The high price of poor power quality

The main power quality issues confronting offshore rigs and platforms, and the mitigation methods currently available, are examined here by Harmonic Solutions' **Ian Evans** and DSE Oil & Gas' **Richard Keijser**.

Electrical variable speed drives are commonplace onboard drilling rigs/ships and offshore platforms. Their operation, however, can significantly degrade the electrical power quality of the vessel or installation. Marine classification societies and other bodies have rules and recommendations to limit the harmonic voltage distortion. However, these rules and recommendations are rarely policed as effectively as they should be, resulting in a considerable number of installations having many times the permitted maximum voltage distortion limit.

The quality and security of voltage supplies are crucial to the safety and operational integrity of any vessel or installation, irrespective of class or type. This simply cannot be overstated. Any failure or malfunction of equipment due to poor power quality can result in loss of production or an incident with possible severe or disastrous consequences. This article takes a brief look at the main power quality issues and provides simple guidance regarding the mitigation methods presently available.

Drives with SCR rectifiers

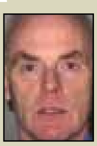
Fully controllable SCR (ie thyristor) rectifiers such as those found in DC drives are characterized by 'line notching'. This phenomenon occurs naturally during the commutation period (ie when one phase passes current to the next). Due the inductance in the circuit the commutation does not take place instantaneously. As one SCR is turning off but still conducting, the next SCR in the sequence is turning on and commencing conduction. The result is a short circuit of the supply voltage, only limited by the inductance in the circuit. If the inductance in circuit is minimal then the supply voltage can fall almost to zero.

Figure 1 shows one phase of the supply voltage from a 600V drilling switchboard with 6000hp (4476kW) of installed 6-pulse, DC SCR drives. Following what seems to be common but poor offshore engineering practice, no AC side commutation reactors had been installed at the input of each DC drive. The result was the voltage waveform and current waveforms illustrated in *Figure 1.*

Fully controlled SCR rectifiers (and all other types of conventional power converters) draw non-linear current from the supply which contains harmonic currents. These harmonic currents interact (ie Ohms law, V=IR) with the impedances in the system at their respective frequencies to produce their respective voltage drops, termed 'harmonic voltages'. These voltages, up to the 50th harmonic are summed appropriately to obtain the 'total harmonic voltage distortion' or 'THDv'.

The objective of rules and recommendations is to limit the THDv, most commonly to 5% or 8%. To achieve this, the magnitude of the harmonic currents drawn by the non-linear load(s),

About the authors



Ian C Evans is managing director of Scottish-based Harmonic Solutions, which also has a UAE office and agents in 12 countries providing harmonic and power quality solutions worldwide. A qualified electrical engineer with a solid marine and offshore electrical engineering background, he introduced active filters into Europe in 1997, Lineator wide spectrum filters in 2002 and wrote the harmonics guidance notes for ABS in 2005. More recently, he co-founded (with Dr Rudy Limpaecher) AC Link Power Conversion, which is developing AC Link active transformer-based common DC bus and DC ring main systems for marine and offshore VFD and subsea applications using arguably the world's first harmonic-less, transformer-less power conversion technology.

Richard Keijser, a former electrical engineer with Corus Steel, initially became involved in power quality problems on offshore oil and gas installations while working for Shell Labs in Amsterdam in 1995. In 2001 he co-founded Eprofs Engineering, a company specialising in resolving offshore power quality issues on offshore drilling and production installations, with merged with DSE Oil & Gas BV last year. Keijser and his staff have co-operated closely with Harmonic Solutions on challenging harmonic and power quality issues worldwide for over six years.

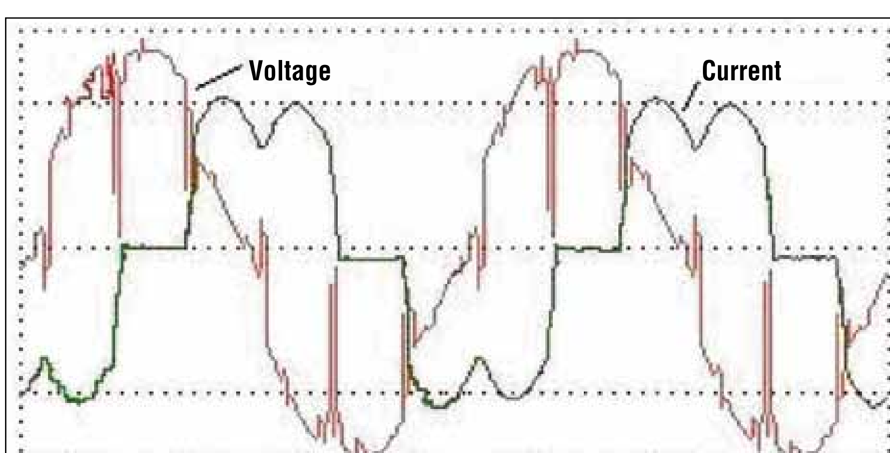


Figure 1: Line notching on voltage supply due to fully controlled SCR rectifiers on DC drilling package drives.

which otherwise flow in the system, has to be reduced significantly. This is the essence of all harmonic mitigation.

