

ENGINEERING
TOMORROW

Harmonics –
A costly problem easily solved

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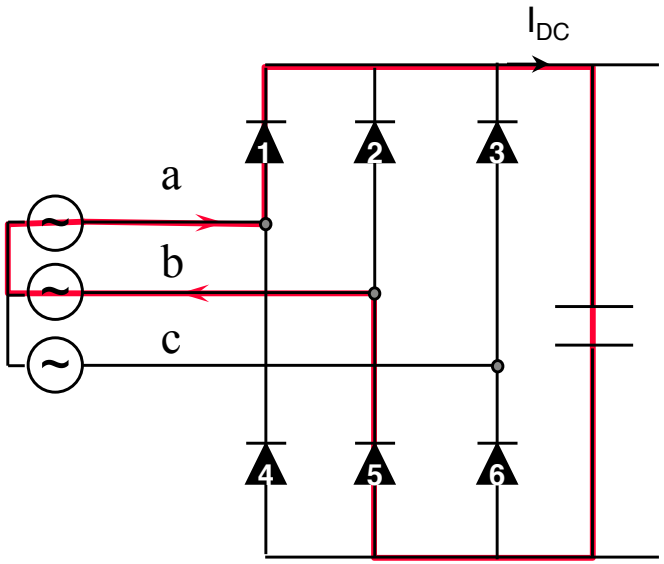
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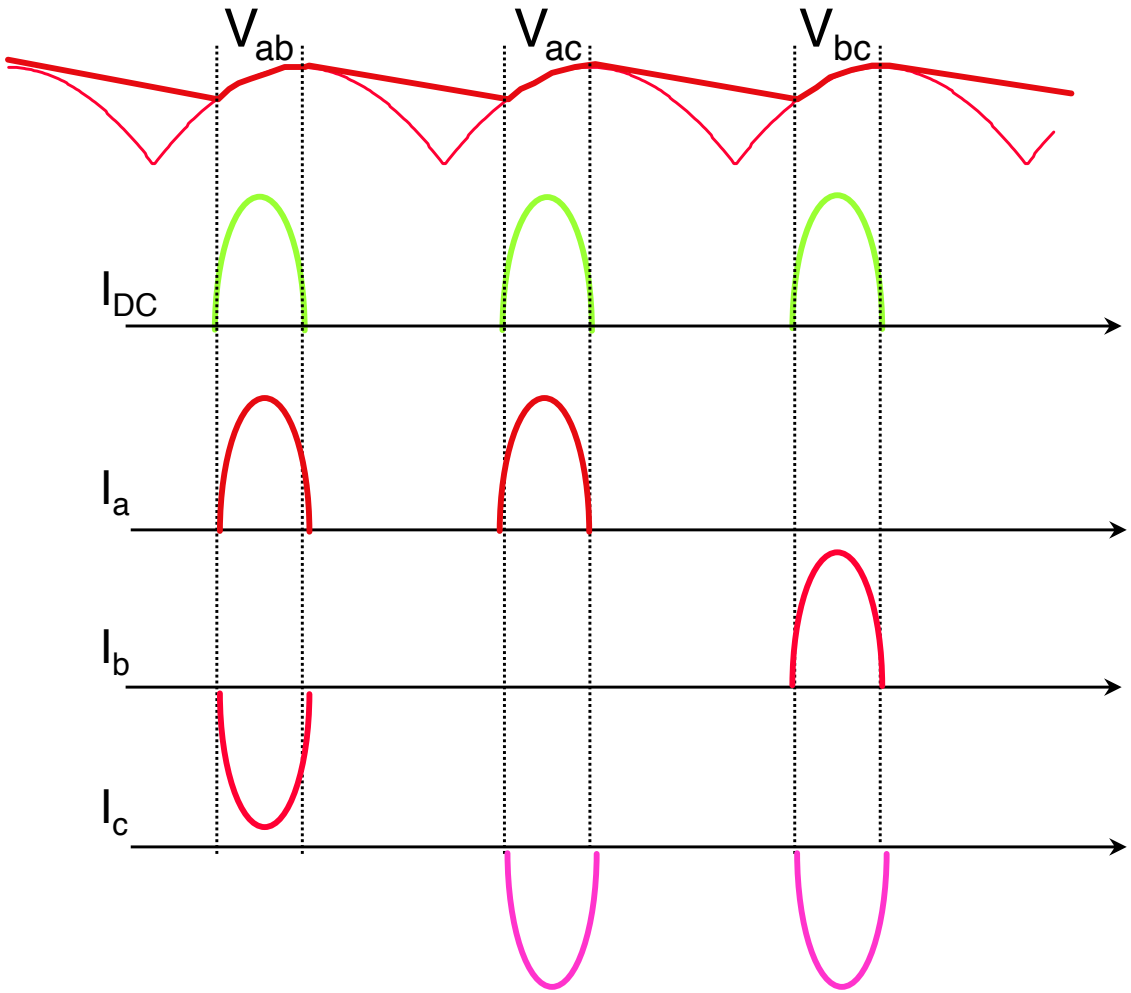


Content

- What is Harmonic Distortion?
- What are the possible problems?
- Harmonic limiting standards
- Harmonic reduction techniques

