



EUROPEAN POWER SUPPLIES MANUFACTURERS' ASSOCIATION  
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# *PFC Harmonic Current Emissions – Guide to EN61000-3-2:2014*

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Second Edition, July 2018

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The European Power Supplies Manufacturers' Association was established in 1995 to represent the European power supply industry

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## 2 Introduction

Increasing use of electronic devices in daily life has greatly increased the stress caused by harmonic currents on low-voltage alternating-current public mains networks. To maintain the quality of these networks, European Standard EN 60555-2 was created and published in 1982 to set levels for harmonic currents injected by loads back on to the supply network. There has, however, been much discussion about equipment classes and limits to apply to electronic equipment in general and equipment power supplies in particular. EN 60555-2 has been superseded by EN 61000-3-2 which sets some more practical rules and provides a clearer definition of equipment classes.

This document is issued by the European Power Supply Manufacturers Association (EPSMA) and aims to improve the understanding of harmonic line current reduction and the requirements and implication of the standard EN 61000-3-2.

## 3 EMI – Standards

**EMI** = Electro-Magnetic Interference (EMI): Unwanted electromagnetic energy polluting the environment. Sources of EMI are everywhere! They can be:

**Natural**

Lightning, Sun Radiation, Atomic particles, Astronomical effects...

**Man-Made - Intentional**

Radio, TV, Telephone Transmissions, X-Rays...

**Man-Made - Unintentional**

Load switching, arcing, power distribution, vehicle ignition...  
and Switch-Mode Power Supplies

Its effects can be a nuisance (TV / Phone interference etc.) and can be destructive leading to equipment failure.

**EMC** = Electro-Magnetic Compatibility (EMC): This is the ability of system to function reliably in the presence of significant levels of EMI (its immunity) and at the same time its ability to limit internally generated EMI (its emissions) to avoid interfering with surrounding systems or products. Thus, EMC determines that a system or product may not be adversely affected by, or adversely contribute to, the pollution of the electromagnetic environment.

EMI can be controlled only. You cannot get rid of it completely. There is a real need to control the electromagnetic environment so that electronic equipment will be reliable and safe while in use. Thus, in order to set common expectations, standards have been developed that need to be adhered to.

**Standards Define:**

- The applicability / scope
- The environment / location
- The measuring method, equipment, and set-up
- The characteristics of the EMI or Interfering signal
- The limits of acceptability
- The performance criterion expected and result reporting

The International Global Body responsible for producing EMC Standards is the International Electrotechnical Commission (IEC) headquartered in Geneva. It is made up of technical experts (from Industry = Manufacturers & Users), test laboratories & regulatory bodies from around the world. The IEC Technical Committee dealing with EMC is known as TC77. Every attempt is made to ensure a common consensus on what is relevant and acceptable to all national interests. Thus, IEC Standards (e.g. IEC61000-4-x series) receive world-wide recognition & many national authorities (e.g. CENELEC in Europe) adopt such IEC standards, but modify them slightly to incorporate national level specific & minor deviations.

In Europe, the body responsible for dealing with Standards is CENELEC and specifically for EMC Standards the Technical Committee responsible is known as TC210. Generally, the European EMC standards can be grouped into 3 sections (see Guides 24 & 25 on the CENELEC website).

### 3.1 BASIC

These standards give a definition and description of the phenomenon, detailed test and measurement methods, test instrumentation and basic test set up (e.g. EN61000-4-x series).

- They do NOT tell you what your product needs to meet
- Unfortunately, NO basic standards exist for emission presently. Thus, one must adhere to emission standards as called out under Product Specific or Product Family Standards or Generic Standards

### 3.2 GENERIC

These standards describe the requirements, test and levels (limits) specific to the environment (e.g. EN61000-6-x Series)

- 2 Types of environment exist = Residential (Domestic/Home) & Industrial
- State limits & performance criteria. (i.e. they tell you what your product needs to meet)
- Call on Basic Standards for measurement of immunity
- Call on Product Standards for emissions (which outline the pass levels expected)
- To be used when NO Product Standard exists

### 3.3 PRODUCT

These standards describe the requirements, test and levels (limits) specific to a Product or Family of Products (e.g. EN60601-1-2 for Medical Products)

- Call on Basic Standards for measurement of immunity.
- Have their own standards for emissions (which outline the pass levels expected)
- State limits and performance criteria. (i.e. they tell you what your product needs to meet).

#### Notes:

1. Product Standards take precedence over Generic Standards.
2. **EN61000-3-2** for harmonic current control is a **Product Family Standard** for all electronic goods connected to the mains at <16A. It therefore defines and describes the phenomenon, details the test and measurement methods, test instrumentation and basic test set up. It also advises what Levels (limits) your product is expected to meet.

