

6 pulse vs. 12 and 18 pulse harmonics effect reduction

White paper

File No: 94.22
Date: JUNE 05, 2015
Supersedes: 94.22
Date: MAY 21, 2015

—

—

—

—

INTRODUCTION

In most Commercial HVAC applications, the HVAC circuit components share the AC Power supply with other electronic equipment such as computers or telecommunication networks. To meet energy efficiency regulations, most of the HVAC major components employ load modulating strategies which in most cases involve a Variable Frequency Drive (VFD) connected to rotating equipment. These components, as most other electronic equipment and fluorescent lamps, inherently generate harmonic distortion in the AC Power Line. The concern is that the cumulative harmonic distortion produced by all these devices may reach levels that affect the operation of some sensitive equipment nearby, or exceed regulatory limits.

DEFINITION: HARMONIC DISTORTION

Harmonic distortion is considered to be a type of electrical pollution that can cause some equipment to malfunction if it exceeds certain limits. Harmonic current is specified with a frequency at multiples of the Base Frequency. For instance a 300 Hz current on a 60 Hz network is the 5th harmonic. Systems with such a 300 Hz current will see a 300Hz distortion of its voltage supply which could be detrimental to the other components in the system.

In accordance with the International Electrotechnical Commission (IEC) the level of harmonics is described in a single parameter by the total harmonic distortion (THD), which is the sum of the distortion at all frequencies, and expressed as a percentage of the total voltage or current at the Base Frequency (60Hz or 50Hz).

NEGATIVE EFFECTS OF HARMONICS

The most significant negative effects of uncontrolled harmonics are:

Cables overheating due to the extra current

Capacitors enduring insulation-damaging voltages due to resonance

Uncontrolled noise and torque oscillations in motors that could lead to mechanical resonance and vibration

And communication equipment or instruments providing incorrect readings due to signal interference.

BASIC POINTS OF HARMONICS

- Total Harmonic Distortion is the summation of sine waves of various amplitudes and frequencies that combine to distort the fundamental sinusoidal waveform expected from an AC supply.
- Harmonics are generated by non-linear loads on an electrical system, which include most electronic equipment and discharge lamps (fluorescent and HID).
- Harmonics can have negative effects on any piece of equipment in an affected system.
- Electrical standard (IEEE 519) addresses this phenomenon and quantifies the allowable limits of 'harmonics' an electrical consumer can produce.
- The commercial HVAC market in North America has adopted the IEEE 519 standard.
- Power factor is often not included in supply distortion discussions.

REGULATIONS REGARDING HARMONICS

North America

In 1992 the Institute of Electrical and Electronic Engineers, IEEE, established "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Systems". The IEEE Standard 519-1992 is now the norm for harmonic specifications in USA and countries with NEMA electrical standards.

IEEE 519-1992 defines the following key aspects:

- The definition of a system
- The operational condition of the system
- The allowable harmonic distortion levels in a system for current, voltage, and total demand distortion

The THVD, or Total Harmonic Voltage Distortion more stringent limits from IEEE 519 are shown below:

	SPECIAL APPLICATION	GENERAL APPLICATION	DEDICATED SYSTEM
	Airport, Hospitals, Telecommunication networks etc.	Office Building, School etc.	Factories, Industries etc.
THVD	3%	5%	10%

FIG. 1 IEEE 519 standards for total harmonic voltage distortion limit

Points to remember on IEEE519 Harmonics standard:

- The standard is written based on full load currents. Notice most HVAC installations, using VFDs and Sensorless Control™ rarely run at full load current.
- The voltages in the recommendation are typically utility voltages and are not necessarily intended to be applied to low voltage installations.
- The standard is designed to ensure power quality on the utility side of the distribution gridline. It is a standard for whole installations rather than a device standard.
- When applied to devices the standard is exceedingly strict and can be interpreted in different ways.
- The short circuit impedance of the supply determines how current harmonics distort the voltage signal.

Europe

The International Electrotechnical Commission (IEC) regulates harmonics emissions with standards IEC/EN 61000-3-2 (for equipment up to 16A) and IEC/EN 61000-3-12 (for equipment consuming more than 16A).

Unlike the IEEE standard, the IEC/EN standards regulate the current harmonics that devices are allowed to produce, and are independent of where and how devices are installed. This allows for verifying and certifying the equipment compliance before installation.

Manufacturers usually publish their products' adherence to these standards. However, since the standards were built on general assumptions about the percentage of harmonics producing loads and transformer size, an installation entirely built with compliant devices may still have issues.

