THE FIRST STEP IN THE RESOLUTION OF VOLTAGE DISTORTION FOR SHARED GENERATORS AND MV UNDERSEA RING MAIN IN AN OFFSHORE OIL FIELD

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Ian C. Evans
Managing Partner
Harmonics Solutions Co. UK
Dunfermline, Fife, Scotland UK
harmonicsolutions@tiscali.co.uk

James R. Johnson
Member, IEEE
Product Manager – AccuSine
Schneider Electric – North America
Salem, Oregon USA
jjohnson@accusine.com

Abstract

Offshore oil platforms employ a number of types of AC and DC motor speed control systems to perform the majority of the functions required for drilling, pumping, and processing of the crude oil. The harmonics and subsequent voltage distortion produced by the drives can be problematic for generator systems, fixed speed explosion proof motors and other equipment.

Additionally, some companies are consolidating generator operations to dramatically reduce fuel consumption. Medium voltage (MV) ring main systems where one or more generating platforms supply power to other platforms via undersea power cabling are being installed. While this does prove to be an effective method to reduce fuel costs, there are some unintended, adverse consequences due to the harmonics and undersea cable capacitance.

Many harmonic related problems were discovered. One example being the THDv (total harmonic voltage distortion) on a platform at the 600 VAC distribution bus was close to 25% (see Fig 2). This exceeds all reasonable safe levels of all harmonic standards around the world. Additionally, the resultant over heating of the windings of generators and fixed speed motors occurs. The voltage distortion levels are seen at all functioning levels for the connected platforms.

This paper will present data collected during the investigation of the problems in a North Sea oil field that has similarities throughout the global oil industry and the results of applying harmonic and power factor correction systems to resolve the issues.

Index Terms – harmonics, total harmonic voltage distortion (THDv), total harmonic current distortion (THDi), resonance, active harmonic filter (AHF), generators, undersea ring main, offshore oil platforms

Introduction

Harmonic voltage distortion is very much a fact of life on offshore oil production platforms, drilling rigs and ships where the majority of the non linear loading usually emanates from drilling drive systems (DC or AC) and AC electrical submersible pump drives (ESPs), thrusters, main propulsion systems, winches, etc. These loads often comprise up to 85% of the operating capacity the generator system.

It is now acknowledged that it is not outside the realms of possibility that a combination of excessive harmonic voltage distortion (THDv), fixed speed ExN (non sparking motors for use in Zone 2 only) with deep bar or double cage rotors driving the compressors and an escape of gas or vapour may have contributed to the Piper Alpha Disaster, the world's worst offshore oilfield disaster, which occurred off Scotland in 1988 killing 167 personnel. More recently, in March 2006, an electric motor 'blew up' (according to the press) in the Scottish North Sea and started a fire which took four hours to extinguish. The platform in question, owned and operated by a major multi-national oil company, was acknowledged to have high levels of voltage distortion.

Regarding, protection concepts for fixed speed explosion proof motors, it is interesting to note that in Europe EN 600034-1 limits the 'harmonic voltage factor' (HVF – similar to background THDv) to 2% for EExe (increased safety), EExd (flameproof) and EExp (pressurized) motors. Under EN 60034-12 3% HVF is permitted for EExN (non sparking) motors for Zone 2 only. When one of the authors contacted both UL and NEMA in 2004 they had not recognized the problem and each stated that it was the responsibility of the other.

It should be understood that if fixed speed explosion proof motors of European design or certification are subject to harmonic voltage distortion above stated compliance levels then they are "no longer operating under the conditions envisaged when they are certified" accordant to EN 600034-1 and, therefore, the certificate for third party approvals that they are safe for the purpose are no longer valid. For US explosion-proof motors the situation remains unclear. There may be a potential danger but, unlike Europe, UL and NEMA do not recognize the problem, so the motors still may be certified but remain potentially dangerous.

There are problems associated with harmonic distortion when present in generator supplied electrical systems. The high impedance (subtransient reactance, X"d) of generators exacerbates the voltage distortion immensely.

Harmonic complications due to cabling

A US company operating in the Scottish North Sea decided to redesign the power generation and supply system on a recently acquired oilfield in order to save a significant amount of operating costs on the fuel used to power the diesel generators. The original oilfield power design had four platforms, A, B, C and D. All had onboard generating capacity. A fifth satellite platform (E) was supplied from both platforms A and D at 11kV. The majority of the platforms had been in operation for a number of years with no obvious harmonics problems.

The new design called for the removal of all diesel generators and the installation of large gas turbine generators on two of the platforms. A ring main was installed to supply all five platforms with power. Due to the distances between platforms and other issues, 33kV was used as the transmission voltage. Each platform has 33kV/11kV transformers to supply the respective power systems.

During a detailed study of the revised system the consultants calculated that due to the 33kV cable capacitive reactance, resonance was possible between 250 and 550 hertz (Hz) on this 50 Hz system, also identified as between the 5th to 11th harmonic orders. Additionally, the resonant frequency would vary within that bandwidth according to operating conditions.

Solutions were investigated in order to reduce the possibility of resonance. All passive L-C (inductor-capacitor) based systems using PF capacitors were eliminated at an early stage. When these devices are added to the existing electrical system, the passive filters had the effect of moving the resonant frequency to even lower harmonic orders. The expected result is resonance at lower frequencies than presently observed with higher amplitude peak voltage and current levels, a much more hazardous situation.

Multi-pulsing was a possibility because PF capacitors were not involved. However, retrofitting the numerous drives was deemed a massive amount of expense and extremely time consuming and would seriously disrupt operations.

In order to use the existing drives equipment but achieve a stable electrical system, the consultants selected active harmonic filters (AHF) to perform the harmonic clean up and the power factor correction for the low voltage DC SCR drives. Since there are several types of AHF, they conducted an in depth analysis looking to maximize the intended results of maximum dynamic harmonic response and correction of power factor.

