta run motor is often described as a YY-ΔΔ motor, since there are twice as many windings for twelve-lead motors, due to the two half-windings per phase.

The behavior of a twelve-lead, three phase motor wired in delta is the same as that of a three-lead or a six-lead motor wired in delta. The main difference is the additional connections to put the half-windings in series for the higher voltage, as illustrated in Figure 8, or in parallel for the lower voltage, as illustrated in Figure 9.

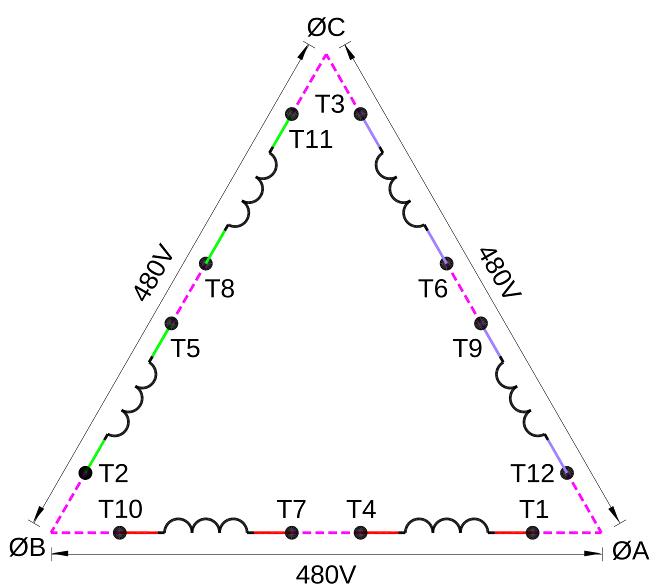


Figure 8 – Delta-Connected Twelve-Lead, Three-Phase Motor at 480V, Three-Phase

The same half-windings in Figure 8, wired in series for 480 V, are rearranged in parallel for use on 240 V, three-phase power in Figure 9.

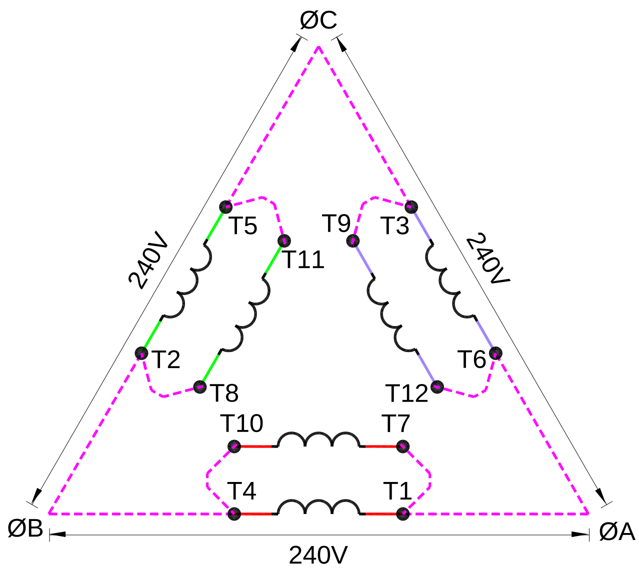


Figure 9 – Delta-Connected Twelve-Lead, Three-Phase Motor at 240V, Three-Phase

Notice in Figure 8 and Figure 9 that there will be 240 V across each half-winding whether the motor is connected for the higher voltage (480 V) or the lower voltage (240 V). At the higher voltage in Figure 8, the 480 V is divided evenly across the two half-windings in series such that each half-winding is subjected to 240 V. In Figure 9, 240 V is impressed across both of the half-windings in parallel. Notice, also, in both of those figures that the current flows through the windings in the same direction, whether the windings are connected in series or parallel. For example, starting at Phase A, the current flows from T1 to T4 and from T7 to T10 in both figures, which is illustrated more clearly in Figure 14 on page 18 (480 V) and Figure 16 on page 20 (240 V).

Wye-Connected Twelve-Lead, Three-Phase Motors

The behavior of a twelve-lead three phase motor wired in wye is the same as that of a six-lead motor wired in wye, like the one shown in Figure 5 on page 10. The main difference for a twelve-lead motor is adding connections to put the half-windings in series for the higher voltage, as illustrated in Figure 10, or in parallel for the lower voltage, as illustrated in Figure 11.

Six Power Conductors Instead of Three:

In figures 12 through 23, the power conductors going to the motor from the starter are shown as being only three conductors for the sake of simplicity of these illustrations and related discussions. In actuality, six power conductors are required from a wye-delta starter a wye-start/delta-run motor; a fact that is covered in more detail in the section called Sizing Power Conductors and Contactors for Wye-Delta Motors, *which begins on page 49.*

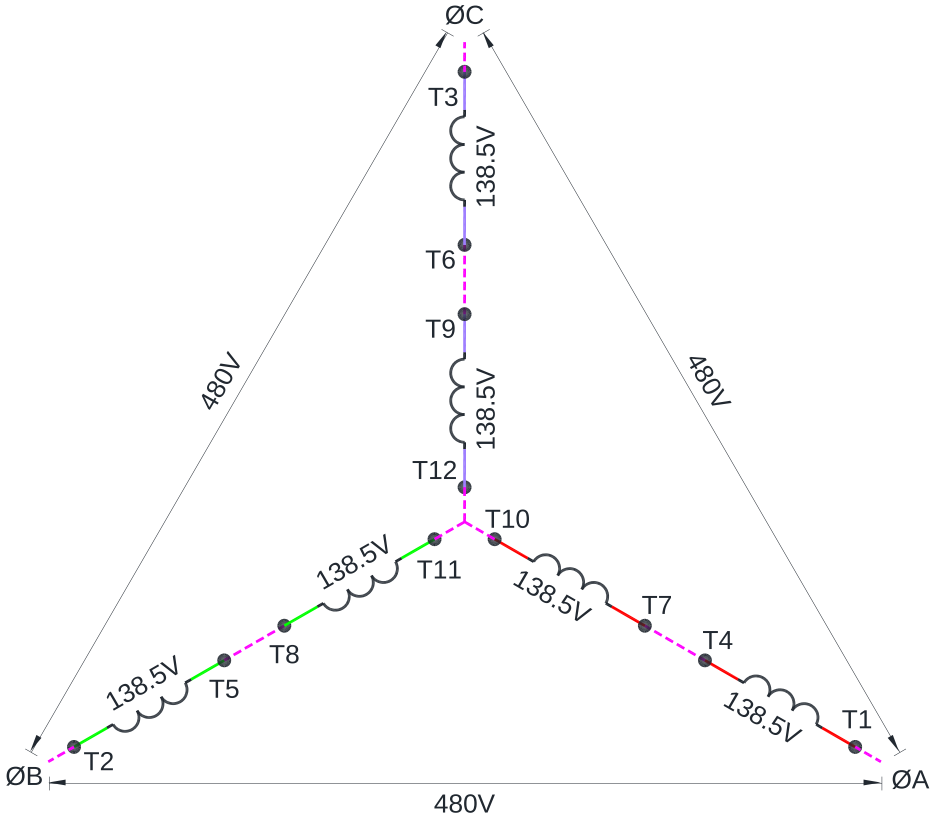


Figure 10 – Wye-Connected Twelve-Lead, Three-Phase Motor at 480V, Three-Phase

Since the voltage in each of the three legs of the wye in Figure 10 is split evenly across the two half-windings in series in that leg, the voltage across each half-winding in Figure 10 is 480 V / √3 / 2 = 277 V / 2 = 138.5 V. When the voltages across the two half-windings in each leg are added together, the result is (2) * 138.5 V = 277 V per leg for each of the three legs of the wye. Let's consider the same motor, but wired for the lower voltage, which is 240 V.

Since the full wye voltage is impressed across both of the half-windings in parallel in each leg, the voltage across each half-winding in Figure 11 is 240 V / √3 = 138.5 V. As previously stated, even though 480 V was applied to the motor in Figure 10 and 240 V is applied to the same motor in Figure 11, the voltage across each half-winding is the same in both cases – specifically 138.5 V.

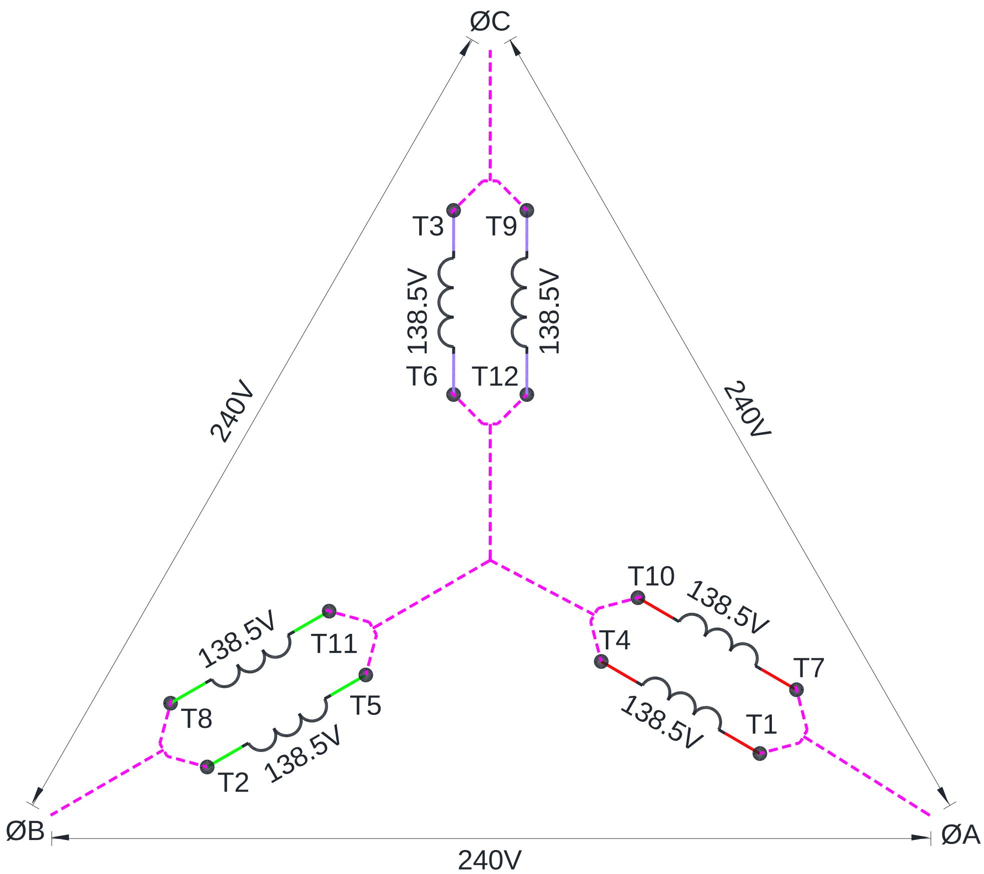


Figure 11 – Wye-Connected Twelve-Lead, Three-Phase Motor at 240V, Three-Phase

Currents in Delta- and Wye-Connected Motors

We have looked at the wiring connections and resulting voltages for wye- and delta-connected motors, but now let's get into the actual values for line and phase (winding) current for both connection types.

Currents in Delta-Connected Motors

As we have seen, the full 480 V is applied to the windings in each of the three legs of a delta-connected motor. This usually results in a starting current of approximately 600% of the full-load current, and 100% of the full-load current when the motor is running under full load. In a three-lead, delta-connected motor, the line currents Ia, Ib, and Ic, which are the currents in the power conductors going to the motor starter, are equal to the vector sum of the currents in the two windings to which they are connected. In other words, Ia = I1 – I3, Ib = I2 – I1, and Ic = I3 – I2, as illustrated in Figure 12, which is applicable to three-lead, six-lead, and twelve-lead motors connected in delta from the perspective of the power source. The motor starter is not shown in Figure 12, but the line currents Ia, Ib, and Ic represent the currents that would flow from the power source to the motor starter.

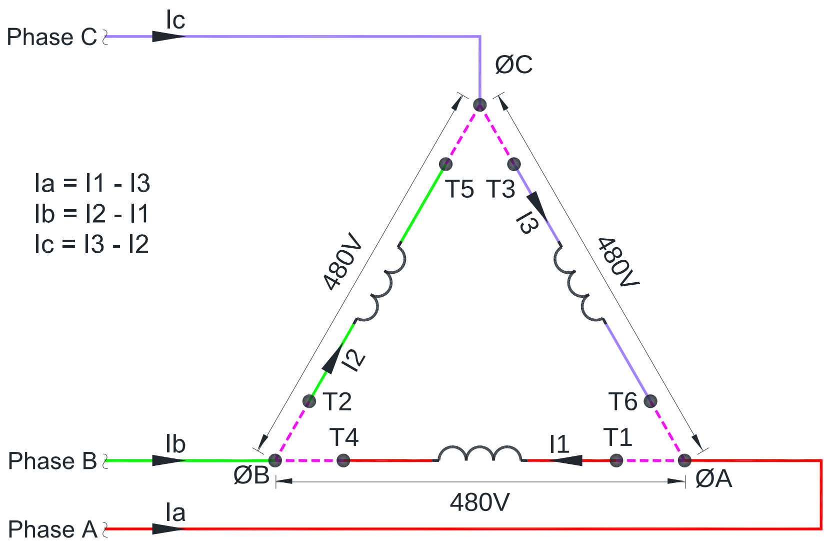


Figure 12 – Currents and Voltages in a Delta-Connected, Six-Lead Motor

Let's give a specific horsepower value of 200 Hp to the motor in the figure above and show the resulting full-load currents in Figure 13. Table 430.250 in the NEC gives a full-load current value of 240 amps, at 480 V, three-phase. That amperage is the line current, the current in the power conductors coming from the power source, which is a more meaningful value when sizing those power conductors than would be the value of the current in the motor windings. The actual current in each of the three legs of motor windings is 240 A / √3 = 138.5 A, due to the way the motor winding current vectors add up. Let's look at the line current Ia going to the motor starter from Phase A. Line current Ia is equal to the vector sum of the currents I1 and negative I3 in the two windings to which Phase A is connected. This is illustrated in Figure 13 below and represented by vectors in Figure 15 on page 19.

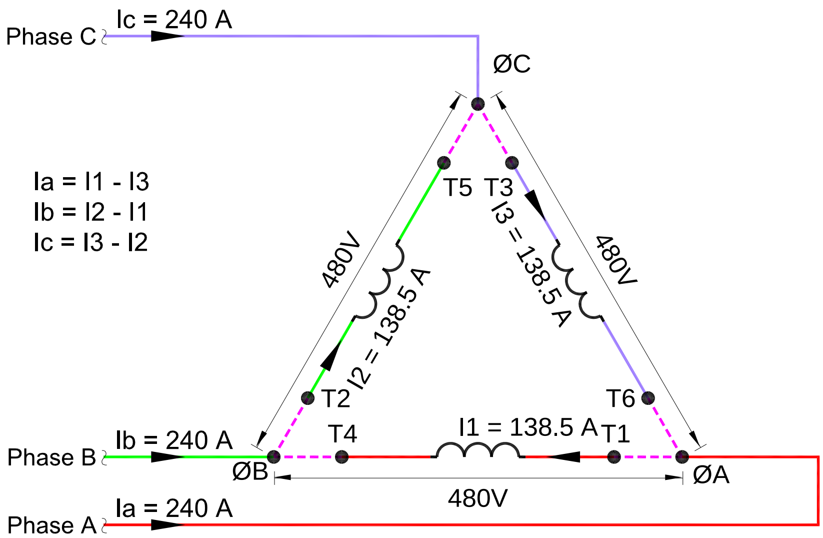


Figure 13 – Currents and Voltages in a 200 Hp, Delta-Connected, Six-Lead Motor at 480V, Three-Phase

The currents for a delta-connected six-lead motor are the same as for a delta–connected twelve-lead motor at higher voltage, as shown in Figure 14.

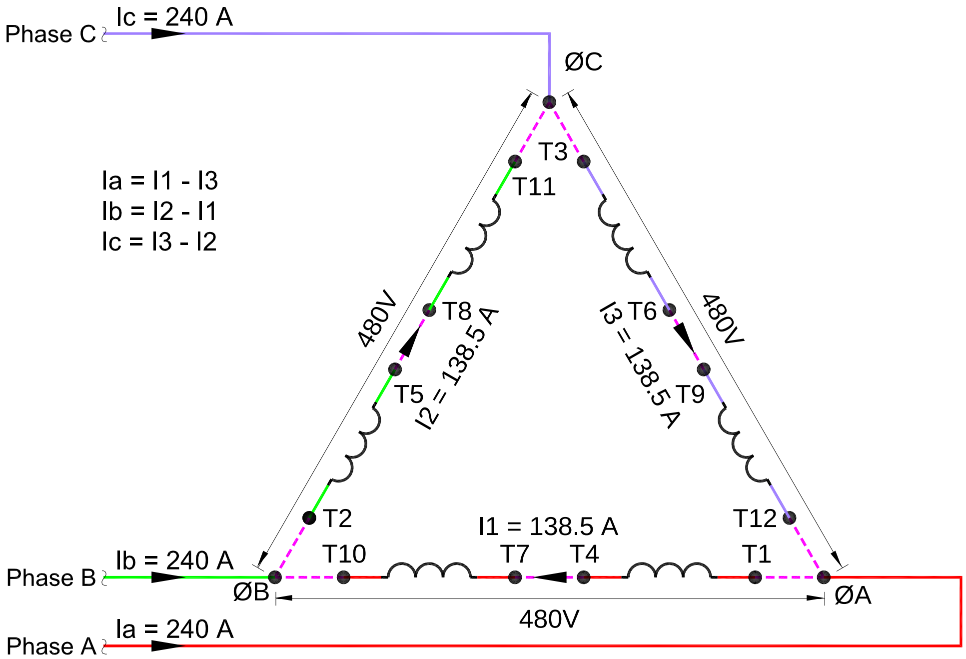


Figure 14 – Currents and Voltages in a Delta-Connected, Twelve-Lead Motor at 480V, Three-Phase

It is easy to confirm that two 138.5 A vectors that are 120° apart will result in a 240 A vector when subtracting one from the other. In the same way that the voltages were drawn to scale in Figure 6 on page 11, the line and winding (phase) currents for a delta-connected 200 Hp motor at 480 V, three-phase, are drawn to scale in Figure 15 below, using the current vectors from Figure 13, which are the same as in Figure 14.

Wye-Start/Delta-Run Motors Are Single-Speed Motors:

After a wye-start/delta-run motor reaches or comes near to its normal speed while starting in wye, the wye-delta motor starter switches the motor wiring to a delta connection and the motor continues to turn at its normal speed.

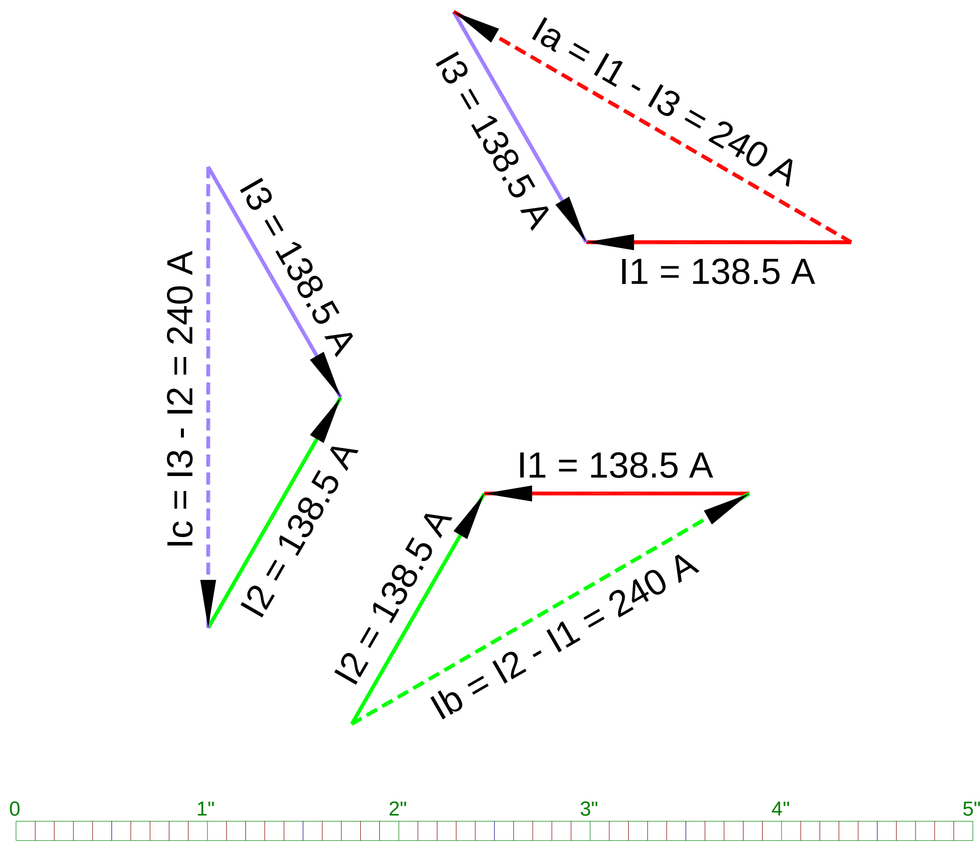


Figure 15 – Line and Winding (Phase) Currents in a 200 Hp, Delta-Connected Motor at 480 V, Three-Phase

If this page of the PDF version of this course is printed out without being scaled to fit the paper (when printing, set Page Scaling to None, or Actual Size, or 100%, depending on your version), a ruler, scale, or tape measure can be used to confirm the lengths of the lines in Figure 15. The current vectors that are 138.5 A will be 1.385" long and the current vectors that are 240 A will be 2.4" long (approximately).

