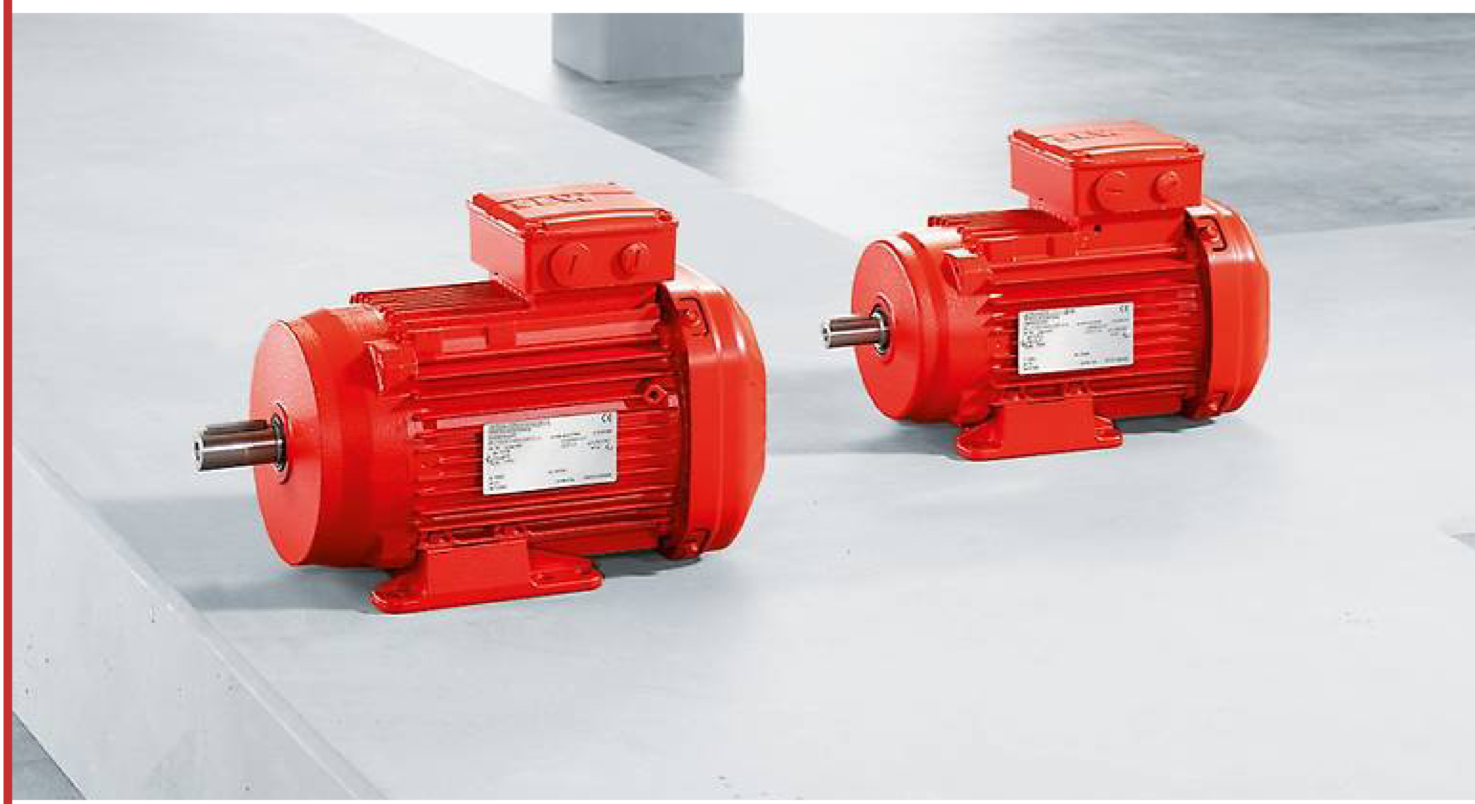
THE COMPLETE GUIDE TO **3-PHASE MOTOR WIRING**

EBOOK



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Introduction to AC Motors

Alternating current (AC) electricity is one of the two prevailing systems that drive the world of electrical motion, both for consumer and for industrial devices. AC electricity is the common go-to method of powering large industrial motors.

For large industrial systems with continuous motion, 3-phase electricity is the most common. Between the various standards and voltage levels, however, it can be difficult to identify the correct motor for every application.

In this eBook, created in cooperation with SEW Eurodrive, we explain the AC voltage system as it applies to motors. We begin with a comparison of single-phase (1-phase) and three-phase (3-phase) voltage applications but then illustrate the many ways in which 3-phase motors can be wired to accept high or low voltages, depending on the type of motor desired.

Finally, we discuss the important concept of 'neutral' in a 3-phase system, explaining why it exists in a supply, but not in a motor load wiring scenario.

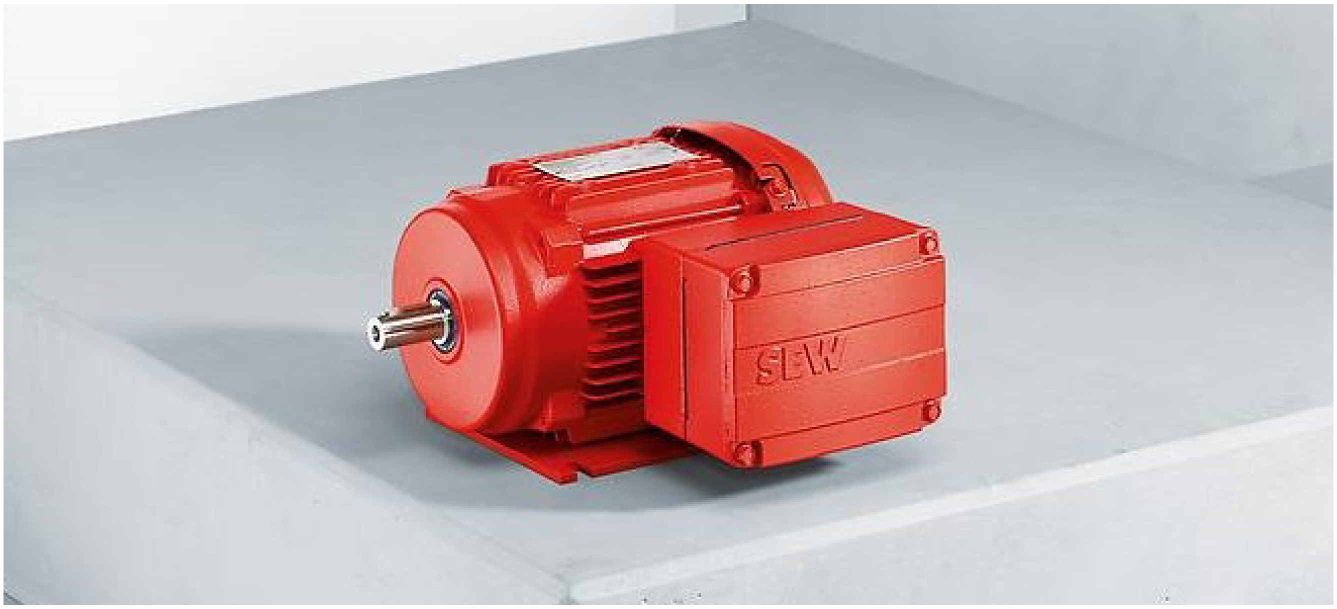
Comparing 1-Phase and 3-Phase Motors

Motors operate using the principle of magnetic fields generated by coils of wire. In the unique situation of a direct current (DC) motor, the poles of the magnetic field must be somehow switched externally. This is most often accomplished with commutator brushes, or by artificially alternating the voltage with an external driver circuit (such as in a brushless or stepper motor).

