ENGINEERING
TOMORROW

Danfoss

Brochure | Harmonic mitigation

Harmonics in HVAC applications – Surprisingly simple ways to reduce costs

Reduce harmonic mitigation power consumption for HVAC by

37%

drives.danfoss.com | VLT®

Stay alert to alternatives

When it comes to harmonic mitigation, there is no single solution on the market that does it all:

- delivers the best performance
- at lowest cost with highest system efficiency
- satisfies all norms
- is applicable to all sizes of drives,
- can be used in new and retrofit installations

The most economical and technically superior solution for a given installation will always be based on the application requirements, the severity of harmonics, the costs, and the benefits associated with the various technologies.

So can we even speak of cost-efficient harmonic mitigation at all? We certainly can and here's why:

The presence of harmonics escalates risk, affects product quality and increases operating costs. Mitigating harmonics delivers indirect energy savings by reducing the losses in transformers, cables and devices. These indirect savings are the reason why systems equipped with harmonic mitigation solutions, independent of the technology used, demonstrate a better overall system efficiency.

The use of active front-end drives (AFE drives) for mitigating harmonics has become rapidly popular. But if the regenerative feature of the AFE drive is not required, there are more economic solutions available with lower losses that result in significant lower OPEX. So, it is vital to stay alert when making your choice.

Read on to find out how much an active filter solution for harmonic mitigation can save you on your power bill, compared to traditional solutions.

What are harmonics?

An electrical AC supply is ideally a pure sine-wave of either 50 or 60 Hz fundamental frequency and all electrical equipment is designed for optimal performance on this supply.

Harmonics are voltages and currents which have frequency components that are integers multiple of the fundamental frequency – polluting the pure sinusoidal waveform.

Power electronics such as those used in rectifiers, variable speed drives, UPS, lighting dimmer switches, televisions and hosts of other equipment, draw current in a non-sinusoidal fashion.

This non-sine current interacts with the mains supply and distorts the voltage to a greater or lesser degree depending upon the strength or weakness (grid impedance) of the supply.

Generally, the greater the amount of installed electronic power switching equipment on-site, the greater the degree of harmonic distortion.

Why are harmonics a challenge?

Excessive harmonic distortion of the mains supply implies that the source not only carries 50 or 60 Hz frequencies but also components of higher frequencies.

These components can not be utilized by electrical equipment and adverse effects can be severe and include:

- Limitations on supply and network utilisation
- Increased losses
- Increased transformer, motor and cable heating
- Reduced equipment life-time
- Costly unintended production stops
- Control system malfunctions
- Pulsating and reduced motor torque
- Audible noise

Put simply, harmonics reduce reliability, affect product quality and increase operating costs.

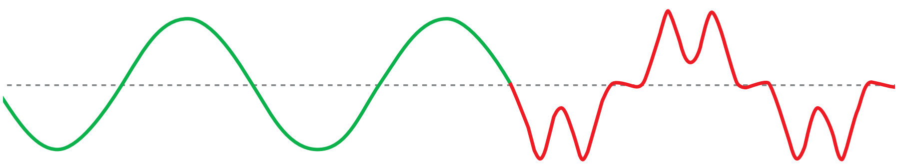


Illustration of a pure sinusoidal waveform being polluted

All drives are not equal
– Equipped to mitigate harmonics

Does every drive installation result in harmonics issues? Not at all.
All Danfoss VLT® drives come with built-in DC-coils* to reduce the harmonics interference and in most cases this is sufficient to avoid voltage pollution.

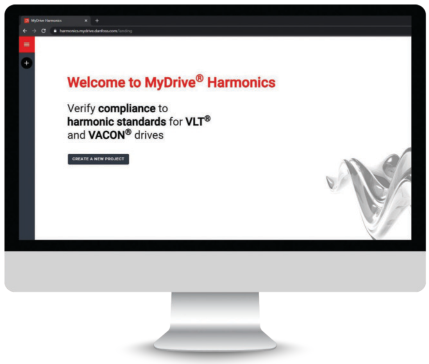
In some cases additional harmonic suppression might be required due to grid conditions or when multiple drives are installed.

For that purpose Danfoss offers a wide range of individual mitigation solutions such as 12-pulse drives and standard drives with either built-in or external, active or passive harmonic filters, including AFEs.

In addition to this, Danfoss also offers active solutions for central harmonic suppression where several loads can be compensated simultaneously.