On further examination of *Figure 1*, two salient issues emerge:

- The line voltage is 'non-sinusoidal' and indicates a combination of excessive voltage distortion and severe line notching. The drilling package Irms current was unbalanced as can be seen in the differing current pulse amplitudes. A THDi of 27.2% was measured but did not contribute an excessive level of voltage distortion however. A large portion of voltage distortion (THDv) was 'pre-existing' (ie due to other drive loads on the system).
- The depth of the primary line notches to almost zero may interfere with equipment which depend on 'zero-crossovers' for timing. This includes generator AVRs and other DC drives which depend on the fundamental frequency for correct triggering of the SCRs. Any additional zero-crossovers in the latter can result in misfiring in the DC drives which can blow fuses and possibly SCR devices, both rendering the drive(s) inoperable.

Voltage spikes. A serious side-effect of line notching, which has become more prevalent since the introduction of VFDs, is that of voltage spikes which often manifest themselves in the destruction of the VFD DC bus capacitors and other equipment. This is often made worse by the installation of EMC filters as the EMC capacitors actually accelerate the destruction of the DC bus capacitors.

The primary cause of the voltage spikes is the lack of AC line or 'commutation' reactors on DC drives. A 3% commutation reactor would reduce the notch depth by around 50% (which removes the additional zero crossover problem) but would then widen it also by around 50%. The energy in the notch can only be reduced by the injection of reactive power. Reactors also attenuate harmonic currents but tend to have a greater effect on AC PWM variable frequency drives (VFDs) than on DC drives, due to large inductance in the latter. Reactors are inexpensive but retrofitting them is often rejected on space grounds.

Protection for VFDs from voltage spikes. One solution may be to protect VFDs from damaging voltage spikes by installing a Lineator wide spectrum filter. This is primarily used as a high performance, passive harmonic mitigation device which reduces the total harmonic current distortion produced 6-pulse DC drives and VFDs to around 4-6% It also acts as an excellent blocking filter, attenuating any voltage spikes and other mains side disturbances (see *Figure 2*).

An active option. High performance, broadband active filter can provide both harmonic mitigation and reactive power control. When used with 3% AC line reactors for each DC drive, they can effectively attenuate line notching on SCR rectifiers, thus resolving the voltage spike issue at source. The active filter also reduces the THDi to <5%.

Although broadband filters are expensive (all active filters are expensive), they can be very effective if applied correctly. Be aware, however, that standard 'selective FFT' type active filters do not have the required response to treat dynamic loads such as DC drilling package drives. They respond in 40mS where 'broadband' types are in the range 40-100uS for both harmonic mitigation and line notching attenuation.

