AFE DRIVES

Energy Regeneration & Low Harmonic Performance

Phase Technologies White Paper

1.0 Evolution of Variable Frequency Drives

Variable frequency drives (VFDs) have transformed industrial motor control, enabling precise speed and torque management across countless applications — from irrigation pumps and oil field equipment to conveyors and compressors. As the technology matures, the latest generation of Active Front End (AFE) VFDs represents a significant leap forward, combining harmonic mitigation, power conditioning, and energy regeneration in a single, compact package.

Phase Technologies, headquartered in Rapid City, South Dakota, has built its product identity around AFE technology. Founded in 1999 as a pioneer in digital phase conversion, the company expanded into VFDs with a clear focus: produce the only low harmonic, fully regenerative, phase-converting drive that natively complies with IEEE 519 — without bolt-on external filters.

Today, Phase Technologies manufactures an extensive lineup of LH Series drives — spanning both single-phase input (1LH) and three-phase input (3LH) models from 20 HP to 650 HP — along with the new LHX series offering voltage-doubling capability, all engineered and assembled in-house at their Rapid City facility.

2.0 What Is an Active Front End?

A traditional VFD uses a passive diode bridge rectifier to convert incoming AC power to a DC bus. This approach is simple and cost-effective, but it introduces significant drawbacks: high harmonic currents are injected back into the utility system, and any energy generated during motor braking has nowhere to go — it must be dissipated as heat through braking resistors.

An **Active Front End (AFE)** replaces the passive diode bridge with a fully controllable IGBT switching stage. Instead of passively rectifying incoming AC, the AFE actively shapes the input current waveform, pulling power from the grid in a nearly sinusoidal form. This creates two powerful advantages:

- **Harmonic Cancellation:** The IGBT stage generates canceling harmonics, actively suppressing distortion before it can propagate into the distribution system.
- **Bidirectional Power Flow:** Power can flow in both directions — from the grid to the motor during acceleration, and from the motor back to the grid during braking.

Figure 1: Phase Technologies LH Series AFE drive architecture showing bidirectional power flow

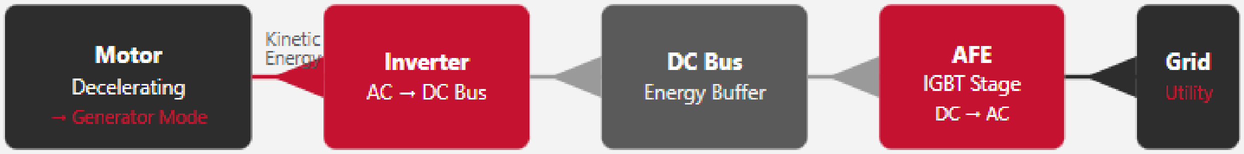
An LCL harmonic filter at the input works in concert with the AFE switching stage to achieve the low THD values Phase Technologies guarantees — eliminating the need for large, expensive external passive filters that can weigh hundreds of pounds.

Key Differentiator: Phase Technologies' LH Series drives are the only low harmonic, fully regenerative, phase-converting VFDs on the market that comply with IEEE 519 without any additional external harmonic filtering equipment.

3.0 Energy Regeneration: Recovering What Would Be Lost

In standard non-regenerative VFD installations, stopping or decelerating a motor presents an energy problem. The rotating mass of a motor and its connected load stores kinetic energy. When the drive commands deceleration, that energy must be absorbed somewhere. In a conventional drive, a braking resistor dissipates the energy as heat — wasted, and requiring cooling, maintenance, and periodic replacement.

The Regenerative Braking Principle
When a motor decelerates faster than its synchronous speed — driven by the inertia of the load — it transitions from motor to generator mode. In an AFE-equipped drive, this generated power flows back through the inverter stage onto the DC bus. The AFE IGBT rectifier then actively converts this DC energy back to AC, synchronized to the utility, and feeds it back into the grid — or redirects it to power other loads on the same bus.



Regenerative energy path during motor braking / deceleration

Figure 2: Regenerative energy recovery path — braking energy flows from motor back to the utility grid

Benefits of Regenerative Operation

- **Reduced energy consumption:** Recovered braking energy reduces net power draw from the utility, directly lowering electricity costs in high-cycle applications.
- **Elimination of braking resistors:** Resistive braking banks are costly, heavy, and require regular maintenance. Regenerative drives remove the need for them in most applications.
- **Reduced cooling loads:** Because energy is returned to the grid rather than dissipated as heat, panel and ambient temperatures are lower, reducing cooling infrastructure requirements.
- **Near-unity power factor:** The AFE stage actively maintains near-unity power factor during both motoring and regenerative operation, improving overall power system efficiency.
- **Extended equipment life:** Elimination of dynamic braking reduces thermal cycling stress on drive components and the motor itself.

Ideal Applications for Regenerative AFE Drives: Crane and hoist operations (frequent load braking), pump and fan systems with high inertia, oil and gas production equipment, irrigation systems, conveyor drives with variable loads, and industrial processes requiring controlled deceleration.

