Origin of Low Frequency Harmonic Pollution and Conventional Compensation Techniques

Outline

- (Definitions: PF, THD, DF)
- Diode rectifiers
- (Phase controlled rectifiers)
- Dimmers
- Passive compensation

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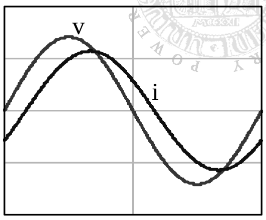
Power Factor - Definition

Input voltage and current are periodic waveforms with period T.

For sinusoidal waveforms, active power P is given by:

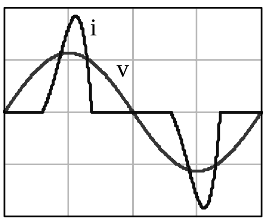
$$P = \frac{1}{T}\cdot\int v\,i\,dt = V\,I\cdot\cos(\phi)$$



cos(ϕ)=0.87

while, for generic waveforms:

$$P = \frac{1}{T}\cdot\int v\,i\,dt = V\,I\cdot PF$$



PF=0.74

where term PF is the POWER FACTOR

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Power Factor - Definition

By definition, Power Factor PF is given by:

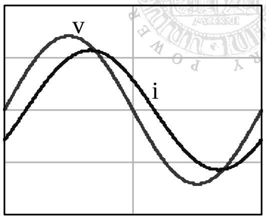
$$PF \equiv \frac{P}{V \cdot I}$$

where P is the average power:

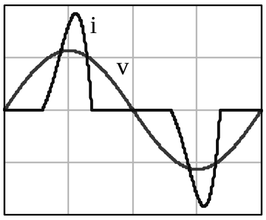
$$P = \frac{1}{T} \cdot \int_T v\, i\, dt$$

while V and I are the r.m.s. values of line voltage and current:

$$V \equiv V_{rms} \equiv \sqrt{\frac{1}{T}\int_T v^2 dt} \qquad I \equiv I_{rms} \equiv \sqrt{\frac{1}{T}\int_T i^2 dt}$$



cos(ϕ)=0.87



PF=0.74

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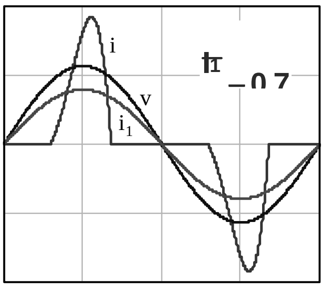
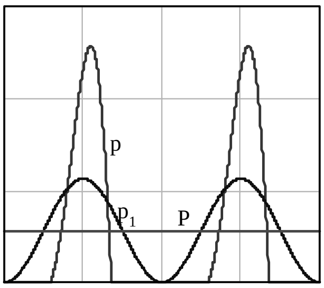
Power Factor - Definition

Case of SINUSOIDAL INPUT VOLTAGE

The average power is given by first harmonic term only





Current terms:
- Instantaneous i
- In-phase first harmonic i_1

Power terms:
- Instantaneous p
- First harmonic p_1
- Average P

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Power Factor - Definition

Case of SINUSOIDAL INPUT VOLTAGE

$$PF = \frac{P}{VI} = \frac{V_1 I_1 \cos(\phi_1)}{V_1 I} = \frac{I_1}{I}\cos(\phi_1)$$

$D.F. = \frac{I_1}{I}$ **= Distortion Factor**

$\cos(\phi_1)$ **= Displacement Factor**

$$D.F. = \frac{1}{\sqrt{1+(THD)^2}}$$

$$THD = \frac{\sqrt{I^2 - I_1^2}}{I_1} = \frac{\sqrt{\sum_{n\geq 2} I_n^2}}{I_1}$$

$$PF = \frac{\cos(\phi_1)}{\sqrt{1+(THD)^2}}$$

THD = Total Harmonic Distortion

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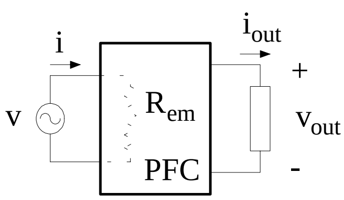
Power Factor - Definition

$$0 \leq PF \leq 1$$

PF = 1 only if current and voltage are proportional

*An ideal line-fed converter is a power interface which takes from the supply a current proportional to the given voltage thus **emulating a resistor***



This kind of converter is called
Power Factor Corrector (PFC)

