Entergy TECH BRIEF

Published by the EPRI Power Electronics Applications Center | Brief No. 33 | December 1996

Shared-Neutral Current in Branch Circuits Serving Office Equipment

Background

Many of the single-phase electronic appliances found in today's commercial buildings have switch-mode power supplies, which draw non-sinusoidal current. Cash registers, fax machines, personal computers, and fluorescent lighting are all examples of nonlinear appliances. In a three-phase wiring system with a shared-neutral conductor, the current of these nonlinear appliances may combine in the neutral conductor—but just how much current has been a subject of debate and confusion. Some say that the neutral current can be as high as two times the maximum phase current. Others say that the neutral current can be as much as 2.7 or even three times the maximum phase current. According to the NEC committee on nonlinear loads, the theoretical maximum current in a shared-neutral conductor due to harmonics cannot exceed 1.73 times the highest phase current.

Objective

The objective of the tests performed at the EPRI Power Electronics Applications Center (PEAC) was to determine how phase currents of typical office appliances combine in a shared-neutral conductor of a three-phase branch circuit.

Test Setup

As shown in Figure 1, each phase (A, B, and C) of a three-phase branch circuit was loaded according to the ten loading configurations in Table 1. Fifty feet of 12-gauge wire representing a typical branch circuit was used to connect the shared-neutral, ground, and each phase conductor to the loads. The phase-to-neutral voltage at each load was maintained at approximately 120 volts RMS. During each test, true-RMS ammeters measured the RMS current through each phase conductor and the shared-neutral conductor.

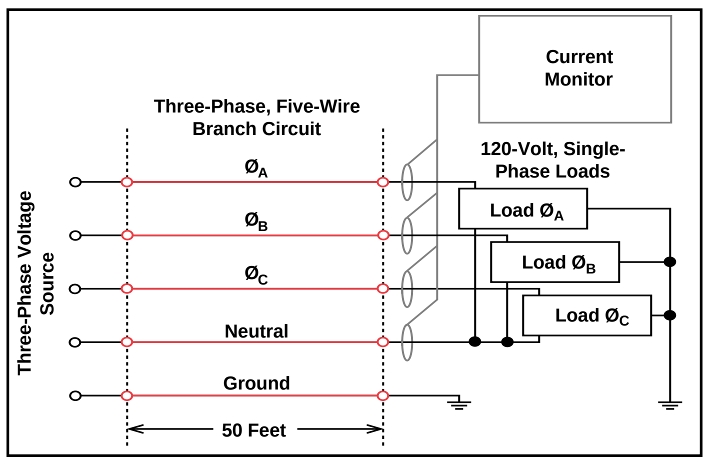

Figure 1. Test Setup

Table 1. The Nine Load Configurations

Config. Number	*Load Type per Phase**	*Loading*†		
		Phase A	*Phase B*	*Phase C*
1	100% L	Half	Half	Max
2	100% L	Max	Max	None
3	100% L	Max	Max	Max
4	70% NL, 30% L	Half	Half	Max
5	70% NL, 30% L	Max	Max	None
6	70% NL, 30% L	Max	Max	Max
7	100% NL	Half	Half	Max
8	100% NL	Max	Max	None
9	100% NL	Max	Max	Max
10	100% NL	80%	80%	80%

***L = Linear (less than 5% current harmonic distortion)**
NL = Nonlinear (greater than 100% current harmonic distortion)
†Maximum loading was considered 20 amps RMS (breaker protection limit).

To identify the types of office appliances most likely to generate non-sinusoidal neutral currents, the harmonic current spectrum of typical office loads was recorded. These loads included appliances such as personal computers, laser printers, monitors, fax machines, water coolers, television sets, VCRs, electronic clock/radios, microwave ovens, and several types of magnetic and electronic fluorescent lamps. Of all these appliances, the power supplies of typical personal computers generated the most harmonic current. Therefore, computer power supplies were used as the nonlinear loads for the loading configurations in Table 1. The linear loads were purely resistive incandescent light bulbs.

TEST RESULTS

To determine how phase currents combine in the shared neutral of a three-phase system where all three phases contribute to the shared-neutral current, the neutral current was measured for each load configuration in Table 1. As shown in Table 2, the highest neutral current was achieved by fully loading all three phases with nonlinear power supplies (configuration 9). The neutral current in this loading configuration was about 32 amps of predominately 3rd harmonic, or about 1.7 times the highest phase current (20 amps). Configuration 10 represented the maximum *continuous* load allowed by the National Electric Code (16 amps in a 20-amp circuit for three hours or more), Article 210-22. Again, when each phase was loaded with nonlinear power supplies, the neutral current was about 1.7 times the highest phase current (16 amps), or about 26 amps. When each phase was fully loaded with a nearly-balanced linear load (configuration 3), the phase currents almost canceled each other, yielding only about one amp of current in the neutral. For all the linear-load configurations, the neutral current did not exceed the highest phase current. Figure 2 shows a comparison between the maximum phase current (20 amps) and the shared-neutral current according to the ratio of nonlinear-to-linear loading (0/100%, 70/30%, and 100/0%).

