Active Front End Drives: Lower Harmonics, Higher Energy Savings

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1.0 Evolution of VFDs

When variable-frequency drives (VFDs) arrived on the industrial scene in the late 1950s, they were unwieldy, unreliable and costly. Today, they are the indispensable masterminds that help manage and control electric motors on the factory floor.

The evolution of VFDs continues with the new generation of active front-end solutions for low-voltage AC drives. For industrial users, active front-end (AFE) technology translates to significant gains in production control, cost savings, energy regeneration and harmonic mitigation. To appreciate those gains, it is helpful to understand the fundamentals of motor control, variable frequency and low voltage drives.

2.0 Basic Motor Control

VFDs control a wide range of variables in electrical machinery – operating speed and acceleration, flow, monitoring, pressure, temperature, tension, torque and power demands. They have rapidly advanced industrial process and quality improvements. As a result, their use is growing.

VFDs can be broadly classified into non-regenerative and regenerative types. A typical non-regenerative VFD can be realized using a three-phase, six-pulse, rectifier bridge with either diodes or SCRs for front-end AC-DC power conversion. Non-regenerative drives are available with a DC link choke in-circuit and an optional input line reactor kit, as pictured in Figure 1.

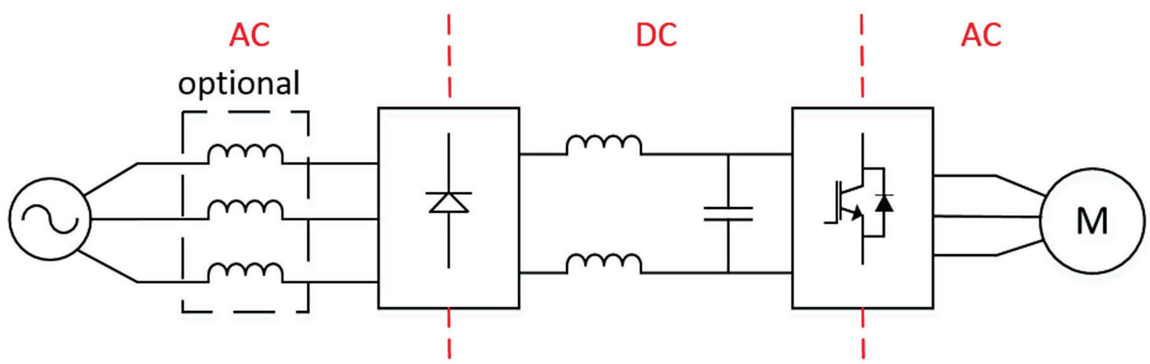

Figure 1: PowerFlex 755 non-regenerative drives architecture

Traditional benefits of VFDs include:

- Extending motor life by moderating start/stop functions, controlling current, and reducing wear and tear
- Improving quality control by moderating motor torque
- Eliminating mechanical drive components
- Reducing energy consumption by reducing load demand from fans, pumps and compressors
- Improving power factor, reducing risk to electricity supply system and complying with industry standards

Today's drives, when backed by active front-end technology, are capable of additional benefits including energy regeneration and harmonic mitigation.

3.0 Low-voltage Drives for High-demand Applications

Electric motors are a major source of energy consumption in industrial applications, consuming about one-fourth of the world's electrical energy.

In an attempt to reduce this significant production cost, more industrial producers are installing VFDs to control everything from appliances to compressors.

VFDs offer value in every industrial sector. Because low-voltage VFDs can adjust motor speed to demand, they are valuable in high-demand industries or applications, including drives that use hydraulic or pneumatic drilling systems.

Some of the greatest energy-saving benefits accrue in high-demand or energy-intensive applications and machinery used in metals and mining, wastewater treatment plants, cranes and hoists, centrifuges, tire and rubber, and oil and gas. In these applications, low-voltage AC drives control motor speed and torque, mitigating mechanical stress damage to machinery.

VFDs are available in varied voltages and ratings. Low voltage drives that operate at 690 volts or less are most often used to adjust speed and torque of standard AC motors. These drives help industrial users achieve high-efficiency machine performance at reduced voltage and frequency, making machinery more energy-efficient.

