TECHNICAL WEBINAR

Harmonics in Drive Systems

Causes, problems and mitigation

ABB UK & Ireland

ENGINEERS IRELAND

REGISTERED TRAINING PROVIDER 2022

Talking Points…..

Contents

1. Introduction – What are harmonics?
2. The effects of harmonics
3. Standards and regulations
4. Mitigation methods
5. Comparing mitigation techniques
6. Summary

Introduction

What are harmonics?

Introduction

What are harmonics?

The **ideal supply network** voltage & current waveforms should be sinusoidal.

In reality, a range of power quality issues exist such as:

dips, transients, voltage and frequency fluctuations etc.

When a repetitive and predictable **non-sinusoidal** voltage or current distortion exists, this means the supply contains **harmonic distortion**.

Introduction

What are harmonics?

Electrical Supplies

An Electricity Supply is hardly ever :

- a pure sine wave
- with voltage and current in phase

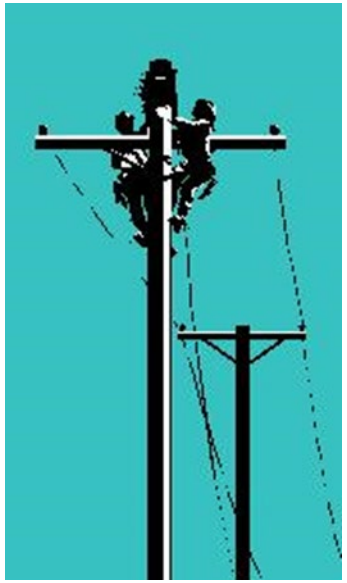
The current will normally lag the voltage resulting in Power Factor lower than 1.0

The voltage is normally distorted

The distorted voltage waveform can be analysed by Fourier Transform

Overall distortion is the Total Harmonic Distortion (THD)

Both low Power Factor and Harmonic Distortion represent inefficiencies in the supply network

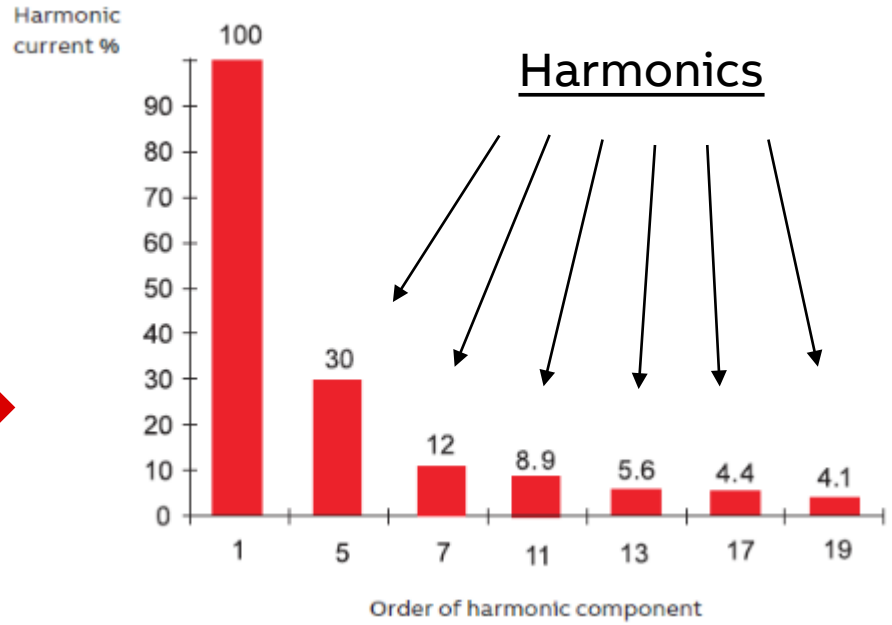


Introduction

What are harmonics?

Fourier Transform: Is a mathematical function to show different parts of a continuous signal.

i(t) = ??



Introduction

Cause of harmonics

Non-linear loads draw current in a periodic non-sinusoidal or distorted manner.

– Think of a diode opening / closing and the associated current.

Harmonics or harmonic content is a mathematical concept that allows quantification and simplified analysis of non-linear waveforms.

Harmonics are typically present in both network currents and network voltages.

Non-linear current draw creates non-linear voltage as it flows through the electrical network

– Current harmonics → Voltage harmonics

– Harmonic Currents cause inefficiencies and system losses (cabling / transformers)

– Harmonic Voltages cause interference with other equipment

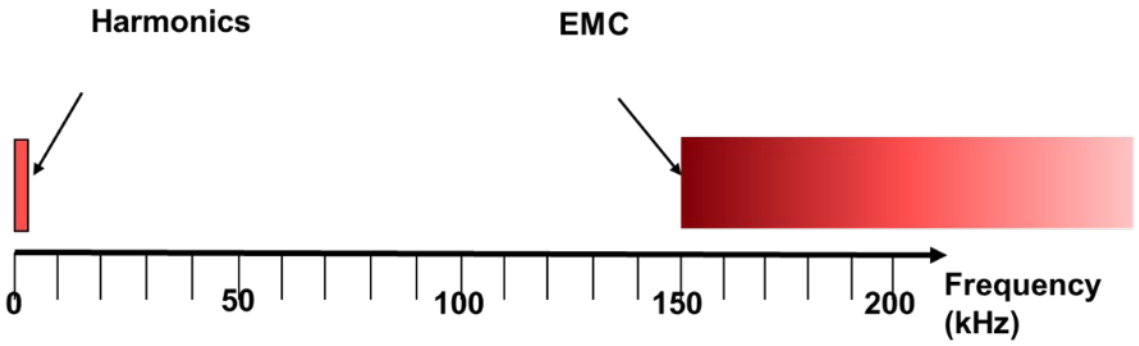
Main culprits: AC / DC Drives / UPS Systems and commercial equipment with Switch Mode Power supplies in them (computers / photocopiers, fluorescent lighting)

Introduction

Harmonics or EMC?

Frequency Spectrum

- Harmonics are not EMC disturbances
- Harmonic voltages/currents are a low frequency phenomena, typical range between 100 Hz – 3 kHz
- For example 50 Hz network;
  - 50 Hz x 100th order number = 5 kHz



Introduction

Source of harmonics

Anything with Switching Devices

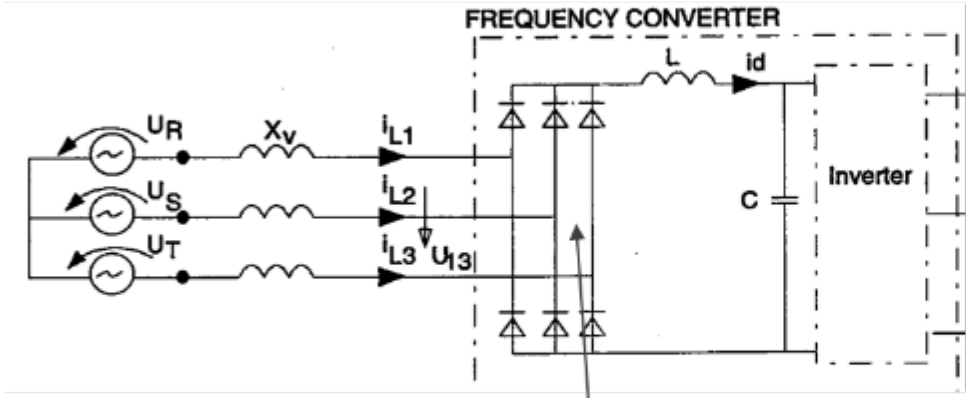
Fluorescent bulbs
Dimmer switches
Other lighting systems
UPS systems
HVAC
Telecom installations
Switch mode power supplies (PC's, TV's, DVD players etc)
Converters / drives used on:

- Pumps
- High-speed lifts
- Motors
- Computers
- Household equipment
- Electronic equipment

