Choose the best harmonic mitigation solution for your drive

(Comparison of harmonic mitigation solutions)

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Introduction

An increasing number of AC drives are controlled by inverters. This fact, combined with the presence of high technology solutions, makes harmonics a major issue for industrial customers. The topic is under frequent discussion and many adapted harmonic mitigation solutions are available. In this context, a more in-depth presentation of technical possibilities seems suitable.

The objective of this paper is to discuss and compare the most popular harmonic mitigation solutions. To enable a better understanding of the topic, a short description of harmonics, their origins and consequences is given. This is followed by a description and comparison of harmonic mitigation solutions.

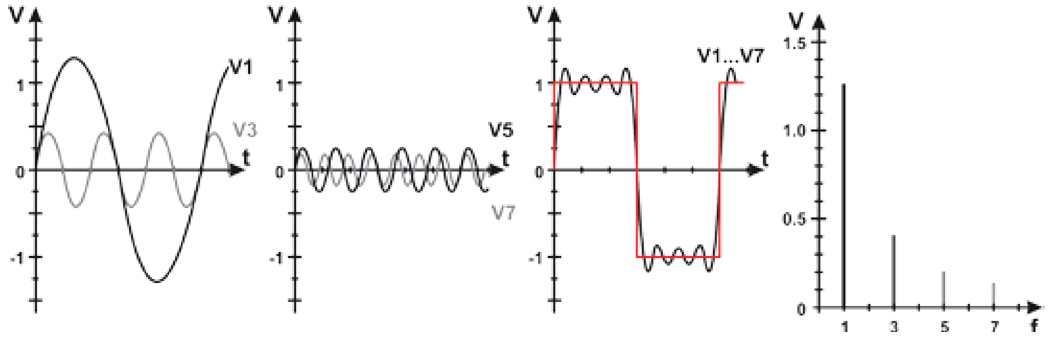
The right choice of a harmonic mitigation solution enables an estimated CAPEX reduction of up to 15% as well as an OPEX reduction of up to 10%.

Fourier series

Many procedures in nature and engineering are repetitive and periodical. These functions can be very complex. The Fourier series decomposes periodic functions into the sum of all their included sines and cosines. This means that every periodic function is the result of an overlay of many harmonic oscillations.

In honour of Joseph Fourier (1768-1830) these series of harmonics are called Fourier series.To describe the functionality, the following pictures show the principle of composition of harmonics of a square wave: The pictures show (from left to right) the harmonic wave, the different harmonics and the sum of harmonics in comparison with the square wave. On the right, the spectrum is shown.

Fig.1: A rectangle signal analysis from the 1st to the 7th harmonic



The idea behind the Fourier analysis is to get an equation of these harmonics in order to obtain a mathematical description of the sum of the harmonics.

Common Definition

To explain the common definition of the formula, a periodical function is taken (period T>0). This function can be described as a series of sines and cosines. The frequency of them is a whole-number multiple of the fundamental frequency.

$$f(\mathrm{t}) = \frac{a_0}{2} + \sum_{\mathrm{k}=1}^{\infty} [a_{\mathrm{k}} \bullet \cos(\mathrm{k} \bullet \omega \bullet \mathrm{t}) + b_{\mathrm{k}} \bullet \sin(\mathrm{k} \bullet \omega \bullet \mathrm{t})] \qquad \omega = \frac{2 \bullet \pi}{\mathrm{T}}$$

In practice a finite approximation is enough (a subtotal $f_{\mathrm{n}}(\mathrm{t})$)

$$f_{\mathrm{n}}(\mathrm{t}) = \frac{a_0}{2} + \sum_{\mathrm{k}=1}^{\mathrm{n}} [a_{\mathrm{k}} \bullet \cos(\mathrm{k} \bullet \omega \bullet \mathrm{t}) + b_{\mathrm{k}} \bullet \sin(\mathrm{k} \bullet \omega \bullet \mathrm{t})]$$

The coefficients for this formula are:

$$a_{\mathrm{k}} = \frac{2}{\mathrm{T}} \int_{\mathrm{c}}^{\mathrm{c+T}} [f(\mathrm{t}) \bullet \cos(\mathrm{k} \bullet \omega \bullet \mathrm{t})]\mathrm{dt} \qquad b_{\mathrm{k}} = \frac{2}{\mathrm{T}} \int_{\mathrm{c}}^{\mathrm{c+T}} [f(\mathrm{t}) \bullet \sin(\mathrm{k} \bullet \omega \bullet \mathrm{t})]\mathrm{dt}$$

c stands for an offset of the interval and can vary for simplification.
The constant component of the equation is the component without alteration.

$$\frac{a_0}{2} = \frac{2}{\mathrm{T}} \int_{\mathrm{c}}^{\mathrm{c+T}} [f(\mathrm{t})]\mathrm{dt}$$

Simple characteristics of the formula are:

- For all even functions $b_{\mathrm{k}}=0$
  $f(\text{-x}) = f(\mathrm{x})$
- For all odd functions $a_{\mathrm{k}}=0$
  $f(\text{-x}) = \text{-}f(\mathrm{x})$

Harmonics: origin and consequences

An ideal mains voltage should be a sinusoidal voltage with constant amplitude and frequency. But in reality this ideal mains does not exist because of impedances, voltage distortion and current distortions. These distortions are caused by different loads. The loads can be classified into two families:

- Linear loads,
- Non linear loads.

We are talking about a linear load if the current has the same waveform as the supply voltage i.e. a sine wave. Motors, incandescent lights, heating elements using resistor, capacitors and inductances are linear loads.

Industrial equipment comprising power electronics circuits are, most of the time, non-linear loads (welding machines, arc and induction furnaces, battery chargers). Variable speed drives for AC or DC motors, uninterruptible power supplies, office equipment (PCs, printers, servers, etc.) are non-linear loads and their currents deviate from sinusoidal waveforms. Those loads create some harmonic current through the distribution system and, due to the network impedance, cause voltage distortion.

The following pictures present typical current waveforms for single-phase (top) and three-phase non-linear loads (bottom).

Fig. 2: Single phase - line current of rectifier

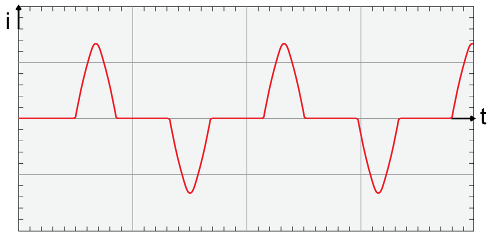


Fig. 3: Single phase – line current of phase angle control

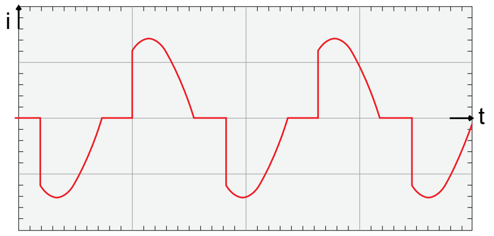


Fig. 4: Three-phase – line current on 6-pulse rectifier

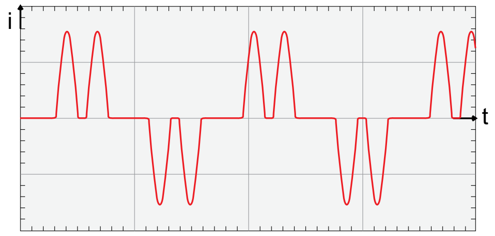
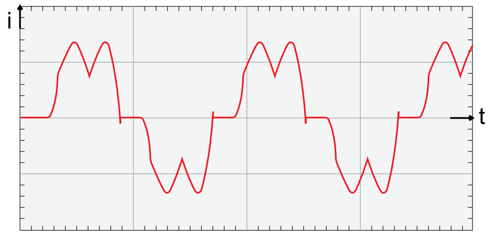


Fig. 5: Three-phase - line current on 6-pulse rectifier with DC-Chokes



When dealing with non-linear loads, we should consider the individual current of each non-linear device and the combination of currents for all loads, including linear loads.

