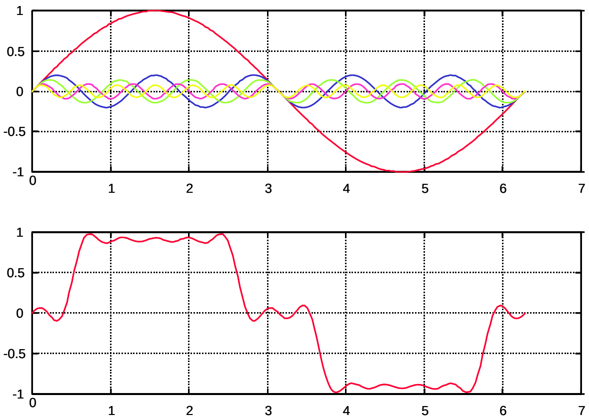
Comparing the Danfoss Harmonic Filter AHF 005 and AHF 010 with traditional multi-pulse solutions

Abstract:

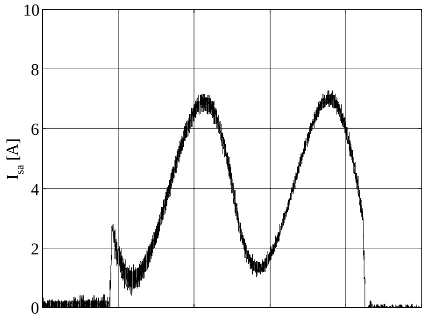
General information on harmonics,
The effect of harmonics,
Harmonic reduction techniques,
The Danfoss solution,
Performance at non-ideal supply voltage,
Harmonic limiting standards and recommendations
Conclusion

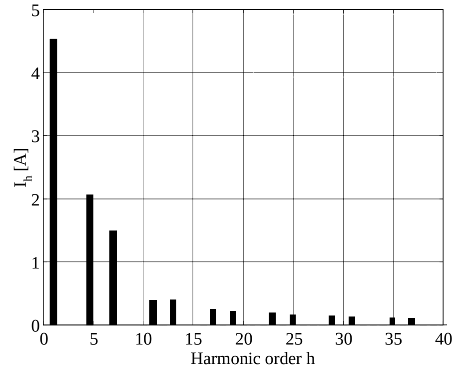
General information on "harmonics"

The term "harmonics" has often been used in connection with variable frequency drives. But what are harmonics anyway? Basically, any periodic signal can be represented as a sum of sine-functions with frequencies equal to an integer number of the fundamental frequency. For example, in the figure below, the sum of the fundamental frequency and signals with frequencies 5, 7,11 and 13 times the fundamental results in a near square waveform. The signal with a frequency 5 times the fundamental is called the 5th harmonic.



Thus, for a non-sinusoidal current, such as the input current of a typical Variable Frequency Drive (VFD), a harmonic analysis refers to the break-down of the current into the fundamental current (60Hz) and into currents with frequencies equal to a integer number times the fundamental frequency. This breakdown is called a Fourier analysis. An example of a Fourier analysis can be seen in the diagrams below, where the current of a VFD (only half a period is shown) is broken-down into its harmonic currents.





Note here that the harmonic current caused by the rectifier part of the variable frequency drive, typically a 6-pulse diode bridge rectifier, has no even or 3rd order harmonics. If the signal is symmetrical to the time/x-axis, as the current of a 6-pulse diode rectifier normally is, no even harmonics will exist. Hence, only under severe unbalance of the supply voltage or different voltage drops of the upper diodes and lower diodes of a rectifier bridge (i.e. half controlled rectifiers or half wave rectifiers) would even harmonics appear. Third order harmonics are said to be zero-sequence currents (3rd order harmonics have the same phase-angle in all three phases and can therefore not be summed to zero in a star-connection as the fundamental is displaced by 120°) and can therefore not appear in a three-phase load with no neutral connection; which would work as a return path. If, however, 3rd order harmonics appear in a three-phase load without a neutral conductor, the cause is then voltage unbalance. This is, because that the 3rd order harmonics are no longer zero-sequence. Third order harmonics may also be caused by single-phase equipment connected between one phase and the neutral. In this case, the 3rd order harmonics can cause severe overheating of the neutral conductor even though the equipment is balanced over the three-phases. This would be the case as the 3rd order harmonics would sum up arithmetically and then the neutral would conduct up to three times the 3rd order of one phase.