When it comes to the naturally alternating voltage curve of AC, this creates an ideal situation for driving the motor without the bulk of the extra circuitry or noisy, inefficient carbon brushes. Alternating voltages are the perfect supply for moving heavy loads with as little loss as possible. However, even between the two voltage systems (1-phase and 3-phase), there are differences in operation, leading to advantages and disadvantages, depending on what the application demands.

1-Phase AC Motors

Inside a 1-phase motor, the main drive coil is actually a series of coils distributed equally around the inside to smoothly drive the rotor inside. The voltage will be applied, leading to the electrically-driven magnetic field of each coil alternating north and south at the main line frequency. The rotor will be magnetized to those poles, carrying it in a continuous circle.



1-phase AC motor with a built-in start/run capacitor. Image provided by SEW Eurodrive

This works while the motor is running at full speed, but there is a problem at start-up. The rotor will come to a halt at a random place when the motor is turned off, so the next time the voltage is applied at startup, it's hard to know whether a N-S magnetic attraction will cause it to go forward or backward to begin its rotation at startup. A random rotation direction is obviously unacceptable for any application.

The most common method of correcting this problem is by using a capacitor in series with a secondary coil, usually called a 'starting coil'. Since the nature of a capacitor is to apply a burst of current at the very beginning of a voltage waveform, the current through this starting coil will occur a fraction of a second before the main coil. This causes the rotor to be attracted first to this start coil, then to the main drive coil in close succession, providing a predictable rotation direction. The polarity of this start coil can be reversed to reverse the startup direction. Once the motor is sufficiently started, a very distinct "click" will indicate that a centrifugal switch has opened up the start coil, its job being finished. A bulge on the side of the housing usually contains the capacitor, so if that bulge is present, it is almost certainly a capacitor-start, 1-phase motor.

These 1-phase motors have advantages when the voltage supply is a house or a shop without a 3-phase supply.

The wires into the motor will consist of just the line and neutral (L and N) from a standard 120 V supply—or the two line (L1 and L2) wires in the case of a 240 V system. In either case, this single circuit of conduction must contain the entire driving current. If the hp demands of the motor are large, the wires must be huge to sustain that amount of current. This directly leads to the main disadvantage of 1-phase motors—they will usually only be limited to relatively small applications. But regardless, since 1-phase supplies are so common, this type of motor is found everywhere on shop machinery.

3-Phase AC Motors

The core driving principles of the coils inside of a 3-phase motor are exactly the same as the 1-phase. The only difference is that with three phases, the magnetic poles of the coil progress in increments of $1/3$ of the way around the rotor as each line (called L1, L2, and L3) reaches full voltage. This means that, depending on the sequence of coils being magnetized, the direction of rotation will no longer be random as it was in the 1-phase motor—it's completely predictable and consistent. The starting circuit with the capacitor is no longer necessary, since the motor drives quite naturally.

An example of a typical 3-phase motor with the integrated wiring box on the top. This motor does not have a starting capacitor as the single-phase motors contain. Image provided by SEW Eurodrive

The main advantage of this kind of motor is in large-power applications. The supply system and the conductors are capable of providing far larger amounts of current than in typical residential systems. Additionally, each of the three conductor lines will carry less current individually than if the entire current was traveling through one circuit. This makes the motor very appealing in larger power applications. In the case of most 3-phase motors, the wiring can be configured for either high or low voltage by the electrician. This can decrease the current consumption if a higher voltage supply is provided.

An obvious disadvantage of this kind of motor is that a 3-phase supply must be present to drive such a motor. However, with modern control systems, we do have the ability to install a low-power variable frequency drive (VFD), many of which can be supplied with 1-phase power but deliver a 3-phase output. This is typically only available for motors up to $^{1}/_{2}$ or 1 hp. Anything above that power consumption will almost certainly require a VFD with a 3-phase power input.

Applications of 1-Phase or 3-Phase Motors

For most small-shop applications that require motors with low-power consumption, it would be normal to see a 1-phase motor with a capacitor starting coil.

For reference, in terms of 'power', a 5 hp motor run at 240 V AC would consume about 15 A. Run at only 120 V AC, the same 5 hp motor would consume 30 A. This is quite a significant amount of current. For larger industrial applications, the natural solution would be a 3-phase motor since the voltage and current supplies are much larger. There's an ideal solution for nearly every motor application!

3-phase motors will almost always have a bundle of wires coming out the side, meant for connections to both incoming line power as well as establishing connections between windings. However, there is much more to the story than simply connecting wires—there are both high and low voltage, as well as both Wye and Delta internal connections. Not only are there various voltage levels, but there are many different numbers of wires in each of these motor categories, depending on the application.

Common 3-Phase Motor Windings and Wiring

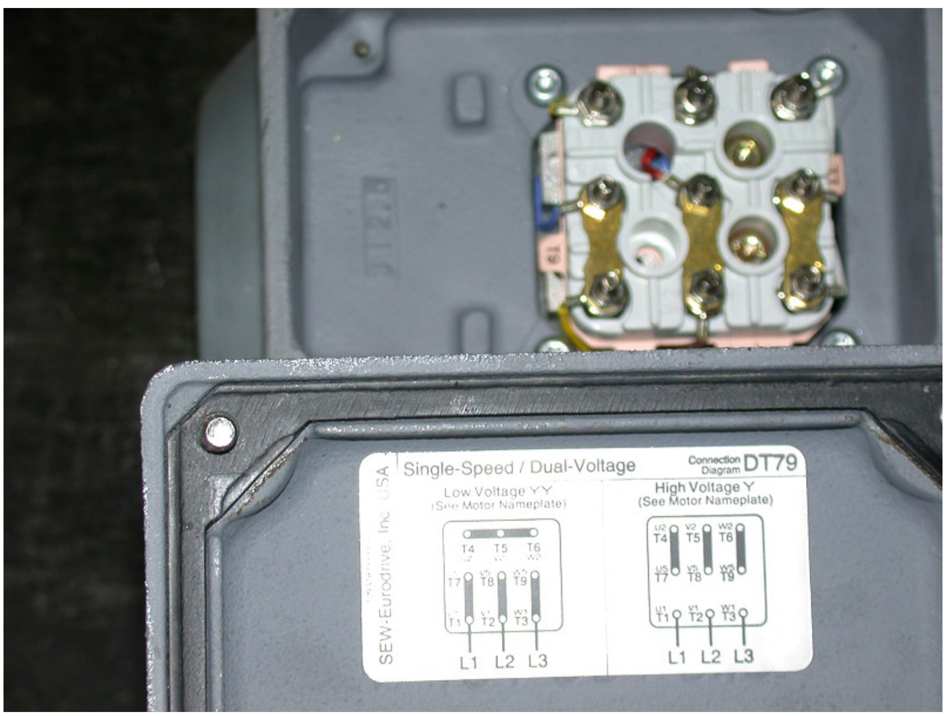
It would be misleading to imply that one type of motor is superior to all others; if there was a 'best' kind of motor, that's the only kind of motor that would exist. Instead, we see a few different motor types, usually indicated by the wires and the data plate on the side.

The variety of motors is most obvious and important in understanding the number of wires requiring connections. For the electrician, nothing is more important than understanding which wires should be connected to the incoming voltage lines, controls, and loads for proper operation.

9-Wire 3-Phase Motors

The most common type of 3-phase motor is the kind which has nine labeled (and often colored) wires coming out of the box on the side. There are many motors with more or fewer wires, but nine is the most common.