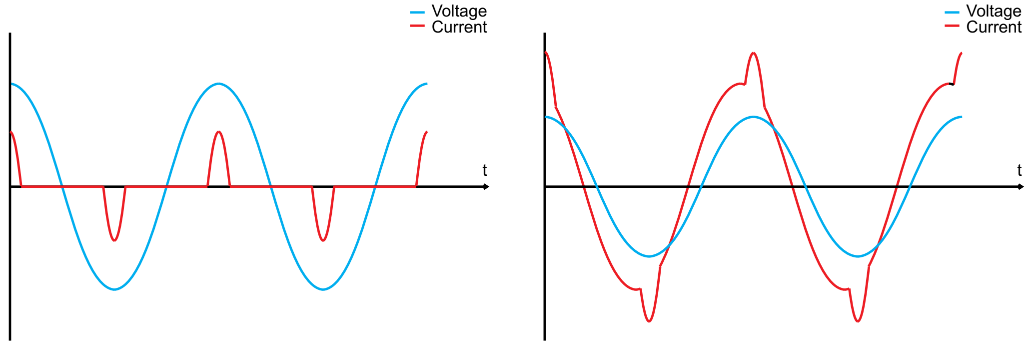
Harmonics have an effect on devices connected in series with non-linear loads, and voltage distortion has an impact on devices connected in parallel. These effects may be quite different.

Impact according to the load nature

Non-linear loads on the mains current

Individual currents from each load are combined and their magnitude may give a current noticeably different from a pure sinewave. The figures below represent a single-phase AC drive current and the combination with a linear current. Obviously the current distortion will depend on the values of these currents. Usually single-phase drives are in the low power range and the current distortion may be unnoticeable.

Fig. 6: Impact of non-linear loads on the current waveform

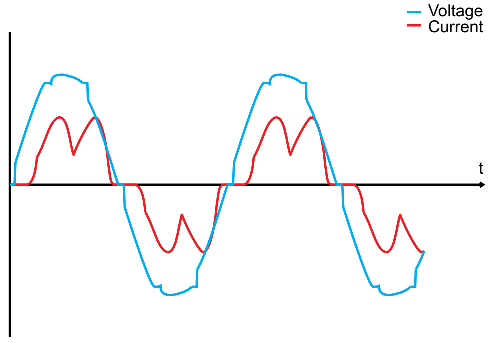


As the r.m.s. value is the square mean of a continuous-time waveform, a distorted current has a higher r.m.s. value than its fundamental.

Non-linear loads on the mains voltage

Due to the network impedance, non-linear currents cause a voltage distortion.

Fig. 7: Impact of non-linear current on the voltage



Devices connected in series with non-linear loads

Cables, circuit breaker and transformers are connected in series with non-linear loads. Harmonic currents will produce additional losses and these components may need to be oversized. This will increase the cost of the equipment. If the current at the front end of the manufacturing plant has a high content of harmonics, the incoming transformer will have to be oversized and the contract subscribed with the energy supplier will cost more.

Devices connected in parallel with non-linear loads

Distorted current is likely to produce a distorted voltage with severe consequences: devices connected to the network may trip and cause plant shutdown, or the current in capacitors bank, used to correct the power factor, can increase drastically. Eventually resonance may occur and can cause voltage peaks and drops.

Economical consequences of harmonics

The major consequences of harmonics are the increase of the r.m.s. current in the different circuits and the deterioration of the supply voltage quality. The negative impact may remain unnoticed with economical adverse results.

That is why proper harmonic mitigation will contribute to improving the competitiveness of companies in different ways:

- Reduced overloading of the electrical system, thereby releasing useable capacity,
- Reduced system loss and power demand,
- Reduced risk of outage,
- Extended equipment lifetime.

What is THD?

The total harmonic distortion (THD) is the usual parameter to evaluate the level of distortion of an alternating signal. The harmonic distortion can be seen for voltage distortion THD_u as well as for current distortion THD_i.

The THD is defined as the ratio of the sum of all Harmonic-Power (P_h) to the Power of the first harmonic (P_1). The indication is done in %.

$$THD_{\%} = \frac{P_h}{P_1} \times 100$$

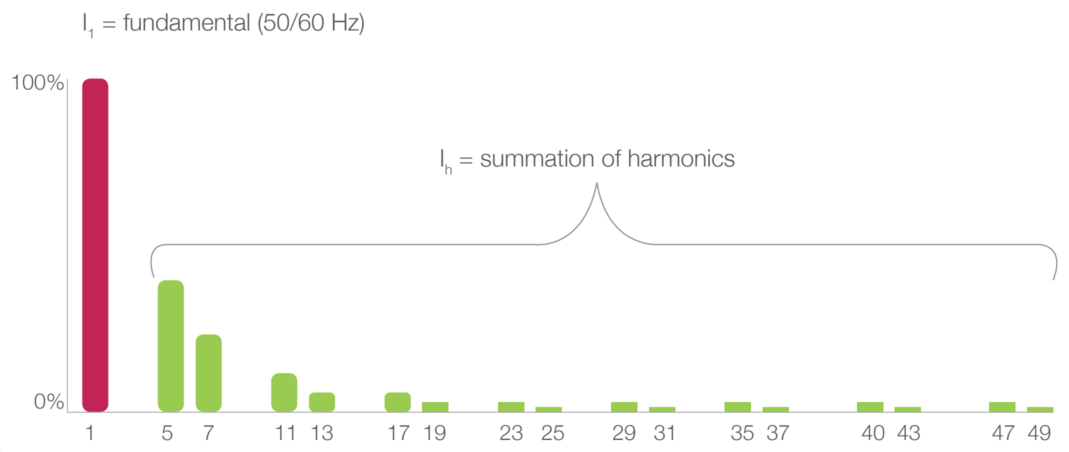
The calculation of the THD_u and THD_i is therefore the following:

$$THD_u = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \ldots + V_n^2}}{V_1} \qquad THD_i = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \ldots + I_n^2}}{I_1}$$

I2, I3, I4, ... In ... harmonics (100, 150, 200, ... Hz or 120, 180, 240, ... Hz

I1 ... fundamental current (50 Hz or 60 Hz)

Fig. 8: Harmonic spectrum 6 pulse rectifier



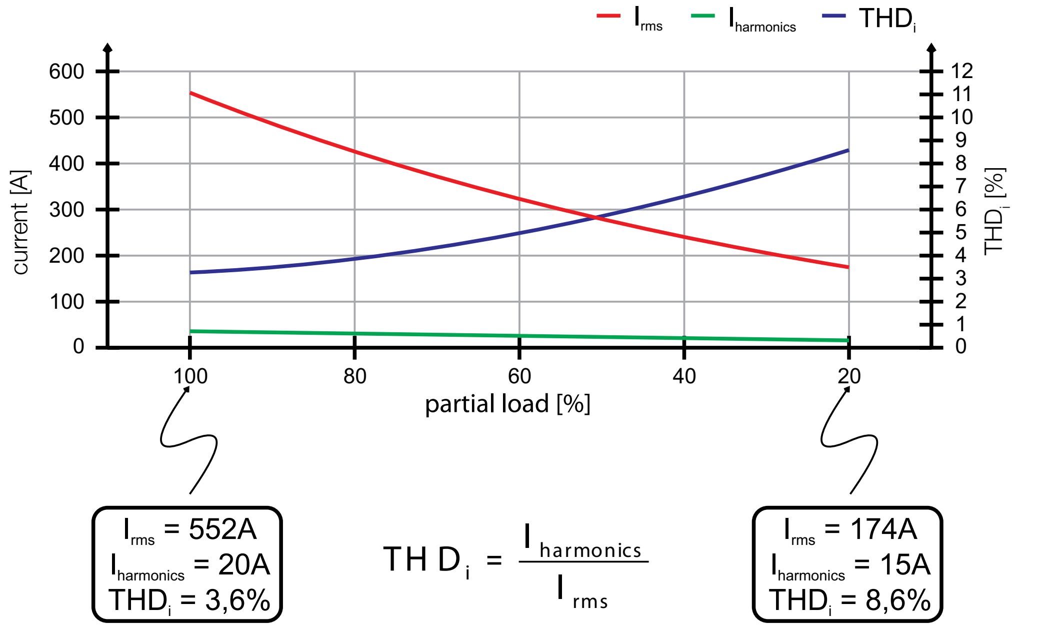
Misinterpretation of THD_i measurement with partial load

The operating point of the variable speed drives (VSD) is optimized for the production and often they do not work under full load conditions. These partial load operations create a lot of misinterpretation in the measurement of harmonics.