It's the responsibility of the electrical engineer to ensure the levels of harmonics are acceptable for the equipment in an installation. To help with this, some manufacturers offer software which estimates the THD that will be produced.

DEFINITION OF DIFFERENT PULSE VFDs

Based on the configuration of the input rectifier bridge, 3-phase commercially available VFDs can be classified as: 6, 12, 18 and 24-pulse VFD

- 6-pulse VFD
The most common rectifier circuit in three-phase PWM drives, 6-pulse VFD uses six-pulse diode rectifier. A 6-pulse rectifier is the most robust and cost effective solution in the VFD industry as of today, even though input current contains some amount of low order harmonics.

- 12-pulse VFD
12-pulse VFDs, as shown in figure 2, consists of 12-pulse rectifier, formed by connecting two six-pulse rectifiers in parallel to feed the same DC bus voltage. These rectifiers are fed through a transformer with two secondary windings: one Δ and one Y.
- 18 and 24-pulse VFD
18 and 24-pulse VFDs form 18 and 24-pulse rectifiers by connecting three or four six-pulse rectifiers in parallel to feed the same DC bus voltage. These rectifiers are fed through a transformer with three or four secondary transformers respectively.

Electrical schematic below showing 12-pulse VFD with two 6-pulse Rectifier Circuit in parallel:

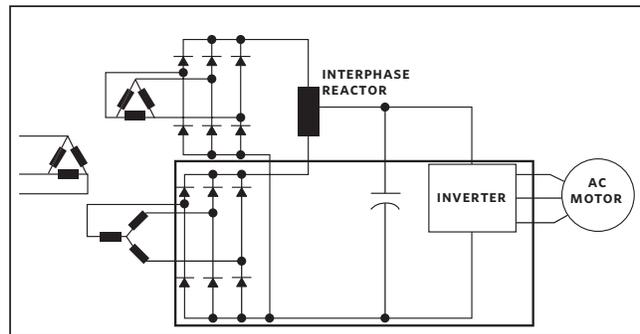


FIG. 2 Schematic of 12-pulse VFD with one primary transformer and two secondary transformers (6-pulse VFD is represented by the dark black rectangular area, requires no transformer)

When their component and the supply voltage phases are perfectly balanced, 12, 18 and 24-pulse drives, produce significantly less current harmonics than 6 pulse drives with 5% DC link reactance ([1], [2]). However, their performance degrades quickly in voltage unbalanced situations ([2]).

Physical Footprint comparison

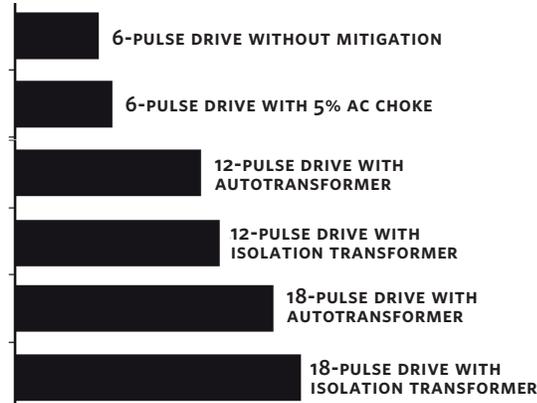


FIG 3: Physical footprint for 6-pulse VFD vs. 12-18 pulse VFD

Compared to 6-pulse drive, the higher pulse models require significantly extra space reservations for their hardware.

EVALUATED COST

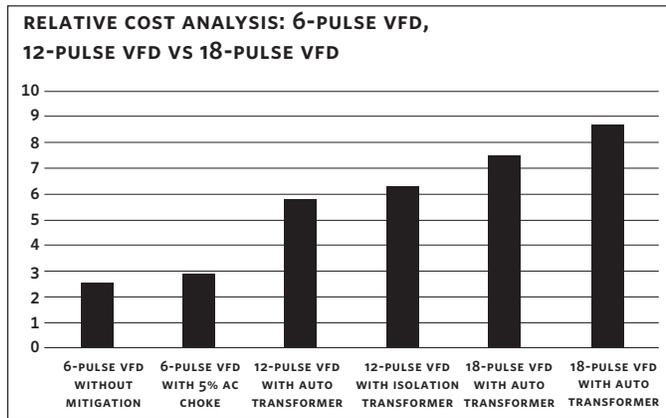


FIG. 4 Relative cost analysis for 6-pulse VFD with & without Filter vs. 12-18 pulse VFD with Transformer

There are various solutions to mitigate harmonic distortion. When considering the best fit for an application one should remember that total cost of the system will include not only VFD and accessories price, but also installation, maintenance, footprint and hauling cost.