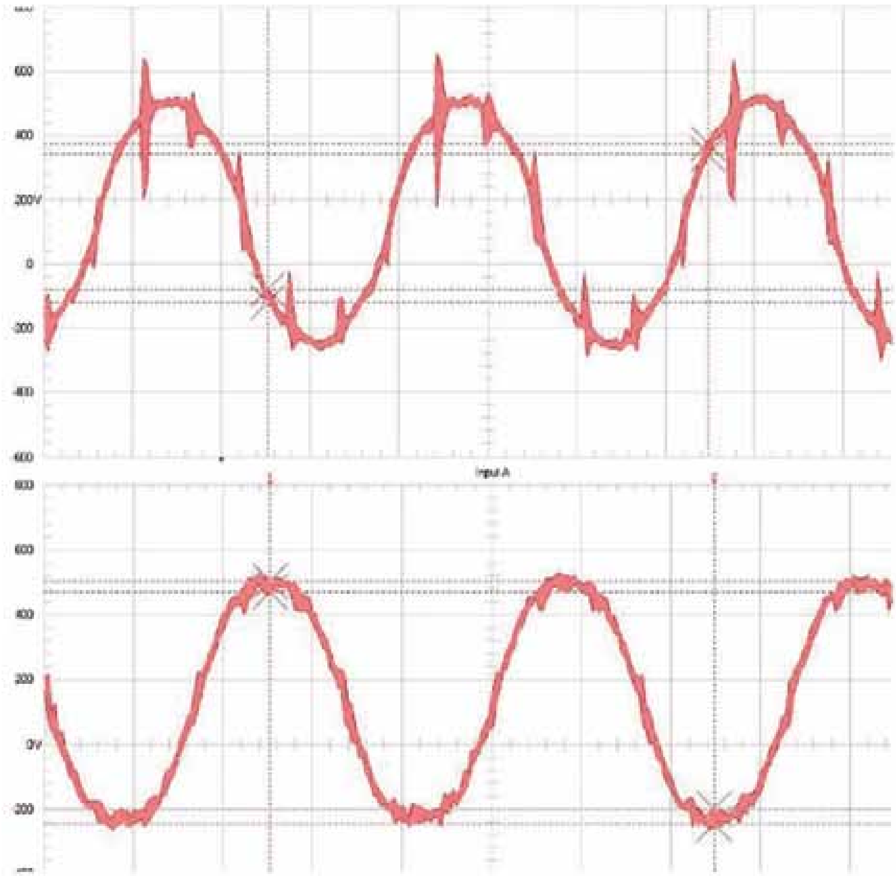


Figure 2: The input (upper trace) and output (lower trace) of a Lineator on a DC drilling package system with significant voltage spikes. The VFDs are connected to supply on the lower trace.

AC VFDs and systems

Applications for VFDs on drilling rigs/ships also include drilling packages, either standalone or within common DC bus systems, as well as pumps, shakers, centrifuges and other applications. On offshore oil installations VFDs are used, for example, to drive large compressors and electrical submersible pumps (ESPs).

The diode and SCR pre-charge rectifiers used in VFDs do not usually produce significant notching. The main problem is that of voltage distortion produced a result of the harmonic currents drawn from the supply. The THDi for a 6-pulse VFD fitted with a standard 3% AC line reactors is around 38-40%. (For 6-pulse DC drives, the THDi is in region of 28-32%).

There are a number of methods to reduce the harmonic current drawn by VFDs:

i) Multi-pulse drives. These VFDs comprise of multiple 6-pulse rectifiers with phase shift transformers. 18 and 24-pulse VFDs are the more common for larger VFDs and reduce, in ideal conditions, the THDi to around 5-7% and 3-4% respectively. These types of VFD are generally very reliable but are costly with a large overall space requirement. Real world mitigation performance is significantly degraded due to imbalances in the transformer/converter and/or the supply and/or if significant background THDv is present.

ii) Quasi multi-pulse systems. This solution is similar to multi-pulse drives but uses phase shift transformers for each drive or load to try and achieve the required harmonic cancellation. The design performance is dependent upon balanced loading between all the drives and is degraded by imbalances and

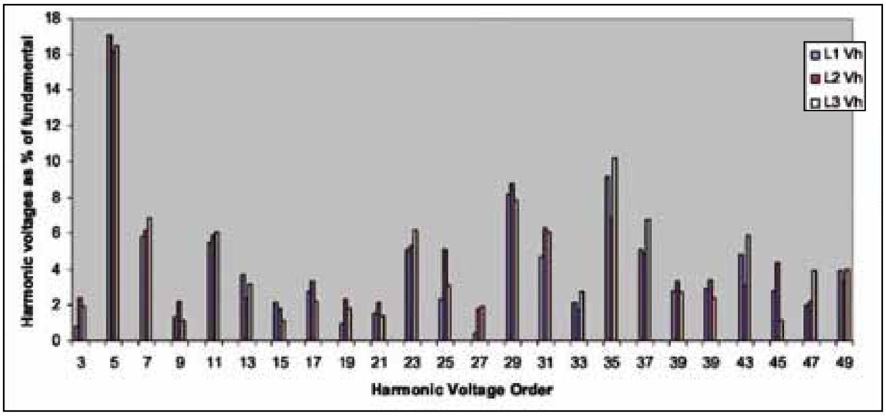


Figure 3: Example of offshore oil platform harmonic voltage spectrum (without fundamental) measured on 690V busbars. Average THDv is 26.61% of which 18.87% is >21st harmonic due to large number of 24-pulse VFDs.

background voltage distortion. Quasi-24-pulse systems are popular on common DC bus systems with variable results depending on whether the bus-tie is open or closed.