The panel meter shows the ratio between sums of harmonics currents in percent to the fundamental current. If the VSD is working at 100% load operation, the current of the fundamental I_1 is equivalent to the nominal current Inom. The shown THD_i measured in percent approximately conforms with the percent value given by the producers of VSDs (differences are possible due to different mains impedances). In case of partial load operation, the fundamental current I_1 declines (red line) but the sum of the harmonics currents is relatively constant (green line), and so the THD_i [%] increases (violet line) according to the functional relationship of THD_i.

Due the ratio it seems that the THD_i increases but the absolute values of the harmonic currents will be constant or decreased.

Fig. 9: THD_i - partial load operation



How is THD used in Harmonic Emission standards?

Regarding harmonics, the purpose of standardization is to ensure that the voltage distortion at the Point of Common Coupling (PCC) is kept sufficiently low, so that other customers connected through the same point are not disturbed. This is the basic idea behind the concept of Electromagnetic Compatibility (EMC).

For low power equipment connected directly to the Low Voltage (LV) supply system, current emission limits given by international standards are applicable to pieces of equipment.

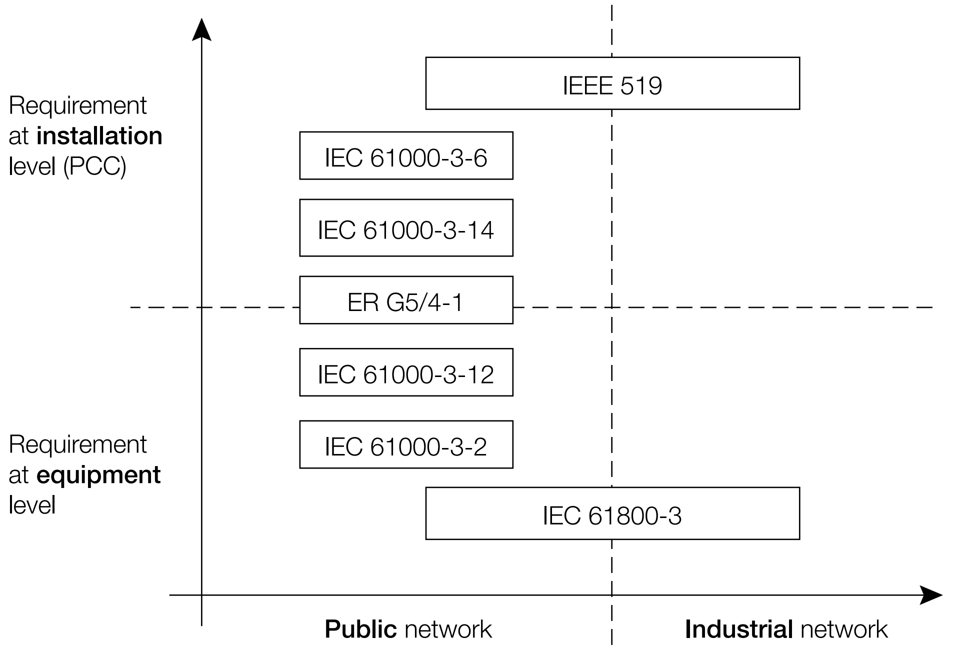
For global installations, emission limits are set by the Utilities based on the local applicable standards or regulations. Generally, limits are established for the Total Harmonic Voltage Distortion (THD_u), the Total Harmonic Current Distortion (THD_i), and individual harmonic currents (I_h).

The main parameters taken into account are the short-circuit power Ssc of the supply system and the agreed power (or total demand power) of the customer installation.

The principle is to allow each customer to contribute to the global distortion, in proportion to the agreed power of the installation. The global resulting distortion must be kept under certain limits so that the Electromagnetic Compatibility can be ensured.

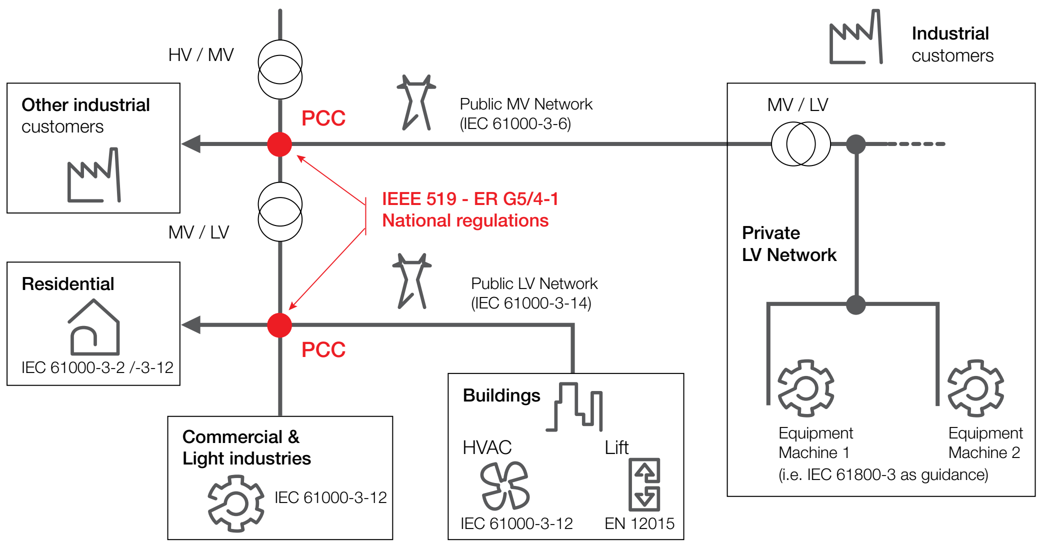
The application area of the main standards dealing with harmonics is presented in the following figure.

Fig. 10: Standards and recommendations concerning harmonics



It should be noted that overly stringent harmonic emission limits could become very expensive. That's why a careful application of standards should be performed. The following diagram can clarify this.

Fig. 11: Point of common coupling



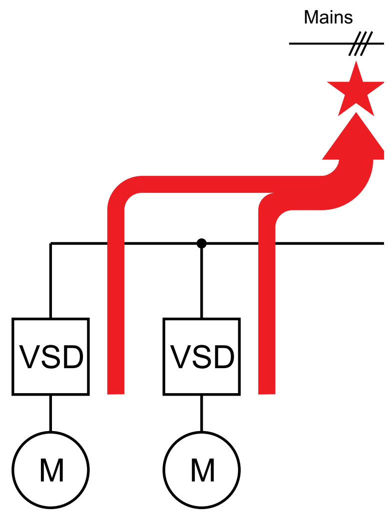
The THD_u limits are considered at the Point of Common Coupling (PCC) within the public network (low voltage (LV) or medium voltage (MV)) from which the different customers are supplied by the Utility. Limits must be applied at the PCC in order to ensure that the Utility (often by duty constraints) supplies the different customers with a good quality of power, i.e. with non-distorted voltage.

For LV customers, IEC 61000-3-2 and 61000-3-12 are harmonic emission standards applicable at equipment level. THD_i and individual LH limits are required for pieces of equipment up to 75A. Above this value, an agreement is usually needed between the Utility and the customer before connection.

Local country regulations, based on other standards or codes (such as ER G5/4- 1 or IEEE 519), should be considered when requested.

What are the available solutions?

