Exclusive Technology Feature

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A Practical Primer On Motor Drives (Part 4): Single-Phase AC Line Current

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Having concluded the discussion of ac line voltages in the previous sections, here in part 4 the focus shifts to measurement of ac line currents. Specifically, this part explains the basics of making current measurements in single-phase systems.

AC Line Current

Formally, we state ac line current values in amperes RMS (Arms), but in practice they are simply stated as A or Aac. In this context, the terms A, Aac, and Arms are interchangeable.

Measurements of ac line current are always from a single line (conductor). In the case of a wye (star) three-phase connection, the measurement is a line-neutral measurement, which corresponds to the current flowing through a single winding to neutral (line-neutral).

In the case of a three-phase delta connection, the line currents are flowing into a terminal supplying current to two windings. In this case, there is no way to determine how much current is flowing in each of the two windings, unlike the wye (star) case where the line-neutral current is the winding current (more on this later).

In a balanced, three-phase system driving a linear, balanced load, the neutral current should be zero. If not, then the system is not balanced; there are leakage currents, or the current flow measured in the neutral is the uncertainty in the current measurement equipment.

AC line currents supplied from the electric utility are always sinusoidal, with typical utility requirements that they contain <5% total harmonic distortion (THD) and that customers not disturb the service entrance with >5% THD.

Single-Phase AC Line Current

A single-phase, two-wire ac system contains a single current-carrying wire and a neutral wire. A single-phase, three-wire ac system contains two current-carrying wires.

As with voltage, the ac current is a rotating vector with a magnitude and an angle. The magnitude varies sinusoidally because the single-phase ac current is a rotating vector with a magnitude and an angle. The rotation period is the inverse of the supply frequency. The magnitude of this current vector is the instantaneous line-neutral current value, with a peak current Ipeak equal to √2 * Irms.

The voltage vector completes one revolution at a rate of one period = 1/frequency (50 Hz or 60 Hz). At any given moment in time, the current magnitude is equal to Ipeak * sin(α) where α = the angle of rotation in radians (Fig. 1.)

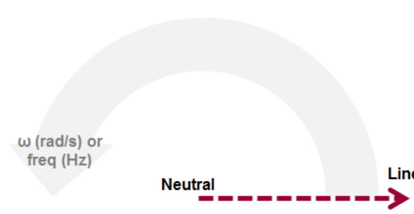

Fig. 1. Single-phase current vector system.

When electrically observed as a current-versus-time waveform, the "rotating" current vector appears as a sinusoidal waveform with a fixed frequency (as described above) and as illustrated in Fig. 2.

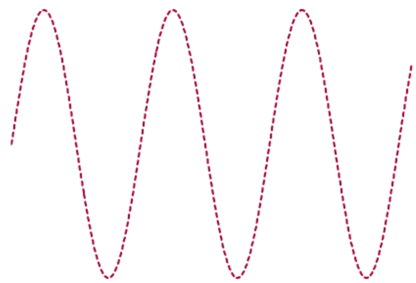

Fig. 2. A time-domain view of the single-phase current vector system.

As an example, if this sinusoid carries a 5-A or 5-Aac rating, what that really means is 5 Arms. Applying that knowledge allows us to calculate other current values, as follows:

Apk = √2 * Aac, or √2 * Arms = 7.07 A

Apk-pk = 2 * Apk = 14.14 A.

When using a Motor Drive Analyzer with an appropriate current probe (e.g., Teledyne LeCroy's CP030) to probe a 120-V electric utility ac supply, we may verify these signal levels through use of measurement parameters. The screen capture below shows an example of an ac line current signal acquisition with a complete set of current measurements. In this case, we are using the same toaster as described in the single-phase voltage section and measuring current while the toaster is "toasting." The current signal is on Channel 8 (C8, orange signal) (Fig. 3.)