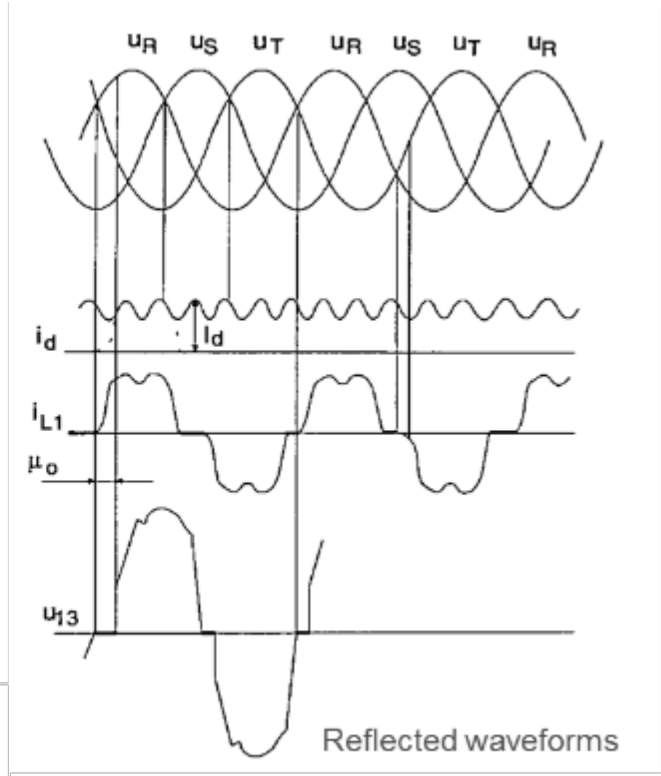
Introduction

Variable speed drives (VSD's)

Formation of DC link voltage with diode bridge



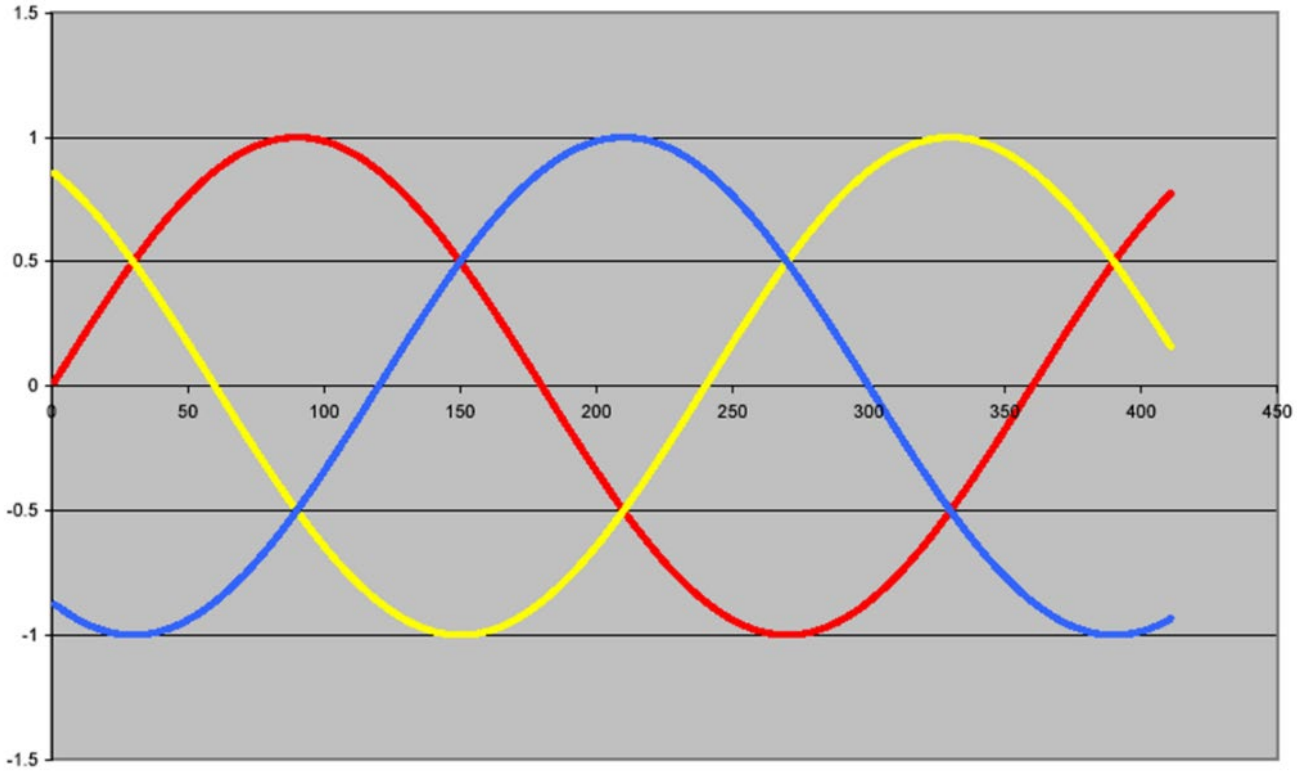
6 diodes means this is a 6 pulse drive (old DC drives term)



