

# Harmonic Current Reduction Techniques For Computer Systems

## SUMMARY

While standards to limit the generation of harmonic currents are under consideration, harmonic control today relies primarily on remedial techniques. Passive filters are the most popular, but require careful application, can be expensive, and may produce unwanted side effects. Active filters are costly and not widely available. Harmonic currents can be controlled by carefully selected special purpose transformers, e.g.:

- Delta-wye: cancels balanced triplens (3rd, 9th, 15th, ... harmonics)
- Zig-zag: diverts triplens from neutral to phase conductors
- Dual-output: cancels 3rd, 5th, 7th, 9th, 15th, 17th, 21st, ...
- Quad-output: cancels 3rd, 5th, 7th, 9th, 11th, 13th, 15th, 17th, 19th, 21st, ...

Liebert Precision Power Centers offer a variety of standard and optional features to control harmonic currents, including a load distortion filter and delta-wye (standard), K-20 rated, dual-output, and quad-output transformers.

With today's increased use of modern electronics has come a corresponding concern about harmonic currents and their effects on the power system. Most modern electronic equipment contains static power converters which generate harmonic currents. Harmonic currents flow in the power system as reactive power (VAR), adding to the apparent power demand (VA). In addition to the increased apparent power demand of nonlinear loads, the harmonic currents cause additional heating and stresses in the power system components due to their higher frequencies. In some circumstances, the nonlinear load's harmonic currents can excite harmonic resonances, cause undesirable system interactions, or cause misoperation of other equipment.

Computers and similar electronic loads have traditionally been nonlinear loads. While the development of switch-mode power supplies (SMPS) has been blamed for the harmonic current problems associated with computers, the earlier "linear" power supplies also were nonlinear loads which generated similar harmonic currents but generally at lower levels than the SMPS. It is arguable that improvements in computers which spawned the great proliferation of single-phase, 120 volt computers and electronics outside the protected environments of traditional data processing rooms are responsible for the present industry attention to harmonics issues. Nonetheless, there is great interest in harmonic current reduction techniques.

Industry standards are being formulated which are intended to limit harmonic currents in electric power systems. Two such standards are IEC 555 and IEEE 519. In Europe, IEC 555 limits the levels of harmonic currents that can be generated by individual load equipment intended to be connected to public power systems. In the United States, IEEE 519 establishes recommended limits on the level of harmonic currents that users can inject into the public power system (see

Table 1). Until these and other standards take hold and successfully encourage the availability of computers and other electronic loads that do not generate significant levels of harmonic currents, users and building system designers must employ remedial harmonic current reduction methods.

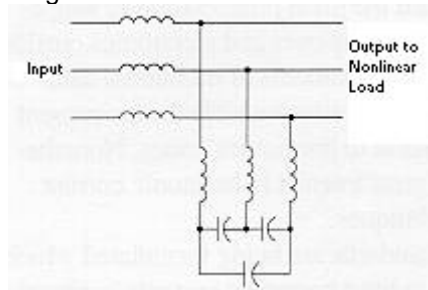
Table 1. Revised IEEE 519 Limits for Harmonic Currents at the Point of Common Coupling

$I_{sc} / I_L$	Odd Harmonics					TDD
	<11	11-17	17-23	23-35	>35	
<20	4.0	2.0	1.5	0.6	0.3	5.0%
20-50	7.0	3.5	2.5	1.0	0.5	8.0%
50-100	10.0	4.5	4.0	1.5	0.7	12.0%
100-1000	12.0	5.5	5.0	2.0	1.0	15.0%
>1000	15.0	7.0	6.0	2.5	1.4	20.0%

$I_{sc}$  = available short circuit current at point of common coupling  
 $I_L$  = maximum fundamental current demand  
TDD = total demand distortion

One of the most popular methods of harmonic current reduction involves the use of passive harmonic filters. Passive harmonic filters use inductors and capacitors tuned to block or absorb particular harmonic currents. A typical harmonic current filter is shown in Figure 1. Harmonic filters generally require careful application to ensure their compatibility with the power system and all present and future nonlinear loads. Harmonic filters tend to be relatively large and can be expensive.

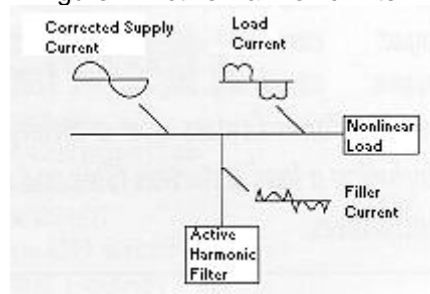
Figure 1. Passive Harmonic Filter.