Determining the degree of voltage pollution on your network is easy using the free MyDrive® Harmonics digital tool.

MyDrive® Harmonics is a professional harmonic simulation tool that lets you determine whether harmonics will be an issue in your installation when drives are installed. It estimates the comparative benefits of implementing different harmonic mitigation solutions from the Danfoss product portfolio, then calculates harmonic distortion to confirm system compliance with a range of relevant standards. It is the ideal design tool both for new-build and upgrade projects.



Discover ***MyDrive® Suite,*** *from where you can access* ***MyDrive® Harmonics***

**With exception of VLT® Micro Drive FC 51 rated 7.5 kW or less,– where an external mitigation solution is available.*

Danfoss provides design support to recommend the most suitable harmonics mitigation solution for each project. When relevant, Danfoss support includes an on-site harmonic survey.

Choosing the best harmonic solution

Different equipment exists to reduce harmonic pollution and each has its advantages and disadvantages.

No single solution offers a perfect match for all applications and grid conditions.

To achieve the optimum mitigation solution, several parameters have to be considered.

The key parameters can be divided into these groups:

- Grid conditions including other loads
- Application
- Compliance with standards
- Cost
- Energy efficiency

Danfoss will, upon request, carry out a full harmonic survey and recommend the most appropriate and most cost-effective solution for your site.

The survey will take the installed loads, the regulatory standards and the diversity of your operation and applications into consideration.

The essential considerations
– a holistic approach optimizes your business

Zero interference ventilation is also highly efficient in this long-cable installation at the Micheville Tunnel, Luxembourg

Compliant and efficient cooling ensures reliability and optimal PUE at Equinix data centers, the Netherlands.

How do grid conditions affect harmonics pollution?

The most important factor in determining the harmonic pollution of a supply grid is the system impedance.

The system impedance is mostly dependent on the transformer size in relation to the total power consumption of the installed loads. The bigger the transformer is in relation to non-sinusoidal power consumption, the smaller the pollution.

The power grid is an interconnected system of power supplies and power consumers all connected via transformers. All loads drawing a non-sinusoidal current contribute to the pollution of the power grid – not just at the low voltage supply but also at higher voltage levels.

When measuring at a power socket, some degree of pollution will thus always be present. This is referred to as harmonic pre-distortion.
As not all consumers draw three-phase current, the load on each phase is dissimilar. This leads to unequal voltage values on each phase, causing phase imbalance.

Different harmonic solutions have different immunity against pre-distortion and imbalance and so this has to be evaluated when determining the most suitable harmonic mitigation solution.

Safe, secure and zero interference comfort for staff and patients at University Medical Centre, Slovenia

As one of the world's most efficient hotels, Crowne Plaza Copenhagen Towers benefits from perfectly harmonically balanced HVAC systems

What application aspects must be considered?

Harmonic distortion increases with the amount of power consumed by the non-linear load and so both the number of drives installed, and their individual power sizes and load profiles, must be considered.

The distortion of a drive is defined by the total harmonic current distortion (THDi) which is the relationship between the sum of harmonic components and the fundamental frequency.

The loading of each drive is important because the THDi increases at partial load, thus over-sizing drives increases the harmonic pollution on the grid.

Additionally, environmental and physical constraints must be taken into account because the different solutions all have characteristics making them more or less suited to specific conditions.

What needs to be considered is, for example, wall space, cooling air (polluted/contaminated), vibration, ambient temperature, altitude, humidity, etc.

Is compliance with standards consistent globally?

To ensure a certain grid quality, most power distribution companies demand that consumers comply with standards and recommendations.

Different standards apply in different geographical areas and industries but all of them have one basic goal, – to limit the grid voltage distortion.

Standards depend on grid conditions. Therefore it is impossible to guarantee compliance with standards without knowing the grid specifications.

Standards themselves do not compel a specific mitigation solution and so an understanding of standards and recommendations is important to avoid unnecessary cost for mitigation equipment.

What are the cost implications of applying harmonic mitigation?

Finally, the initial costs and running expenses have to be evaluated to ensure that the most cost-effective solution is found.

The initial cost of the different harmonic mitigation solutions in comparison to the drive varies with the power range. The mitigation solution that is most cost efficient for one power range is not necessary best cost fit over the full power range.

The running costs are determined by the efficiency of the solutions across the load profile and their lifetime maintenance/service costs.