The effects of harmonics

In variable frequency drive applications both the harmonic current distortion and voltage distortion are of interest. The harmonic current and voltage distortion have different effects on the power system and it is therefore important to separate between these two when discussing the effects of "harmonics".

The harmonic currents can be described as a reactive current adding to the active current. Consequently, the harmonic current distortion increases the RMS current and, if not taken into account, can result in overheating of components such as the supply transformer or cables. The amount of harmonic current distortion is often described as a percentage of the fundamental current also known as the total harmonic current distortion (THID).

$$THID = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1}$$

Harmonic current normally flows from the harmonic current generator (the VFD) to the main power. The voltage drop caused by the harmonic currents over the supply impedance then causes harmonic voltage distortion. The harmonic voltage distortion is the product of harmonic current distortion and the supply impedance; where a grid with the largest impedance (weak grid) yields the highest voltage distortion.

Harmonic voltage distortion can interfere with equipment connected to the same line such as motors or electronic equipment and could eventually cause this equipment to fail or operate erratically. The amount of harmonic voltage distortion is often described as a percentage of the fundamental voltage also known as the total harmonic voltage distortion (THVD).

$$THVD = \frac{\sqrt{\sum_{h=2}^{\infty} U_h^2}}{U_1}$$

Harmonic reduction techniques

To avoid potential harmonic problems or to comply with standards and recommendations, such as IEEE 519-1992, several different harmonic reduction techniques for variable frequency drives exist. The most well known solutions are:

- AC coils
- Built-in DC-coils
- Multi-pulse (12- and 18-pulse) Front ends
- Active filters
- Passive filters

The most common and easiest harmonic reduction technique is the use of AC-line reactors in front of the VFD. The line reactor smoothes the line current drawn by the VFD and provides significantly reduced current distortion that cannot be achieved by a standard 6 pulse VFD without line reactors. Similar effects can be obtained with DC-coils built into the VFD. The biggest advantage with this is that the DC-coils are smaller in size than AC-coils, have higher efficiency, and result in no reduction of the DC-link voltage.

Twelve and eighteen pulse input bridge rectifiers are another solution used to reduce the harmonic distortion from drives. In theory, the 5th and 7th harmonic currents (for 18-pulse also the 11th and 13th) are cancelled by phase shifting transformers coupled with the use of two (or three) six-pulse diode rectifiers. However, a significant disadvantage of the multi-pulse harmonic reduction technique is the susceptibility to non-ideal supply voltage. As some voltage unbalance and/or harmonic background distortion is present, in reality, complete cancellation of the 5th and 7th (11th and 13th) is rarely achieved. Additionally, transformer losses increase heating and reduce the efficiency of the entire VFD system.

Active filtration is an emerging technology with the potential to reduce the harmonic distortion to almost zero. However, for the active filter to be a successful harmonic reduction technique in the future, some significant challenges needs to be addressed. For example, the active filter switches high voltages directly on the main power resulting in the introduction of high frequency noise. For the time being there are no norms to regulate the amount of the switching frequency noise (2kHz – 150 kHz) allowed onto the main power, thus a major task for the future is to determine a reasonable level of high frequency noise to ensure that no damage occurs on other equipment.

The Danfoss solution

Danfoss offers two different levels of harmonic reduction techniques.

1. As standard, all Danfoss VFD's are equipped with built-in dc-link inductors. This reduces the harmonics typically by 50% as compared to VFD's without dc-link inductors. The built-in dc-link inductance not only ensures compliance with harmonic limits in most applications, but also ensures a longer lifetime for the dc-link capacitors.
2. Danfoss also offers the **Danfoss Advanced Harmonic Filters, AHF 010** and **AHF 005,** where the AHF 010 reduces the total harmonic current to less than 10% and the AHF 005 reduces the total harmonic current to less than 5%.