Emulated Resistance $R_{em} = v$

Small Power Factor ⇒ **Current absorption higher than necessary**

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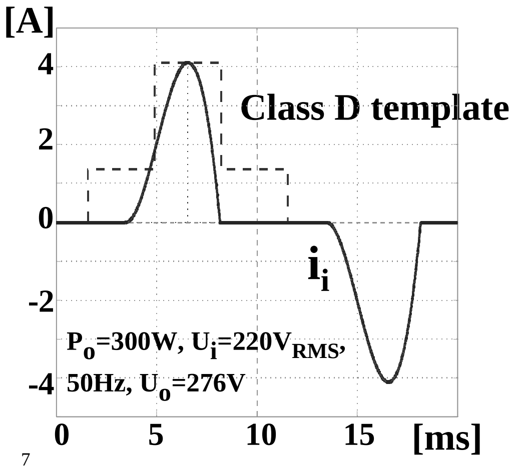
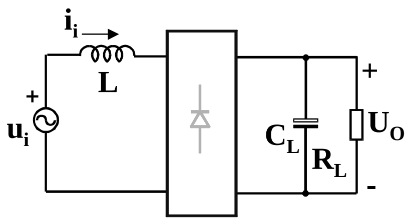
Origin of Harmonic Pollution

Diode rectifiers with capacitive filter



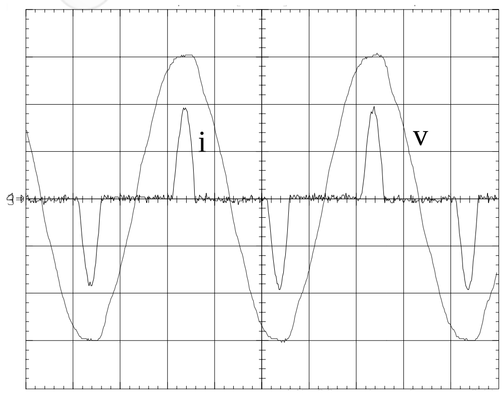


Compliance with Class D limits requires:

L=19mH

Origin of Harmonic Pollution

Diode rectifiers with capacitive filter



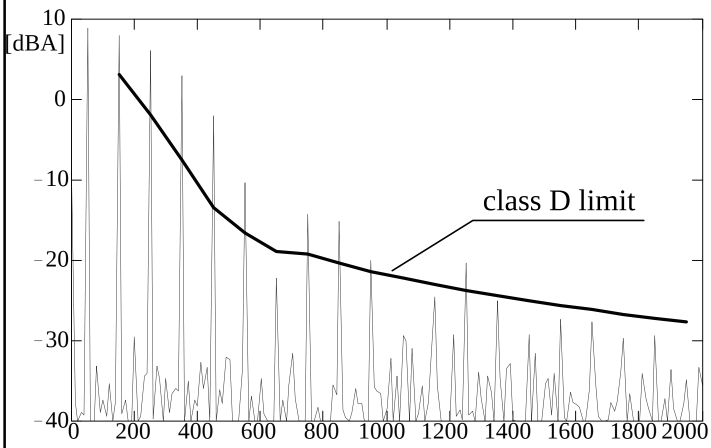
P = 423 W
V = 217 V
I = 3.24 A
I_1 = 1.96 A
PF = 0.6
THD_I = 130%
THD_V = 2.6%
DF = 0.857

- **Poor PF**
- **High rms current**
- **Line voltage distortion**

Origin of Harmonic Pollution

Diode rectifiers with capacitive filter

Harmonic absorption and class D limit



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Origin of Harmonic Pollution

Diode rectifiers with capacitive filter

- **Single-phase and three-phase rectifiers show low PF (high Distortion Factor)**
- **Class D limits have to be considered owing to the high crest factor of line current waveform**
- **Typical applications exceed standard limits**
- **Passive filters (inductors) are usually employed to reduce line current THD**
- **Voltage fluctuations at start-up must be considered**

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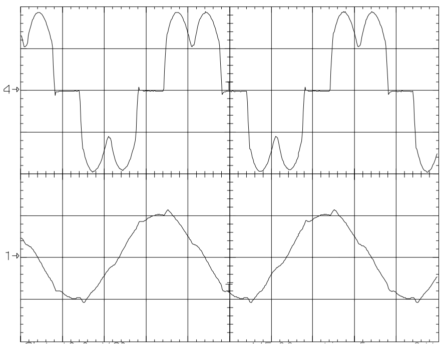
Origin of Harmonic Pollution

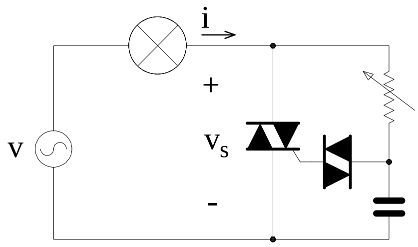
SCR rectifiers (inductive load)