Figure 15 shows us that, since line current Ia = I1 – I3, we find vector Ia by starting with vector I1, the current in the winding connected to phases A and B, then subtracting the vector I3, which is the current in the winding connected to phases C and A, by putting the head of vector I3 at the head of vector I1. The resulting Ia vector is measured from the beginning of vector I1 to the end of vector negative I3 and is shown as a dashed line equal to 240 A, the full-load line current Ia of the motor when connected in delta. The Ia vector is pointing in the 150° direction. In the same fashion, the Ib vector, which is the line current in the B phase, is equal to the I2 vector minus the I1 vector, resulting in a 240 A in the 30° direction. The Ic vector is 240 A in the 270° direction. Line current Ia is 120° ahead of line current Ib, which is 120° ahead of line current Ic, which is 120° ahead of line current Ia, et cetera.

In the case of a twelve-lead, 200 Hp, delta-connected motor at higher voltage (Figure 8 on page 13 and Figure 14 on page 18), it is easy to picture that the current going through the two half-windings in series is the same in each half-winding and the results would look the same as shown in Figure 15. However, the currents going through two parallel windings in a twelve-lead, 200 Hp, delta-connected motor at lower voltage (Figure 9 on page 14 and Figure 16 below) would take two separate paths of equal impedance, so the currents in each half-winding would be equal to the half-winding current when connected at the higher voltage, namely 138.5 A, as shown in Figure 16, since the voltage across each half-winding is the same whether the motor is connected at the higher voltage or the lower voltage. To phrase it differently, since there would be 240 V across each half-winding whether the motor is connected at the high voltage or the low voltage, the current through each half-winding would be the same in either case, but the currents add together in the low voltage connection such that the total current in the low voltage case is twice that in the high voltage case. To re-state the above, we have already seen in Figure 14 on page 18 that impressing 480 V across the two winding halves (240 V per half-winding) in series will produce 138.5 A in both winding halves. Since each of the two winding halves in Figure 14 and in Figure 16 below is actually subjected to 240 V, putting the two half-windings in parallel will result in a current of 138.5 A in each of the half-windings and will double the amount of current that resulted from connecting the half-windings in series.

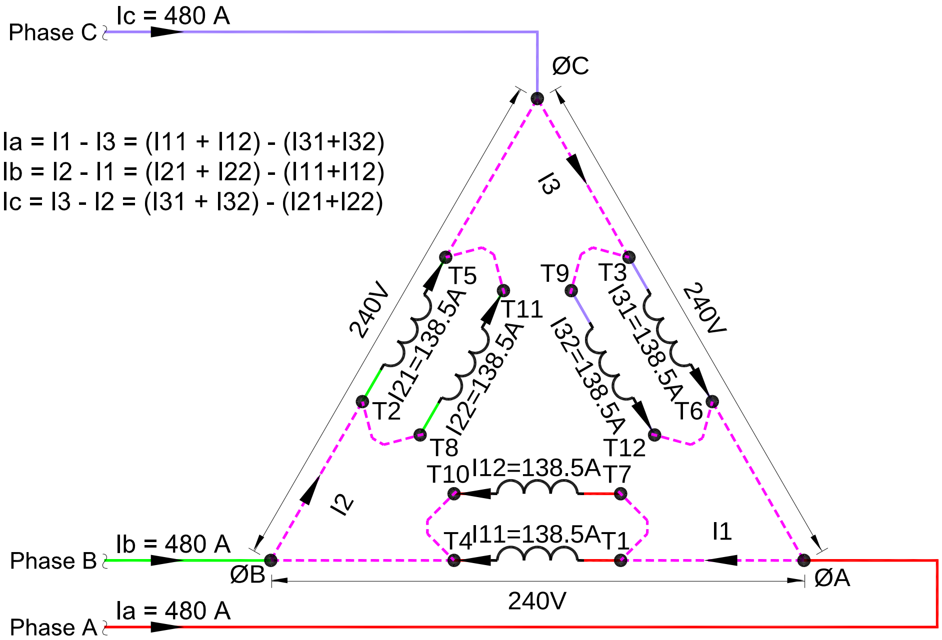


Figure 16 – Currents and Voltages in a 200 Hp, Delta-Connected, Twelve-Lead Motor at 240V, Three-Phase

A general rule of thumb is that the full-load current for a certain motor horsepower at 240 V will be twice the full-load current for that same motor horsepower at 480 V. Compare, for example, the currents for a 100 Hp motor at 240 V and 480 V in NEC Table 430.250, wherein the full-load current is 248 A at 240 V and 124 A at 480 V. The parallel currents in Figure 16 add together and yield the results in Figure 17.

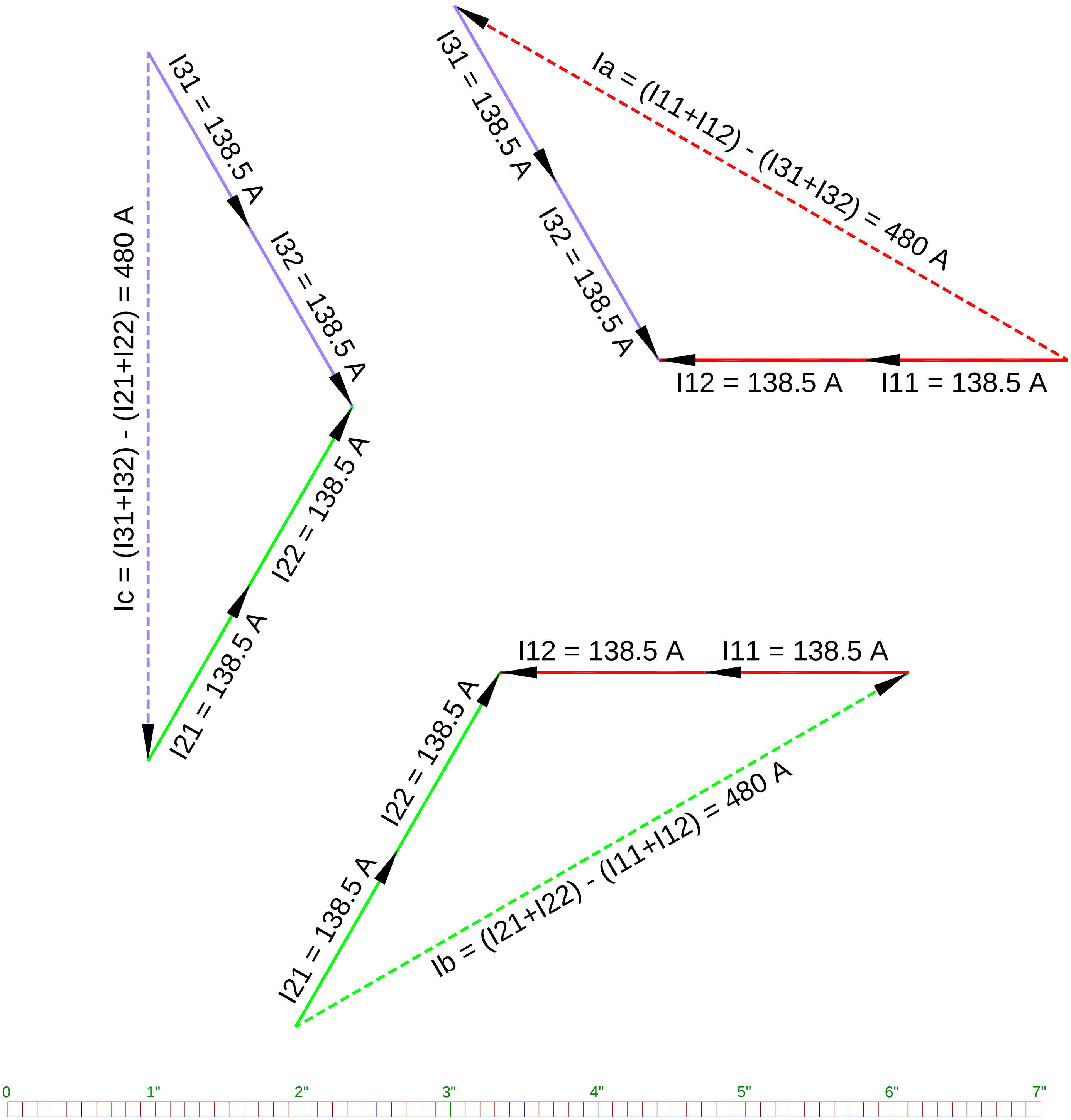


Figure 17 – Line and Winding (Phase) Currents in a 200 Hp, Delta-Connected, Twelve-Lead Motor at 240V, Three-Phase

In Figure 17, the currents in the parallel half-windings in each of the phases add up to give 138.5 A + 138.5 A = 277 A per phase inside the delta. When two 277 A vectors from adjacent phases are combined by subtracting one from the other, the result is a 480 A vector. Notice that the angles of the vectors in Figure 17 are the same as the angles of the vectors in Figure 15 on page 19.

Let's consider the currents and voltages in a six-lead and a twelve-lead 200 Hp motor wired in the wye configuration, rather than the delta configuration.

Currents in Wye-Connected Motors

The same six-lead motor that was connected in delta in Figure 12 on page 17 is connected in wye in Figure 18. The voltage across each winding is 277 V, as illustrated in Figure 6 on page 11. The line current in the conductors going to the motor is equal to the current in the winding to which it is connected. In other words, Ia = I1, Ib = I2, and Ic = I3.

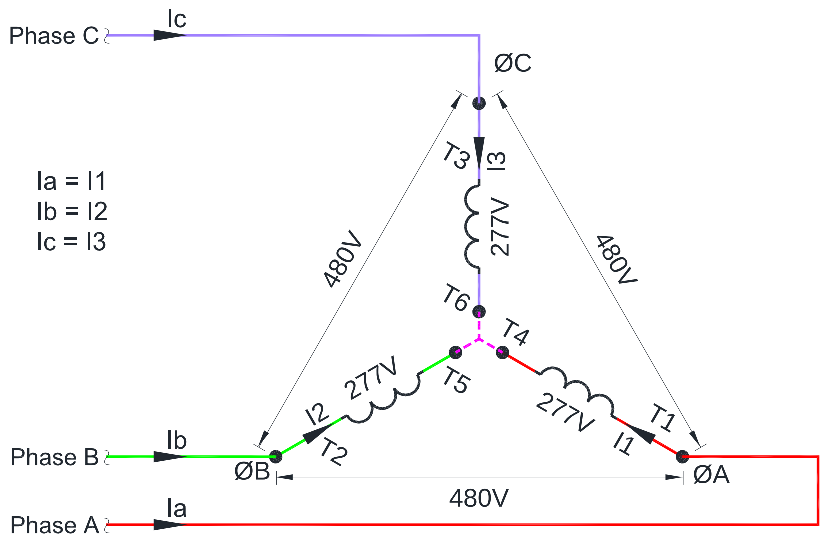


Figure 18 – Currents and Voltages in a Wye-Connected, Six-Lead Motor

The current through the motor windings when different voltages are applied will be proportional to that voltage divided by the rated voltage. Let's consider applying 277 V across the motor windings that are rated for 480 V, which is what happens in Figure 18. The ratio would be 277 / 480 = 1 / √3. Using our 200 Hp example, the winding currents for the wye-connected motor at 480 V, which puts 277 V across each motor winding, will be 1 / √3 times the delta full-load phase or winding current, or 138.5 A / √3 = 80 A. This is illustrated in Figure 19 below.

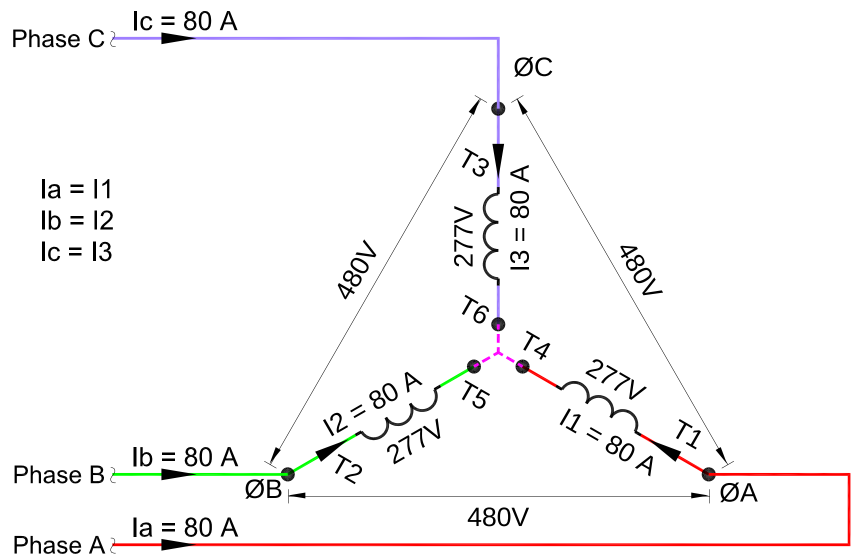


Figure 19 – Currents and Voltages in a 200 Hp, Wye-Connected, Six-Lead Motor at 480 V, Three-Phase

Notice in Figure 19 above and Figure 13 on page 17 that the motor winding current is flowing from T1 to T4 in the wye configuration, and continues to flow from T1 to T4 in the delta configuration, after a momentary interruption during an open transition, or with no interruption in the case of a closed transition. The same holds true for current flowing from T2 to T5 and current flowing from T3 to T6. Since the line currents are equal to the winding (phase) currents when the motor is in the wye configuration, there is no vector math to do, as shown in Figure 20, where Ia = I1 = 80 A in the 150° direction, Ib = I2 = 80 A in the 30° direction, and Ic = I3 = 80 A in the 270° direction.

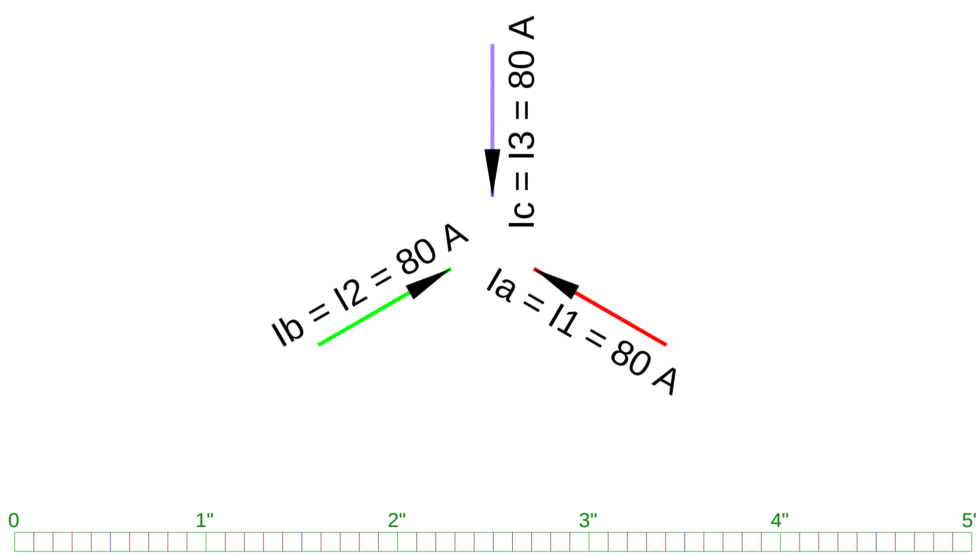


Figure 20 – Line = Winding (Phase) Currents in a 200 Hp, Wye-Connected Motor at 480 V, Three-Phase

The currents going to the motor and inside the motor windings for a six-lead motor connected in wye are the same as for a twelve-lead motor connected in wye at the higher voltage, as shown in Figure 21.

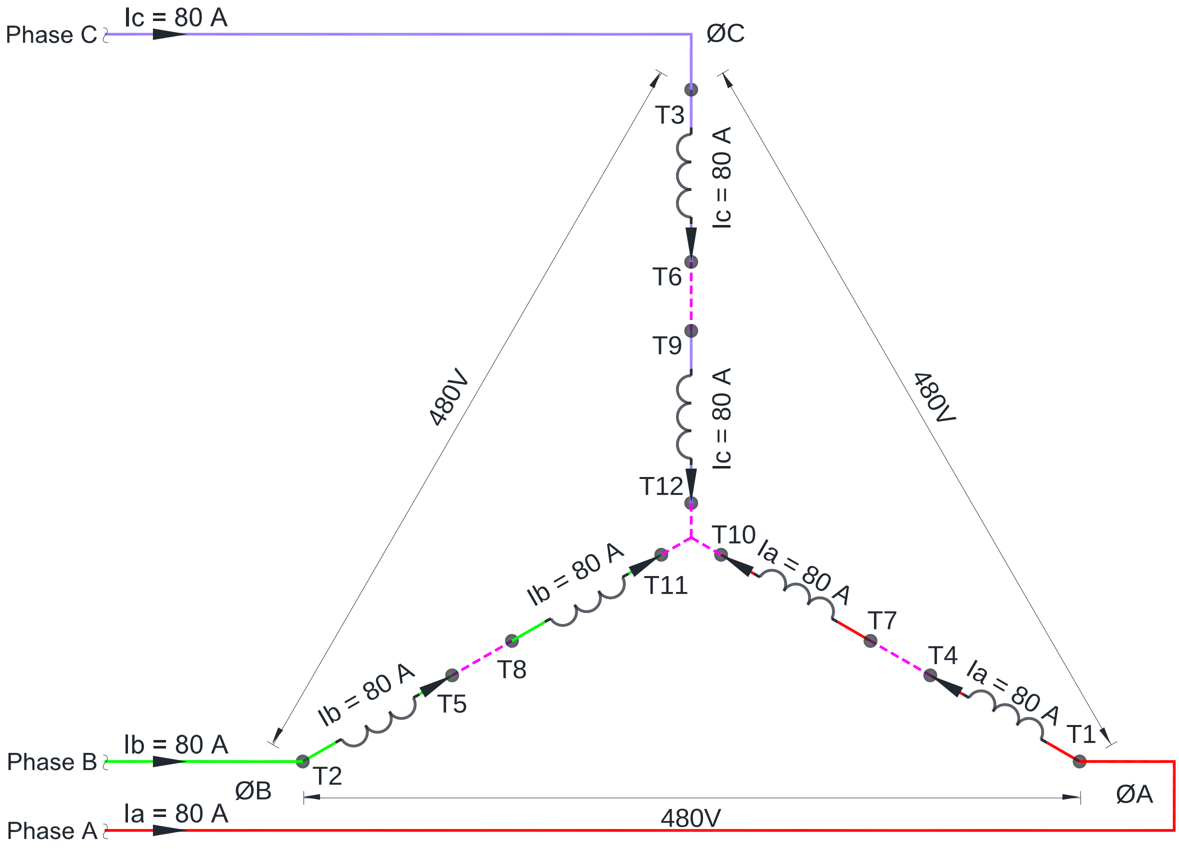


Figure 21 – Winding Currents in a 200 Hp, Wye-Connected, Twelve-Lead Motor at 480V, Three-Phase

As can be seen in Figure 21, a twelve-lead, 200 Hp, wye-connected motor will pull a full-load current of 80 A when connected to 480 V, three-phase power. By contrast, for the same twelve-wire, wye-connected 200 Hp motor powered at the lower voltage of 240 VAC, the winding current in each phase would be 80 A in both of the parallel half-windings, such that each wye leg at 240 V would carry 80 A * 2 = 160 A, as shown in Figure 22.

