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A New Solution for Harmonics Generated by Variable Speed Drives

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The need for harmonic mitigating devices is growing because of the rapid increase in variable speed drive (VSD) usage in industrial and commercial applications and the corresponding growth in harmonic-related problems. A new state-of-the-art passive universal harmonic filter (UHF) is designed to enhance the conversion of ac power to dc power within a VSD or other equipment with a 3-phase, 6-pulse diode bridge rectifier front-end.

In addition to its harmonic mitigating capabilities, this wide spectrum harmonic filter helps protect a VSD from transient overvoltages caused by capacitor switching and other fast changing loads. It is suitable for virtually any application involving a VSD or similar 3-phase, 6-pulse diode bridge rectifier load.

Harmonic Problems

The front-end diode bridge rectifiers of 3-phase, 6-pulse static power convertors (ac-dc), such as those found in variable speed drives, are considered nonlinear because they draw current in a non-sinusoidal manner. The current harmonics they generate are defined by the following formula:

$h = np \pm 1$

Where:

h = the harmonics generated

n = any integer (1, 2, 3, etc.)

p = the rectifier pulse number

A simple 6-pulse rectifier ($p = 6$) is shown in *Figure 1*. Without any harmonic treatment, the total harmonic current distortion (THID) of this rectifier would be in the 100-140% range with the predominant harmonics being the 5th and 7th. The 11th, 13th, and other higher orders are also present but at lower levels. In the example shown in *Figure 1*, the 5th harmonic current is about 75% of the fundamental (60Hz) current and the 7th nearly 60%. This means that a rectifier of this configuration, which draws 100A of 60Hz current, will also draw 75A of the 5th harmonic current and 60A of the 7th harmonic.

Power distribution systems carrying a heavy nonlinear load component will often experience problems caused by excessive harmonic currents. Problems that arise include:

- Power factor correction capacitor failures due to overloading and/or system resonance

Editor's Note:

This article focuses on a specific new product from MIRUS International Inc. Although this article is manufacturer-oriented, based upon the information we observed when the product was displayed at our recent **Power Quality '99** conference, PQ Magazine believes this product deserves to be presented to our readers so that they may investigate its claims on their own.

- Overheating cables, transformers and other distribution equipment reducing their life span
- High voltage distortion (typically in the form of flat-topping), especially when operating on weak sources such as emergency generators
- False tripping of circuit breakers
- Premature failure of rotating equipment (motors, generators, etc.)
- Misoperation or component failure in PLCs, computers or other sensitive loads

Existing Methods of Harmonic Treatment for VSDs

There are several methods available for treatment of VSD harmonics. Ac input reactors (either 3 or 5% impedance) are the most commonly used treatment. They have a relatively low cost but are only moderately effective in reducing harmonic current distortion (see *Figure 2* and *Table 1* for typical values). The high impedance of ac input reactors helps protect the drive from transient overvoltages caused by capacitor switching and/or fast changing loads but they can often introduce troublesome voltage drops at the rectifier input. Some VSDs are equipped with a dc link reactor that is slightly more effective at reducing harmonic currents than the ac reactor, and it does not cause an ac voltage drop. The dc link reactor, however, is somewhat less effective than the ac reactor in overvoltage protection.

Conventional tuned LC or trap filters, as their name implies, require tuning to a specific harmonic frequency. Usually, 6-pulse rectifier loads are tuned to the most predominant harmonic – the 5th. Their effectiveness is limited, however, unless multiple tuned elements are incorporated to remove the 7th and other higher order harmonics. They are prone to problems such as importation of harmonics from upstream nonlinear loads and the introduction of a leading power factor.

By treating a wider spectrum of harmonics, low-pass filters are more effective than tuned filters, but are also more expensive. Although they address some of the issues associated with tuned filters, they are not problem-free. Specifically, their large series inductor necessitates the use of a large capacitor bank to compensate for voltage drops. These capacitors create a leading power factor that may cause excitation control and voltage fluctuation problems with generators.

In multipulsed systems, the drive manufacturer will phase shift between multiple front-end rectifiers to cancel harmonics. Some 18 and 24-pulsed systems can achieve THID levels of < 8%, but they require a large footprint and are quite expensive. The application of phase shifting transformers can be a very cost-effective method of harmonic treatment where multiple 6-pulse VSDs are in operation. A quasi 12-pulse scheme (i.e., cancellation of 5th and 7th harmonics) can be created by phase shifting one VSD against a second similar VSD. The 18 and 24-pulse schemes require three and four VSDs, respectively.

