PHASE TECHNOLOGIES

LH SERIES DRIVES

Phase Converting, Low Harmonics,
Regenerative Drives

1LH & 3LH SERIES VFD HARMONICS
&
IEEE 519-2022

Phase Technologies, LLC
222 DiskDr.
Rapid City, SD 57701
605-343-7934
www.phasetechnologies.com

NEGATIVE EFFECTS OF HARMONICS

Harmonics have a number of negative effects including higher temperature rise in transformers and motors causing a reduction in life, conductor insulation overheating, and disruptions for other customers on the line. Depending on the power requirement of your installation and the utility supply, harmonics can have a severe negative effect on the power distribution network. Many electric utilities require VFD installations to comply with IEEE 519, the standard for acceptable harmonic distortion on utility mains.

IEEE 519 RECOMMENDED LIMITS FOR CURRENT DISTORTION

Recommended IEEE 519 harmonic limits are specified for the point of common coupling (PCC). The PCC is the point on the public power system, electrically nearest to a particular load, at which other loads are, or could be, connected. The PCC is a point located upstream of the installation.

Varying phase relationships of harmonics produced from all the devices connected to a common power system will combine generally cancelling one another out. Thus, harmonics from multiple devices on the same power system do not add directly. Therefore, compliance with IEEE 519-2022 is a system design issue. LH Series variable frequency drives facilitate compliance by drawing very little harmonic current.

Limits for voltage harmonics are specified for total harmonic distortion (THD). THD is the ratio of the root mean square (RMS) of the harmonic content of up to the 50^{th} harmonic, specifically excluding interharmonics, expressed as a percent of the fundamental. Harmonics above the 50^{th} order may be included when necessary. For bus voltages below 1kV short time harmonic measurements (10 minute interval) for individual harmonics are limited to less than 5% of the fundamental and THD is limited to 8%. Measurements over a 3 second window must not exceed 7.5% for individual harmonics and 12% for THD.

Limits for current harmonics are specified for total demand distortion (TDD). TDD is the ratio of the RMS harmonic content of up to the 50^{th} harmonic, specifically excluding interharmonics, expressed as a percent of the maximum demand current. Harmonics above the 50^{th} may be included when necessary. Limits for current harmonics are given in IEEE 519-2022 Table 2.

Special attention is given to both induced DC currents and higher order harmonics since both have outsized impact on transformer heating and performance. DC currents, induced by half-wave converters for example, are not allowed. DC currents increase transformer core losses and heating by inducing DC voltages, which lead to excess heating due to saturation and hysteresis effects in the core. Higher order harmonics produce excess power/heat losses. These losses include copper losses (I^2R) in transformer windings, Eddy current losses in the core and structural parts and losses from negative sequence harmonics that directly oppose the positive sequence component of the fundamental source voltage.

IEEE 519-2022
Table 2

Current Distortion Limits for Systems rated 120V through 69kV

Maximum Harmonic Current Distortion in Percent of I_L Individual Harmonic Order (Odd Harmonics)[a,b]						
I_{SC}/I_L	3≤h<11	11≤h<17	17≤ h<23	23≤h<35	35≤h≤50	TDD
<20*	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

[a]Even harmonics are limited to 25% of the odd harmonic limits above.
[b]Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.
*All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.
Where