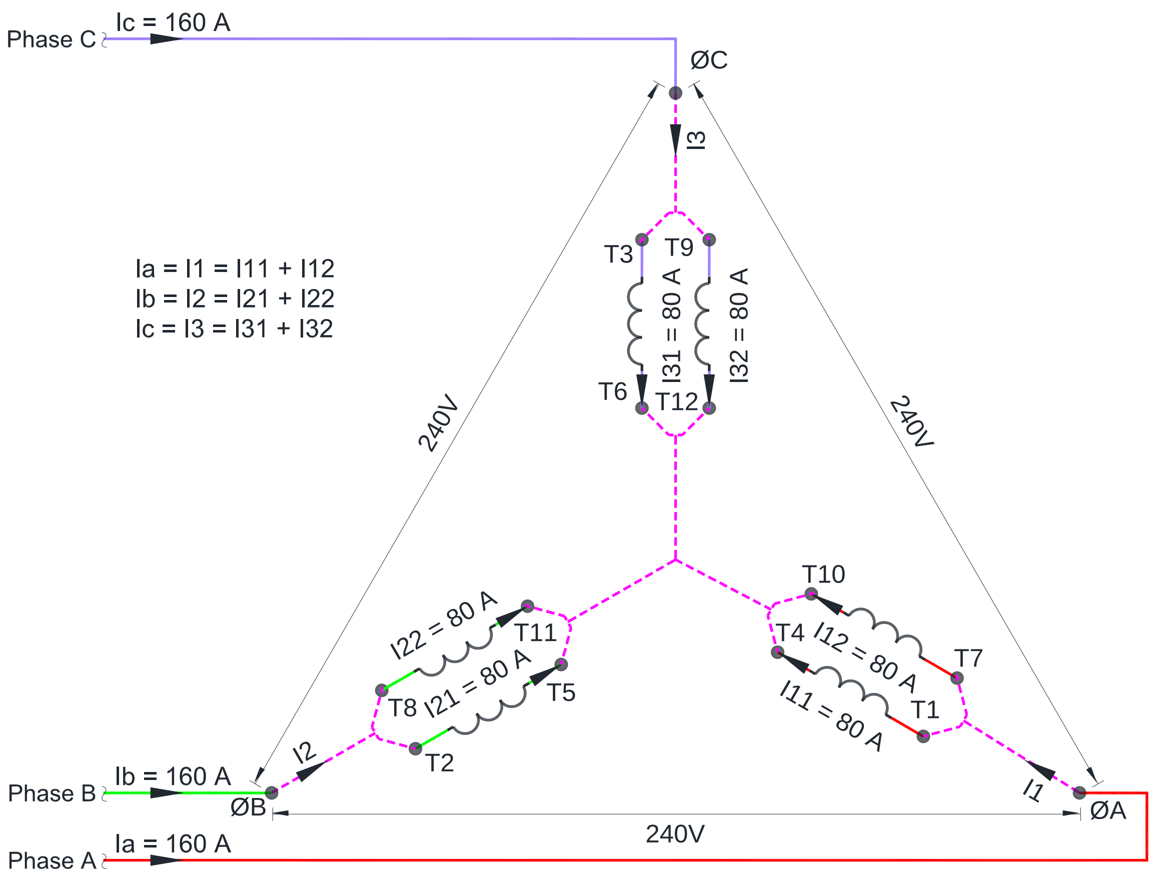


Figure 22 – Winding Currents in a 200 Hp, Wye-Connected, Twelve-Lead Motor at 240V, Three-Phase

When 240 V, three-phase power is applied to the wye-configured motor in Figure 22, there will be 240 V / √3 = 138.5 V applied across each of the three legs of the wye. This means the current through each half-winding is also reduced to 1 / √3 of its delta-configured value at 240 V, which would be 138.5 A / √3 = 80 A. But there are two parallel windings in each leg, so the total current in each of the three wye legs would be 2 * 80 A = 160 A, as shown in vector form in Figure 23.

If you add vectors Ia, Ib, and Ic together in Figure 23, the result would be zero, meaning that this is a balanced three-phase load. In other words, Ia + Ib + Ic = 0, which is also true for all of the wye- and delta-connected motors discussed in this course.

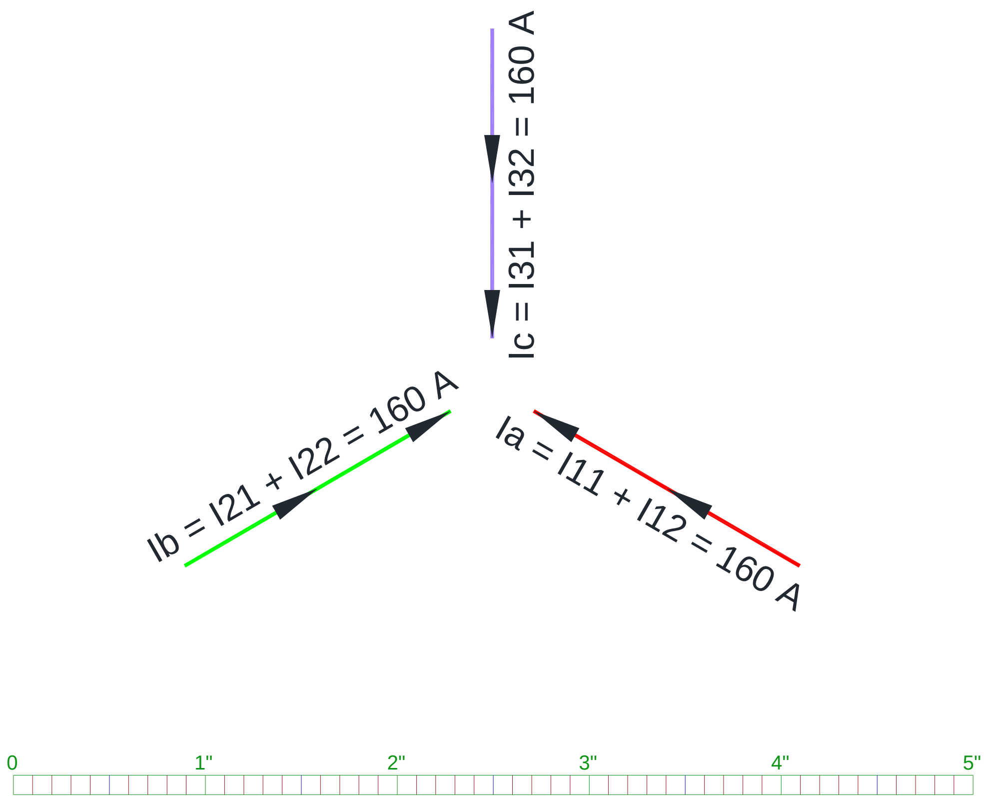
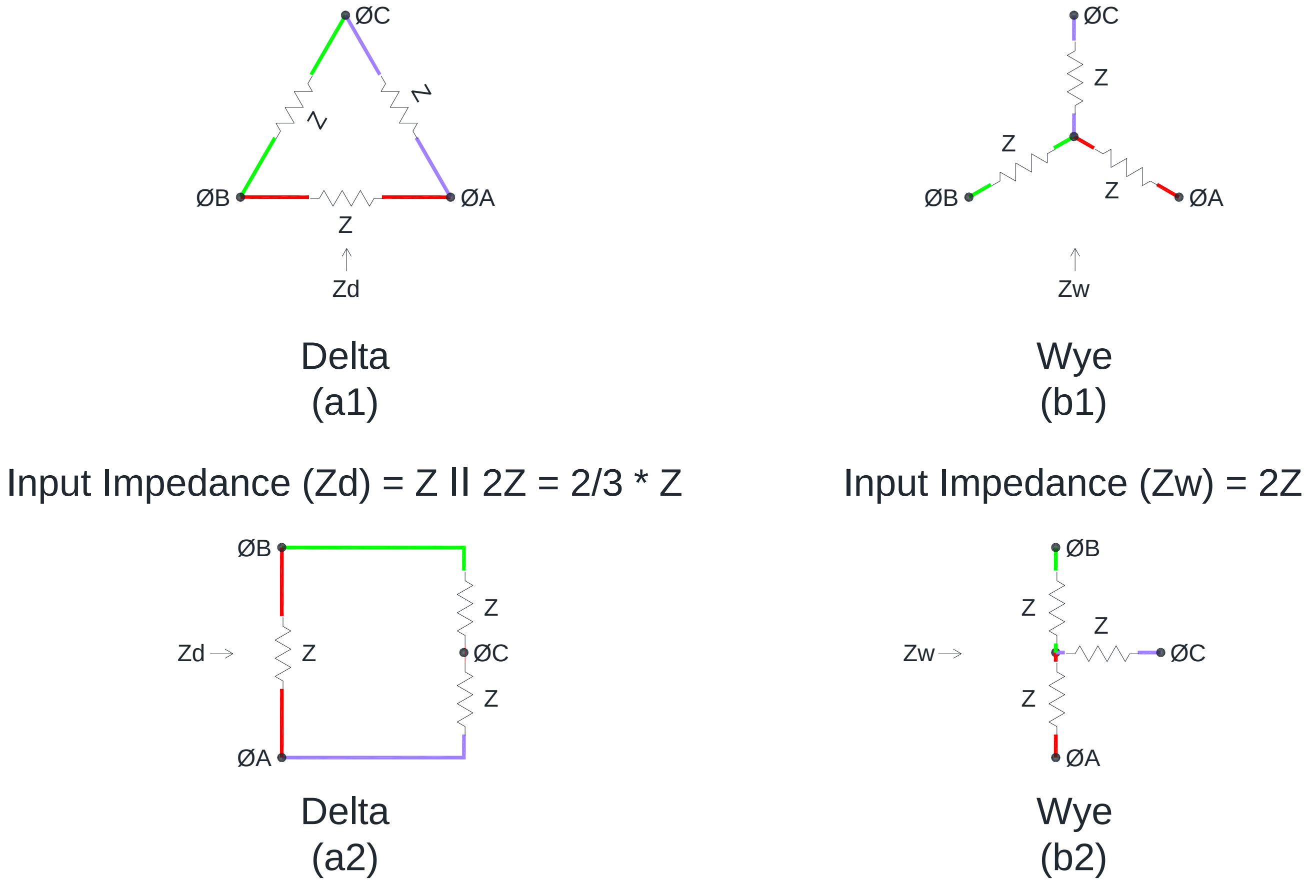


Figure 23 – Line = Winding (Phase) Currents in a 200 Hp, Wye-Connected, Twelve-Lead Motor at 240V, Three-Phase

Another way to look at delta-connected and wye-connected motors is to compare the input impedance for the two types of connections. This is illustrated in Figure 24 below.

A Three-Phase Motor as Three Single-Phase Loads:

From the perspective of the power source, the wye-start, delta-run motor appears as a three-phase load. From the perspective of the motor starter, a six-lead wye-start, delta run motor appears to be three single-phase loads: one single-phase load is between T1 and T4, another single-phase load is between T2 and T5, and the last single-phase load is between T3 and T6. The three single-phase loads are combined into one three-phase load on the line side of a non-reversing wye-delta motor starter, when the two ends of each single-phase load are connected to one end of each of the other single-phase loads. This is similar to a three-phase transformer, which is actually composed of three single-phase transformers, the primaries of which are typically connected end-to-end to form a delta configuration and the secondaries of which are typically connected in a wye configuration. The topic of three single-phase loads is described in more detail in the section titled Sizing Power Conductors and Contactors for Wye-Delta Motors, *which begins on page 49. A twelve-lead wye-start/delta-run motor will behave the same way.*



Input Impedance Ratio for Delta (Zd) : Wye (Zw) = 2/3 : 2 = 1 : 3

Figure 24 – Delta versus Wye Input Impedance

As can be seen at the bottom of Figure 24, the input impedance for a delta connection is one-third the input impedance for a wye connection. To phrase it differently, the power source will see three times the input impedance for a motor connected in wye when compared to the same motor connected in delta. This helps to explain why the current for a wye-connected motor is one-third the current for the same motor connected in delta.

The circuits in Figure 24(a1) and (b1) can be re-drawn as shown in Figure 24(a2) and (b2), respectively, to more easily determine the motor's input impedance. Since the impedance should be the same for each winding, each winding is represented with an arbitrary impedance value of Z. The input impedance between Phase A and Phase B for a delta connection, denoted as Zd in Figure 24(a1) and (a2), is equal to Z in parallel with 2Z, which is equal to 2/3 * Z. The input impedance between Phase A and Phase B for a wye connection, denoted as Zw in Figure 24(b1) and (b2), is equal to 2Z, since one end of the third impedance is left floating. Therefore, the ratio of Zd to Zw is 1 to 3, as previously stated.

The input impedance ratio calculated in Figure 24 was between Phase A and Phase B only, but the same ratio would hold true between Phase B and Phase C and between Phase C and Phase A.

Resistor symbols were used as visual aids in that figure, but the motor windings are actually impedances, composed of both resistance and inductance.

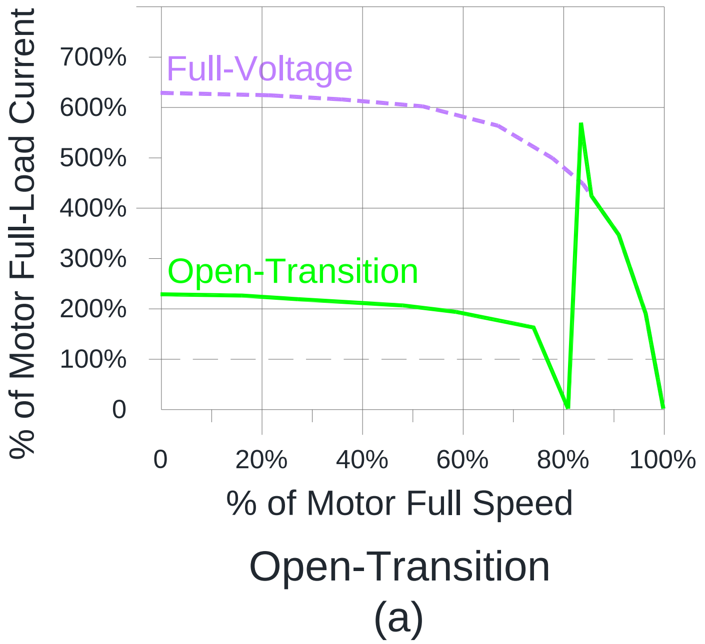
Wye-Delta Motor Starters

There are two main types of wye-delta motor starters: open-transition and closed-transition, the more popular of which is open-transition. Closed-transition wye-delta motor starters work the same way and use the same components as open-transition types, but closed-transition wye-delta motor starters also require one additional three-pole contactor and three power resistors for momentary use during the closed transition. Open-transition wye-delta motor starters are recommended for inertial loads, while closed-transition starters are better suited for frictional loading. Reversing wye-delta motor starters will be discussed later in the section named Reversing Open-Transition Wye-Delta Motor Starters, which begins on page 44.

When open-transition wye-delta motor starters change from the wye-start configuration to the delta-run configuration, there is a brief moment during which the wye formed by T4, T5, and T6 is opened, before those terminals are then connected with L2, L3, and L1, respectively, to form a delta. During this open transition, the current going to the motor could suddenly spike down, then spike back up above the full-load current value as the delta connection is formed, as shown in Figure 25(a). This is dependent on the loading of the motor and the timing of the open transition. During the reconnection after the open transition, there might also be a spike of increased torque which could be enough to damage mechanical components, such as a drive shaft. If the electrical system or mechanical equipment cannot tolerate these types of possible stress, a closed-transition wye-delta starter might be considered.

Closed-transition wye-delta motor starters temporarily insert a resistance into each of the three phases between L1/T1 & T6, L2/T2 & T4, and L3/T3 & T5 as the starter changes the motor power connections from the wye to the delta configuration. This is discussed further in the Closed-Transition Wye-Delta Motor Starters section, which begins on page 40. During the closed transition, the current may rise up to its normal, full-voltage starting value, but will not exceed it, as shown in Figure 25(b).

The graphs in Figure 25 are not intended to represent exact current and speed values but to illustrate the differences in full-voltage starting compared to open-transition and closed-transition wye-delta starting. The wye-configured starting current in both (a) and (b) begins around 200% FLC, tapers down eventually, then possibly dips down and rises up as in (a), or only rises up, as in (b).



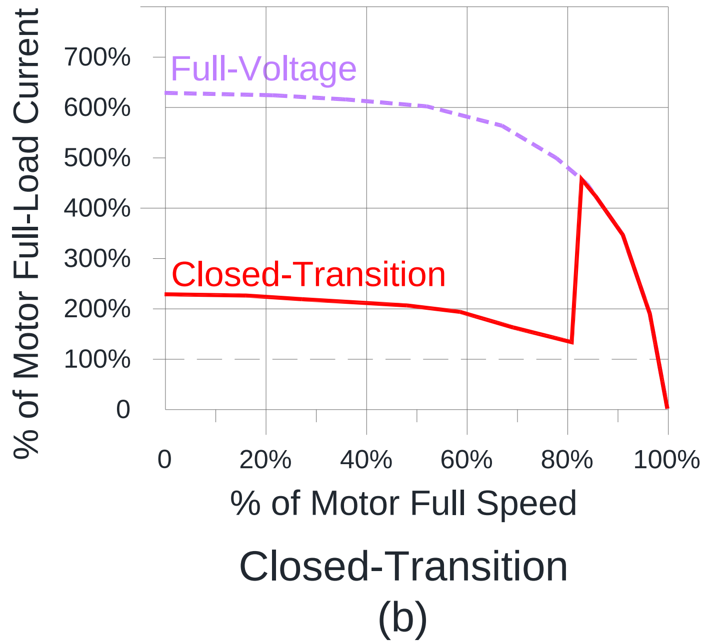


Figure 25 – Full-Voltage versus Wye-Delta Starting Current Curves

Open-Transition Wye-Delta Motor Starters

An open-transition wye-delta motor starter uses three contactors in a certain sequence to start the motor in a wye configuration then switch the motor while it is still spinning to run in a delta configuration. The three contactors are labeled S, 1M, and 2M in Table 3 below, in Figure 26, in Figure 27 on page 31, and Figure 28 on page 34. These contactors have power contacts, through which the motor is powered, and auxiliary contacts, which are in the control circuit. Table 3 is based on Figure 2-3-6 in NEMA publication *ICS 2 Industrial Control and Systems Controllers, Contactors, and Overload Relays Rated 600 Volts* (see Additional Reading beginning on page 60).

NEMA Starter	**S (Wye Start)**	**1M (Mains or Start & Run)**	**2M (Delta Run)**	**TR (Time Delay Relay)**
STOPPED	OFF	OFF	OFF	NOT ENERGIZED
START IN WYE	ON	ON	OFF	ENERGIZED
TRANSITION	OFF	ON	OFF	ENERGIZED
RUN IN DELTA	OFF	ON	ON	ENERGIZED
IEC Starter	**-Q13**	**-Q11**	**-Q15**	**-K1**

Table 3 – Open-Transition Wye-Delta Starter Contactors and Time Delay Relay Sequence

The IEC contactors shown at the bottom of Table 3 appear in Figure 29 on page 36 and Figure 30 on page 38. They also appear in reversing wye-delta motor starter circuits, such as

Figure 35 on page 45, Figure 36 on page 47, and Figure 37 on page 48. IEC contactors are typically used in starters for European applications.

The sequence chart in Figure 26 shows the state of the time delay relay and the contactors at each part of the open-transition wye-delta starter sequence.

