Cutting AC Line Harmonics: A Three-Phase Challenge

by Mark Tublisky, Behlman Electronics

In years past, all loads that were connected to AC supply lines were either resistive loads such as light bulbs and heaters, or simple inductive loads such as fixed-speed AC motors. These types of loads drew sinusoidal currents from the AC supply lines and would not result in problematic harmonics. In fact, utility companies would require factories operating many motors to install capacitors that would bring the power factor of the factory from inductive to close-to-unity, or the utility would add a surcharge on the cost per kilowatt hour.

Today, an increasing portion of loads connected to AC supply lines draw currents that are not sinusoidal. Examples of such loads are power supplies used in devices such as computers (**Figure 1**). When AC voltage is applied to the power supply's diode bridge, the voltage is rectified by the bridge and the capacitor charges to near the peak of the rectified AC voltage. The result is a current waveform containing multiple harmonics (**Figure 2**).

Harmonics introduce a number of undesired consequences. They do not transmit power, which means they produce wasted power in the form of heat without increasing the DC power supplied. Harmonics increase the RMS current by as much as 50% and produce excessive heat in wires, contacts, fuses, and circuit breakers, which necessitates the added expense of using larger fuses and circuit breakers, and even heavier power lines. If the total harmonic current is large enough to distort the supply waveform, proper operation of the equipment can be compromised. Harmonics affect the power factor, which is the ratio of useful current to the total current. If for example the RMS current is 50% larger then the useful current, the power factor is 0.67.

The military has recognized that harmonic distortion can cause excessive heat in induction motors, as well as vibration and wear in bearings. Harmonics are detectable as signatures by sonar, and can also inadvertently be capacitively coupled to a ship's hull, inducing hull currents that disrupt the operation of systems such as degaussing equipment. In MIL-STD-1399 (Section 5.2.8, "Input Current Waveform") the Navy states the following:

"The operation of user equipment shall have the minimum harmonic distortion effect on the electric system. The operation of user equipment of the following specified ratings (**Table 1**) shall not cause single harmonic line currents to be generated that are greater then 3% of the unit's full rated load fundamental current between the second and thirty-second harmonic.

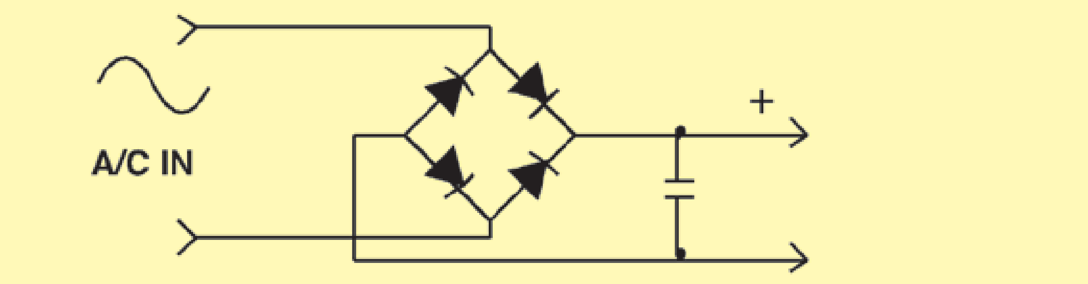

Figure 1: The input circuitry of a typical single-phase input power supply

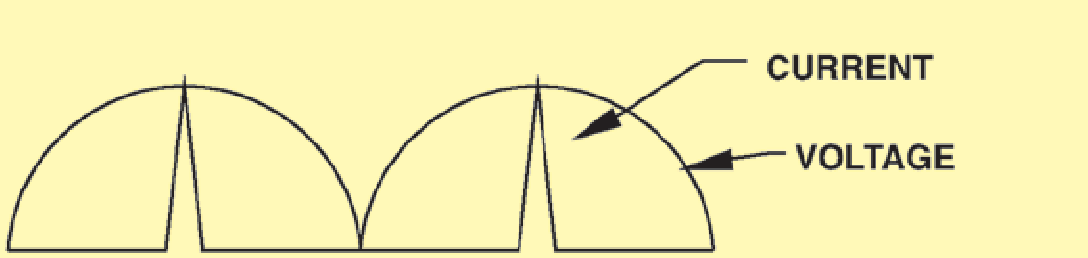

Figure 2: Current waveform of Diode Bridge

Currents with frequencies from the thirty-second harmonic through 20 kHz shall not exceed 100/n% of the unit's rated full load fundamental current, where n is the harmonic multiple number. Units with power ratings less than those specified above shall be current-amplitude limited so that no individual line current from the second harmonic through 20 KHz exceeds a magnitude of 100/n% of the unit's rated full load fundamental current."

What can be done?

Obviously, current harmonics on the input to any unit are problematic. For low-power, single-phase inputs, an ideal solution is electronic power factor correction devices. These devices, which are available as power modules up to about 1 kW, force the input current though a PWM scheme to be sinusoidal and in phase with the input voltage. The design of these devices can be incorporated into any power supply, and in fact there are many circuits available for doing so.

