

Power Quality and Lighting (Part II)
EN61000-3-2;
Controlling Harmonic Emissions in Lighting Applications

This article will continue the discussion of power quality in lighting and look at some of the ways to control harmonic content. There are several standards in use and the categorization of emissions limits varies from one standard to the next, though they have much in common. Compliancy is based on the standard referenced for each. EN61000-3-2 Class C is the standard which considers only the harmonic emissions themselves as shown below. (For more information regarding the basic principles of EN61000-3-2 Class C see the Astrodyne article titled, "[Power Quality and Lighting](#)").

EN 61000-3-2 Class C Lighting	
Harmonic Order n	Maximum Harmonic Input Current % of Fundamental
2	2
3	30° PF
5	10
7	7
9	5
11 = n = 39	3

Other regulations include Energy Star standards for luminaires as well as the ANSI (American National Standards institute) C82.77-2002.

- **Energy Star**
The [Energy Star Product Specification for Luminaires \(Light Fixtures\)](#) is very comprehensive, containing criteria for photometric, safety and electrical performance to name a few. For the purposes of this article we will only consider a subset of the electrical performance section, which is the power factor requirements section seen below.

Note that that the measurement and reference standard for Solid State Lighting is none other than ANSI C82.77-2002 which will be discussed next.

Power Factor Requirements: Directional and Non-Directional Luminaires Source Type	ENERGY STAR Requirements	Methods of Measurement and/or Reference Standards	Supplemental Testing Guidance
Fluorescent ➤ Linear ➤ Compact ➤ Self Ballasted Compact (GU24) ➤ Circline	Residential : ≥ 0.5 Commercial: ≥ 0.9	ANSI C82.2-2002	Laboratory test results shall be produced using the specific models of lamp and ballast or LED package, LED module or LED array and LED driver that will be used in production. Sample Size: ≥ 3 samples of each model combination shall be tested.
High Intensity Discharge ➤ metal halide ➤ ceramic metal halide ➤ high pressure sodium	≥ 0.90	ANSI C82.6-2005	
Solid State	➤ Total luminaire input power less than or equal to 5 watts: PF ≥ 0.5 ➤ Total luminaire input power greater than 5 watts: Residential: PF ≥ 0.7 Commercial: PF ≥ 0.9	ANSI C82.77-2002 sections 6 and 7	Passing Test: all samples shall pass.
Halogen Incandescent (outdoor only)	Exempt		

Source: ENERGY STAR® Program Requirements for Luminaires (Light Fixtures) Eligibility Criteria Version 1.0

(For more specific information about Energy Star and Solid State Lighting see the Astrodyne article titled, "[New Energy Star Requirements Impact Powering of Solid-State Lighting](#)".

ANSI C82.77-2002

ANSI C82.77-2002 is only concerned with power quality and as such it includes limits for THD, power factor and harmonic emissions. While EN61000-3-2 Class C is wattage dependent standard, ANSI is similar to Energy Star in that its requirements are application specific. This last point is illustrated by tables from ANSI C82/77-2002 shown below (Table 1).

Disclaimer: The tables are not intended to represent the full scope of the standard. They serve only as a quick visual guide to the representative nature of the requirements as a whole and as talking points for this discussion.

The full ANSI standard contains information on other types of lighting and their defined limits, as well as testing and measuring methodology for lighting products (www.ansi.org). Terminology used in the tables should only be referenced to the specific definitions shown in the standard.

Requirements for integrally ballasted medium screw base compact light sources (CFL, HID, or halogen types) for use indoor or outdoor are shown below:

Input Power (P)	Minimum Power Factor	Maximum Line Current THD (fundamental)
$P \leq 35$ Watts	.5	200%
$35W < P \leq 60$ W	.8	80%
$60W < P \leq 100W$.9	50%
$P > 100W$.9	20%

Table 1: Residential Integrally Ballasted Medium Screw Base Compact Light Sources*

Requirements for indoor hard-wired luminaries and indoor portable luminaries for all lighting applications (fluorescent, HID and halogen) are specified below:

Input Power (P)	Minimum Power Factor	Maximum Line Current THD (fundamental)
$P \leq 120$ watts	.5	200%
$120\text{ W} < P \leq 150W$.9	32%
$P > 150\text{ W}$.9	20%

Table 2 Residential Indoor hard-wired and portable luminaries for all lighting applications

Requirements for indoor, hard-wired ballasts or luminaries for general lighting applications (fluorescent, HID, plug-in compact lamp sources) are shown below:

Input Power (P)	Minimum Power Factor	Maximum Line Current THD (fundamental)
All	.9	32% and requirements of Annex 1

Table 3 Commercial indoor hard wired ballasts or luminaries

Requirements for indoor, hard-wired ballasts or luminaries for task lighting, down lighting and nodular office furniture (fluorescent, HID, plug-in compact lamp sources including hard-wired halogen power supplies, luminaries and track lighting systems).

