ENGINEERING
TOMORROW

Brochure | Harmonic mitigation

Harmonics in water & wastewater installations - choose wisely to curb costs

Slash

44%

off your harmonic mitigation power bill with Danfoss active filter solutions

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. AFE drives are built for regeneration and are the optimal choice when regeneration is required. However using AFE drives for mitigating harmonics results in a significant yearly OPEX increase due to inherently higher losses. So it's vital to stay alert when making your choice.

Looking for a more economic solution which mitigates harmonics equally well? Active filters are a highly viable alternative, saving up to 44% on the 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 (fault level) 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.

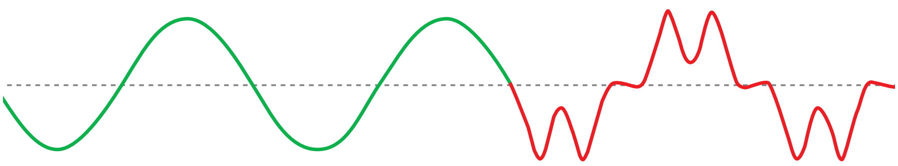


Illustration of a pure sinusoidal waveform being polluted

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.

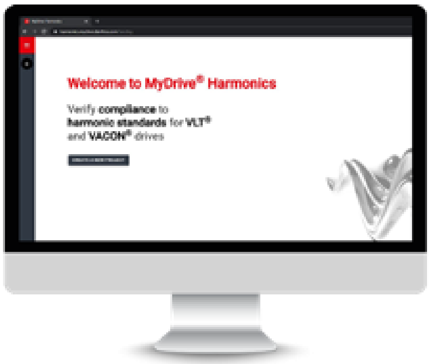
In some cases additional harmonic suppression might be required due to grid conditions or when multiple drives are installed.

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 application into consideration.

The essential considerations
- a holistic approach optimizes your business

This wastewater treatment plant achieves exceptional efficiency based on active filters for harmonic mitigation.

Three active harmonic filters ensure reliability in recirculating aquaculture for young salmon.

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 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.

More than 100 drives run in perfect harmonic balance at this wastewater treatment plant, which generates surplus energy.

Three VLT® Low Harmonic Drives installed at waste water station ensure compliance with IEEE519.

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.

Are 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. We are ready to assist you in finding the optimal harmonic mitigation solution for your system.

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 thousands of dollars. Evaluate the entire system to find the best solution.

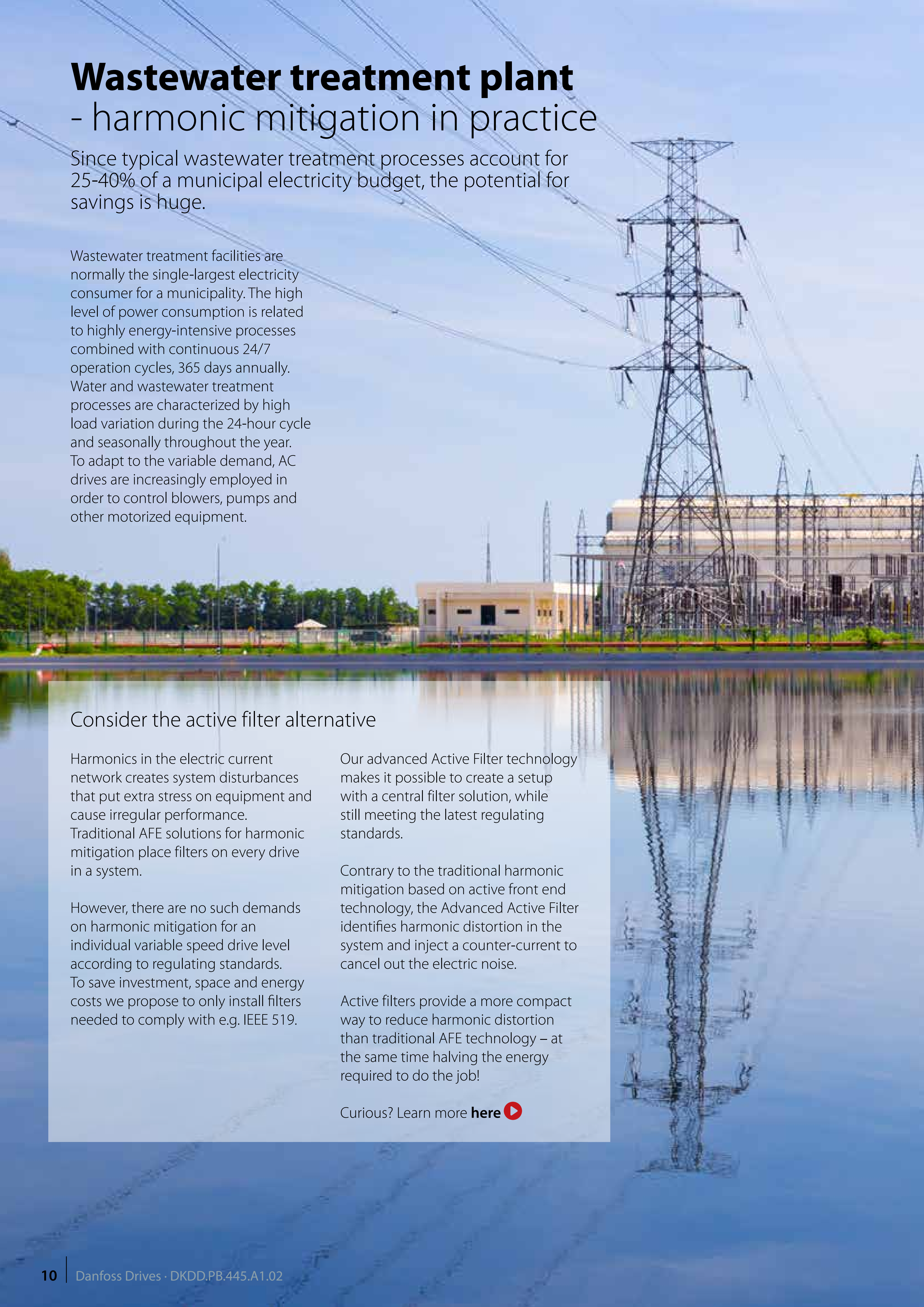
This is easily done using our free version of MyDrive® Harmonics.