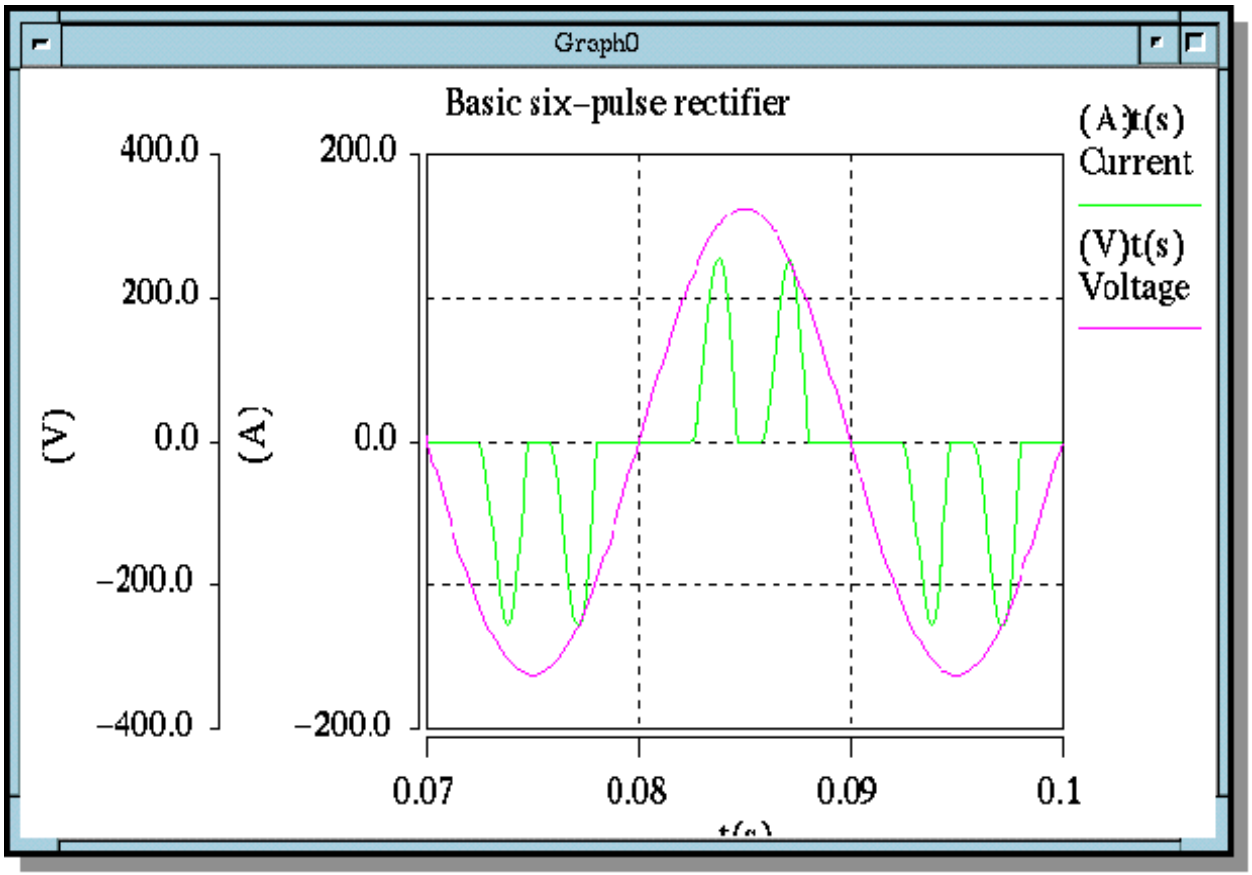
Harmonic current of a basic 6-pulse rectifier





- Non-sinusoidal currents are drawn from the supply
- Pulsating power from the supply source

