Voltage supply impedance can cause havoc in power systems. Unfortunately, many project contractors that agree to abide by harmonic standards specified in contracts often have very limited knowledge of harmonics, their effects or the real cost of compliance. Ian Evans of Harmonic Solutions reports.

Methods of mitigation

Above: Water pumping station with variable speed pumps

The increase in use of AC variable frequency drives in the Middle East over the past five years has been tremendous. Applications are diverse, including water and sewage and air conditioning plant.

An issue giving increasing cause for concern in the region, however, is the harmonic distortion of voltage supplies due to non-sinusoidal currents drawn during the power conversion process inside drive converters and other types of electronic equipment.

Harmonic currents cause havoc in power systems, especially with generators, such as those found on remote pumping stations and standby plant.

These are 'weak' sources where impedances can be as high as 15-18% compared to 'stiff' sources (5-6%), more common in utility connections. The 'weaker' the source, the higher the harmonic voltage distortion, for a given harmonic current distortion. Figure 1 illustrates the effect of excessive harmonic currents on a generator voltage output.

Typical effects of harmonic distortion include:

- Overheating and destruction of power factor correction capacitors. Danger of resonance (i.e., voltage amplification) if 'detuning reactors' are not fitted to the capacitor bank, causing catastrophic damage to capacitors and other equipment.
- Overheating of stators and rotors of fixed speed electric motors; risk of bearing collapse due to hot rotors, especially problematic on explosion-proof motors with increased risk of explosion. In any case, if the voltage distortion exceeds the prescribed limit stated on the certification, explosion-proof motors are no longer certified, losing any third party assurance regarding safety.
- Spurious tripping of electrical circuit breakers. Interference with electrical, electronic and control system equipment, including computers, radio/TV communications and CCTV, measuring devices, lighting, etc.
- Overheating of cables, including neutral conductors; additional risk of failure due to resonance. Decreased ability to carry rated current due to 'skin effect', which reduces a cable's effective cross sectional area.

Recommendations

To limit the magnitude of harmonics 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' and is by far the most common specified by Middle East consultants, followed some way behind by UK's new G5/4 (2001).

IEEE 519 (1992) is easily understood; the maximum harmonic current permissible at a designated 'point of common coupling' being related to the short circuit capacity of the supply.

Below: Figure 1 – Effect of excessive harmonic currents on generator voltage

According to IEEE 519 (1992), "within an industrial plant, the PCC is the point of connection between the non-linear load(s) and other loads". This ensures that if IEEE 519 (1992) is complied with there will be no damage to, or adverse effects upon, the equipment connected within that plant, and the utility supply will be protected.

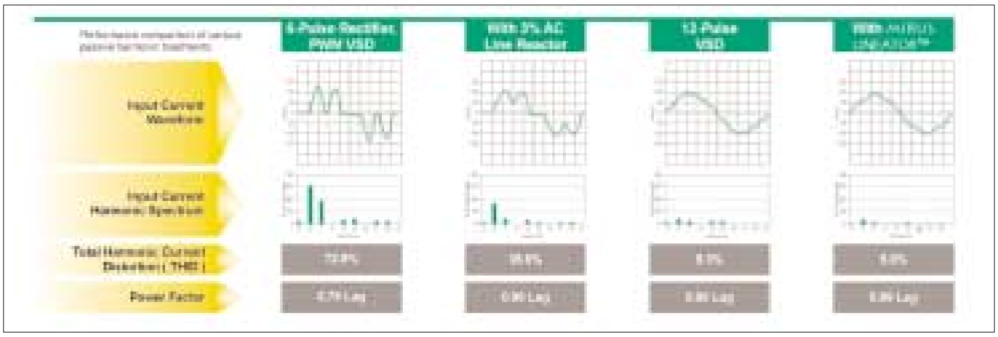
In comparison, the UK's G5/4 (2001) is only concerned with protection of the utility supply network, not consumer plant and equipment. It is therefore not surprising that IEEE 519 (1992) is a more popular standard.

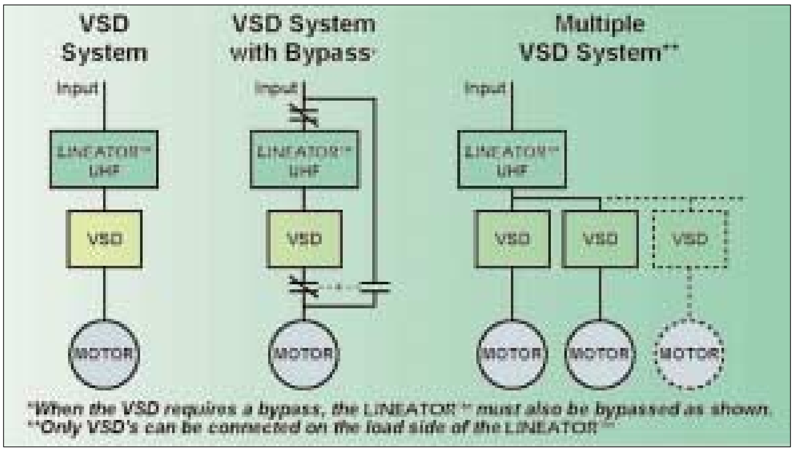
IEEE 519 (1992) defines the maximum recommended voltage distortion (VTHD) for 'general systems' to be 5% with no more than 3% of any individual harmonic. For 'special applications' such as hospitals and airports a lower limit of 3% applies. For 'dedicated systems' with 100% converter load (i.e., no non-linear loads) a higher limit of 10% voltage distortion is permitted.