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 only 0.5% between different drives suppliers. However, efficiency differences of as much as 1-2% are not unusual in mitigation equipment from different suppliers. It's important to do the calculations before you make your choice.



Wastewater treatment plant
- harmonic mitigation in practice

Since typical wastewater treatment processes account for 25-40% of a municipal electricity budget, the potential for savings is huge.

Wastewater treatment facilities are normally the single-largest electricity consumer for a municipality. The high level of power consumption is related to highly energy-intensive processes combined with continuous 24/7 operation cycles, 365 days annually. Water and wastewater treatment processes are characterized by high load variation during the 24-hour cycle and seasonally throughout the year. To adapt to the variable demand, AC drives are increasingly employed in order to control blowers, pumps and other motorized equipment.

Consider the active filter alternative

Harmonics in the electric current network creates 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 for 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 inject a counter-current to cancel out the electric noise.

Active filters provide a more compact way to reduce harmonic distortion than traditional AFE technology – at the same time halving the energy required to do the job!

Curious? Learn more **here**

Example

A capacity upgrade is required for an existing wastewater treatment plant. Besides complying to the local standards, the investor often requires a technically unnecessary safety margin just to be on the safe side: a THDi level no greater than 5%, irrespective of the load.

What most investors do not realize, is that this extra buffer in the THDi limit can lead to significant extra operating costs. The supplier is expected to deliver an efficient, reliable system with a high level of redundancy, service and technical support, and most importantly with high focus on efficiency and energy savings.

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

- Scenario A: Standard VLT® AQUA FC 202 combined with an active filter
- Scenario B: AFE low harmonic drive technology

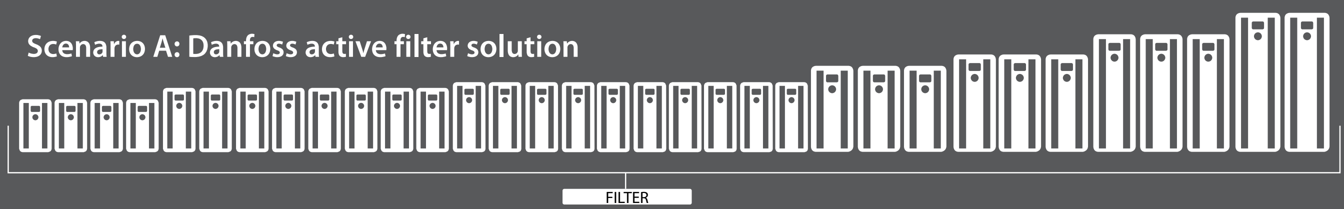
The equipment required for each scenario is listed in Table 1.