Reflected waveforms

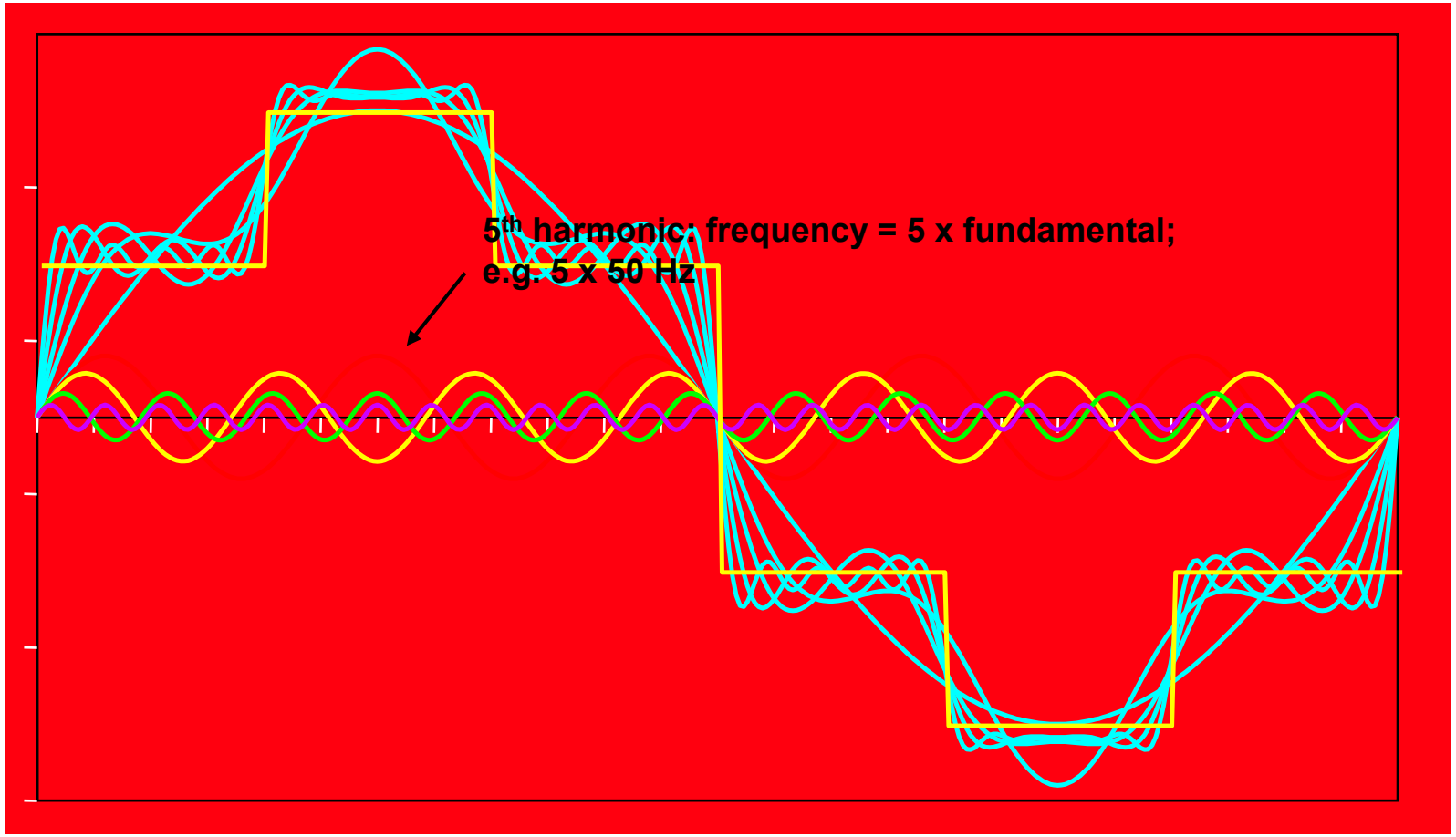
Introduction

Pure sine wave – Voltage or current



Introduction

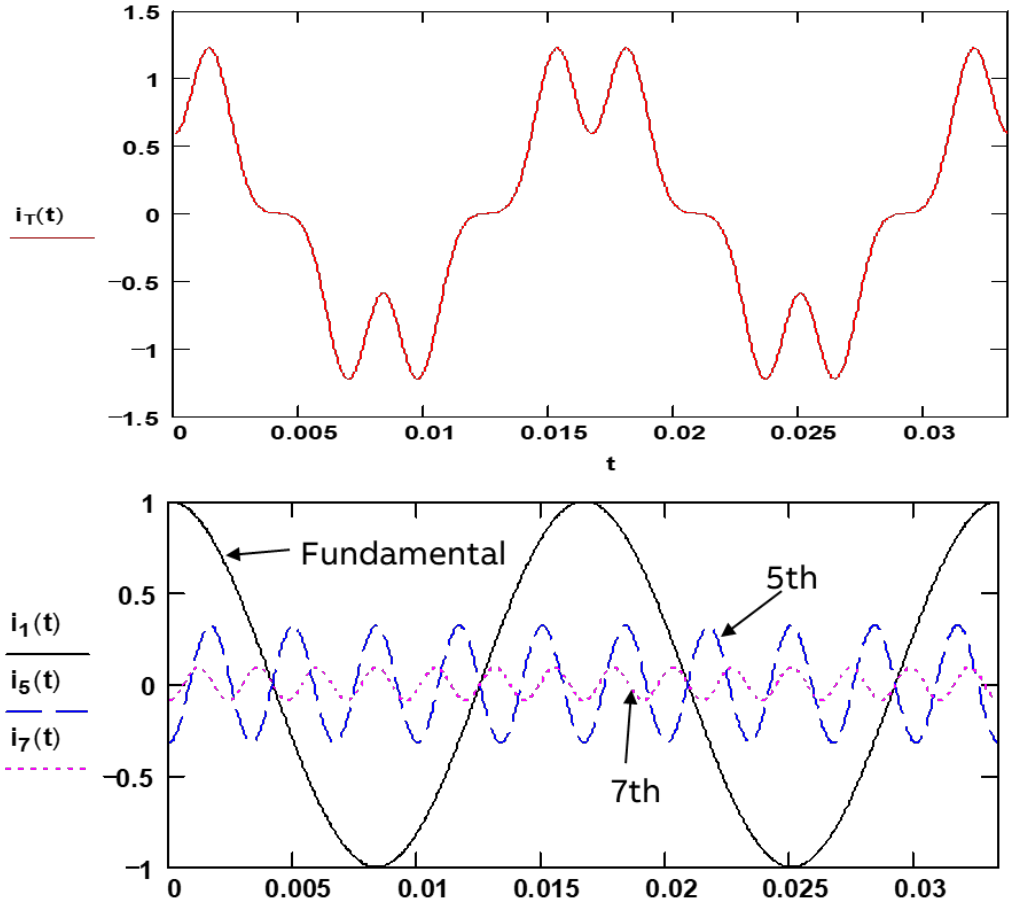
Distortion example



Fundamental + fifth (H5) +seventh (H7) +thirteenth (H13) +twenty-fifth (H25) = diode current

Introduction

Distortion example

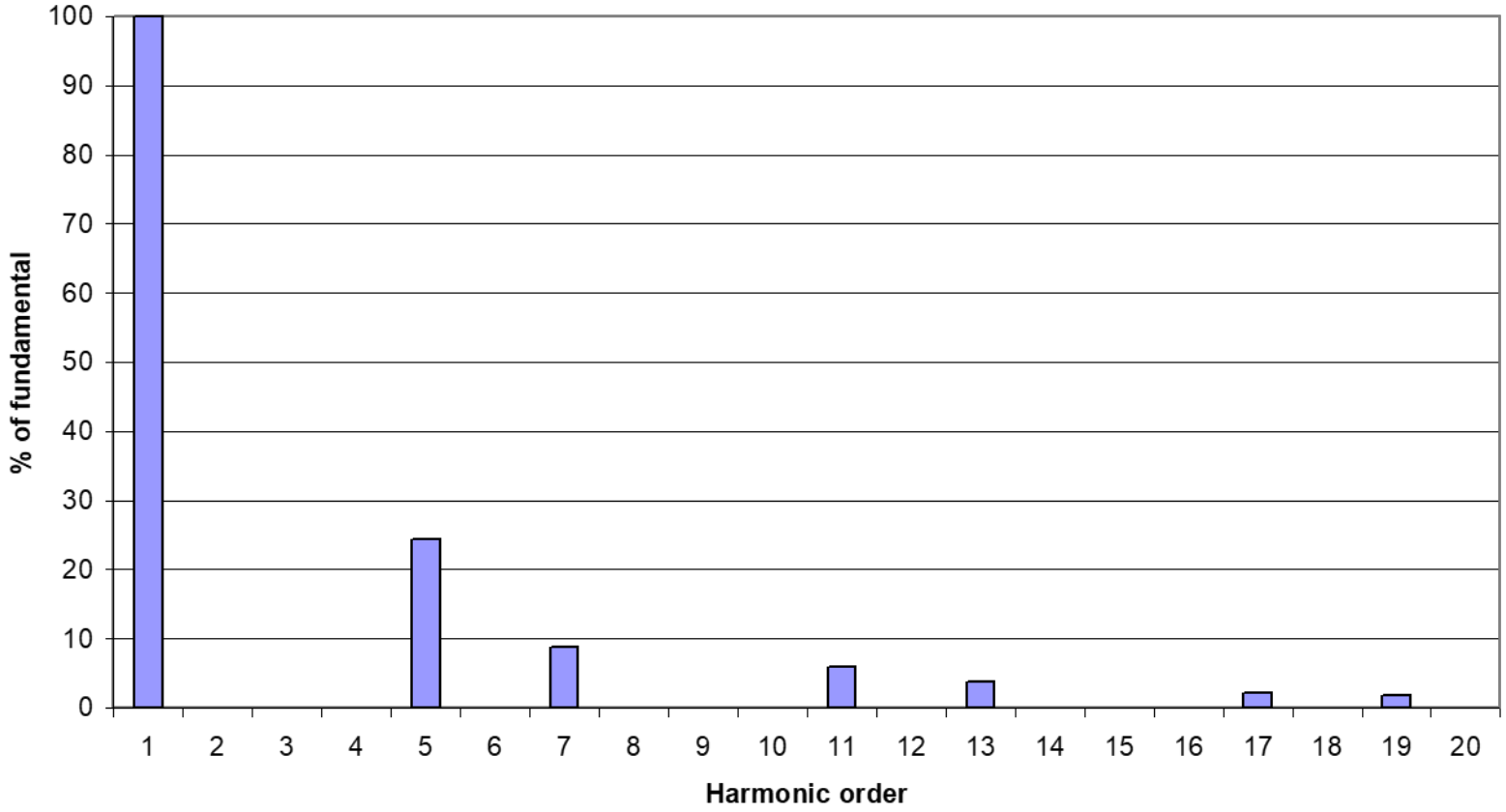


Real signal

Harmonic components

Introduction

Frequency spectrum



The Effects of Harmonics

Problems caused

The Effects of Harmonics

Potential problems created

Overheating of Components

Failure of Protection Devices

Damage to sensitive electronics

Troublesome operation of your system, down-time, high running costs (inefficiency), high lifecycle costs

The Effects of Harmonics

Generator operation

Generators operating with high harmonic loads present their own problems.

The generator must provide the harmonic current which will de-rate its capacity.

A rule of thumb is that a generator supplying 6 pulse inverters needs to be de-rated by 50%.

Additionally, particularly with older generators, the AVR can become unstable with high harmonic loads.

Check with the generator manufacturer for its use on harmonic loads.