## 4 Harmonics

### 4.1 Explanation:

The actual standard that covers Utility (AC Mains supply from source) quality in Europe is EN50160. The flow of energy to the network user's appliances gives rise to electric currents which are more or less proportional to the magnitudes of the network user's demands. As these currents flow through the conductors of the supply system, they give rise to voltage drops and/or distortions. The magnitude and shape of the supply voltage for an individual network user at any instant is a function of the cumulative voltage drops and/or distortions on all the components of the system through which that network user is supplied and is determined both by the individual's demand and by the simultaneous demands of other network users. In essence, the utility supply (AC mains voltage from source) endeavours to give as near as possible a pure AC sinusoid voltage to all network users.

When dealing with alternating voltages in electrical circuits at the network user level, it is assumed that they are pure and sinusoidal in shape with only one frequency value, called the "fundamental frequency" being present, but this is not always the case. More often than not the AC supply at the network user level is a complex waveshape made up of a fundamental waveform plus harmonics.

The term "harmonics" is rooted in mathematical and physics theory (trigonometry and Fourier analysis). The Fourier series has many applications in electrical and electronic engineering, vibration analysis, acoustics, optics, signal processing, image processing, quantum mechanics etc.

In electrical circuits, harmonics are voltages or currents that operate at a frequency that is an integer (whole-number) multiple of the fundamental frequency (**Figure 1**). So, given a 50Hz fundamental waveform, this means a 2nd harmonic frequency would be 100Hz (2 x 50Hz), a 3rd harmonic would be 150Hz (3 x 50Hz), a 5th at 250Hz, a 7th at 350Hz and so on.

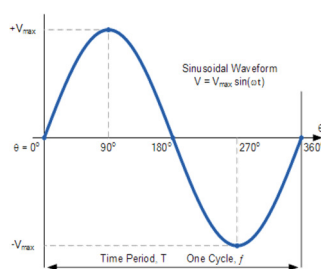


Figure 1. Pure sine wave at fundamental frequency

Whatever its shape, a complex waveform (voltage or current) can be split up mathematically into its individual components at the fundamental frequency and a number of harmonic frequencies (**Figures 2, 3, 4**).

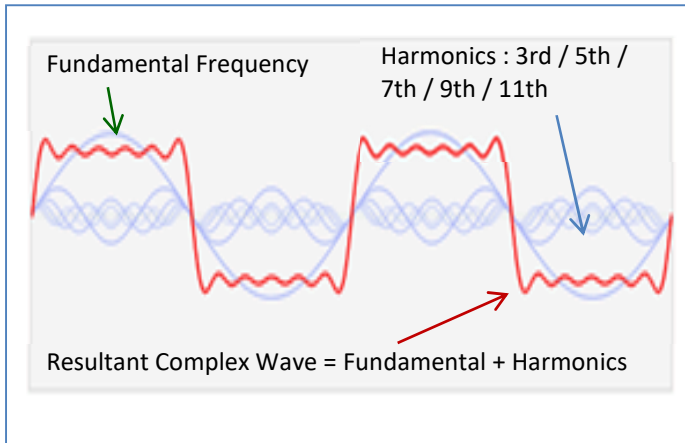


Figure 2. A complex waveform represented by a fundamental with harmonic frequencies (a)

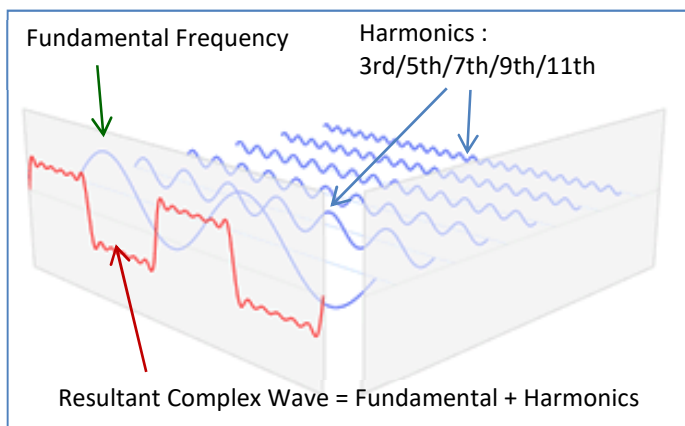


Figure 3. A complex waveform represented by a fundamental with harmonic frequencies (b)

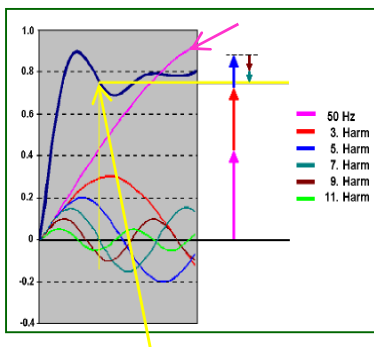


Figure 4. Resultant complex wavepoint = fundamental + harmonics at point

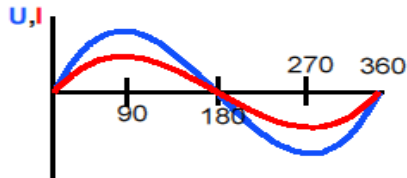
In Electrical Circuits the Total Harmonic Distortion, or THD, is the summation of all harmonic components of the voltage or current waveform compared with the fundamental component of the voltage or current wave. Thus, harmonic distortion is the degree to which a waveform deviates from its pure sinusoidal. The ideal sine wave has zero harmonic components (i.e. there is no distortion in a perfect sinusoidal wave shape).