Fig. 12: Harmonic generation

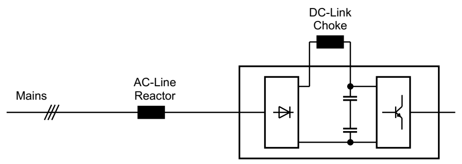


An operating inverter produces harmonics and can be seen from the view of the network as a harmonic generator. These harmonics will be fed into the net where they cause additional loss and disturbance on other components. To save cost with regards to power consumption and maintenance, it is necessary to compensate them.

There is a broad range of solutions for harmonic mitigation depending on the type of demand.
The following sub-chapters introduce the four most relevant solutions.

AC-Line Reactor or DC-Link Chokes for Drives

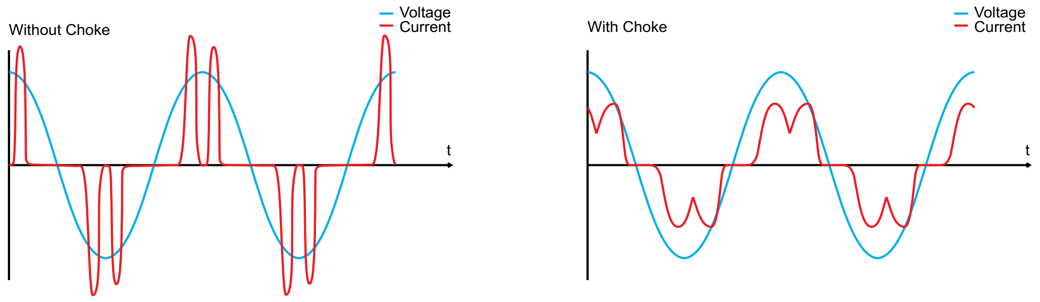
Fig. 13: Simplified diagram of inverter with chokes



A choke is often used to plan the current peaks in a circuit. The choke can be used on different positions within a drive for reducing harmonics.

Without chokes the inverter produces high current peaks. With chokes the current flow is expanded and the amplitude is reduced. Due to this the parts of harmonics will be reduced.

Fig. 14: Current without and with choke



Chokes are commonly used up to about 500 kW unit power or 1,000 kW total drives power. In this power range the transformer should be at least 1.25 to 1.5 times the drives power. Depending on the short circuit power of the mains, transformer size and cabling, the resulting THD_u will be up to about 6%. This could result in possible noise disturbance but is usually well accepted in industrial networks.

When a large number of drives are present within an installation, the use of AC-Line or DC-link chokes for each individual drive is recommended. This measure increases the life time of the drives and enables the use of cost-effective mitigation solutions at installation level, such as active filters.

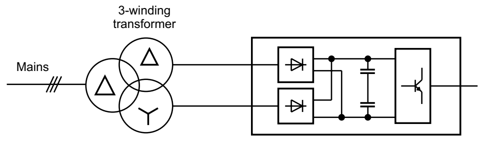
If AC-line or DC-link chokes are not sufficient for a large drive, a multi-pulse arrangement is the next step to consider.

12-pulse arrangement

A three-phase rectifier system needs a 6-pulse converter bridge. To achieve a multi-pulse operation a transformer that has phase-displaced outputs with respect to one other is needed.

A 12-pulse transformer with a star and delta-connected secondary winding generates a 30° phase shift. By connecting 6-pulse converter bridges on each output, it will give an overall 12-pulse operation. With multi-winding-transformers in different variations, this constellation can be extended to n*6-pulse operation (for industrial customers up to 18-pulse and 24-pulse).

Fig. 15: Simplified diagram of 12-pulse inverter



The following figures show a simple illustration of a 6-pulse (Fig. 16) and 12-pulse (Fig. 17) rectifier to explain the difference.

Fig. 16: 6-pulse rectifier

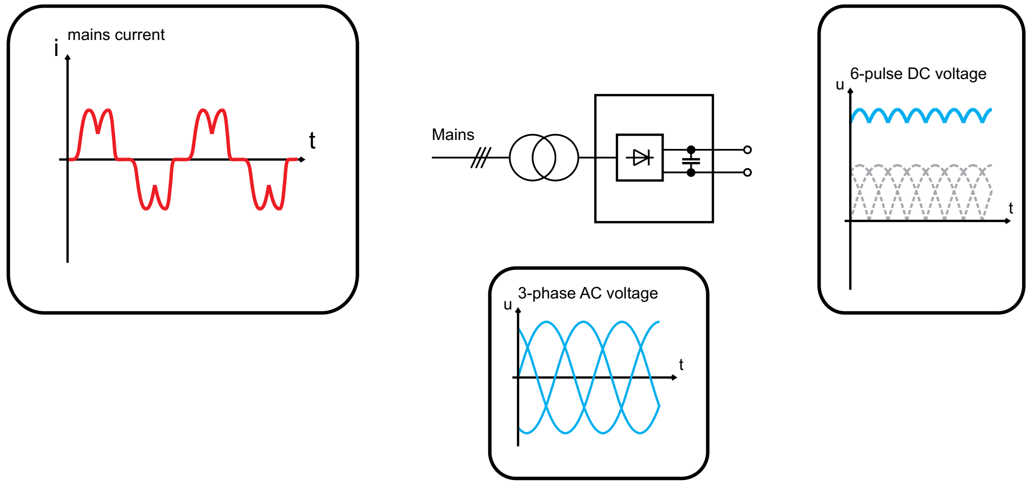
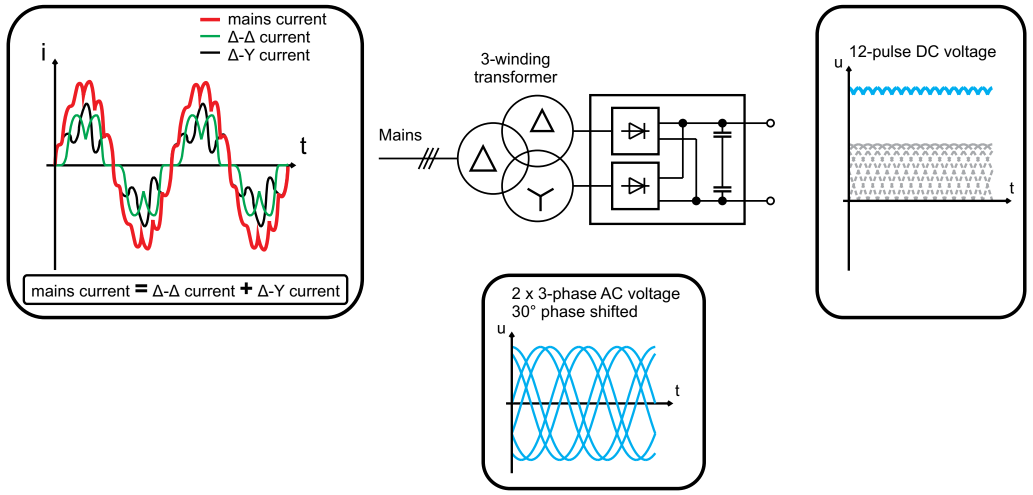


Fig. 17: 12-pulse rectifier



Within the transformer windings several harmonics will be terminated. The order of generated harmonics can be simply calculated by the following formula:

$h = n \bullet p \pm 1$

h ... order of harmonics

n ... inter 1, 2, 3, ...