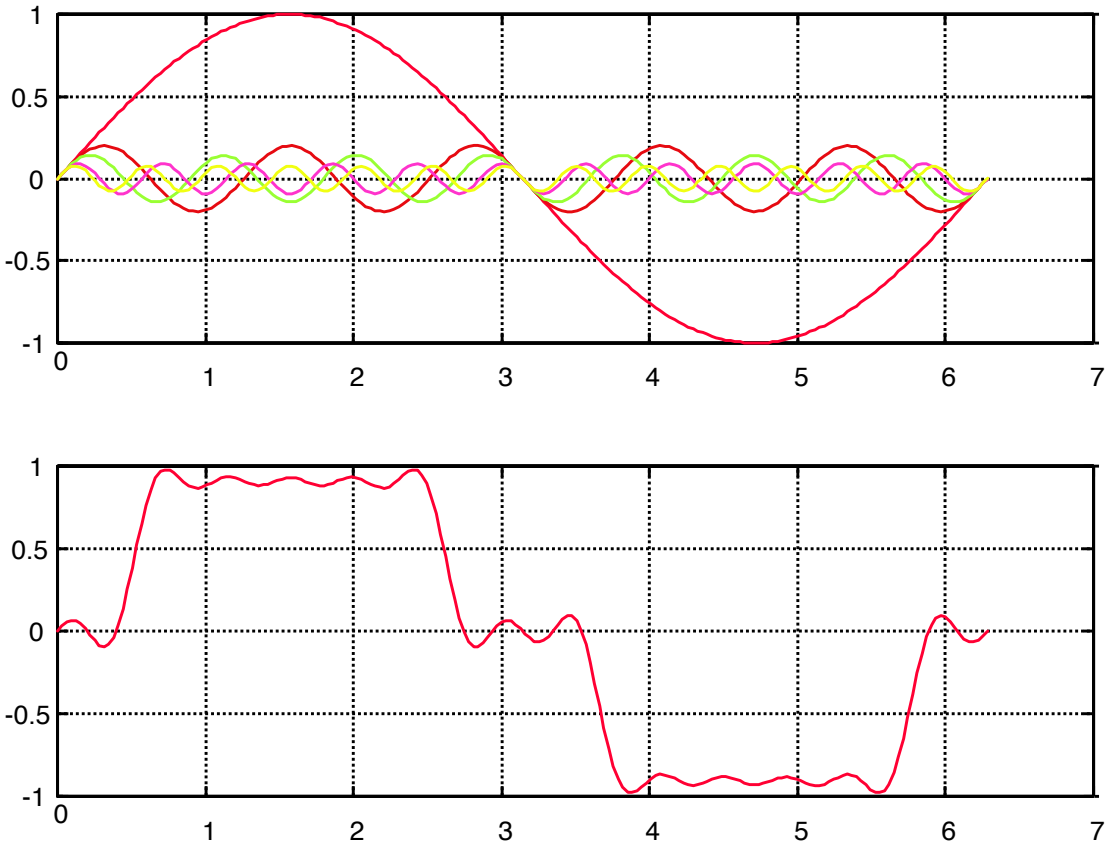
Input Current of a basic rectifier



HARMONIC CURRENT ANALYSIS

Fund. Current	**38.57 A**
THD	**104.52%**
RMS current	**55.79 A**
5'th Harmonic	**30.41 A**
7'th Harmonic	**23.64 A**
11'th Harmonic	**10.01 A**
13'th Harmonic	**5.07 A**

Harmonic Analysis

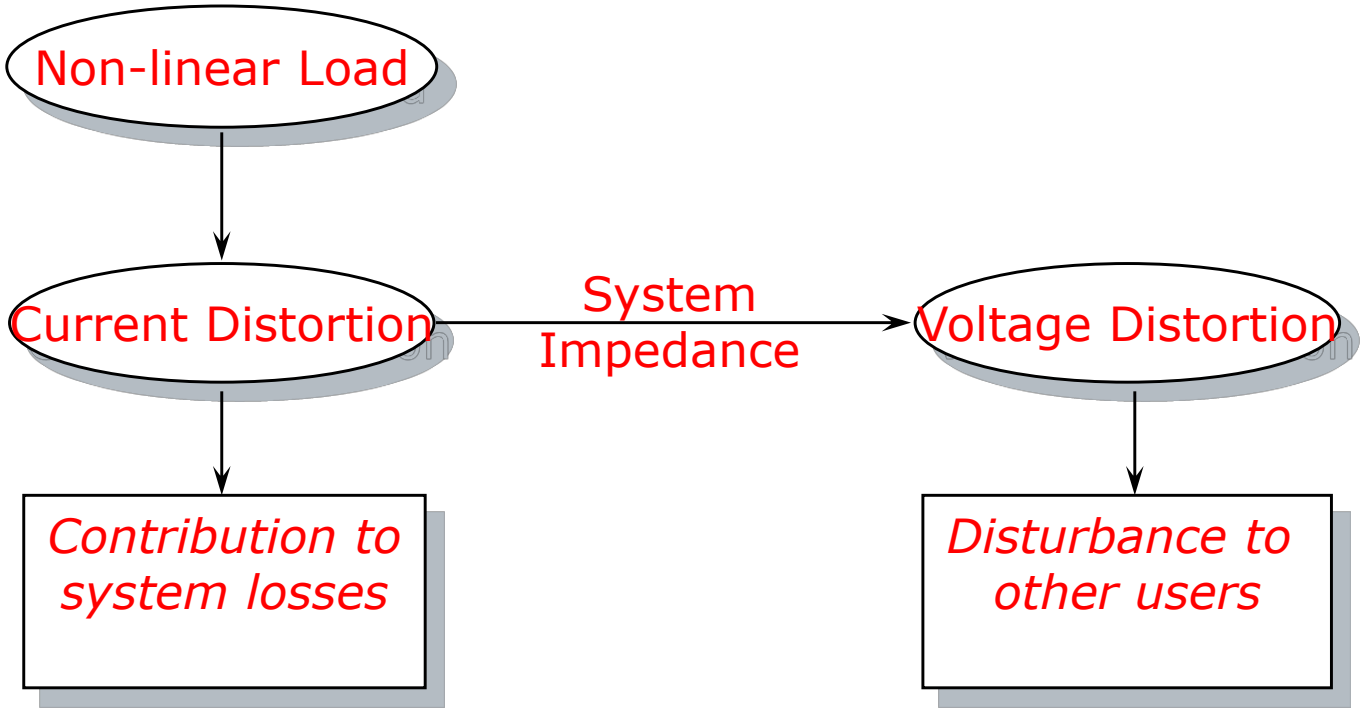


All periodic signals can be represented as a sum of sine-functions with periods equal to integer numbers of the fundamental component