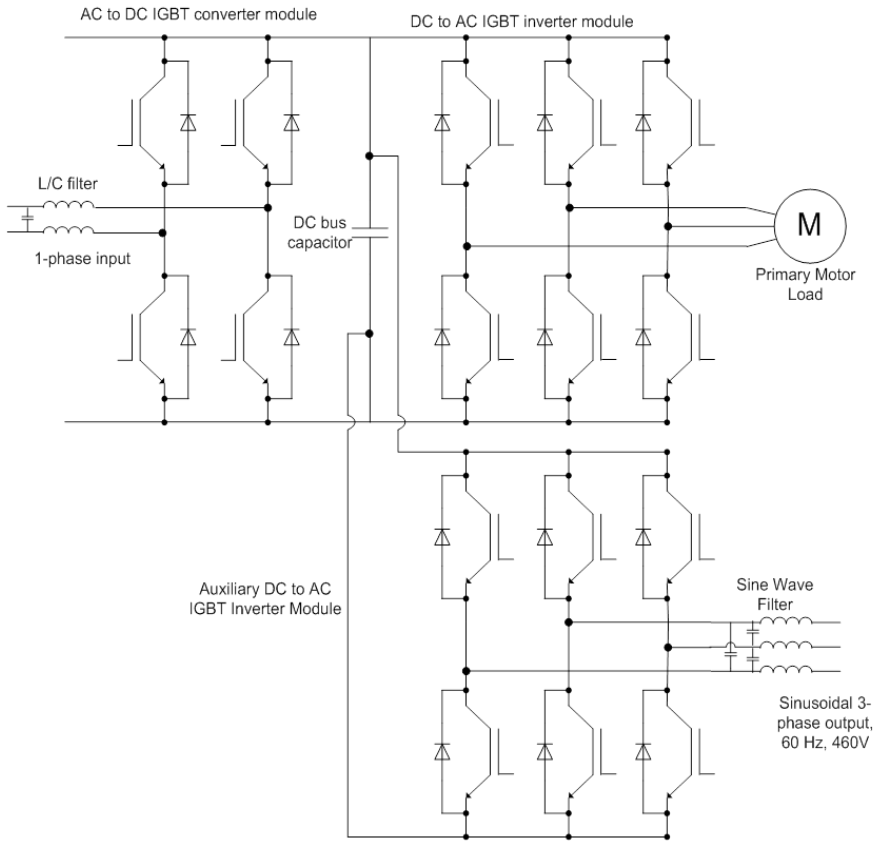
I_{sc} = maximum short-circuit current at the PCC
I_L = maximum demand load current (fundamental frequency component) at the PCC under normal load operating conditions.

HARMONIC MITIGATION WITH LH SERIES VFDs

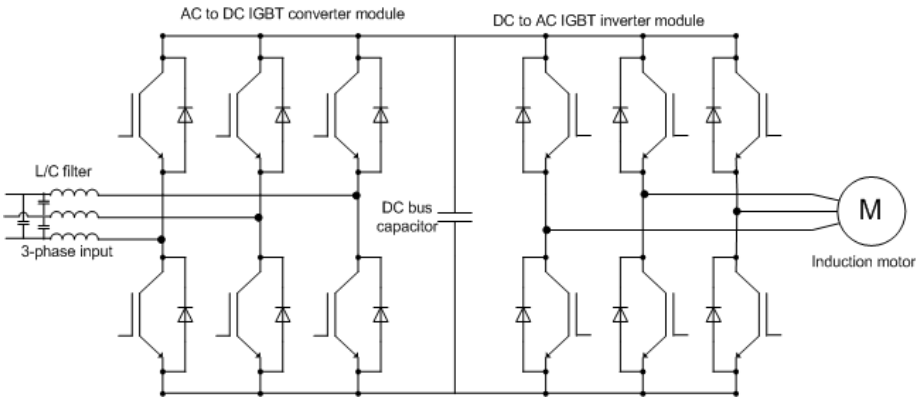
Active Front End Technology

An active front end VFD actively switches and regulates input current in a process known as electronic power factor correction. The switching algorithm ensures the input current to the drive is sinusoidal at the fundamental frequency of 60 Hz. The switches are combined with an inductor/capacitor (L/C) low pass filter, which blocks the high frequency voltages and currents from appearing at the input terminals of the VFD. The input current is sinusoidal and harmonics are generally low enough to facilitate compliance with IEEE 519-2022. LH Series VFDs are also regenerative, allowing power to flow in either direction. This improves efficiency by putting power into the power system while braking/shutting down the motor load.