Active solutions offer the advantage of keeping the true power-factor close to unity over the entire load range, resulting in good energy utilization at partial load.

Also, future development plans for the plant or system need to be taken into account because although one solution will be optimal for a static system, another will be more flexible if the system needs to be extended.

Cost-efficient harmonic mitigation – more than one route

When planning a system, protecting resources and the environment are priorities just as important as the performance and technical reliability of a product.

Key selection criteria: energy consumption and OPEX

Seen from both environmental sustainability and economic perspectives, we must use energy as efficiently as possible.
Therefore a logical approach is to adapt energy consumption to the actual needs of the installation. There is more than one way to achieve this.

Fans and pumps often run 24/7, meaning that optimal energy usage and low operating expenses (OPEX) are key selection criteria in planning an installation.

Did you know that low-efficiency mitigation techniques and blind adherence to overly-strict specifications can result in unnecessary costs? Danfoss recommends making cost-effective choices which are also sustainable, based on good judgement and practical considerations.

Active front-end – or not?

When the target is low harmonic levels, the so-called active front-end (AFE) technique has rapidly become popular. Using an AFE-based product can be a good solution, but it needs to be applied with due consideration.

To understand how, consider the 3 routes to cost-effective mitigation and check the example on page 11 which looks at the cost impact of different harmonic mitigation alternatives. One of them is an AFE solution. The other solution is based on active filters.

Three routes to cost-effective mitigation

1. Use harmonic mitigation equipment only when required

There is no need to regulate below the required standard. Aim to regulate harmonics only to the required standard and according to the installation requirements. A wiring analogy: Would you over-dimension the motor cables just in case you may need a larger motor sometime in the future? Probably not.

No single solution fits all needs. Consider different aspects of system performance in order to find an optimal solution. Danfoss can assist you in finding the optimal harmonic mitigation solution for your system.

Rule of thumb: do not mitigate when the drive load is below 40% of total transformer loading. Be cautious about generator supply (backup supply)

2. Design to meet regulations

Regulations set THDv requirements, but do not specify THDi requirements.

Therefore, design to 5% THDv, to meet regulations. No regulations require THDi≤5% or even THDi ≤ 8% at drive mains terminals. When these THDi levels are specified, designing to meet them adds unnecessary costs.

Perform simple analyses. Fewer than 10 minutes of calculations can save you a lot of money. Evaluate the entire system to find the best solution.

This is easily done using our free version of MyDrive® Harmonics.

Discover ***MyDrive® Harmonics***

3. Select harmonic mitigation equipment based on OPEX calculations

In an installation, energy consumption of drives is a major contributor to the operating costs. That is why validation of efficiency, including calculation of energy losses, is an important step when choosing harmonic mitigation equipment.

Efficiency of 6-pulse drives normally differs by a small percentage between different drives suppliers. However, more than double these efficiency differences are not unusual in mitigation equipment from different suppliers. It's important to do the calculations before you make your choice.

Hospital air conditioning
– harmonic mitigation in practice

Air-conditioning and ventilation systems are crucial in hospitals. Optimal temperature and indoor air quality (IAQ) are important factors when treating patients.

During treatment, patients spend most of their time in hospital rooms, especially those who are more seriously ill, and cannot go outdoors. Patient recovery is faster and more efficient in rooms with adequate temperature control than in overheated and unventilated spaces.

As well as optimal temperature and indoor air quality (IAQ), compliance with IEC/EN 61000-2-4, class 1 is required.
See how you can save a quarter of a mill Eur by choosing the most optimal mitigation solution on page 11.

The following example clearly shows that an active filter-based solution achieves 37% lower operating cost and higher efficiency than an AFE-based solution. The savings in the example amount to 250 tEUR over 10 years.

Consider the active filter alternative

Harmonics in the electric current network create system disturbances that put extra stress on equipment and cause irregular performance. Traditional AFE solutions for harmonic mitigation place filters on every drive in a system.

However, there are no such demands on harmonic mitigation at an individual variable speed drive level according to regulating standards. To save investment, space and energy costs we propose to only install filters needed to comply with e.g. IEEE 519.

Our advanced Active Filter technology makes it possible to create a setup with a central filter solution, while still meeting the latest regulating standards.

Contrary to the traditional harmonic mitigation based on active front end technology, the Advanced Active Filter identifies harmonic distortion in the system and injects a counter-current to cancel out the electric noise.