The approach above does not work for three-phase inputs, although three single-phase converters could be used in place of a three-phase input when the input is a WYE and the load is very symmetrical. The real problem comes into focus when the power level is much higher and the input is a DELTA. Without a neutral, three single-phase converters cannot be used.

However, when rectifying three-phase power, the harmonics are less than what would occur in single-phase power rectification. **Table 2** shows the effect of multi-phase rectification with an "ideal" choke input filter. Using **Table 2**, the number of phases required to limit harmonic content can be determined. Meeting MIL-STD-1399 requirements calls for 18 phases which produce 36 pulse rectification. In this case the first harmonic is the thirty-fifth and its contribution is 2.9%.

When a transformer is used on the three-phase input, the unit can be configured to have a multi-phase output. For example, if

Table 1.

Frequency of power source (Hz)	Rating of unit
60	1 kVA or more
400	0.2 kVA or more on other than a single-phase, 115 V source. 2 A or more on a single-phase, 115 V source

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the secondary of the transformer has a WYE and a DELTA, it would have the equivalent of six phases. A secondary with three sets of WYEs and DELTAs properly phase-shifted will have the equivalent of 18 phases. An 18-phase rectified output is referred to as having 36-pulse rectification since it would use 36 diodes (**Figure 3**). With so many pulses, the choke becomes reasonably small and is easily realizable.

Not many devices have 18-phase, 36-pulse rectification capabilities. One that does is the BL+ 120 from Behlman Electronics (**Figure 4**). The BL+ 120 is a 120 kVA frequency converter with a specially-wound input transformer that produces an 18-phase output that is rectified and filtered for 36-pulse rectification with the resultant DC supplied to a switching frequency inverter. It can produce low-distortion sine waves from 45 to 500 Hz, and up to 2000 Hz where required. Input voltage can range from 120/208 VAC to 277/480 VAC in either WYE or DELTA connection. The unit can be controlled manually or through an optional computer interface via RS-232, IEEE-488, USB, or Ethernet.

Summary

Problems caused by AC line harmonics are receiving more attention as a critical power quality concern with the growing percentage of electricity now passing through loads drawing non-sinusoidal currents. Clearly, today's engineers must be aware of the negative impact of AC line harmonics in their systems, and of the solutions available to address problem.

About the Author

Mark Tublisky has a BEE from City College of New York and a MSEE from Polytechnic University. He has more than 40 years of experience in the design of digital and analog electronics. Early in his career, he worked on the control system for the NASA lunar module. He has been working at Behlman and its predecessor, Astrosystems, for more than 30 years and is currently president and chief engineer. He can be reached at (631) 435-0410 or markt@behlman.com.

Table 2. Normalized Harmonic Amplitudes For Ideal Choke Input Filter.

	1-Phase	3- Phase	6- Phase	18-Phase
	Power Factor			
	0.900	0.957	0.990	0.999
	RMS Current			
	1.111	1.045	1.010	1.001
Harmonic	**Harmonic amplitude**			
3rd	0.333	--	--	--
5th	0.200	0.200	--	--
7th	0.143	0.143	--	--
9th	0.111	--	--	--
11th	0.091	0.091	0.091	--
13th	0.077	0.077	0.077	--
15th	0.067	--	--	--
17th	0.059	0.059	--	--
19th	0.053	0.053	--	--
21st	0.048	--	--	--
23rd	0.043	0.043	0.043	--
25th	0.040	0.040	0.040	--
27th	0.037	--	--	--
29th	0.034	0.034	--	--
31st	0.032	0.032	--	--
33rd	0.030	--	--	--
35th	0.029	0.029	0.029	0.029
37th	0.027	0.027	0.027	0.027
39th	0.026	--	--	--
41st	0.024	0.024	--	--
43rd	0.023	0.023	--	--
45th	0.022	--	--	--
47th	0.021	0.021	0.021	--
49th	0.020	0.020	0.020	--
51st	0.020	--	--	--
53rd	0.019	0.019	--	--
55th	0.018	0.018	--	--

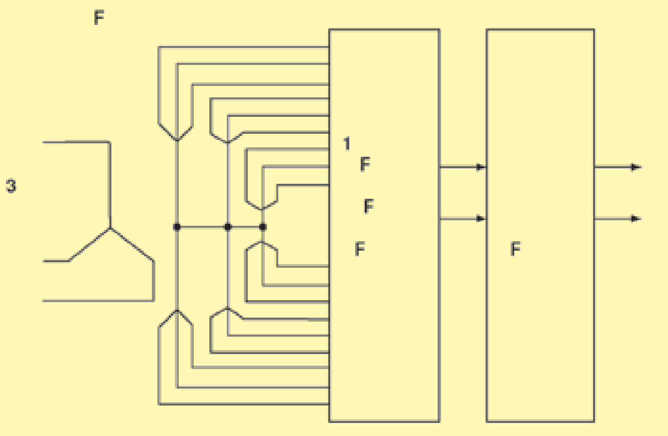

Figure 3: Frequency converter block diagram

Figure 4 The Behlman BL+ 120 frequency converter has 18-phase, 36-pulse rectification capabilities.