

—
Technical Note 073

Active front end drive versus passive filter

Comparison of harmonic mitigation technology

There is a wide selection of harmonic mitigating solutions available for variable frequency drives. Having a variety of solutions offers flexibility to an engineer. After a brief review of harmonics and drive technologies, Technical Note 073 describes, compares, and contrasts two of those mitigation solutions – an active front end drive compared to a 6-pulse drive with an input passive harmonic filter. ABB offers both solutions. Typically, the active front end drive is the optimal mitigation solution for most installations, but there are some installations where passive filter drive packages may be a preferred solution.

Most drive manufactures offer both an active front end drive and a 6-pulse drive with an integrated passive filter in an enclosure. That being said, not all active front end drives and passive filter drive packages are created equal. Comparisons in this paper would not necessarily apply to all active front end drives and passive filter drive packages available in the market today. The ABB Ultra-low harmonic (ULH) drive, currently in its fourth generation, is used for the active front end drive comments. For the passive filter packages the comments are made with modern LCL passive harmonic filter designs in mind.

Harmonics

Standard variable frequency drives, along with many other electronic devices, draw current in a non-linear fashion. The non-linear consumption of current from the power grid creates current distortion, which in turn creates voltage distortion. The amount of distortion, both current and voltage, is expressed as a percentage occurring at the fundamental frequency.

This Technical Note 073 will reference terms from IEEE 519. THD_i is the total harmonic current distortion. THD_v is the total harmonic voltage distortion. TDD is the total demand distortion, which is essentially the current distortion of the system during maximum demand period of the facility. The higher the THD_v or TDD value the worse the harmonics are in that system. Since current distortion creates the voltage distortion, THD_i is the focus when reducing harmonics. If more information on the subject of harmonics is desired ABB offers documents such as [Harmonics in HVAC](#), other Technical Notes, and webinars.

Drives with passive filters

Figure 1 shows the construction of a passive filter drive assembly. The assembly consists of a passive filter, gray highlight, in series with the input of the 6-pulse drive, blue highlight.

For harmonic comparison, the 6-pulse drive with no internal impedance has a THD_i (measured at the lugs) of around 80%, but can reach as high as 120% with some designs. An input AC line reactor or DC bus chokes can be added to a 6-pulse drive, to bring the THD_i down into a 35 - 50% range.

A passive filter drive uses a combination of inductors and capacitors. The capacitors in the filter are charged from the power line. The drive then draws its current from the capacitors when needed. The inductors between the capacitors and the power line prevent the current to the drive from having a significant impact on the power line. This combination filters out the harmonic current distortion over a wide range but are generally tuned between the 5th and 7th harmonics where the highest magnitude of the harmonic content originates from. Passive filters are effective in reducing the harmonic content to a THD_i of 5%.

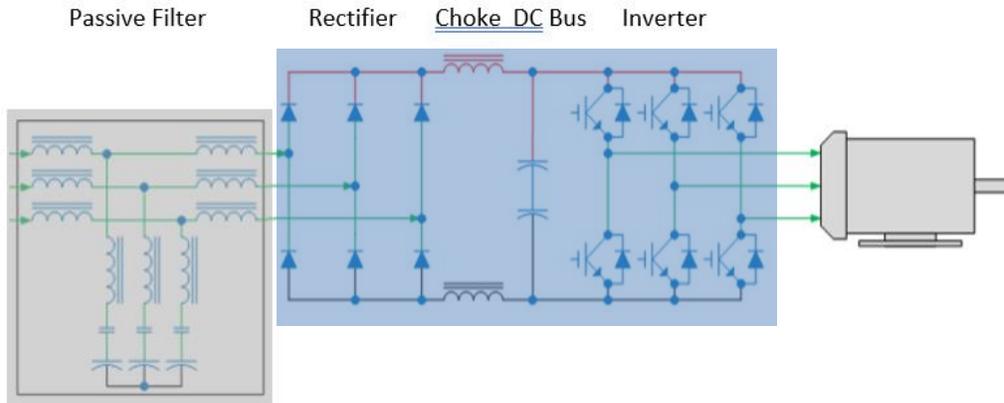


Figure 1 Passive filter drive schematic

Active front end drives

An active front end (AFE) drive uses insulated gate bipolar transistors (IGBTs) instead of diodes in the rectifier circuit. As shown in Figure 2, there is also an LCL (inductor-capacitor-inductor) filter included with an AFE drive. The combination of the front end's actively controlled IGBTs, along with the LCL filter, allows the AFE drive to draw current almost linearly, and not creating the troublesome harmonics in the first place. The LCL filter is tuned to mitigate any distortions caused by higher end frequencies. The DC bus and inverter section of an AFE drive are essentially the same as on a 6-pulse drive. AFE drives have a very low THD_i of 3 - 5%, with ABB's latest generation Ultra-low harmonic (ULH) AFE drive offering THD_i performance below 3%.