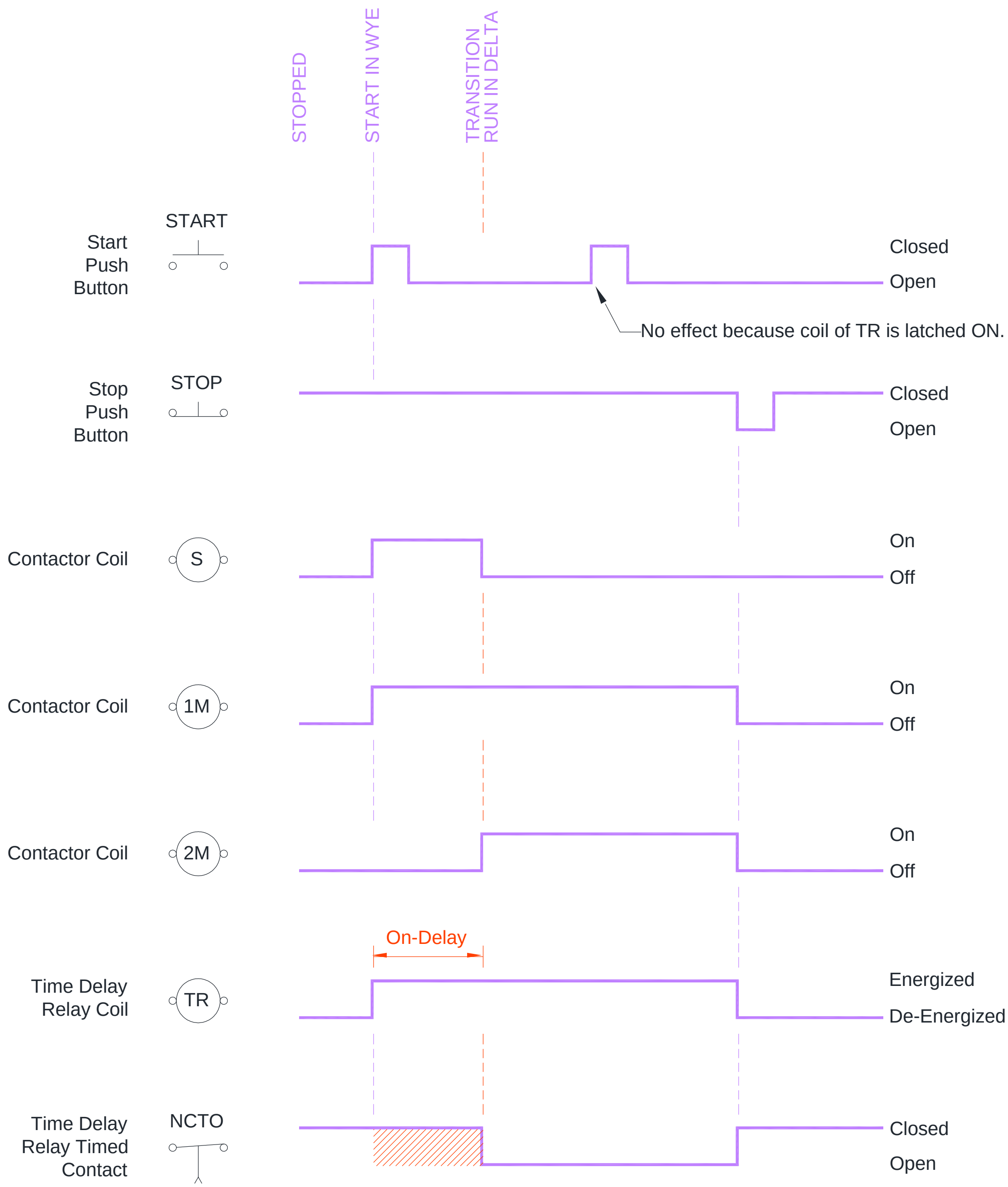


Figure 26 – Open-Transition Wye-Delta Starter Sequence Chart

The jumper shown between terminals 1 & 1A on the NEMA-based elementary diagrams in this course can be removed in order to insert a shutdown interlock contact. Such a contact might be an output from a fire alarm control panel, an emergency stop system, or some other means of stopping and disabling the motor. The shutdown interlock contact would be closed during so-called 'normal' conditions and would open in order to shut down the motor. When the shutdown interlock contact, if present, opens, it resets the control circuit such that manual intervention would be required in that the Start push button would have to be pressed again in order to start the motor.

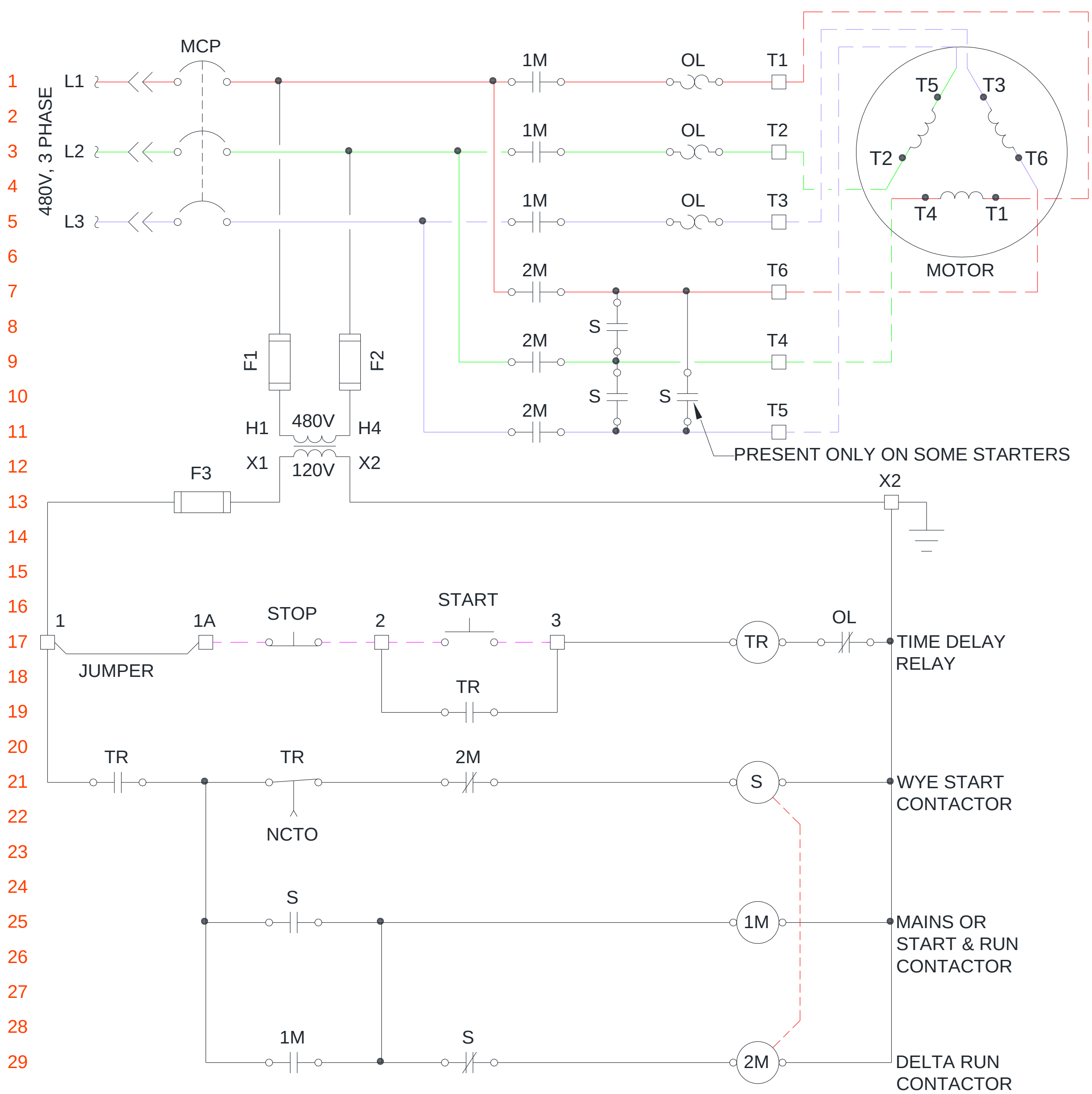


Figure 27 – Open-Transition Wye-Delta Motor Starter Elementary Diagram

The following description of the open-transition wye-delta motor starter sequence of operations is also described in Table 3 on page 29 and Figure 26. Rung numbers have been included in the elementary diagram in Figure 27, and other such figures in this course, for reference in the related discussions, though it is unusual for rung numbers to be shown on motor elementary diagrams.

STOPPED: The initial conditions of the wye-delta motor starter in Figure 27 would call for none of the coils to be energized, as described in Table 3 on page 29 and Figure 26 on page 30.

START IN WYE: When the start push button at rung 17 is pressed, the coil of time delay relay TR at rung 17 is energized (unless the overload contact in that same rung is tripped open) and an instantaneous (not timed) contact of TR at rung 19 seals in around the start push button to keep the coil of TR energized until the stop push button is pressed. The time delay function of time delay relay TR does not affect the instantaneous contacts of TR, they act just like regular relay contacts.

The other instantaneous contact of TR closes at rung 21 to enable the rest of the control circuit. The only timed contact of TR, the contact with the Y shape dangling from it at rung 21, is normally closed but will open when TR times out, usually around 10 seconds or thereabouts for open-transition wye-delta motor starters. This type of time delay relay contact is known as normally-closed, timed-open or NCTO. The coil of contactor S is energized when the instantaneous TR contact at rung 21 closes, which in turn closes the NO contact of S at rung 25 to energize the coil of contactor 1M at rung 25. The 1M contact at rung 29 seals in around the S contact at rung 25 to keep 1M energized after contactor S is de-energized. The power contacts of S at rungs 8 and 10 close to connect T4, T5, and T6 together to make the center of the wye configuration. In some wye-delta starters, there are only two power contacts of contactor S, but other wye-delta starters will have three power contacts for this contactor, as noted in Figure 27. The NC contact of S at rung 29 prevents contactor 2M from energizing until TR times out, which then de-energizes contactor S (more on this later). Power is applied to motor terminals T1, T2, and T3 through the power contacts of 1M at rungs 1, 3, and 5, respectively. As mentioned previously, with the motor in the wye configuration, it is pulling 1/3 of its delta-configured full load current (FLC) value after the initial starting current. Consider a 200 Hp motor with 240 A FLC in delta. When wired in delta, the actual current in each of the three motor windings is FLC / √3, or 138.5 A for this example. It is helpful to assemble the vectors in order to see this, as was done using Figure 13 on page 17 and Figure 15 on page 19. When wired in wye, however, the current is 1 / 3 of the delta-connected value because:

1. The voltage across each of the three motor windings is only 480 V / √3 = 277 V;
2. The resulting current through each of the three windings at this voltage is the (480 V winding current) / √3 = 138.5 A / √3 = 80 A; and
3. The phase current is the same as the line current, which is 80 A in this example, rather than 240 A. See Figure 19 on page 23 and Figure 20 on page 23 for this wye-connected example.

TRANSITION: When time delay relay TR times out, the NCTO contact of TR at rung 21 will open, de-energizing the coil of contactor S. The instantaneous NO contacts of TR do not open, since the coil of TR is still energized. When the NCTO contact of TR opens, this allows the coil of contactor 2M at rung 29 to energize through the closed NO 1M contact and the now closed NC contact of S. The power contacts of S also open, interrupting the current flow to the motor briefly, until the power contacts of contactor 2M apply power to motor leads T4, T5, and T6 at rungs 9, 11, and 7, respectively. Contactor 1M is still energized and power is still applied to motor terminals T1, T2, and T3.

RUN IN DELTA: With the power contacts of 1M and 2M closed and the power contacts of S open, the motor is now wired in delta. The motor winding known as T1-T4 is connected to L1 & L2, respectively, motor winding T2-T5 is connected to L2 & L3, respectively, and motor winding T3-T6 is connected to L3 & L1, respectively. The motor will now run like a 'regular' delta motor, pulling the expected full load current, 240 A in this example, from the power source.

It is assumed that the motor has gotten up to around full speed by the time TR times out – there is no speed monitoring in this circuit to confirm that it has. For some motors, it may damage the motor to run it in the wye configuration for more than 30 seconds, and such a limitation should appear in the motor manufacturer's literature for the particular motor in question.

Notice that only one set of three thermal overloads is required for a wye-delta motor starter, and they are in the motor's power circuit whether the motor is in the wye or the delta configuration in the examples shown in this course. Likewise, only one contact of the overload relay is used in Figure 27 on page 31, located in the neutral connection to the coil of time delay relay TR at rung 17. The selection of overloads for wye-delta motor starter is different from that for full-voltage motor starters, as explained later in the section called NEC Ground-Fault, Short-Circuit, and Overload Protection Requirements, which begins on page 58.

The coils of contactor S at rung 21 and contactor 2M at rung 29 in Figure 27 on page 31 are kept from being energized at the same time by two methods: an electrical interlock and a mechanical interlock. The electrical interlock is composed of the NC contact of 2M ahead of the S coil at rung 21 and the NC contact of S ahead of the 2M coil at rung 29. The mechanical interlock is indicated by the dashed line connecting the S coil to the 2M coil. The mechanical interlock is accomplished by physically installing the contactors adjacent to each other and using the appropriate hardware furnished by the contactor manufacturer. When one of the coils is energized, this hardware, the design of which varies from manufacturer to manufacturer, prevents the contacts of the second contactor from moving if the second contactor coil is inadvertently energized while the first contactor is energized, and vice-versa.

Notice that, once the motor starter has been started, pressing the Start push button will have no effect on the motor starter, since an instantaneous NO contact of TR will be latched around the Start push button. The Stop push button must be pressed to reset the motor starter control circuit to its initial condition, in which the motor starter is stopped and all of the contactor and time delay relay coils are de-energized. If the overload contact trips or the circuit breaker trips, the motor starter control circuit will also go to its stopped position and will typically require manual action to re-start the motor. Some wye-delta motor starters use a selector switch or other hand switch control schemes in lieu of the simple start/stop push button scheme shown in this course, but the logic for the rest of the starter control circuit would still work the same way.

There are different ways to design the logic for a wye-delta motor starter, some of which might seem more efficient or elegant. It could be argued that rung 21 in Figure 27 could actually start at terminal 3 on rung 19, if the one TR contact at rung 19 has a sufficient pilot duty rating, instead of using two instantaneous NO contacts of TR. An example of an alternative design for the controls for an open-transition wye-delta motor starter is shown in Figure 28.

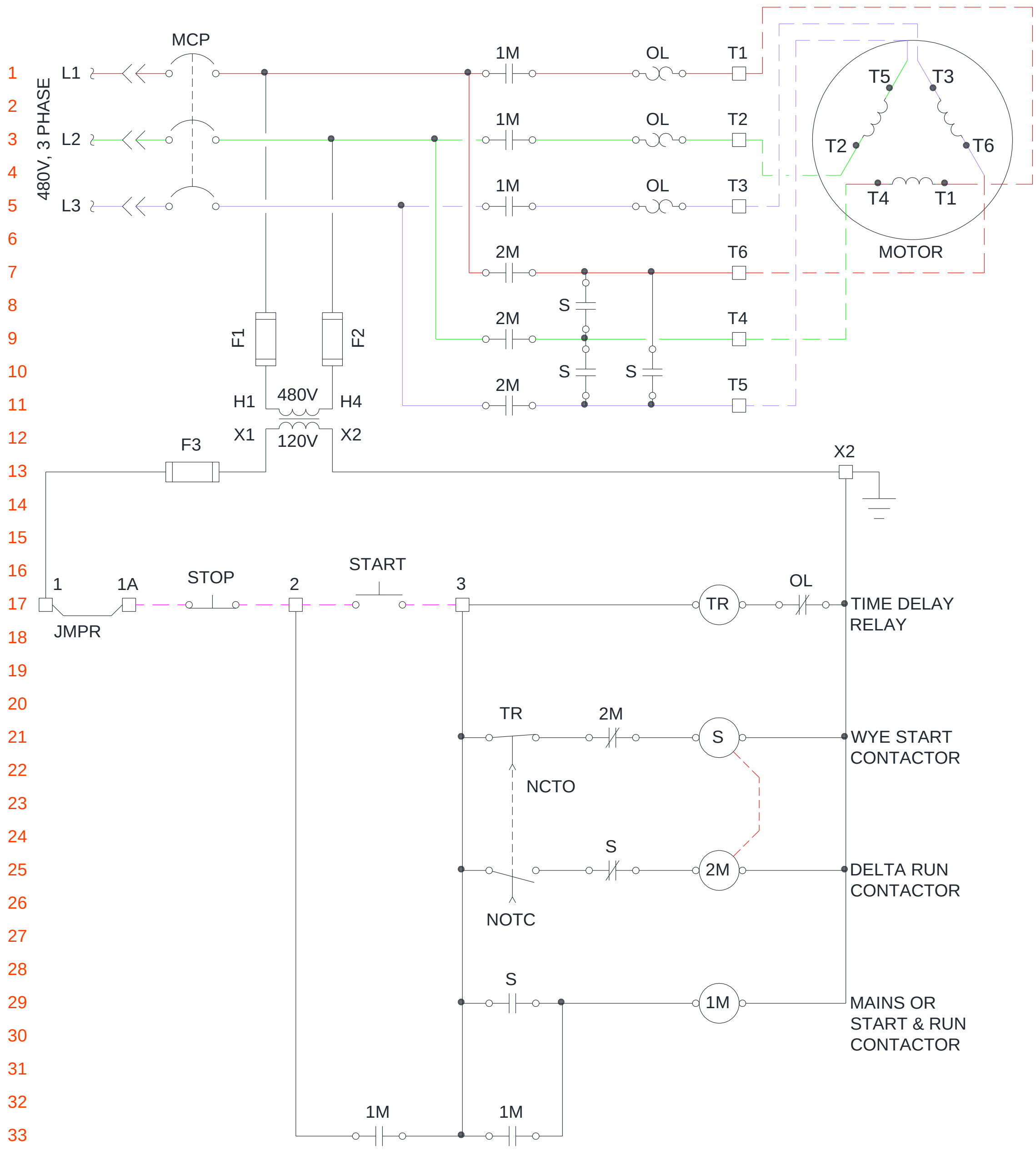


Figure 28 – Different Control Scheme for Open-Transition Wye-Delta Motor Starter

In Figure 28, both an NCTO and an NOTC contact of time delay relay TR are used, but the two instantaneous contact functions of TR at rungs 19 and 21 of Figure 27 on page 31 have been replaced by one NO contact of 1M at rung 33 of Figure 28. The circuits in both figures still operate identically and still follow the sequence in Table 3 on page 29 and Figure 26 on page 30. It is probably obvious that the NCTO and NOTC contacts change state at the same time, since they are opposite or complementary functions of each other. The dashed line between the two contacts indicates a type of mechanical interlock. The circuit in Figure 28 operates as follows:

STOPPED: The initial conditions of the wye-delta motor starter in Figure 28 would call for none of the coils to be energized, as described in Table 3 on page 29 and Figure 26 on page 30.

START IN WYE: When the start push button at rung 17 is pressed, the coil of time delay relay TR at rung 17 is energized (unless the overload contact in that same rung is tripped open), but two other contactor coils need to be energized before the upstream (left-most) NO contact of 1M at rung 33 seals in around the start push button to keep the rest of the control circuit energized until the stop push button is pressed; those two contactor coils are S and 1M.

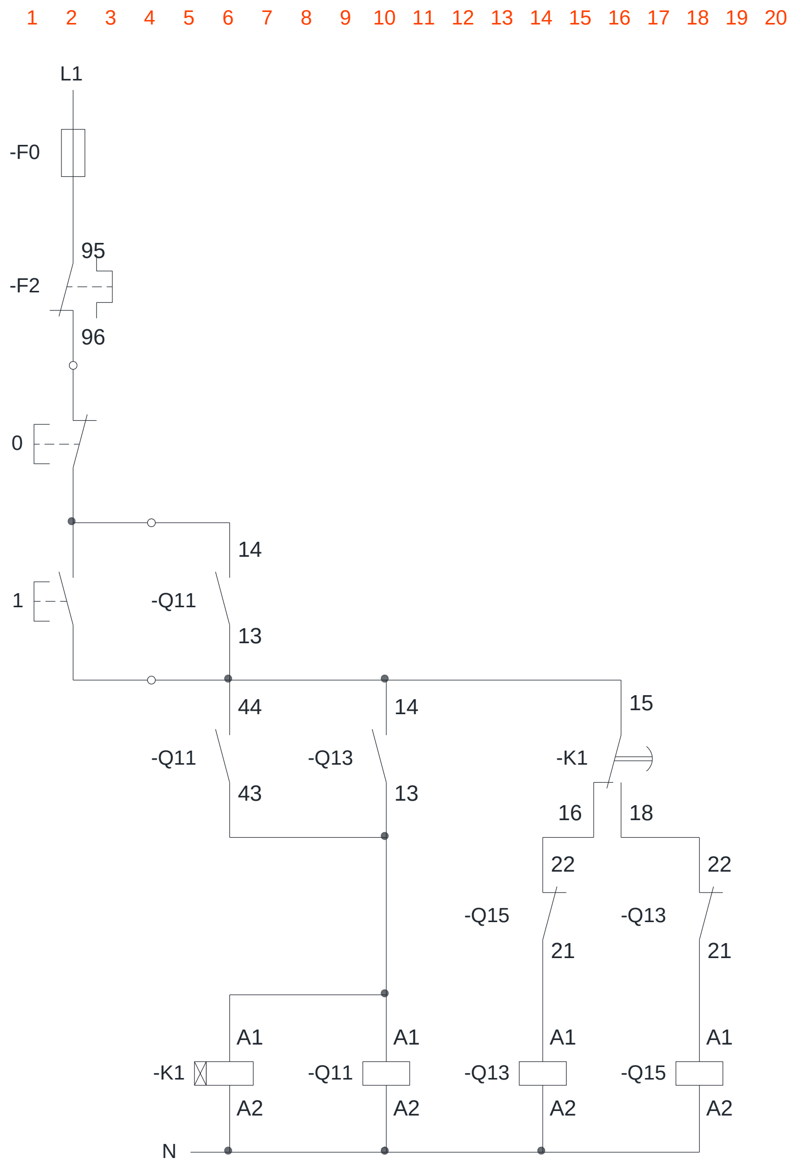
The coil of contactor S at rung 21 is energized through the NCTO contact of TR and the NC contact of 2M when the Start push button at rung 17 closes, which closes the NO contact of S at rung 29 to energize the coil of contactor 1M at rung 29. The first 1M contact at rung 33 seals in around the Start pushbutton contact at rung 17 to keep the rest of the control circuit energized. The second NO contact of 1M at rung 33 keeps the coil of contactor 1M energized after contactor S is de-energized. The power contacts of S at rungs 8 and 10 close to connect T4, T5, and T6 together to make the center of the wye configuration. Power is applied to motor terminals T1, T2, and T3 through the power contacts of 1M at rungs 1, 3, and 5. The motor is now powered in the wye connection.