These 9-wire motors may be internally connected with either a Wye (star) or a Delta (Δ) configuration, established by the manufacturer. Both have different purposes, but fortunately, they can usually be used interchangeably. As an additional note, these Wye motors are also often referred to as simply the letter 'Y', and both common notations may be encountered in any situation.



3-phase motor wiring diagram showing an internal Wye (Y) wiring, meant to be connected in a low-voltage parallel (YY) or high-voltage series (Y) configuration. Image provided by SEW Eurodrive

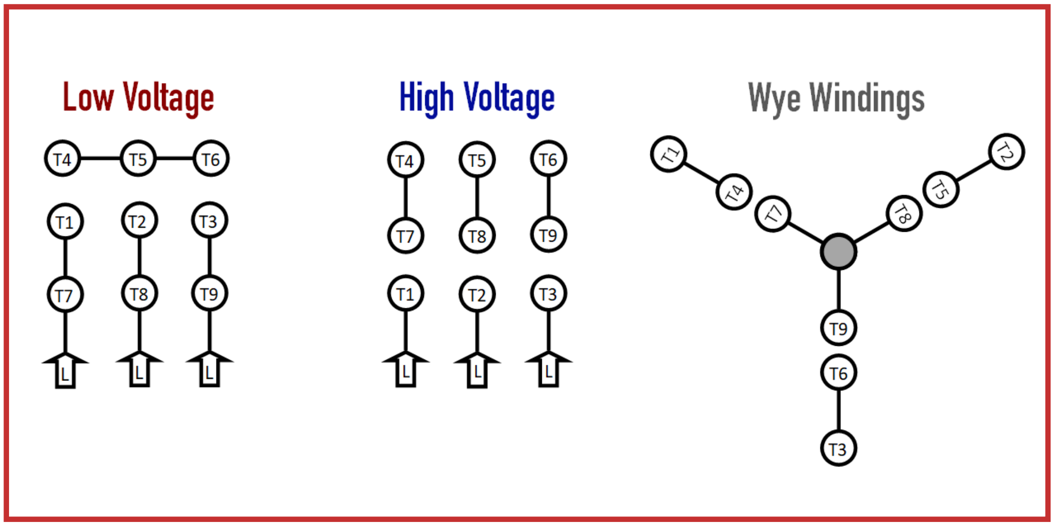
Regardless of the internal type of wiring, these motors can be connected to either a Wye or Delta supply—the supply and the motor are two entirely different subjects.

However, the output voltage of the supply is very important. If a motor is wired for low voltage, do not EVER connect it to a high-voltage source (either Wye or Delta), as it will overheat. On the other hand, if a motor is wired for high voltage, it will fail to operate if connected to a low-voltage source.

Internal Wye Connections

For those standard 9-wire motors that have internal Wye connections from the factory, a mental image of the winding arrangement may provide some insight for the reason behind making certain connections.

For these motors, there will be an indicator on the data plate of two different wiring scenarios—one for low voltage (208-240) and another for high voltage (480).



The internal arrangement of a Wye-wound 3-phase motor with nine leads. These nine leads provide an option for supplying power from either high- or low-voltage sources.

For the low-voltage option, the instructions show to connect the following:
T4-T5-T6, T1-T7-Line, T2-T8-Line, and finally T3-T9-Line.

For high voltage, the wiring changes:
T4-T7, T5-T8, T6-T9, T1-Line, T2-Line, and T3-Line.

Internally, there are six distinct wound coils distributed equally around the outside of the rotor. The main purpose of the wiring is to ensure that the coils on opposite sides of the rotor are energized equally at any time.

With a lower-source voltage, those two opposite windings must be in parallel to receive the proper voltage simultaneously. For high voltage, the opposite windings in series will yield the proper voltage at the same moment.

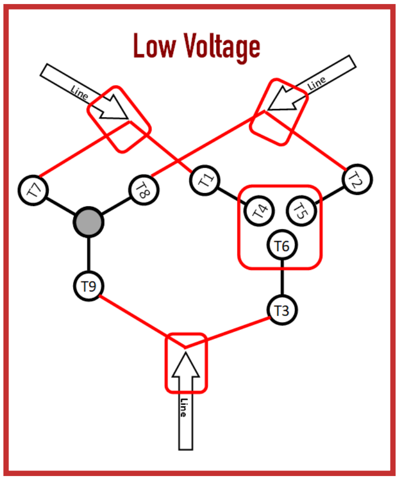
Low-voltage Wye Wiring

When the supply voltage is lower, the total resistance of the load must also be lower in order to generate the same output power. As long as the resistance stays equal, then an equal application of voltage should then also yield an equal output power for each winding. According to Watt's Law:

$$Power = \frac{Voltage^2}{Resistance}$$

Since the voltage is squared, doubling that voltage from a low (240) to a high (480) source would require a 4x increase in resistance to maintain an equal output power.

In order to achieve this lower resistance, the ideal configuration would be a parallel network. This is accomplished by creating a second small bonded Wye set of coils in the motor. Both of these small parallel Wyes will be supplied with an incoming line lead. This parallel arrangement is why some motors will illustrate the wiring with the given name YY—two small Wye formations in parallel.



The connections required for low-voltage wiring of a Wye-wound motor.

This image shows the representation of those two small Wye shapes by first bonding T leads 4-5-6, then by connecting T4 and T7 to a line, as well as T5 and T8, then T6 and T9 each to line leads as well.

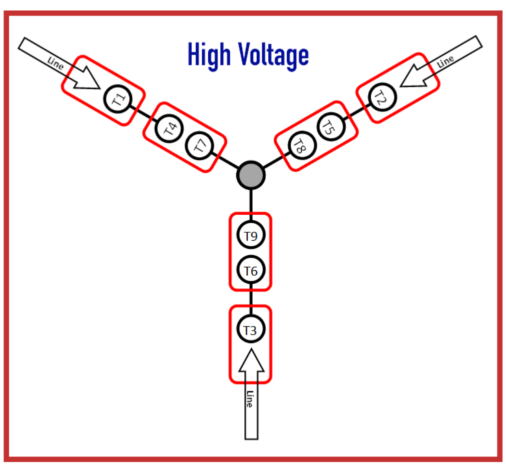
Imagine from L1 to L2: the current may travel from line, through T7, to T8 back to line. In parallel, it may travel from line, through T1, T4, T5, and T2 back to line. Both parallel paths contain two series windings. The total resistance, therefore, will be equal to the resistance of one winding alone.

For a 240 V input, each of the windings will drop 120 volts, since there are two windings in series in each path.

High-voltage Wye Wiring

For high voltage, the total resistance must be 4x higher than for low voltage in order to maintain the rated output power. This means the motor must be wired with the coils in series with each other, rather than in parallel as before. Since the series formation simply elongates the individual legs of the Y shape, the common given title for this wiring type is simply 'Y'.

The visual representation of this wiring scheme aids in understanding this system. The below wiring diagram shows the proper arrangement of windings to create a larger Wye system in which there are four equal windings between any two leads.