1LH Series VFD Block Diagram



3LH Series VFD Block Diagram



LOW HARMONIC SOLUTION
FOR PHASE CONVERTING VFD APPLICATIONS

Phase Technologies' LH Series drives are fully regenerative, low harmonic drives with a line-side active switching module providing power to the DC bus and a three-phase inverter module to drive the load. Electronic power factor correction on the line-side produces a sine-wave current, greatly reducing the current distortion and line harmonics.

LH Series Drive Harmonics

LH Series VFDs were tested using a Fluke 435 Series II power quality and energy analyzer. The following test results from a 3LH450 are typical of 1LH and 3LH Series VFDs.

The voltage harmonics were measured from no load to 88% of full load (76A) on all three phases. The THD never exceeded 2.73% on any phase and averaged about 2.1% for the duration of testing.

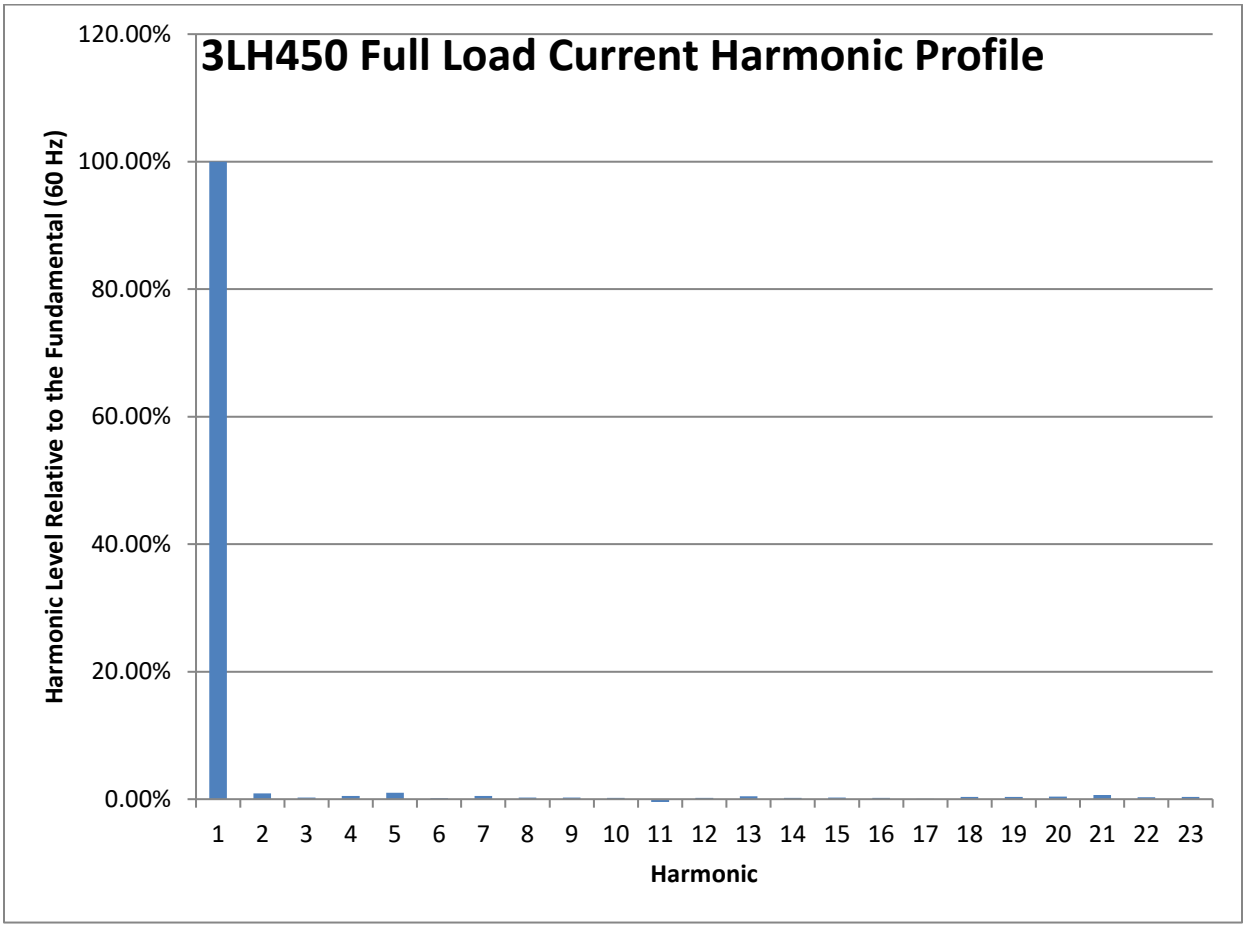


Figure 1: 3LH450 Typical Current Harmonic Profile
Generated Current THD = 2.2%

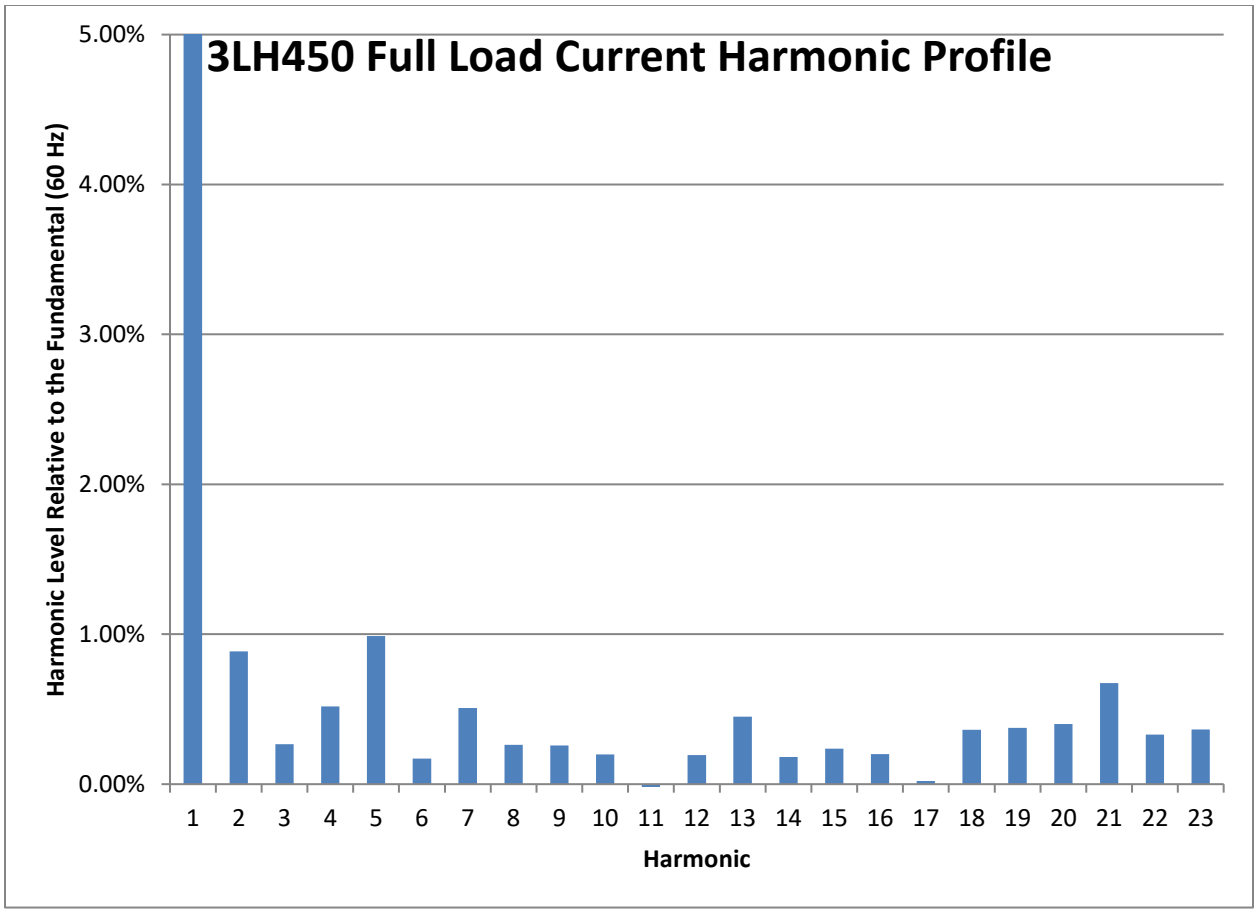


Figure 2: 3LH450 Typical Current Harmonic Profile
Individual current harmonics shown relative to 5%--the strictest IEEE 519 limit for current THD

