

	<b>Understanding Harmonics, IEEE 519-2014, and the Johnson Controls OptiSpeed Offering</b>	
<b>MARKETING GUIDE</b>	New Release	Form: 160.00-MG5(515)

## Introduction:

*IEEE Standard 519 - 2014 – Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems* addresses harmonic mitigation techniques and provides harmonic distortion guidelines for electrical systems. IEEE 519 is a useful standard, but a large portion of the HVAC industry does not fully understand how to analyze, interpret, and test this standard. The purpose of this paper is to explain harmonics and IEEE 519 in clear terms so they can be understood by sales teams, customers, or anyone interested in learning about harmonics. Also, this paper will discuss how the OptiSpeed VSD can address harmonics to ensure it can accommodate any customer's harmonic requirements.

Over the past few decades, the combination of advances in Power Electronics and emphasis on energy efficiency created a promising market for Variable Speed Drives (VSDs). A VSD can manipulate the frequency of its output signal, ultimately varying the speed of a motor and yielding significant savings relative to constant speed starters. The YORK by Johnson Controls OptiSpeed VSD series provides an effective solution for part load chiller applications, saving customers thousands of dollars in energy charged annually.

Although Variable Speed Drives are popular because of their many benefits (energy savings, high part-load efficiency, small footprint, low starting current, etc.), one consequence of using a VSD is that harmonics are reflected from the input of the VSD back to the utility distribution network. There has been growing customer concern regarding harmonics and whether their application dictates they should be mitigated.

## A VSD and Harmonics Overview:

A VSD operates by rectifying (or converting) an AC signal to DC. The VSD then takes this DC signal and uses Pulse Width Modulation (PWM) to change back from DC to an AC signal of desired amplitude and frequency. Controls and software systems can then manipulate this output signal to ensure the compressor of a chiller is being run at the ideal speed to realize maximum energy savings.

However, when the signal is originally being rectified from DC to AC, the circuit draws a non-linear current (or current that is not proportional to the voltage signal). This causes harmonics to be reflected back to the utility distribution network. Harmonics are reflected sinusoidal signals, measured in terms of current or voltage, which have a frequency that is a multiple of the fundamental frequency (50 Hz or 60 Hz). For example, if the fundamental frequency is 60 Hz, the 5<sup>th</sup> harmonic would have frequency of  $5 \times 60 \text{ Hz} = 300 \text{ Hz}$ . Some potential problems that can result from harmonics are:

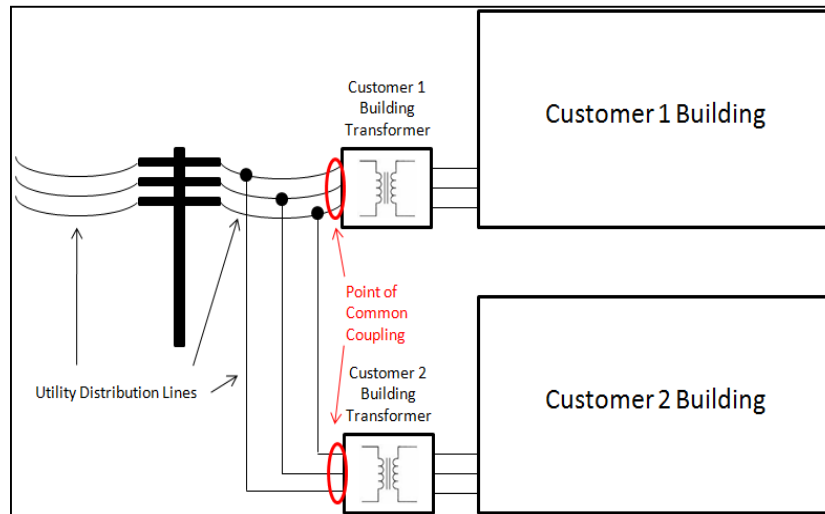
- Increased heating in conductors, transformers, and other electrical components
- Interference with other sensitive electrical equipment
- Reduced true power factor

Many issues listed above account for the increased customer concern about harmonics, but when deciding whether harmonic attenuation is necessary for a certain chiller application, it is very important to analyze each situation separately. Factors such as application, chiller size, circuit breaker size, and other equipment on the power line all factor in to whether harmonic attenuation is needed. IEEE 519 provides valuable information and guidelines regarding acceptable harmonic levels and mitigation techniques.