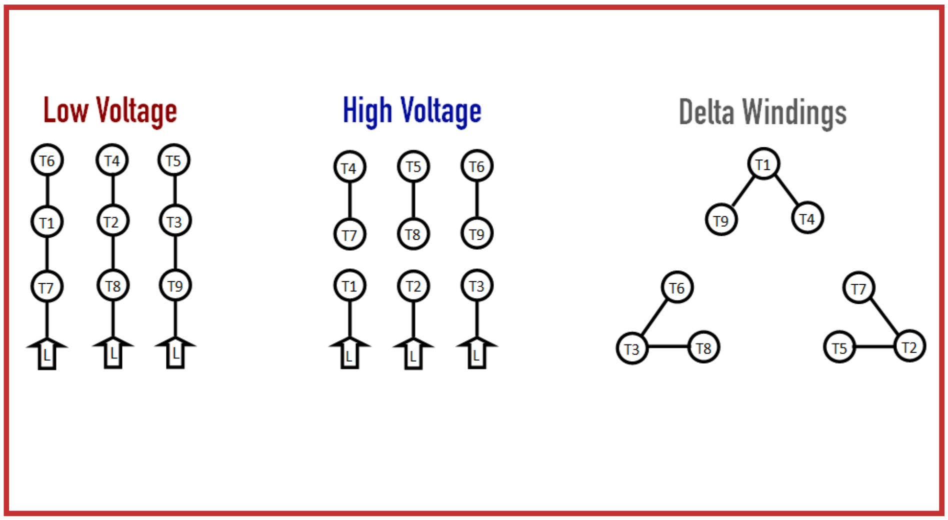
The connections required for high-voltage wiring of a Wye-wound motor.

In this wiring setup, there are four windings in series between any two line leads. For example, from L1 to L2, the current only has one path through the following four windings: T1-T4, T7-center, center-T8, and T5-T2. This gives a resistance equal to 4x the value of one single winding.

Again, comparing the power to the low voltage, if the input voltage is 480 V, each of the 4-series windings will drop 120 V. This is the same voltage, and therefore power, as the low-voltage scheme.

Internal Delta Connections

The use of the term Delta refers to the Greek letter resembling a triangle (Δ). The schematic arrangement of the Delta motor is this triangle pattern, with the exception that it is broken on each side to allow configurable connections for either high or low voltage.



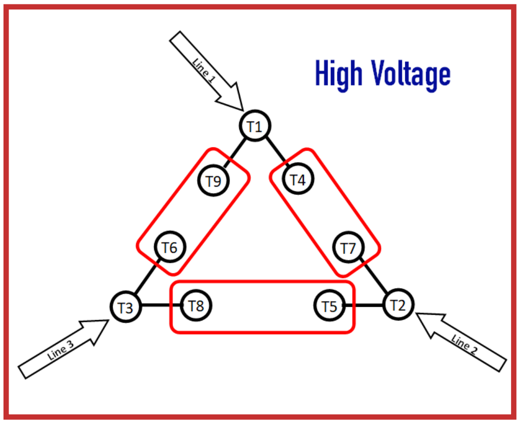
Schematic arrangement of low and high arrangements following a Delta motor winding configuration.

As with any 3-phase motor, those six windings (which appear as the straight lines on the diagram) are distributed around the perimeter of the motor to create a balanced rotation.

The previous section discussing Wye-wound motors described the need for lower resistance with lower-voltage supplies. This is equally true in the Delta arrangement. In a short summary, if the voltage is lowered from 480 to 240 V ($^1/_2$ the voltage), the current must double in order to create equal hp. However, if the voltage has been cut in half, the resistance must be cut to $^1/_4$ of the previous amount in order to produce twice the current. This must be true in the case of both motors—high-voltage wiring should have 4x the resistance of low-voltage wiring.

High-voltage Delta Wiring

Delta motors are a bit more difficult to represent mathematically than their Wye counterparts. The high-voltage Delta system is the simpler of the two and will be presented first, with the intention that the more complex low-voltage scenario may be easier to analyze. The diagram below shows the required lead connections for a high-voltage supply.



Required lead connections for high voltage (series) Delta motor windings.

When the high voltage connections are made, this diagram shows the resulting connections.

Incidentally, the terminal connections are exactly the same for high voltage in both the Wye and Delta motor configurations.

In the Wye motor, high voltage results in a connection of the large Wye with coils in series. In comparison inside a Delta motor, the high voltage results in a large Delta shape. However, the coils are not simply in series anymore. What results is a series-parallel combination circuit.

Imagine the current from L1 to L2. Two different current branch paths exist.

First, current may travel through T1-T4-T7-T2 directly. This branch is a simple series of two windings.

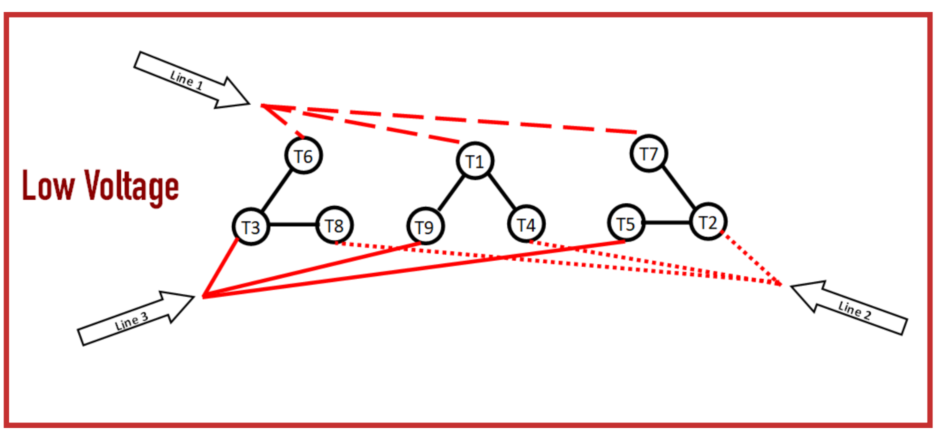
Second, it may travel through the path T1-T9-T6-T3-T8-T5-T2. This second branch consists of four windings in series.

If two parallel paths exist, one having the resistance of two windings, the other with four windings, the result is the parallel combination of 2R || 4R which yields 4/3R, or 1.33 x the value of one winding.

Compare this to the value found in the high-voltage scheme for a Wye motor. In a Wye motor, the value is 4x the resistance of one winding alone. As you can imagine, this yields much more current (and therefore power output) in the Delta motor if all other parameters are equal.

Low-voltage Delta Wiring

The low-voltage scenario is saved for last due to the complexity of the math required to analyze the winding resistance.



Required lead connections for low-voltage (parallel) Delta wiring.

When the low voltage connections are made, this diagram shows the resulting connections.

You won't find a diagram on a motor plate in the outside world that matches the image above. It has been rearranged in order to simplify the situation as much as possible. Each line input is connected to one of the small Delta triangles inside the motor. This setup only requires three connections. If you open up a motor casing and find the familiar nine wires, but only three-wire nuts, you have identified a low-voltage Delta motor.

In this scheme, imagine L1 to L2. There are three different possible current paths in this case, so we can list each option for clarity:

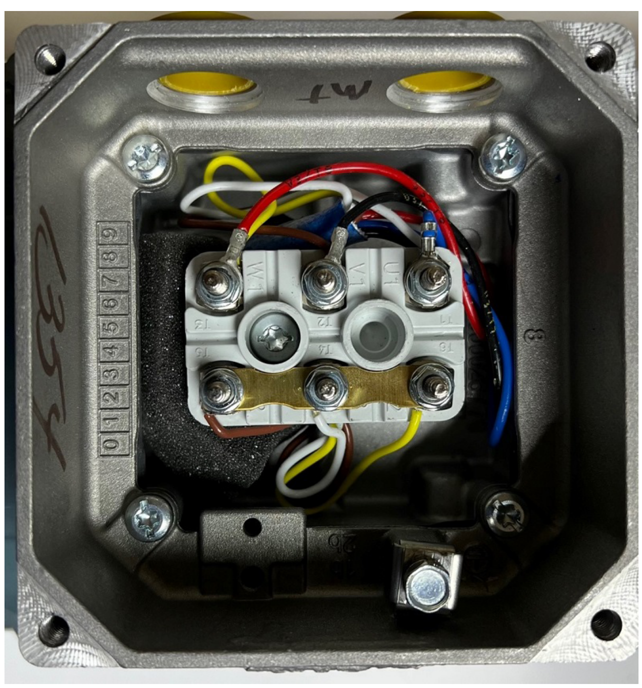
1. T1-T4 through one winding.
2. T7-T2 through one winding
3. This complex path is split into two steps, using the diagram to follow:
   a. Two windings, T6-T3 and T1-T9, start at the L1 junction and are arranged in parallel to reach the junction at L3.
   b. From the L3 junction, T3-T8 and T5-T2 are again in parallel to reach the T2 junction.

