# Three Phase AC Motor Theory

Motors have been described as a transformer with a rotating secondary. Motors, generators, and transformers are similar in that their basic principle of operation involves induction. The premise for motor operation is that if you can create a rotating magnetic field in the stator of the motor, it will induce a voltage in the armature that will have magnetic properties causing it to 'chase' the field in the stator. This premise applies to AC motors that employ a squirrel cage rotor, and it is probably the most simple and basic of all motor designs. The three phase motor is widely used in industry because of it's low maintenance characteristics. Due to the nature of three phase power, creating a rotating magnetic field in the stator of this motor is simple and straight forward.
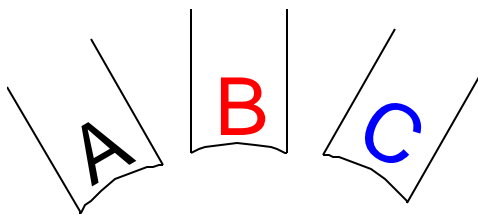
The stator windings are arranged on the stator poles in a way that results in magnetic flux lines that seem to rotate. In this example, the direction of rotation would be clockwise. Can you see that changing any two leads would result in counter-clockwise rotation?
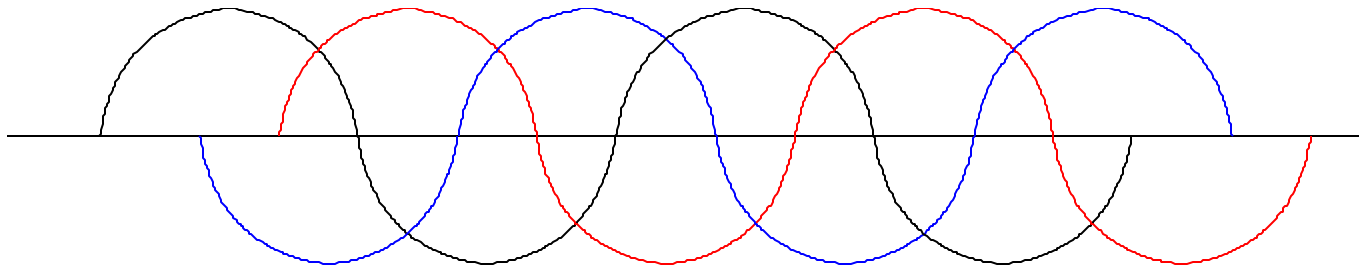

The strength of the magnetic field changes, as the current flow in the coils of wire around the stator poles change. Just as the current in the field windings rise and fall 120 electrical degrees apart, so does the resulting magnetic field on the pole face. In other words, when the magnetic polarity on pole 'A' reaches it's peak, 120 electrical degrees later pole 'B' will reach it's peak, and 120 electrical degrees after that, pole 'C' will reach it's peak. Then the cycle repeats itself, and a rotating magnetic field is developed in the stator of the motor.

Swap any two of the three pole face polarities by changing any two leads of the supply voltage, and you will see that the, 'ABC' order reverses. Phase rotation of the supply voltage is not always the same from one electrical service to the next, and the electrician has a fifty-fifty chance of getting the correct direction of rotation when connecting a three phase motor. The phase rotation of the electrical service can be determined with the use of a phase rotation meter, but the way the individual motor was manufactured also determines it's direction of rotation. Every three phase motor should be energized for a very brief moment, in order to check rotation before being placed into service.