Table 2. Current Measurements of the Ten Loading Configurations

Config. Number		*Current (Amperes)*			
		Phase A	*Phase B*	*Phase C*	*Neutral*
1	L	9.8	9.8	20.0	10.3
2	L	20.0	20.0	0	19.6
3	L	19.6	19.6	20.0	1.3
4	MIX	10.1	10.3	20.0	19.8
5	MIX	20.0	20.0	0	24.1
6	MIX	20.0	20.0	20.0	24.9
7	NL	10.0	9.8	20.0	23.8
8	NL	20.0	19.9	0	26.6
9	NL	20.0	19.9	20.1	32.2
10	NL	15.8	15.5	16.0	26.4

DISCUSSION

The test results demonstrate that the neutral current increases as the ratio of nonlinear-to-linear loading increases. Configuration 9, where all loads were nonlinear, yielded a neutral current slightly less than 1.73 times the maximum phase current, which matches mathematical predictions (see the Tutorial). However, in most office buildings, the loads are a mixture of linear appliances, such as incandescent lighting and fans, and nonlinear appliances, such as computers and fluorescent lighting. The ratio of nonlinear-to-linear loading in most office buildings may be similar to the ratio in configurations 4–6 (70/30%), which yielded a neutral current of less than 125% of the highest phase current. Therefore, if a circuit is operated as designed—with a maximum continuous load less than 80% of the circuit-breaker rating—then a properly sized neutral conductor (see “Significance”) will be large enough for the current of such mixed loads. In the case of 100% nonlinear loading, such as configuration

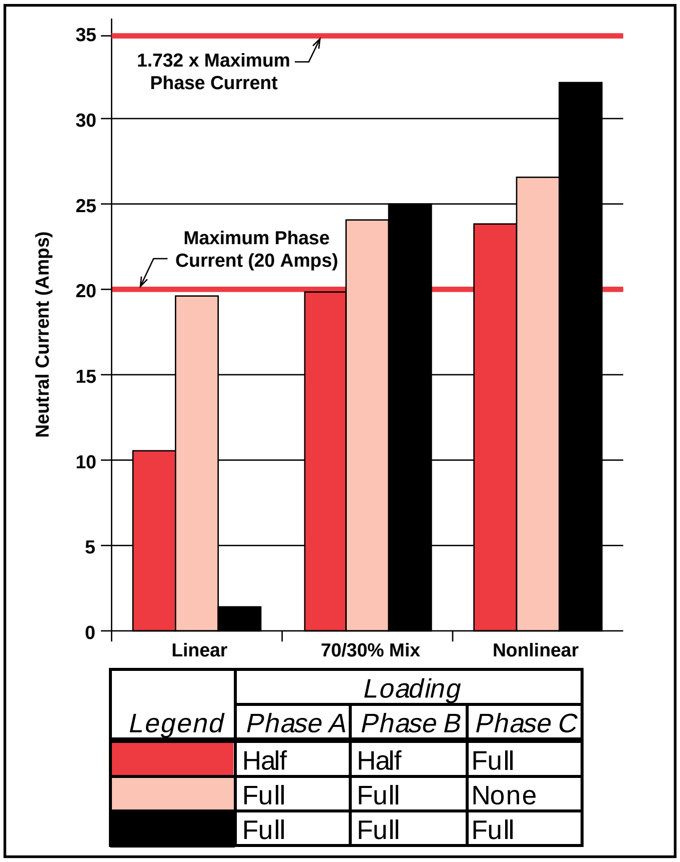

Figure 2. Comparison of Neutral Currents According to Loading Configuration and Load Type

10, compliance with the NEC maximum continuous current of 80% reduces the shared-neutral current from 170% to 130% of the circuit-protective device rating.

SIGNIFICANCE

It is unlikely that all office appliances in a three-phase system would be nonlinear. However, such a case can be accommodated by using a larger neutral conductor. For example, using a properly rated 10-gauge neutral conductor with 12-gauge phase conductors in a 20-amp circuit or a 12-gauge neutral conductor with 14-gauge phase conductors in a 15-amp circuit would eliminate potential overheating problems of branch circuit conductors. Also, for existing wiring, running a parallel neutral, which is permitted by NEC 310-1996 for wiring sizes equal to or greater than No. 2 AWG, will eliminate potential overheating of panel neutral conductors. If the pre-existing wiring cannot be modified, then a third-harmonic filter may be the most cost-effective solution. Another alternative is to use a power-factor-corrected UPS or another low-harmonic type of power conditioner, such as a ferro-resonant transformer, to supply nonlinear loads. An effective long-term solution is to specify power-factor-corrected power supplies, which eliminate additive harmonic currents.

TUTORIAL: Determining RMS Current in Shared Neutrals

As shown in Figure A, if linear loads are balanced across all three phases, phase currents cancel each other in a neutral conductor. However, as test results show, currents of balanced nonlinear loads, also shown in Figure A, do not cancel but combine in a shared neutral because the currents contain a significant amount of odd triplen harmonics (3rd, 9th, 15th, and so on).

