Schaffner EMC Inc. 52 Mayfield Avenue Edison, N.J. 08837 T+1-732-225-9533 F +1-732-225-4789 www.schaffnerusa.com

White Paper

Harmonic Power Quality Analysis and Equipment Recommendation

Introduction - Electrical Power System, Harmonics Overview

Frequency inverters are among the most widely used pieces of equipment for AC motor control. These types of components and systems are found in virtually every area of industry, in applications as diverse as pumps, HVAC, conveyors and machine tools. In the quest for ultra-compact, efficient power conversion, inverter manufacturers employ high-speed semi-conductor switching and pulse width modulation (PWM) techniques, which can create harmonic problems.

In general, harmonic currents are the result of the non-linear behavior of electrical devices. The sources of harmonic currents and thus subsequently harmonic voltage in power systems are multiple and vary in size, which can range from a few KVA up to several MVA. Typically, devices with magnetic iron cores like transformers or generators have been a key area of harmonic concern, as are arc furnaces and welders. Today, with the demand for energy efficiency of power electronic equipment, such as UPS and variable frequency drives, mitigation or reduction of harmonics continues to be a priority for many industrial customers, as well as those in oil-gas, marine and water and waste water markets.

Harmonics and Equipment

The electronic components within CNC machines, VFD’s and programmable controllers are particularly sensitive to “electrical imperfections” found on the power distribution system. Problems here can include malfunction of the equipment or program, along with damage of the parts and material.

Arc furnaces for example, are usually a very large power consuming application. This high power, combined with a highly nonlinear voltage-current characteristic, produce substantial amounts of harmonic distortion. The unique design of this equipment’s operation leads to an unusual harmonic spectrum with even and odd multiples of the fundamental frequency.

Variable Frequency Drives for pumps and fans can produce current harmonics which may cause thermal overload of the electrical systems and produce malfunctions of sensitive equipment and components.

Most of the power problems experienced at the facility level are derived from within the operation of a plant/operation itself, as the majority of electrical power supplied to the user comes from an electric utility source or provider.

Harmonics can play havoc on the electrical power network, and the resulting issues range from a "simple" nuisance to catastrophic loss. Harmonics can manifest themselves in many ways, as they can cause tripped circuit breakers, blown fuses, overheating of motors and transformers, insulation break-down and reduced service life of equipment. Even a simple nuisance can have negative effects, as production downtime/restart-time and shipment (revenue) loss, along with repair costs may result in reduced company profits.

Harmonic filtering helps to eliminate the problematic harmonics, enhance efficiency and improve overall plant performance.

Harmonic Data Collection, IEEE 519

A harmonic site survey (use of power meters/analyzers) or a full engineering study may be necessary to completely determine existing harmonics and other PQ issues, in order to provide a recommended solution to the user. In many, but not all cases, IEEE 519 (2014) guidelines are followed as to the acceptable level of distortion. A complete review of the existing system, new/planned or retrofitted equipment along with any plant expansions should be considered.

IEEE 519-2014 current distortion limits [%] — **Harmonic order (odd harmonics)**

I_{SC}/I_L	TDD	<11	11≤h<17	17≤h<23	23≤h<35	35≤h
<20	5.0	4.0	2.0	1.5	0.6	0.3
20<50	8.0	7.0	3.5	2.5	1.0	0.5
50<100	12.0	10.0	4.5	4.0	1.5	0.7
100<1000	15.0	12.0	5.5	5.0	2.0	1.0
>1000	20.0	15.0	7.0	6.0	2.5	1.4

Maximum harmonic current distortion in percent of I_L (even harmonics are limited to 25 % of the odd harmonic limits above).

IEEE-519-2014 is a widely recognized set of recommendations which includes the maximum permissible current and voltage distortion values at the point of common coupling (PCC). The distortion limit is given as a function of the system loading, i.e. the relationship between the maximum short circuit current (I_{SC}) and the maximum demand load current (I_L) at the PCC.

After harmonics have been identified and it has been determined that a mitigation solution is required, then the proper equipment selection and placement will need to be reviewed and implemented. With the many problems associated with harmonics, (equipment failure, replacement and maintenance costs, improper component or system operation, production down time etc.), it is suggested to keep records on these costs, to help with the ROI of any future mitigation equipment to be purchased.

PQ Site Survey and Equipment Recommendation Example

The following is a detailed description of a PQ site survey and equipment recommendation. The customer asked to determine harmonic current-levels on two specific “power drops”, 480VAC, 60hz. A power-drop consists of three individual single-phase transformers 12.47kV/480vac, delta connected to a secondary. This site has numerous power drops and differing harmonic load-levels, due to the total number and horsepower (HP) rating of each installed variable-frequency drive (VFD).