The frequency of the applied voltage, and the number of poles, determines the "synchronous speed" of the rotating magnetic field in the stator of a motor. The 12 pole motor is the most common configuration, and it produces a speed of 1800rpm. The formula for finding the synchronous speed of a motor is as follows;

$$\frac{\text{frequency of applied voltage x 120}}{\text{number of poles / number of phases}} = \text{synchronous speed of rotation}$$
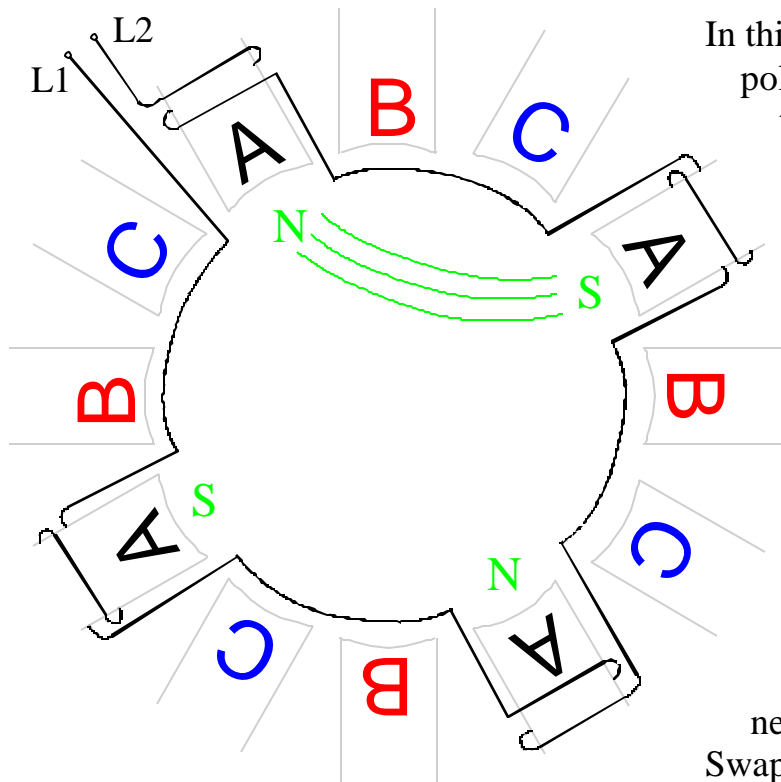
In this simplified illustration of a 12 pole motor, the stator windings on the 'A' poles are connected to the voltage source between line 1 and 2. Stator windings on the 'B' poles are connected to 2 and 3, and the 'C' poles are associated with line 3 and 1. When the current flow in the stator windings produces maximum magnetic polarity as shown, 120 degrees later the 'B' poles will be at max, and in another 120 degrees, the 'C' poles will be the strongest. Notice that the rotation of the magnetic field in the stator is clockwise. Swap any two poles to reverse direction.

Lines of magnetic flux protrude into the area occupied by the armature. As the flux lines move around the inside of the stator, they cut the conductive bars of the rotor, inducing a voltage in the armature. The conductive bars run the length of the armature, and are connected to shorting rings at each end. This provides numerous paths for current to flow, due to the induced voltages. The armature is constructed in such a manner that the current flow in the armature produces magnetic fields that chase the rotating magnetic field in the stator, resulting in torque, (the twisting motion on the rotor). Induction of voltage in the armature only takes place when there is relative motion between the flux and the conductive bars of the rotor. Consequently, the rotor speed can never reach the synchronous speed of the rotating magnetic field in the stator. If it did, there would be no relative motion, no induced voltage, no magnetic field on the armature, and no torque.

The difference between the synchronous speed of the rotating magnetic field in the stator and the actual speed of the armature is called "slip". The actual RPM rating of this motor would be somewhere between 1745 and 1765, indicating a slip of 35 to 55 Revolutions Per Minute. Speed of rotation in this type of motor tends to be self regulating;

When voltage is applied to the motor leads, huge currents flow in the stator windings. As the rotor starts to turn, the magnetic fields of the armature induce a Counter Electro-Motive Force, (or CEMF), into the stator windings. The faster the rotor turns, the greater the magnitude of the CEMF. Since this CEMF opposes the applied EMF, it reduces the current flow in the stator. This is why the starting current of an induction motor is around 6 times the running current, (starting current is sometimes referred to as locked rotor current). The armature of the motor comes up to it's design speed and achieves a balance between applied EMF, induced CEMF, and the torque required to overcome friction. When the load on the motor increases, it tries to slow the speed of the rotor, but this reduces the CEMF, which increases current in the stator giving the motor more torque to compensate for the increased load.