TRANSITION: The NCTO and NOTC contacts of time delay relay TR change state at the same time, as indicated by the dashed line connecting those two contacts. The NCTO timed contact of TR at rung 21 is normally closed but will open when TR times out, usually around 10 seconds or thereabouts for open-transition wye-delta starters. When time delay relay TR times out, the NCTO contact of TR at rung 21 will open, de-energizing contactor S. This allows the coil of contactor 2M at rung 25 to energize through the now closed NOTC contact of TR and the NC contact of S at rung 25. The power contacts of S now open, momentarily interrupting the current flow to the motor, then the power contacts of contactor 2M apply power to motor leads T4, T5, and T6 at rungs 9, 11 and 7, respectively. Contactor 1M is still energized and power is still applied to motor terminals T1, T2, and T3. Notice that there are no instantaneous contacts of time delay relay TR in this version of an open-transition wye-delta motor starter.

> *NEMA versus IEC Numbering Convention:*
>
> *The output terminals T1, T2, T3, T4, T5, and T6 in the elementary diagrams follow a NEMA-based number convention, but are often numbered U1, V1, W1, U2, V2, and W2, respectively, for IEC-based designs, as illustrated in Figure 30 on page 38.*

RUN IN DELTA: With the power contacts of 1M and 2M closed and the power contacts of S open, the motor is now wired in delta. The motor winding known as T1-T4 is connected to L1 & L2, respectively, motor winding T2-T5 is connected to L2 & L3, respectively, and motor winding T3-T6 is connected to L3 & L1, respectively. The motor will now run like a 'regular' delta motor.

Two NEMA versions of elementary diagrams for an open-transition wye-delta motor starter have been shown thus far. For contrast, a European version of an open-transition wye-delta motor starter elementary diagram is shown in Figure 29 (controls portion), as well as and Figure 30 (power portion) on page 38.



-K1: TIMING RELAY APPROX. 10 SECONDS
-Q11: MAINS CONTACTOR (START & RUN)
-Q13: STAR CONTACTOR (WYE START)
-Q15: DELTA CONTACTOR (DELTA RUN)

Figure 29 – European Version of an Open-Transition Wye-Delta Motor Starter - Controls

If you turn it 90° counterclockwise, the control circuit shown in Figure 29 looks similar to the one shown in Figure 28 on page 34 and the contactors shown in Figure 29 follow the same operational sequence shown in Table 3 on page 29, substituting contactor -Q11 for 1M, contactor

-Q13 for S, and contactor -Q15 for 2M and substituting time delay relay -K1 for TR as shown at the bottom of that table. One of the main differences in the European version compared to the NEMA version of the control circuit is that the thermal overload contact is near the “hot” rail in the European version, instead of being adjacent to the neutral rail, after the time delay relay coil. The fuse designated as –F0 in Figure 29 is the same function as fuse F3 in Figure 27 on page 31 and Figure 28 on page 34.

STOPPED: As in the previous control circuits in this course, the initial conditions of Figure 29 call for all of the contactor coils and the time delay relay coil to be de-energized.

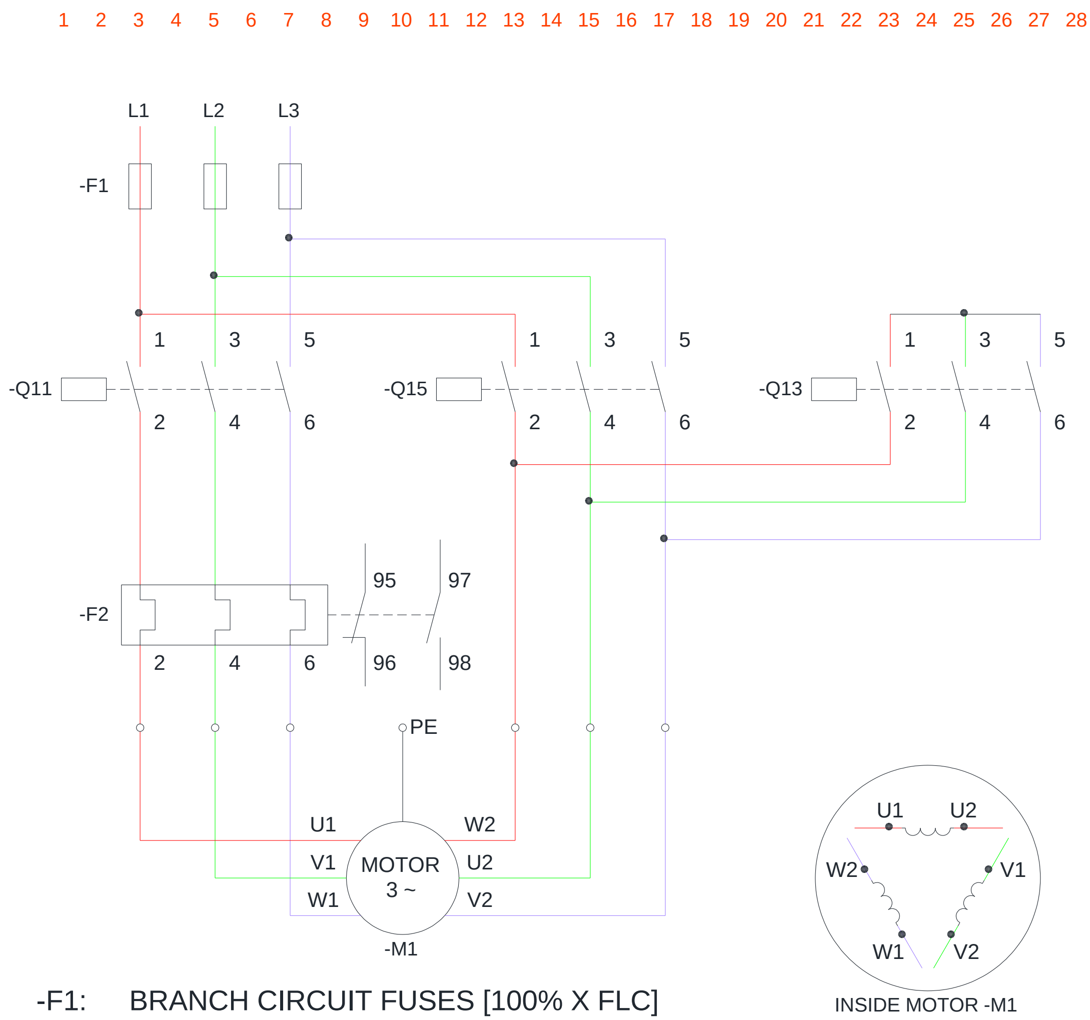
START IN WYE: When the “1” push button at rung 2 is pressed to start the motor, the coil of contactor –Q13 at rung 14 is energized through the NCTO terminals 15-16 of the –K1 timed contacts at rung 15 and the NC contact of -Q15 at rung 14. As a result, the NO contact of –Q13 at rung 10 closes to energize the coil of contactor –Q11 at rung 10 and the coil of time delay relay –K1 at rung 6. The lower-most NO contact of –Q11 at rung 6 closes to provide a seal-in for the coil of –Q11 for when –Q13 de-energizes later; the other (upper) NO contact of –Q11 at rung 6 seals in around the “1” push button. With the power contacts of contactor –Q11 and contactor –Q13 closed, the motor is wired in a wye configuration, with motor terminals U2, V2, and W2 shorted together and power applied to motor terminals U1, V1, and W1, as seen in Figure 30 below.

TRANSITION: The timed contacts of –K1 at rungs 15 and 16 don’t change state until after the time delay of –K1 times out, at which point the bottom part of the –K1 contact symbol moves from terminal 16 to terminal 18, thus de-energizing the coil of contactor –Q13 and energizing the coil of contactor –Q15. There is an electrical interlock between the coil of –Q13 and the coil of –Q15, in the form of NC contacts of the other contactor, that prevent the coils of –Q13 and –Q15 from being energized at the same time.

RUN IN DELTA: With the coil of contactor –Q13 de-energized and its power contacts open and with the power contacts of contactors –Q11 and –Q15 closed, the motor is wired in a delta configuration, with L1 voltage applied to motor terminals U1 and W2, L2 voltage applied to motor terminals V1 and U2, and L3 voltage applied to motor terminals W1 and V2.

Control Circuit Power Source:

The examples of NEMA wye-delta motor starters in this course show the 120 VAC control circuit power as being derived from the 480 V, three-phase motor power source using a control power transformer. This is usually more desirable than providing a separate, external 120 VAC control power source because, if the 480 V power source fails but the 120 VAC power source does not, the control circuit will still be energized and latched when the 480 V power source returns, which might cause the motor to be started in delta. This undesirable scenario can be avoided by deriving the control circuit power from the 480 V, three-phase motor power source. That way, if the 480 V power fails, the control circuit power will also fail and put the controls back into the initial condition in which none of the coils are energized and manual action is required to start the motor.



-F1: BRANCH CIRCUIT FUSES [100% X FLC]
-F2: THERMAL OVERLOAD [58% X FLC]
-Q11: MAINS CONTACTOR (START & RUN) [58% X FLC]
-Q13: STAR CONTACTOR (WYE START) [33% X FLC]
-Q15: DELTA CONTACTOR (DELTA RUN) [58% X FLC]

Figure 30 – European Version of an Open-Transition Wye-Delta Motor Starter - Power

The –F2 component in Figure 30 is the motor thermal overload unit, which has a contact between terminals 95 and 96 that is used in rung 2 in Figure 29 on page 36.

Figure 27 on page 31, Figure 28 on page 34, and Figure 30 above show power connections for a 480 V, three-phase, six-lead wye-start, delta-run motor, but how would one wire a twelve-lead motor at 480 V to a NEMA wye-delta motor starter? The answer is shown in Figure 31.

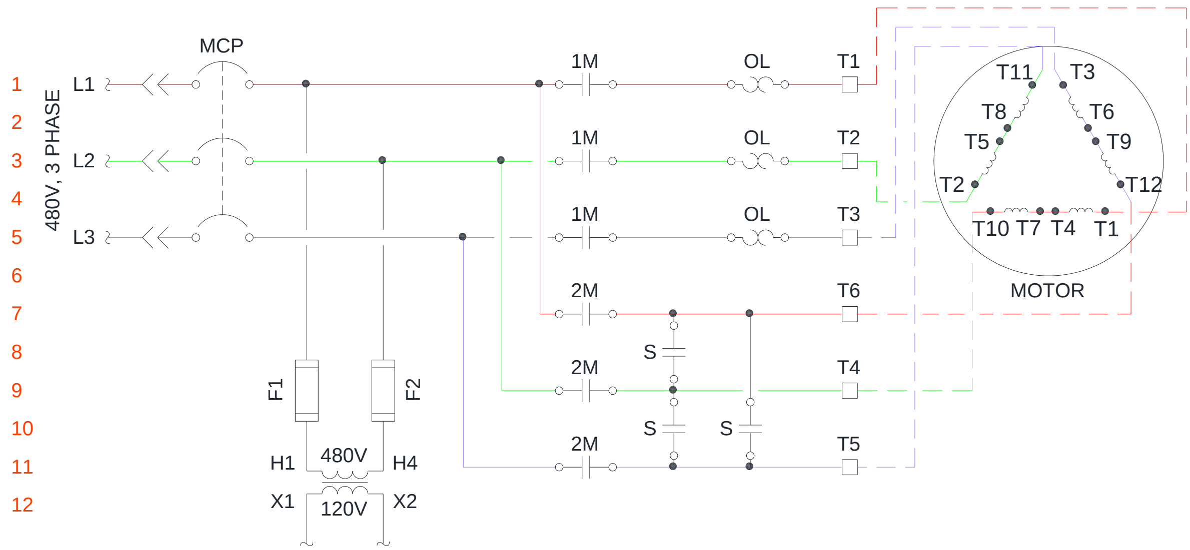


Figure 31 – Wye-Delta Starter Connection to Twelve-Lead Motor at 480V, Three-Phase

Figure 31 shows how to wire a twelve-lead motor at 480 V, three-phase. The three jumpers or splices between T4-T7, between T5-T8, and between T6-T9 would be installed within the motor termination box on the motor in order to use the motor at the higher voltage of 480 V. How would we wire the same motor at 240 V? This is shown in Figure 32.

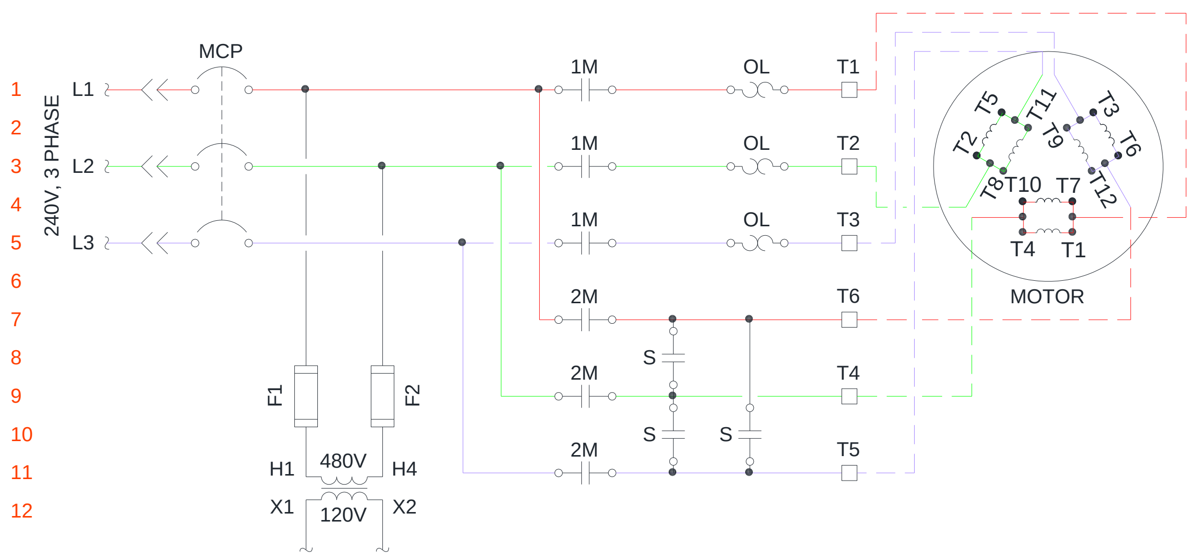


Figure 32 – Wye-Delta Starter Connection to Twelve-Lead Motor at 240V, Three-Phase

Notice in Figure 32 that the three-phase voltage is 240 V at rungs 1, 3, and 5, not 480 V as shown in other such figures in this course. The six jumpers or splices between T1-T7, T4-T10, T2-T8, T5-T11, T3-T9, and T6-T12 would be installed within the motor termination box at the motor in order to use the motor at the lower voltage of 240 V.

Notice, also, in Figure 31 and Figure 32 that a twelve-lead, three-phase, wye-start, delta-run motor only needs six power conductors coming from the open-transition wye-delta starter, whether connected at the higher voltage or the lower voltage. The twelve-lead motor wiring examples in those two figures also apply for closed-transition NEMA wye-delta motor starters.

Closed-Transition Wye-Delta Motor Starters

There is little difference in the operation of open-transition and closed-transition wye-delta motor starters. As mentioned earlier, two types of additional components are required to change an open-transition wye-delta motor starter to a closed-transition type: one three-pole contactor (2S) and three power resistors, as shown in Figure 34 on page 42. The S contactor in Table 3 on page 29 is re-named as contactor 1S in Table 4. Contactor 2S is the additional contactor for the power resistors. Table 4 is based on Figure 2-3-6 in NEMA publication *ICS 2*.

NEMA Starter	1S (Wye Start)	2S (Closed Transition)	1M (Mains or Start & Run)	2M (Delta Run)	TR (Time Delay Relay)
STOPPED	OFF	OFF	OFF	OFF	NOT ENERGIZED
START IN WYE	ON	OFF	ON	OFF	ENERGIZED
TRANSITION 1	ON	ON	ON	OFF	ENERGIZED
TRANSITION 2	OFF	ON	ON	OFF	ENERGIZED
TRANSITION 3	OFF	ON	ON	ON	ENERGIZED
RUN IN DELTA	OFF	OFF	ON	ON	ENERGIZED

Table 4 – Closed-Transition Wye-Delta Starter Contactors and Time Delay Relay Sequence

See Figure 25(b) on page 29. A closed-transition wye-delta starter will not have a downward current spike when the wye configuration begins to change to the delta configuration because current will continue to flow momentarily through the power resistors as terminals T4, T5, and T6 disconnect from each other and begin to connect to L2, L3, and L1, respectively, as shown at rungs 11, 13, and 9, respectively, in Figure 34 on page 42. The power resistors are sized to match the motor winding impedance such that current flow will be maintained until the 2M contactor picks up.

Time Delay Relays TR and –K1:

Time delay relays TR and –K1 shown in the elementary diagrams in this course are the on-delay type, which means when their coils are energized, nothing happens to their timed contacts until the time delay times out. Their instantaneous NO and NC contacts, if present, close or open, respectively, immediately when their coil is energized and open or close immediately when their coil is de-energized.

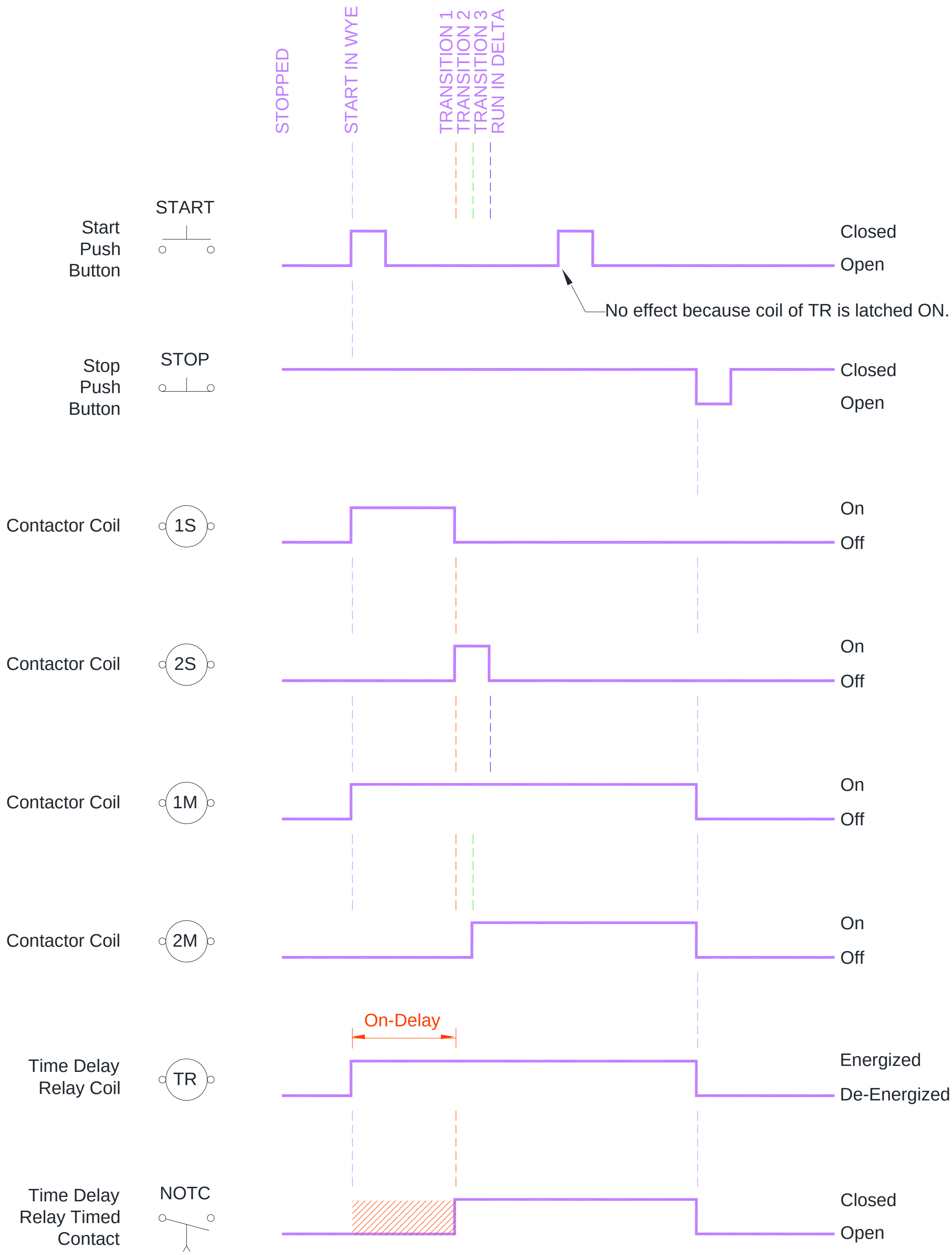


Figure 33 – Closed-Transition Wye-Delta Starter Sequence Chart

The time between the red and blue dashed, vertical lines on either side of Transition 2 in Figure 33 is exaggerated to illustrate the short duration in which contactor 2S is energized. That duration is the length of time it takes between de-energizing the coil of contactor 1S with the NC contact of 2S and energizing the coil of contactor 2M, plus the time it takes the NC auxiliary contact of 2M to de-energize the coil of contactor 2S. Notice that there is an overlap during which contactor 2S and contactor 2M are energized simultaneously in order to have a seamless or closed transition from wye start to delta run.