Often, passive filters cannot provide optimal harmonic current reduction without unwanted side effects such as ringing transient response, unwanted resonances, and overcompensation. Diode-rectifier loads, typical of computer power supplies, often require very little 60 Hz power factor correction capacitance relative to the level of harmonic currents generated. As such, it is extremely difficult to provide a passive harmonic filter that does not overcompensate at 60 Hz, causing a leading displacement power factor.

Active harmonic filters (see Figure 2) are becoming commercially available. In principle, with sophisticated power electronics, it is possible to produce a device that either provides a variable harmonic impedance to absorb some or all of the harmonic currents generated by the nonlinear load(s) or provides harmonic currents of opposite polarity to cancel the nonlinear load's harmonic currents. To date, active filters have been very costly and are not widely available.

Figure 2. Active Harmonic Filter.



Other harmonic current reduction techniques which have been applied to computer loads involve the use of transformers to cancel certain harmonic currents. In three-phase, four-wire power systems supplying single-phase nonlinear loads, delta-wye isolation transformers (see Figure 3) will cancel the balanced triplen harmonic currents (3rd, 9th, 15th, ...). The triplen harmonics, being zero-sequence components, add instead of cancel in the neutral of three-phase, four-wire power systems and are responsible for neutral current being greater than the phase currents, even with balanced loading.

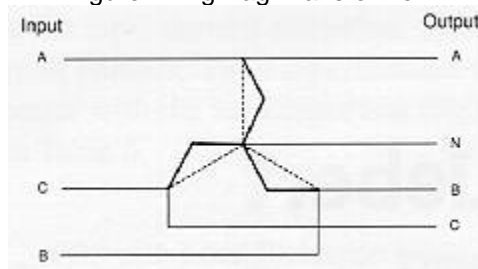
Figure 3. Delta-Wye Transformer.



The triplen harmonics circulate in the delta of the transformer with only the unbalanced portion present in the transformer input line currents.

Zig-zag autotransformers can also be used to reduce the triplen harmonics. A zig-zag transformer consists of 6 identical windings, two per phase, connected such that the winding vectors "zig" and "zag" from neutral to each line as shown in Figure 4. With this arrangement, the triplen harmonics are diverted from the neutral to the phase conductors like a triplen harmonic filter. While the load current contains triplen harmonics, the input line current contains only the unbalanced triplen harmonics.

Figure 4. Zig-Zag Transformer.



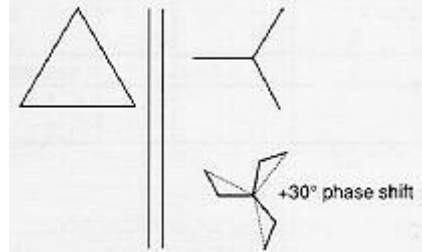
Multi-phase power systems can be used to cancel harmonic currents. A six-phase power system, consisting of two three-phase power sources phase-shifted 30 degrees relative to each other, has been used for quite some time with rectifier circuits to reduce input current distortion. For higher power rectifier circuits, even 12-phase power systems have been used for further harmonic current reduction.

Recently, these same techniques (multi-phase power sources) have been applied to computer mainframes and other data processing equipment to reduce harmonic current distortion. Special isolation transformers with multiple output windings have been devised to cancel particular harmonic currents. Typical computer system requirements of balanced voltages to ground and a

common ground reference require that the multiple outputs be multiple wye outputs with a common neutral.

A dual-output transformer (see Figure 5) is constructed with two wye outputs having a 30 degree phase shift. The delta primary allows cancellation of the balanced triplen harmonic currents. The 30 degree phase shift between outputs provides cancellation of the 5th, 7th, 17th, 19th, ... harmonic currents which are balanced between the two outputs. For maximum harmonic current cancellation, identical nonlinear loads need to be connected to each output. If the harmonic current content of the loads on each output is not identical in amplitude and phase displacement relative to the applied voltage, then less than total cancellation of the harmonic currents is obtained. This configuration is particularly applicable to mainframe applications where virtually identical loads can be connected to each output.

Figure 5. Dual Output Transformer.



Another multiple wye-output transformer configuration is a quad-output with the outputs phase-displaced in 15 degree increments as shown in Figure 6. The delta primary provides cancellation of the balanced triplen harmonic currents, while the 15 degree phase-shifts between outputs provide cancellation of the 5th, 7th, 11th, 13th, 17th, 19th, 29th, 31st, ... harmonic currents which are balanced across the four outputs. Again, if the harmonic current content is not identical on all four outputs, then less than total cancellation is obtained.