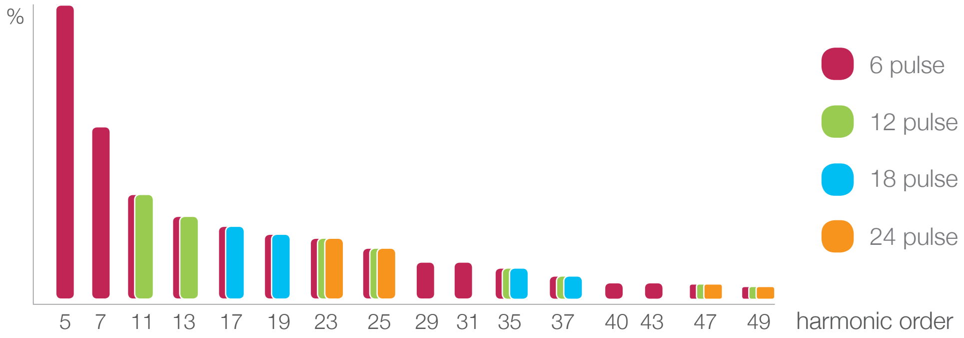
p ... number of pulse arrangement

For example, a 6-pulse (p=6) and a 12-pulse arrangement (p=12):

$h = n \bullet 6 \pm 1 \rightarrow h = 5, 7, 11, 13, 17, 19, \ldots$

$h = n \bullet 12 \pm 1 \rightarrow h = 5, 7, 11, 13, 17, 19, \ldots$

Fig. 18: harmonic spectrum for multi-pulse



Multi-pulse supply is usually used for drives above 400 kW, but could also be used for smaller power ratings. Precondition is a dedicated transformer directly supplied from the MV network.
The standard is to use a 3-winding transformer providing a 12-pulse supply for the drive.

This limits the harmonic emission considerably and usually no further mitigation is necessary. In addition to this, multi-pulse solutions are the most efficient in terms of power loss.

Passive Filter

A passive filter consists of reactors and capacitors set up in a resonant circuit configuration, tuned to the frequency of the harmonic order to be eliminated. A system may be composed of a number of filters to eliminate several harmonic orders.

Fig. 19: Simplified diagram of inverter with passive filter

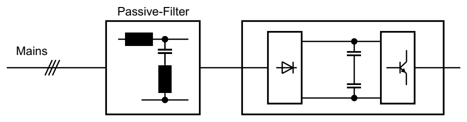
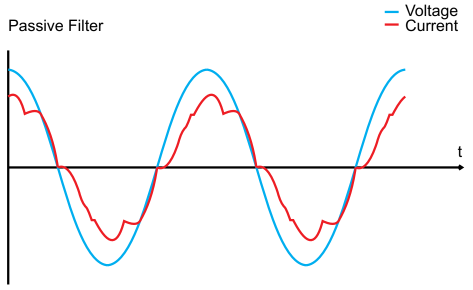


Fig. 20: Current with passive filter

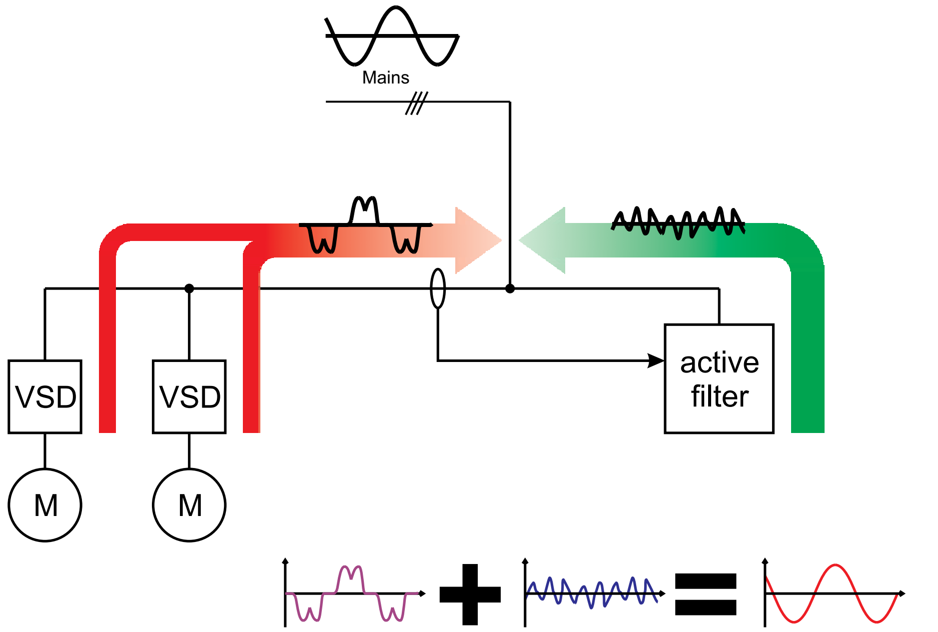


A passive filter compared to an active filter has a lower price and only covers one operating point. Thereby, at partial load it works inefficiently. Furthermore, due to the internal constellation of chokes and capacitors, it causes a bad power factor (cos (φ_1)).

Active Filter

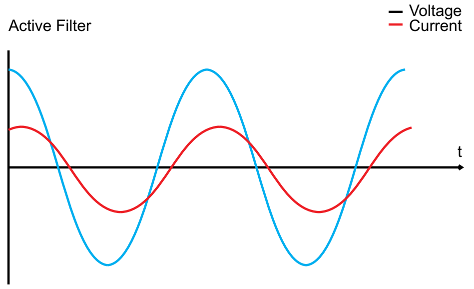
Usually an active filter is switched in parallel to the inverter. The active filter can be seen as a generator of harmonics. It produces the opposite harmonics of the measured distortions to compensate all harmonics in sum.

Fig. 21: Simplified explanation of an active filter



Active filters cover a large extent of customer needs. They are available in different supply voltages (three-phase with and without neutral) and can be used for filtering networks (several drives up to 3000A with parallel operation). A cancellation of up to the 50th harmonic is possible as well as a correction of individual harmonics.

Fig. 22: Sine current and voltage



Low Harmonic Drive

Due to the replacement of the diode rectifier by an active IGBT converter, it is possible to consume energy (like a normal inverter) and in addition to adjust the waveform of the mains current. Usually the nominal waveform of the line current is sinusoidal. In this case we are talking about a low harmonic drive. Thereby the impact on the mains due to harmonics and idle power can be avoided.

To feed energy back is possible with an Active Front End which is basically built in a similar way.

A low harmonic drive is the best performing solution for harmonic mitigation, limiting the THD$_i$ to below 5%. All the applicable standard requirements can be met. No detailed system evaluation is necessary, making this solution the easiest to implement.

In the graph below, you can see the waveforms of line voltage and current.

Fig. 23: Simplified diagram of Low Harmonic Drive

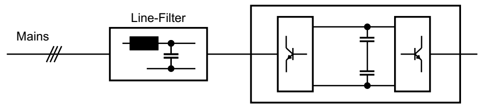
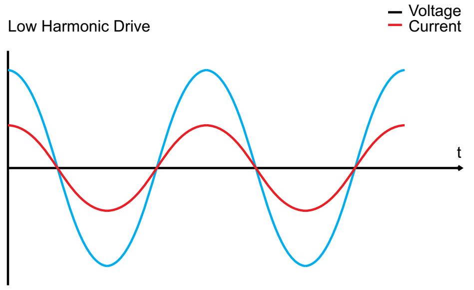


Fig. 24: Sine current and voltage with cos (φ)=1



How to choose the best solution for your application?

The scope of this paper is a comparison of the described harmonic mitigation solutions. The analyzed criteria will include:

- Compactness
  This part will analyze which solution requires the least space.
- Simplicity
  This part will identify the solution that is the easiest to operate.
- THD_i – mitigation
  This part will compare the solutions in terms of their harmonic mitigation.
- Efficiency
  This part will discuss the energy efficiency level of the solutions.
- Value for money
  This parts will analyze the solutions in terms of costs.

To enable comparison with regards to these criteria, the following quality rating system shall be used based on points. Each solution is awarded one to five points for each criterion, where one point means the solution requires more effort and five points mean it requires less effort. The rating is performed in relation to the other harmonic mitigating solutions under evaluation. Due to the fact that not all of the five criteria can be evaluated in the same way, the assignment of points is discussed in each section to make it clearer.

It is hard to compare the different solutions in an objective manner. An active filter is often used to mitigate the harmonics from several drives. The 12-pulse solution is the only one in this type of solution where the transformer is included in the comparison. Due to the unique disadvantages of the passive filter when compared with the other solutions like low power factor at partial load, risk of causing resonances within the grid, etc., will not be included in the comparison section.

Compactness (least space required)

All components of a system need space, and more of it is required when a choke is installed in addition to the inverter or if an active filter for reducing harmonics is used. For this reason, a comparison of the amount of required space was performed.