$$f(t) = \sum a_h \sin(h\omega_1 t)$$

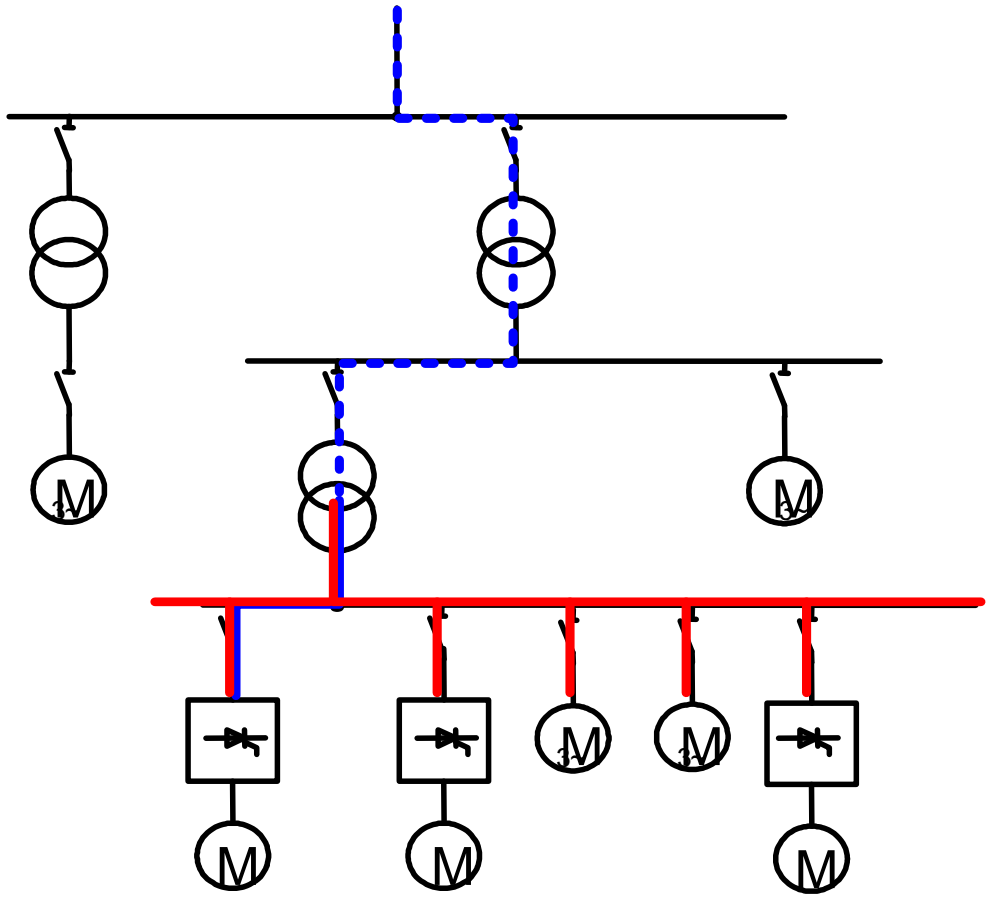
Harmonics is decomposition of a signal into different (integer of fundamental) frequencies

Harmonic distortion by nonlinear loads



- Current distortion is apparatus level performance
- Voltage distortion is system level performance

Harmonic distortion by nonlinear loads



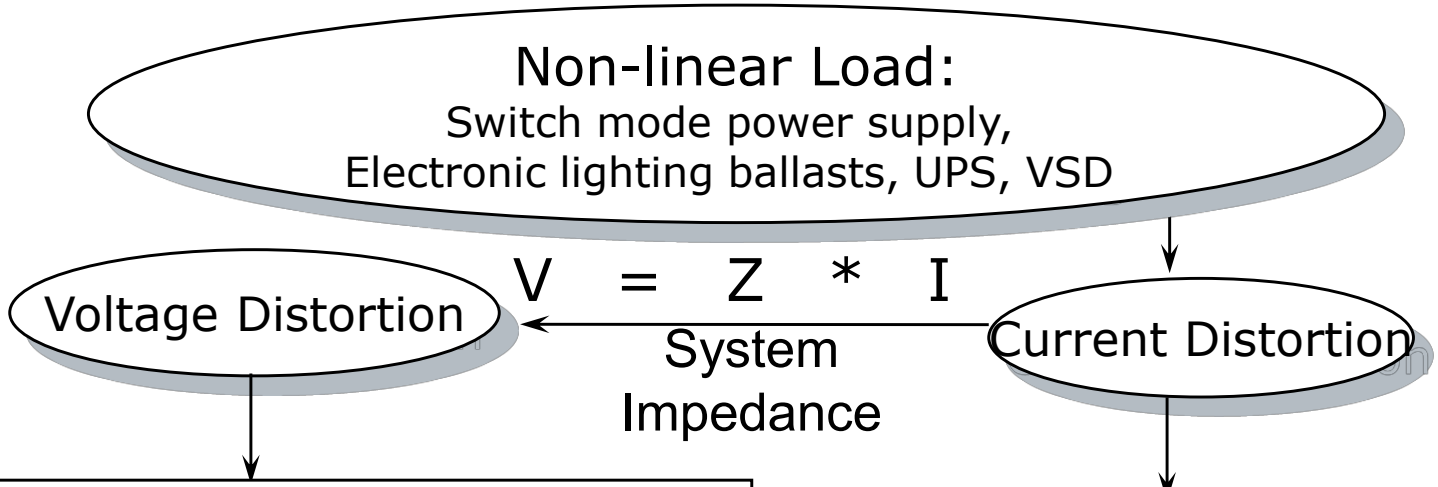
Current distortion is apparatus level performance

$$I * R = U$$

Voltage distortion is system level performance

- Required knowledge to calculate voltage distortion is the harmonic currents of the non-linear load AND the system short-circuit impedance.
- It is NOT possible to predict the voltage distortion knowing only the drive's performance.

