# Technical Paper

# Hybrid Power Quality Solutions using Line Reactors, Active and Passive Filters

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## Introduction

Variable frequency drives (VFD) are used in many industrial applications to improve efficiency and enhance process control. Low cost six pulse VFDs with simple diode rectifiers on the input are the workhorse of the industry. Six pulse VFDs draw high levels of harmonic currents from the utility that may affect the operation of other plant loads and nearby users. A common standard (IEEE 519) has been established that limits the allowable current harmonics drawn from the utility [1]. Common solutions for harmonic mitigation are line reactors, active filters and passive filters. Most industrial and wastewater installations have an array of six pulse VFDs, ranging from multiple small (<300HP) units mounted in motor control centers (MCC) to large (>300HP) VFDs located external to the MCCs. These installations also have sizable linear loads, primarily in the form of induction motors connected across the line via contactors or reduced voltage soft starters. In many installations, the most economical solution can be a properly sized combination of line reactors, active and passive filters.

Such combinations of passive and active components are well known in industry [2] and have been proven to be effective [3]. However, two issues have prevented such solutions from being widely proposed. The first issue is the lack of a single integrated source that can provide the full range of active and passive solutions driving to the lowest cost solution. The second issue is overly restrictive specifications that force the selection of either active, passive or 18-pulse solutions.

## Input Harmonic Solutions

Traditional harmonic mitigation solutions include drive applied line reactors and passive filters. Over the past few years, bus applied active filters have also gained traction in the industry.

### Line Reactors

Line reactors provide additional impedance between the grid and the variable frequency drive input terminals. Standard 3% or 5% three phase ac line reactors are the most inexpensive and simplest solution available. If sized correctly, line reactors can reduce the full load total harmonic distortion (THD) of the line current down to about 30%-35%, as shown in Figure 1. The reduction of the peak currents due to the line reactor reduces the stresses on the VFD rectifier and dc bus capacitors, and may help extend their lifetime. For installations that have major linear loads and minor VFD loads, line reactors may be adequate to achieve overall harmonic compliance. However, with most modern installations, the VFD loads are too significant for line reactors to provide the necessary mitigation.
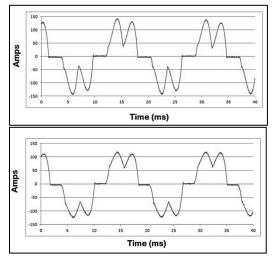


*Figure 1: Line current waveforms without (top) and with (bottom) line reactor*

# Passive Harmonic Filters

Passive harmonic filters are also applied between the grid and the input to the variable frequency drive. Passive filters contain tuned circuits that provide a low impedance node that force the harmonic currents to circulate between the VFD and the filter. Passive filters that limit line current THD to IEEE 519 levels of 5% and 8% are available commercially – the line current waveforms obtained using a TCI HarmonicGuard® Passive Filter (HGP) is shown in Figure 2. The use of passive filters greatly reduces the amount of harmonic current flowing through the distribution system and results in improved power factor, lower RMS currents, lower harmonic current distortion, lower harmonic voltage distortion, and increased system capacity. Unlike line reactors, passive filters can reduce the THD to compliance levels; however, they are more expensive than line reactors.
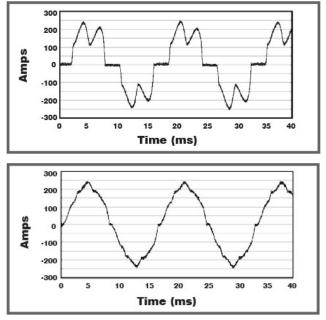
# Active Harmonic Filters

Active harmonic filters monitor the line or load current to determine the nature and quantity of harmonic currents in the system and cancel the same by injecting equal amounts of harmonic currents opposite in phase. TCI's HarmonicGuard® Active Filter (HGA) contains a high speed DSP controller and a pulse width modulated (PWM) IGBT based power converter to help provide virtual real time compensation of non-linear load demanded by VFDs and other applications as shown in Figure 3. Most active filters have advanced phase locked loop that precisely synchronizes the filter current with the ac line voltage, enabling both reactive current and harmonic current compensation. Active filters are the most flexible solution, but are more expensive than passive filters.
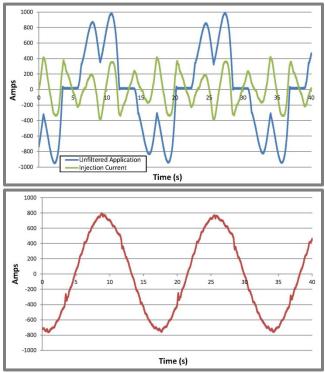




