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A Practical Primer On Motor Drives (Part 5): Three-phase AC Line Current And Winding Configurations

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In the previous part, the measurement of single-phase ac currents was described. The discussion continues here with a description of the current vectors in three-phase ac systems, how current flows in wye and delta winding configurations, and how it is measured.

Three-Phase AC Line Currents

Three-phase ac systems are more complicated than single-phase systems with regard to describing currents. One may distribute three-phase current with a variety of different "wye" or "delta" connection configurations—it is beyond the scope of this document to describe all the various permutations, so this document will only describe the most common types.

In a three-phase system, there is (by design) "balance," meaning that the three-phase current vectors have the same current magnitude and are separated from the other phases by 120°, or 1/3 of a full sinusoid period, and should therefore vector sum to zero. Thus, in a balanced three-phase system, the sum of all the line currents is zero.

Practically speaking, this means that the return current for each phase travels in the opposite direction in the other two phases. Contrary to a single-phase system, the three-phase neutral connection carries no current under normal operating conditions. However, if there is a fault (failure) condition or a leakage of current to ground, the neutral may have some voltage potential and carry some current.

As in a single-phase system, the three-phase current vectors rotate at a constant rate. This rotation and phase difference between each phase in a three-phase system makes it possible to produce rotating magnetic fields that can perform work, such as in an electric motor.

The three-phase current vector system appears in Fig. 1.

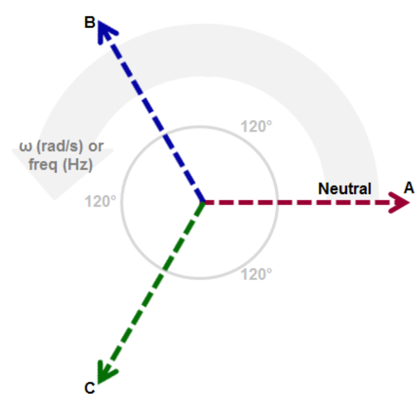

Fig. 1. Three-phase current vector system.

When electrically observed as three current-versus-time waveforms, the "rotating" current vector system appears as three sinusoidal waveforms, each with the same fixed frequency, and out of phase with respect to each other by 120° (as described above, see Fig 2.)

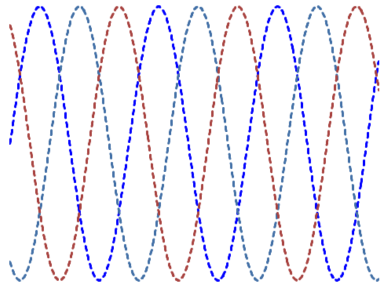

Fig. 2. A time-domain view of the three-phase current vector system.

We may also refer to line current as phase current. The convention for indicating a line current measurement is to show the current symbol "I" followed by a subscripted "$_{line}$" designation. Thus, phase A line current would be represented as I_A.

Because we measure three-phase line currents to a neutral in a wye (Y or star) configuration and to a terminal in a delta (or Δ) configuration, the calculation of the various current values is identical to that of the single-phase case.

As described in the single-phase case, the line current could supply a linear or a non-linear load. In the case of a linear load, the three line currents are sinusoidal (within distortion limits). A motor drive provides a non-linear load, and the currents are distorted as in the single-phase case. The screen image in Fig. 3 shows an example of the three-phase current input to a 480-V_{AC} motor drive.