#### 4.2 Sources

Harmonic disturbances are generally caused by equipment with nonlinear voltage/current characteristics and are mainly the result of modern electronic controlled power consumption.

### 4.2.1 Linear Loads

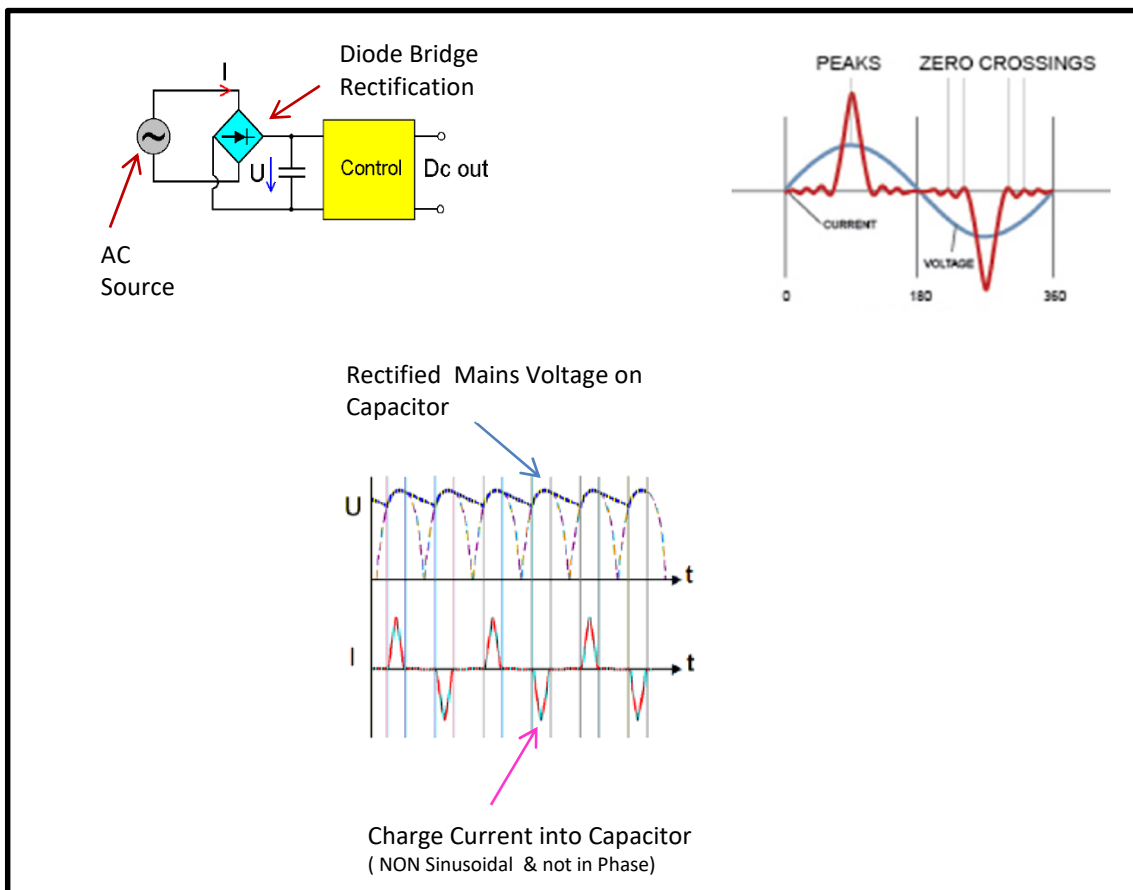
Linear loads are loads in which the current waveform matches the applied voltage waveform (**Figure 5**). For a linear load powered by a mains supply, the current waveform will be sinusoidal. Harmonics do not enter the equation when dealing with linear loads. Unfortunately, there are not many linear loads in modern electrical circuits these days.



**Figure 5.** Source voltage and load current drawn are sinusoidal and in phase for linear loads

### 4.2.2 Non-Linear Loads

Non-linear loads are loads in which the current waveform does not resemble the applied voltage waveform. Traditional bridge rectifiers are a good example of non-linear loads. The source voltage versus load current is illustrated in **Figure 6**.