Input Power (P)	Minimum Power Factor	Maximum Line Current THD (fundamental)
Modular Office furniture P ≤ 50W	.5	32% and requirements of Annex 1
All Others	.9	32% and requirements of Annex 1

Table 4 Commercial task lighting, own lighting and modular office furniture

A power supply may be considered an electronic ballast and accordingly needs to meet the same limits shown for ballasts.

Annex 1	
Fundamental by Definition	100%
2 nd Harmonic	5%
3 rd Harmonic	30%
Individual Harmonics > 11 th	7%
Odd Triples	30%*root mean square of the 3 rd , 9 th , 15 th and 21 stharmonics
THD fundamental	32%

1. Root mean square of the 3rd, 9th, 15th and 21st....harmonics
2. All percentages are % of the fundamental RMS input current

With the inclusion of THD and power factor parameters, we can now summarize the technical relationship which has harmonic emissions at its core.

- **Harmonic** content whether voltage or current affects power quality.
- Total harmonic distortion is the aggregate or total of all **harmonics** measured as the total RMS value of all harmonics to the *I* fundamental or first harmonic expressed as a percentage or THD % fundamental = $I_{\text{rms}}(\text{distortion}) / I_{\text{rms}}(\text{fundamental})$.
- Power Factor is one of the corrective actions employed to resolve unacceptable levels of **harmonics**.

Power factor correction (PFC) can be classified as either passive or active.
A brief summary follows:

Passive PFC

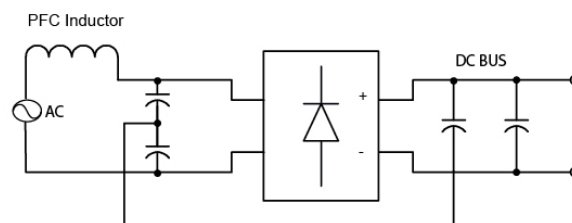
Passive power factor uses low frequency inductors and capacitors to counter the line reactance caused by harmonics. Passive PFC will typically yield a power factor of .60 - .90.

Advantages

- Simple and robust circuitry
- Less costly than active PFC
- No sinusoidal input current

Disadvantages

- Large and heavy low frequency magnetics needed
- Not applicable for wide input range



Active PFC

Active PFC uses components such as semiconductors and switching elements like diodes and transistors to achieve PFC numbers generally higher than .9, some greater than .95, and some as high as .99

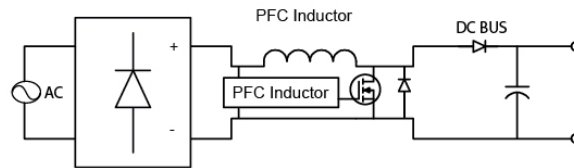
Advantages

- Extensive elimination of line current harmonics
- Power factor near 1
- Increased available power from the distribution system through reduction of load
- Wide input voltage range possible

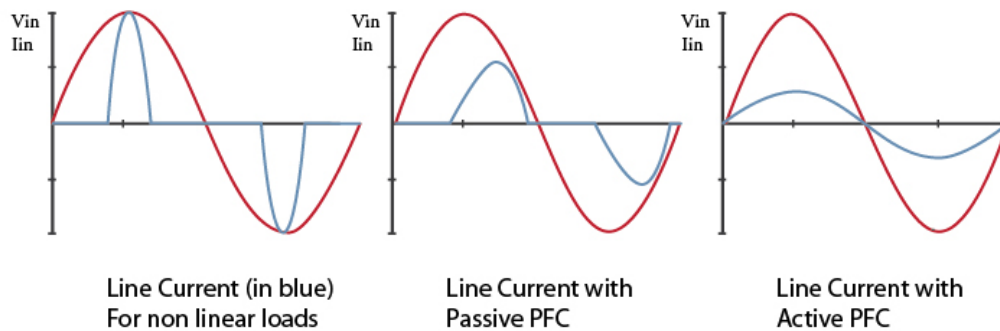
Disadvantages

- Additional expense of circuitry
- Increased number of parts
- Negative impact on efficiency