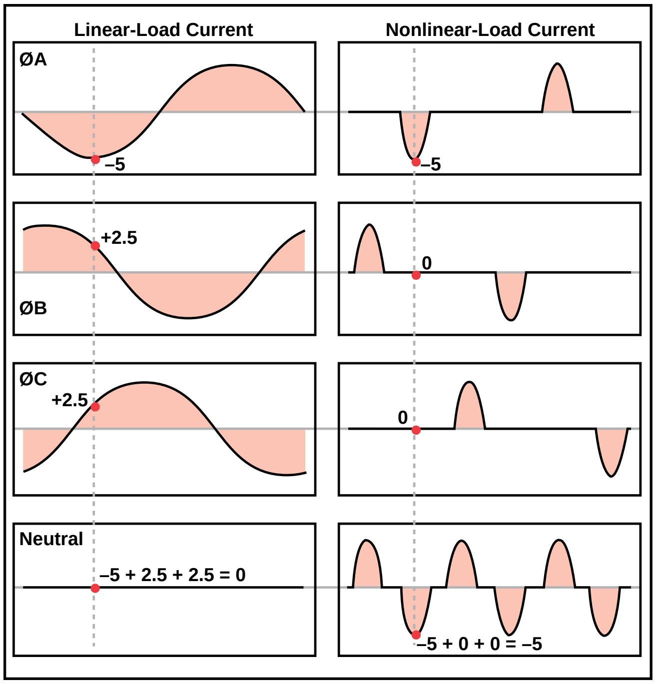

Figure A

At first glance, the non-sinusoidal neutral current in Figure A appears to be exactly three times the current in any one phase. However, test results demonstrate that shared-neutral current cannot be greater than 1.73 times the highest phase current. Looking at a sample calculation based upon the formula for RMS current reveals why:

$$I_{\text{rms}} = \sqrt{\frac{\int_0^T i^2(t)\,dt}{T}} = \sqrt{\frac{\text{area}\,[i^2 t]}{T}}$$

The RMS (root-mean-square) current value is used to determine conductor loading because it accounts for the different heat-generating characteristics of different types of current (ac or dc, sinusoidal or non-sinusoidal). To determine the RMS value of a current over a particular period of time *(T)*, first *square* the function *i(t)*. Then find the area under the curve as described by the function $i^2(t)$. Next, divide by the length of one cycle *(T)* to get a *mean* value of the squared waveform. Finally, take the square *root* of the mean to yield the RMS value.

Continued on back page.

TUTORIAL, Continued

Applying the RMS formula to the worst-case scenario of shared-neutral loading (that is, all three phases fully loaded with single-phase nonlinear appliances) should yield the maximum possible neutral current. To simplify the math for this example, the areas of non-sinusoidal current in Figure A have been approximated with rectangles in Figure B. For the following calculations, assume that all current amplitudes (a_1 through a_6) are equal and that all pulse durations (t_1 through t_6) are equal. The phase current is:

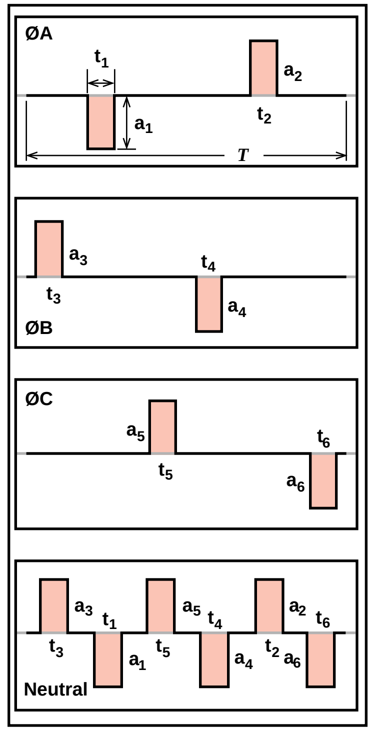

Figure B

$$I_{\text{Ørms}} = \sqrt{\frac{\text{area}\,[i^2t]}{T}} = \sqrt{\frac{a^2t + a^2t}{T}} = \sqrt{\frac{2a^2t}{T}}$$

The neutral current is:

$$I_{\text{Nrms}} = \sqrt{\frac{\text{area}\,[i^2t]}{T}} = \sqrt{\frac{a_1^2t + a_2^2t + \ldots a_6^2t}{T}} = \sqrt{\frac{6a^2t}{T}}$$

The relationship between the phase and neutral currents is:

$$\frac{I_{\text{Ørms}}}{I_{\text{Nrms}}} = \frac{\sqrt{\frac{2a^2t}{T}}}{\sqrt{\frac{6a^2t}{T}}} = \frac{\sqrt{1}}{\sqrt{3}} \approx \frac{1}{1.73}$$

The shared RMS neutral current for the worst-case scenario is:

$$I_{\text{Nrms}} = \sqrt{3} \times I_{\text{Ørms}} \approx 1.73 \times I_{\text{Ørms}}$$

FOR MORE INFORMATION, CONTACT:

Entergy

Your Entergy account representative.