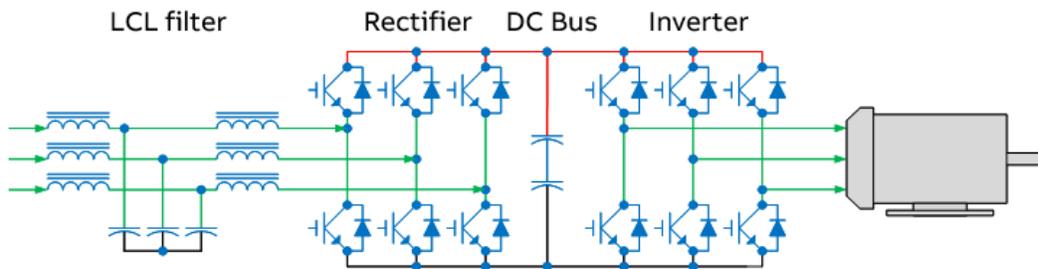


Figure 2 Active front end drive schematic

Active front end versus passive filter mitigation solutions

Table 1 draws key comparisons between an active front end drive and a passive filter drive package. Each of the topics in the table will be reviewed in more detail in the sections following the table.

Table 1: Active front end drive versus passive filter drive comparison

Topic	Active front end	Passive filter
Protects the internal and external grid	✓	✓
Power factor improvement (utility bill)	✓	
Possible leading Power Factor (PF) concerns		✗
Can correct poor incoming power from utility	✓	
Emergency backup generator friendly	✓	
Common mode voltage impact	✗	
Bring existing facility into IEEE 519 compliance	✓	✓
Cost impact on retrofitting drive systems		✓
Compact solution	✓	
Cost impact on fully redundant drive systems	✗	
Unexpected system interference (resonance)		✗
Coordination considerations		✗

The following sections go into greater detail on the topics found in Table 1:

Protects the internal and external grid

- An AFE drive does not create meaningful levels of harmonics therefore does not impact the utility grid outside the facility or other components inside the facility.
- A passive filter drive reduces the harmonic current distortion at each drive protecting everything upstream of the passive filter from harmonics.

Power factor improvement (utility bill) & Possible leading Power Factor (PF) concerns

- AFE drives naturally have a unity power factor. They can also be programmed to inject additional positive or negative kVAR into the network to help offset existing power factor issues.
- The capacitors in a passive filter have a considerable amount of capacitance. When the drive is lightly loaded, the capacitors will produce a leading power factor. Depending on the system design and the number of passive filters being used, this could contribute to the entire building having a leading power factor. To mitigate this, the passive filter can be equipped with a contactor installed to disconnect the capacitor during low load situations.

Can correct poor incoming power from utility

- Because the AFE has IGBTs in lieu of rectifiers the voltage being transferred to the DC bus is corrected and stabilized. The AFE has ability to tolerate voltage imbalance, boost low line voltage and adjust kVAR.
- The filter's capacitors can help increase the voltage to the drives DC bus slightly. As stated above at times the capacitors may need to be removed from the circuit at low loads. By removing the capacitors this leaves only the inductors operating in the filter which results in a voltage drop across the filter. This voltage drop can adversely affect the drive and motor if the input power voltage was already low.

Emergency backup generator friendly

- The minimal AFE drive harmonics do not interfere with the voltage regulation of a generator. A generator will operate fine with AFE drive loading. The unity power factor can reduce the amount needed to upsize a generator due to feeding VFD loads.
- Passive filters can safely operate on systems when sourced by generators, but there must be some considerations when designing the system so that the correct generator is selected. Since many HVAC systems are not run at full load the possibility of the passive filters creating a leading power factor increases. By isolating the capacitors during low load conditions, to eliminate the leading power factor, the percentage of harmonics will increase. Since the amount of fundamental current being drawn is lower, the net amount of current distortion is relatively small. There is a greater voltage drop due to the inductors still being in series with the drive. Different generators are better at handling a leading power factor while others are better at handling harmonics and voltage fluctuation.
Evaluation the nature of the VFD loads and their distortion contribution is an important consideration when selecting the generator or adding drives to an existing generator source system.

Common mode voltage impact

- AFE drives are known to create more common mode voltage (CMV) than 6-pulse drives. Higher levels of CMV increase the likelihood of motor bearing currents. ABB addresses this fact with additional CMV filtering within the ULH drive design. ABB's ACH580 ULH drives come from the factory with CMV filters included. When specifying AFE drives, engineers should include CMV filters as an AFE drive specification item, and/or specify motors with integral grounding brushes.
- The passive filter drive assembly contains a 6-pulse drive. The IGBTs and motor control of the 6-pulse drive is still a source for CMV, but the CMV magnitude is less than an AFE drive.