Figure 6. Quad-Output Transformer.

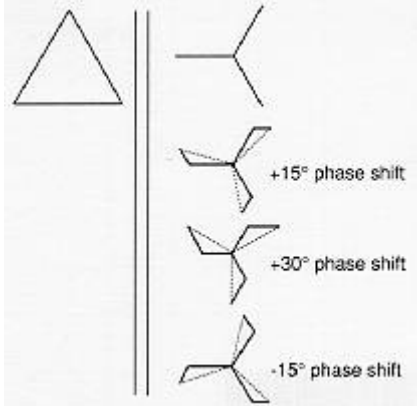


Figure 7 and Table 2 are examples of a typical mainframe and expected harmonic current cancellation using dual-output and quad-output transformers in a Liebert Precision Power Center (PPC) power distribution unit. Applying a two-input mainframe to a dual-output transformer (Configuration 1), even with considerable imbalance on the two outputs, results in significant harmonic current reduction. Applying a four-input mainframe (or two two-input units) to a quad-output transformer (Configuration 2) results in even greater harmonic current reduction. Applying a four-input mainframe (or two two-input units) to a dual-output transformer (Configuration 3) results in the best harmonic current reduction because the loading on the two outputs is almost perfectly balanced.

Figure 7. Typical Multiple-Output Liebert PPC Applications with Mainframe Computers

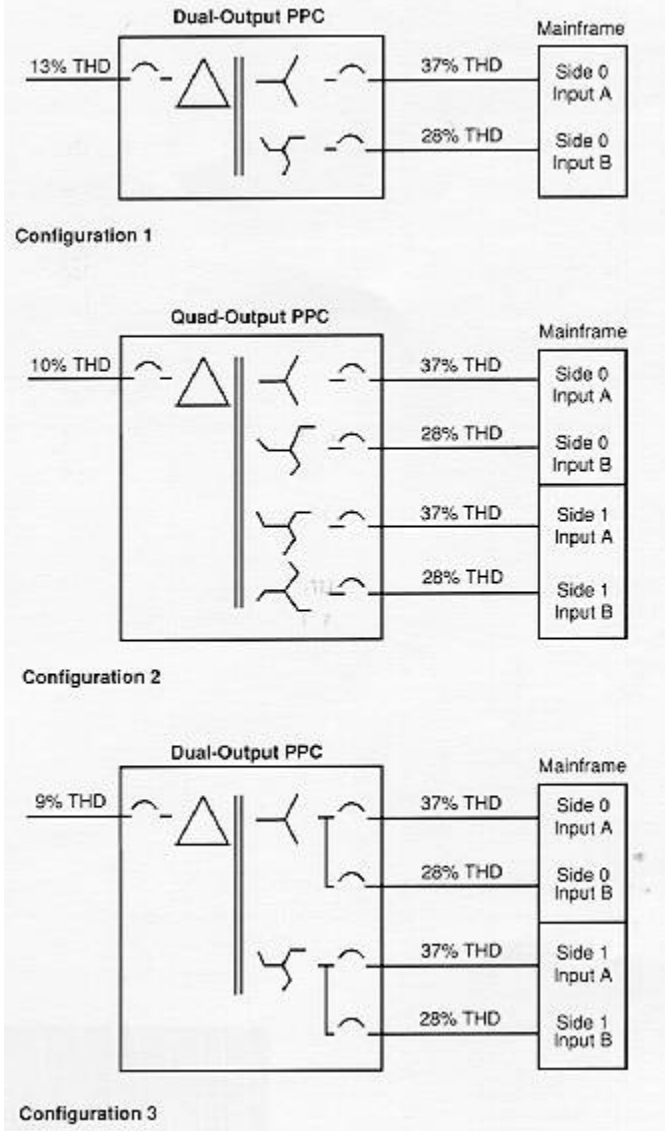


Table 2. Expected Current Cancellations for a Typical Mainframe

Harmonic	Input Current Distortion						
	Typical Mainframe Computer				With Precision Power Center		
	Side 0		Side 1		Conf. 1*	Conf. 2**	Conf. 3***
	Input A	Input B	Input A	Input B	Dual-Output	Quad-Output	Dual-Output
1	100%	100%	100%	100%	100%	100%	100%
3	3	2	3	2	0	0	0
5	31	24	31	24	7	7	0
7	16	11	16	11	4	4	0
9	0	1	0	1	0	0	0
11	8	3	8	3	6	3	6
13	6	6	6	6	6	1	6