The Effects of Harmonics

Power quality

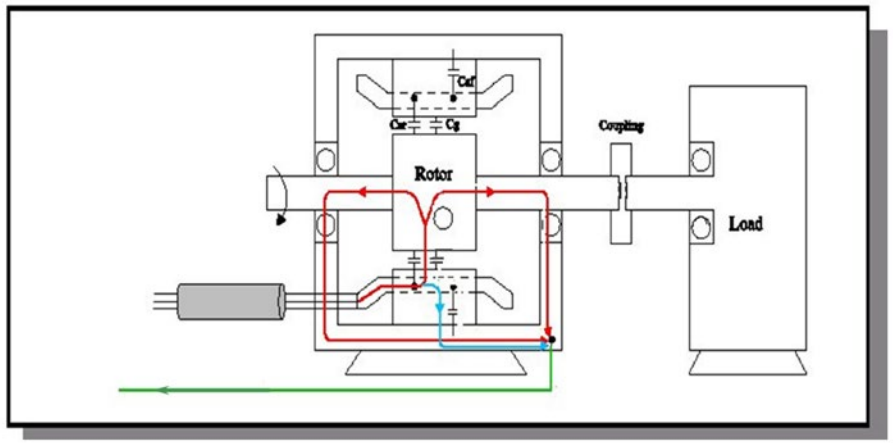
Harmonics are always the Bad Guy…….

Harmonics get blamed for many problems;

- Ultrasonic measurement devices reading crazy values
- Instrumentation interference (Flowmeters)
- Hand dryers and automatic taps turning on by magic

Actual causes are often not Harmonics;

- Common Mode Voltage
- EMC
- Poor design / installation
  - Fuse selection
  - Compatibility (old equipment with inadequate filtering)
  - Earth / Neutral Links / connections
  - Poor Earthing design / installation (Junction Boxes)
  - Earthing rings on flowmeters
  - Cable routing / cable selection (not screened – especially on borehole and submersible pumps)



Standards and Regulations

Recommendations

Standards and Regulations

Recommendations

Depends on geography:

Emissions

– ‘Product Standards’
  - IEC/EN 61000-3-2 (<16A per phase)
  - IEC/EN 61000-3-12 (>16 and <75A per phase)
  - IEC/EN 61000-3-4 (Not a standard but technical report for >75A per phase)

– System Standards
  - IEEE 519 (System Standard)
  - G5/5 (System ‘Standard’) UK

Compatibility

– IEC 61000-2-2 and IEC61000-2-4 are compatibility levels for equipment on LV supplies (withstand levels, not emmissions)

Standards and Regulations

G5/5 – Engineering recommendation

In ≤ 16A

In >16A

Stage 2
in a line

Stage 3
harmon

esigned

r the

Table 3 — Planning levels for harmonic voltages above 0.4 kV and less than or equal to 25 kV

Odd harmonics (non-multiple of 3)		Odd harmonics (multiple of 3)	
Harmonic order (*h*)	Harmonic voltage % *h* = 1	Harmonic order (*h*)	Harmonic voltage % *h* = 1
5	3.0	3	3.0
7	3.0	9	1.2
11	2.0	15	0.4
13	2.0	≥ 21	0.2
17	1.6	—	—
19	1.5	—	—
23	1.2	—	—
≥ 25	25/*h*	—	—

Table 9 — Compatibility levels for harmonic voltages above 0.4 kV and less than or equal to 25 kV

Odd harmonics (non-multiple of 3)		Odd harmonics (multiple of 3)		Even harmonics	
Harmonic order (*h*)	Harmonic voltage % *h* = 1	Harmonic order (*h*)	Harmonic voltage % *h* = 1	Harmonic order (*h*)	Harmonic voltage % *h* = 1
5	6.0	3	5.0	2	2.0
7	5.0	9	1.5	4	1.0
11	3.5	15	0.4	6	0.5
13	3.0	21	0.3	8	0.5
17 ≤ *h* ≤ 49	2.27(17/*h*) − 0.27	> 21	0.2	≥ 10	0.25(10/*h*) + 0.25
53 ≤ *h* ≤ 97	27/*h*	—	—	—	—

*Assuming you can meet Stage 1A requirements.

Mitigation Methods

How to combat harmonics

Mitigation Methods

Overview

Oversize/special transformer	• Customized designed windings to withstand harmonic currents. • For instance, K-factor transformer
Isolating nonlinear sources	• Dedicated feeders / transformers for non-linear sources
Passive filters	• Tuned Inductor and Capacitor (LC) circuit providing low impedance path for certain order harmonic current
Multi-pulse	• Phase shifting transformer to cancel low order harmonic currents (12 pulse, 18 pulse etc)
Low Harmonics drives	• IGBT rectifier draws nearly sinewave current from power supply
Active filters	• Remove each harmonic by injecting opposite phase harmonic current

Mitigation Methods

Evaluating harmonics

Pre-Installation

Design simulations:

- To contribute to the design process to ensure distributor / designer targets and limits are adhered to.
- e.g. ABB Drive Size*.

Post installation

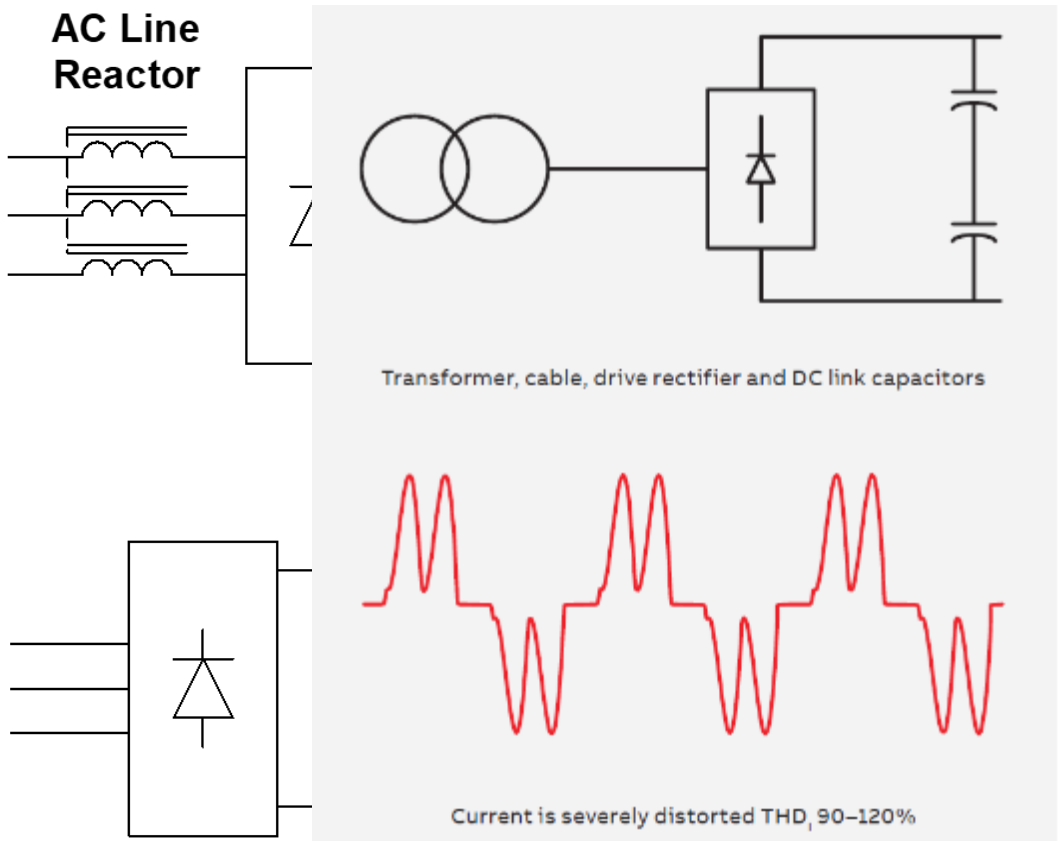
Site surveys:

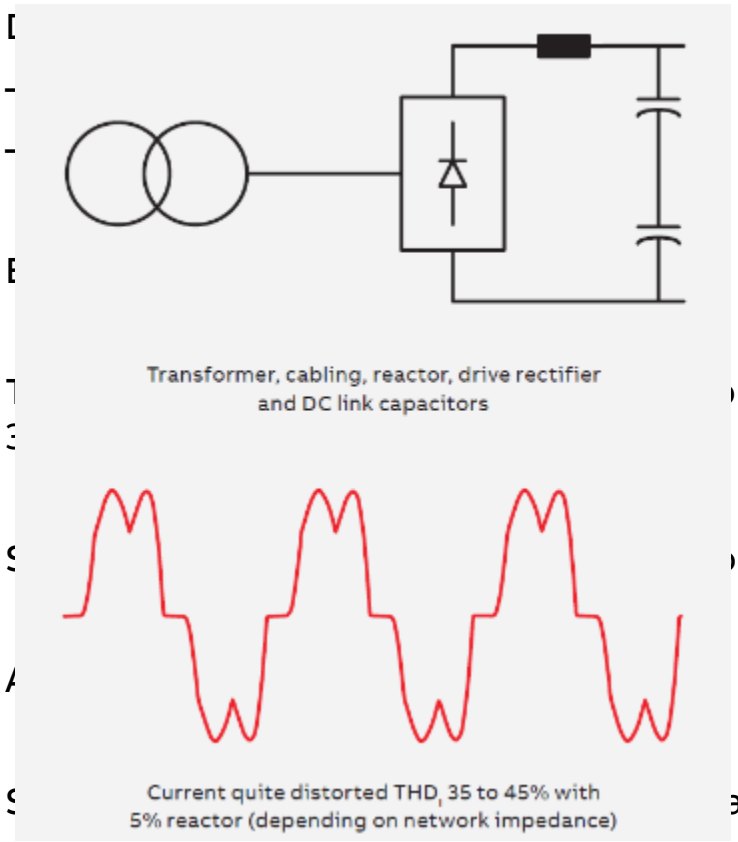
- Logging or troubleshooting sites experiencing issues.
- For logging the installation prior to:
  - Site expansions, changes.
  - Upgrades from DOL to 6-Pulse VSD’s etc. etc.

*https://new.abb.com/drives/software-tools/drivesize

Mitigation Methods

6-Pulse drive and choke - Reduction





ut terminals

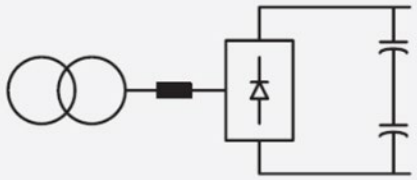
kes as standard

andard

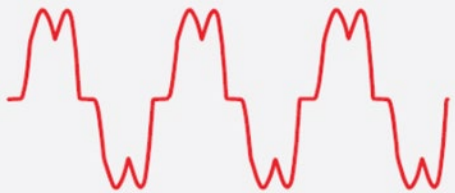
Mitigation Methods

Multi-pulse systems - Cancellation

6-Pulse rectifier

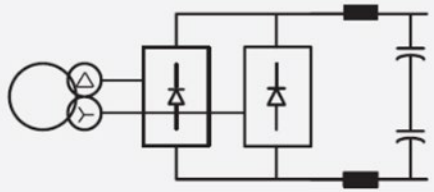


Transformer, reactor, drive rectifier and DC link capacitors

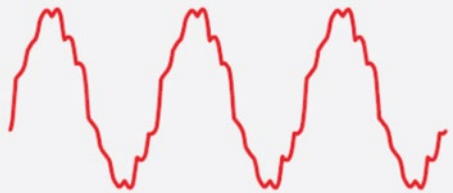


Current quite distorted
THD_i 35 to 45% with 5% reactor
(depending on network impedance)

12-Pulse rectifier

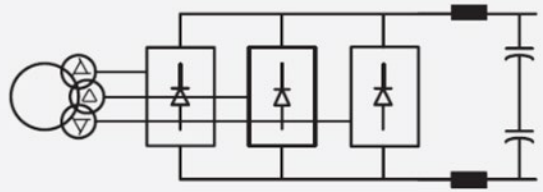


More complex transformer and cabling, drive rectifiers, DC chokes and DC link capacitors

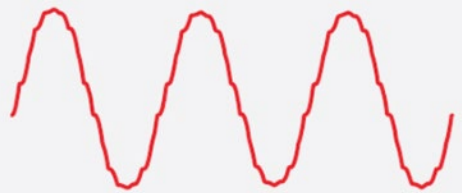


Current slightly distorted
THD_i 10 to 12% (depending on network impedance)

≥ 18-Pulse rectifier



Even more complex transformer, more cabling, drive rectifiers, DC chokes and DC link capacitors



Current wave form good
THD_i 5 to 6% (depending on network impedance)

Mitigation Methods

Passive filter - Diversion

Passive filters:

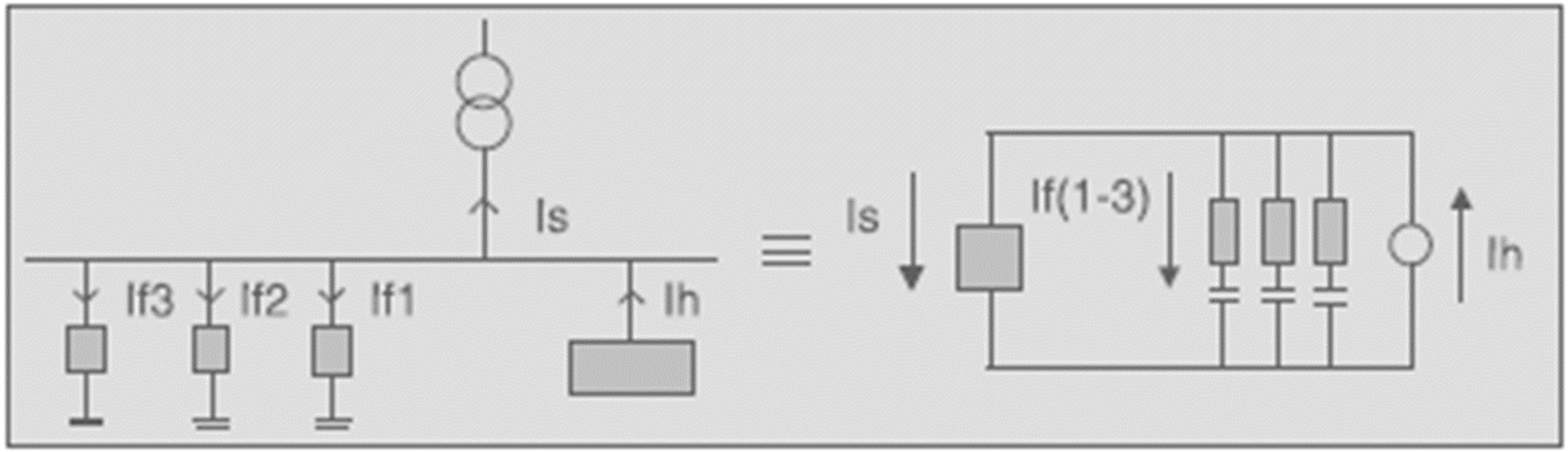
- Reactor and
- One set per

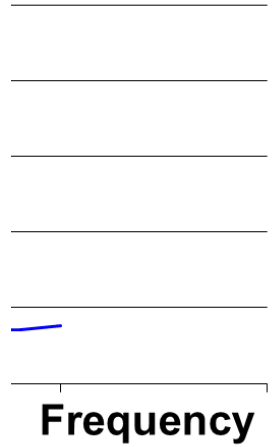
Offers 'low' impe

Filtering efficien

- Network pa

Danger for overl





Difficult to extend the system as needs re-engineering

Passive Filters are not recommended by ABB UK

Mitigation Methods

Passive filter - Issues

Danger for resonance.

Multiple branches required for filtering more t

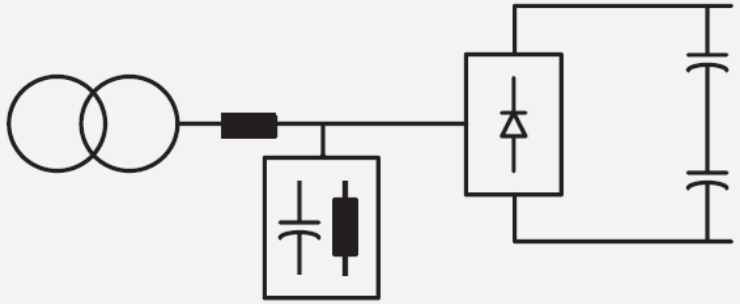
Large space requirement.