This final path by itself yields a series of two sets of parallel equal windings—the result is one winding equivalent. In circuit resistance notation, the formula would be: (1R || 1R) + (1R || 1R) = 1R.

When these three overall paths of one winding equivalent are placed in parallel with each other, the final resistance is equal to $^{1}/_{3}$ R or 0.33 x the value of one winding. As expected, this is exactly $^{1}/_{4}$ of the value of the resistance in the high-voltage configuration.

For most projects, it really doesn't matter what the internal wiring setup might be. If you have a 5 hp motor wired for high voltage, that motor is appropriate for any 480 V application that needs 5 hp.

In some cases, the terminal connections will not immediately appear as nine individual wires in an exposed 'pigtail' format. Instead, they may be secured to screw terminal posts where a single post may bond two or three wires but in exactly the same connection pattern as with wire nuts. This concept is shown in the motor below (an R76 series from SEW Eurodrive) where the connection points form an internal parallel YY for low voltage. The internal connections remain exactly the same as illustrated above, regardless of whether the method involves screw posts or wire nuts.



Screw post style wiring for a 9-wire motor. When the T-leads are connected to the top three posts, wires T3/T9, T2/T8, and T1/T7 will be supplied with power to provide a parallel, low-voltage YY setup. Image provided by SEW Eurodrive

3-Phase Motors with 3 or 6 Wires

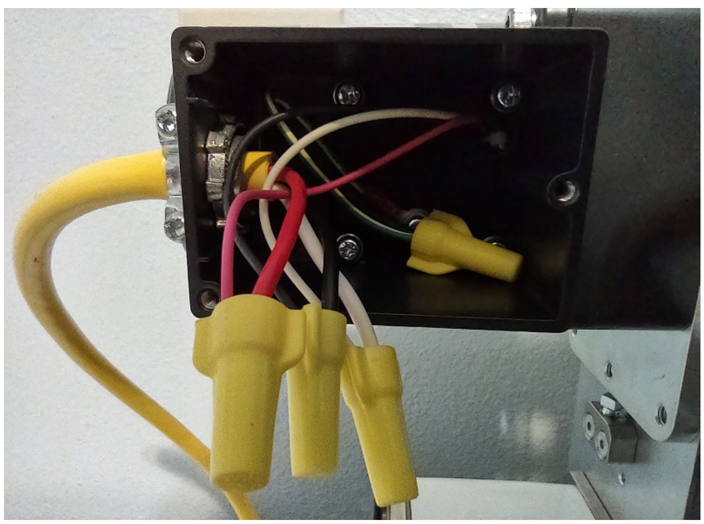
Most 3-phase electric motors use an internal arrangement of coils that defines them as either Wye or Delta—this is established by the manufacturer. The data plates on those motors have a familiar wiring scheme. Occasionally, a motor appears with a different number of wires. These scenarios can be confusing without some background about the internal construction.

That most familiar scheme uses nine wires and can be used to connect the motor to operate equally when supplied with either high or low voltage. Typically, higher voltage is used for larger motors, but each type can have its advantages.

3-Wire Motors

The first of the less familiar cases is perhaps the easiest to use—it only has three wires extending from the wiring box on the side. As an electrician might expect, if there are only three wires, they correspond to the input phase 'line' wires. Connections to VFDs are very simple for these motors, just connect the leads to the VFD outputs, often T1, T2, and T3. Just like any 3-phase motor, the direction of rotation can be reversed just by switching two of the T-leads. Be aware of this fact when installing a motor.

To understand what is happening inside, there are six coils distributed around the rotor. This way, each of the three phases will magnetize opposite sides of the rotor, providing a smooth rotation. From the factory, these motors are connected with the coils in series or in parallel, and they may be either Wye or Delta in arrangement. The electrician cannot change any of that internal arrangement. This means the data plate may show 208-240 V for low voltage, or it may show 440-480 V for high voltage—these motors will never be compatible with both voltages. No change to the external wires' leads will be able to change the voltage compatibility of the motor.



This motor connection box provides access only to the three coil wires of the motor, plus a terminal for ground.
This 3-wire motor must be purchased for either a low-voltage or high-voltage application only.

Always be aware of what voltage is stated on the plate. The connected VFD parameters may be set so that it is providing the proper output voltage.

The wire colors are not always consistent, so in the case of these motors, it is helpful to research and be sure of what kind of motor is being used. This 3-phase kind of motor is not the only that has three wires. Applying too much voltage can destroy a motor that is meant for lower voltages.

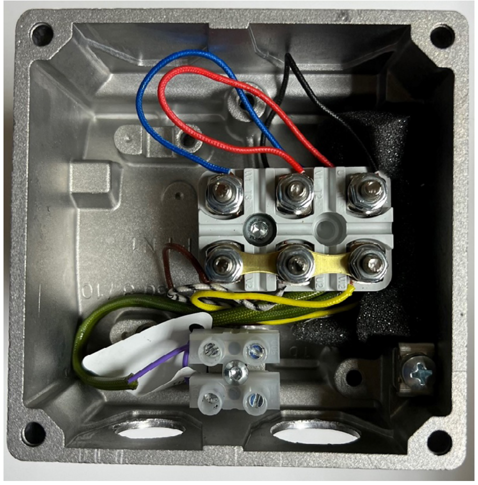
The 3-wire setup may indicate any of the following types of motors: the 3-phase type like discussed above, some brushless DC motors, and many 1-phase AC motors with external capacitor connections, all which use three wires. There are even some standard brushed DC motors with a third wire attached to the metal case for signal noise resistance. Any of these other motors would be destroyed by energizing the coils with high or low-voltage AC.

6-Wire Motors

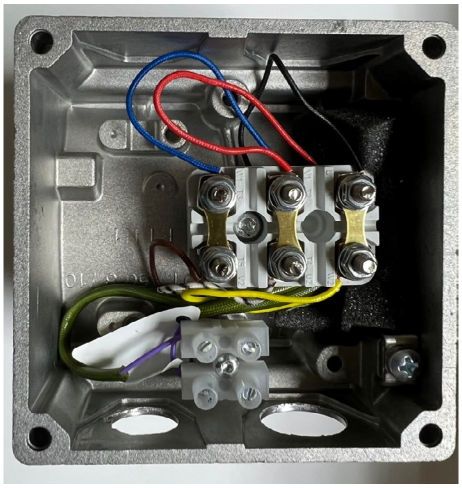
When the motor has six leads accessible to the electrician, they might be attached to a set of six metal screw terminals inside the motor junction box. It is common to see this set of six screws inside the cover on these kinds of motors. Regardless of whether they appear as terminals or wires, they will be referred to here as 'leads'.

Internally, the manufacturer has taken each set of two coils on opposite sides of the rotor and bonded them together. This creates three long coils inside the motor. The two ends of each of the three coils are accessible in the junction box, giving six total lead wires.