The comparison of space required by each solution can be split into three subcriteria.

The subcriterion of additional installation includes all relevant components needed to install the harmonic mitigation solution, such as additional cables, cubicles, etc.

The subcriterion of additional components includes only the harmonic mitigation solution itself, namely:

- only the line choke
- the size difference between 6-pulse and 12-pulse transformer
- the active filter (alone), and
- the low harmonic drive

The subcriterion of drive refers to the necessary alterations of the whole system, such as when an enclosure which includes the inverter has to be extended or replaced by a bigger enclosure.

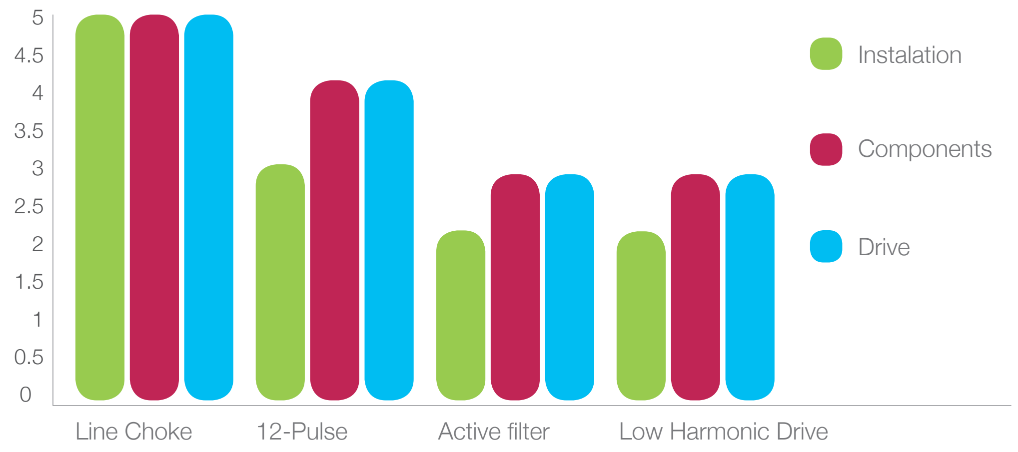
One to five points were given. Five points mean compact and one point means large size.

The resulting ratings can be seen in the following table:

Tab. 1: Ratings for compactness

Compactness	Line Choke	12-pulse	Active Filter	Low Harmonic Drive
Additional installation	5	3	2	2
Additional components	5	4	3	3
Drive	5	4	3	3
Average	5,0	3,7	2,7	2,7

Fig. 25: Comparison of size



Simplicity (easiest design, installation and maintenance)

To examine the level of simplicity of each solution, a rating was performed. The analysis compares and evaluates it with respect to three subcriteria: design, installation, and maintenance.

The subcriterion of design includes the effort required before the system is built.

The subcriterion of installation refers to all additional workload that is necessary, such as additional wiring and additional components for an inverter without any harmonic mitigation solution.

The last subcriterion, maintenance, addresses the additional requirement for service and maintenance.

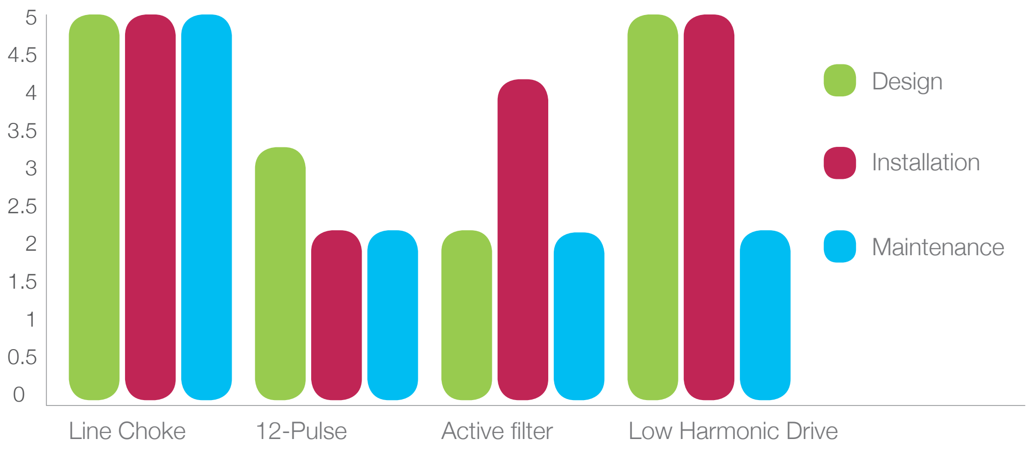
One to five points were given.
One point means much effort is required for the design, installation, and maintenance of the solution. Five points mean the solution is a simple system requiring only minimum effort.

The resulting ratings can be seen in the following table:

Tab. 2: Ratings for simplicity

Simplicity	Line Choke	12-pulse	Active Filter	Low Harmonic Drive
Design	5	3	2	5
Installation	5	2	4	5
Maintenance	5	2	2	2
Average	5,0	2,3	2,7	4,0

Fig. 26: Comparison of simplicity

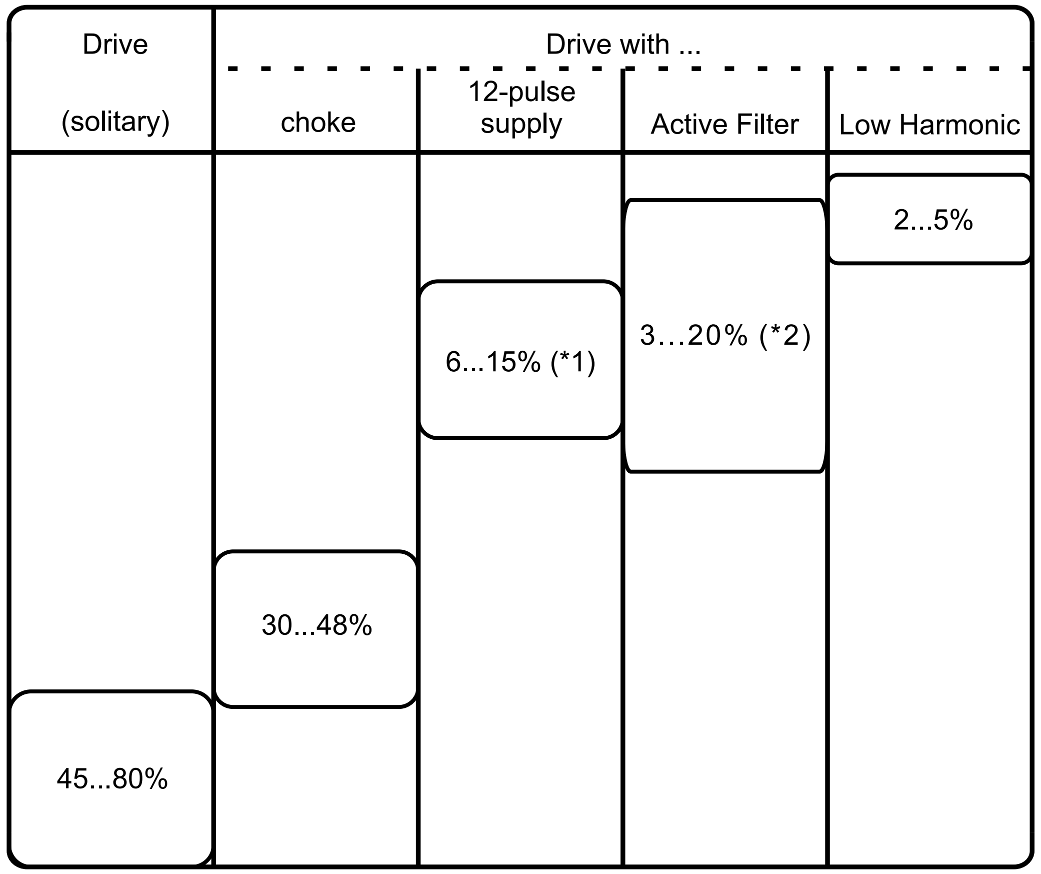


Total harmonic mitigation

The disassembling of the line current into their shares of frequency shows the fundamental and the harmonics. After the inductive idle power, the harmonics cause the second largest distortion in the mains.