Energy efficient solutions is also a key aspect when selecting your harmonic mitigation solution. By selecting a highly efficient harmonic mitigation solution you can often save 2% of your energy consumption and reduce your ROI with 1 year. Together we can take a big step towards meeting our climate goals.

Learn more **here**

Danfoss Advanced Active Filter AAF 007

The Danfoss Advanced Active Filter AAF 007 is designed to reduce harmonic distortion of central or decentrally installed Danfoss drives. The newest-generation SiC switches give unmatched high efficiency with 60% lower power losses compared to similar filters and effective elimination of high-order harmonics. The filter is compatible with all drives in the Danfoss product portfolio, and is delivered pre-configured and tuned from factory, ready to use with the accompanying current transducers.

Learn more about the Danfoss Advanced Active Filter AAF 007

Example

The hospital ventilation control system consists of a total of 88 drives with approximately 2100 kW drive power split in two identical subsystems, each connected to its own transformer. For backup there is one generator, as shown in the overview in Figure 1.

Besides compliance with the standards, the investor has the following requirements:

- Reliable performance with a high level of redundancy
- Zero interference with the primary hospital equipment, service, and technical support
- Reduced energy consumption

To meet the requirements, we will consider the efficiency and cost impact of 2 possible drive solutions:

- Scenario A: Standard VLT® HVAC Drive FC 102 from Danfoss, with advanced active filter
- Scenario B: Traditional AFE low harmonic drive

The installed equipment for each scenario is listed in Table 1.

Table 1: Equipment required for harmonic mitigation of the hospital ventilation system, scenarios A & B

Equipment installed for both scenarios									**Total**	
Motor shaft power [kW]	4	5.5	11	18.5	45	75	110	400		
No. of fans (variable torque)	6	2	10	2						
No. of pumps (variable torque)	4	4	2	6	4	4	2			
Number of chillers (Constant torque)								4		
Total No. of drives	10	6	12	8	4	4	2	4	50	
Scenario A: Standard VLT® HVAC FC 102 from Danfoss including Advanced active filter									**Total**	**Filter losses**
Losses per drive [W] [1]	124	187	392	465	835	1384	2559	8084		10,790 € assuming 715 A AAF 007
Electricity cost of losses for 10 years of operation [2]	8,680 €	7,860 €	32,970 €	26,070 €	23,410 €	38,800 €	35,870 €	226,600 €	400,260 €	18,900 € assuming 715 A filter
Total for drives and filter									419,160 €	
Scenario B: Equivalent AFE based drives									**Total**	
Losses per drive [W] [1]	226	329	579	751	3808	2963	3990	11065		
Electricity cost of losses for 10 years of operation [2]	15,840 €	13,830 €	48,690 €	42,100 €	106,750 €	83,060 €	55,920 €	310,170 €	676,360 €	
Total for all drives									676,370 €	
Difference in cost of losses for 10 years									257,201 €	

1] *Losses in the motor are not considered. Estimated power loss as listed in drive manuals*

2] *(0,1€ pr. kWh x 24 hours x 365 days x 10 years) per device utilization is 80%*