Since there are essentially three coils acting as resistors, they may be connected in series for high voltages in order to decrease the current. This would look exactly like a high-voltage setup in a normal 9-wire Wye motor.



A 6-wire motor with three coil connections bonded to create the center of the Y (for high voltage), leaving the incoming T-leads yet to be connected to the opposite ends of each coil. Image provided by SEW Eurodrive



A 6-wire motor with the incoming T-leads yet to be connected to each point of the triangular Delta pattern (for low voltage), each Line input providing power to two coils. Image provided by SEW Eurodrive

The data plate on a motor like this would often show the low-voltage wiring scheme with a Greek Delta (Δ) symbol, and the high voltage with the common Wye (Y) symbol. This is slightly different from the 9-wire motors since in those cases, a Delta motor can be wired for either high or low voltage, and similarly, a Wye motor can be either high or low voltage. The similarity is that a single motor can be purchased that can be used in either voltage case.

3-Phase Motors with 12 Wires

As we have seen, the most common motor wiring method uses nine wires, but there are also many examples of motors with three and six wires. Finally, we arrive at the last wiring type, the 12-wire motor. This method provides the most flexible options for connecting based on voltage and system configuration (Wye or Delta). Although they may seem like the most intimidating, they are actually easier to understand than any other motor type.

Many industrial electricians will go through an entire career and never work with this type of motor. However, motors with twelve wires are universally applicable to any 3-phase power system, no matter if the voltage is high or low, or whether the demands of the machine call for a Delta or Wye configuration.

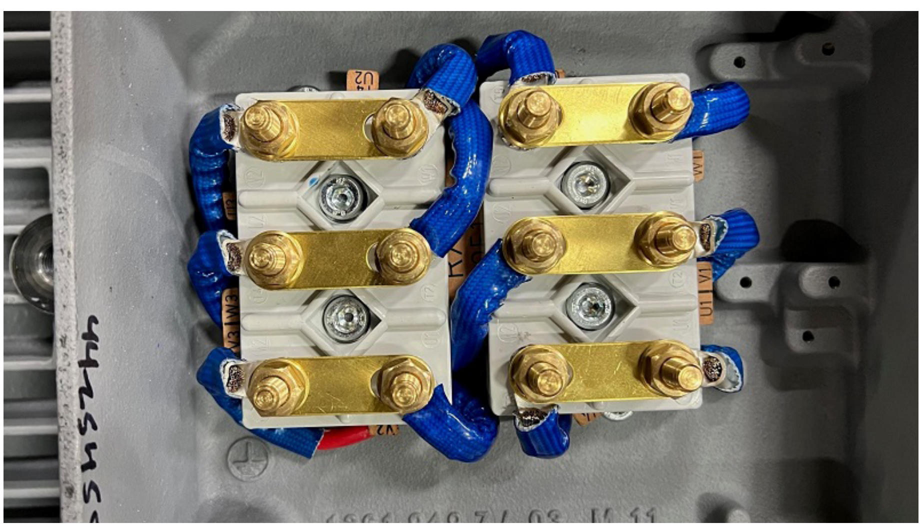
Examining a typical 12-wire motor data plate reveals a complex combination of wire bondings. Since they are unusual, and the number of connections is greater, it seems like these motors should be more difficult to understand. The good news is that this is not the case. With a little knowledge of how they are constructed, these motors and the wiring connections are pretty straightforward.

Why 12 Wires?

Inside a 3-phase motor, there are three sets of coils, one directly acted by each voltage phase. They do not all have an equal voltage, but rather they divide the voltage (as series and parallel resistors) between the three input line phases. An important note is that there are actually more than three coils—they simply act in pairs. There are, in fact, six coils distributed equally around the inside of the housing around the rotor. Each pair of coils is located directly opposite from each other across the rotor, and both of those two opposing coils should have equal voltage (and therefore equal current and driving force). The result is a well-balanced rotation from the six coils.

In a typical 9-wire motor, several of the coils are bonded internally from the factory. In Wye and Delta configuration, several bonds are established which cannot be disconnected by the electrician. They can simply be wired to accept higher or lower voltage, but the fact remains that for these motors, Wye is always Wye and Delta is always Delta.

In the 12-wire motor, that internal restriction has been removed. The electrician has access to both ends of all six coils, giving twelve total wire leads coming from the motor. This means that this motor can be applied in an application that demands varying factors for starting and running.



3-phase motor with 12-wiring connections (shown here bonded in pairs). Image provided by SEW Eurodrive

Motor Starting Methods

There are two common ways that 3-phase motors can be started without the aid of a digital tool such as a VFD or soft starter. Both of these 'manual' methods are created by simply changing the wiring to arrange the coils in different series or parallel paths to increase or decrease resistance.

First, there is across-the-line starting. This is a simple contactor with three phase lines that make instant contact when the coil is engaged. It's a very simple starting method, but the motor draws much more current. In this circumstance, the motor is wired permanently for its voltage application. In other words, it should be wired for the scenario that will allow the highest current through the coils all the time. This is a Delta configuration—Wye will always have higher resistance and less current.

So, for the case of across-the-line starting, we would expect to wire the motor up for a high-voltage Delta or a low-voltage Delta configuration.

The other kind of starting method is called reduced-voltage starting. This places a lower voltage across the coils, and therefore, a lower current during a start-up phase until the motor has reached a sufficient velocity to shift to the full-speed voltage. This start-up method takes longer, but it greatly reduces the start-up current.

For this kind of reduced-voltage starting, we should wire the motor for the highest possible resistance for the starting contactor and lower resistance for the run contactor. This is achieved by using a Wye winding for starting only, then switching to a Delta winding for the continuous run. For this reason, this starting method is often called Wye start Delta run.

When the supply is high voltage, use a high voltage Wye winding for start up then a high voltage Delta for the continuous run. For low voltage, it's the same except use low voltage Wye for start-up and low voltage Delta for running.

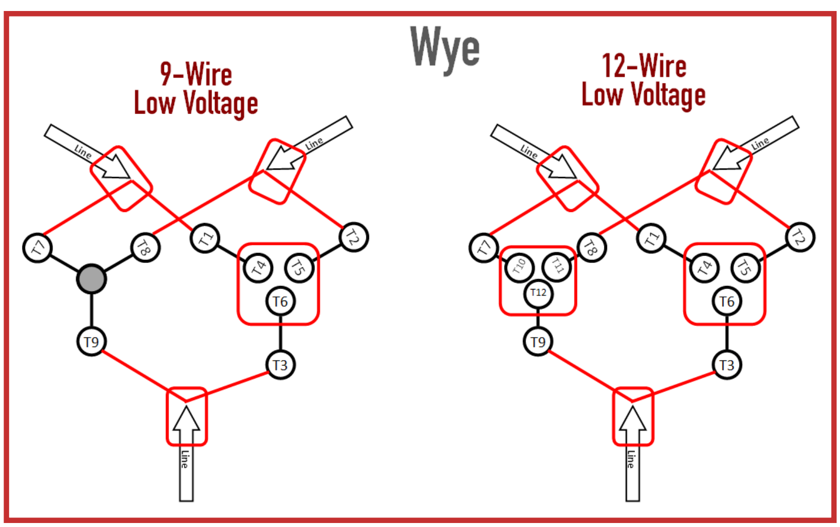
Since the VFD is such a commonplace fixture in modern equipment, the VFD handles the slow ramping of the motors, and it's becoming less common to require a motor that can be connected for the reduced voltage scenario. The 9-wire motor is the most common for VFD and soft-start connections.