The total harmonic distortion (THD) is a specification that qualifes the rate of non-linear deformation of the current or voltage. In the following graph, the comparison of all solutions is shown. The low harmonic drive achieves the best results.

Fig. 27: Comparison of THD$_i$



(*1)... View on the MV side
(*2)... Compensation rate depending on settings and sizing

One to five points were given.

One point means bad level of harmonic mitigation.
Five points mean very good level of harmonic mitigation.

The resulting ratings can be seen in the following table:

Tab. 3: Ratings for THD_i

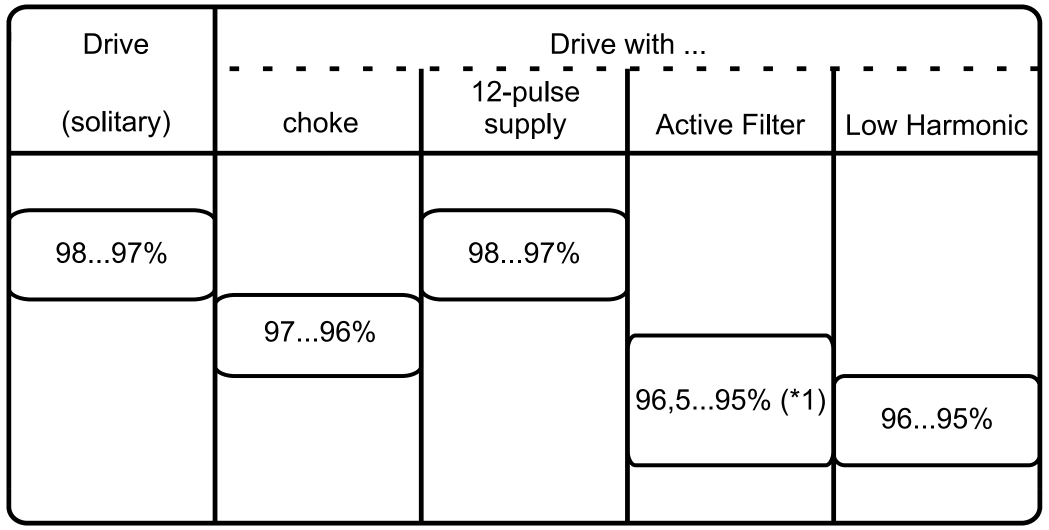
Harmonic mitigation	Line Choke	12-pulse	Active Filter	Low Harmonic Drive
THD_i	1	3	4	5
Average	1	3	4	5

Energy efficiency

Industry needs a lot of energy to power the production process. Efficient energy use is an important topic as energy costs continue to grow.

The following graph compares the efficiency of some solutions:

Fig. 28: Comparison of efficiency



(*1)... Efficiency depending on compansation rate

For criterion of energy efficiency only the losses of each solution are observed. Savings resulting from reduction of losses on other consumer loads (with harmonic mitigation) or a power factor (cos (φ) = 1) as an indicator for real power are not pictured in this figure.

One to five points were given. One point means low efficiency and five points mean high efficiency.

The resulting ratings can be seen in the following table:

Tab. 4: Ratings for efficiency

Effeciency	Line Choke	12-pulse	Active Filter	Low Harmonic Drive
Energy efficiency	4	5	3	3
Average	4	5	3	3

Value for money

Calculating the cost of adding a new solution requires totalling up the cost of all parts, such as transformers, supply cables, and the whole drive. It ultimately depends on the specific solution and the planning associated with it to determine the list and the dimensions of components required. Therefore, some costs are often visible right from the start. As an example, a seemingly economically priced solution for harmonic mitigation may not include the projected costs of energy or installation.

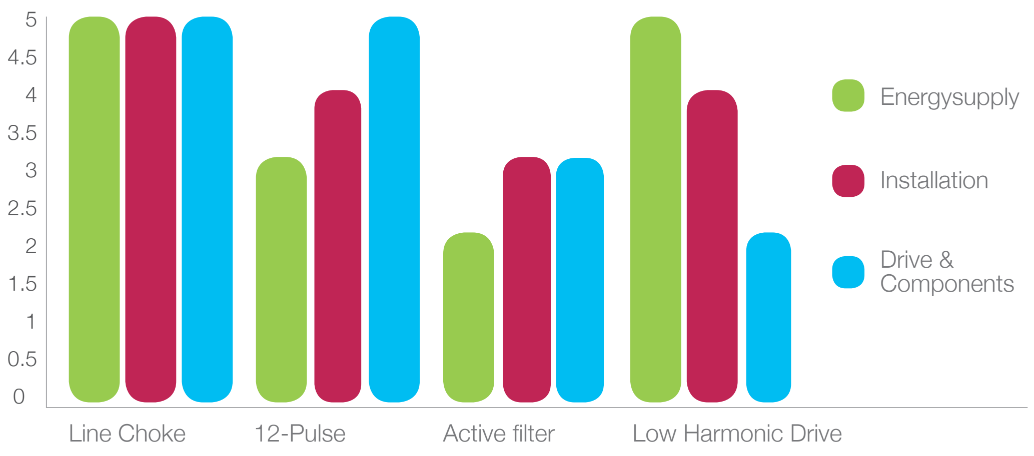
A rating was performed to identify the solution offering the best value for money. The projected costs of energy supply, installation and the drive itself were reviewed and evaluated by experts.

One to five points were given.
One point means low cost-effectiveness, and five points mean the best value for money.
The resulting ratings can be seen in the following table:

Tab. 5: Ratings for cost-effectiveness

Value for money	Line Choke	12-pulse	Active Filter	Low Harmonic Drive
Energy supply	5	3	2	5
Installation	5	4	3	4
Drive and components	5	5	3	2
Average	5,0	4,0	2,7	3,7

Fig. 29: Comparison of cost-effectiveness



What is the most suitable solution for you?

For a compact demonstration of the final scores, we shall use net diagrams, created by distributing the ratings over five axes.

A net diagram delivers a clear visualization of the evaluation results. For each criterion there is a separate axis. The same orientation for all axes is important. In this case, the higher values lie consistent further out. The highest value of five points is marked on the outer edge.

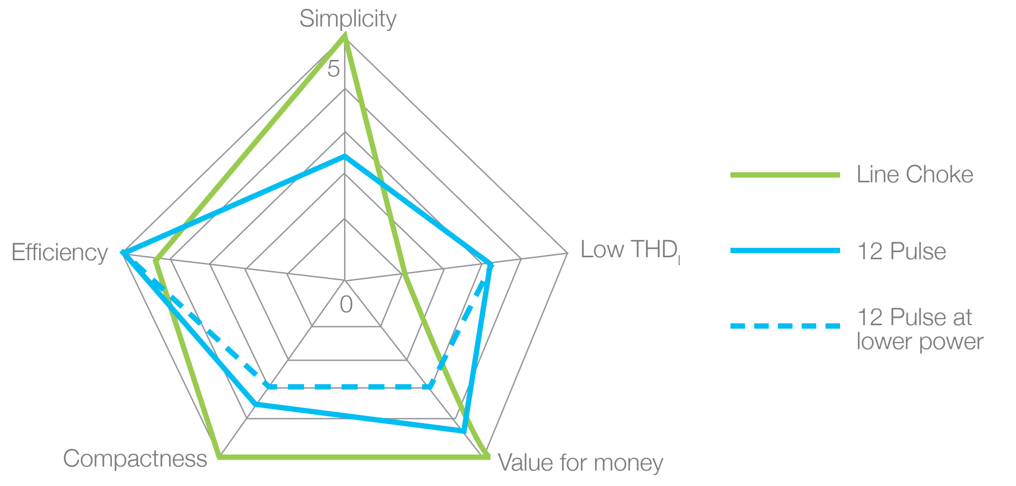
Diagrams are based on the average scores from each evaluated criteria (given in following table).