Power Factor and Voltage Boost

Because the AFE actively controls current draw, Phase Technologies' LH Series drives can also **boost output voltage** above the supply voltage level — valuable in areas with low or inconsistent utility voltage. The drive conditions incoming power and delivers the voltage level the motor requires, without an external transformer.

4.0 Harmonic Mitigation and IEEE 519 Compliance

VFDs are non-linear loads. Traditional six-pulse diode bridge drives draw current in short, non-sinusoidal bursts, injecting harmonic currents at multiples of the fundamental 60 Hz — primarily the 5th, 7th, 11th, and 13th harmonics. These currents cause transformer overheating, conductor losses, voltage distortion, interference with sensitive electronics, and increased motor temperatures from winding voltage stress.

Two Types of Harmonic Distortion: Current and Voltage

IEEE 519-2022 governs **both current distortion and voltage distortion** at the point of common coupling (PCC) with the utility — and both matter. Current distortion is generated directly by non-linear loads such as VFDs. As those harmonic currents flow through the impedance of the distribution system, they produce **voltage distortion** that affects every piece of equipment sharing the electrical network. Addressing current distortion at the source is therefore the most effective way to control voltage distortion system-wide.

It is also important to understand the distinction between **THD** (Total Harmonic Distortion — expressed as a percent of the fundamental frequency current) and **TDD** (Total Demand Distortion — expressed as a percent of the maximum demand load current). IEEE 519-2022 specifies current limits in terms of TDD, which is a more representative measure of real-world harmonic impact at the system level.

Phase Technologies tested the 3LH450 using a Fluke 435 Series II power quality analyzer from no load to 88% of full load (76A). **Voltage THD never exceeded 2.73% on any phase and averaged approximately 2.1%** for the duration of testing — well within the 8% limit for bus voltages below 1kV. Current THD measured 2.25% at 88% load and 2.48% at 75% load, both comfortably within the strictest IEEE 519 TDD limits.

Bus Voltage at PCC	Max Individual Voltage Harmonic (%)	Max Voltage THD (%)
V ≤ 1.0 kV	5.0	8.0
1 kV < V ≤ 69 kV	3.0	5.0
69 kV < V ≤ 161 kV	1.5	2.5
161 kV < V	1.0	1.5

Table 1: Voltage distortion limits per IEEE 519-2022

ISC / IL Ratio	3≤h<11 (%)	11≤h<17 (%)	17≤h<23 (%)	23≤h<35 (%)	TDD (%)
< 20	4.0	2.0	1.5	0.6	5.0
20–50	7.0	3.5	2.5	1.0	8.0
50–100	10.0	4.5	4.0	1.5	12.0
100–1000	12.0	5.5	5.0	2.0	15.0
> 1000	15.0	7.0	6.0	2.5	20.0

Table 2: Maximum harmonic current distortion limits (% of IL) per IEEE 519-2022. ISC = max short-circuit current at PCC; IL = max load current at PCC.

How AFE Drives Mitigate Both Current and Voltage Distortion

Rather than filtering harmonics passively after they are created, Phase Technologies' AFE drives prevent their injection into the grid in the first place. The IGBT input stage is continuously modulated to draw sinusoidal current from the utility. Combined with an integral LC filter, this active approach delivers dramatically lower current THD — and as a direct result, significantly lower voltage distortion — compared to standard drives.

LH Series vs. Six-Pulse + Harmonic Filter: A Direct Comparison

A common alternative to AFE drives is adding a passive harmonic filter to an existing six-pulse VFD. While this can reduce current THD to roughly 8–10%, it falls significantly short of what the LH Series achieves natively — with no external equipment, no added panel space, and no ongoing maintenance cost.

Drive Configuration	Typical Current THD	Measured Voltage THD	IEEE 519 Compliant?	External Filter Needed?
Six-Pulse VFD (no filter)	46–75%	High — causes equipment issues	No	Yes
Six-Pulse VFD + Passive Harmonic Filter	~8–10%	Moderate — borderline compliant	Conditional	Yes (costly, bulky)
Phase Technologies 3LH (AFE) — lab tested	**2.25–2.48%**	**≤2.73% avg ~2.1% — well within limits**	**Yes — Guaranteed**	**No**
Phase Technologies 1LH (AFE)	**~3.1%**	**Minimal — well within limits**	**Yes — Guaranteed**	**No**

3LH figures from Fluke 435 Series II lab testing of a 3LH450 at 75–88% full load. 1LH figures from Phase Technologies website data. Current harmonics reduced 90–95% vs. standard diode bridge drives.

3LH450 Individual Harmonic Test Results vs. IEEE 519 Limits

The table below shows actual measured generated harmonic current data from the 3LH450 at two load levels, compared against the strictest IEEE 519-2022 limits (ISC/IL <20, TDD = 5%). Every measured harmonic falls well within the IEEE 519 specification.