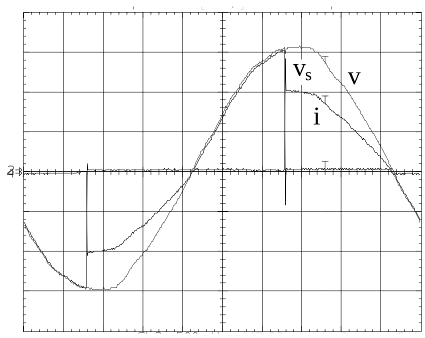
- Single-phase and three-phase rectifiers show low PF (high Distortion Factor and low Displacement Factor)
- Class A limits have to be considered owing to line current waveform
- Small power applications do not exceed class A limits
- Passive filters (inductors) are usually employed to reduce high-frequency current components
- High-frequency pollution must be considered (SCR commutation)



Origin of Harmonic Pollution

Traditional Light dimmers

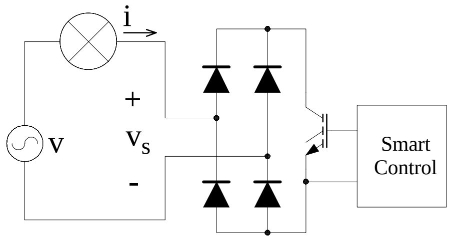


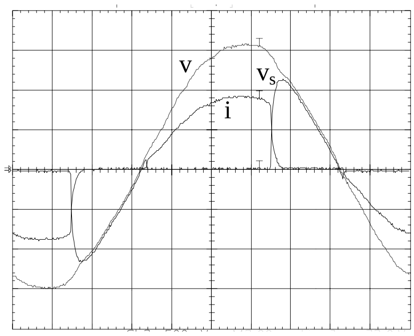


Traditional light dimmers show both low-frequency and high-frequency pollution

Origin of Harmonic Pollution

Last-generation light dimmers





Modern light dimmers comply with standards requirements

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Needs for Power Factor Correction

- **Improved source utilization**
  - **lower loss on line resistance**
  - **less voltage distortion at the load terminals (cross-coupling)**
  - **more power available from a given voltage source**
- **Reduced low-frequency harmonic pollution**
- **Reduced acoustic noise**
- **Compliance with low-frequency EMC standards**

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Power Factor Correction Techniques

PASSIVE METHODS

- high reliability
- suitable for very small or high power equipment
- power factor less than unity
- bulky components

ACTIVE METHODS

(high-frequency switching converters)

- unity power factor
- possibility to use high-frequency transformers
- suitable for small and medium power levels
- high-frequency harmonics pollution (EMI)

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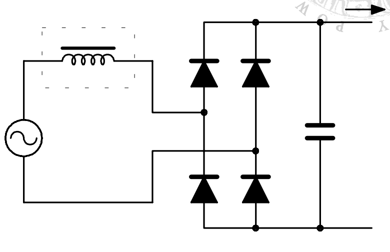
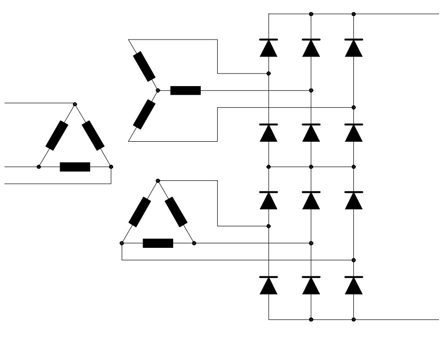
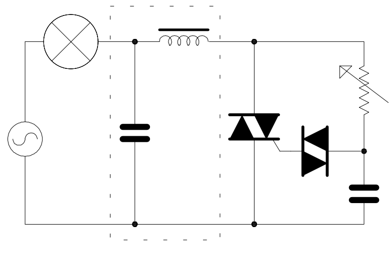
Passive Power Factor Correction

- Passive Filters (L, LC, resonant)
- Multiphase rectifiers (high power systems)