Why anxiety?



Problems caused by voltage distortion:

- Multiple zero crossing:
  - Malfunction of electronic equipment
  - Brake down of electronic equipment
  - Transient generation
  - Increased EMI
- Impact on other equipment:
  - Increased eddy current losses in motors
  - Torque ripples in motors
  - Resonance generation
- Erratic operation of different equipment

Problems caused by current distortion:

- Increased losses in transformer
- Nuisance tripping of circuit breaker equipment
- Stressing of PF correction capacitors and worse possible resonance generation
- Spurious operation and tripping of equipment
- Skin effects of conductors
- Neutral conductor overload (single phased)
- Overload of cables and transformers

Standards and recommendations

Standard / recommendation	Countries
IEEE 519-1992 *	North America
EN 61000-3-12 (..-2)	Europe
G5/4 *	UK
HK Code of Practice *	Hong Kong

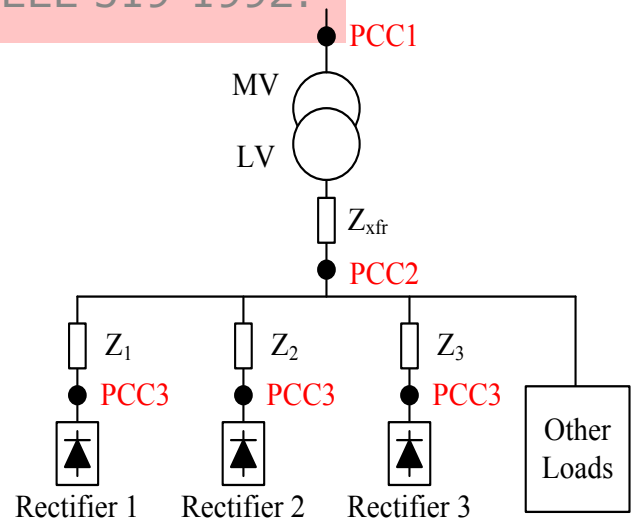
* Recommendations

Goal of maximum voltage distortion:

IEEE 519-1992	Critical application	General system	Dedicated system
THvD	3 %	5 %	10 %

IEC 61000-2-4	Class 1	Class 2	Class 3
THvD	5%	8%	10%

IEEE 519-1992:



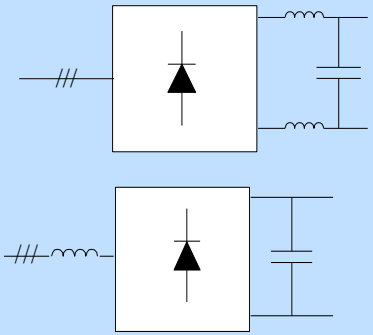
PCC1. The Primary Side of the Medium Voltage Transformer.
This level is of course of great concern to Electricity Suppliers, causing them to ask for better harmonic performance. IEEE519-1992 is one example.

PCC2. A level of concern to the Actual Layout of the Network.
If THvD is too high, other users on this side of the network could be disturbed. This is not typically of interest to the Electricity Suppliers! If THID is too high, larger transformers, cables, etc. are required

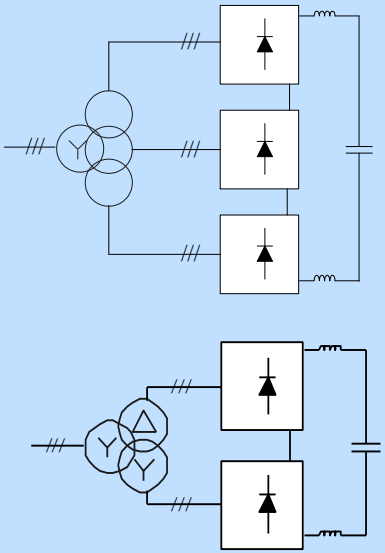
PCC3. Equipment related only! Has no relevance.
Is only relevant to check if a certain THvD allows this equipment to operate.

