Harmonic Filtering Techniques

Reducing the harmonic distortion of a system can be accomplished with centralized or localized harmonic filters. Centralized filters include filtered automatic power factor correction units and active harmonic filters. Localized filtering can be accomplished by applying drive filters or active filters at the harmonic generating loads themselves.

A comparison of the harmonic filtering methods follows. For the purposes of this article the harmonic generators will be considered individual variable speed drives (VSD) of 6 pulse configuration on low voltage systems. The harmonics created by the VSD are 5th, 7th, 11th, 13th, etc. The largest amount of harmonic current produced would be the 5th harmonic, followed by the 7th harmonic, then the 11th harmonic and so on.

Harmonics flow to low impedance devices. Many of the harmonic filters used consist of parallel connected capacitor inductor circuits to create a low impedance device. These types of filters are considered passive devices. The low impedance devices attract harmonic current from all sources connected to the system (considered export harmonics) and those exterior to the plant (considered imported harmonics). They then dissipate the harmonic current as heat. Note heat dissipation should not be considered a loss caused by the harmonic filters as this waste heat already existed in the system in unusable frequencies. This heat is dissipated by the harmonic filter instead of being exported to the utility grid to be dissipated by other low impedance devices.

An alternative to the passive devices are active devices. They cancel harmonics by producing them at 180 degrees phase angle to the harmonics being created by the VSD's.

Centralized harmonic filters are connected to the main bus of the system and are designed for plant wide harmonic reduction. Localized harmonic filters are connected as close to the source of the harmonics as possible and are typically provided as one harmonic filter for each harmonic generator.

Each Type of harmonic filter is described below:

A) **Filtered Automatic Power Factor Correction Units (FAPFCU).** Type: Passive, Centralized. Requires dedicated disconnect. Absorbs export and import harmonics from all sources connected to the distribution.
Typically the filter is sized to maintain a target power factor of 100% for all loads combined. Generally used for applications where there are many VSD's. The filter consists of several capacitor and inductor circuits (stages) which are switched on or off by an electronic power factor controller. The more load which is running, the more filter stages will be switched on by the controller.

Each filter stage is tuned to create a low impedance point typically just below the 5th harmonic. The filter will absorb most of the 5th harmonics being generated by the VSD's and dissipate them as heat. The filter tuned to the 5th harmonic will also absorb 7th, 11th, 13th, etc harmonics, but the higher the harmonic frequency, the less the filter will absorb. Multiple tuning frequencies such as 5th, 7th, 11th, etc are used in cases where severe harmonic reduction is required, such as in cases where telephone interference limits mandate a low amount of harmonic current being exported to the utility grid even at higher frequencies.

Harmonic resonance is a possibility if capacitors without harmonic filters are installed. However, capacitors without harmonic filters should not be installed in harmonic contaminated environments since they may fail catastrophically.

This filter is effective for generator applications as a leading power factor can be avoided.

Plant expansions can be accommodated by added more filter stages.

B) **Drive Filters.** Type: Passive, Localized, but may also be used to feed several VSD's which would

normally run at the same time. Does not requires dedicated disconnect. Absorbs export harmonics from the connected load and negligible amount of harmonics from other sources.
These filters are series connected at the input terminals to each VSD or on the load side of the MCC breaker, thus they are sized based on the amount of VSD load connected. This type of filter is most often used when there is a small quantity of VSD's present.

This technique uses a series connected line reactor and a parallel connected capacitor inductor circuit tuned at the 5th harmonic to create a low impedance point. The combination of the series line reactor and the passive capacitor inductor circuit virtually eliminates harmonic resonance issues and the concern of importing harmonics from other sources or VSDs not connected to the load side of the drive filter. The line reactor is used to increase the source impedance which makes the capacitor inductor circuit extremely efficient at absorbing and dissipating harmonic current as heat. This filter is very effective in providing severe harmonic reduction.

On more advanced versions, the capacitor and inductor circuit can be switched on and off when the VSD is switched on and off preventing leading power factor when the VSD is not running. This type of filter will provide power factor correction but if the capacitor inductor circuit is oversized there is a greater risk of leading power factor at low loads, particularly with voltage source drives.

Properly sized drive filters will provide excellent harmonic reduction and still maintain a lagging power factor down to VSD loads less than 75% for voltage source drives. At loads less than 50% the power factor would most certainly be leading with voltage source drives if meeting IEEE 519 secondary targets at 100% load is required. Leading power factor should not be a concern with current source drives at any speed. Drive filters are suitable for generator applications provided they are sized properly for the loads.

Plant expansions can be accommodated by adding a drive filter for each VSD added.

C) **Active Harmonic Filters.** Type: Active, Centralized or may be applied near each VSD. Requires dedicated disconnect. Creates harmonics to compensate for both import and export harmonics.

This is new technology. Typically these filters are sized based on how much harmonic current the filter can produce, normally in amperage increments of 50 Amps. Once the amount of harmonic cancellation current is determined the proper amperage of active filter can be chosen.

Essentially the filter consists of a VSD with a special electronic controller which injects harmonic current on to the system 180 out of phase to the system or drive harmonics. This results in a cancelling effect of the harmonics. For example if the VSD's create 100 amps of 5th harmonic current and the active filter produced 75 Amps of 5th harmonic current, the amount of 5th harmonic current exported to the utility grid would be 25 Amps.

The controller will measure the amount of harmonics being created by the VSD's and will inject as much harmonic cancelling current back on to the system as it is capable of producing, or until there is no harmonic current remaining to be cancelled. When the amount of VSD's load is small there is a benefit of some power factor correction available at low loads, however this should be considered a negligible benefit as the power factor correction is not available when the active filter produces high amounts of harmonic current, which would normally occur at peak loads when power factor correction is required most.