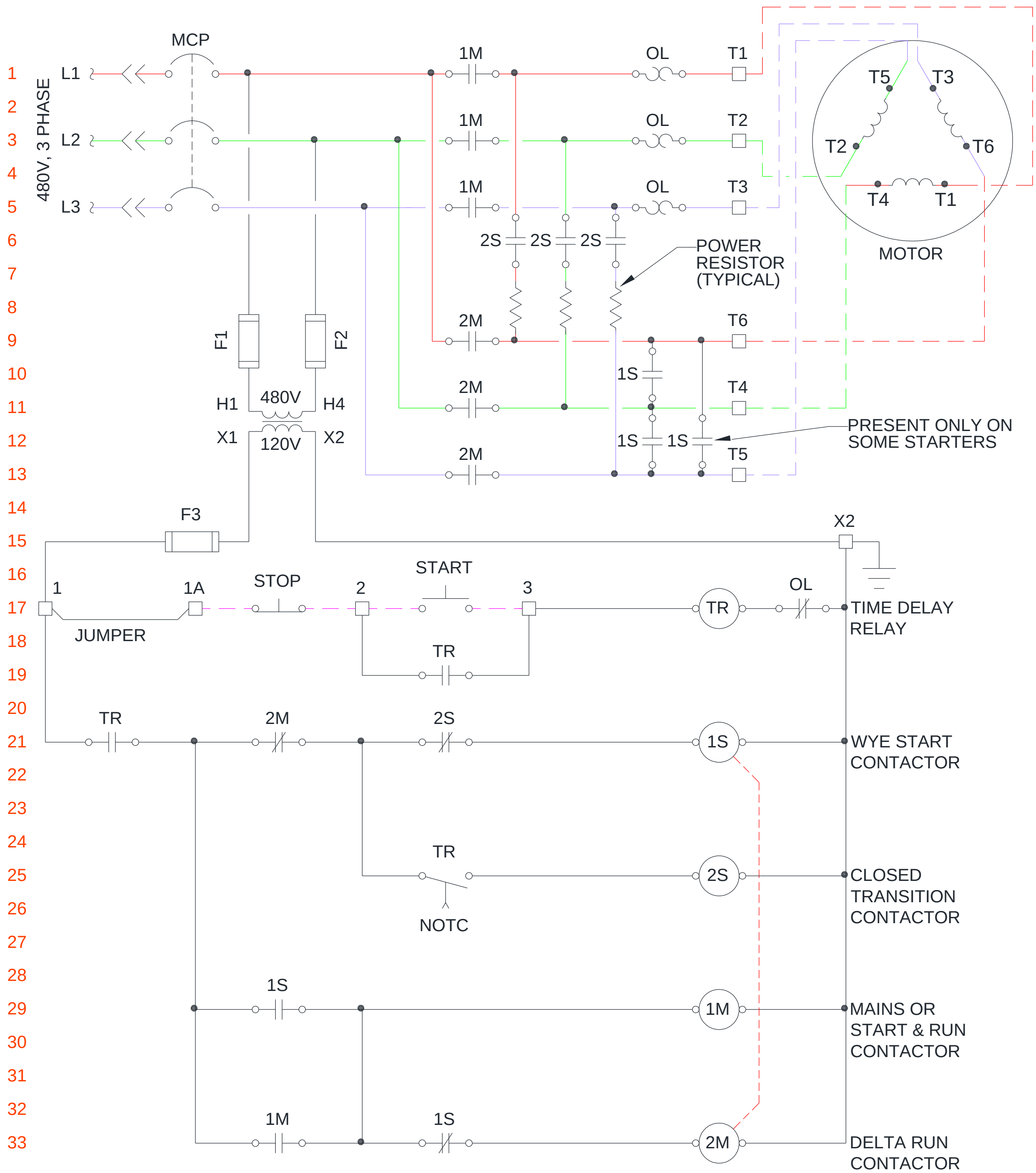


Figure 34 – Closed-Transition Wye-Delta Motor Starter Elementary Diagram

STOPPED: The initial conditions of the wye-delta motor starter in Figure 34 would call for none of the coils to be energized, as described in Table 4 on page 40.

START IN WYE: When the start push button at rung 17 is pressed, the coil of time delay relay TR at rung 17 is energized (unless the overload contact in that same rung is tripped open) and an instantaneous contact of TR at rung 19 seals in around the start push button to keep the coil of TR energized until the stop push button is pressed.

The other instantaneous contact of TR closes at rung 21 to enable the rest of the control circuit. The only timed contact of TR, the NOTC contact at rung 25, is normally open but will close when TR times out, usually around 15 seconds or thereabouts for a closed-transition wye-delta motor starter. Contactor 1S is energized when the instantaneous TR contact at rung 21 closes, which also closes the NO contact of 1S at rung 29 to energize the coil of contactor 1M at rung 29. The power contacts of 1S at rungs 10 and 12 close to connect T4, T5, and T6 together to make the center of the wye configuration. The NC contact of 1S at rung 33 prevents contactor 2M from energizing until TR times out. Power is applied to motor terminals T1, T2, and T3 through the power contacts of 1M at rungs 1, 3, and 5. The 1M contact at rung 33 seals in around the 1S contact at rung 29 to keep the coil of contactor 1M energized after contactor 1S is de-energized. The motor is now in the wye configuration, so it is pulling 1/3 of its normal full-load current (FLC) value.

TRANSITION1: When time delay relay TR times out, the NOTC contact of TR at rung 25 will close, energizing contactor 2S.

TRANSITION 2: When the coil of 2S is energized, its NC contact at rung 21 opens and drops out the coil of contactor 1S while the power contacts of contactor 2S insert the power resistors from L1 to T6, L2 to T4, and L3 to T5 in preparation for the delta connection by contactor 2M, which happens almost instantaneously, usually within a few 60 Hz cycles. As soon as the coil of contactor 1S is de-energized, the NC contact of 1S at rung 33 energizes the coil of contactor 2M.

TRANSITION 3: When the coil of contactor 2M is energized, the NC contact of 2M at rung 21 de-energizes the coil of contactor 2S, dropping out the power resistors after closing the power contacts of 2M. There is a moment during which the power contacts of both 2S and 2M are closed simultaneously in order to prevent an interruption to the current flow to the motor during the transition from wye to delta. The power contacts of contactor 2M apply power to motor leads T4, T5, and T6. Contactor 1M is still energized and power is still applied to motor terminals T1, T2, and T3. Some closed-transition wye-delta motor starters also have a timed contact that will trip and lock out the control circuit if the duty cycle of the power resistors is exceeded.

RUN IN DELTA: With the power contacts of 1M and 2M closed and the power contacts of 1S and 2S open, the motor is now wired in delta. The motor winding known as T1-T4 is connected to L1 & L2, respectively, motor winding T2-T5 is connected to L2 & L3, respectively, and motor winding T3-T6 is connected to L3 & L1, respectively. The motor will now run like a 'regular' delta motor from the perspective of the power source, pulling the expected full load current.

Similar to Figure 27 on page 31 and Figure 28 on page 34, the coils of 1S at rung 21 and 2M at rung 33 in Figure 34 are kept from being energized at the same time by two methods: an electrical interlock and a mechanical interlock. The electrical interlock is composed of the NC contact of 2M ahead of the 1S coil at rung 21 and the NC contact of 1S ahead of the 2M coil at rung 33. The mechanical interlock is indicated by the dashed line connecting the 1S coil to the 2M coil.

Reversing Open-Transition Wye-Delta Motor Starters

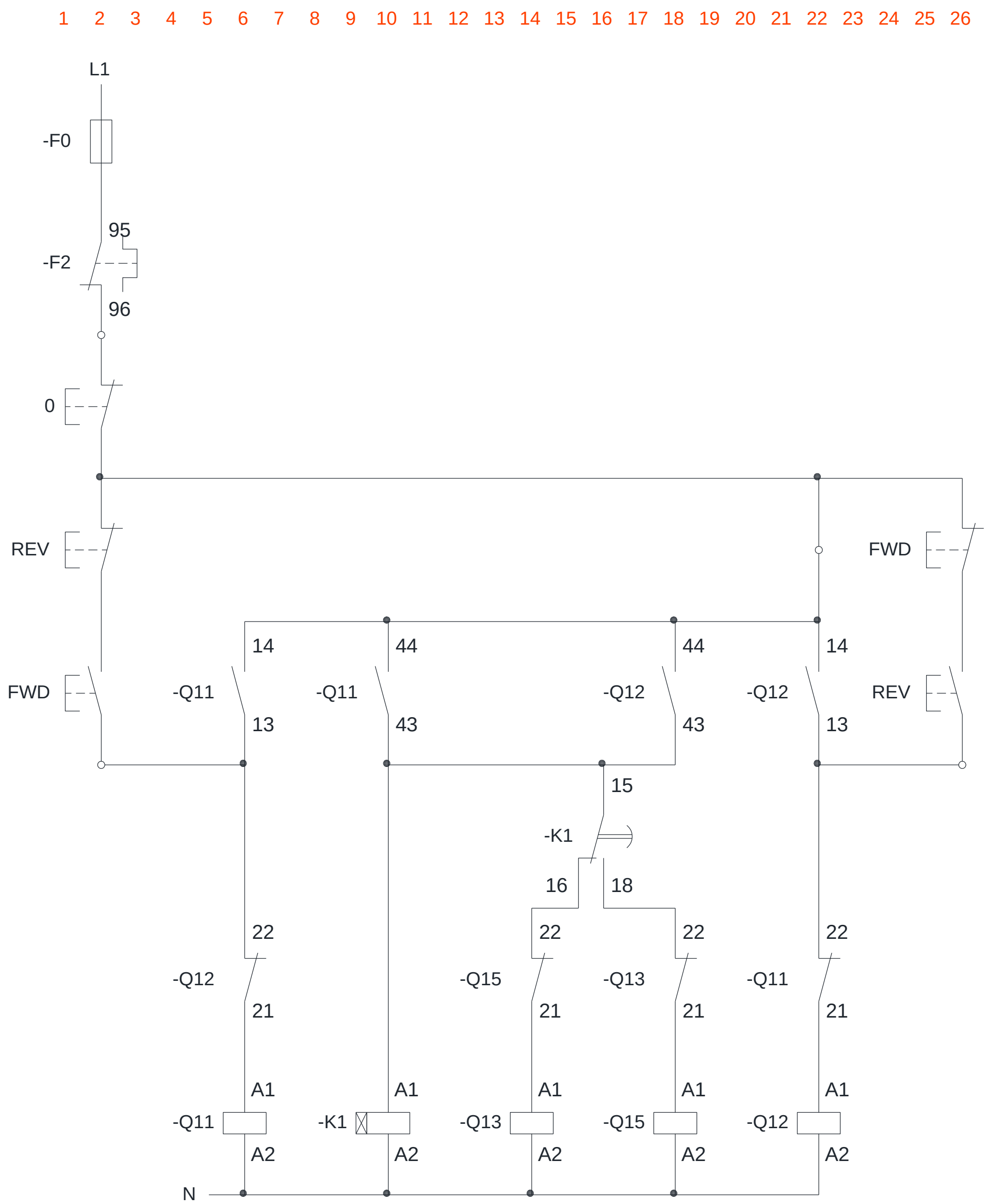
Another, albeit less common, application for wye-delta motor starters is one in which the motor can be started and run in either direction. Two examples will be presented in this section: one in which the 0 (Stop) push button must be pressed in order to change the direction of the motor and one in which the 0 push button does not have to be pressed in order to change the motor's direction. Let's begin by looking at the elementary diagram for the control for the former type, as shown in upcoming Figure 35.

The control circuit in Figure 35 is similar to the one shown in Figure 29 on page 36, except that Forward (FWD) and Reverse (REV) push buttons have been added in place of the 1 (Start) push button. Both the FWD and REV push buttons have an NO and an NC contact. Also, reversing contactor –Q12 has been added. The control circuit for a reversing wye-delta motor starter behaves in a similar way to a non-reversing wye-delta motor starter, with a few differences.

STOPPED: As in the other control circuits, the initial conditions of Figure 35 call for all of the contactor coils and the time delay relay coil to be de-energized. Let's assume that we want forward rotation, but reverse rotation will operate in the same manner, except that the REV contactor –Q12 at rung 22 will take the place of the FWD contactor –Q11 in the description of the logic.

START IN WYE: When the "FWD" push button at rung 2 is pressed to start the motor, the coil of FWD contactor –Q11 at rung 6 is energized and the NO contact of –Q11 at rung 6 closes to seal in around the FWD and REV push buttons, keeping the –Q11 coil energized until the 0 push button is pressed to stop the motor. The NO contact of –Q11 at rung 10 works alternately with the NO contact of –Q12 at rung 18 to energize the rest of the control circuit whether the motor is called upon to turn in the forward direction (–Q11) or the reverse direction (–Q12). When either of those contacts closes, the coil of time delay relay –K1 is energized. As we have seen before, this timer controls how long the motor is kept in the wye start configuration. When the time delay relay is first energized, the 15-16 contact of –K1 at rung 15 is closed, which energizes the coil of contactor –Q13 through the NC contact of –Q15. With the power contacts of the two contactors –Q11 and –Q13 closed, the motor is wired in a wye configuration, with motor terminals U2, V2, and W2 shorted together and power applied to motor terminals U1, V1, and W1, as seen in Figure 37 on page 48.

TRANSITION: The timed contacts of –K1 at rungs 15 and 16 don't change state until after the time delay of –K1 times out, at which point the bottom part of the –K1 contact symbol moves from terminal 16 to terminal 18, thus de-energizing the coil of contactor –Q13 and energizing contactor –Q15. There is an electrical interlock between the coil of –Q13 and the coil of –Q15, in the form of NC contacts of the other contactor, that prevents the coils of –Q13 and –Q15 from being energized at the same time. There is a similar interlock shown ahead of the coils of contactors –Q11 and –Q12. Sometimes, there is also a mechanical interlock between contactors –Q13 and –Q15.



-K1: TIMING RELAY APPROX. 10 SECONDS
-Q11: FWD MAINS CONTACTOR (START & RUN)
-Q12: REV MAINS CONTACTOR (START & RUN)
-Q13: STAR CONTACTOR (WYE START)
-Q15: DELTA CONTACTOR (DELTA RUN)

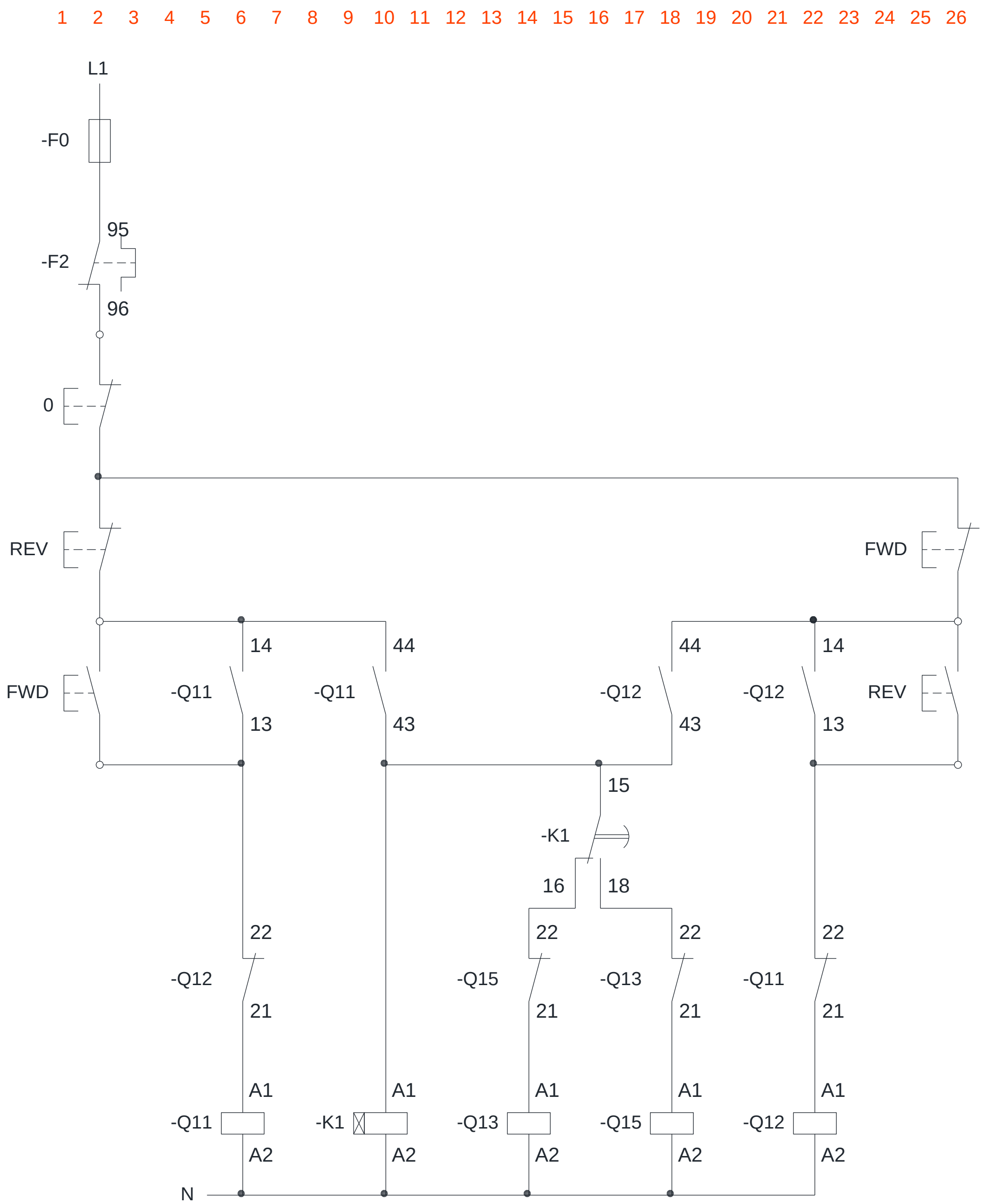
Figure 35 – Reversing Open-Transition Wye-Delta Motor Starter Elementary Diagram – Control Version 1

RUN IN DELTA: With the coil of contactor –Q13 de-energized and its power contacts open, and with the power contacts of contactors –Q11 and –Q15 closed, the motor is now wired in a forward-direction delta configuration, with L1 voltage applied to motor terminals U1 and W2, L2 voltage applied to motor terminals V1 and U2, and L3 voltage applied to motor terminals W1 and V2, as shown in Figure 37 on page 48.

For rotation in the reverse direction, the main difference to note on Figure 37 is that the power contacts of –Q12 swap phase L1 with phase L3 for bringing power to the motor. In other words, when the power contacts of –Q12 are closed, phase L1 from the power source goes to W1, not U1, and phase L3 from the power source goes to U1, not W1. The phase L2 connection is not affected or changed. To change the direction of a three-phase motor, all that is required is to swap two of the phases; it doesn't matter which two, but phases L1 and L3 are typically the ones that get swapped in a reversing starter. Contactors –Q11 and –Q12 are interlocked such that they cannot be energized simultaneously.

When the starter is stopped and either the FWD or REV push button in Figure 35 is pressed, it latches the control circuit in that direction until the 0 push button is pressed.