4.0 AFE Drives Empower Energy Savings, Harmonic Mitigation

In recent years, various technical advances – in power electronics technology, topologies, and control hardware and software – have greatly improved the performance and precision of low-voltage VFDs.

VFDs with embedded AFE technology, also called regenerative drives, make the most of new technology by offering industrial energy regeneration capabilities and input current harmonic mitigation. Today's industrial users often install AFEs as a replacement for 12-pulse rectifiers.

Most AFE drive systems consist of a dedicated AC drive with an active front-end controller. Drive systems also provide EMC filtering, providing lower input current harmonic distortion than is possible through traditional rectifiers.

Twelve-pulse rectifiers typically reduce total harmonic distortion to 10 percent, compared to about three percent for AFE drives. However, the values can vary depending on the source voltage distortion, imbalance and impedance. The reason: traditional rectifiers address harmonics passively, filtering them out after the fact.

In contrast, AFE drives actively help prevent harmonic distortions detected inside the drive from entering and affecting the broader electrical network. By continuously counteracting harmonics created by non-linear current generated within the drive, active filtration brings harmonics within required range – despite input voltage fluctuations.

Figure 2 below gives an example of harmonic distortion in a non-regenerative drive compared to distortion as controlled by a regenerative drive. In field applications, multiple variables – from the type of loads to power voltage – will affect actual results.

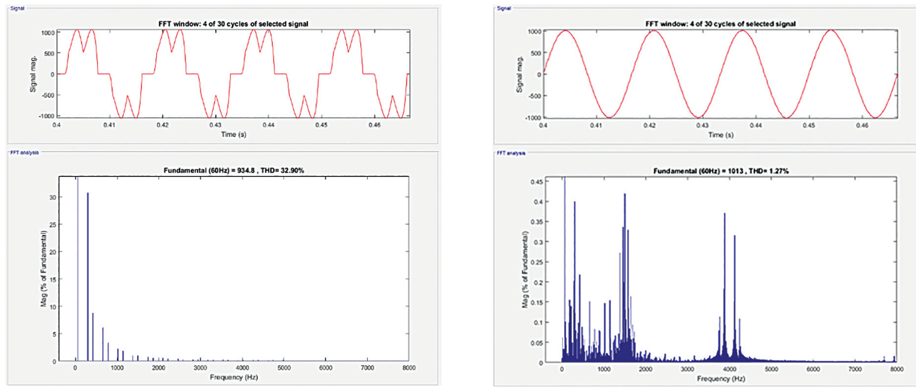

Figure 2: Input current harmonic profile of non-regenerative (left) and regenerative (right) VFDs

In an AFE drive, the rectifier is implemented using an active switching stage. Generally, IGBT-based drives use two power sections. An active rectifier mitigates harmonic distortion by drawing nearly sinusoidal current from the power grid. Whereas most non-active drives create harmonics that produce distortion, the active rectifier in the AFE drive creates canceling harmonics.

Figure 3 below shows an example architecture of the PowerFlex® 755T drives with back-to-back inverters isolated by DC bus capacitors. Generally, an LCL filter is used at input of the AFE drive to provide noise filtering.

AFE drives also help industrial users save space and simplify installation. Passive filter equipment can weigh as much as 500 pounds, posing space challenges within panels and on the factory floor. It can also be difficult to install and move. AFE drives offer self-enclosed filtration, lessening the need to invest in costly, cumbersome external devices.