Active filters treat harmonics by measuring the level of harmonic current present in the system and injecting currents of opposite polarity to cancel them out. Excellent performance can be achieved but reliability is sometimes an issue and their high cost has limited their use. Due to the dynamic characteristics associated with detection and treatment, fast changing conditions may not be adequately addressed.

The Universal Harmonic Filter vs. Other Conventional Passive Filters

The UHF is a purely passive series connected device, which can be installed at the input of any 3-phase, 6-pulse diode bridge rectifier to dramatically reduce its input current harmonics. Its revolutionary design achieves cancellation of all the major harmonic currents generated by the rectifier, resulting in THID of <8% and often as low as 5%. This meets IEEE std 519 harmonic current limits for all but the weakest of supply sources. The unique feature of the UHF is its 3-phase reactor design consisting of multiple windings on a common magnetic core. This reactor allows for the use of a much smaller capacitor bank without sacrificing filter performance or introducing unacceptable voltage drops. Capacitive reactive power is typically 3-4x lower than that of conventional filters. This is significant in reducing cost and space requirements. Moreover, it prevents power system interaction problems that often result from a leading power factor.

The large capacitor banks found in both tuned and low-pass filters present a capacitive reactance to the system, especially under light loads. This is a beneficial feature where inductive loads require a compensating reactance to improve a low displacement power factor. But in most VSD applications, displacement power factor is close to unity even though overall power factor may be low due to the harmonic content in the current. Compensation for inductive loads is usually not necessary and, in fact, can cause problems, especially when supplied by an emergency standby generator. To

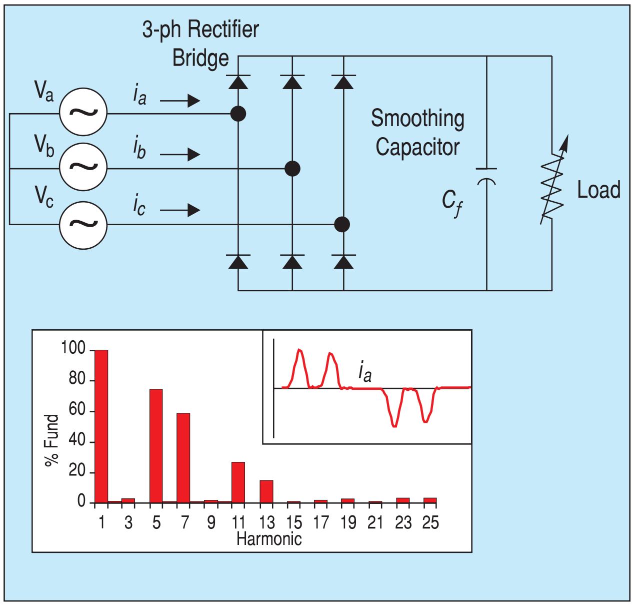


Figure 1. *Simple 3-phase, 6-pulse diode bridge rectifier with no harmonic treatment.*

address this issue, some filter manufacturers offer mechanisms for switching out the capacitors under light loads, which increases cost and complexity. Even under no load conditions, the capacitive reactance of the UHF is so low that switching out the capacitors is unnecessary.

Another concern with tuned filters is that unless they incorporate a detuning reactor in series with the supply feeder, they can easily be overloaded by attracting harmonics from upstream sources. The detuning reactor will introduce a voltage drop at the dc bus as load is applied to the VSD. The multiple winding configuration of the UHF, on the other hand, prevents the attraction of harmonics from upstream sources without introducing an excessive voltage drop as VSD load increases.

The filtering effectiveness of a tuned filter is dependent upon the amount of harmonics present at untuned frequencies as well as the residual at the tuned frequency. To obtain performance better than 15% THID, multiple tuned branches are often required. Low-pass filters achieve <12% THID but require relatively large capacitor banks. Even larger capacitors are required if further reduction in THID is desired. The UHF reduces current distortion to <8% over the entire operating range and typically achieves near 5% THID at normal operating levels.