Considering footprint, a 12-pulse VFD will consist of similar rectifier circuit as two 6-pulse VFD with added transformers. Similarly 18-pulse VFD could be triple in size and cost compared to a 6-pulse VFD.

To comply with regulations, different solutions should be considered;

- 6-pulse VFD + Built in DC line reactor
- 6-pulse VFD + Built in DC line reactor + External Harmonic Filter
- Higher pulse VFD

Table four compares few of the key features between suggested solutions.

FEATURES	6-PULSE VFD + BUILT-IN DC LINE REACTOR	6-PULSE VFD + BUILT-IN DC LINE REACTOR + EXTERNAL MATRIX FILTER	12-PULSE VFD
Meet IEE 519 THVD limits if less than this % of the transformer capacity ¹	55%	85%	70%
Degradation due to Unbalanced Voltage and imperfectly matched components	Very Low	Low	Medium
Meet IEC THD limits	Yes	Yes	Yes
Meet IEE 519 THD limits ²	No	Yes	No
THD at full load	≈ 28 %	≈ 5 %	≈ 15 %
Total current harmonics as % of full load current. @ 50% of BEP flow ³	≈ 15%	≈ 2.5 %	≈ 8 %
Complexity	Low	Low	High
Cost	Low (Same as 6-Pulse VFD)	Slightly Higher than 6-Pulse VFD	High
Size	Compact (Same as 6-Pulse VFD)	Medium (Smaller than two 6-pulse VFDs)	Large (≈ two 6-pulse VFDs + transformer)
Efficiency	High	High	High
Reliability	Highly reliable and robust	Highly reliable and robust	Medium-High (More Components internally)

6

NOTE 1: Assuming no other harmonic causing loads in the system and a transformer with 5% secondary impedance. Lower impedances increase proportionally those thresholds. For example, a 6-pulse drive with built in reactor can be 100% of the load of a transformer with a 2.5% impedance without exceeding the IEEE519 THD limits. Current harmonics from other sources have to be added to those of the drives to calculate the voltage THD.

NOTE 2: This is the most stringent interpretation of IEEE519, requiring specific current harmonics ranges (for example 11th to 17th) to not exceed set limits.

NOTE 3: Usually advanced circulators and pumps using sensorless control, spend most of their operational life around the 50% load point. The characteristics of system calculated at this point has a key indication to system health and robustness.

CONCLUSION

Offering the Design Envelop product range, Armstrong has focused on delivering the most value to its customers with the lowest first cost and lowest life cost.

Keeping those as design and selection bases, of the various options to reduce harmonic distortion and also comply with IEEE519 specification and IEC/EN standards, Armstrong Fluid Technology has chosen the most cost effective and the most compact solution, currently available, for Design Envelope product offering: 6-pulse VFD with Built-in DC Line Reactor, which effectively reduces harmonic distortion and helps safeguard sensitive

equipment in applications such as hospitals, airport, telecommunication facilities etc.

Please note that because of the significant affect on the overall footprint, weight and cost while providing no extra required benefit, higher pulse rate VFDs, 12 and 18, will not be offered with Armstrong Design Envelop solutions.

For extreme cases where the harmonics contribution of other equipment in the installation make it necessary for further reduction in the contribution of pumps, Armstrong Fluid Technology offers a line of matrix filters which provide outstanding harmonic mitigation in the simplest, the most cost effective and the most robust manner while requiring the least possible footprint increase.

FURTHER READING

- 1 For experimental data comparing a 12-pulse VFD vs. a 6-pulse VFD with a Matrix Harmonic Filter see <http://198.154.200.138/pages/wp-content/uploads/12pulse.pdf>
- 2 For theoretical comparison between 6, 12 and 24 pulse VFDs performance and other methods to reduce harmonics, see [http://www05.abb.com/global/scot/scot201.nsf/veritydisplay/cedba3af94239d90c1257b0f004712c4/\\$file/abb_technical_guide_no_6_rev.d.pdf](http://www05.abb.com/global/scot/scot201.nsf/veritydisplay/cedba3af94239d90c1257b0f004712c4/$file/abb_technical_guide_no_6_rev.d.pdf)
- 3 For typical transformer secondary impedances see http://www.hydroonebrampton.com/pdfs/2010/standard1950_r8.pdf

TORONTO

+1 416 755 2291

BUFFALO

+1 716 693 8813

BIRMINGHAM

+44 (0) 8444 145 145

MANCHESTER

+44 (0) 8444 145 145

BANGALORE

+91 (0) 80 4906 3555

SHANGHAI

+86 21 3756 6696