## ***IEEE Standard 519-2014 – Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems:***

IEEE 519 was developed to provide harmonic content guidelines and harmonic mitigation techniques, but there is still confusion about what IEEE 519 is and how it is met. First, as referred to in the title, IEEE 519 is an "electrical power system" code, not a manufacturer's code. This means that harmonics are to be measured at the point of

common coupling, or PCC, and **not** at the terminals of each device. IEEE 519 defines the PCC as the “point on the public power supply system, electrically nearest to a particular load, at which other loads are, or could be, connected.” Figure 1 shows a possible location of the PCC.



**Figure 1 – Point of Common Coupling Location in an Electrical System**

The reason IEEE 519 provides guidelines at the PCC is because the standard is concerned with harmonics on the power system. In other words, IEEE does not want harmonics from a consumer to affect the power quality of the utility or another consumer, but they are not concerned about the harmonics within a customer’s building. However, methods to test harmonics at the PCC are difficult and expensive (consultants, test equipment, duration of test requirements), so an increasing number of customers are requiring each nonlinear device to meet IEEE 519 harmonic levels. Although this method may seem easier than measuring at the PCC, IEEE 519 states that the recommendations are not intended to apply to individual devices. It says:

*The recommended limits in this clause apply only at the point of common coupling and **should not** be applied to either individual pieces of equipment or at locations within a user’s facility. In most cases, harmonic voltages and currents at these locations could be found to be significantly greater than the limits recommended at the PCC due to lack of diversity, cancellation, and other phenomena that tend to reduce the combined effects of multiple harmonic sources to levels below their algebraic summation.*

Ensuring the components of a building meet IEEE 519 does not necessarily result in meeting IEEE 519 at the PCC; other elements of the building, conductors, transformers, power factor correction capacitors, etc. need to be considered to determine how the building will absorb harmonics. For this reason, Johnson Controls cannot commit to harmonic content levels at the PCC. Therefore, when Johnson Controls offers an “IEEE 519” filter, we ensure that IEEE 519 is met at the input terminals to the VSD.

Another confusing issue about IEEE 519 is how to follow the harmonic content guidelines provided by the standard. Note that this standard only presents guidelines; it is not a standard where strict written compliance can be obtained.

### IEEE 519 Guidelines Part 1: Voltage Total Harmonic Distortion (THD<sub>v</sub>)

THD<sub>v</sub> is the voltage harmonic content with respect to the fundamental voltage, and it is calculated by the following equation:

$$THD_v = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \dots + V_{50}^2}}{V_1} \quad (Eqn. 1)$$

**Note: The subscript represents the harmonic number. For three phase applications, multiples of two and three cancel out.**

**Table 1—Voltage distortion limits**

Bus voltage $V$ at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV < $V \leq 69$ kV	3.0	5.0
69 kV < $V \leq 161$ kV	1.5	2.5
161 kV < $V$	1.0	1.5 <sup>a</sup>

<sup>a</sup>High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal whose effects will have attenuated at points in the network where future users may be connected.

Low-Voltage System Classification of Distortion Limits (Voltage Distortion), as described in IEEE Std 519-2014, Table 1

Each value in the numerator of Equation 1 represents the magnitude of the specified voltage harmonic. Table 1 shows the acceptable voltage distortion levels (THD<sub>V</sub>) as defined by IEEE 519. If we measure harmonics at the PCC, the bus voltage will usually fall within the 1kV to 69kV range. However, if harmonics are measured at the input to the VSD, the bus voltage may be less than 1.0 kV, so 8% THD<sub>V</sub> would be allowed. Voltage harmonics are usually of less concern than current harmonics since the current distortion guidelines are harder to achieve and voltage harmonics can usually be mitigated by implementing proper grounding and neutral connections.