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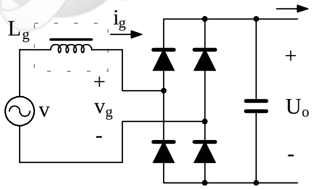
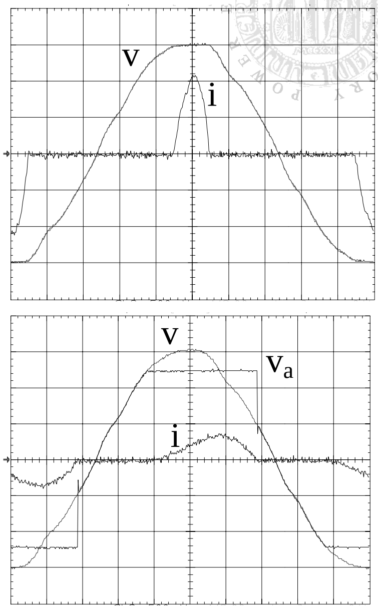
Passive Power Factor Correction





Inductive filter causes:
- Dependence of voltage drop on load current
- Increase of rectifier output impedance
- Phase lag of line current
- High frequency EMI due to diode reverse recovery

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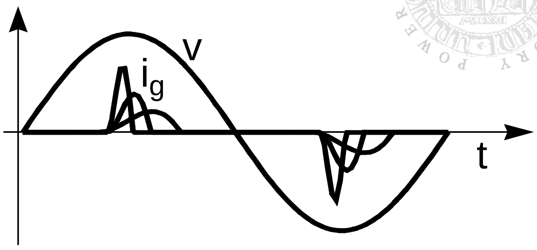
Passive Power Factor Correction

Performances vs Inductive Filter Selection (L_g)

(Line inductance = 200 µH)



L_g [mH]	$\hat{I}_g$ [A]	PF	THD(v_g)	THD(i_g)	U_o [V]
0	7.2	0.48	0.3%	180%	324
1.8	4.3	0.56	0.2%	147%	320
19.8	2.3	0.70	0.1%	95%	306

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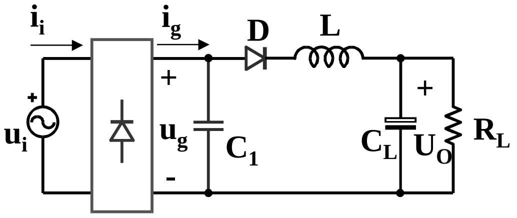
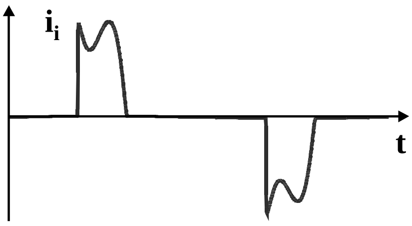
Passive Power Factor Correction

Modified Passive Filter





- Exploits difference between Class D (relative) and Class A (absolute) standard limits (IEC 1000-3-2) to reduce reactive component size
- Suitable for low power applications
- No output voltage regulation

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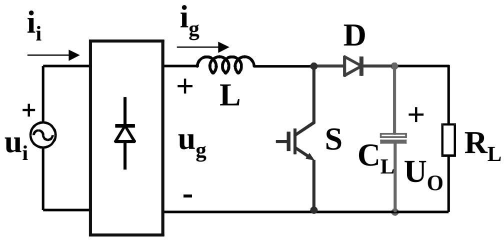
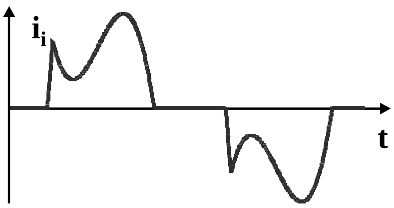
PFC Structures: Active Power Factor Correction Techniques

Line-frequency commutation





- Switch commutation at twice the line frequency (minimal switching losses)
- Reduced reactive element volume compared to passive filters
- Reduced EMI compared to high frequency rectifiers
- Limited power factor and output voltage regulation
- Simple and cheap

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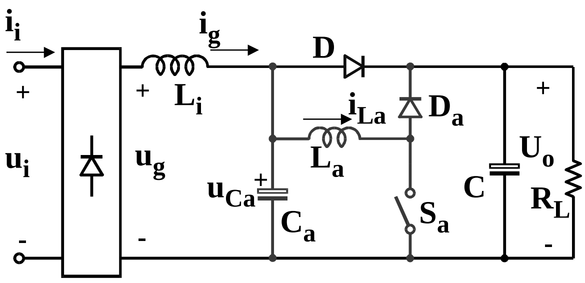
Active Power Factor Correction

Line-frequency commutation



- Suitable for higher power (smoother input waveform)
- Limited power factor and output voltage regulation