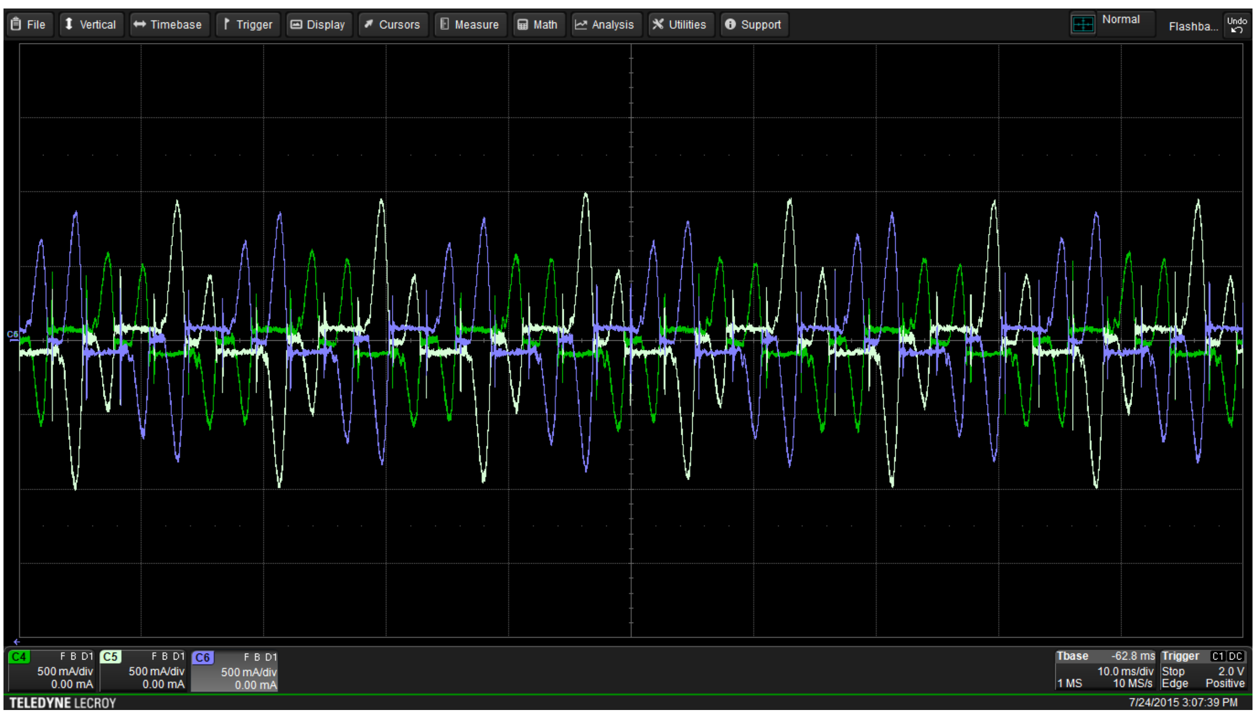

Fig. 3. Three-phase current input to a 480-Vac motor drive captured with a Teledyne LeCroy 8-channel, 12-bit Motor Drive Analyzer.

Three-Phase Winding Configurations

Until now, we have discussed only the voltage and current phase vectors. For a single-phase, two-wire system, there is one voltage and one current vector, and for a single-phase three-wire system, there are two voltage and two current vectors. However, for a three-phase system, there are three voltage and three current vectors, and how we produce these voltage vectors and how current flows when voltage is present depends on the three-phase winding configuration.

The neutral wire may or may not be available in a three-phase system, and the three phases may be arranged in a wye (Y or star, shown at left in Fig. 4) or delta (or Δ, shown at right in Fig. 4) configuration.

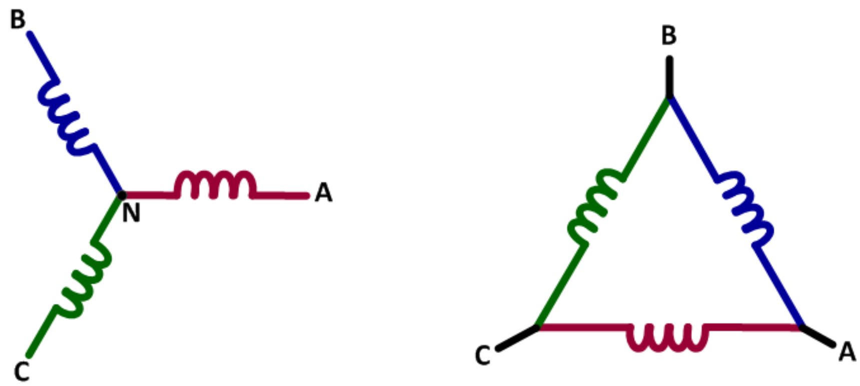

Fig. 4. Wye or star (left) and delta (right) three-phase winding configurations.

Wye (Y or star) configurations always have a neutral in the winding, but it might be inaccessible depending on the physical construction of the winding. In motors, the neutral is typically inaccessible.

Delta (Δ) configurations may or may not have a neutral connection. When they do, it is usually one phase ("leg") of the delta tied to neutral (e.g., phase A), or one winding with a neutral connection at the midway point in the winding. Delta (Δ) configurations with neutral connections are uncommon in motors or drives.

Measuring winding current in a three-phase system can be problematic. In a delta winding, a known current flows into a terminal, but that terminal current is shared by two different windings. In this case, there is no way to measure the current in the winding because the winding rotates as a function of motor operation. Therefore, we may measure power at the terminal, but it is not possible to measure power in a single winding in a delta configuration. For wye (star) windings, it is more straightforward because the winding current is the line current.

Conclusion

This section reviewed the basics of current flow in three-phase ac systems, described the two popular three-phase winding configurations, and how currents are measured in them. The upcoming part 6 will explore the topic of ac line power calculations. For a full list of topics that will be addressed in this series, see part 1.

About The Author

Kenneth Johnson is a director of marketing and product architect at Teledyne LeCroy. He began his career in the field of high voltage test and measurement at Hipotronics, with a focus on <69-kV electrical apparatus ac, dc and impulse testing with a particular focus on testing of transformers, induction motors and generators. In 2000, Ken joined Teledyne LeCroy as a product manager and has managed a wide range of oscilloscope, serial data protocol and probe products. He has three patents in the area of simultaneous physical layer and protocol *analysis. His current focus is in the fields of power electronics and motor drive test solutions, and works primarily in a technical marketing role as a product architect for new solution sets in this area. Ken holds a B.S.E.E. from Rensselaer Polytechnic Institute.*

For further reading on motor drives, see the How2Power Design Guide, locate the "Power Supply Function" category, and click on the "Motor drives" link.