**IEEE 519 Guidelines Part 2: Current Distortion (TDD and THD<sub>C</sub>)**

**Table 2—Current distortion limits for systems rated 120 V through 69 kV**

Maximum harmonic current distortion in percent of $I_L$						
Individual harmonic order (odd harmonics) <sup>a, b</sup>						
$I_{sc}/I_L$	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	TDD
< 20 <sup>c</sup>	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50 < 100	10.0	4.5	4.0	1.5	0.7	12.0
100 < 1000	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

<sup>a</sup>Even harmonics are limited to 25% of the odd harmonic limits above.

<sup>b</sup>Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

<sup>c</sup>All power generation equipment is limited to these values of current distortion, regardless of actual  $I_{sc}/I_L$  where

$I_{sc}$  = maximum short-circuit current at PCC  
 $I_L$  = maximum demand load current (fundamental frequency component) at the PCC under normal load operating conditions

Table 2 – Current Distortion Limits for General Distribution Systems (120V – 69,000V), as described in IEEE Std 519-2014, Table 2

Table 2 depicts guidelines for current demand distortion (TDD) values. THD<sub>C</sub> and TDD are both current distortion measurements, but there is a significant difference that must be understood to understand IEEE 519. The equation for each current distortion measurement is below.

$$THD_C = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \dots + I_{50}^2}}{I_1} \text{ (Eqn. 2)} \quad TDD = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \dots + I_{50}^2}}{I_L} \text{ (Eqn. 3)}$$

**Note: The subscript represents the harmonic number. For three phase applications, multiples of two and three cancel out.**

Notice that the only difference between these measurements is that TDD is the harmonic content with respect to  $I_L$  (the peak demand load current) while THD<sub>C</sub> is with respect to the fundamental current. IEEE 519 **only** created guidelines for TDD values because the fundamental current included in THD<sub>C</sub> decreases as VSD speed decreases. This causes THD<sub>C</sub> to increase as VSD speed decreases, penalizing consumers at partial speeds.  $I_L$  stays constant as speed changes, so TDD yields no penalty for part load operation.

According to IEEE 519, the maximum load current  $I_L$  should be obtained by measuring “the average current of the maximum demand for the preceding 12 months”. It would be very difficult and expensive to actually find  $I_L$  with this technique, but we can make a few simplifications and assumptions to evaluate the IEEE 519 guidelines. First, harmonic distortion can be measured from the secondary windings of the distribution transformer regardless of the location of the PCC. Current distortion will be approximately equal, and although  $THD_v$  will change depending on the side of the transformer, meeting current distortion guidelines will usually result in meeting  $THD_v$  guidelines as well. Second,  $THD_c$  can be measured instead of TDD to further simplify the measurements. If  $THD_c$  meets IEEE 519 guidelines at any speed, TDD will meet the guidelines as well. However, if  $THD_c$  exceeds the current distortion guidelines, TDD needs to be measured to confirm if IEEE 519 is met.

Another important section of Table 2 is the  $I_{sc}/I_L$  ratio. Although many times 5% TDD is automatically selected when discussing IEEE 519, calculating the  $I_{sc}/I_L$  ratio may yield different guidelines. If we assume the chiller is the only load in the system, a good estimate for  $I_{sc}/I_L$  is to assume  $I_{sc}$  is the breaker withstand ratio for the transformer feeding the non-linear load, and  $I_L$  is the total full load amps (FLA) of the chiller which is the worst case (maximum) value. Table 3 shows  $I_{sc}/I_L$  ratios for various air-cooled YORK chillers. Notice that the  $I_{sc}/I_L$  ratio is only below 20 in two breaker/FLA combinations. In addition, all YORK VSDs are sold with no less than a 35kA rating.