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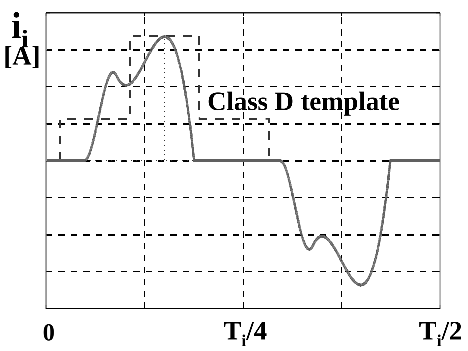
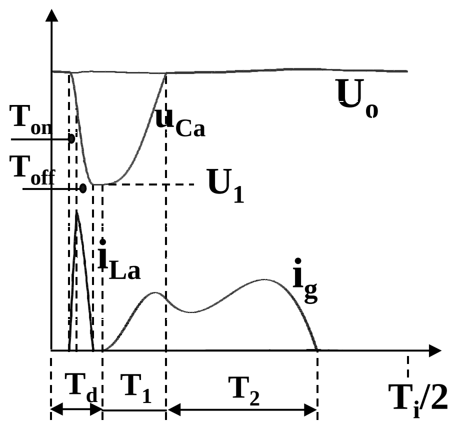
Active Power Factor Correction

Line-frequency commutation

Input current waveform





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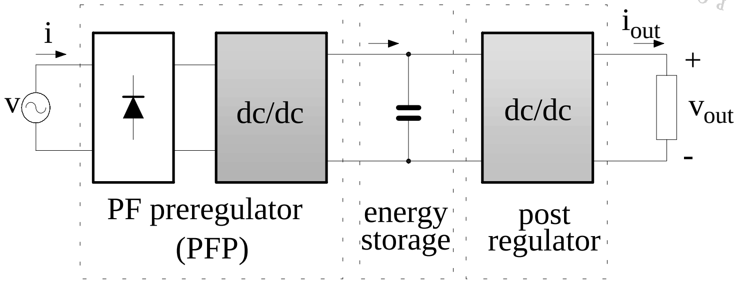
PFC: Basic Configurations

Two stages PFC: Cascade Configuration



PREREGULATORS: **AC/DC converters with high power factor and poor output voltage regulation**

- **Post regulator, rated for constant input voltage (optimized design), has minimum current absorption, thus allowing minimum converter switch size**
- **Reduced efficiency (load power is processed twice)**

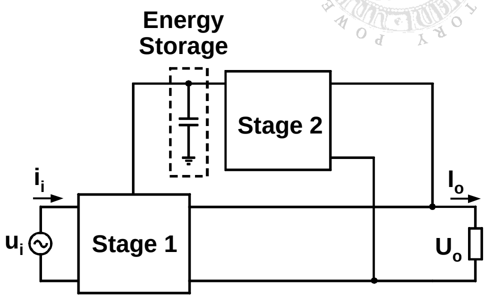
PFC: Basic Configurations

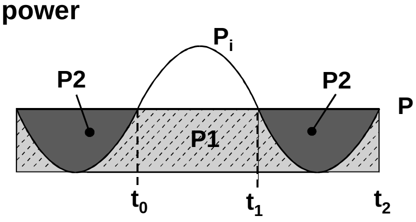
Two stages PFC: Parallel Configuration

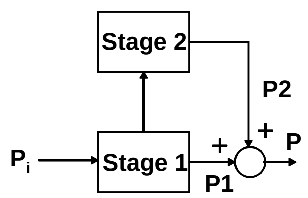
The output voltage can be accurately regulated

and

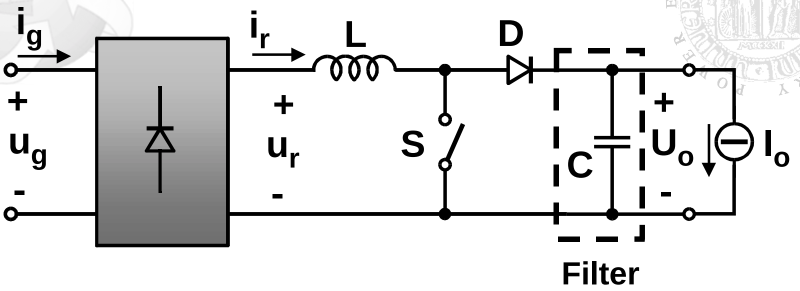
- **about 68% of input power goes directly to the output through stage 1**
- **stage 2 processes only 32% of input power**







Basic Pre-regulators: Boost Topology



CHARACTERISTICS:

- **Simple topology**
- **Inherent input filter (small input current THD)**
- **High Power Factor**
- **Output voltage higher than peak input voltage**
- **No start-up nor short circuit protection**
- **No high-frequency insulation**