Always provide capacitive power:

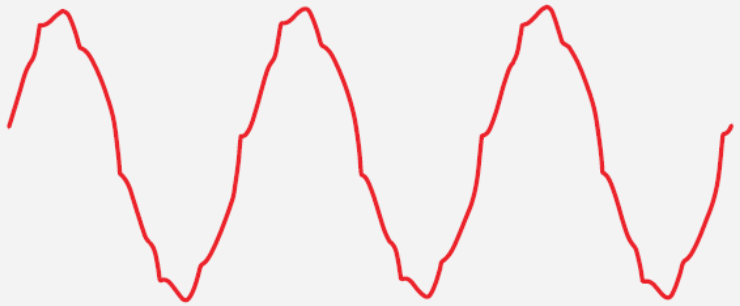
- AC drives do not require capacitive power
- Generators may not cope with leading po

Cannot balance loads.

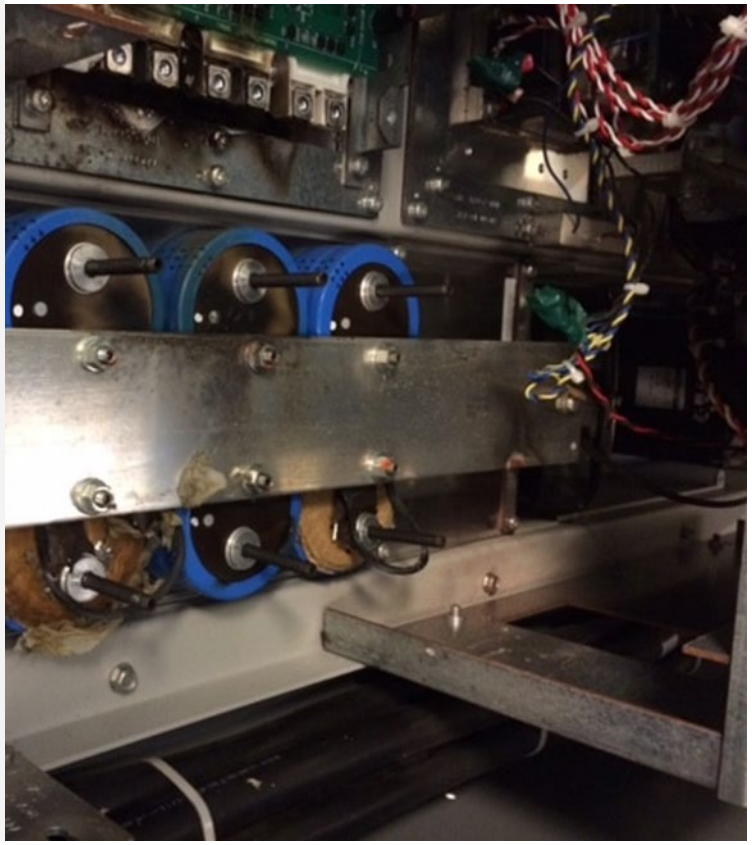
System design needs to beaccurate.