Figure 1. Overview of hospital ventilation control system, Normal mode

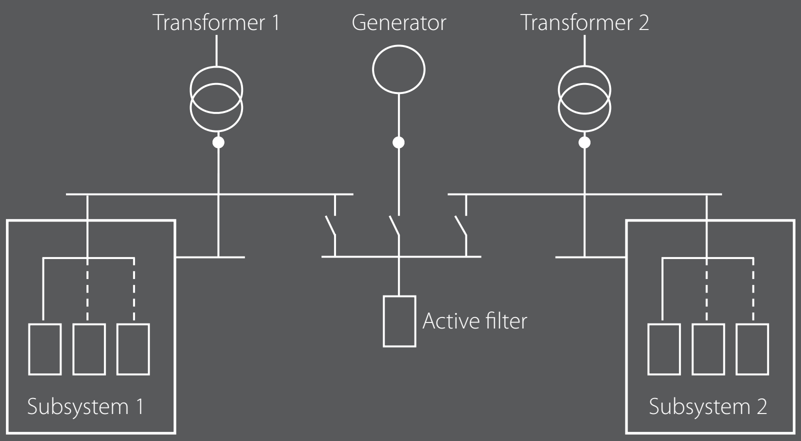


Figure 2. Overview of hospital ventilation control system, Backup mode 1

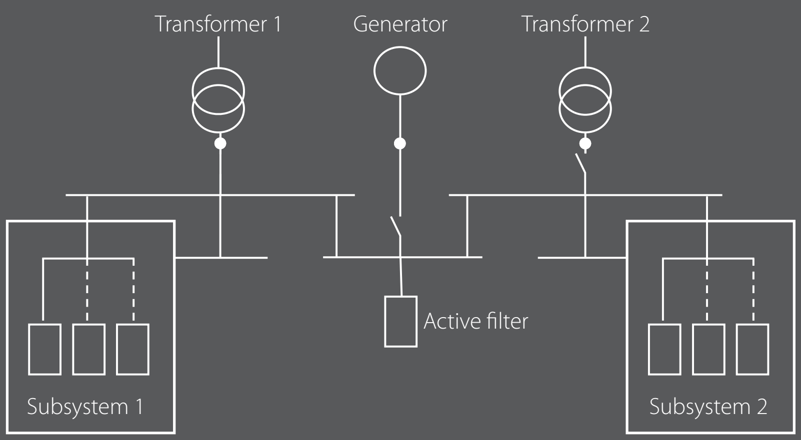
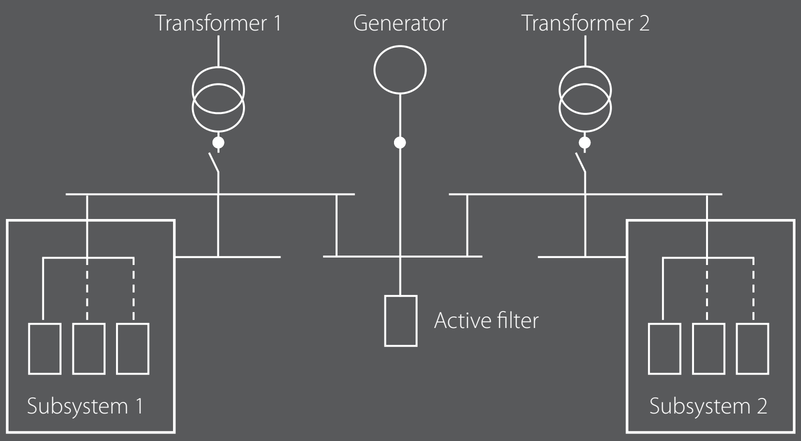


Figure 3. Overview of hospital ventilation control system, Backup mode 2



Hospital air conditioning
– harmonic mitigation in practice

Analysis

Scenario A: Danfoss active filter solution

We consider three operation modes:

- Normal mode: Two transformers of 2500 kVA, each feeding its own subsystem
- Backup mode 1: One 2500 kVA transformer feeding both subsystems
- Backup mode 2: Emergency generator feeding both subsystems

A quick simulation using MyDrive® Harmonics shows that in order to comply with IEC IEC/EN 61000-2-4 Class 1 in all three modes, harmonic mitigation is required for *Backup mode 1*. The simulation results are shown in Table 2.

Table 2: Compliance for Danfoss solutions with and without harmonic mitigation in the form of active filter

VLT® HVAC Drive FC 102	THDv			IEC/EN 61000-2-4, class 1 compliance THDv < 5%
	Normal mode	Backup mode 1	Backup mode 2	
	Single transformer @2500 kVA feeds one subsystem	Single transformer @2500 kVA feeds both subsystems	No transformer Backup generator @4600 kVA	
THDv for standard 6-pulse drives	4.42%	7.05%	3.77%	Backup mode 1 is not compliant
THDv for standard 6-pulse drives +715 A active filter	4.42%*	4.96%	2.87%	Compliant in all modes

Filter installed but not running

Which harmonic mitigation solutions should be considered?

Since the system typically runs in Normal mode, and in this case standard drives comply to the IEC standard, harmonic mitigation is only required when the system is in Backup mode 1 or 2.

Calculations in the MyDrive® Harmonics tool indicate that a filter of 715 A is needed in order to comply with the harmonic mitigation requirement of THDv of 5 % at point of common coupling.

Throughout the calculation, we assume that the filter is running 20% of the time.