Danfoss AHF 005 and AHF 010 are Advanced Harmonic Filters not to be compared with traditional harmonic trap filters. The Danfoss harmonic filters have been specially designed to match Danfoss internal VFD characteristics.

Compared to other known solutions Danfoss harmonic filters offer excellent harmonic performance

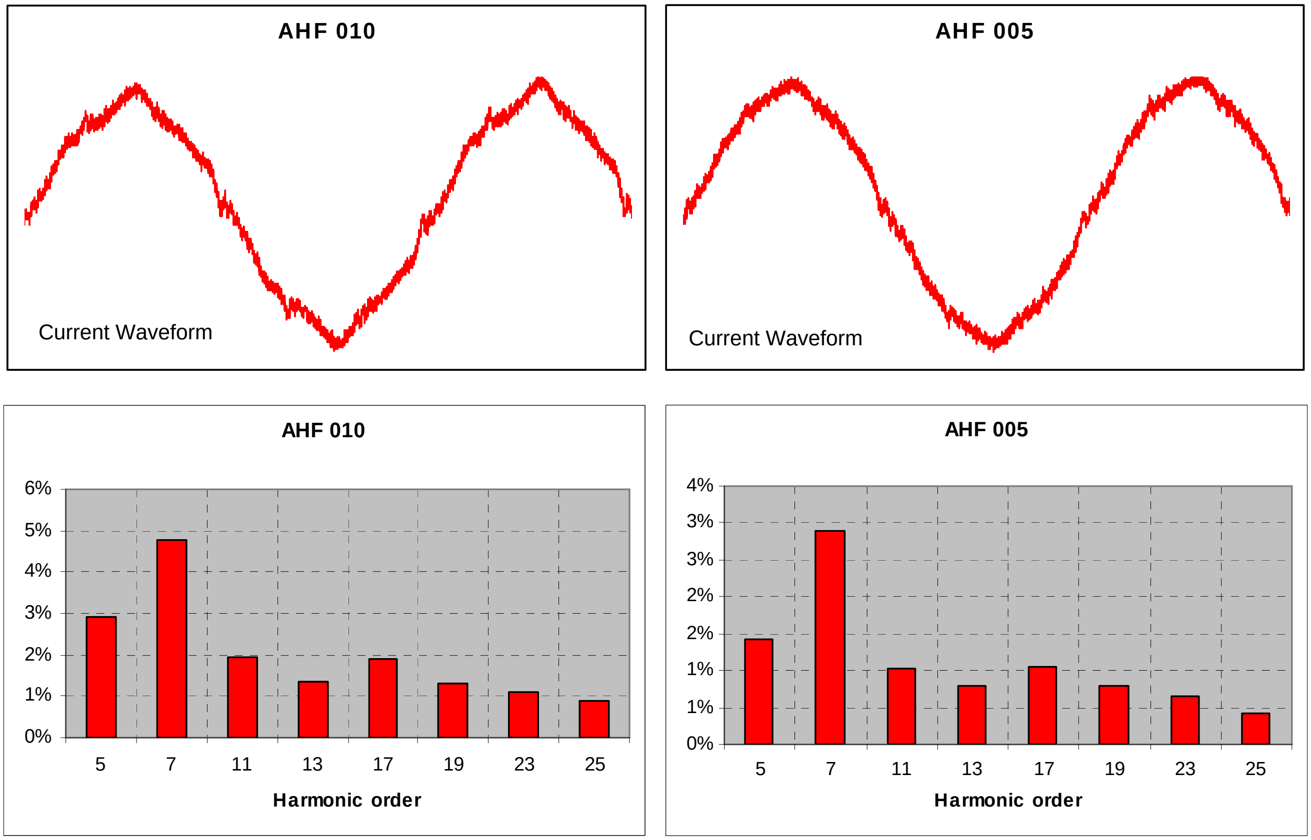
	THiD
Basic three phase six pulse rectifier	60% – 100%
Three-phase rectifier with AC input line reactor	35% – 45%
Danfoss with built-in dc-link reactor	< 45%
12-pulse rectifier	10% – 15%
Danfoss VFD with AHF 010	< 10%
18-pulse rectifier	4% – 7%
Active filters	3% - 8%
Danfoss VFD with AHF 005	< 5%