Transformer, passive filter, drive rectifier and DC link

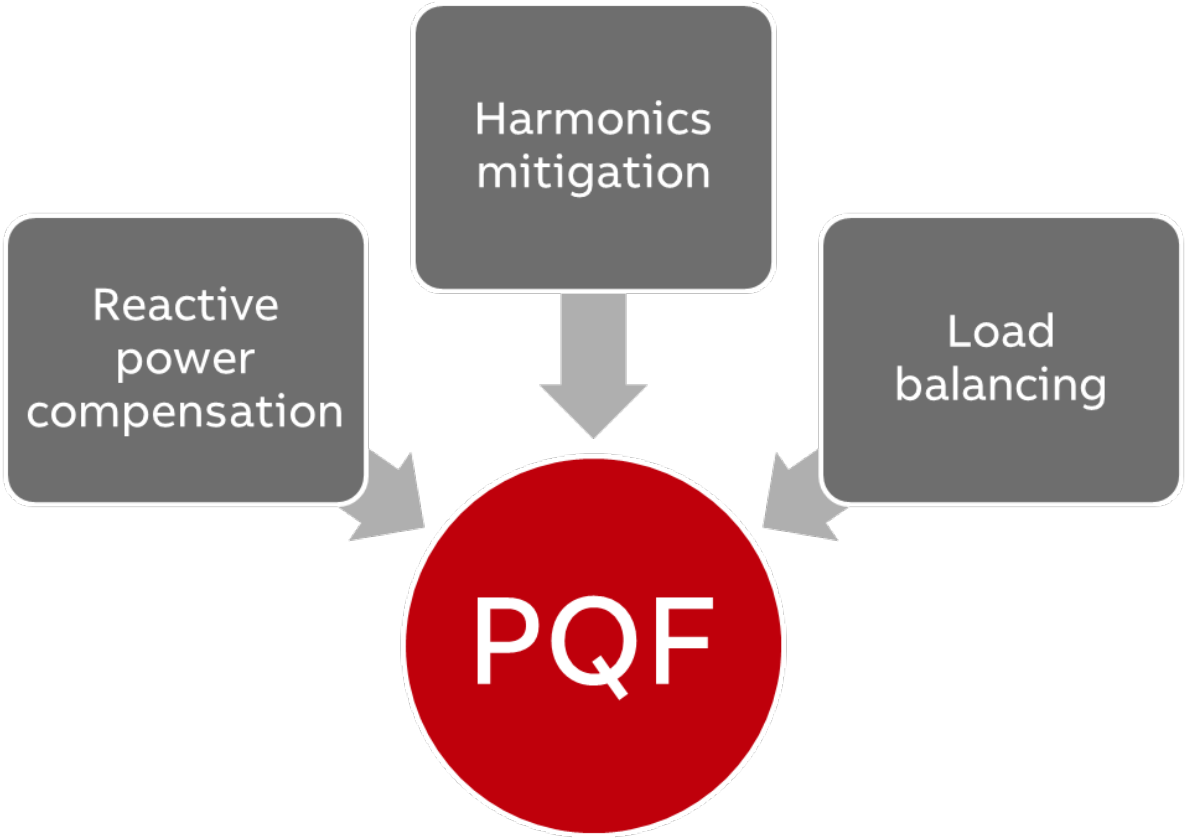


Current is quite smooth THD_i 5–10%



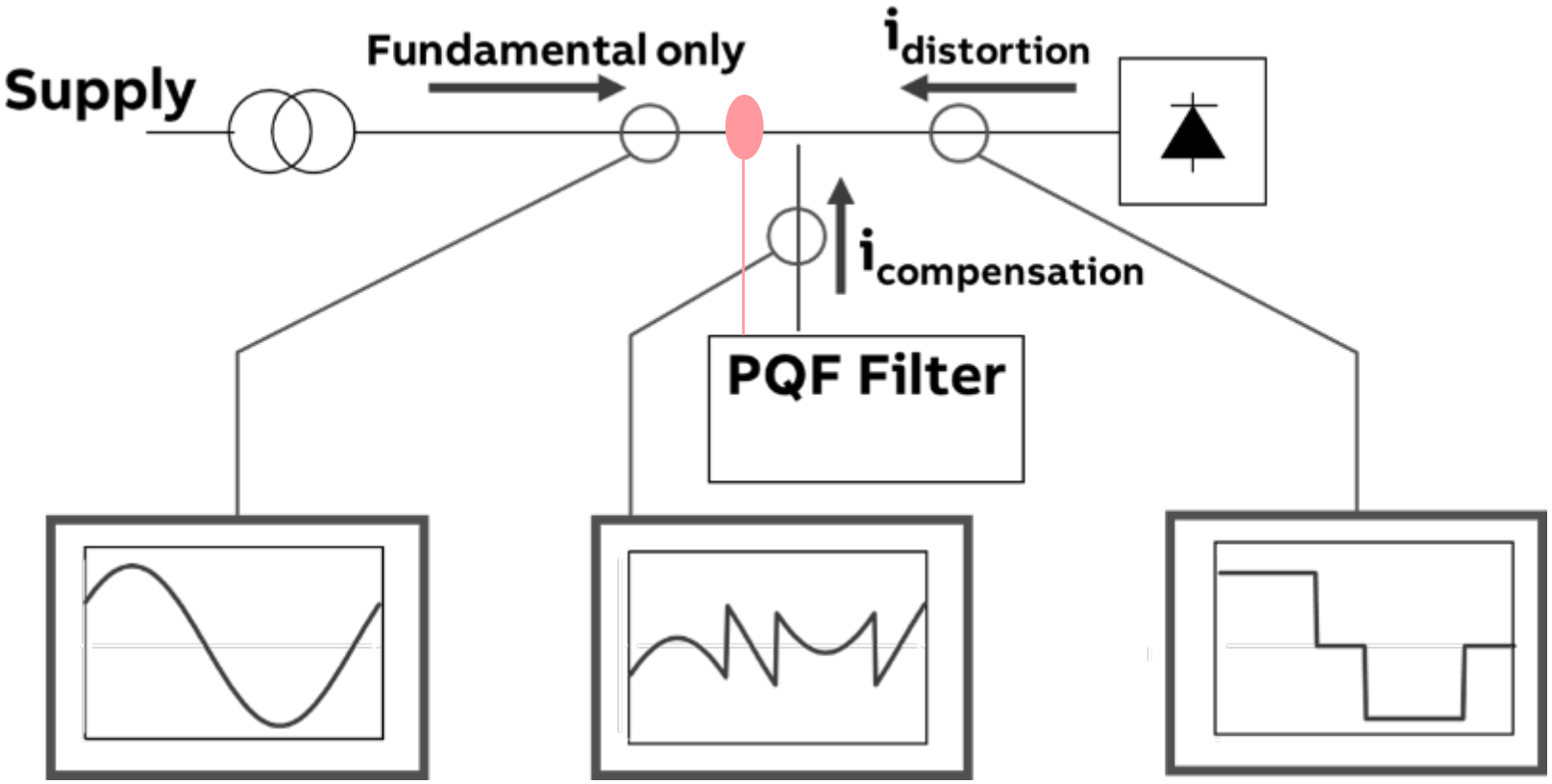
Mitigation Methods

Active filter - Cancellation



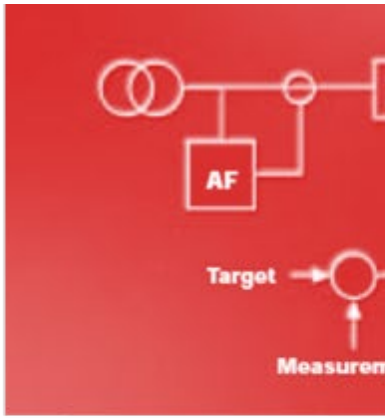
Mitigation Methods

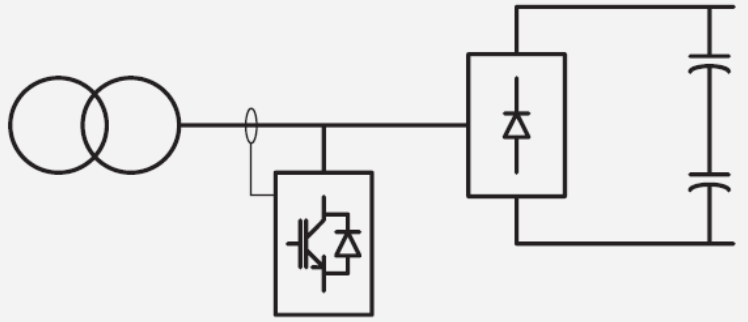
Active filter - Cancellation



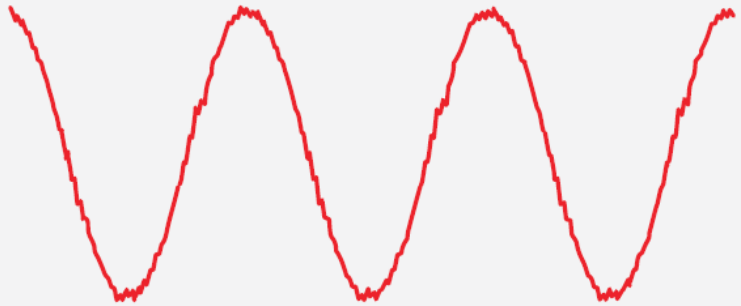
Mitigation Methods

Active filter – Closed vs open loop control

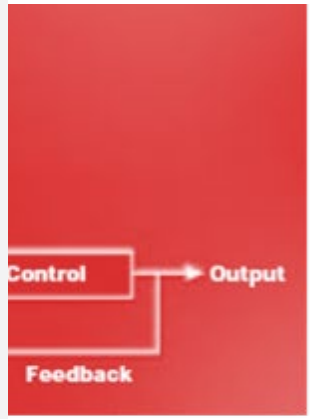




Transformer, active filter, drive rectifier and DC link capacitors



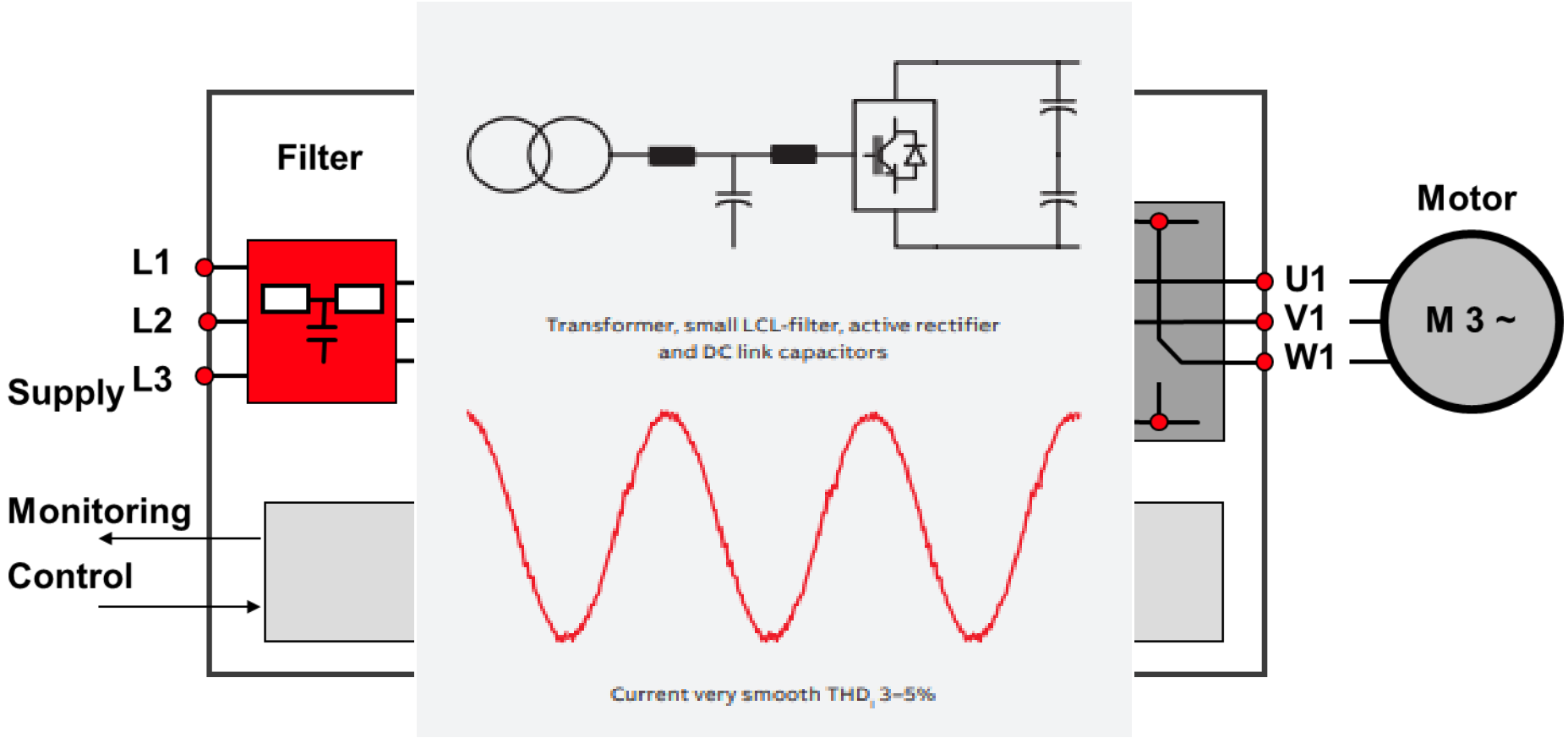
Current quite smooth THD_I 4–7%



	Closed loop
Filtering result	Controlled
Measurement errors	Immuned
Filtering accuracy	High
CT cost	Average

Mitigation Methods

Low harmonic drive - Managing



Mitigation Methods

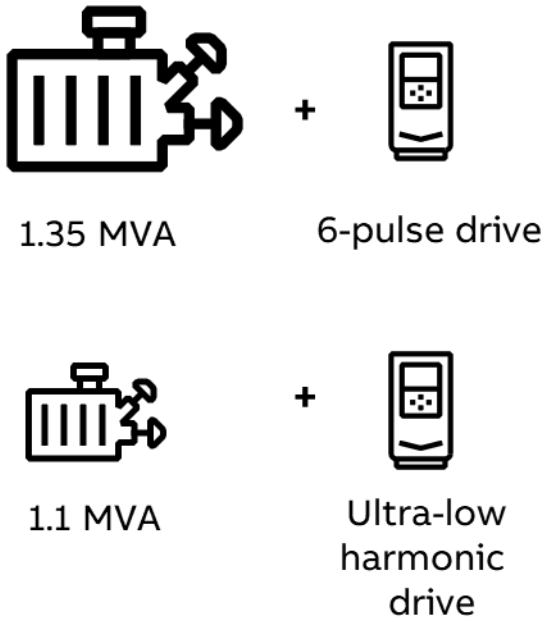
Low harmonic drive – Customer value

Transformer sizing

When using 6-pulse drives, the transformer is selected using a factor of 1.35 x motor kVA to take into account power factor and harmonic distortion.