The Control Version 2 circuit shown in Figure 36 is similar to that shown in Figure 35, but the direction of the motor can be changed without pressing the 0 (Stop) push button first in the circuit in Figure 36. This is accomplished by latching around only the NO contacts of the FWD and REV push buttons, thus allowing the NC contacts of the FWD and REV push buttons to unlatch contactor –Q12 (REV) and –Q11 (FWD), respectively, when that push button is pressed.



-K1: TIMING RELAY APPROX. 10 SECONDS
-Q11: FWD MAINS CONTACTOR (START & RUN)
-Q12: REV MAINS CONTACTOR (START & RUN)
-Q13: STAR CONTACTOR (WYE START)
-Q15: DELTA CONTACTOR (DELTA RUN)

Figure 36 – Reversing Open-Transition Wye-Delta Motor Starter Elementary Diagram – Control Version 2

As mentioned previously, the only major difference between Figure 35 and Figure 36 is that the forward or reverse direction can be unlatched in Figure 36 without having to press the 0 push button. In Figure 36, pressing the FWD push button unlatches the reverse direction and pressing the REV push button unlatches the forward direction. Both versions of the reversing wye-delta motor starter control circuit operate almost identically and will allow a wye-start/delta-run motor to start and run in one direction or start and run in the other direction. Let's look at the elementary for the power circuit, which is the same for both versions of the control circuit.

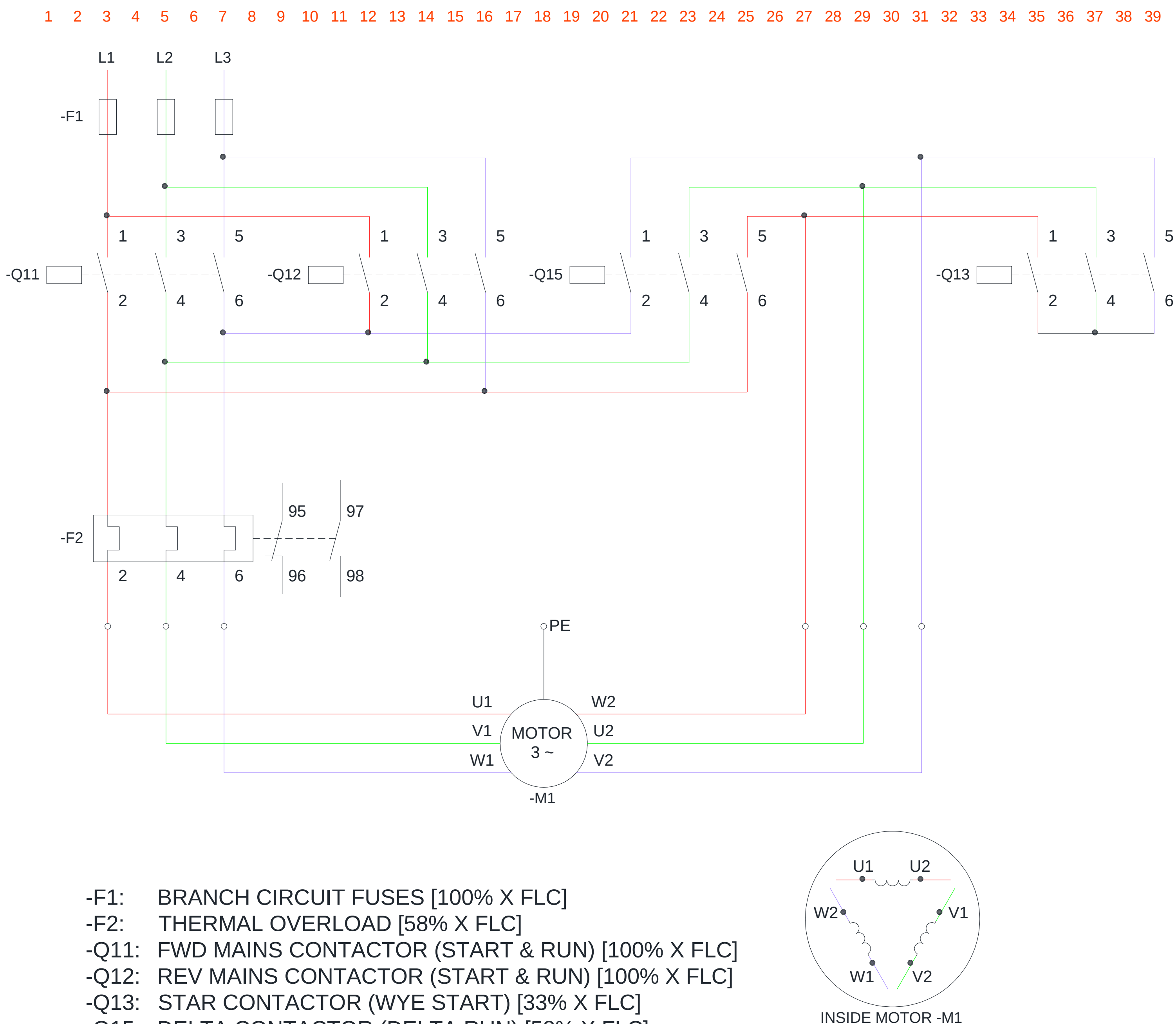


Figure 37 – Reversing Open-Transition Wye-Delta Motor Starter Elementary Diagram – Power

Notice in Figure 37 that the power conductors going to the motor don't change from three conductors to six conductors until the load side of Start & Run contactors –Q11 and –Q12. This means that both the FWD (–Q11) and REV (–Q12) start & run contactors will be required to carry 100% of the full-load current, since the load is not divided into six conductors until after the current goes through the three power poles of the FWD or REV contactor. On the line side of these contactors, the motor load is seen as one three-phase load. On the load side of these contactors, the motor load is seen as three single-phase loads, as will be explained in more detail in the next section.

Since the FWD and REV contactors are required to carry 100% of the full-load current, they must be full-sized, like those of a full-voltage motor starter – they cannot be down-sized like those in a non-reversing wye-delta motor starter, as described on Table 5 on page 55 and the discussion before and after that table.

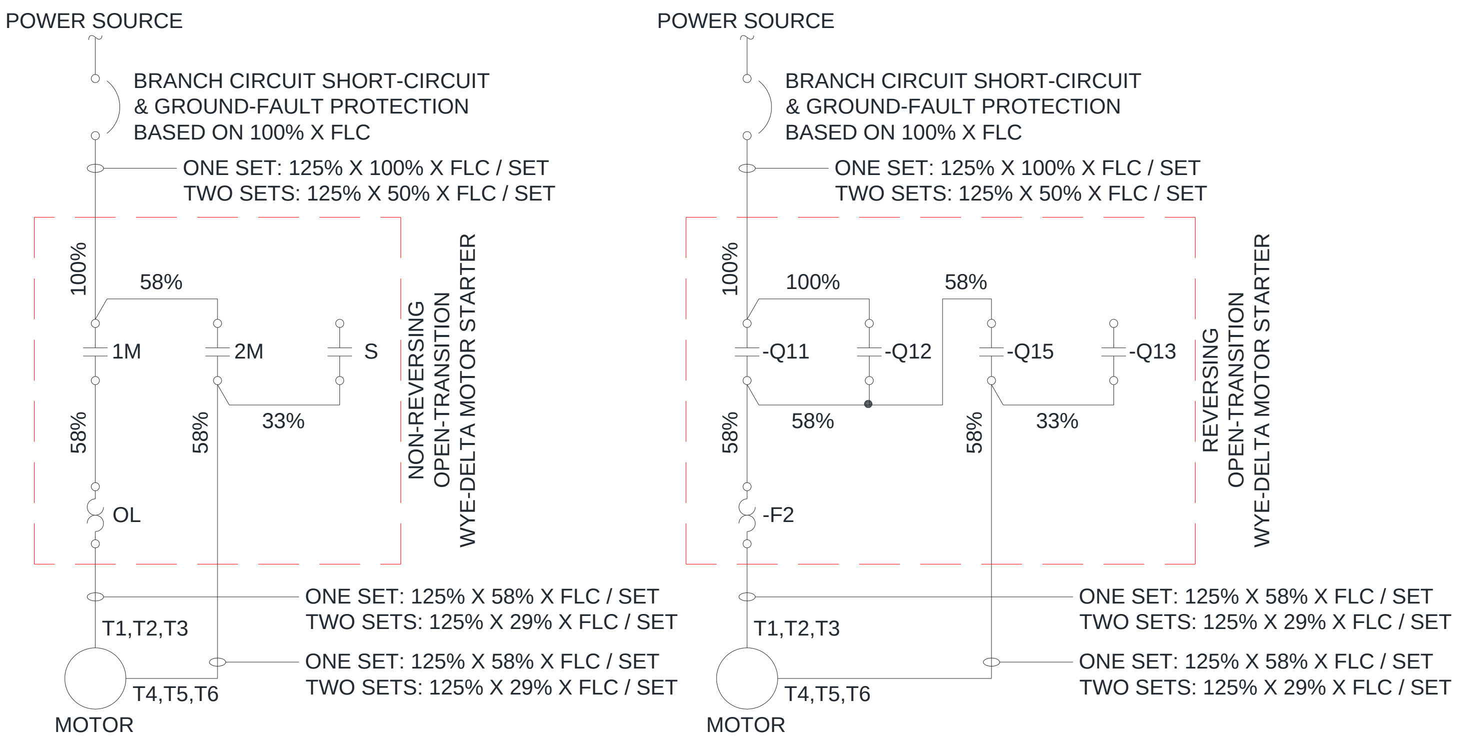
Sizing Power Conductors and Contactors for Wye-Delta Motors

The sizing requirements for the entire power circuit, from the branch-circuit protective device (fuses or circuit breaker) to the motor, will be presented in this section, but we will start with the motor and work backwards to the power source. Figure 38 shows an overview of the entire power circuit for non-reversing and reversing open-transition wye-delta motor starters. The branch-circuit short-circuit & ground fault protection device is typically a circuit breaker or set of three fuses. In the case of motor control centers or combination starters, this fuse or circuit breaker is mounted in the same bucket, compartment, cubicle, or enclosure as the wye-delta motor starter.

Phases L1, L2, and L3 versus phases A, B, and C:

Most electrical diagrams and electrical equipment line terminals use the designations L1, L2, and L3 instead of Phase A, Phase B, and Phase C because not every utility or facility uses A, B, and C as phase designations. Some utilities or facilities might use 1, 2, 3 or X, Y, Z or some other method to label their three-phase power source. The L1, L2, and L3 labeling requirements can be found in Table 2-7-1 of NEMA Publication ICS 2.

The reason that some of the conductor, contactor, and thermal overload sizes are different for wye-delta motor starters compared to full-voltage motor starters is because the three windings of a wye-start/delta-run motor are actually three single-phase loads. These three single-phase loads aren't perceived as a single three-phase load until the point where motor terminal T1 connects to T6, T2 connects to T4, and T3 connects to T5. As can be seen in Figure 38, this happens on the line side of contactor 1M for a non-reversing wye-delta motor starter, but on the load side of contactors –Q11 and –Q12 for reversing wye-delta motor starters. See Table 2 on page 8 for the IEC equivalents of the NEMA motor terminal designations T1 through T6.



Non-Reversing Open-Transition
(a)

Reversing Open-Transition
(b)

Figure 38 – Sizing Components for Open-Transition Wye-Delta Starters

In Figure 38, it might be incorrectly inferred that the branch-circuit short-circuit and ground-fault protection device should be selected to be equal to 100% of the motor's full-load current, but that is not the case. The size of this circuit breaker or set of fuses will vary, depending on the type of device that is chosen, but should be selected from the circuit breaker or fuse manufacturer's catalog based on 100% of the motor's FLC, limited to the maximum rating permitted by NEC Table 430.52. For example, a 200 Hp motor at 480 V has a full-load current of 240 A. A typical Class J time-delay fuse selection for this motor would be rated at 350 A. This is within the upper limit of 240 A * 175% = 420 A that is required by NEC Table 430.52.

In previous examples, such as those shown in Figure 13 on page 17 and Figure 16 on page 20, we have said that the full-load current flowing to a wye-start/delta-run motor starter for a motor connected in the delta configuration is equal to the full-load current shown in Table 430.250 of the NEC. For example, a 200 Hp wye-delta motor would have 240 A flowing to the starter when wired in the delta configuration at 480 V, three-phase. Let's now discuss the fact that there are six power conductors, not three, going to the wye-delta motor downstream from this starter. It might seem that the 240 A full-load current would be divided equally across the two conductors per phase to give us 120 A in each of the conductors going to the motor from each of the three phases of the power supply, but it is a little more complicated than that. The 240 A per phase is actually composed of two 138.5 A current vectors that are 120° out of phase with each other, as illustrated in Figure 39 and Figure 40.

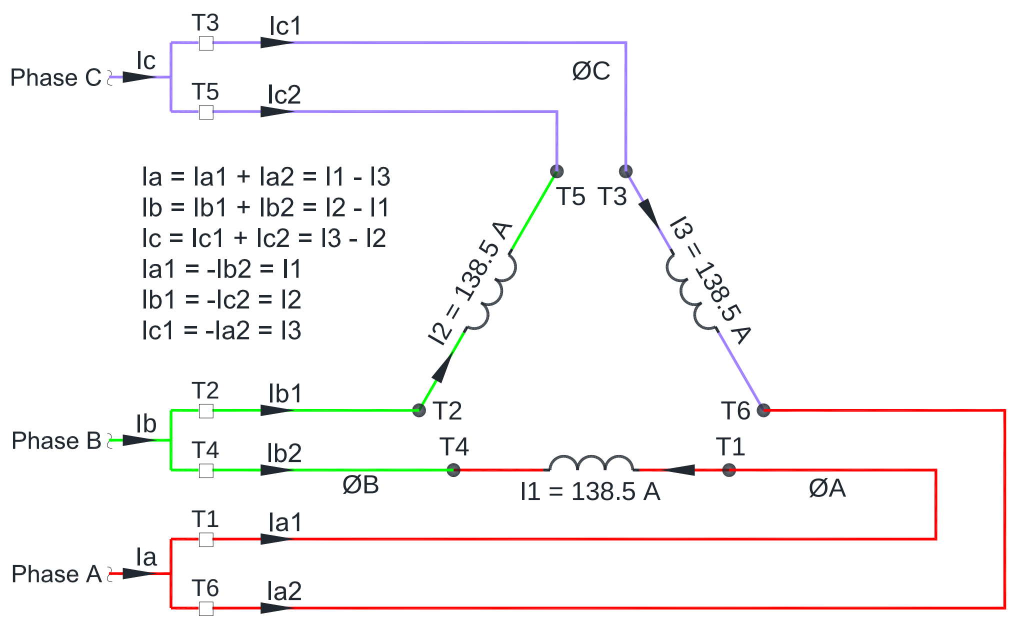


Figure 39 – Line Currents Going to a Delta-Connected Six-Lead or Twelve-Lead Motor at 480V, Three-Phase

In Figure 39, the current vector Ia, which is the current from phase A of the power source, is composed of current vectors Ia1 + Ia2, which can be restated as Ia1 - Ic1 or I1 - I3. The two current vectors per phase are shown in Figure 40 below. This split or change from current vector Ia to the two current vectors Ia1 and Ia2 occurs wherever the two conductors per phase are connected together, which typically happens at the line terminals of the power contacts of contactor 1M for non-reversing wye-delta motor starters, or on the load side of the power contacts of contactors –Q11 and –Q12 for reversing wye-delta motor starters, as shown in Figure 38.

There are intervening components between Phase A and terminals T1 & T6 in Figure 39, such as contactor power contacts, but these components are not shown, for the sake of simplicity. This also applies to the other two phases, of course.

Full-Voltage Motor Starter Contactor Ratings:

The full-voltage contactor ratings and sizes in Table 5 on page 55 and Table 6 on page 57 apply to full-voltage non-reversing (FVNR) and to full-voltage reversing (FVR) motor starters. Even though FVR motor starters have two contactors, only one of them is used at a time, so both of its contactors must be rated at 100% of the full-load current of the motor.

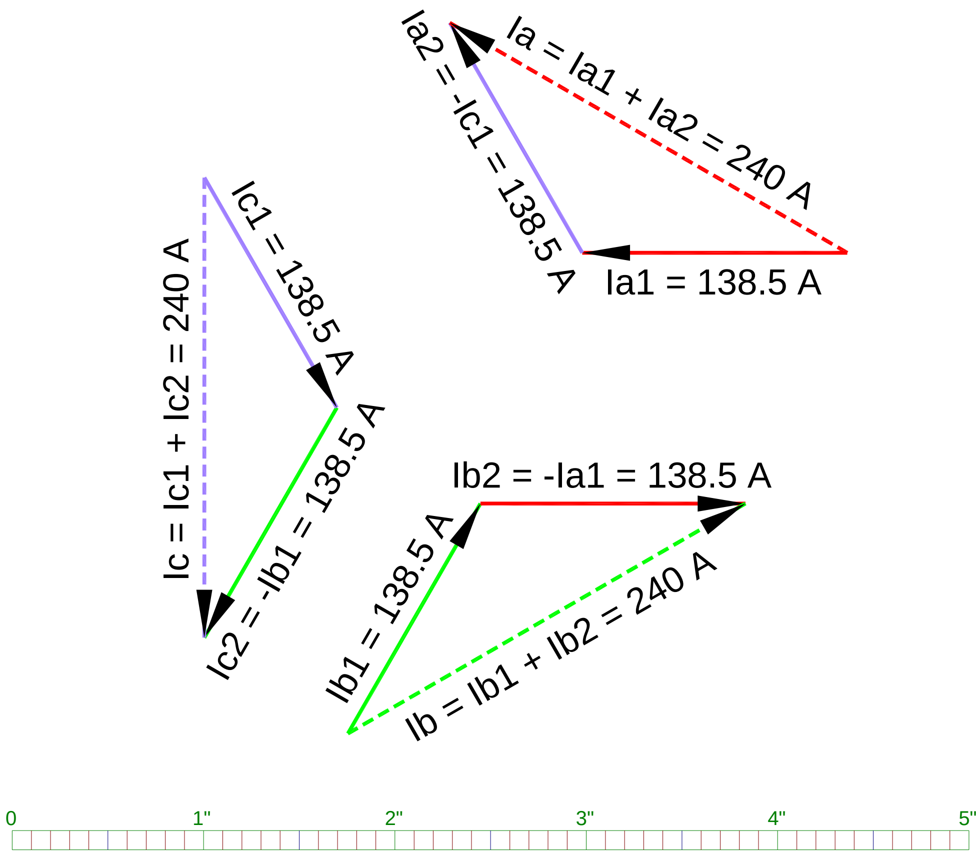


Figure 40 – Line Currents Going to a Delta-Connected Six-Lead or Twelve-Lead Motor at 480V, Three-Phase

Notice that Figure 40 looks very similar to Figure 15 on page 19, but the shorter vectors in Figure 40 are tail-to-head, instead of head-to-head as in Figure 15, since the vectors in Figure 40 are being added together, rather than subtracted. The vectors in both figures are the same, they are just relabeled as listed at the left side of Figure 39. For example, Ia1 = I1 and Ia2 = -I3, so Ia is still defined as Ia = I1 - I3.

We have looked at the delta-connected wye-start/delta-run motor as three single-phase loads, so now let's also consider a wye-connected six-lead or twelve-lead motor as three single-phase loads. Figure 41 is the same motor connection that was illustrated earlier in Figure 19 on page 23, except now all six conductors to the motors are shown in the version in Figure 41.

The currents going to a wye-connected motor are easier to understand than the currents going to a delta-connected motor. The current vector Ia, which is the current from phase A of the power source, is composed of only of current vector I1, which is equal to 80 A in our 200 Hp example. There is no vector addition to do.