Note: Comparable ballast power factor classes are normal power factor (NPF) < .9 and high power factor (HPF) > .9



Harmonic line currents reduced through Power Factor



Reduction of harmonic current in lighting is essential for several key reasons:

- Ensuring the safety of the consumer and his/her environs
- Promoting sustainable energy efficient designs
- Maximizing lighting performance
- More cost effective utilization of distribution networks (see sidebar on power factor cost)*
- Limit valuable resources by meeting the requirements of IEEE519-1992 for distribution systems

Maximum Harmonic Current Distortion in % of I _L						
Individual Harmonic Order (Odd Harmonics)						
I _{sc} /I _L	<11	11<h<17	17<h<23	23<h<35	35<h	TDD
<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<1,000	12.0	5.5	5.0	2.0	1.0	15.0
>1,000	15.0	7.0	6.0	2.5	1.4	20.0

Even harmonics are limited to 25% of the odd harmonic limits. TDD refers to Total Demand distortion and is based on the average maximum demand current at the fundamental frequency, taken at the Point of Common Coupling (PCC).

*All power generation equipment is limited to these values of current distortion regardless of I_{sc}/I_L.

I_{sc} = Maximum short circuit current at the PCC
 I_L = maximum demand load current (fundamental) at the PCC
 h = Harmonic number