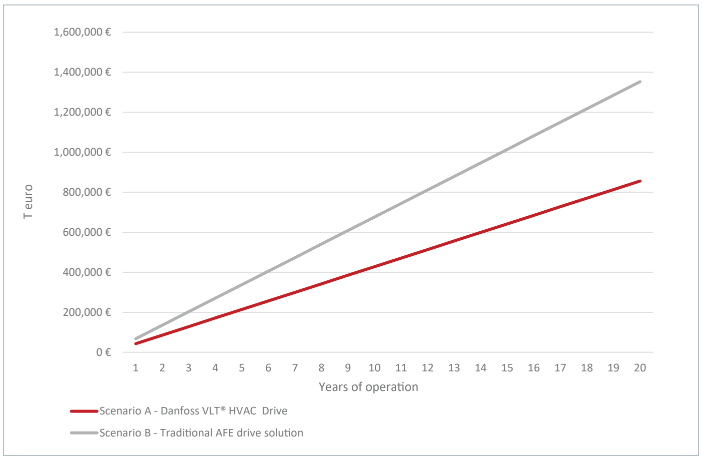
Active filter solution delivers valuable lifetime savings

Scenario B – AFE drive solution

The AFE-based drives already comply with the harmonic mitigation requirement of THDv below 5%.

Figure 4 shows clearly that the Danfoss solution using advanced active filters (A) consumes 38% with the AAF 007 *(above used numbers)* less power than the next best alternative, the traditional AFE drive solution (B).

Figure 4. Total cost of electricity losses over time



Unique heat management delivers even more savings

Losses from drives are dissipated in the form of heat and every kW of losses require approximately 0.4 kW of energy to remove the heat. So not only do the losses result in higher energy cost, they also result in increased cost for air conditioning. With drives from Danfoss, more savings are possible as back-channel cooling ensures that 90% of the heat generated by losses can be kept outside the control room. An extra benefit is that due to the lower air conditioning demand, the physical space required for the control room can be smaller, resulting in more savings.

If we look at the above example and table 1, this means respective total losses for scenarios A and B of 67 kW and 96.5 kW. We apply the utilization factor of 0.8, which reflects the actual usage of the system compared to full load over the full year.

For scenario A, drives with total losses of 37 kW can utilize back-channel cooling, as we only take drives bigger than 90 kW into account for this solution. That means only 3.7 kW of those drives dissipate into the control room. Adding the filter losses and the losses of the drives without back-channel cooling, 44.5 kW needs to be cooled in the control room for scenario A, whereas 96.5 kW needs to be cooled in scenario B.

Taking the difference in power consumption with the utilization factor of 0.8 and the need of 0.4 kW/kW in cooling applications, savings for one year sum up to 14,500 € – assuming energy prices of 10 € Cent/kWh. Looking at the ten-year period, this would give savings of 145.000 EUR in air conditioning need by selecting a Danfoss solution. This is in addition to the 257.000 € savings from the central compensation solution from the above case.

Why is the efficiency so important?

Fans and pumps often run 24/7, meaning that optimal energy usage and low operating expenses (OPEX) are key selection criteria in planning an installation.

Over recent decades, the relative cost of variable speed control by AC drives has dropped, and energy prices have increased. This makes it more attractive to use drives on more or less all rotating equipment.

Over the lifetime of the drive, energy cost is the dominating economical factor, especially since air conditioning fans in the hospital run 24/7. When selecting a harmonically mitigated drive solution, the efficiency and cost of losses are therefore key selection parameters.

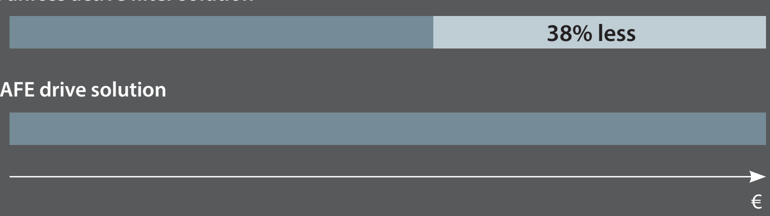
The example demonstrates that a harmonically mitigated drive solution from Danfoss is vastly more efficient than the traditional alternative, due to the combination of drive and active filter efficiency.

As shown in Table 1, the cost of losses is respectively €42,806 for the Danfoss solution and €67,637 for the traditional solution. Based on Table 1, the Danfoss solution uses 37% less power than the traditional solution. Therefore the hospital will save 37% on harmonic mitigation power costs by choosing the Danfoss active filter approach, as illustrated in Figure 3.

Figure 5. Energy consumption comparison

Scenario A- Danfoss active filter solution

Scenario B – AFE drive solution



Hospital air conditioning system
– harmonic mitigation in practice

Conclusion

The example clearly shows that an active filter-based solution achieves 38% lower operating cost and higher efficiency than an AFE-based solution. The savings amount to 0.25 M€ over 10 years.