Harmonic reduction techniques

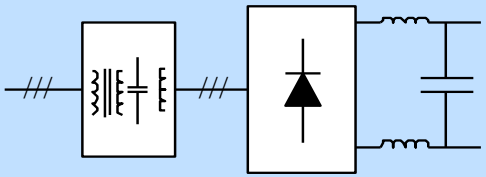
Passive:



Inductors

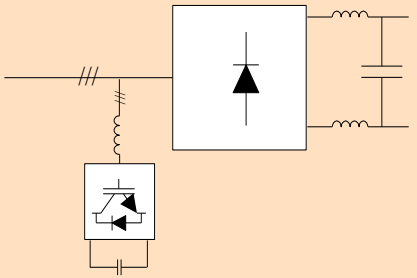


Multi-pulse

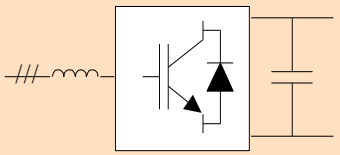


Advanced
Harmonic Filters

Active:

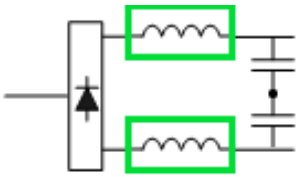


Active filter

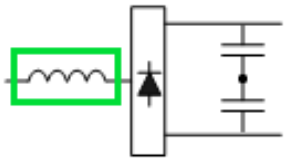


PWM-rectifier
Active Front End

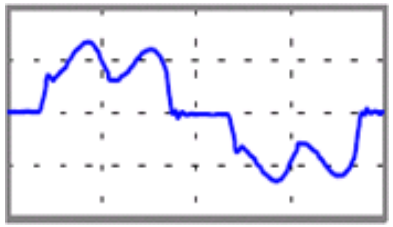
Six-pulse rectifier with AC or DC inductor



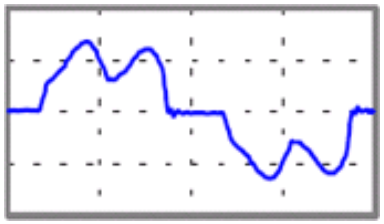
DC-
Inductors



AC-
Inductors



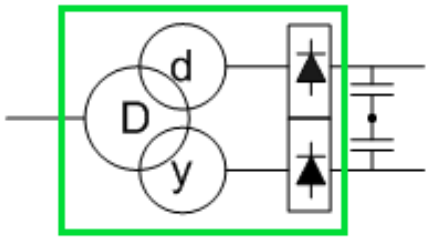
HARMONIC CURRENT	
Fund.	36.22 A
THiD	42.51%
RMS current	39.47 A



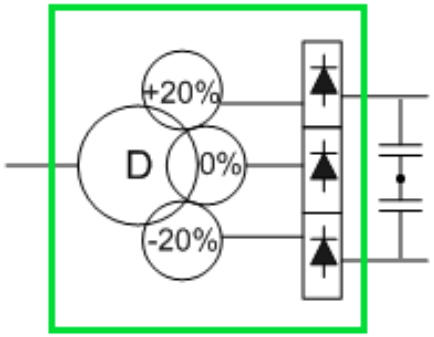
HARMONIC CURRENT	
Fund.	36.84 A
THiD	43.84%
RMS current	40.22 A

- AC and DC inductors add an Inductive reactance to the circuit.
- The added Inductive Reactance reduces the total reactance caused by the rectifier circuit and DC capacitors.
- Displacement Power Factor or cosΦ ≈ 1
- The added reactance also reduces distortion by phase shifting the harmonic currents.

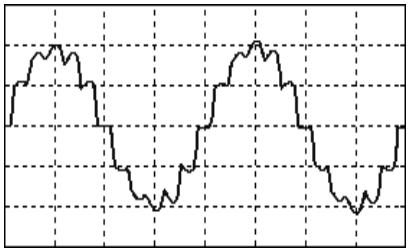
12 & 18 Pulse Rectifiers



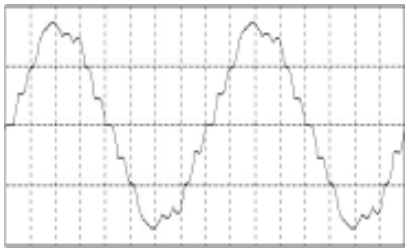
12-pulse rectifier



18-pulse rectifier



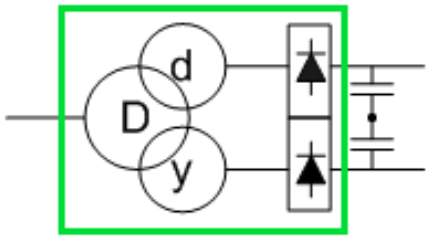
HARMONIC ANALYSIS
Fund. Current 36.11 A
THiD 17% (11%)
RMS current 36.32 A



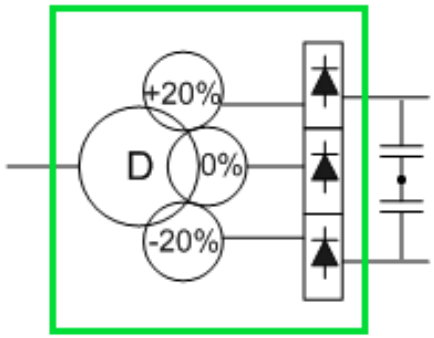
HARMONIC ANALYSIS
Fund. Current 36.05 A
THiD 8.9% (5%)
RMS current 36.28 A

- The current coming into each rectifier block has a different phase.
- Special transformer combinations of Wye and Delta types are used to create the phase shifts.
- Performance is dependent on load and grid.
- Within each multipulse solution there are many variations of designs.
- The 12-pulse aims to reduce 5th & 7th harmonics, and multiples.
- The 18-pulse aims to reduce 5th, 7th, 11th & 13th harmonics, and multiples.