Breaker Withstand Ratings (A)	4-comp	3-comp	2-comp	Total (FLA)
	1132	1014	676	
100,000	88	99	148	$I_{sc}/I_L$
65,000	57	64	96	
35,000	31	35	52	
25,000	22	25	37	
18,000	16	18	27	

Table 3 – Breaker Ratings to FLA Ratio ( $I_{sc}/I_L$  estimate)

**Johnson Controls Harmonic Mitigation Offerings:**

If the application is one where harmonic content needs to be kept low — hospitals, airports, critical cooling — YORK by Johnson Controls OptiSpeed VSDs have harmonic filtering options for any customer interested in designing their building system with IEEE 519 in mind. All YORK VSDs include standard filtering techniques such as a DC choke and a line reactor. These standard features reduce current demand distortion values from as high as 80% to acceptable levels for applications where harmonics are not a primary concern. Also as a standard feature, YORK VSDs will meet or fall below 5%  $THD_v$  by implementing proper groundings, neutral connections, and component sizing.

For screw and scroll chillers, each VSD can be supplied with a passive filter that will help mitigate harmonic distortion levels. Also, all low voltage VSDs for YK chillers have an active filter option that is produced by JCI and placed in the same enclosure as the VSD. VSDs on YMC<sup>2</sup> chillers have an active front end rectifier as standard, and all medium voltage VSDs on YK chillers use a 24 pulse rectifier.

For VSDs with harmonic attenuation options, it is prudent to analyze each specific project to determine if harmonic mitigation is needed. Hopefully this document provides the tools to intelligently approach the IEEE 519 and harmonics discussion.

**Conclusion/Summary:**

- VSDs are increasing in popularity due to their many benefits such as lower energy costs, high part-load efficiency, small footprint, low starting current, etc.
- Since VSDs are a nonlinear device, meaning they draw current that is not proportional to the voltage signal, they cause harmonics that are reflected back to the utility distribution network.
- Some problems harmonics cause are increased heating in electrical components, interference with other sensitive electrical equipment, and reduced true power factor.

- IEEE 519-2014 is an “electrical system code”, not a manufacturer’s code. Therefore, harmonics should be measured at the point of common coupling and not at the input to each nonlinear device.
- IEEE 519 defines the PCC as the “point on the public power supply system, electrically nearest to a particular load, at which other loads are, or could be, connected.”
- IEEE provides guidelines for Voltage Total Harmonic Distortion (THD<sub>v</sub>) and Total Demand Distortion (TDD). IEEE does not set guidelines for Current Total Harmonic Distortion (THD<sub>c</sub>).
  - THD<sub>v</sub> – Voltage harmonic distortion with respect to the fundamental voltage.
  - TDD – Current harmonic distortion with respect to the peak demand current (I<sub>L</sub>).
  - THD<sub>c</sub> – Current harmonic distortion with respect to the fundamental current.
- To simplify harmonic measurements, harmonics can always be measured from the secondary winding of the distribution transformer (regardless of location of PCC). Also, THD<sub>c</sub> can be measured instead of TDD. If THD<sub>c</sub> meets current distortion guidelines, then TDD will as well. If THD<sub>c</sub> does not meet current distortion guidelines, then TDD must be measured to see if the current distortion guidelines are met.
- The I<sub>sc</sub>/I<sub>L</sub> ratio is important to ensure the proper guidelines are being met. Table 2 shows how the I<sub>sc</sub>/I<sub>L</sub> ratio affects current distortion limits.
- YORK by Johnson Controls offers various harmonic mitigation techniques for its VSDs to ensure they can meet and exceed the expectations of every customer.
  - All VSDs include as standard a DC Choke and a line reactor to achieve sufficient harmonic levels for applications where harmonics are not a main concern.
  - For Screw and Scroll chillers, a passive filter is available.
  - For low voltage YK chillers, an active filter is available that will fit in the same enclosure as the VSD.
  - VSDs on YMC<sup>2</sup> or Medium Voltage YK chillers both have standard harmonic filtering options.

**References:**

*IEEE Std 519 – 2014, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, Published by the Institute of Electrical and Electronics Engineers, New York, NY, June 11, 2014.*