Harmonic	Measured @ 64A (~75% load)	Measured @ 76A (~88% load)	IEEE 519 Limit (ISC/IL <20)
THD / TDD	**2.48%**	**2.25%**	TDD = 5.0%
DC	0.00%	0.00%	0% (not allowed)
3rd	0.342%	0.252%	4.00%
5th	1.022%	0.984%	4.00%
7th	0.325%	0.536%	4.00%
11th	0.697%	0.637%	2.00%
13th	0.658%	0.473%	2.00%
17th	0.081%	0.005%	1.50%
19th	0.304%	0.364%	1.50%
23rd	0.459%	0.369%	0.60%

Table 3: Selected 3LH450 generated harmonic current test data (Fluke 435 Series II). Full data available in Phase Technologies LH Series Harmonics & IEEE 519-2022 white paper.

Bottom Line: A six-pulse VFD with a passive harmonic filter is a reactive, expensive workaround that still leaves current THD at 8–10% — three to four times higher than Phase Technologies' lab-measured LH Series results. The LH Series delivers superior performance on both current and voltage distortion, with no external filter, no added panel space, zero DC offset, and a full IEEE 519 compliance guarantee.

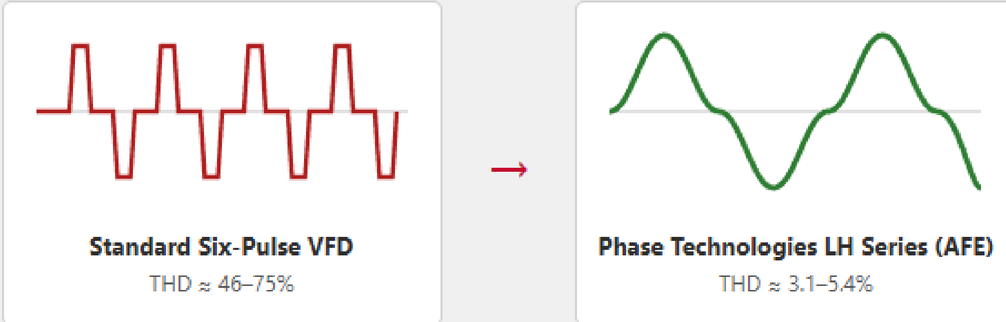


Figure 3: Input current harmonic profile — standard VFD (left) vs. Phase Technologies AFE drive (right)

Note on IEEE 519-2022: The LH Series document references the updated IEEE 519-2022 standard. Phase Technologies' LH Series drives are designed to comply with both the 2014 and 2022 versions of the standard, which maintain the same core voltage and current distortion limits at low-voltage installations.

Phase Technologies offers a comprehensive AFE drive portfolio spanning residential, agricultural, commercial, and industrial applications. Every unit is engineered, assembled, and tested in Rapid City, SD, with in-house PCB manufacturing, wire assembly, magnetics fabrication, and UL 508A panel shop integration.

5.0 Phase Technologies AFE Product Line

1LH Series
20–125 HP | Single-Phase Input

- AFE, IEEE 519 compliant
- Fully regenerative
- Phase-converting (1φ → 3φ)
- Output voltage boost
- AUXPOWER™ pump + pivot option

3LH Series
20–650 HP | Three-Phase Input

- AFE, IEEE 519 compliant
- Fully regenerative
- Three-phase input
- Irrigation, oil & gas, industrial
- UL 508A panel shop options

LHX Series
5–500 HP | AFE + Voltage Doubling

- Low harmonics + AFE
- Voltage doubling capability
- Reduces wire costs (deep-set pumps)
- Compact design
- Widest HP range in AFE class

Phase Technologies IEEE 519 Compliance Guarantee
Phase Technologies guarantees that LH Series product lines will meet the IEEE 519-2014 standard when at least 80% of rated current load is maintained. If a system does not comply, Phase Technologies will either provide a fix to bring the panel into compliance or offer a full refund for the purchase price of the panel upon return.

6.0 Summary: The AFE Advantage

For industrial and agricultural users evaluating VFD technology, the choice between a standard six-pulse drive and an Active Front End solution involves weighing upfront cost against long-term operational savings. Phase Technologies' AFE drives offer a compelling total-cost-of-ownership proposition:

Factor	Standard Six-Pulse VFD	Phase Technologies AFE (LH Series)
Input Current THD	46–75%	2.25–3.1% (lab tested)
Input Voltage THD	Significant — degrades power quality	≤2.73%, avg ~2.1% (lab tested)
IEEE 519 Compliance	Requires external filter	Built-in, guaranteed
Braking Energy	Dissipated as heat (resistors)	Returned to grid
Braking Resistors Required	Yes (most applications)	No
Output Voltage Boost	Not available	Available
Power Factor	~0.85 lagging	Near unity (motoring & regen)
Phase Conversion	Requires separate converter	Built-in (1LH Series)
Manufacturing Origin	Varies	USA (Rapid City, SD)

Phase Technologies' commitment to in-house engineering — from firmware and PCBs to magnetics and enclosures — enables shorter lead times, deep technical support, and the flexibility to treat every panel as a custom build without custom lead times.

Resources

For more information on Phase Technologies' AFE VFD solutions, contact:

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