*Figure 2: Line current waveforms without (top) and with a TCI HGP.*





*Figure 3: VFD input current, active filter current (top) and resulting line current (bottom) using a TCI HGA*
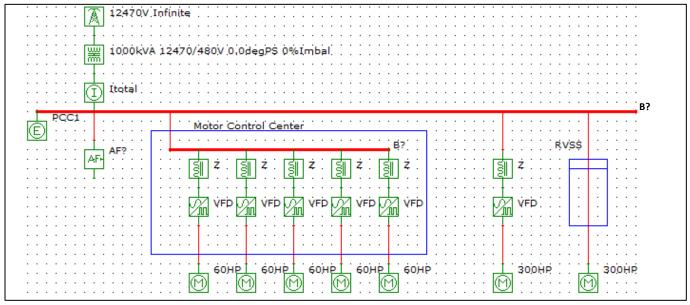
# Hybrid Solutions



*Figure 4: Simplified installation showing VFD and motor loads*

An appropriately sized active filter will enable the system to mitigate harmonics and improve power factor, however, this may not always be the most economical solution. The analysis of a typical plant installation shown in Figure 4 can be used to illustrate this effect.

The point of common coupling (PCC) is shown at the secondary of the input transformer. This is usually a convenient location to measure the system compliance. The example has five 60HP VFDs in an MCC, a 300HP VFD located external to the VFD and an across the line 300HP induction motor. The VFDs are assumed to be standard six pulse VFDs with 4% DC chokes and are assumed to be running at full load. The power quality goals are <5% current THD and a power factor greater than 0.95. The following potential solutions can be evaluated:

- Option 1: An active filter is placed at the secondary of the transformer to improve the power quality at the PCC. A standard frame size (100A, 200A, 300A, 400A) is selected.
- Option 2: 3% line reactors are placed in front of each of the VFDs in the MCC as well as the external VFD and the appropriate active filter is selected.
- Option 3: 3% line reactors are placed in front of each of the VFDs in the MCC. An 8% passive filter is applied to the external VFD. The active filter frame size selection is assessed.

The results are shown in Table 1.

The addition of line reactors reduces the harmonic content produced by the VFDs leaving less harmonic

*Table 1: Comparison of active and hybrid options*

|  | Baseline system | Option 1 | Option 2 | Option 3 |
|---|---|---|---|---|
| Input rms current (A) | 993 | 916 | 902 | 894 |
| Input Fundamental current (A) | 950 | 915 | 902 | 894 |
| Input Harmonic current (A) | 288 | 37 | 36 | 36 |
| Input harmonic distortion % | 30% | 4% | 4% | 4% |
| Input Displacement PF | 0.93 | 0.96 | 0.98 | 0.99 |
| Input Reactive current (A) | 355 | 245 | 189 | 147 |
|  |  |  |  |  |
| Active Filter rms current (A) |  | 398 | 293 | 195 |
| Active Filter reactive current (A) |  | 118 | 182 | 133 |
| Active Filter harmonic current (A) |  | 378 | 222 | 135 |
| Active Filter Frame (A) |  | 400 | 300 | 200 |
|  |  |  |  |  |
| Active filter cost |  | 100% | 75% | 50% |
| Line reactor cost |  | 0% | 4% | 3% |
| Passive filter cost |  | 0% | 0% | 11% |
| Total cost |  | 100% | 79% | 64% |

current for the active filter to correct. Similarly, the passive filter eliminates a major portion of the harmonics from the large external VFD, thus unloading the active filter. More importantly, the passive filter operates at near unity power factor at full load and leading power factor at light loads. This helps compensate in part for the lagging power factor of the line connected motors. At light loads, any degradation of performance of the passive filter can be partially offset by the active filter. The performance of the three options is similar and all

solutions will be compliant. The displacement power factor achieved by the all active solution is actually a little worse than the two other options.

The most pertinent benefit of the hybrid solution is the cost savings as can be seen from the table. The addition of 3% line reactors reduces the cost by 20% by lowering the active filter rating. The insertion of selective passive filters reduces the cost by a further 16%. The actual savings may be higher or lower depending on the system configuration. TCI has published a simple sizing tool that allows the user to make these tradeoffs easily and identify the optimal solution.

# Applications

Wastewater treatment plants have many MCC housed small drives that can create harmonic issues in the system. They also have some large compressors and across the line motor loads. Installing passive or active filters on the system will help solve the problem, but if both filters are installed together, a lower cost solution may be realized. Commercial facilities with HVAC systems, such as hospitals are another candidate. These facilities use distributed drives and MCC units for various purposes, but have several large chillers. The large chillers can be placed on passive filters, and a bus applied active filter can handle the remainder of the VFD loads.

# Conclusions

There are several harmonic mitigation solutions available in the marketplace. This paper attempts to develop a methodology that uses the lowest cost component first, followed by the subsequently higher value components. The solutions developed using this method are more cost effective and still maintain harmonic compliance at the PCC. TCI's power quality products can be integrated seamlessly to produce effective hybrid system solutions.

# Authors

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# References

[1] "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems", IEEE Std. 519-1992.
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[3] F. Z. Peng, H. Akagi, and A. Nabae, "A New Approach to Harmonic Compensation in Power Systems - A Combined System of Shunt Passive and Series Active Filters", IEEE Trans. on Industry Applications, vol. 26, No. 6, Nov./Dec. 1990".