Cutting AC Line Harmonics: A Three-Phase challenge

September 2015
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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 KWH.

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 shows the input circuitry of a typical single-phase input power supply.

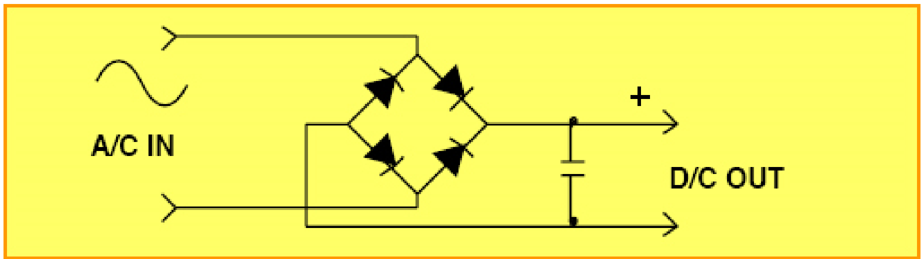

Fig. 1

Input of a Single-phase Power Supply

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, as shown in Figure 2.

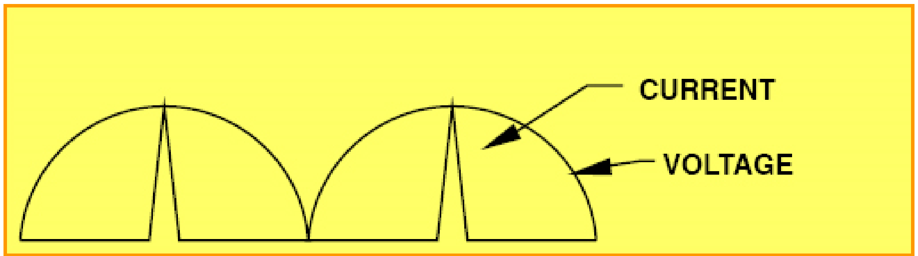

Fig. 2

Current Waveform of Diode Bridge

Harmonics introduce a number of undesired consequences. For one thing 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 percent, and produce excessive heat in such things as wires, contacts, fuses and circuit breakers – which necessitates the added expenses 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 percent larger than 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 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.*

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 volt source. 2 amperes or more on a single-phase, 115 volt source

> *Additionally, 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 then 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 units 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 approximately 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.

On the other hand when rectifying three-phase power, the harmonics are less than what would occur in single-phase power rectification. Table 1 shows the effect of multi-phase rectification with an "ideal" choke input filter. Using Table 1, 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, one can configure the unit to have a multi-phase output. For example, if 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 as shown in Figure 3. With so many pulses the choke becomes reasonably small and is easily realizable.

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	--	--

Table 1

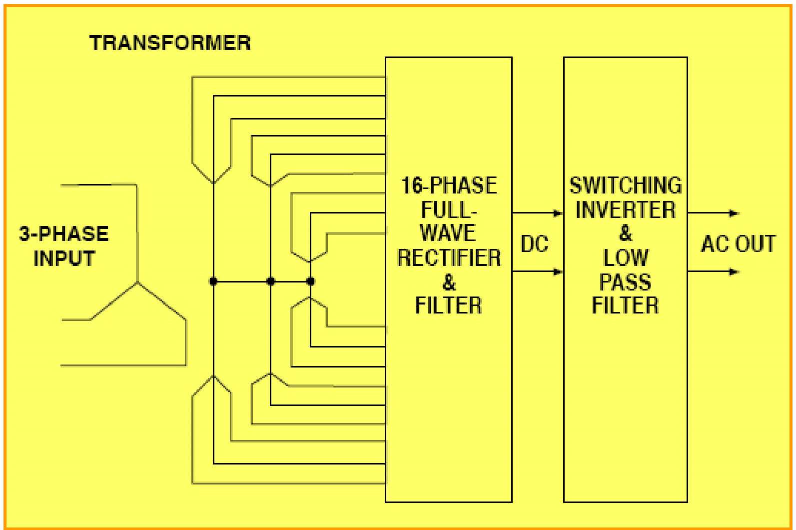

Fig. 3

Frequency Converter Block Diagram

Not many devices have 18-phase, 36 pulse rectification capabilities. One that does is the BL+ 120 from Behlman Electronics. The BL+ 120 is a 120 KVA frequency converter having 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 (Figure 4). Input voltage can range from 120/208 to 277/480 in either WYE or DELTA connection. The unit is available with fixed voltage and frequency or can be controlled manually or through an optional computer interface via RS232, IEEE 488, USB or Ethernet.

Fig. 4
Behlman BL+120
Frequency Converter

In Summary

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

About the Author

Jerry Hovdestad has a BEE from Manhattan College, and an MSEE from NYU. He has over 45 years of experience in the design of analog and digital electronics. Early in his career, he worked on D/A converters for the ground tracking radar in the F111. He also designed many analog and digital control and display systems for the US submarine fleet. Many of these systems are still in use today. Jerry has worked at Behlman and its predecessor, Astrosystems for his entire career. He is currently the Director of COTS Engineering at Behlman and can be reached at 631-435-0410 X 194, jerryh@behlman.com, or via their web site at www.behlman.com