Harmonic resonance is not an issue with this type of filter. Some active filters are not suitable for generator applications as the capacitors are fixed and thus there will be a leading power factor under lightly loaded conditions. Active filters with variable capacitors are suitable for generator applications since the leading power factor issue can be prevented.

Plant expansions can be accommodated by adding more active filter modules.

Filter Comparison:

1) Harmonic Export Reduction:

Adequate export harmonic reduction can be achieved with all types of filters and locations.

2) Harmonic Reduction on feeders:

Installing filters at each VSD presents the ideal situation since the harmonics are addressed at the source of the problem, thus most of the harmonics created by the VSD's are prevented from circulating in the rest of the distribution. Excellent harmonic reduction results will be obtained by using active filters or passive drive filters at each VSD.

Centralized filters will only reduce harmonics from the point of connection of the harmonic filter out to the utility source. The harmonic distortion on the feeders to each VSD will not be reduced.

3) Line Loss Reduction:

The ultimate reduction of line losses on the system is available when a combination of methods is used. FAPFCU can be designed to maintain the power factor at 100%. A 100% power factor results in the lowest kVA demand and thus the lowest amperage on the system from the point the automatic unit is connected to the utility metering point. A lower amperage means lower heat losses in wire, breakers, and transformers etc.

Drive filters again reduce the amperage from the point of connection to the utility metering point, but the power factor can not be corrected to 100% through the entire speed range if the VSD's can operate at low speeds and loads.

For optimal line loss reduction drive filters and a filtered automatic unit should be used. The drive filter reduces the amperage from the motor to the utility meter, then the filtered automatic unit finishes the job by correcting the power factor further to 100% for optimal amperage reduction and thus optimal line loss reduction.

Typically, large VSD's can have filters connected at the VSD's and a filtered automatic unit installed for the most economical system and optimized savings on both demand charges and reduced losses.

Active filters will only reduce the harmonic line losses and will not reduce line amperage due to power factor correction whereas FAPFCU and drive filters will reduce harmonic line losses and reduce line amperage due to power factor correction.

4) Achieving the Target Power Factor:

If the utility charges the customer based on peak kVA demand, the customer has a target power factor of 100% since a power factor of 100% will result in the lowest possible cost for the demand charges on the electrical bills.

A FAPFCU will maintain the power factor at or very close to 100% by switching filters on and off as required by the load to maintain a 100% power factor. Therefor the cost of the demand charges on the power bills is as low as possible.

Drive filters are normally sized to correct the full load motor power factor close to 100%. In many cases VSD's may be too small to economically have filters added. A 100% power factor is impossible to maintain with drive filters unless the VSD always operates at 100% speed and load, therefor optimal savings can not be achieved.

Active filters do not provide power factor correction at high load therefor they can not be considered for this purpose.

5) Voltage Rise:

When capacitors are installed there is a voltage rise on the system. As more capacitors are added the voltage on the system will increase, which could potentially cause damage to motors and other equipment. Main transformers may need tap adjustments to bring the voltage down to acceptable levels after applying capacitors.

A FAPFCU will only switch on as much kVAr as required to maintain a preset target power factor. This results in large amounts of kVAr being switched on under high load conditions, which is when voltage support is required due to higher transformer loading. Under low load conditions, only a small amount of capacitors are switched on, and thus the voltage support is reduced, which is when voltage support is not required due to low transformer loading. The voltage is the most stable when FAPFCU are used.

With drive filters the voltage support provided is a result of lower amperages on the feeder to the individual VSD due to power factor correction. It is similar to that of an automatic unit as the capacitors will be turned on when the VSD is operating. Plant wide voltage support is not available with drive filters since they are only switched on when their associated load is connected, thus the remainder of the plant can operate without the drive filter if the VSD is not operating.

Active filters do not provide voltage support at high load. They will provide voltage support at low loads, typically when voltage support is not required.

6) Filter Operating Losses:

Compared with loads on the system such as VSD's, losses created by all the harmonic filters is relatively low. For example, on a 480V system active filters will produce about 2 kW of losses for every 250HP of VSD load. A drive filter and a FAPFCU would each produce about 1.5kW of losses for every 250 HP. Part of the losses from operating a drive filter or FAPFCU is actually the harmonic heat being dissipated and is therefor not created by the filter but rather by the VSDs. Net operating losses (not including harmonic losses) for the drive filter and FAPFCU would be closer to 1kW for every 250HP of load.

7) Maintenance:

From a maintenance point of view the centralized filters are much less time consuming. It will take more time to maintain localized filters than maintaining centralized filters.

8) Reliability:

The active filter is the newest technology of all types of filters, and due to the highly electronic nature is considered the least reliable and most difficult to trouble shoot. Product improvements are still being implemented due to the infancy of this product.

FAPFCU have proven reliable over the years, with defects and failure rates being very low due to the mature technology. Replacement parts are normally available from manufacturer stock.

Drive filters are reliable provided separate reactor cores are used for the line reactor and capacitor inductor circuits. A common core for the line reactor and capacitor inductor can cause excessive voltage rise under low load conditions which can not only cause failures on the drive filter but also on the VSD's themselves.

9) Cost:

Drive filters are normally the least expensive alternative for applications with a small amount of VSD's. FAPFCU are normally the least expensive for applications with many VSD's. Active filters are presently about 5 times the cost compared to a drive filter or FAPFCU.

In order to determine which method, or combination of methods is best for your situation, please contact
Electrotek Ltd. at 1 800 404 9114 (or 287 2200 for local calls - Calgary, AB) for assistance.