Wiring Examples for 12-Wire motors

The wiring itself can be most simply explained by comparing these motors to their Wye and Delta 9-lead counterparts. We will simply examine where the wiring differs. There are four distinct scenarios.

Low-voltage Wye

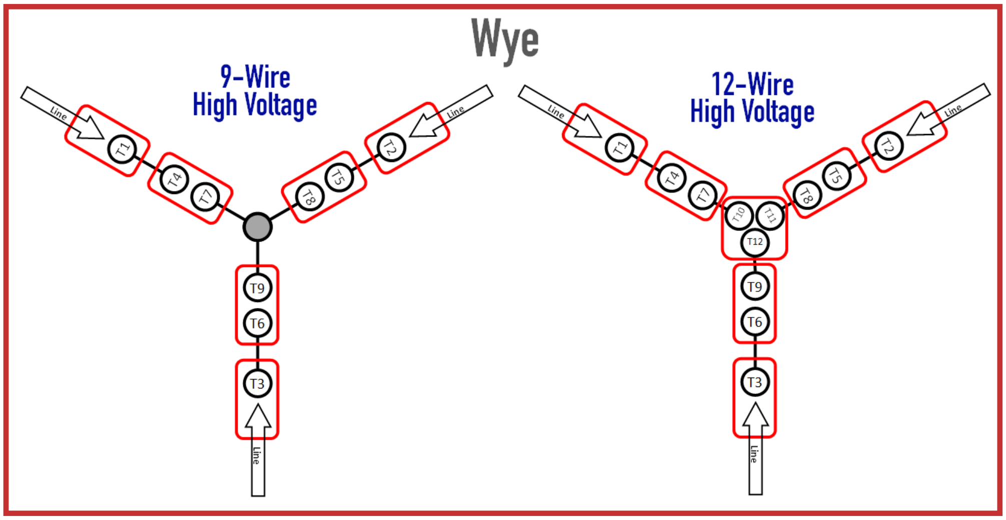
Two small Wye windings are placed in parallel with each other. This diagram compares the two motors, but the gray circle indicates where the bonding is internal in a 9-wire motor.



Comparison of 9-wire and 12-wire low-voltage Wye arrangement.

High-voltage Wye

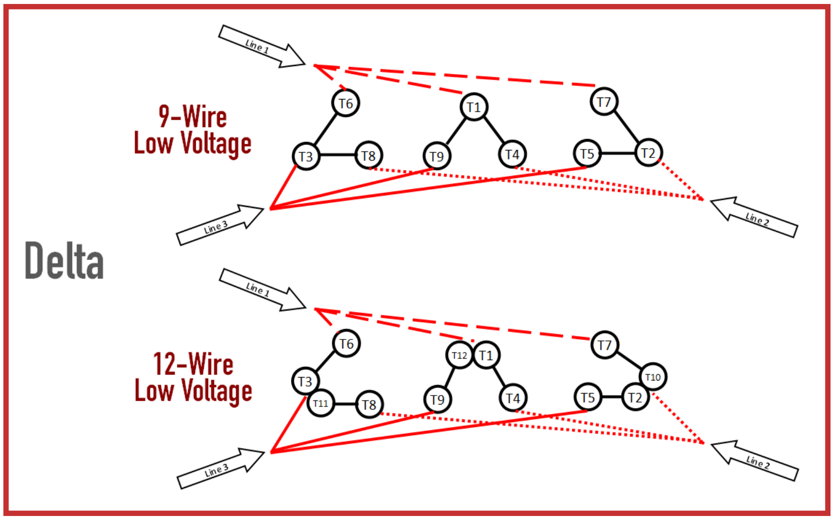
The coils are placed in series from each phase to the internal connection of three coil ends. This connection point is the only difference between the winding diagrams.



Comparison of 9-wire and 12-wire high-voltage Wye arrangement.

Low-voltage Delta

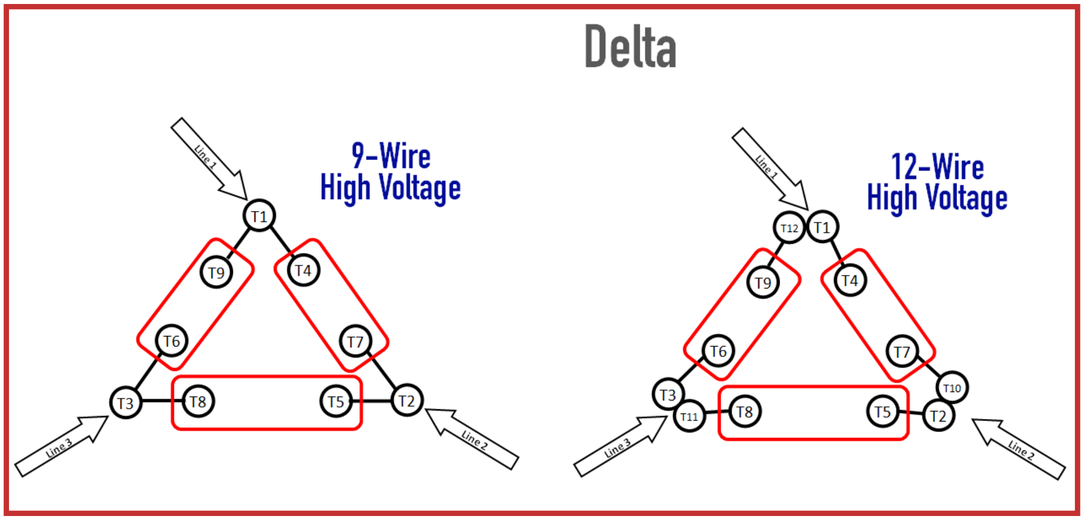
Two small Delta triangles are placed in parallel with each other. The diagrams are similar, but again, there are multiple coils bonded at T1, T2, and T3 in the case of the 9-wire motor.



Comparison of 9-wire and 12-wire low-voltage Delta arrangement.

High-voltage Delta

Two coils are again placed in series, but unlike the Wye configuration, there is no common bonding point in the center, each set of coils is directly between two phases. This results in less resistance and higher current for Delta than for Wye.



Comparison of 9-wire and 12-wire low-voltage Delta arrangement.

Neutral in a 3-Phase System

To conclude the discussion of motor wiring, we should examine the intriguing contrast between 1-phase and 3-phase wiring. In 1 phase, a neutral wire (often white or blue) will always be present to power the motor. In a 3-phase system, however, sometimes the neutral wire exists, and sometimes it doesn't. When it does exist in the 3-phase supply architecture, load devices (like those previously discussed 3-phase motors) do not include a connection for neutral. Why?

In an AC system, the neutral wire is a non-energized wire that carries current. It's non-energized because it's not connected to any active energy source from the incoming main service—that's the job of the line conductor. It carries current back to the return of the main service panel which should have a connection directly to the earth ground.

Because of the earth ground connection, the neutral wire will not supply energy if it touches a grounded object—no spark will occur and no current will travel.

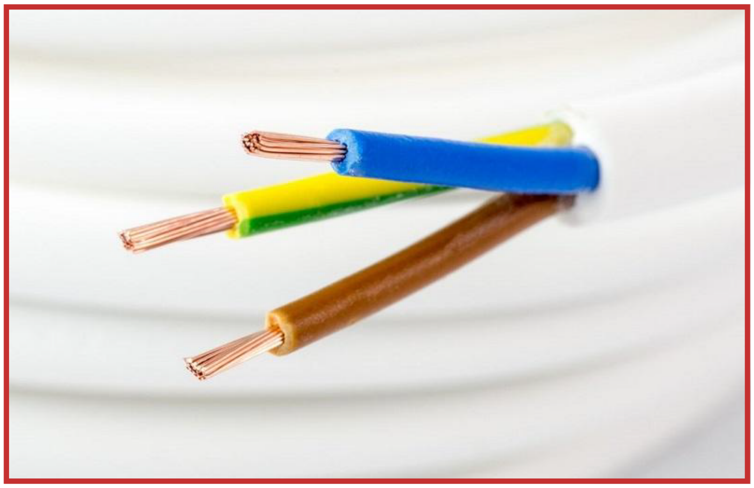
In examining a 3-phase power system, some power supplies will include the 3-phase lines, neutral, and ground. Others may omit the neutral, leaving only three lines plus ground. If neutral is needed to carry current, why can some system leave this wire out of the connections?