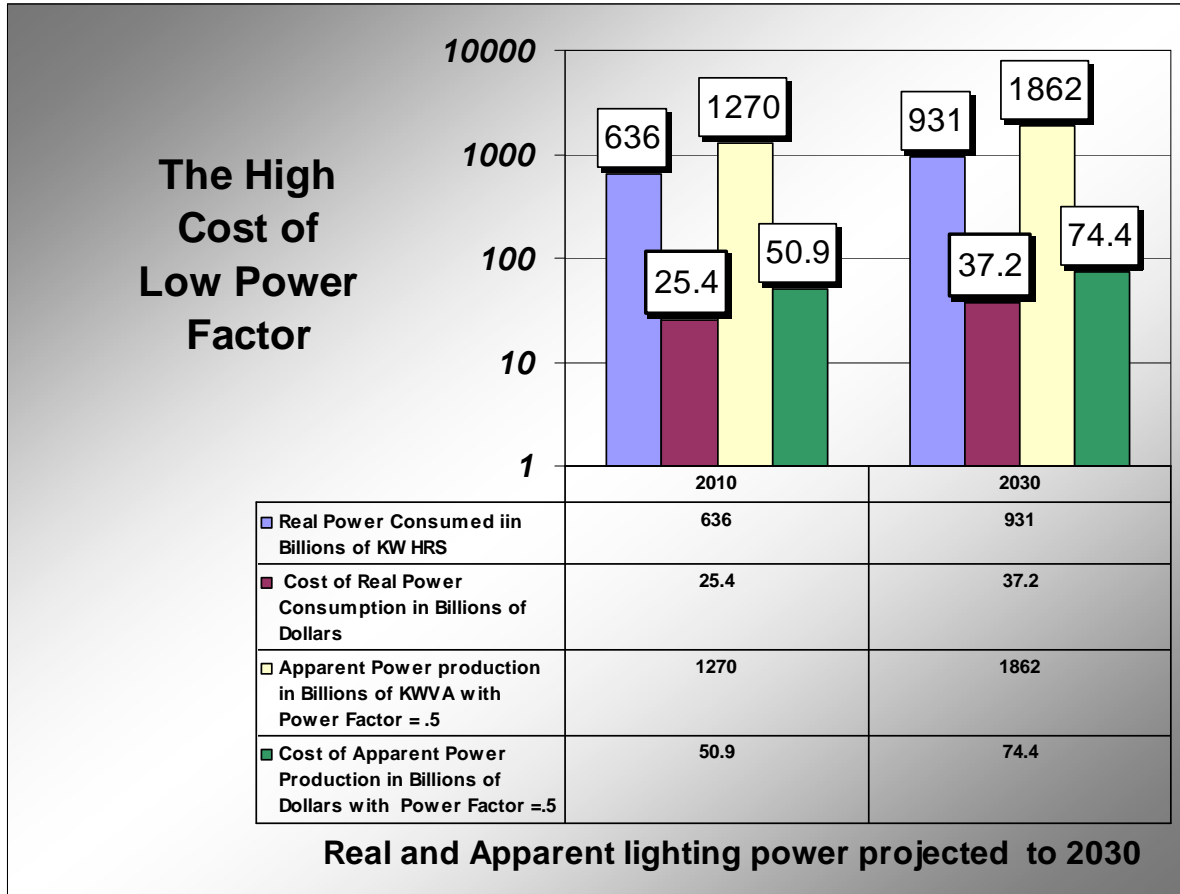
The High Cost of Low Power Factor

Assume a T12 40 watt fluorescent lamp has normal power factor (NPF) electronic ballast resulting in a power factor of .5. The utility company would need to provide 80VA of apparent power to meet the demand of this lamp. 25 of these 40 watt lamps would represent 1Kilowatt hour of real power, but because of the power factor, 2KW VA of apparent power would actually be required from the utility company.

The estimated cost of producing 1 kilowatt hour is 4 cents. You may think this amount is inconsequential until you consider that the estimated KW hrs of all electricity in the United States consumed by the year 2030 will be a staggering 5478 billion kilowatt hours!

Of this figure, lighting has historically accounted for approximately 17% of power consumption or in this case 931 billion KW hours. If all US lighting were provided by fluorescent lamps or products like it, the real KWVA would be 1862 billion KW hrs, and the cost to produce the extra power would be an additional 37.2 billion for a total of 74.4 billion!

It should be noted that some utility companies charge a penalty fee to commercial or residential customers for low power factor. Either way the cost is absorbed into the lighting industry and its customers.



Methods of reducing harmonic emissions in lighting

Harmonic emissions are the problem of both the power consumer (in this case the lighting designer) and the power provider/utility company. This is why the IEEE592-192 requirement does not include a THD number, but rather a requirement for the total demand distortion (TDD). This is the combination of THD from the utility company as well as the local harmonics emitted from different sources in the system. At the distribution level current harmonics can be as low as 5% but increase rather quickly and sometimes significantly with non-linear lighting loads. The lighting design must be one that takes into account the diversity of loads on the system and the appropriate standards therein.

Centralized methods of harmonic reduction used by utility companies is beyond the scope of this article, so we'll look at several well known localized solutions that the end customer can utilize.

One important device for the proper operation of lighting equipment and the reduction of harmonic emissions involves the use of ballasts. Ballasts are devices used to establish starting voltages and currents and regulate current flow and power. They are used with gas discharge light sources, i.e. fluorescents and High-intensity Discharge Lamps (HID). They can be as simple as a fixed resistor for use in low power lamps to the more complex remote-controlled electronic ballasts. For most applications ballasts are categorized as either magnetic or electronic.

Magnetic Ballasts

Magnetic Ballasts use electro-magnetic induction in the form of coils and transformers to provide and maintain operating voltages and currents. Magnetic ballasts typically have a THD of greater than 25%, though some energy efficiency models are slightly lower. Magnetic ballasts have been around since the days of the original fluorescent lights, but recently have fallen out of favor due to their size, weight, increased cost and most importantly their inefficiencies. The federal government has mandated that they be phased out over the next several years.



Magnetic Ballast

Electronic Ballasts

Electronic ballasts employ Solid State Technology to operate fluorescent and HID lighting. They are smaller, lighter, more cost effective devices that use on average 25% less energy than their magnetic counterparts. Their ability to provide and maintain necessary voltages, currents and frequencies make them a more dynamic alternative to magnetic ballasts.



Electronic Ballast

Electronic ballasts have typical THD of less than 20% and some are less than 10%. They come equipped with either passive or active filtering which increases power factor and lowers harmonics. There has been some discussion about their efficiency versus initial cost, but when you consider their longer life cycles there is a long-term cost benefit. Not to mention that a savings can be realized through smaller capacitors, transformers and smaller wires reducing overall system costs. Impending energy legislation will increase demand and continue to drive costs down. Other features such as frequency control for eliminating flicker, dimming controls and the advance of intelligent monitoring systems make the electronic ballast a key component in the lighting industry.