At present, the total electrical load is 35MVA. The majority of the 480vac loads are VFD’s and harmonic loading of the main utility-supply is a concern. The two power-drops being investigated are the two most heavily loaded. The total HP rating of VFD’s exceed the kVA rating of the supply-transformers by nearly 100%. However, this is acceptable since the actual loading of the VFD’s rarely exceed 50%. Potential thermal overload due to harmonic current-levels of the supply-transformers, both at the individual power-drops and at the two main substations, is the main concern. In order to substantially reduce the harmonic loading of this power distribution-system, filtering is a high priority.

The site survey measurements on power-drops were performed using a power analyser. The transformers were rated at 166kVA/phase with an impedance of 2.7%.

Figure 1 shows a three-hour time line of average and maximum line-current at this power-drop with average currents of 220 Amps and occasional peaks of 350 Amps. An instantaneous reading of power and power-factor gave 169kW, 190kVA, and .89 power factor.

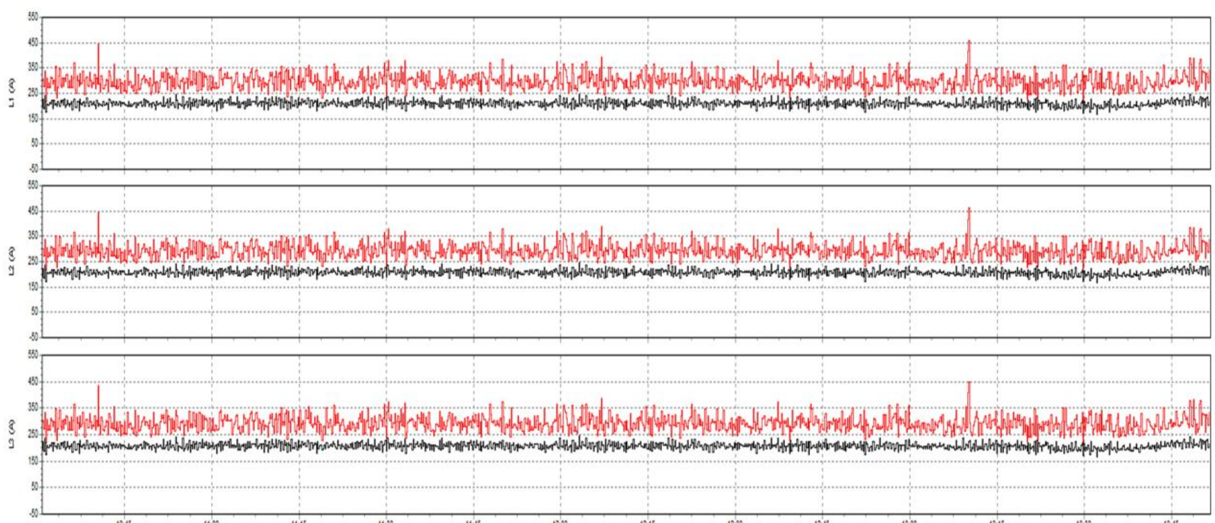

Figure 1 Peak and average kVA-load

Figure 2 shows an oscilloscope-picture of the momentary phase-to-phase voltage and phase-current on this power-drop.

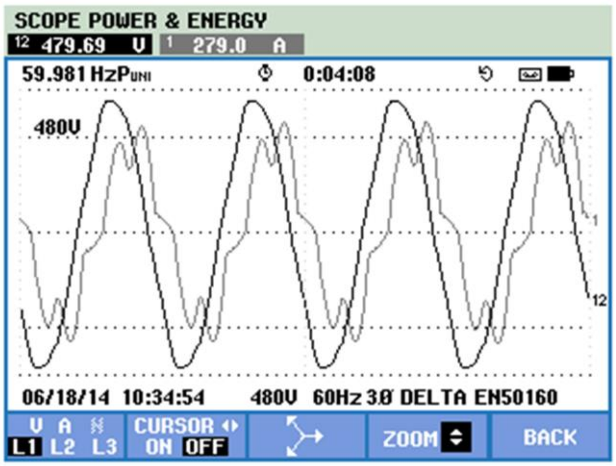

Figure 2 Oscilloscope-picture of line-voltage and –current

Figure 3 shows the harmonic current-distortion. The THDi is approximately 30% and the dominant harmonic is the 5th order harmonic.