1-Phase Wiring

When one individual phase line is used to supply energy to a load device, there must be a return path for the circuit to be completed. The neutral and ground wires provide respectively that return path and a redundant return path in case of faults.

In this sense, you could use a 3-phase power system, then access one line plus the neutral, and you have gained a 1-phase supply. This is how most power distribution provides 1-phase power into a house or shop. It started as 3-phase power, but that can easily be turned into three separate 1-phase supplies which would each be directed to small communities.

Since there is only one powered line, it is absolutely essential that a second wire provides the return path. This is the neutral wire. If you were to connect a 1-phase motor, or any normal light or household device, you will connect both the line input and the neutral. The bare ground only provides a backup return path in case of problems.



1-phase supply wires contain a Line (or two lines in high voltage 1-ph), a Neutral, and a green Ground wire.

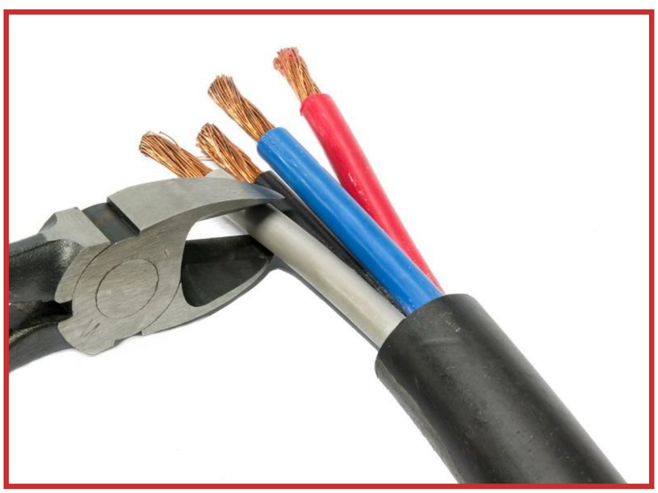
Because of the structure of 1-phase power as is found in normal outlets and lighting circuits, there will always be equal current in the line and neutral wires.

One additional note: a 240 V 1-phase supply actually consists of 2 line conductors. If those are used, the neutral is not necessary for a similar reason as the 3-phase explained next.

3-Phase Wiring: Loads

In the 3-phase power system, it's quite different. Since the lines are all alternating at the same frequency, only delayed by $^1/_3$ of a rotation for each line, there will always be at least one wire with a forward current and one with reverse current with respect to the load. No two wires will ever have the same current.

At any given moment, if you add up the current in all 3-phase wires, the total sum of the current to or from the load is 0 A. This does NOT mean that there is no current, it simply means that between the shared current load of all three lines, there is no EXTRA current going to or from the load. This means that even if a neutral wire was provided to the load, it will never be used.



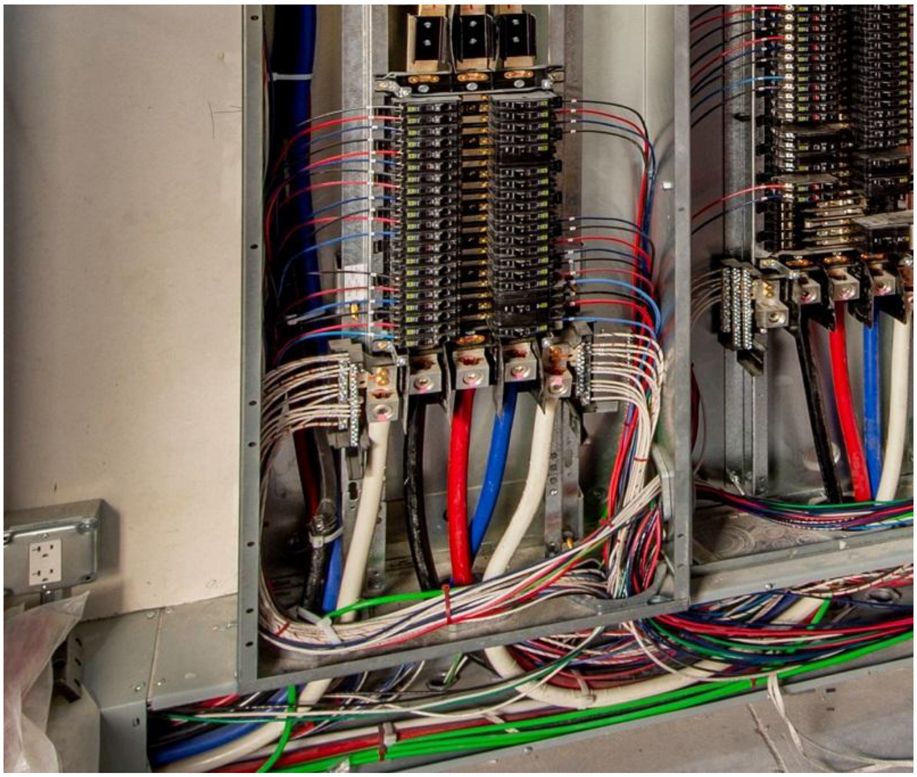
3-phase cable configured for low-voltage 3-phase electricity. The gray wire is the neutral, absent in the wiring of motor loads.

This is why 3-phase load devices only have three line inputs. The ground wire still must be connected to provide the redundant safety connection in case of failure. If a line touches the outside case, there is no longer a shared zero sum of current between the three line inputs, so the ground must exist so the excess current can safely trip the overcurrent device.

3-Phase Wiring: Sources

It might now be clearer as to why load devices only use the line inputs, but another question arises with 3-phase sources. Sometimes, they have a neutral wire. Other times they don't.

If a 3-phase power panel provides a neutral wire in addition to the three lines and ground, then it indicates either a 4-wire Wye configuration or a 4-wire Wild-Leg Delta configuration. It's most likely the Wye system if it's a modern service panel.



3-phase power panel with the three colored phase lines and the white neutral line, which is missing from motor load wiring applications.

The purpose of the neutral wire is that it allows the connection of both the 3-phase load devices as normal, but it also allows an electrician to use any of the three lines along with the neutral to form a 1-phase supply. In fact, there can be three equal 1-phase supplies. This is the normal supply for industrial lighting circuits and receptacles for the main offices and 1-phase equipment.

The Wild-Leg Delta model is slightly less common but actually allows the use of 3-phase loads, and multiple 1-phase voltages, all with one supply and no extra transformers. This is helpful in some cases, but it is hard to balance the three lines properly and can be less than ideal for the longevity of equipment.

Summary of Motor Wiring Systems

AC motor wiring is a critical skill for any industrial electrician or technician. Different situations may only allow the hands-on wiring for certain licensed individuals, but understanding how and why these voltage systems operate for various devices will save hours and dollars from wasted downtime and help to prevent hazardous situations.

We thank SEW Eurodrive for their contribution of photos and documentation to improve this eBook, and we invite you to **visit SEW Eurodrive** to solve your future motor and motion design requirements.