**Figure 6. Circuit and waveforms for a bridge rectifier**

The Current drawn from the AC mains source is not a pure sinusoidal and not in phase. Component Switch Mode Power Supplies (SMPSs) used within electrical and electronic apparatus are a major source of non-linear current draw. Thus, potential sources of harmonics are:

- Current regulators
- UPS Systems / frequency converters
- Electrical arc-furnaces / Arc welding machines
- Induction motors with irregular magnetizing current associated with saturation of the iron
- Office equipment (PCs, printers, servers, etc.)
- Household appliances (TV sets, microwaves, ovens, fluorescent lighting, light dimmers etc.)
- All equipment with built-in switching devices or with internal loads that have non-linear voltage/current characteristics

#### 4.2.3 Effects

Harmonics flowing in distribution networks represent disturbances in the flow of electricity. The quality of electrical power is deteriorated, and the efficiency of the system is decreased. Further effects are:

- Overload of distribution networks due to the increase of rms currents
- Overload of neutral conductors, where current can exceed the phase currents
- Overload, vibration and premature ageing of supply generators, supply transformers and motors as well as increased transformer hum (audible noise)
- Overload and premature ageing of Power Factor Correction capacitors
- Distortion of the supply voltage that can disturb sensitive loads connected to the network
- Disturbance in communication network lines & telephone lines
- Flicker in Lighting products
- Intermittent circuit breaker trip or fuse ruptures
- Increases in radiated & conducted EMI within systems and supply cables

#### 4.2.4 Measurement

The specifics of harmonic measurement are outlined in detail within the EN61000-3-2 standard. The distortion of the mains supply voltage can be limited by reducing the current harmonic content taken by the connected equipment. Thus, the Harmonic Current Analyser is looking at the current wave shape (**Figure 7**).



**Figure 7. Harmonic current analysis**

Some points to note:



- The harmonic current analyser should measure to the 40<sup>th</sup> current harmonic with measurement accuracy of 5%. The analyser uses a Discrete Fourier Transformation (DFT) algorithm to calculate the harmonic values
- The AC source must be stable for voltage (+/-2%) / frequency (+/-0.5%) and phase angle for 3-phase supply (+/- 1.5 Deg)
- The AC source must have low distortion before measurement as specified in the standard
- The Equipment Under Test (EUT) should be operational for 10 seconds minimum
- The Equipment Under Test (EUT) should be operated to produce the maximum harmonics under normal operation
- The average value for the individual harmonic currents taken over the entire test observation period needs to be less than or equal to the applicable limits

#### 4.2.5 Harmonics summary

A non-sinusoidal (and therefore harmonic-rich) current consumption causes voltage distortion on the mains utility supply voltage. This distortion is the reason for a deviation of the voltage wave shape away from ideal sinusoidal. Electrical and electronic application designers cannot act on the voltage source wave shape directly, but they can act on the current wave shape drawn by their non-linear loads. Thus, they must design for minimum harmonics on their current wave shape so that the wave shape is as close as possible to the current fundamental sinusoid. In doing so, they will ensure that they minimise the possible voltage distortion on the mains source supply.

## 5 EN61000-3-2

### 5.1 Scope

As of 1<sup>st</sup> January 2001, all electrical and electronic equipment that is connected to the Public Utility (Mains Supply) up to and including 16A (max) rated input current must comply with EN 61000-3-2.

This standard is part of the European 'EMC-directive', which must be complied with for the purpose of CE marking as of 1<sup>st</sup> January 2001.

Passive and active harmonic line current reduction solutions can be used to fulfil the limits of the standard which greatly influences the design of all electronic equipment and more specifically power supplies.

### 5.2 Application and revisions

#### 5.2.1 Application

EN 61000-3-2:2014 applies to all electrical and electronic equipment that has an input current of up to 16A per phase, suitable for connection to the low-voltage AC public mains distribution network.

A public mains low-voltage distribution network exists if more than one independent consumer can draw power from it.

This standard does not apply to (and has no limits for):

- Non-public networks
- Non-lighting equipment with rated power of 75W or less
- Equipment for rated voltages less than 220 VAC (limit has not yet been considered)
- Arc welding equipment intended for professional use as specified in IEC 60974-1

- Professional equipment (not intended for sale to the general public) with rated power greater than 1kW
- Heating elements with symmetrical control methods and input power less than or equal to 200W
- Independent dimmers for incandescent lamps with rated power less than or equal to 1kW

## 5.2.2 Revisions and transitional periods

EN 61000-3-2 came into effect on 16<sup>th</sup> September 1995 (published in The Official Journal of the European Communities) and has replaced EN 60555-2 as of 10<sup>th</sup> February 2001. The last version EN 61000-3-2:2014 has been accepted by CENELEC on 30<sup>th</sup> June 2014. It is based on EN 61000-3-2:2006 +A1+A2.