iii) Active front end (AFE) drives or rectifiers. The rectifier(s) in a standard VFD or common DC bus system are replaced with an IGBT 'sinusoidal rectifier(s)' and large input passive filter in order to synthesize an input sine wave. Performance is 4-7% THDi (<50th harmonic only). They are costly, large and can have several serious downsides including the production of significant additional harmonic currents >50th, large emissions of EMI between 10-100kHz, an AFE switching frequency ripple on the supply voltage which can interact adversely with 6-pulse VFDs and possible input passive filter capacitor interaction with generators when energized with no AFE drive load. AFE drives are also very complex and difficult to repair by local electrical staff without specialist training.

iv) Lineator wide spectrum filters. Lineators are patented, passive, tri-limbed reactors with a very small capacitor bank designed to reduce the THDi of 6-pulse VFDs or DC drives to around 5-6%, irrespective of whether drive reactors are installed. As mentioned earlier, Lineators also effectively isolate the drive(s) from any mains disturbances and background THDv (ie they also act as a blocking filter). On SCR rectifiers, line notching is also very effectively reduced. They can be used for both single or multiple drive mitigation. Lineators are extremely rugged electrically, reliable and require minimum maintenance. Power availability is currently to 4600HP/3500kW up to 690V/950V. Applications include drilling packages (AC and DC), thrusters, standby drilling generators and other duties.

v) Broadband active filters. All active filters are based on technology similar to VFDs with IGBTs and a DC bus. However, active filters are a low impedance source (<1%) for the load harmonic currents. The active filter provides, in the case of broadband filters, the non-fundament current, so the generators in theory only provide the fundamental current.

Broadband active filters can offer excellent performance to <5% THDi. Cost can be minimized if the filter is connected where it can best benefit from any 'phase angle diversification' (ie natural harmonic cancellation) due to multiple drives (AC or DC) on the same supply. AC line reactors are usually required (if not fitted to the drives) to protect the snubbers on the on SCRs (DC drives) from any high frequency ripple and to reduce 'additional' harmonic current due to the filter's very low source impedance. Using low impedance transformers, operation up to 11kV possible.

They are complex products but maintainable by local staff with appropriate training.

An unwelcome downside

Figure 3 illustrates an example of the harmonic voltage spectrum measured on the 690V busbars of an oil production platform. As can be seen, the THDv is very high (over 26%). However, what is of more concern is the level of voltage distortion above the 21st harmonic (ie almost 19%). This distortion was attributed to a large number of high power VFDs, mainly 24-pulse, driving electrical submersible pumps (ESPs) from connected upstream MV supplies which appears as background THDv on the 690V switchboard.

Section 6 of the IEC/EN 60034-1 permits explosion-proof motors a maximum of 2% harmonic voltage distortion (3% for Type N under IEC/EN 60034012) before the motors become legally uncertified. The overall THDv in *Figure 3* is significantly in excess of those limits. However, this is not an isolated case. What is now starting to give real cause for concern for health & safety authorities worldwide and others is the potential effect of such large high-order (eg >21st) voltage harmonics on explosion-proof motors, especially on rotors, subject to these very high levels of distortion at 'induction heating' frequencies. The IEC is now finally aware of the problem and hopefully will investigate it urgently. It is also hoped the safety authorities will start taking the matter more seriously before an incident occurs.

This type of high-order harmonic distortion is extremely difficult and costly to treat using conventional technologies. However, there is a new 'harmonic-less (<1% THDi), transformer-less' power conversion technology called AC Link. The technology can be configured as an AC-AC 'active transformer' which acts as a series harmonic filter to resolve issues such as outlined in *Figure 3*. For LV or MV common DC bus or DC ring main systems which supply VFD IGBT rectifiers with DC power AC-DC active transformers can be utilized. AC Link converters or active transformers do not require conventional transformers; instead they use internal 20kHz nanocrystalline types which are orders of magnitude smaller than conventional types [eg, a 250kW AC Link transformer weighs 11kg/24lbs]. AC Link technology will undoubtedly offer advanced, compact, true 'clean power' solutions to offshore drilling and production sectors in the near future.

However, at present there are a number of possible conventional solutions available but each has to be considered on its own merit for each application (none is perfect). There are no 'one fix' solutions despite what the salesman tries to tell you.

The wrong type of 'solution' or the right type of solution in the wrong place, can make matters considerably worse and can lead to disaster.

A full system single line diagram and a full set of harmonic measurements for the given application is the only sound starting point.

From these the possible routes to the options will be clearer. Many offshore power quality applications may be challenging but eminently resolvable based on the expertise, knowledge and the correct options. **OE**