The input harmonic distortion measurements were adjusted by subtracting the harmonic currents flowing in the passive front-end filter capacitor caused by external voltage harmonics in the test power system. Therefore, the calculated generated harmonics from the VFD were much lower than the measured harmonics at the input of the VFD. This step must be done to accurately determine the VFD impact on system harmonics. Passive capacitive filter components by nature draw harmonic current induced by harmonic voltages. However, in the absence of external harmonic voltages these harmonic currents would not be present.

Table 1 3LH450 Generated Harmonic Current Test Data

	Amps (A)		IEEE 519 Limits at PCC (Heavily loaded supply)	
	64	76	I_{sc}/I_L <20	20<I_{sc}/I_L <50
THD %	2.48%	2.25%	TDD=5%	TDD=8%
DC	0.00%	0.00%	0%	0%
1	100.00%	100.00%	Reference = 100%	
2	0.968%	0.842%	No Spec	
3	0.342%	0.252%	4.00%	7%
4	0.556%	0.541%	1.00%	1.75%
5	1.022%	0.984%	4.00%	7.00%
6	0.186%	0.172%	1.00%	1.75%
7	0.325%	0.536%	4.00%	7.00%
8	0.270%	0.248%	1.00%	1.75%
9	0.241%	0.296%	4.00%	7.00%
10	0.225%	0.199%	1.00%	1.75%
11	0.697%	-0.637%	2.00%	3.50%
12	0.177%	0.198%	0.50%	0.875%
13	0.658%	0.473%	2.00%	3.50%
14	0.252%	0.167%	0.50%	0.875%
15	0.268%	0.230%	2.00%	3.50%
16	0.261%	0.202%	0.50%	0.875%
17	0.081%	-0.005%	1.50%	2.50%
18	0.394%	0.383%	0.375%	0.625%
19	0.304%	0.364%	1.50%	2.50%
20	0.419%	0.382%	0.375%	0.625%
21	0.580%	0.732%	1.50%	2.50%
22	0.343%	0.312%	0.375%	0.625%
23	0.459%	0.369%	0.60%	1.00%

The measured harmonics at 76A input current (88% FLA) were within the strictest IEEE 519 limits for the PCC. The 18th and 20th harmonics appear to be slightly above the limits (about 2% high), but even these are within the ±5% measuring accuracy of the Fluke 435 used in the test. The harmonic levels improve/fall as the load increases so the THD and individual component harmonic levels will be slightly lower at full load. At 64A (≈75% FLA) the THD easily meets the IEEE 519 strictest limit with THD=2.48%. Again, only the 18th and 20th harmonics slightly exceed the limits, with the 18th within the ±5% measuring accuracy of the test equipment.

The power system used in the test was not filtered. External sources of voltage harmonics may have influenced the harmonic measurements. It is important to emphasize that IEEE 519 is a system standard. Therefore other components in the system may mitigate or magnify harmonic currents in the system and the LH Series VFDs harmonic contribution must be considered in the context of the total system.