

# Reducing harmonic distortion

**Ian Evans of Harmonic Solutions looks at a new technology to reduce harmonics for AC drives.**

**A**C variable frequency drives are now commonplace throughout the world, covering the complete spectrum of sectors from air conditioning through to process industries, pumping systems and even main propulsion for ships. Growth continues at around 20 per cent per year. The benefits of AC variable speed drives are widely acknowledged; energy efficiency, decreased maintenance, ease of automatic control being the salient ones.

An issue, however, which is giving increasing cause for concern throughout the world is the harmonic distortion of voltage supplies caused by the non-sinusoidal currents drawn during the power

conversion process inside drive converters and other types of electronic equipment.

The current design of AC PWM drives results in a pulsed current being drawn from the supply which contain harmonic components. These additional currents are multiples of the fundamental frequency current. For example, on 50Hz power, the 5th harmonic would be 250Hz current, the 7th 350Hz, etc. To attenuate this pulsed current, designers usually install inductors in either the AC line or DC bus of the drive. Figure 1 illustrates a typical 6 pulse AC drive with 3 per cent DC bus inductance fitted resulting in total 'harmonic current distortion' (ITHD) of 39.5 per cent. (Without the DC bus inductor the  $I_{THD}$  would be around 67 per cent).

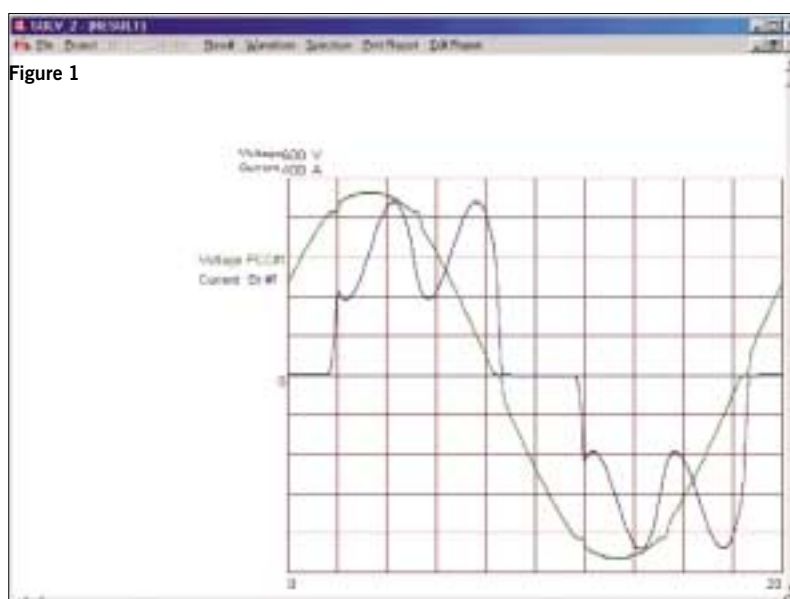


Figure 1

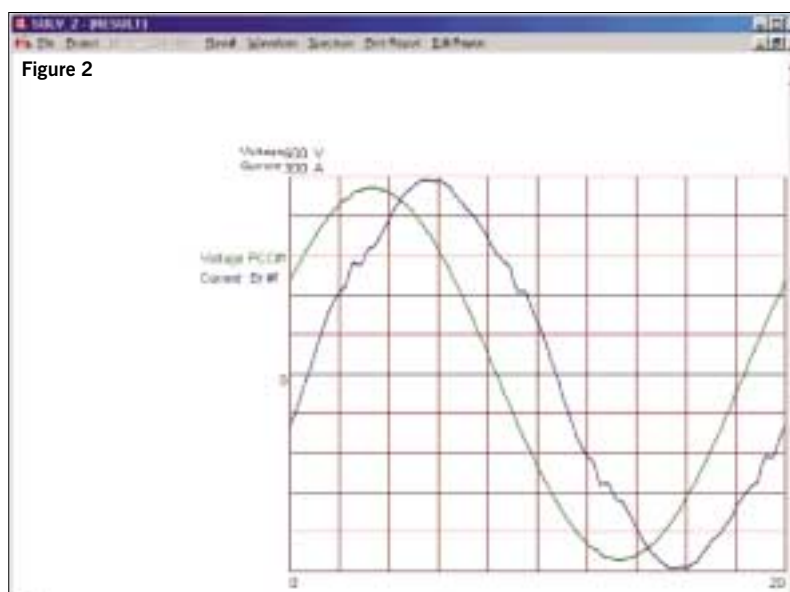


Figure 2

Fig 2 illustrates the effect of the Lineator on the same AC drive shown in Fig 1. In Fig 1 the drive used a 3 per cent DC bus inductor resulting in a ITHD of 39.1 per cent. With the Lineator connected the ITHD dramatically dropped to 5.1 per cent. For optimum performance AC line reactors or DC bus inductors could be omitted from the drive, ideally making the drive slightly less expensive.

## Recommendations

To reduce harmonic distortion in the electricity supply networks various countries implement harmonic recommendations. In North America, and to a major degree, internationally, IEEE 519 (1992) is the recognised 'standard'. In the UK Engineering Recommendation G5/4 (2001) came into force in 2001 for equipment connected to the public electricity supply network (i.e. not connected to discrete generators).