Bring existing facility into IEEE 519 compliance

- An AFE drive solution is always a good consideration for helping an electrical network meet IEEE 519 and a very good choice when the existing drives are near the end of their life cycle and due for replacement. However, if most of the existing drives are new, then the AFE drive solution may not be ideal for existing systems that are failing IEEE 519. This is because the existing 6-pulse drives would need to be removed and replaced with an AFE drive. Future drives, replacement or new, could be AFE drives.
- Passive filter drives are often a better solution when a system is not meeting IEEE 519 and has a high volume of drives early in their lifecycle. Loose passive filters can usually be retrofitted in series with the existing drives to reduce their harmonic current contribution.

Cost impact on retrofitting drive systems

- This topic is very similar to the previous topic on bringing a building into IEEE 519 compliance. If the drives are near the end of their life cycle and replacing them with all new drives/enclosures is expected, the AFE solution is ideal. If the drives are at the beginning of their life cycle, removing the existing drives and mounting new drives/enclosures and possibly rerouting cables can become economically unfeasible.
- Passive filters can be supplied loose, in several enclosure ratings. The filter can typically be installed near the VFD making retrofitting a system within a mechanical room more economical.

Compact solution

- An AFE is larger than a standard 6-pulse drive but the front end IGBTs and LCL filter are still encompassed in the drive itself making it smaller than the overall passive filter drive package offering. The ABB ULH drive is wall mountable to 150 HP at 480 VAC. A 60 HP ULH drive with a disconnect is 10" wide which is only 2 inches wider than a 60 HP 6-pulse drive with a disconnect.
- The passive filter drive package solution includes the 6-pulse drive and a passive filter inside the same enclosure, so it is typically larger than the AFE drive. Freestanding enclosures are required for 75HP and larger passive filter drive packages. A 60 HP drive with a passive filter and disconnect is 19.3" wide which is more than twice as wide as a 60 HP 6-pulse drive with a disconnect.

Cost impact on fully redundant drive systems

- Some system or equipment designs have a primary drive and a backup drive. The backup drive only runs when the primary drive is unavailable. In that case, having AFE technology on the backup drive adds cost that is unused for most of the system operating time. As an alternative strategy, a lower cost 6-pulse with impedance drive can be used as the backup drive. Larger systems should not be impacted by the short-term harmonic impact of running a single drive with higher harmonics.
- Passive filter drive packages become more economical in drive system designs with a higher number of redundant / backup drives. The passive filter is sized based only on the load of one drive. Thus, only one passive filter is required for the two-drive redundant assembly as it is used for the operating drive, the primary or the backup.

Unexpected system interactions (resonance)

- AFE drives are designed to prevent the drive from creating harmonics and include an LCL filter. This combination avoids most unexpected electrical system interaction associated with filters in general.
- Passive filters have a substantial tuned capacitor. Sometimes this capacitor resonates with the capacitors within the drive. When this condition is present it may require some additional tuning of the drive for proper operation. Resonance can also occur with other capacitors within the electrical system.

Coordination considerations

- AFE drives generally don't have coordination issues during installation. They are self-contained and require only the traditional input, output and control wiring associated with standard drives.
- Passive filter drive packages ship from the factory as integrated assemblies and generally do not have coordination issues during installation as the factory has installed the filter in the enclosure correctly. When passive filters are shipped loose in separate enclosures there are opportunities for coordination issues.
 - Installing contractor was unaware that the passive filter(s) were going to be separate and didn't factor in installation cost or time.
 - Installing contractor can mistake the passive filter for an output load reactor or dv/dt filter and install on output of drive and not the input.
 - On bypass packages, the passive filter is to be installed in the path of the drive and not in the path of the bypass. The additional impedance created by the filter can introduce voltage drop to the motor. If the line voltage was already low, then that additional voltage drop will negatively impact the motor.

Which solution is best: AFE drive or passive filtered drive?

Customers want the "Best" solution and as sales, design, and consulting engineers we want to provide them with that best solution. If you have been doing this for any length of time you know every site and or system is different. Sometimes even the same exact system in 2 buildings across the street don't behave the same. This confirms that there is no rule of thumb to say always go with the AFE drive or always go with the passive filter solution. Each installation has its own unique attributes. In most cases, investing in and installing AFE drives will have the lowest overall, lifecycle and operating cost while providing the highest harmonic reduction solution. However, if the drive mix heavily favors small HPs or the drives are at the beginning of their life and the building needs to be brought into compliance with IEEE 519, then drives configured with passive filters is most likely the best choice.