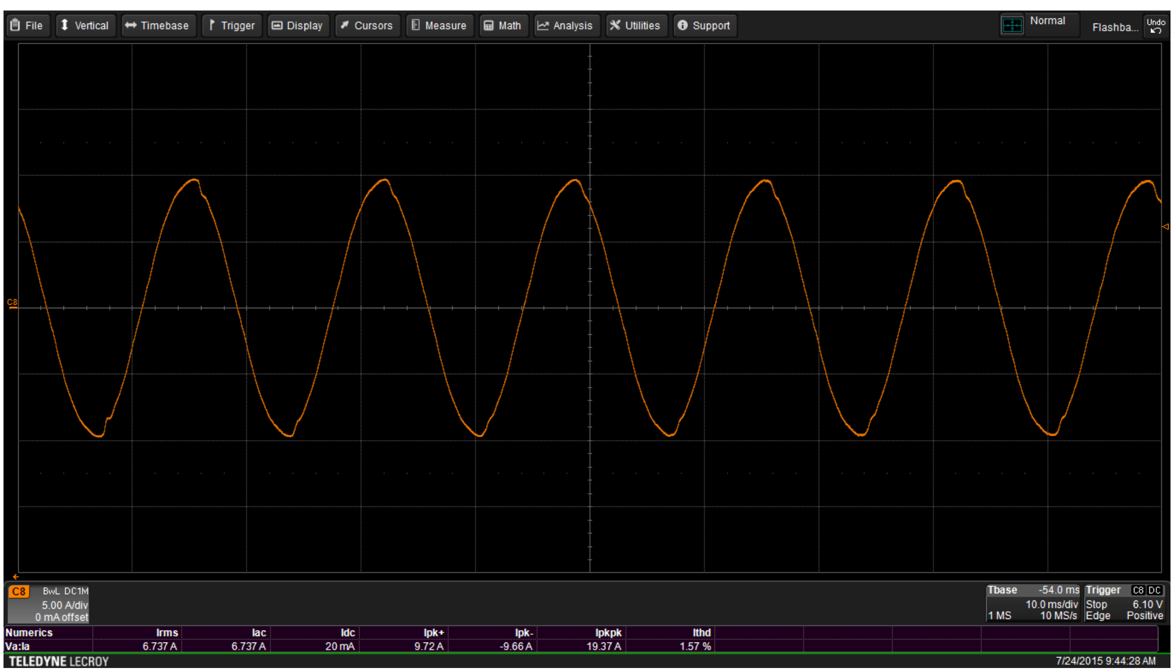

Fig. 3. 120-Vac current signal captured with a Teledyne LeCroy 8-channel, 12-bit Motor Drive Analyzer. This measurement is identical to the voltage measurement of the 120-Vac signal in part 2, except for the use of a current probe in place of a high-voltage probe.

The Numerics table at bottom of the display provides measurement parameters:

Numerics	Irms	Iac	Idc	Ipk+	Ipk-	Ipkpk	Ithd
Va:Ia	6.737 A	6.737 A	20 mA	9.72 A	-9.66 A	19.37 A	1.57 %

Fig. 4. The Numerics table lists key measurement values from the waveform in Fig. 3.

Note that the line current measured in this example is supplying a resistive load. Therefore, the current waveform and the voltage waveform are in-phase, as shown in Fig. 5 below.

Fig. 5. 120-Vac current (orange trace) and voltage (yellow trace) waveforms captured with a Teledyne LeCroy 8-channel, 12-bit Motor Drive Analyzer. The two signals are in phase as expected with a resistive load.

Additionally, note that the resistive load above is linear—the resistance is constant and the applied voltage results in a current that is linear in relation to the applied voltage. Therefore, the distortion profile ("shape") of the line current closely matches that of the line voltage, which is distinctly sinusoidal. If the load were non-linear, as in the case of a switched-mode power supply whereby the voltage is pulse-width modulated (PWM), the current waveform would consist of a series of pulses and would be very non-sinusoidal, as shown in Fig. 6.

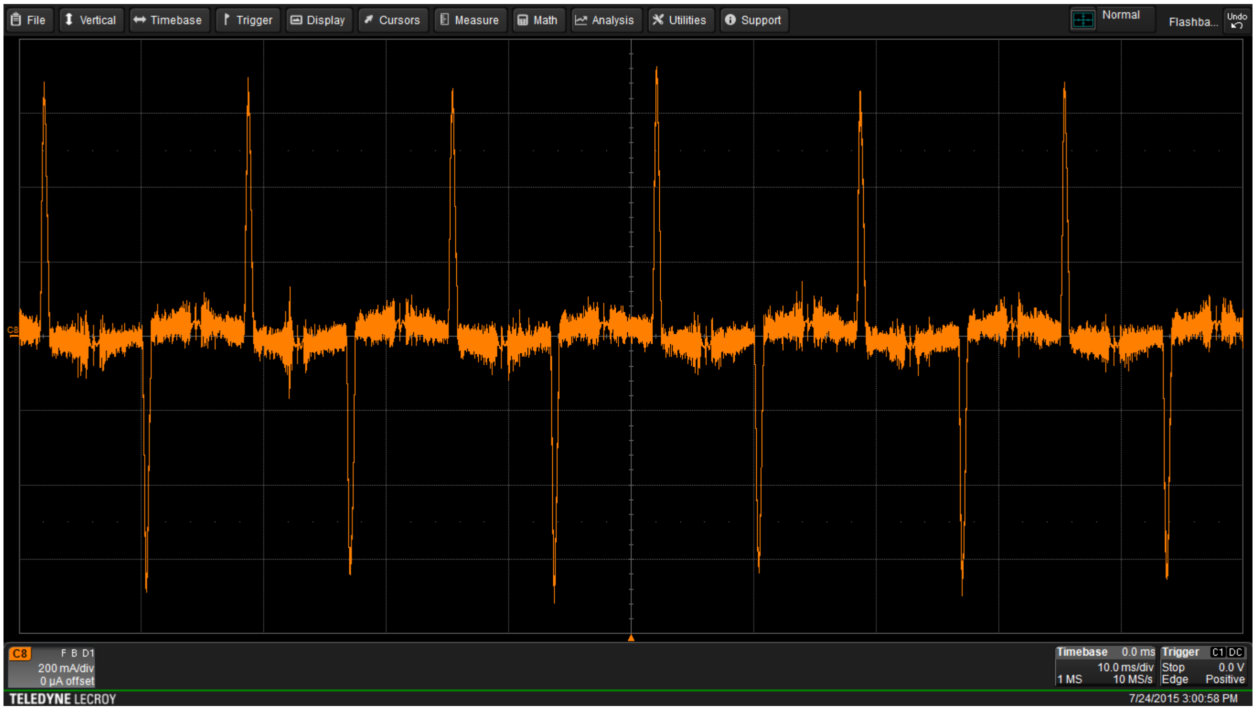

Fig. 6. Current measurement on the input of a switched-mode power supply. The nonlinear nature of the load produces this non-sinusoidal current waveform.

Conclusion

The concepts and techniques required for making ac current measurements such as will be required in motor drive applications are similar to those discussed previously for voltage measurement. This section reviewed the basics of measuring current in single-phase ac systems. In the upcoming part 5, the discussion is extended to measurement of three-phase ac line currents and the impact of different winding configurations. 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.