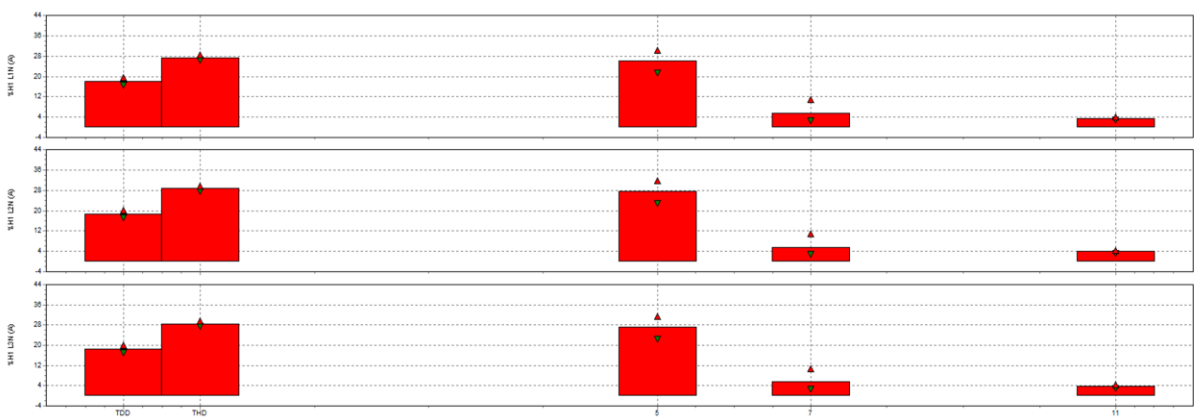

Figure 3 Harmonic current-distortion

From the monitoring, the existing load picture shows an average of 66 amps of harmonic compensation current would be required. The second power drop indicated very similar readings.

With the number of power drops, varying loads and low power factor, an active harmonic filter is the recommended solution. The 66A value is well within the capabilities of a 100A active filter. The filter capacity will also allow for a significant amount of higher momentary loads that have been recorded. Unused filter capacity could be utilized to raise the power-factor on this power-drop. The actual filter configuration may use individual units, or one integrated system to potentially accommodate multiple drops.

100Amp Active Harmonic Filter

Additional monitoring will need to be performed for the other power drops, to confirm similar conditions. Once completed, a final equipment recommendation and design configuration can be provided. A 100A active harmonic filter for each connection would be properly sized to compensate the harmonic currents present on these two most heavily loaded power-drops.

Active Harmonic Filter Solution

Active harmonic filters (AHF) are power quality devices that permanently monitor the nonlinear load and dynamically provide precisely controlled current, helping to prevent distortion in a power network. This current has the same amplitude of the harmonic current but is injected in the opposite phase-shift, canceling out the harmonic currents in the electrical system. As a result, the current supplied by the power source will remain sinusoidal since the harmonics will negate each other and the harmonic distortion is reduced to less than 5% THDi, meeting all standards.

Additionally, the AHF power electronics platform is designed to operate at levels that continuously adapt to rapid load variations. With load conditions creating harmonics up to the 50th order, active filters operate in a wide frequency range, adapting their operation to the resultant harmonic spectrum.

An installed active harmonic filter

Active harmonic filters can also correct poor displacement power factor by compensating for the system's reactive current. The filter also performs load balancing of the phases. Presently, these higher sophisticated devices are equipped with Insulated Gate Bipolar Transistors (IGBT) and Digital Signal Processing (DSP) components. Generally, active harmonic filters can be installed at any point in a low voltage AC network (parallel device) and they usually offer much more functionality than their passive filter counterparts.

Combining these features with its small physical size and efficient operation, active harmonic filters are an ideal choice for a wide variety of applications. Active filters can be provided for 3-wire or 4-wire connections (3-wire is the most common in North America). The use of external current transformers deliver a signal to the filter, which can be applied to either the line or the load side of the power network.

Active harmonic filters can be applied to a single or group of nonlinear loads. Other possible AHF installations could be when power factor correction in harmonic rich environments cannot be suitably achieved by the use of capacitors; where both power factor and harmonic correction are required; and where emergency power or distributed generation are present in the electrical network.

In general, active harmonic filters are available in several ratings. This can include individual units for 50, 100, 200, 250 or 300 amperes. Different configurations such as open type, or various NEMA enclosure protection ratings and the ability to parallel multiple active filters, for higher current applications are typical. A standard integrated package to 400A can be provided for either indoor or outdoor use.

Installation voltages are mostly 480vac and 600vac. 600vac requirements can utilize a step-down (600/480vac) transformer with the active harmonic filter, or use a “purpose built” active filter rated for 600/690vac, where a transformer is not necessary. Active filters will include key pad controls and operator display, communications such as RS485 and TCP/IP Ethernet, along with software for communications and monitoring through a Windows-based product.

Where machinery, equipment, and processes are electronically controlled (especially sensitive components), harmonics and power quality can be an everyday concern. In order to meet stringent electrical standards and protect a facility’s electrical power distribution system from harmonic driven anomalies, mitigation solutions are necessary. Using active harmonic filters can help to achieve the proper operation and reliability, while helping to support the financial bottom line.

Authors

Chuck Gougler
Director Power Quality, North America

Claus Weigand
Application Engineering Manager, Power Quality

Acknowledgements

IEEE Std. 519 Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems 2014

IEEE Std. IEEE Recommended Practice for Monitoring Electric Power Quality

IEEE Std. 1531 IEEE Guide for Application and Specification of Harmonic Filters

IEEE Power and Energy Society

IEEE Transmission and Distribution Committee