Most motors of this type are manufactured to be dual voltage motors. In the USA, the most common three phase, dual voltage AC motor has nine leads at the connection point, and is designed to operate on 240v or 480v power. The stator windings consist of 6 distinct circuits, each circuit containing 4 coils wrapped around pole pieces. (It may help to refer to the illustration on page 2). These circuits are identical; same length, same number of coils, same number of turns in each coil, and they are arranged in three pairs. Each pair is wrapped around the same pole pieces, and the leads are numbered like this;
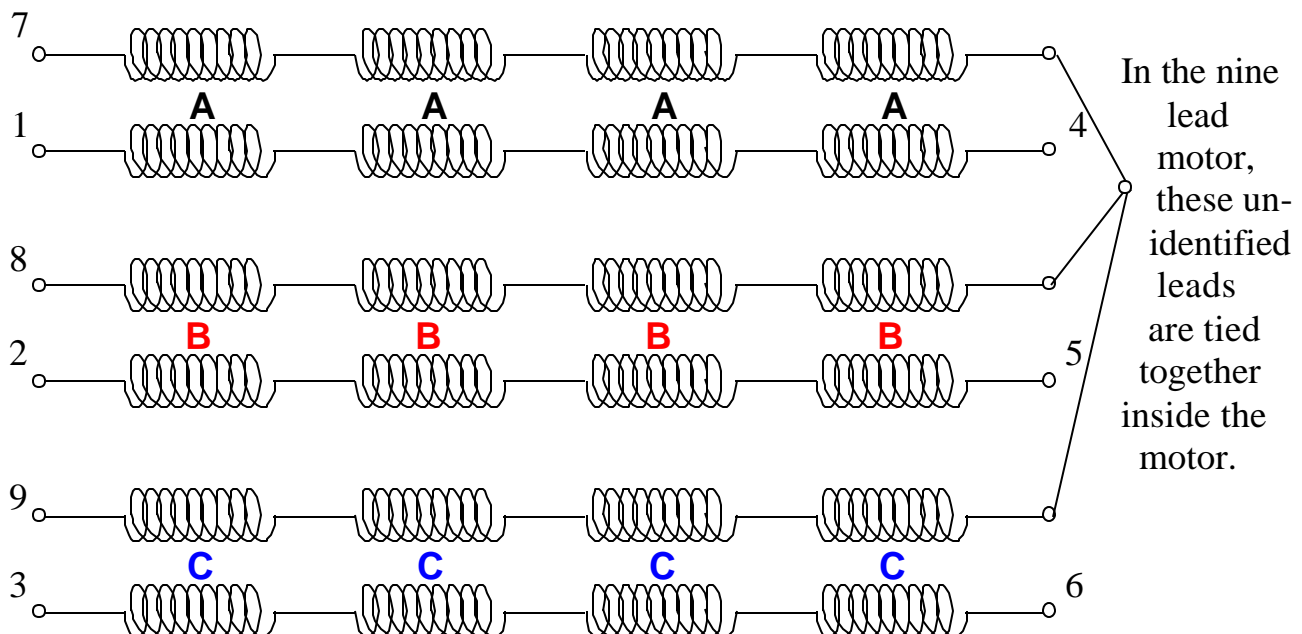
For connection to the lower voltage, (240v), two equal and parallel paths are created by tying 4,5,&6 together, and