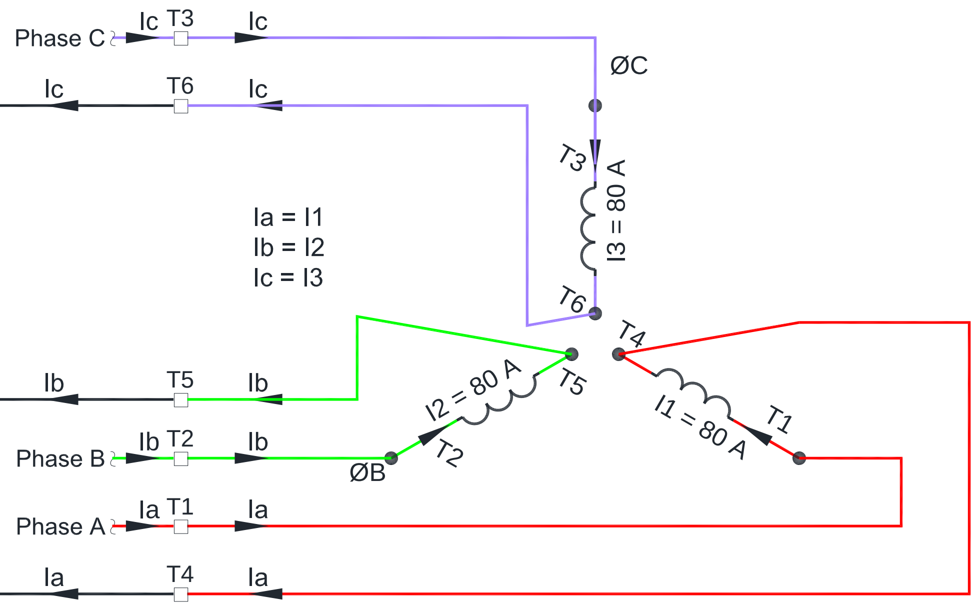


Figure 41 – Line Currents Going to a Wye-Connected Six-Lead or Twelve-Lead Motor at 480V, Three-Phase

The currents in Figure 41 were previously illustrated in Figure 20 on page 23. If the motor in Figure 41 were a twelve-lead 200 Hp motor at 480 V, three-phase, the current would be 80 A in each parallel half-winding and 160 A in each line going to and returning from the motor, just as was shown in Figure 22 on page 25.

Take the three vectors from Figure 20 and arrange them as shown in Figure 42. The three currents Ia, Ib, and Ic that return to the junction point at the extreme left of Figure 41 add up to zero, as shown in Figure 42. In other words, the current at the junction point is equal to Ia + Ib + Ic = 0. Whichever vector you begin with in Figure 42, adding the other two vectors to the first vector merely brings you back to your starting point, with a resulting sum of zero amps.

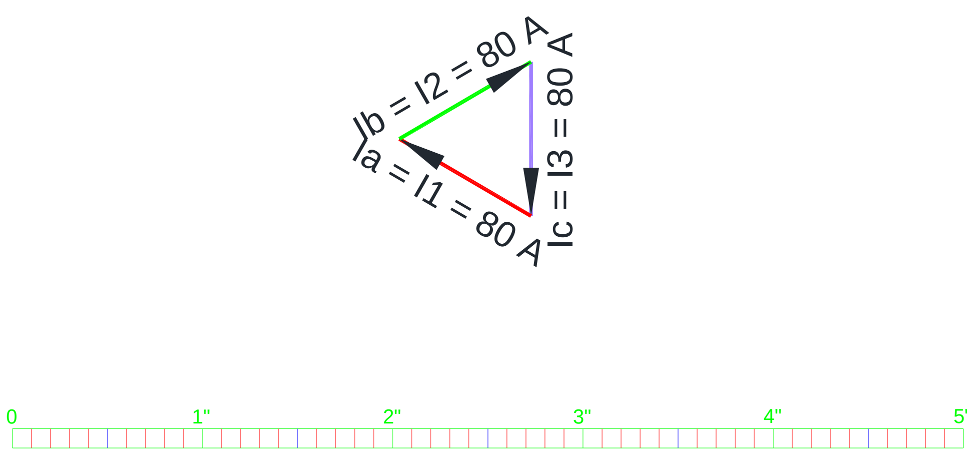


Figure 42 – Line Currents Going to a Wye-Connected Six-Lead or Twelve-Lead Motor at 480V, Three-Phase

Now that we have discussed the concept of a wye-start/delta-run motor as three single-phase loads, let's look at how this affects the sizing requirements of conductors and contactors.

NEC Power Conductor Sizing Requirements – from Starter to Motor

Paragraph 430.22(C) of the NEC gives the requirements for conductor sizing on the line side of the wye-delta starter and also gives different requirements for conductor sizing on the load side of the wye-delta starter, for the reasons discussed in the previous section. Specifically, when the motor is running in the delta configuration, the current in the three wires going from the power source to the line terminals of the wye-delta starter will each carry 100% of the full-load current, but the current in the six wires going from the load terminals of the wye-delta starter to the motor will each carry only $1 / \sqrt{3}$ or 58% of the full-load current. The NEC typically requires the power conductors serving motors to be rated at 125% of the motor's FLC, and NEC 430.22(C) does the same for wye-start/delta-run motors, as well, with the line conductors being sized at 125% of the FLC and the load conductors being sized at 125% * 58% = 72% of the FLC.

How do we run six power conductors from the wye-delta motor starter to the motor? If more than three current-carrying conductors are run in one single raceway or conduit, the ampacities of the conductors must be de-rated according to NEC 310.15(A)(3)(a). To avoid having to de-rate the ampacities of the conductors, we could run more than one raceway to the motor, if the motor termination box is sufficiently large to allow more than one raceway. When running the conductors in multiple raceways from the wye-delta motor starter to the motor, here are some preferred methods of grouping the load conductors:

- <u>Two Raceways</u>: Group T1, T2, & T3 in one raceway and T4, T5, & T6 in the other raceway.
- <u>Three Raceways</u>: Group T1 & T4 in the first raceway, T2 & T5 in the second raceway, and T3 & T6 in the third raceway. Placing only one phase, such as T1 & T4, in a raceway might seem like a violation of NEC 300.20, which requires all phases to be run in the same ferrous (steel) raceway in order to prevent inductive heating of the conduit. This code-required method prevents inductive heating because the balanced currents in the three phases add up to zero, since they are all 120° apart. Similarly, in a wye-start/delta-run motor application, when we place the conductors for T1 & T4 in the same conduit, the currents in the two conductors cancel each other out, since T1 is the current going to the single-phase motor winding load and T4 is the same current returning from the single-phase load. This alleviates inductive heating.
- <u>Four Raceways with Two Parallel Sets of Conductors per Phase</u>: Since wye-delta motor starters are often used for larger motors, there is a good chance that there will be the need for parallel runs of conductors to accommodate the higher amperages. Group one set of T1, T2, & T3 in the first raceway and the other set in the second raceway; group one set of T4, T5, & T6 in the third raceway and the other set in the fourth raceway.

In addition to the phase or power conductors, a full-sized equipment grounding conductor is also required in each of the parallel raceways, according to NEC 250.122(F), but the equipment grounding conductor is not considered to be a current-carrying conductor, according to

NEC 310.15(B)(5), so it is not included in determining the quantity of current-carrying conductors. It does, of course, need to be included in the conduit or cable tray fill calculations. When using parallel runs of multi-conductor cables, it is often difficult to find a multi-conductor cable that has an adequately sized equipment grounding conductor.

Not only are the conductor sizing requirements different for wye-start, delta-run motors, but the ratings of the contactors used in non-reversing wye-delta starters are also different than those for full-voltage starters.

NEMA Contactor Sizing Requirements

NEMA contactor sizes are based on ampacity ratings – the larger the NEMA size number, the higher the ampacity of the contactor. NEMA sizes 00 and 0 typically are not used in most industrial applications and aren't considered in this course write-up.

Contactors of the same NEMA size can have different horsepower ratings, depending on the applied voltage and whether they are being used in full-voltage starters or in non-reversing wye-delta starters. This is because the contactors in full-voltage starters are required to carry the entire full-load current, but the contactors in non-reversing wye-delta starters only carry part of the full-load current, since there are two contactors being utilized simultaneously in a non-reversing wye-delta starter when the motor is running in delta and the three power conductors from the power source change to six conductors ahead of the contactors. Table 5 below lists the three-phase ratings of NEMA contactors in full-voltage and in non-reversing wye-delta motor starters with 480 V, three-phase applied. As was stated previously in the Reversing Open-Transition Wye-Delta Motor Starters section, which began on page 44, the Start & Run contactors –Q11 and –Q12 in reversing wye-delta starters cannot be reduced in size, since they carry 100% of the motor's full-load current.

3Φ Contactor Ratings**				
	Full-Voltage (FVNR & FVR)		Wye-Delta (YD)	
NEMA Size*	Continuous Current	Locked-Rotor Current	Continuous Current	Locked-Rotor Current
1	27	88	47	152
2	45	210	78	363
3	90	418	156	725
4	135	835	233	1,445
5	270	1,670	467	2,510
6	540	3,340	935	5,020
7	810	5,000	1,400	8,660

* NEMA contactor sizes 00 and 0 are not considered in this table.
** Contactor installed in any type of enclosure.

Table 5 – Comparing Full-Voltage to Wye-Delta Contactor Ratings

Notice for each NEMA size in Table 5 that the continuous current rating in a wye-delta starter is $\sqrt{3}$ times the continuous current rating of that same contactor in a full-voltage starter. This doesn't mean that contactors in wye-delta starters can carry more current than those in full-voltage contactors – the continuous current referred to in Table 5 will be divided into two lower values passing through the two contactors for a non-reversing wye-start/delta-run motor.

In choosing a contactor for a certain motor, the continuous current and the locked-rotor current in Table 5, as well as the motor horsepower and voltage in Table 6 must be considered, but mainly the motor horsepower and voltage. Let's look at a three-lead example.

The full-load or continuous current of a 15 Hp motor at 480 V, three-phase is 21 A in NEC Table 430.250, so it would seem that a size 1 contactor would be acceptable, since it has a continuous current rating of 27 A. However, the locked-rotor current of this same motor is 116 A in NEC Table 430.251(B), so a size 2 contactor would be necessary in order to meet the locked-rotor current requirement. This ratio of FLC to LRC is in the rule-of-thumb range of 1-to-6, as is often mentioned in related technical documents. A wye-start/delta-run 15 Hp motor at 480 V, three-phase, however, can use a wye-delta motor starter with size 1 contactors because 1) the continuous current rating is 27 A; 2) the locked-rotor current rating is 152 A; and 3) the horsepower rating is 15 Hp at 480 V, three-phase in Table 6. The locked-rotor current rating for wye-delta motors is based on $1 / \sqrt{3}$ times the delta-connected three-lead locked-rotor current, not $1 / 3$ times the three-lead delta-connected locked-rotor current that would be present when the motor is starting in the wye configuration. This is because the wye-start/delta-run motor might become locked up when running in the delta configuration, so the contactors have to be rated for that worse-case. Let's look at another wye-start/delta-run motor example.

Consider a 20 Hp wye-start/delta-run motor at 480 V, three-phase, which has 27 A full-load current from NEC Table 430.250 and 145 A locked-rotor current NEC Table 430.251(B). It might seem from Table 5 that a size 1 wye-delta starter would be suitable, since it meets both of those criteria, but Table 6 tells us that a size 2 wye-delta starter would actually be required to meet the horsepower rating.

The Reader can find continuous current values for full-voltage and wye-delta contactors in Table 2-4-1 and Table 2-4-7, respectively, in NEMA publication *ICS 2*. It is important to note that presently there are errors in the continuous current values for wye-delta contactor sizes 4YD, 5YD, 6YD, and 7YD in Table 2-4-7 of that publication. The values presently listed in that table for those contactor sizes are actually for full-voltage contactors in those sizes, as shown on Table 2-4-1 of that publication. It is easy to confirm that Table 2-4-7 is in error by looking at an example, such as a 150 Hp motor at 480 V, 3-phase. Table 430.250 of the NEC has an FLC of 180 A for this motor. Table 2-4-7 of *ICS 2* calls for a 4YD wye-delta starter, but also indicates a continuous current rating of 135 A for this starter, which is obviously less than the FLC value of 180 A.

The wye-delta continuous current rating values shown in Table 5 of this course are also shown in Table 2 of *Bulletin 50006-026-01E Wye-Delta Reduced Voltage Starter Open or Closed Transition Class 8630* (see Additional Reading beginning on page 60), as well as other technical publications concerned with this topic.

Just as for the continuous current ratings, the locked-rotor current ratings of the wye-delta contactors in Table 5 are also √3 times the locked-rotor current rating of that same contactor in a full-voltage starter, for reasons mentioned above. Some exceptions to this are size 5 and size 6, which are slightly lower than that ratio.

A comparison of maximum horsepower ratings for full-voltage starters and wye-delta starters at 480 V, three-phase is shown in Table 6. The contactor minimum sizes shown in this table are not necessarily the sizes the wye-delta motor starter manufacturer will use. Notice in Table 6 that there are two columns for contactor S: one for a 2-pole contactor and one for a 3-pole contactor. This is because a 2-pole S contactor has to be the same size as the 1M and 2M contactors, but a 3-pole S contactor can be one size smaller than the 1M and 2M contactors. This is based on clause 3.5.2.1.b in *ICS 2* for open-transition wye-delta motor starters and clause 3.5.2.2.b for closed-transition. Notice, also, that size 00 and 0 contactors are not shown in Table 6. The wye-delta starters shown in that table are the open-transition type, but the same sizing criteria for those contactors applies to closed-transition wye-delta starters. For closed-transition wye-delta motor starters, there is a separate column in Table 2-4-7 in *ICS 2* for the size of contactor 2S, whose power contacts only have to conduct current for a few cycles, through the power resistors.

480V, 3Φ Motor Starters									
		FVNR	Wye-Delta Non-Reversing						
Hp	FLC**	NEMA Size*	NEMA Size*	Wye Current***	2-Pole S Size*	3-Pole S Size*	Delta Current***	1M Size	2M Size
1	2.1	1	1YD	0.7	1	1	1.2	1	1
2	3.0	1	1YD	1.0	1	1	1.7	1	1
5	7.6	1	1YD	2.5	1	1	4.4	1	1
10	14	1	1YD	4.7	1	1	8.1	1	1
15	21	2	1YD	7.0	1	1	12.1	1	1
20	27	2	2YD	9.0	2	1	15.6	2	2
25	34	2	2YD	11.3	2	1	19.6	2	2
30	40	3	2YD	13.3	2	1	23.1	2	2
40	52	3	2YD	17.3	2	1	30.0	2	2
50	65	3	3YD	21.7	3	2	37.5	3	3
60	77	4	3YD	25.7	3	2	44.5	3	3
75	96	4	3YD	32.0	3	2	55.4	3	3
100	124	4	4YD	41.3	4	3	71.6	4	4
125	156	5	4YD	52.0	4	3	90.1	4	4
150	180	5	4YD	60.0	4	3	103.9	4	4
200	240	5	5YD	80.0	5	4	138.6	5	5
250	302	6	5YD	100.7	5	4	174.4	5	5
300	361	6	5YD	120.3	5	4	208.4	5	5
350	414	6	6YD	138.0	6	5	239.0	6	6
400	477	6	6YD	159.0	6	5	275.4	6	6

* NEMA contactor sizes 00 and 0 are not considered in this table.
** Motor's full-load current as seen from power source, flowing in three conductors from the power source to the motor starter.
*** In each power conductor from the motor starter to the motor. There are six power conductors for wye-delta, compared to three conductors for FVNR.

Table 6 –Full-Voltage and Wye-Delta Motor Starter Contactor Sizes

A 3-pole S contactor only has to carry 1 / 3 or 33% of the motor's full-load current while the 3-pole 1M and 2M contactors carry 1 / √3 or 58% of the full-load current, so it seems reasonable that a 3-pole S contactor can be one NEMA size smaller than the 1M and 2M contactors. A 2-pole S contactor, on the other hand, is being asked to break the same amount of current as a 3-pole S contactor, so a 2-pole S contactor is required by *ICS 2* to be the same size as the 1M and 2M contactors.

NEC Power Conductor Sizing Requirements – from Power Source to Starter

See NEC 430.22(C) for conductor sizing from the power source to the starter. When the wye-start/delta-run motor is running in the delta configuration, the current in the power conductors from the branch fuses or circuit breaker to the starter is the same three-phase current that would be going to a 'normal' three-phase motor. Therefore, the power conductors from the branch-circuit fuses or circuit breaker should be based on NEC430.22(C), which requires 125% * the motor's FLC, as shown in Figure 38(a) and (b) on page 50.

Just as for the conductors to the motor, since wye-delta motor starters often serve large motor loads, it is possible that the conductors from the power source to the wye-delta motor starter will also be specified as multiple sets of parallel conductors. If multiple sets of parallel conductors are being routed from the power source to the line terminals of the starter, it is common practice to keep all three phases in each raceway, such that the first set of Phases A, B, and C are in the first raceway and the second set of Phases A, B, and C are in the second raceway, etc. This requirement can be found in NEC 300.20.

NEC Short-Circuit, Ground-Fault, and Overload Protection Requirements

Short-Circuit and Ground-Fault Protective Device: As seen in Figure 38 on page 50, the ground-fault and short-circuit protection for a wye-delta motor starter is based on 100% of the motor's FLC, since the power source sees the wye-start/delta-run motor as a 'regular' delta motor when it is running in the delta configuration. The size or rating of the fuses or circuit breaker used as the ground-fault and short-circuit protection will vary on the type selected, chosen per NEC Table 430.52.

Overload Protective Device: As can also be seen in Figure 38 on page 50, the thermal overload units, sometimes known as heaters, for wye-delta motor starters are to be selected based on 58% of the motor's full-load current, rather than on 100% of the motor's FLC in the case of a full-voltage motor starter. This is specifically mentioned in the last paragraph of NEC 430.32(A)(1). The size of the selected heaters will vary with different manufacturers. Sometimes, the motor starter manufacturer's catalog will have a separate column on the overload selection chart, or possibly a separate chart, to assist in the proper overload selection for wye-delta motor applications, in which case, multiplying by 58% has already been done for you.

If the thermal overloads are placed ahead of the contactors, they need to be selected based on 100% of the FLC.

In Closing

Wye-delta motor starters are one of several types of reduced-voltage motor starting techniques available today. In the United States, wye-delta motor starting usually applies to larger motors, depending on the capacity of the electrical system, the client's preferences, and other factors. Wye-delta or star-delta starters for smaller horsepower motors are more likely to be found in European applications, as well as for higher horsepower motors. Open-transition wye-delta motor starters are the more popular type, but they provide reduced-voltage starting at the risk of possible momentary downward and upward current spikes during the wye-to-delta transition. This drawback can be overcome by using a closed-transition wye-delta motor starter at a slightly higher cost and with slightly higher power usage during the momentary wye-to-delta transition. Reversing wye-delta motor starters are also available.

Wye-delta motor starting requires a special kind of motor, one that has either six leads or twelve leads and that can be started in wye, then run in delta. These motors can also be started and run in delta using a full-voltage starter, just like a three-lead motor. Not all six-lead motors are wye-start/delta-run motors.

There are six power conductors from a wye-delta starter to the motor, rather than three power conductors as from a full-voltage starter to the motor. The six power conductors from a wye-delta starter to the motor can be smaller in size than the three conductors from a full-voltage motor starter to a three-lead motor of the same horsepower rating.

If there is an existing wye-delta motor starter powering a six-lead or twelve-lead wye-start/delta-run motor, the wye-delta motor starter can be replaced with a full-voltage motor starter, a soft starter, or a VFD to power the same motor, but there may be mechanical or electrical reasons not to replace a wye-delta motor starter with a full-voltage motor starter. To use an existing wye-start/delta-run motor in a three-lead application with three new power conductors, splices would have to be installed at the motor to close the delta. To use the existing six-lead power conductors, there would have to be at least two connections per phase at the new starter or VFD.

Abbreviations

A	Amp or Amps
AC	Alternating Current
FLC	Full-Load Current, typical value for motors running at speeds usual for belted motors and motors with normal torque characteristics.
FVNR	Full-Voltage Non-Reversing motor starter
FVR	Full-Voltage Reversing motor starter
HOA	Hand-Off-Auto selector switch
HS	Hand Switch
Hz	Hertz or cycles-per-second
IEC	International Electrotechnical Commission
MCP	Motor Circuit Protector (magnetic-only circuit breaker)

N.A.	Not Applicable
NC	Normally Closed contact
NCTO	Normally Closed, Timed Open time delay relay contact
NEC	National Electrical Code, 2011 Edition
NEMA	National Electrical Manufacturers Association
NO	Normally Open contact
NOTC	Normally Open, Timed Closed time delay relay contact
OL	Overload
PE	Plant Earth, Protective Earth, or Potential Earth, known as "ground" in NEMA applications.
SS	Selector Switch
V	Volt or Volts
VAC	Volts Alternating Current
VFD	Variable Frequency Drive

Additional Reading

Bulletin 50006-026-01E Wye-Delta Reduced Voltage Starter, Open or Closed Transition Class 8630, search for "50006-026-01" at http://products.schneider-electric.us/technical-library/

NFPA 70 National Electrical Code, (NEC) 2011 Edition at www.nfpa.org

IEC 60034-8 Rotating Electrical Machines – Part 8: Terminal Markings and Direction of Rotation, search for "60034-8" at www.iec.ch

NEMA Standards Publication ICS 2 Industrial Control and Systems Controllers, Contactors, and Overload Relays Rated 600 Volts at www.nema.org

NEMA Standards Publication MG 1-2009, Revision 1-2010 Motors and Generators at www.nema.org

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