The following dates are fixed:

DOP: Date of Publication: Latest date by which the document has to be implemented at national level (all European countries) by publication of an identical national standard or by endorsement: 30<sup>th</sup> March 2015

DOW: Date of Withdrawal: Latest date by which the national standards (all European countries) conflicting with the document have to be withdrawn 30<sup>th</sup> June 2017

## 5.3 Differences between the standards EN 61000-3-2:2014 and older versions

- Clarification of the repeatability and reproducibility of measurements
- More accurate specification of the general test conditions for information technology equipment
- The addition of optional test conditions for information technology equipment with external power supplies or battery chargers
- The addition of a simplified test method for equipment that undergoes minor changes or updates
- Update of the test conditions for washing machines
- Clarification of the requirements for Class C equipment with active input power  $\leq 25$  W
- Update of the test conditions for audio amplifiers
- Clarification of the test conditions for lamps
- Update of the test conditions for vacuum cleaners
- The addition of test conditions for high pressure cleaners
- Update of the test conditions for arc welding equipment
- The reclassification of refrigerators and freezers with variable-speed drives into Class D
- The addition of test conditions for refrigerators and freezers

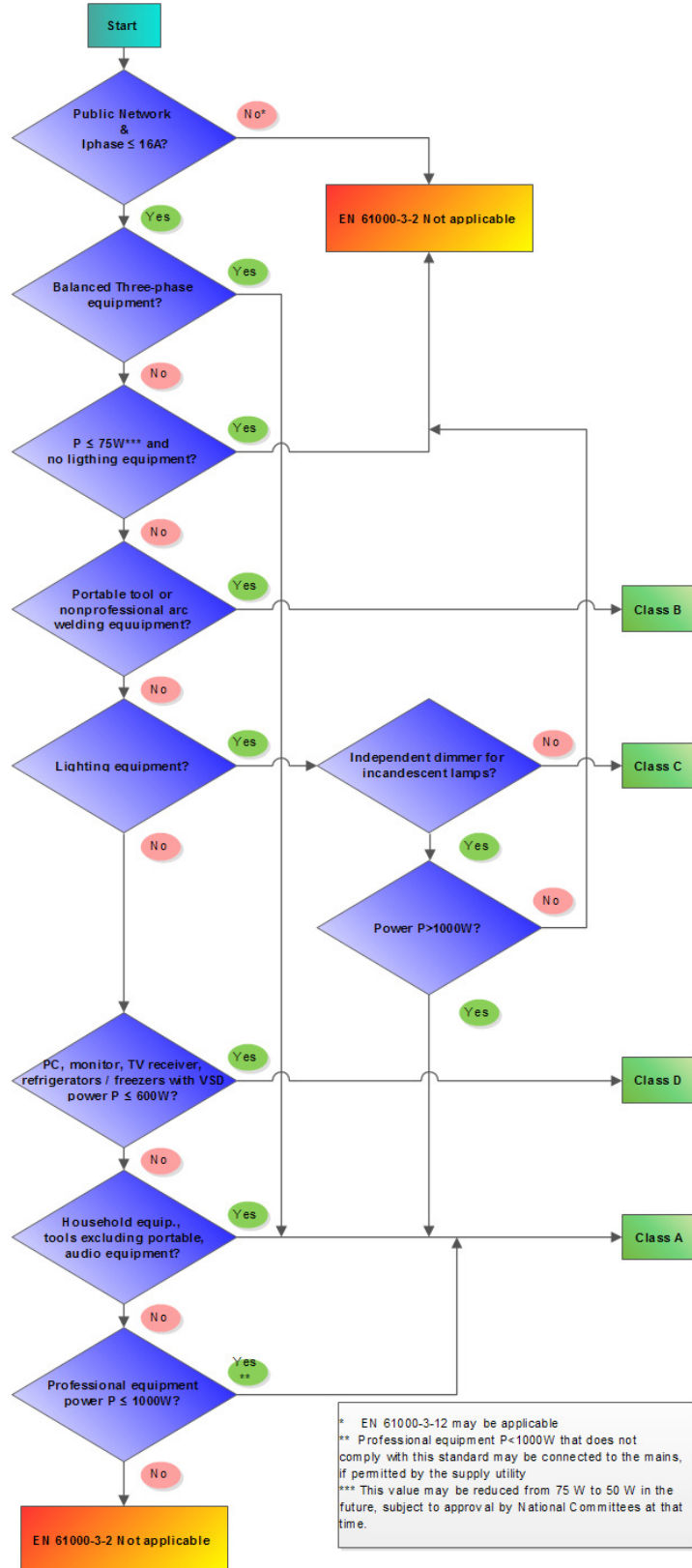
## 5.4 Application Guidelines

The flow chart on the following page is intended as a guideline for the application of EN 61000-3-2:2014. Based on the application-specific conditions, it will determine if the standard is applicable or not and which limits apply.

For equipment with line currents exceeding 16A per phase, EN 61000-3-12 (Limits for harmonic currents produced by equipment connected to the public low-voltage systems with input currents  $> 16$ A and  $\leq 75$ A per phase), may be applicable.