connecting the source voltage lines to 1 & 7, 2 & 8, and 3 & 9. Most 9-lead motors can be operated on 208v, but the running current increases by about 10%, and the overload protection must be increases accordingly.
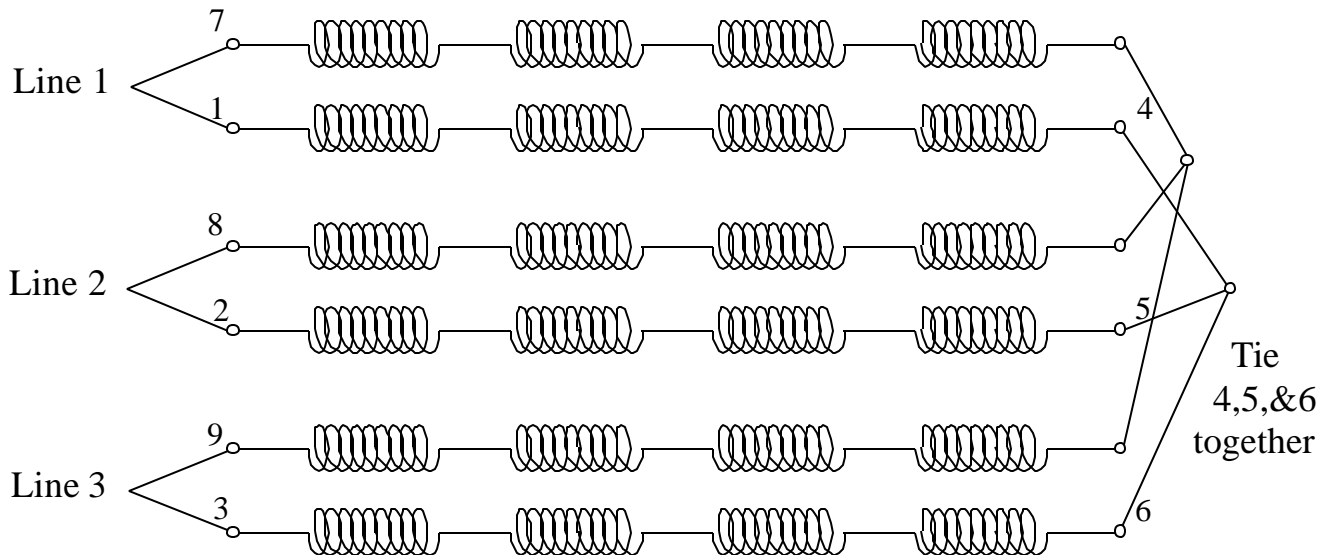
For connection to the higher voltage, (480v), one large series path must be created by tying together; 4&7, 5&8, 6&9, and connecting the source voltage lines to 1, 2, and 3.
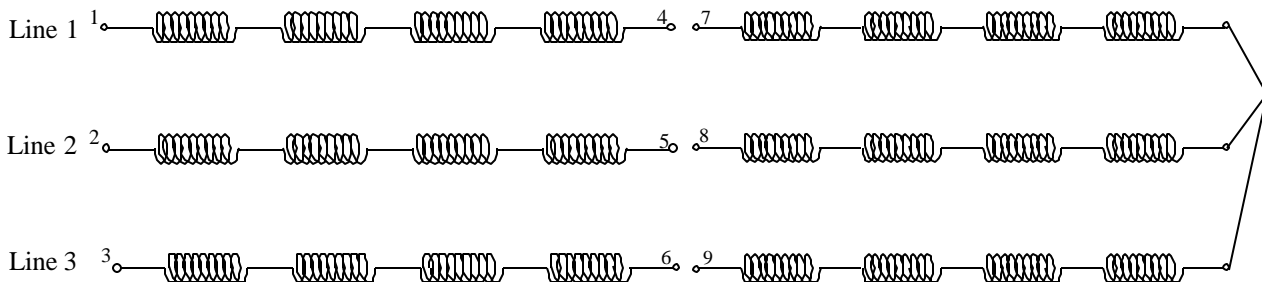
Most dual voltage motors have connection diagrams printed somewhere on the motor, but if you learn these principles, and come to an understanding of why the connections are made in this configuration, it will be easier for you to remember.

Got Questions?

e-mail your questions to a.step@comcast.net