Additional benefits of Danfoss Advanced Active Filter AAF 007

- The active filter is installed in parallel to the AC drive input. Therefore, the AC drive operates normally in the event of filter malfunction, ensuring uninterrupted operation of the hospital air conditioning system. This topology ensures a reliable system with a high level of redundancy.
- The active filter conserves energy by entering “sleep mode” when harmonics levels are low. When this capability is factored into the calculation, even greater electricity savings are possible than those outlined here.

*Read **more about Danfoss Advanced Active Filter AAF 007***

Additional benefits of VLT® HVAC Drive FC 102

- Designed for minimum 10 years’ maintenance-free operation
- Reduces your air conditioning investment by up to 90% thanks to the unique back-channel cooling concept
- Condition-based monitoring functionality based on edge computing is built into the drive

*Read **more about VLT® HVAC Drive***

More questions?
– here are the answers

Should I always use an active filter for harmonic mitigation?

When it comes to harmonic mitigation, there is no single solution on the market that:

- delivers the best performance
- at lowest cost with highest system efficiency
- satisfies all norms
- is applicable to all sizes of drives,
- can be used in new and retrofit installations

The most economical and technically superior solution for a given installation will always be based on the application requirements, the severity of harmonics, the costs, and the benefits associated with the various technologies.
In some cases there is physical space available for installing filters, and in other cases there is not.

Danfoss offers a comprehensive portfolio of products for harmonic mitigation, such as 12-pulse drives and standard drives with either built-in or external, active or passive harmonic filters, including AFEs. It is the goal of Danfoss to equip our customers with the optimal recommended solution, taking all factors into consideration.

Please contact your local sales representative for personal harmonics mitigation support.

Why does the AFE drive result in greater losses than a standard 6 pulse drive?

An AFE drive contains twice the quantity of power electronics as a standard drive, plus an LCL filter, which does not exist in a standard drive. Double the power electronics means twice the risk of component failure, but it also means greater power loss over the drive, as demonstrated in the example.

Does an AFE-based LHD solution result in an better overall system efficiency?

Where harmonic mitigation is required, then any solution which mitigates harmonics will improve the entire system energy efficiency.

Harmonic mitigation is known to give you indirect energy savings, by reducing losses in transformers, cables and devices by improving the true power factor and this is not unique to AFE-based technologies.

The example shows how the losses of the individual components play an important role when selecting a method for harmonic mitigation. These losses have a significant impact on OPEX.

AFEs are built for regeneration and are the optimal choice when regeneration is required.

What is the difference between THDi, THDv, and TDD?

THD is the abbreviation for Total Harmonic Distortion. It can be measured in voltage and current and describes how distorted the signal is compared to its ideal sinusoidal state.

The current distortion, THDi, is the apparatus-specific current distortion hence only describes the effect of the product itself, its supply cable and transformer.

Norms and standards aim to keep voltage distortion (THDv) low. Hence the goal when trying to reduce harmonics should be to reduce THDv to a minimum to ensure that the voltage quality is maintained throughout the installation supply network.

It is irrelevant to look at current distortion (THDi) of individual consumers as only system level parameters impact all consumers on the same supply. The coalition between current and voltage is impedance (Ohms Law). Therefore it is important to consider THDi only in relation to impedance, to evaluate impact of the voltage distortion.

TDD is the system-level total demanded current distortion. It includes all current consumers for the installation. To lower the TDD you can reduce the individual THDi values by a filtering process (active or passive), increase the short circuit current or change the balance between direct online motors and drives use (add more DOL to lower TDD).

Optimal temperature and clean air flow **– University Medical Center, Ljubljana, Slovenia**

A healthy indoor environment is essential for any recovery process – and creating a reliable HVAC system is a true challenge for any hospital.

Not surprisingly, the University Medical Centre (UMC) Ljubljana therefore had a long list of compliance requirements when replacing two cooling compressors which had been in operation for more than 40 years.

A Danfoss advanced active filter solution achieved low harmonic distortion with THDi below 5%, met all safety and security requirements and reduced energy consumption too.

Compressor control meets stringent compliance requirements

University Medical Center, Ljubljana

Read the case study

Discover more case studies for the advanced active filter **here**

Follow us and learn more about AC drives

VLT® | VACON®