Simulation of Harmonic Filter Performance

As previously mentioned, many of today's VSDs are equipped with either ac line reactors or dc link chokes to reduce harmonic current distortion. Computer simulation allows us to compare these solutions with the UHF. The circuit diagram shown in *Figure 1* was used to simulate a 5kW, 380V 6-pulse diode bridge rectifier. Five different harmonic treatment schemes were analyzed as follows:

Scheme 1 – No harmonic treatment

Scheme 2 – With 3% ac line reactor

Scheme 3 – With 8 mH dc link choke

Scheme 4 – With both ac line reactor and dc link choke

Scheme 5 – With universal harmonic filter

The chart in *Figure 2* plots the THID for each scheme over the full operating range of the rectifier. With no harmonic treatment, THID ranged from nearly 180% at extremely light loading to 140% at full load. The reactors implemented in Schemes 2, 3 and 4 reduced the THID by approximately the same amount. THID ranged from 100% near no load to 30-

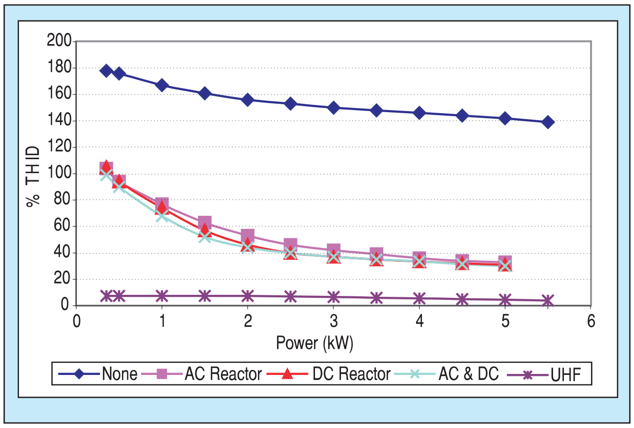


Figure 2. *Total Harmonic Current Distortion through computer simulation of a 5kW, 6-pulse rectifier with various forms of passive harmonic treatment.*

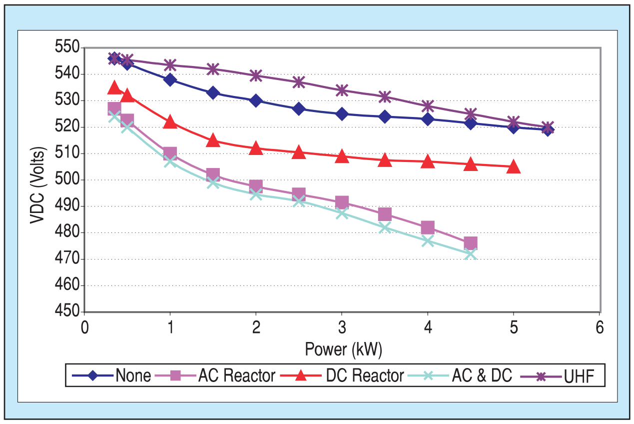


Figure 3. *dc bus voltage through computer simulation of a 5kW, 380V 6-pulse rectifier with various forms of passive harmonic treatment.*

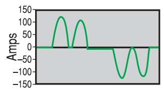
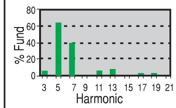
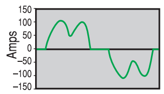
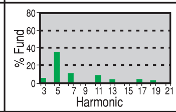
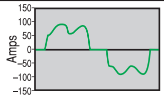
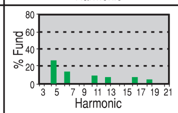
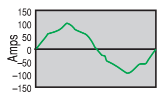
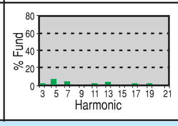
	Input Current Waveform	Input Current Spectrum	THID	Power Factor
60 HP, 6-Pulse Rectifier, PWM VSD			72.9%	.79 lag
With 3% ac Line Reactor			35.6%	.90 lag
With dc Link Reactor			30.9%	.95 lag
With UHF			5.8%	.99 lag

Table 1. *Performance comparison of various passive harmonic treatments on a 3-phase, 6-pulse, 60 HP Variable Speed Drive.*

35% at full load. The UHF was by far the most effective in reducing THID. At full load the THID was reduced to about 5% and it increased to 8% under more lightly loaded conditions.

The computer simulations are confirmed by field tests on a 60HP, 480V PWM variable speed drive (see *Table 1*). While the reactors reduced current distortion by about 50%, the UHF achieved more than a 10 times reduction. The current waveform was nearly sinusoidal with its spectrum containing only small traces of harmonic content. In addition, removal of the harmonic current improved power factor to virtual unity.

The computer simulation showed the variation in dc bus voltage at the output of the rectifier with the various forms of harmonic treatment. With no harmonic treatment, the dc bus voltage was fairly stable over the entire operating range (between 545V to 520V). Additional impedance introduced by the reactors had a fairly significant impact on the dc voltage level. As expected, the worst case was with Scheme 4 when both the ac line reactor and the dc link choke were in the circuit. At the full operating mode, the dc bus voltage was nearly 10% lower than for the rectifier with no treatment. In contrast, when equipped with the harmonic filter, the dc bus voltage remained very stable, always at or above the values without treatment.