Professional equipment that does not comply with the requirements of the standard EN 61000-3-2 may be permitted to be connected to certain low voltage supplies if the instruction manual contains a requirement to ask the supply utility for permission. \*

\*Professional equipment for use in trades, professions or industries and which is not intended for sale to the general public. The designation shall be specified by the manufacturer.



## 5.5 Classification and Limits

There are 4 different classes in the EN 61000-3-2:2014 that have different limit values:

- Class A:       Balanced three-phase equipment  
 Household appliances excluding equipment identified as class D  
 Tools, excluding portable tools  
 Dimmers for incandescent lamps  
 Audio equipment  
 Other equipment, except that stated in one of the following classes
- Class B:       Portable tools  
 Arc welding equipment which is not professional equipment
- Class C:       Lighting equipment
- Class D:       PCs, PC monitors, radio, or TV receivers with Input power  $P \leq 600W$   
 Refrigerators and freezers having one or more variable-speed drives (VDS) to control compressor motor(s)

There are no limits for:

- Symmetrical controlled heating elements with input power  $P \leq 200 W$
- Independent dimming devices for incandescent lamps with a rated power of less or equal 1kW.

The limits for Class A equipment are shown in Table 1.

For class B equipment the limits of Table 1 multiplied by a factor of 1.5 apply. Table 1 refers to fixed values for harmonic currents in the harmonic order from 2 to 40.

For class C equipment having an active power greater than 25W the limits are given in table 2. The maximum permissible harmonic currents are given as a percentage of the fundamental input current. For class C equipment with an input power less than or equal to 25W either:

- The limits of table 3 (column two) apply,
- Or the third harmonic current shall not exceed 86% and the fifth harmonic current shall not exceed 61% of the fundamental current (for further details refer to the standard)

For class D equipment the limits are shown in Table 3 as a power related current (mA/W) with a maximum permissible value given in Table 1 (which will be reached at about 675W for the third harmonic).

Harmonic order n	Maximum permissible harmonic current A
Odd harmonics	
3	2.3
5	1.14
7	0.77
9	0.40
11	0.33
13	0.21
$15 \leq n \leq 39$	$0.15 \cdot 15/n$
Even harmonics	
2	1.08
4	0.43
6	0.30
$8 \leq n \leq 40$	$0.23 \cdot 8/n$

**Table 1: Limits for class A equipment**

Harmonic order N	Maximum permissible harmonic current expressed as a percentage of the input current at the fundamental frequency %
2	2
3	$30 \cdot \lambda$ *
5	10
7	7
9	5
$11 \leq n \leq 39$ (odd harmonics only)	3

\*  $\lambda$  is the circuit power factor

**Table 2: Limits for Class C equipment**

Harmonic order N	Maximum permissible harmonic current per watt mA/W	Maximum permissible harmonic current A
3	3.4	2.30
5	1.9	1.14
7	1.0	0.77
9	0.5	0.40
11	0.35	0.33
$13 \leq n \leq 39$ (odd harmonics only)	$3.85/n$	See table 1

**Table 3: limits for class D equipment**

## 6 Harmonic Current Reduction Techniques

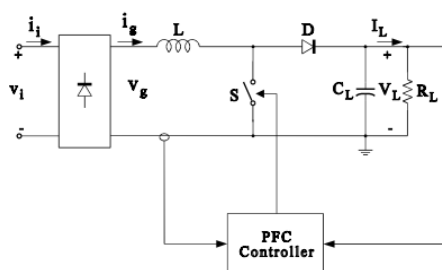
Harmonic line current reduction can be achieved by using different techniques. The most commonly-used techniques are line filters using passive components and active electronic circuitry. Harmonic line current reduction using passive components (inductors and capacitors) introduces high impedance for the harmonics thus smoothing the input current to electronic equipment.

Harmonic line current reduction using active electronic circuitry is shaping the input current of electronic equipment proportional to the applied line voltage thus giving a sinusoidal input current in phase with the line voltage. The corresponding electronic circuitry is often called Power Factor Correction (PFC) circuitry, although power factor correction is not the correct wording, it has become synonymous for harmonic line current reduction.

### 6.1 Active PFC Methods

#### 6.1.1 Boost PFC topology

Very simple (**Figure 8**) and allows low-distorted input currents and almost unity power factor with different control techniques – peak current control, average current control, hysteresis control scheme, border line control, discontinuous current PWM control.



**Figure 8. Boost PFC circuit**

#### 6.1.2 Flyback, Cuk and Sepic

Although boost PFC circuits are the most used, other converters like flyback (**Figure 9**), Cuk and SEPIC (**Figure 10** upper and lower) are well suited for PFC applications. All of these overcome some of the

problems encountered with the boost topology. For example, they allow high-frequency insulation, voltage step-up and step-down as well as start-up and overload protection.