Power Supplies

Power supplies share many features with electronic ballasts. Among these is the ability to reduce harmonics through passive or active front end filtering. Power supplies also have regulated outputs to ensure minimal changes in voltage and current regardless of line and load conditions. They can be employed in either fixed voltage or constant current applications. They can also be used to power inverters that produce fixed frequencies, or directly power Solid State Lighting, such as LED's.



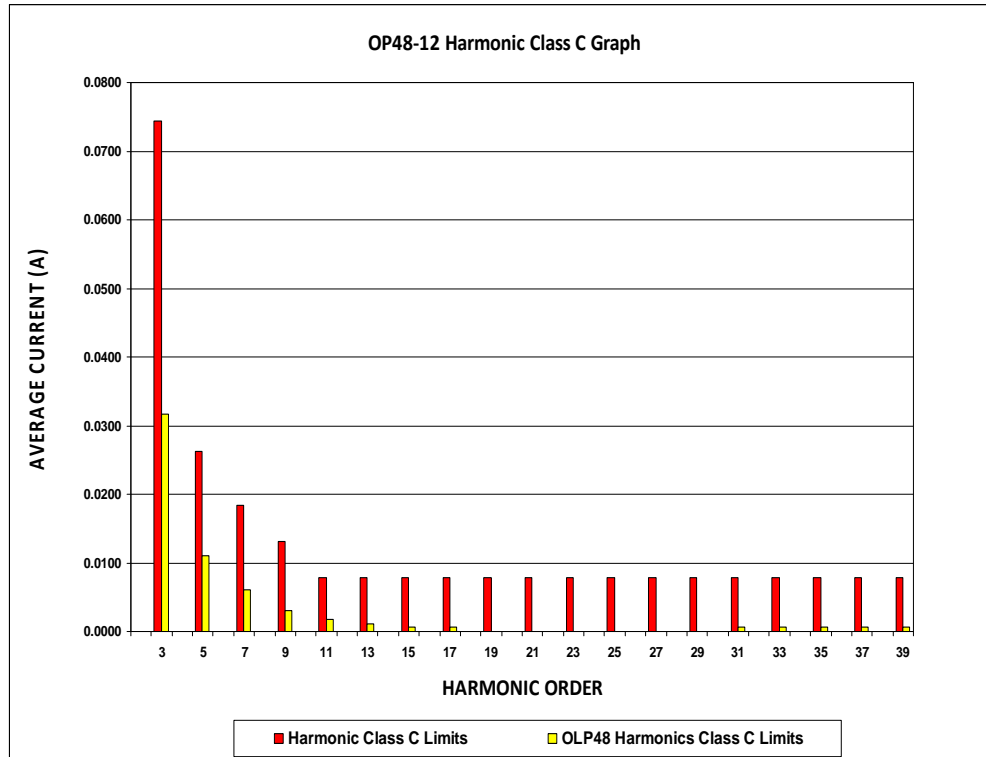
OLP 48 series from Astrodyne

Case study of the OLP48 constant current LED Driver

Problem: A customer has an application for 16 sections of 6-inch tube LED lights in parallel. The power consumption of each tube is 3 watts. The total current in each string is .75A. The total current for the system is 4A of constant current. The unit must comply with ANSI C87-2002, EN61000-3-2 and Energy Star.

Solution: The OLP48 is suggested based on the following information. It meets all the electrical specifications per the [OLP48 data sheet](#) and a look at the graph for harmonics show that it meets this criterion with plenty of margin. The margin is provided by an active power factor circuit of $> .9$ 100-240 Vac.

Note: the actual current limits are shown in actual values rather than percentages to illustrate the data points more clearly.



The Astrodyne OLP48-12 also complies with table 4 of ANSI C82.77-2002 with a THD of just over 22% and meets the requirements of Energy Star for Solid State commercial luminaries with a power factor > .9.

Summary

Reduction of harmonics in lighting systems is key to overall performance and power quality. Advances in ballasts and power supplies have been critical in meeting the requirements of today’s lighting technologies. Careful consideration should be given to the appropriate standards in order to minimize stresses on local lighting networks and central distribution systems. Power supplies and ballasts continue to evolve with lighting markets to drive a more efficient and brighter future.

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