15	1	1	1	1	0	0	0
17	5	4	5	4	1	1	0
19	4	2	4	2	1	1	0
21	0	0	0	0	0	0	0
23	3	1	3	1	2	2	2
25	3	3	3	3	3	3	3
<b>RMS</b>	<b>93A</b>	<b>69A</b>	<b>93A</b>	<b>69A</b>			
<b>THD</b>	<b>37%</b>	<b>28%</b>	<b>37%</b>	<b>28%</b>	<b>13%</b>	<b>10%</b>	<b>9%</b>

\* Configuration 1: PPC with dual-output transformer feeding side 0, inputs A and B. See Figure 7.

\*\* Configuration 2: PPC with quad-output transformer feeding sides 0 and 1, inputs A and B. See Figure 7.

\*\*\* Configuration 3: PPC with dual-output transformer feeding sides 0 and 1, inputs A and B. See Figure 7.

When applying multiple-output transformers to power distribution centers, care must be taken to match the output distribution and monitoring to the number of transformer outputs. The output distribution configuration should allow balancing of the loads across all outputs. For example, a quad-output transformer can not be used with only two output panelboards. A dual-output transformer should not be used with three output panelboards.

With multiple-output transformers, the monitoring scheme on the power distribution unit should allow complete monitoring of each transformer output, including output voltages, currents, and power. With multiple transformer outputs, there is no single output voltage, current, or power measurement which indicates the total transformer output. To provide monitoring of the multiple outputs, a selector switch can be used with a three-phase monitoring system to monitor each of the transformer outputs individually, or multiple three-phase monitoring systems can be used to monitor each of the transformer outputs simultaneously.

Liebert offers a complete range of harmonic solution options in its Precision Power Center, a power distribution unit with a field-proven history dating back to 1979. The basic Precision Power Center is designed to accommodate moderate levels of harmonic currents. The standard delta-wye transformer provides cancellation of the triplen harmonic currents, and all common neutral components are designed to tolerate up to 1.73 times full load.

Where high levels of harmonic currents are anticipated, Precision Power Centers are available with a K-20 rated transformer. These transformers are specially designed to minimize the additional heating effects caused by high harmonic loads and allow operation with nonlinear loads up to a K-Factor of 20 without derating. K-Factor transformers do not provide harmonic current reduction other than the cancellation of the triplen harmonics in the delta primary.

Precision Power Centers can be equipped with a load distortion filter. This option adds passive harmonic current filters to absorb 5th and 7th harmonic currents generated by the nonlinear loads, thus reducing the input current distortion, independent of load current balance. Typical performance of a power center with the load distortion filter option is shown in Table 3.

Table 3. PPC with Load Distortion Filter.

Harmonic	Output	Input
1	100.0%	100.0%
3	80.0	3.6
5	49.7	4.9
7	21.3	3.1
9	3.5	0.2

11	2.6	1.5
13	1.6	0.3
15	0.7	0.0
17	1.3	0.5
19	0.8	0.7
21	0.8	0.0
23	0.5	1.4
25	0.3	0.7
<b>Current THD</b>	<b>96.7%</b>	<b>7.2%</b>
<b>kW</b>	<b>44.0</b>	<b>46.1</b>
<b>kVA</b>	<b>62.7</b>	<b>48.6</b>
<b>PF</b>	<b>0.70</b>	<b>0.95</b>

To provide additional harmonic current cancellation, Precision Power Centers can be furnished with specially designed multiple-output transformers. Both dual-output and quad-output transformers are available to meet particular application requirements.

Precision Power Center harmonic solution options are summarized in Table 4.

Table 4. Liebert PPC Harmonic Solutions Comparison.

<b>Feature</b>	<b>Basic System</b>	<b>With K-factor transformer</b>	<b>With load distortion filter</b>	<b>With multi-output transformer</b>
Designed for nonlinear loads	X	X	X	X
Neutral sized for greater than 1.73 x FLA	X	X	X	X
Available with multiple output breakers for mainframes	X	X	X	X
Reduces harmonic current distortion	X	X	X	X
Improves harmonic power factor	X	X	X	X
Cancels triplen (3, 9, 15, ...) harmonics	X	X	X	X
Tolerates higher levels of harmonic currents		X	X	X
Absorbs 5th and 7th harmonic currents			X	
Provided 60 Hz capacitance			X	
Cancels non-triplen (5, 7, ...) harmonics				X

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