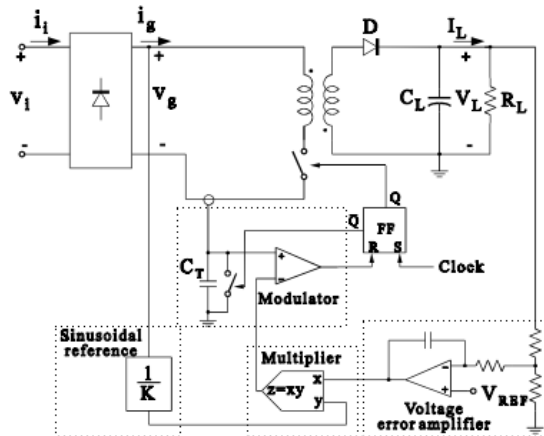


Figure 9. Flyback PFC circuit

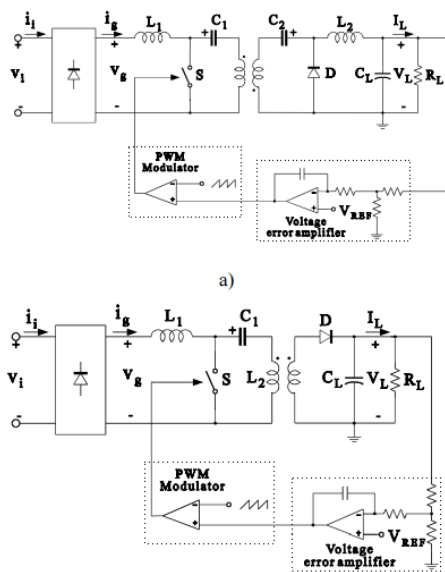
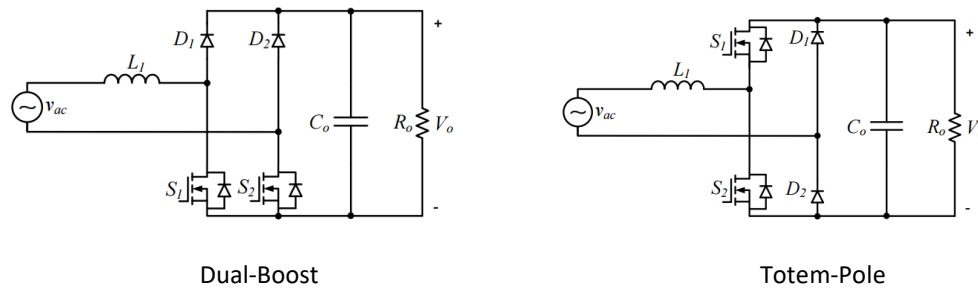


Figure 10. Cuk (upper) and SEPIC (lower) PFC circuits

### 6.1.3 Bridgeless Boost PFC

Electronic devices (such as laptops, cell phones, panel computers, workstations, and data servers) increasingly challenge AC-DC power supplies for higher efficiency requirements. Environmental organizations and government regulations are forcing designers to look for any possible opportunity to minimize power losses. To solve this problem, Bridgeless Boost PFC (**Figure 11**) is proposed and attracts wide range attention. It is effective to reduce the number of devices in the current path to reduce considerable conduction loss and improve total efficiency.



**Figure 11. Bridgeless PFC circuits**

## 6.2 Three Phase PFC Methods

Three-phase power factor correction (PFC) rectifier topologies with sinusoidal input currents and controlled output voltage are derived from known single-phase PFC rectifier systems and/or passive three-phase diode rectifiers. The systems are classified into passive, hybrid and fully active pulse-width modulation boost-type or buck-type rectifiers.

### 6.2.1 Passive

- Single diode bridge (DC or AC side inductors, passive 3<sup>rd</sup> harmonic injection)
- Multi pulse rectification system (transformer isolation or auto-transformer based, AC or DC side interphase transformer, passive pulse multiplication)

### 6.2.2 Hybrid

- Electronic reactance based (singular diode bridge + DC or AC side electronic inductor or capacitor, multi-phase rectifier system employing electronic interphase transformer)
- Active 3<sup>rd</sup> harmonic injection (Passive/Hybrid or active 3<sup>rd</sup> harmonic injection network, buck/boost uncontrolled output, diode bridge or multi-pulse system with harmonic injection)
- Combination of diode rectifier and DC-DC converter (boost, buck)

### 6.2.3 Active

- Phase modular systems (Y, Delta rectifier, 3/2 phase Scott-transformer based)
- Direct three phase systems:
  - Impressed input current boost type
    - DCM (single switch, two switch)
    - CCM (Two level converter Y or delta switch, three level converter Vienna rectifier)
  - Impressed input voltage Buck type
    - DVM (single-switch converter)
    - CVM (three-switch converter, six-switch converter)