Harmonic distortion is widely recognised as a significant cause of damage to, and mal-operation of electrical equipment. On generators however, such as those found on remote pumping stations, ships or on standby plant, the effects of harmonics are significantly more pronounced. These are 'weak' sources where impedances can be as high as (15-20 per cent) compared to 'stiff' sources (4-6 per cent), more common in utility applications. The 'weaker' the source, the higher the voltage distortion, for a given harmonic current.

## Phase shift

Traditionally, drive manufacturers used phase shift transformers and modified drives to reduce harmonic currents, with 12 pulse the most common. 18, 24, 36 and even 48 pulse designs are also used. 12 pulse mitigation provide levels of  $I_{THD}$  from ~15 per cent for polygonal auto-transformers to 8-12 per cent for the more expensive double-wound types. This method however reduces the overall efficiencies of the drive system from 96-97 per cent to as low as 92 per cent, primarily due to additional transformers losses under harmonic loads. The phase shifted limbs of the transformers must be carefully balanced and any pre-existing



**Left: Figure 3 illustrates two 820kW/1,100HP chassis Lineators awaiting crating.**

voltage distortion or voltage imbalance must remain low otherwise performance is significantly degraded.

Active filters, which inject compensation current to 'cancel out' a major portion of the harmonic currents, are available. Due to the filter's low impedance (<1 per cent), connected loads will draw more harmonic current (~10-15 per cent more) compared with no active filter in circuit. This additional harmonic current needs to be taken into account during selection. The increased harmonic current may be problematic to 'upstream' loads.

Fast responding active filters provide excellent performance (<5 per cent  $I_{THD}$ ) however, some analogue based filters may inject excessive reactive current when the harmonic load is light or switched off, causing generator tripping and other problems. Active filters are currently very expensive, costing significantly more than the drive. Reliability of these complex products is a concern and commissioning engineers are necessary to achieve optimum performance.

## Active front ends

Some companies offer 'active front ends' aka 'sinusoidal rectifiers', fitted to their AC drives, producing a sinusoidal input current waveform with less than 5 per cent  $I_{THD}$  whilst also providing regenerative braking. However, the reliability of this approach is also a concern, especially if the drive is used for critical duties. In addition, the switching frequency of the input bridge often require large reactors and passive filter networks to attenuate the EMI and RFI radiated signals and voltage ripple (at carrier frequencies), which could effect other connected equipment. Prices are currently high, often being more than double the price of a conventional drive.

Over the last three years a unique form of passive mitigation specifically designed



**Above: AC variable frequency drives are now commonplace throughout the world, covering the complete spectrum of sectors from air conditioning through to process industries, pumping systems.**

for standard 6 pulse AC drives has been gaining popularity throughout the world. The Lineator™, manufactured by Mirus International, can be connected in series to virtually any 6 pulse AC drive with either diode or SCR pre-charge input bridges to dramatically reduce the harmonic current.

The design achieves cancellation of all major harmonic currents resulting in a  $I_{THD}$  of between 5-8 per cent at full-load operation. This dramatic reduction in harmonic current is achieved through patented multiple reactor winding design, which creates an output voltage waveform shape that allows the drive input diodes to conduct current over a longer time span and with a substantially lower peak value.

Lineator has a three phase reactor design consisting of multiple windings formed on a common core, allowing a

smaller capacitor bank without sacrificing harmonic mitigation performance or introducing unacceptable voltage drops. Due to the low capacitive reactance (<15 per cent of rated kVA) the Lineator is compatible with all forms of power generators.

It is currently available from 3kW to over 2,500kW in voltages up to 690V, can be applied to single or multiple drives (rated at the sum of drive kW) and can be retrofitted to existing drives, enabling standard 6 pulse AC drives to achieve levels of harmonic mitigation better than that normally associated with 18 pulse drives, and unlike active filters effectively isolates the AC drive load from the effects of any pre-existing voltage distortion, very important in marine and offshore applications.

## Low losses

In addition, the Lineator's low losses (>99 per cent efficiency) result in overall efficiencies of the Lineator/drive combination being typically 3-4 per cent better than 12 or 18 pulse designs. This is crucially important in, for example, remote pumping stations supplied from generators where the cost of prime mover fuel is high or where the 'wire to water efficiencies' must be as high as possible to minimise running costs.

The standard Lineator model outperforms 18 pulse drives but for applications where 12 pulse performance is acceptable a 12 per cent  $I_{THD}$  model is available. This unit, when connected to standard 6 pulse drive offers harmonic performance similar to conventional 12 pulse drives (< 12 per cent  $I_{thd}$ ) at a lower cost and slightly smaller footprint than the standard.

## Variant model

Currently in development is a variant which, when connected to the primary winding (LV or MV up to 13.8kV) of a 12 pulse phase shift transformer, results in harmonic performance akin to 24-36 pulse drives without the very high cost and space requirements of 24 or 36 pulse drives. The unit is extremely compact, around 25 per cent the size of a standard Lineator. Although primarily aimed at the marine market the unit can be used with virtually any 12 pulse AC drive.

Lineator can be supplied in chassis form for installation in drive cabinets, MCCs or in stand-alone enclosures. Its rugged construction, simple design and inherent reliability, coupled with excellent harmonic mitigation performance and high efficiency make Lineator technology a very serious contender for the majority of AC variable frequency drive harmonic attenuation demands whether it be IEEE 519 (1992), ER G5/4 (2001) or other harmonic standard. **AE**

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