Performance at non-ideal supply voltage

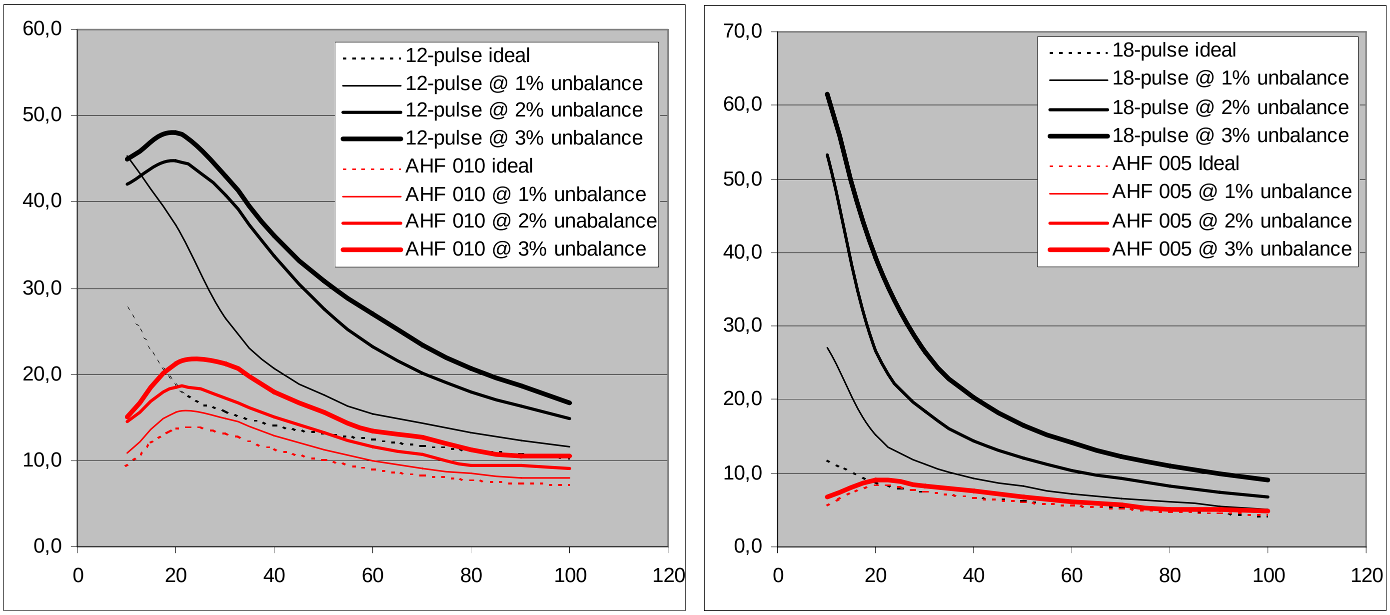
Recognizing that the ideal three-phase supply voltage is nearly non-existent, Danfoss harmonic filters AHF 005 and AHF 010 are developed in such a way that they ensure values close to or better than 10% THID or 5% THID even if the pre-existing total harmonic voltage distortion of the supply voltage is 2% or the voltage unbalance is 2%.

Comparing this performance with the classical solutions such as 12-pulse or 18-pulse rectifier as in the figures below, it becomes clear that the Danfoss harmonic filters under real conditions are superior.