**Representative Three-Phase PFC methods:**



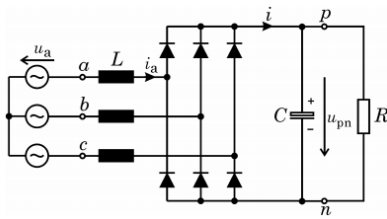


Figure 12. Passive Diode Bridge: converter:

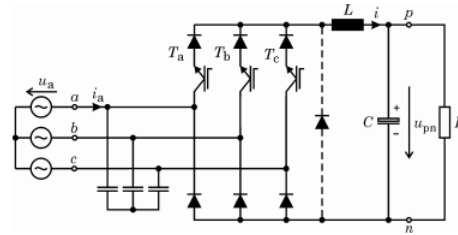


Figure 13. Hybrid Diode Rectifier and DC-DC Buck

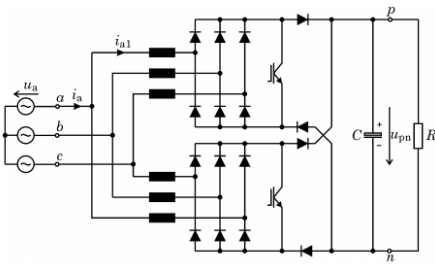


Figure 14. Active Two Interleaved single-switch: (Boost type DCM converter stage)

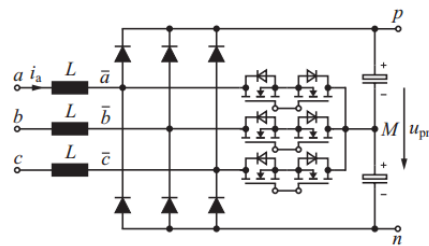


Figure 15. Active Three level CCM Vienna Rectifier

### 6.3 Comparison without / with harmonic line current reduction

The figures below illustrate the principal behaviour of the AC line input current with and without harmonic current reduction. Without any harmonic reduction circuitry (**Figure 16**) the input current achieves very high peaks as the current is only limited by the small input impedance (filter and cabling) of the power supply. Adding additional inductances (passive solution, **Figure 17**) reduces the input current as well as its harmonic content.

The best harmonic current reduction (**Figure 18**) is achieved by active power factor correction.

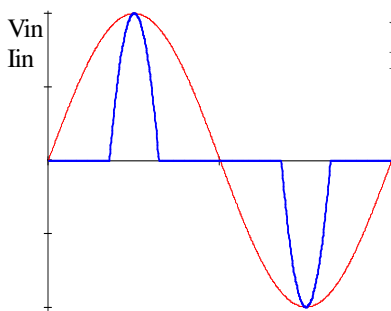


Figure. 16

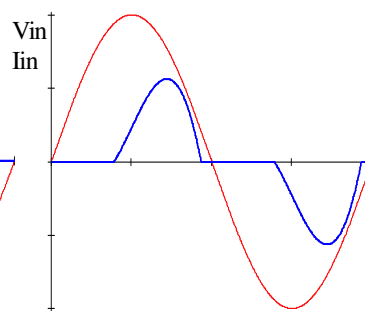


Figure. 17

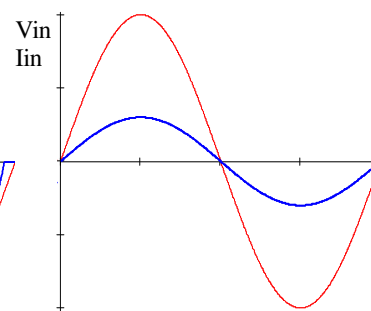


Figure. 18

## 6.4 Advantages / Disadvantages, passive and active PFC

### 6.4.1 Passive Harmonic Line Current reduction

#### **Advantages**

- Simple and robust circuitry needed
- Less costly than active PFC (especially in 3 phase applications)

#### **Disadvantages**

- Large and heavy low frequency magnetics
- Not applicable for wide input range and higher power
- Non-sinusoidal input current

### 6.4.2 Active Harmonic Line Current reduction

#### **Advantages**

- Extensive elimination of line current harmonics
- Power factor near 1 (typically 0.6 uncorrected) and increased available power from the wall socket (public mains)
- Wide input voltage range possible.

#### **Disadvantages**

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

Passive harmonic line current reduction (e.g. 3-phase applications and applications up to approximately 400W) is sometimes a more economic and effective solution. Cost versus performance trade-offs need to be considered when designing for harmonic current reduction.

## 7 References & Bibliography:

- IEC 61000-3-2: Limits for harmonic current emissions for equipment with input current not exceeding 16 A per phase
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- CENELEC Guides 24 & 25:  
<https://www.cenelec.eu/membersandexperts/referencematerial/cenelecguides.html>
- Excelsys Power: Application Note – AN1108
- Schaffner Group: Schaffner Whitepaper - Harmonic distortion: by Alexander Kamenka
- Power Measurement & Harmonic Analysis – Yokogawa

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