Table 1: Equipment required for wastewater treatment plant harmonic mitigation scenarios A & B

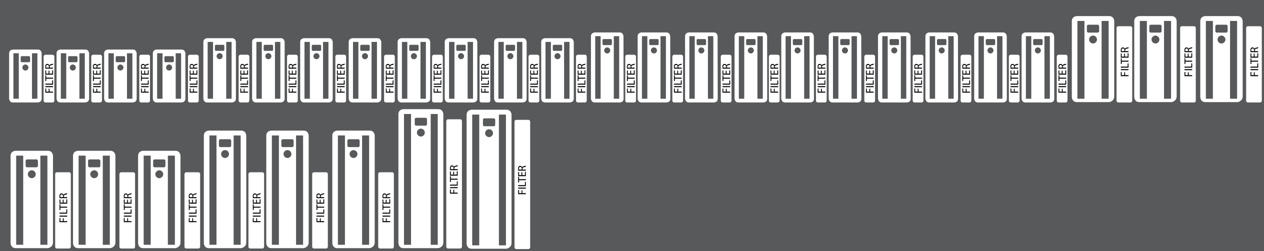
Installed equipment									
Motor shaft power [kW]	5.5	7.5	11	22	75	90	250		
No. of mixers		3	4	2					
No. of pumps	3	3	4		2	2			
No. of blowers							1		
No. of drives	3	6	8	2	2	2	1		
No. of backup mixers/pumps/ blowers & drives	1	2	2	1	1	1	1		
No. of filters								1	
Scenario A: Danfoss harmonic mitigation with VLT® AQUA Drive FC 202 and active filter									
Losses per drive [kW] [1]	0.187	0.225	0.291	0.444	1.022	1.232	4.039		
Filter losses [kW]								7.925	
Electricity cost of losses per drive for 10 years of operation [2]	€1,311	€1,577	€2,039	€3,112	€7,162	€8,634	€28,305	€55,538	
Total cost of losses	€3,931	€9,461	€16,315	€6,223	€14,324	€17,268	€28,305		**€151,366**
Scenario B: Traditional harmonic mitigation with equivalent AFE-based drives									
Losses per drive [kW] [1]	0.329	0.395	0.579	0.912	2.963	3.168	9.135		
Electricity cost of losses per drive for 10 years of operation [2]	€2,306	€2,768	€4,058	€6,391	€20,765	€22,201	€64,018		
Total cost of losses	€6,917	€16,609	€32,461	€12,783	€41,529	€44,403	€64,018		**€218,720**

1] Losses in the motor are not considered. Estimated maximum power loss, sourced from drive manuals
2] 0.1 Euro per kWh x 24 hours x 365 days x 10 years. Device utilization is set to 80%, since drives are not always running at full load

Scenario A: Danfoss active filter solution



Scenario B: Traditional AFE drive solution



Wastewater treatment plant
- harmonic mitigation in practice

Analysis

Scenario A- Danfoss active filter solution

Use the MyDrive® Harmonics tool to simulate the different load conditions and obtain a filter recommendation. The simulation results are shown in Table 2.

Table 2: Simulation results from the MyDrive® Harmonics tool

Performance at transformer secondary side: 80 % load on drives							
AAF size	No AAF	90 A	180 A	270 A	**360 A**	450 A	540 A
THDu (%) transformer secondary	2.6	2.0	1.5	1.2	1.0	1.0	1.0
THDi (%)	27.1	21.5	15.1	9.6	**5.0**	2.2	2.2

Performance at transformer secondary side: 40% load on drives							
AAF size	No AAF	90 A	180 A	270 A	**360 A**	450 A	540 A
THDu (%) transformer secondary	1.7	1.1	0.8	0.6	0.5	0.5	0.5
THDi (%)	35.2	25.2	16.2	8.8	**2.7**	2.7	2.7

AAF: Advanced Active Filter

Let's have a look at the simulation results. For this case, Danfoss does not recommend installing a filter at all. Dimensioning to comply with national THDv requirements of 5% THDv will ensure trouble-free operation at lowest possible investment and highest running efficiency of the installation. This removes the filter investment costs completely and the filter losses are reduced correspondingly.

To comply with the customer-specified THDi requirement of maximum 5% THDi, a filter of 360 A would be required. However, this is an overcompensation which unnecessarily increases both CAPEX and OPEX with no corresponding improvement in robustness of the installation.

However, for the sake of comparison, we will use the 360 A filter throughout the calculations.