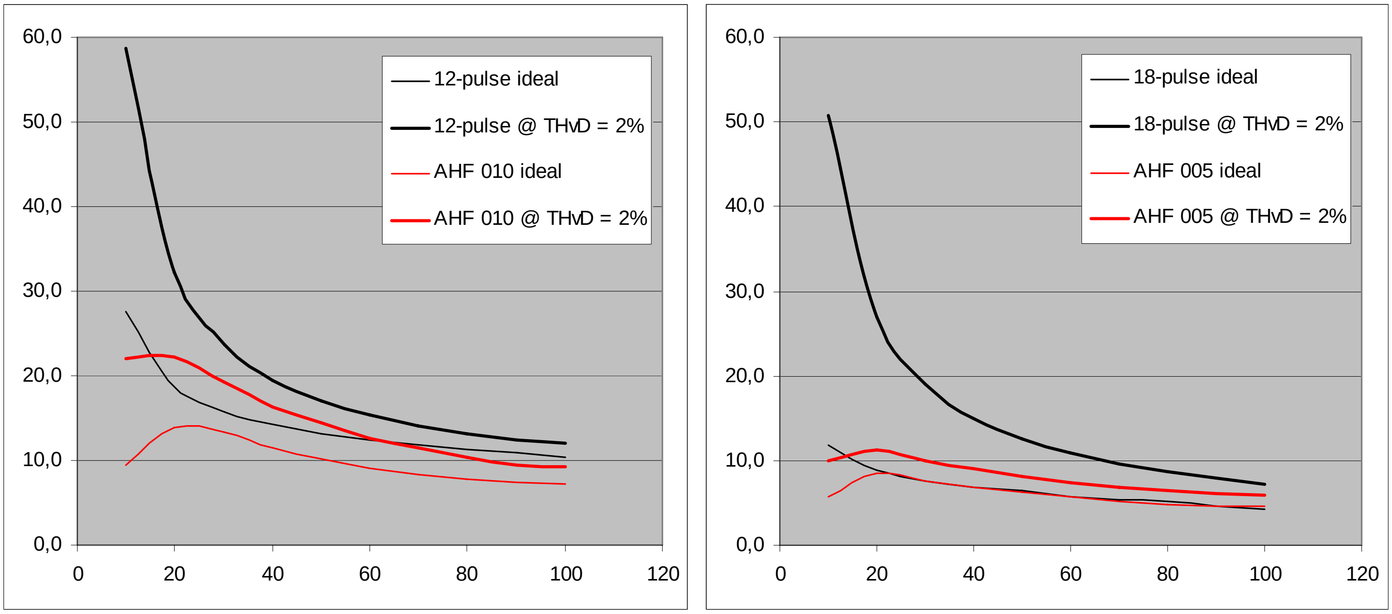
Current and Distortion Spectrum at Full Load



THiD of AHF 010 vs. 12-pulse and AHF 005 vs. 18-pulse with line unbalance



THiD of AHF 010 vs. 12-pulse and AHF 005 vs. 18-pulse with background Voltage Distortion



Harmonic limiting standards and recommendations

Several national and international standards and recommendations exist to prevent potential harmonic problems. One theme common to these standards is the objective of keeping the harmonic voltage distortion below a certain level. In the US, the IEEE recommendation IEEE519-1992 is working with a planning level of THvD = 5% on general systems.

As a consequence of the attempt to keep the voltage distortion at a low level, limits to the harmonic current distortion have been developed or are under development.

Conclusion

Danfoss AHF 005 and AHF 010 are advanced harmonic filters that have been shown to be superior to any previously known harmonic reduction technique for variable speed drives. The true strength of Danfoss harmonic filters is shown to be their robustness to non-ideal (but rather common) supply voltage conditions.

Further advantages of using the Danfoss Advanced Harmonic Filters are:

- Compact housing of the AHF 005 and AHF 010 allow for small enclosures
- Easy to retrofit
- One filter module can be used for several VFD’s
- High efficiency (> 0.98)
- User-friendly start-up – no adjustments or balancing necessary
- No routine maintenance required
- High documentation level