When using low harmonic drives the factor used is 1.1 x motor kVA. For example:

- Motor load = 1000 kVA
- 6-pulse system requires 1.35 MVA transformer
- Ultra-low harmonic solution requires only 1.1 MVA transformer



Mitigation Methods

Low harmonic drive – Customer value

Generator sizing

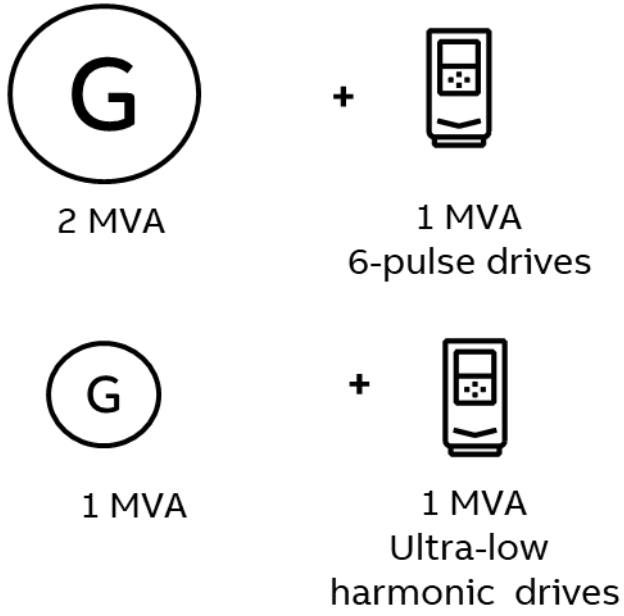
Generators may need to be oversized for the same reasons as the transformer.

In addition, generators AVR (automatic voltage regulator) will not operate properly due to excess harmonics and leading power factor.

A rule of thumb is that a generator supplying 6-pulse inverters needs to be de-rated by 50%.

Using LH drives will prevent the generator from derating.

LH = problem free operation, selection and peace of mind.



Comparing Mitigation Techniques

Overview

Comparing Mitigation Technologies

Different mitigation techniques

Technique	THD% current
6-pulse rectifier, no mitigation, reference level	90 - 120%
6-p with 3% line choke, or equivalent DC choke *	39%
6-p with 5% line choke, or equivalent DC choke	32%
6-p with 5% line choke + 5th harmonic trap filter	12%
12-pulse rectifier with 5% impedance transformer	~10-12%
Hybrid filter (a type of a passive filter)	5% - 10%
18-pulse rectifier with 5% impedance transformer	5%
Active harmonic filter	4%
Low harmonic drive	3%

Comparing Mitigation Technologies

Value comparison

Area	Low harmonic drive	6 Pulse + passive filter	6 Pulse + active filter
Ease of installation	Easy	Medium	Medium
Ease of engineering	Easy	Hard	Medium
Power Factor Compensation	Yes	No (Danger of Leading PF)	Yes
Load balancing	No	No	Yes (Depends on design)
Space Requirement	Low	High	Medium
System Efficiency*	High	Low	Medium
'Standby Mode'	Yes	Yes	Yes
Redundancy	Yes	Maybe – depends on design	Maybe – but may add cost
Harmonic Performance	1.5-3.5% THDi (typical)	5-10% THDi (typical)	3-4% THDi (typical)
Motor Voltage Optimisation	Yes	No	No
Opportunity for cabinet optimisation	High (No Main Contactor req'd)	Low	Medium

Comparing Mitigation Technologies

Different mitigation techniques

Solution is dependant on several factors:

- Existing Equipment (i.e. 12-pulse Tx)
- Footprint & Volume
- VSD Product Cost
- Ease & cost of Installation and Engineering
- Redundancy
- Is it retrofit or new?
- Backup generator present (Temporary or Permanent?)
- Technology familiarity
- Duty (i.e. are they utilised less often, like Storm Pumps?) and nominal ratings
- Future Proofing (are there other new loads planned?)
- Operational cost - system losses & efficiency
- Network Characteristics
  - Multiple feeds & bus couplers present?
  - Network Resonance

Summary

Takeaway points

Summary

Takeaway……

- Appreciate what harmonics are, their source and cause of them.
- The relevant regulations that apply (**system!**).
- Overview of migration methods and comparison.
- Understand which solution is best for an installation (**not a one size fits all!**).

Thank you! Any questions?

ABB in Ireland

At a glance

ENGINEERS IRELAND
REGISTERED TRAINING PROVIDER 2022

180

People work for ABB in Ireland

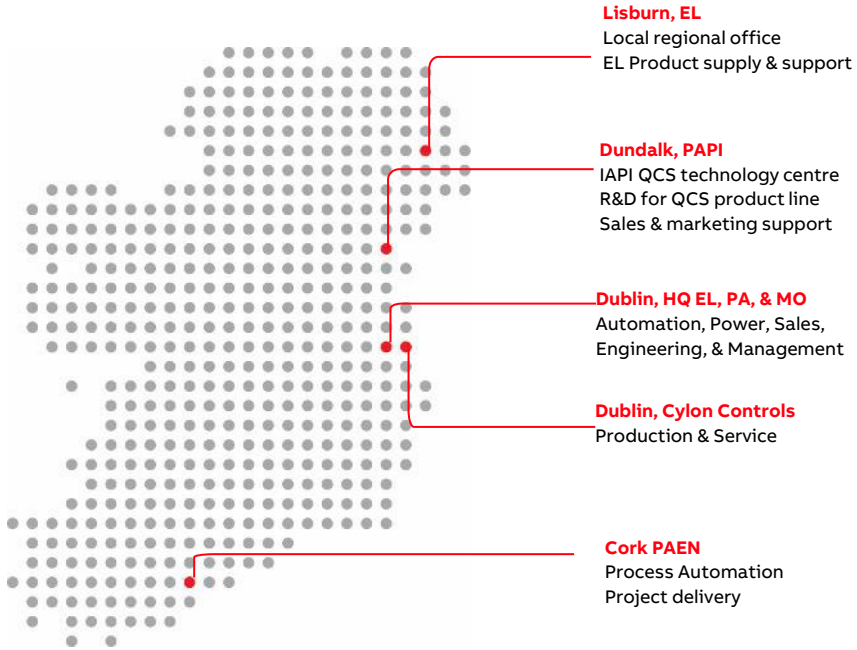
5

Sites where products are sold, serviced or engineered

Want to know more?

marketing@ie.abb.com

www.abb.ie



Skilled and experienced Irish team, backed by global networks

ABB Ireland

Registered Training Provider with Engineers Ireland

ABB Electrification

1. Technical overview of LV Switchgear and Panel Selection.
2. LV Selectivity / Discrimination
3. IEC61439 Standard for Circuit Breakers & Assemblies
4. Arc Fault Detection Devices (New MCBs & RCBOs)
5. Electric Vehicle Charging Infrastructure
6. The Fundamentals & Principles of Building Energy Management Systems
7. Introduction to MV Switchgear
8. Building Services Integration BACnet and other options
9. IIoT for Electrical installations
10. Building Automation – KNX universal protocol & DALI

ABB Motion

1. Harmonics, VSDs & Mitigation technologies
2. IE5 Synchronous Reluctance Drive and Motor Package

Click here to view ABB offering on Engineers Ireland


ABB