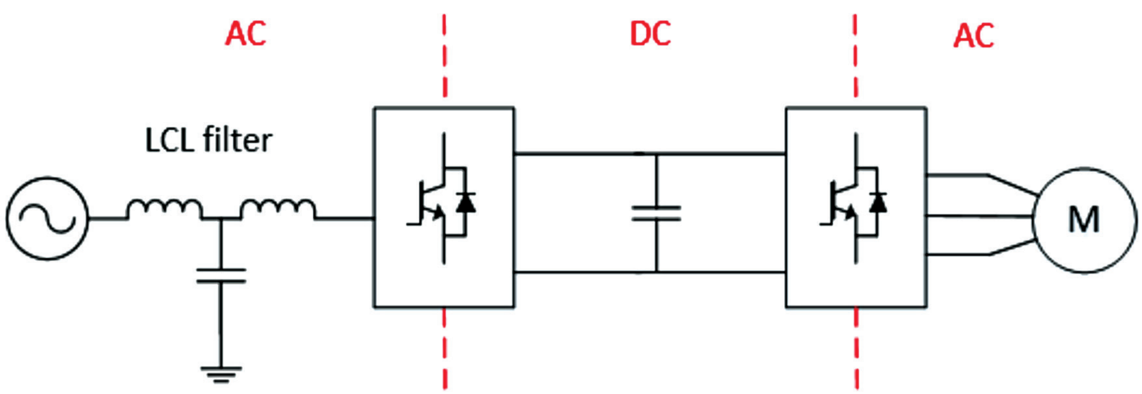

Figure 3: PowerFlex 755T drives architecture

5.0 Mitigating Distortion, Complying with Standards

VFDs are non-linear loads on the power system that can draw current in short, non-continuous bursts. This random form of current is returned to the source, causing the AC input sinusoidal envelope to change: it superimposes new waveforms that are multiples (harmonics) of the original signal.

Industrial applications that produce significant harmonic currents – such as pumping or drilling – are prime candidates for harmonic mitigation. Such currents can negatively affect equipment longevity and performance; they can also alter applied voltage.

To effectively reduce harmonic and voltage distortion – and to optimize power quality within the facility and across the electric utility system – harmonic mitigation should be implemented near the harmonic source: near the load or upstream from the point at which equipment is connected to the electrical system.

The impact of harmonic currents can be felt far beyond the factory floor, too – negatively impacting other power company customers sharing the grid. For this reason, power companies commonly impose harmonic distortion limits on their customers, including VFD manufacturers.

Harmonic guidelines are based on IEC or IEEE standards. IEEE standard 519 provides industry recommended practice and requirements for harmonic control in electric power systems. Manufacturers must not exceed specified maximum levels of total harmonic distortion (THD) of voltage and current. The standards also define maximum recommended contribution of any individual harmonic.

Voltage and current limits from the standard are summarized in Tables 1 and 2 below:

Bus Voltage *V* at PCC	Individual Harmonic (%)	Total Harmonic Distortion 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-519-2014

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
ISC/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

Table 2: Maximum harmonic current distortion limits in percent of I_L per IEEE 519-2014

It is important to understand that the amount of allowable current distortion is dependent on the ratio of short circuit current available at the distribution system (ISC – maximum short circuit current available at point of common coupling PCC), to the maximum load current of the plant (IL – the maximum load current at the PCC).

6.0 AFEs and Energy Regeneration

While some producers favor AFEs for their effectiveness in reducing harmonic distortion, others prioritize their ability to feed energy back to the incoming power supply through regenerative braking.

During the motor braking process, the load drives the motor faster than synchronous speed. As a result, the motor becomes a de facto energy generator. Traditionally, producers have installed and maintained large resistor banks to dissipate heat generated by braking. The resistor brakes themselves can be the source of unwanted heat and require frequent maintenance and cleaning.

But drives with built-in regenerative capabilities can reclaim the excess energy that would otherwise be lost, lessening the need for braking resistors and cooling equipment, and associated wiring, labor installation and maintenance costs.

By converting the mechanical energy produced by the motor and connected load to electrical energy, regenerative drives can return excess electrical energy to the power source. Industrial users can then return recovered energy to the AC motor or to the utility or reuse it to power pumps or cooling fans, for example. The AFE technology can provide both motoring and regenerative power while maintaining near unity power factor.

Regenerative drives are useful in applications requiring overhauling and high-inertia loads. Examples are crane and hoist operations, which require frequent braking during loading, and conveyor belt drives used in parts assembly.

By recovering motor braking energy, regenerative drives help producers reduce energy consumption and are significantly more energy-efficient than resistive braking.

7.0 PowerFlex® AFE Drives

The PowerFlex® 755T drives and bus supplies employ active front-end technology to provide built-in harmonic mitigation and power factor correction, energy regeneration and common bus solutions. The common bus systems enable connection of different types of VFDs, servo drives and other power components to the same DC bus.

The drives are designed to improve energy efficiency, reduce energy costs and minimize power distribution issues in industrial uses. They also meet CE and IEEE 519 standards.

Resources

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