12 & 18 Pulse Rectifiers

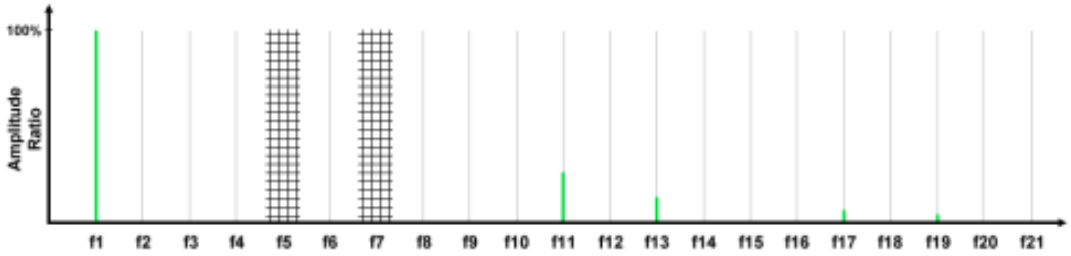


12-pulse rectifier

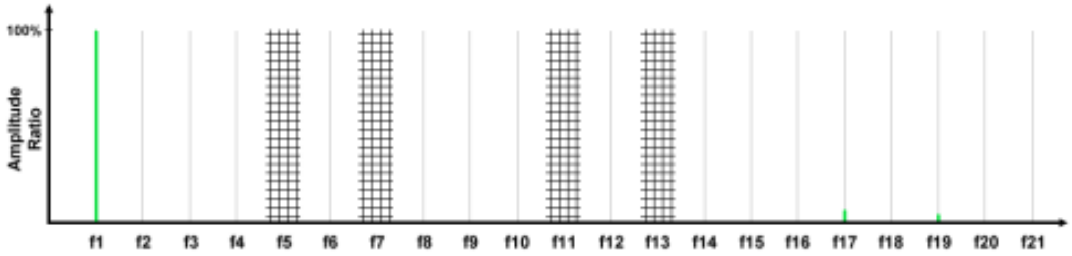


18-pulse rectifier

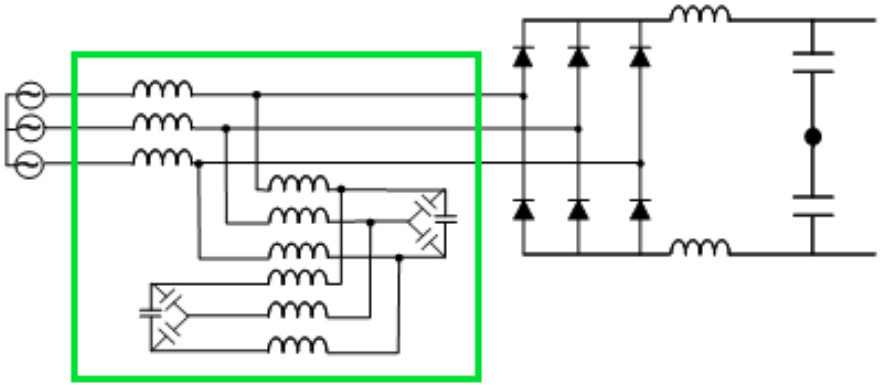
- 12p aims to reduce 5th & 7th harmonics, and multiples.



- 18p aims to reduce 5th, 7th, 11th & 13th harmonics, and multiples.