In IEEE 519 (1992) the permitted current distortion varies with respect to the system fault level and the total load demand as illustrated below.

Unfortunately, in the author's experience a project harmonic standard is frequently disregarded if the costs of compliance are higher than anticipated or the project is over budget. Many contractors agree to abide by the harmonic standards specified in the contract but often have very limited knowledge of harmonics, their effects or the real cost of compliance.

The design of AC variable frequency drives results in a pulsed current being drawn from the supply containing harmonic currents; refer to Fig 2 ('6 pulse rectifier, PWM VSD'). The 'Total Harmonic Current Distortion' (THID) illustrated, 72.9%, is typical. In order to attenuate the magnitude of these pulsed currents drive designers often install inductors in either the AC line or in the DC bus of the drive, occasionally both. The reactance values vary between 2% and 5% with 3% being the norm, usually inserted in the AC line; 3% is the optimal value based on performance and additional drive cost.





Above: Figure 2 – Comparison of passive harmonic mitigation for AC drives

Left: Figure 3 – Lineator connection and application examples

Figure 2 ('with 3% AC line reactor') illustrates a THID of 35.6 per cent. The majority of AC drives up 7.5kW have no inductance fitted, resulting in high level current distortion. The problem is further exacerbated on installations with large numbers of single phase or low kW drives.

In reality, it is impossible to comply with IEEE 519 (1992) using only AC line or DC bus reactors. Other methods of mitigation are needed.

Traditionally, drive manufacturers have used phase shift transformers and modified drives to provide a greater level of harmonic attenuation, with 12 pulse being the most common; 18, 24, 36 and even 48 pulse designs are also used on occasion. A 12 pulse drive consists of 2 x 6 pulse input rectifiers, displaced by 30 electrical degrees, operating in parallel. The 30 degrees phase shift is obtained using a special transformer with three windings. Due to differences in the instantaneous outputs of each rectifier an inter-phase reactor is usually required.

Twelve pulse mitigation provide levels of THID from ~15% for polygonal autotransformers to 9-10% for the more expensive double wound types (figure 2 '12 pulse VSD'). Their use however, reduces the overall efficiencies of drive systems, often by 4-5%, primarily due to the losses of the transformers under harmonic loads.

In addition, the phase shifted limbs of the transformers must be carefully balanced and any pre-existing voltage distortion and voltage imbalance must be low otherwise the harmonic mitigation will be significantly degraded. Twelve pulse drives are not usually available under 55kW (75HP) and cannot be used for multiple drive mitigation. Twelve pulse drives cannot comply with the more stringent IEEE 519 (1992) short circuit ratings. However, 18 pulse drives do comply, which explains their great popularity in North America.

Other more advanced solutions to ensure compliance with IEEE 519 (1992) include AC drives with active front ends and active shunt filters, both of which offer excellent harmonic mitigation performance (<5% THID). However, high cost, decreased efficiency, reduced reliability and adverse interaction with other equipment have resulted to date, in these solutions not being universally popular.

Compliance

If guaranteed compliance with IEEE 519 (1992) is required, and at reasonable cost, there is another solution. The Lineator^{TM}, a patented device manufactured by Mirus International Inc., consists of a series connected multiple winding input line reactor and small capacitor bank which when applied to virtually any 6 pulse AC PWM drive results in a THID of between 5 to 8% at full load operation (figure 2 'with Lineator').

The reduction in harmonic currents is achieved through patented multiple reactor winding design that 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. In addition, due to the low capacitive reactance (<15% of rated kVA) the Lineator is still compatible with all forms of power generators.

As illustrated in figure 3, unlike multi-pulse systems, Lineator an be applied to individual or multiple 6 pulse AC drives between 3kW (4HP) and 2,500kW (3,350HP) and can be retrofitted to existing 6 pulse AC drives. Low losses (>99% efficiency) result in overall efficiencies being typically 3-4% points better than 12 or 18 pulse designs, 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.

Rugged construction, simple design and inherent reliability coupled with excellent harmonic mitigation performance and high efficiency should ensure this device receives serious attention for all AC drive applications alongside traditional methods. MEE

Table 1 : North American IEEE 519 (1992) Recommendations (120V – 69kV)

I_{SC}/I_L	<11	11-17	17-23	23-35	>35	TDD
<20	4%	2%	1.5%	0.6%	0.3%	5%
20<50	7%	3.5%	2.5%	1%	0.5%	8%
50<100	10%	4.5%	4%	1.5%	0.7%	12%
100<1000	12%	5.5%	5%	2%	1%	15%
>1000	15%	7%	6%	2.5%	1.4%	20%

I_{SC} = Short circuit current at point of common coupling (PCC). The PCC can be considered as the connection point between linear and non-linear (harmonic producing) loads.
I_L = Maximum demand load current (fundamental) at PCC.
TDD = 'Total demand distortion' of current (expressed as measured total harmonic current distortion, per unit of load current. For example, a 30% total current distortion measured against a 50% load would result in a TDD of 15%).

Note:
i) Maximum permissible current distortion in % of load current (IL).
ii) Individual Harmonic Order (odd harmonics).

Contact:
harmonicsolutions@tiscali.co.uk