Active filter solution delivers valuable lifetime savings

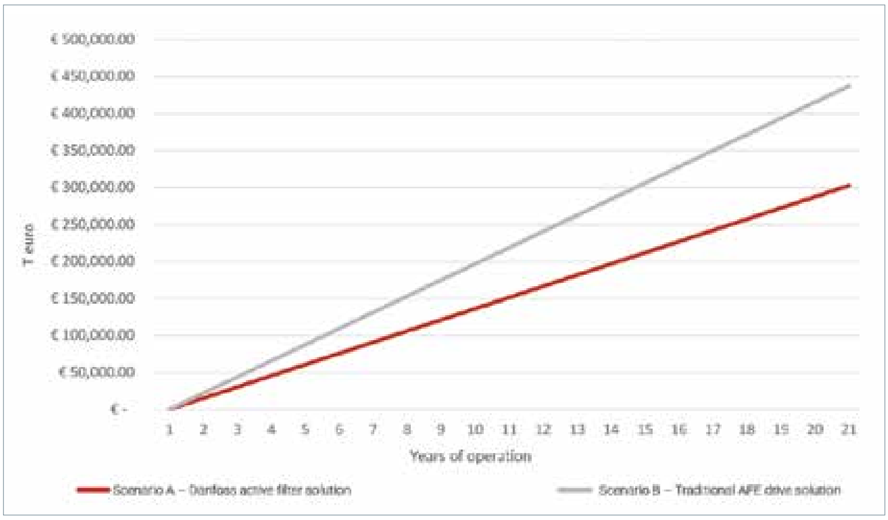
Scenario B – AFE drive solution

The AFE-based low-harmonic drive complies with the requirement of THDi below 5% at all loads.

Why is it so important to look at the efficiency of the solution? Efficiency is by far the most significant operating cost factor. Let's look at the development in cost of electricity losses over time, shown in Figure 1.

It's easy to see that the Danfoss active filter solution (A) generates significantly lower losses over time than the traditional AFE drive solution (B).

Figure 1. Total of electricity losses over time



Why is the efficiency so important?

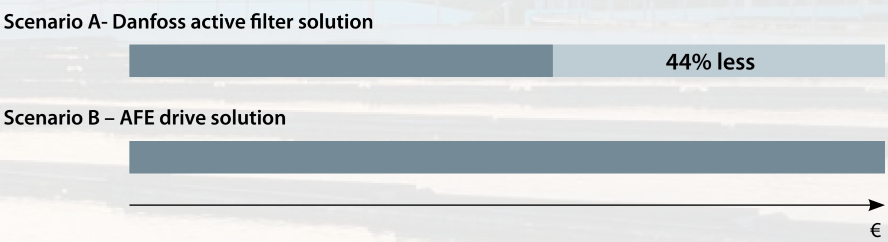
Fans and pumps often run 24/7, meaning that optimal energy usage and low operating expenses (OPEX) are key selection criteria in planning an installation.

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 pumps in the wastewater treatment plant 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 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 €151,366 for the Danfoss solution and €218,720 for the traditional solution. Based on Table 1, the Danfoss solution uses 44% less power than the traditional solution. Therefore the wastewater treatment plant will save 44% on harmonic mitigation power costs by choosing the Danfoss active filter approach, as illustrated in Figure 2.

Figure 2. Energy consumption comparison



Wastewater treatment plant
- harmonic mitigation in practice

Conclusion

The example clearly shows that by using an active filter-based solution, harmonic mitigation is achievable free of plant downtime, at 44% lower operating cost, and at higher efficiency, compared to an AFE-based solution.

In Scenario A, one active filter can provide mitigation for multiple 6-pulse drive systems.
If the backup drives come into operation, they will be mitigated by the same active filter.

In Scenario B, one AFE is required per drive, which can amount to many AFEs for an entire system comprising multiple drives. Extra AFEs are also required for the backup drives, which increases investment cost even more.

Additional benefits of an active filter

- 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 wastewater plant. 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.

Additional benefits of VLT® AQUA Drive

- Designed to be maintenance free for minimum 10 years' service
- Save an additional 10-50% using the Deragging / Pump Clean feature unique to the VLT® AQUA Drive
- Reduce 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® AQUA 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 and it is the goal of Danfoss to equip our customers with 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 reducing 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 wire 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 capacity or change the balance between direct online motors and drives use (add more DOL to lower TDD).

Danfoss active filter solutions at work
– Affinity Water, Great Britain

Affinity Water Chertsey Water Treatment works are forecast to save more than a third of a million pounds in running costs over their 20-year lives, due to selection of VLT® AQUA Drive instead of the 'next-best' solution offered for the project.

The exceptional efficiency of the system is based on active filters for harmonic mitigation and a unique back-channel cooling concept.

Water treatment works
saves £0.3 million in running costs

Chertsey Water Treatment works of Affinity Water, United Kingdom

Read the case study

Discover more case studies for the VLT® AQUA Drive **here**

Follow us and learn more about AC drives