Tab. 6: Summary of points distribution

Criteria	Line Choke	12-pulse	Active Filter	Low Harmonic Drive
Simplicity	5,0	2,3	2,7	4,0
Low THD$_i$	1,0	3,0	4,0	5,0
Value for money	5,0	4,0	2,7	3,7
Compactness	5,0	3,7	2,7	2,7
Efficient	4,0	5,0	3,0	3,0
Average	4,0	3,6	3,0	3,7

Based on this table, the following two net diagrams were created. The first represents the passive solutions:

Fig. 30: Net diagram for passive solutions



The net diagram of the passive solutions shows that the line choke is the most reasonably priced and compact solution but it does not mitigate the THD_i well. The 12-pulse solution is better with regards to efficiency and harmonic mitigation but it is not simple to implement. Therefore it also has to be mentioned that the THD_i of the 12-pulse solution is valued on the MV-site of the transformer.

The dashed line shows the degradation of the 12-pulse solution at lower power The second net diagram represents the active solutions:

Fig. 31: Net diagram for active solutions

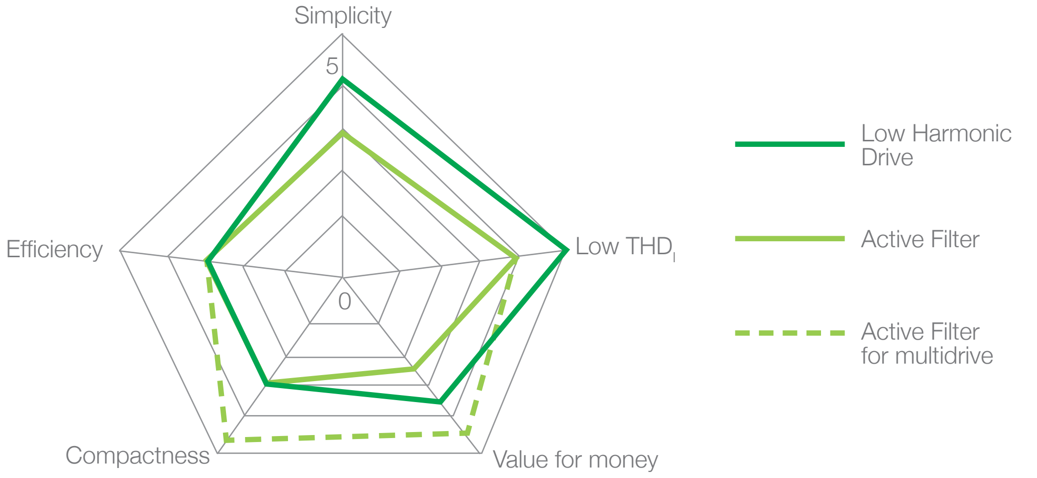
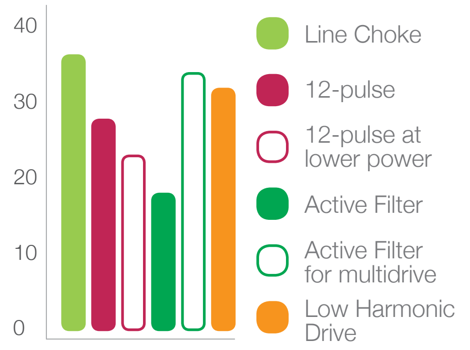


Fig. 32: Bar diagram of overall scores



The net diagram of the active solutions shows that the active filter can be seen as a good harmonic mitigation solution but the low harmonic drive is the great all-rounder that includes a better value for money and more simplicity.

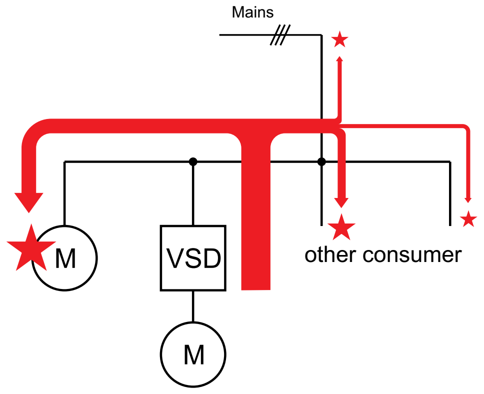
The dashed line shows the improved variant of the active filter for a multidrive solution.

The results presented by the net diagrams have been summarized in the following bar diagram:

Harmonic mitigation at a glance

Every non-linear consumer load can be seen as a harmonic-generator that contaminates the whole electrical system. These harmonics cause losses and additional heating in other electrical consumers, such as motors. This can reduce their life time radically.

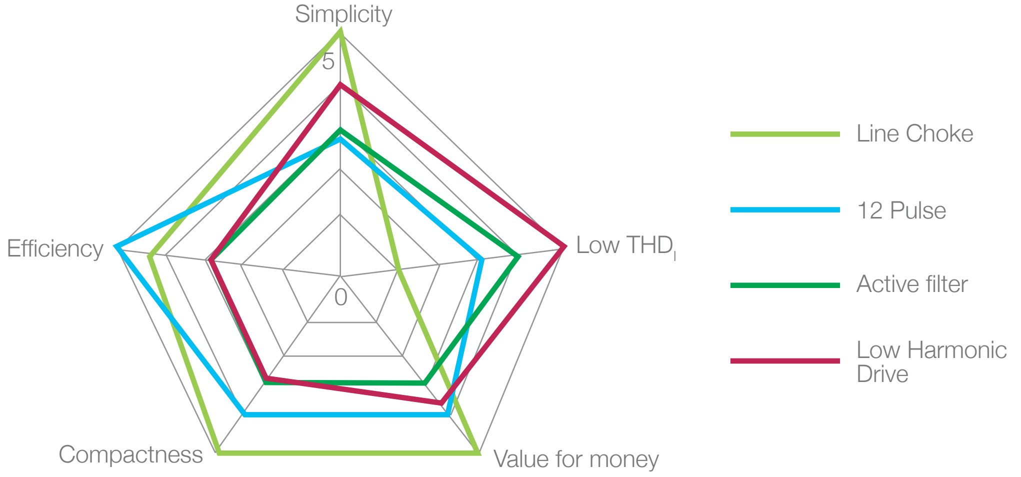
Fig. 33: Cause of harmonics



There is a pressing need to resolve this issue as harmonics generate costs. Panel builders need to be able to offer their customers a good solution. to the problem.

The following net diagram is a final summary of ratings for all the solutions:

Fig. 34: Net diagram for all solutions



This white paper shows that it is worthwhile to compare the different solutions.

To summarize, it can be said that the line choke solution is the best solution for applications where the heaviest distortions should be filtered but where harmonic mitigation is not the first priority.

The active filter is a good solution to mitigate the harmonics of several drives in parallel operating on one point of coupling.

The 12-pulse solution has the best efficiency but is the most complex version and mitigates the harmonics on MV-site.

For applications where harmonic mitigation is very important, the low harmonic drive is the most effective option. It covers all relevant categories and offers the best harmonic mitigation solution.

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List of abbreviation

Abbr.	Description
PCC	Point of Common Coupling
HV	High Voltage
MV	Medium Voltage
LV	Low Voltage
THD	Total Harmonic Distortion
THD_i	Total Harmonic Distortion of Current
THD_u	Total Harmonic Distortion of Voltage
AC	Alternating Current
EMC	Electro-Magnetic Compatibility
LH	Low Harmonic
I_h	Harmonic Current
DC	Direct Current
r.m.s.	Root Mean Square
Ssc	Short Circuit Power
HVAC	Heating, Ventilation and Air Conditioning
AFE	Active Front End
VSD	Variable Speed Drive

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Possible keywords: Harmonic, Harmonic solutions, comparison, Fourier, Fourier series, Fourier analysis, Harmonics origin, Harmonics consequences, Impact non-linear loads, THD, THDi, Low Harmonic, AC-Line Choke, DC-Line Choke, multi-pulse, 12-pulse, active filter, low harmonic drive, AFE.