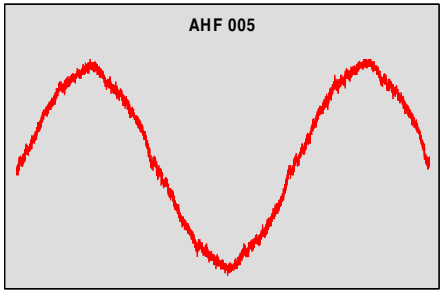


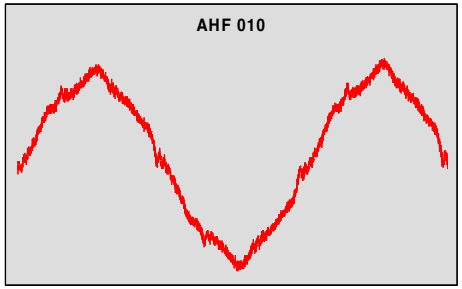
Passive Filters



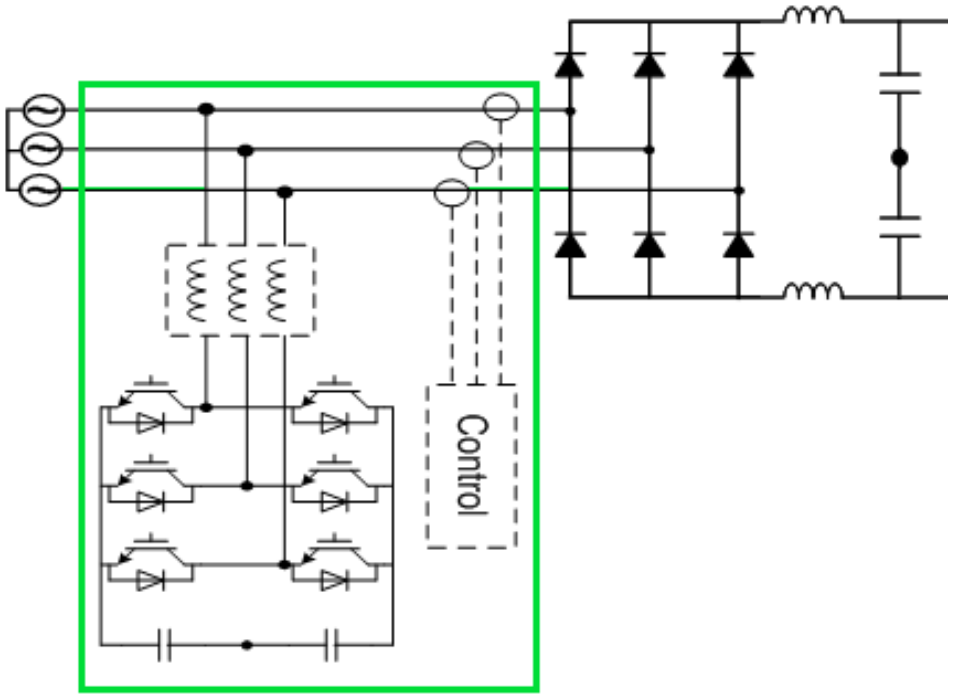
Passive Filter
(Also called Harmonic Trap Filter)

- Combinations of Inductors and Capacitors reduces all harmonics, not just low orders.
- Highly dependent on load matching. Too large a filter for a load leads to power inefficiency.
- Lowest cost of ownership in low power installations.
  - Advanced Harmonic Filter AHF 010 - THiD 10%
  - Advanced Harmonic Filter AHF 005 - THiD 5%





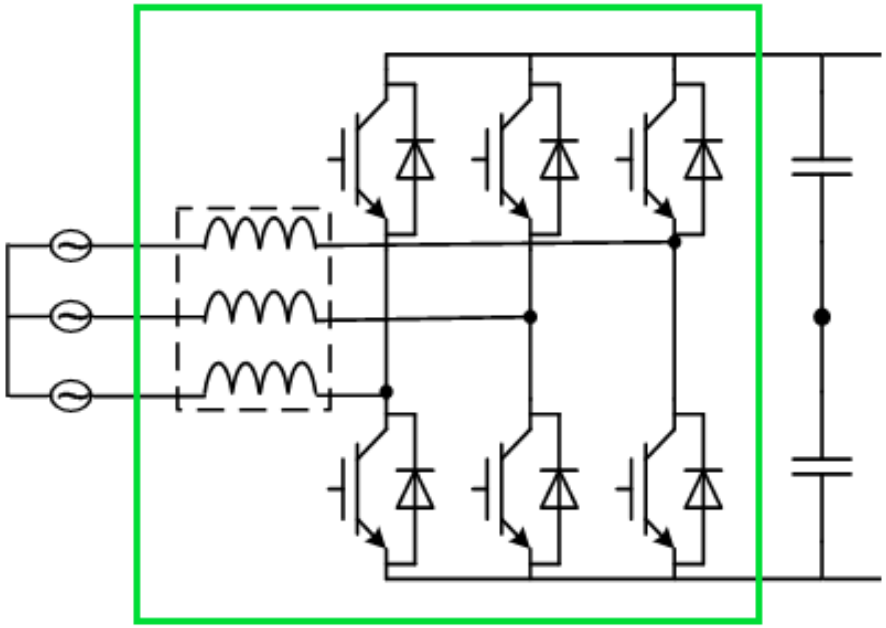
Active Filters



Active Filter

- Offers high performance mitigation
- The filter cancels the distortion by sensing it and inserting an equal signal with the opposite phase.
- Tolerant with load and grid imbalances
- Allows for group compensation, power factor correction and load balance correction.

Active Front End



Active Front End - AFE

- Utilizes Pulse Width Modulation (PWM) in the rectifier section.
- An electronic control circuit sensors and adjusts the PWM for optimum control of the DC bus voltage and harmonic reduction.
- Offers highest mitigation performance.
- Tolerant against load and grid imbalances.
- The only design for optimum regeneration of power.
- Small & compact.
- Can produce high frequency disturbances.

Other Mitigation Techniques







- Oversize hardware components, still abiding to regulations, and allow harmonics to flow.
  - Oversize distribution transformers.
  - Oversize switchgear and distribution cabling to reduce risk of insulation breakdown.
  - Use "K-factor" system transformers to increase heat tolerance.
- Hardware for over-sizing is expensive.
- Harmonic energy is dissipated in the form of heat which is also expensive.
- Harmonics can also be reduced by:
  - Balancing loads on phases.
  - Improving Displacement Power Factor

Summary

- Harmonic Mitigation Techniques are varied and are dealt between passive and active solutions.

- The right mitigation technique depends on the individual customer requirements and goals in mitigating harmonics.

Harmonic Mitigation becomes relevant when:

- Drive loading of transformer is >30%
- The transformer is >90% loaded
- Non linear loads are supplied from a generator
- Loads are installed in sensitive environments

Thank You