There are two types of logic designs prevalent in AHF. Some employ fast Fourier analysis (FFT) logic to determine the harmonic spectrum of the current and inject only selected ranges or specific harmonic orders for correction. Of these products, some cancel discrete harmonic orders from the 2nd to the 25th harmonic order. Others employing FFT logic measure to the 50th harmonic order but only inject at the 20 harmonic orders with the highest amplitude of current. Both of these types of AHF require up to 3 cycles of time (about 48 – 60 milliseconds) to calculate and inject the solution.

Some designs employ analog logic to determine the harmonic current to be injected for cancellation. These, termed 'broadband active filters,' utilize notch filters to remove the fundamental frequency from the current signal received from the line current transformers. Then they inject the inverse of the remaining signal to cancel all 'noise' from the 2nd to the 50th harmonic orders. This includes inter-harmonics above the fundamental frequency and non characteristic harmonic currents. Additionally, the speed of response begins within 100 microseconds of occurrence and attains full resolution within one cycle (16-20 milliseconds).

Additionally, many of the FFT designs do not provide adequate injection of reactive current for displacement power factor (PF) correction. Conversely, the analog designs have the ability to maintain unity lagging PF whether the electrical system is leading or lagging prior to correction.

Given the needs of this application, the 'broadband' analog filter design was chosen for rapid response, full spectrum response to the 50th harmonic order, and to provide displacement power factor correction when required.

Another aspect of this evaluation asked the question, what happens if one active harmonic filter is off line? When the full solution is implemented the harmonic distortion for all loads per platform will be in the 5 to 10% THDi (total harmonic current distortion) range. Each platform will require five or six active filters. If one unit goes off line and the remainder are at rated output cancellation levels, the increase in harmonic current distortion will only add 1/5 or 1/6 of the total harmonic current possible for that platform. If the total active filter operating current were below rated output, the remaining active filters on line will increase their output current to try and satisfy that demand, subject to their respective rated capacity. It was determined that this would not adversely affect operations since there will still be about 7500 to 8000 amperes of harmonic current removed by the remaining active filters for the entire system. Likewise, for the platform on which the inactive unit resides, the total harmonic current still being removed is between 1200 and 1500 amperes of current. Allowing an additional 300 amperes of harmonic current while the rest is removed is a 'no problem' short term issue.

Site Analysis and Results

Measurements were taken on the 600V drilling systems on Platform D since Platform C was not yet operational after being refurbished. The loads are 6 x 800HP DC drives. Due to the open tie bar only one side (i.e. 3 x 800HP) of DC drives could be monitored at one time. Fig 1 illustrates the current harmonic spectrum associated with the 3 x 800HP DC drives operating. [Note that the fundamental has been scaled to 25% just to make the harmonic current spectrum more readable.] The current harmonics are typical for this industry and this type of DC drive. If this drilling package had been the only major nonlinear loads on the system, then the harmonic voltage spectrum would be very similar to the harmonic current spectrum illustrated in Fig 1.

However, as illustrated in Fig 2, the harmonic voltage spectrum does not 'track' the harmonic current spectrum of the drilling system. This is due to the 'ambient or background voltage distortion' produced by the distortion of other loads on the platform; a mixture of 12-pulse, 18-pulse, 24-pulse and active front end (AFE) drives. (Note that the 33kV ring main was not connected at the time of the measurements). As can be seen the THDv above the 21st harmonic is higher than below, except for the 5th harmonic. The 3rd harmonic voltage and other uncharacteristic harmonics are due to the effects of the ambient distortion, imbalance of the lines voltage, and the harmonic spectrums produced by the various drive types utilized. It should be noted that the THDv is almost FIVE times the voltage distortion limits stipulated by most marine classification bodies including the American Bureau of Shipping (ABS), Det Norske Veritas (DnV) and Bureau Veritas (BV) et al to which vessels and offshore installations must now comply. The 5% THDv limit has also been defined in NATO standard STANAG 1008, Edition).

The voltage waveforms of the DC drive drilling package were also captured as illustrated in Fig 3. The voltage notches tending towards zero indicate the absence of any AC line reactance installed on the DC drives. On platforms and drilling rigs the lack of AC line reactors usually results in voltage spikes that can damage the capacitors in smaller AC variable frequency drives (VFDs), as well as, cause other SCR rectifiers to fault. This problem is often exacerbated by the use of EMC filters due to the high frequency nature of the line notches. Other sensitive equipment can also be damaged or disrupted. AC line reactors with 3% or more impedance were specified for Platform C and other future installations.

Fig 4 illustrates the connection of the broadband active filters to the DC drive drilling system. A total of 600 amperes of correction is required for each of the 3 x 800HP DC drives with another 300 ampere unit used on the 900HP top drive installed elsewhere on the platform.

During commissioning the following waveforms were captured on each side of the open tie bar with 3 x 800HP DC DCR drives operating. The waveform sets of the voltage and current show the results first with line reactors installed but without AHF activated and then with AHF activated.

Note in Fig 5, the voltage notch has been reduced by insertion of the line reactors. However, the voltage appears much better in Fig 8 when the AHF is activated. THDv is improved from initial levels of about 24% (Fig 2 - original installation) to 12.2% (Fig 5 – line reactors added) to 2.6% with AHF activated (Fig 8). Also, note the THDi reductions from approximately 34% (Fig 6 – with line reactors) to 3.6% with the AHF activated (Fig 9).

Trend recording was also operating during the commissioning. Figs 11 through 13 illustrate the salient measurements. Each figure depicts the system without AHF operating, then with the AHF operating, and then returns to without AHF operating.

Of particular significance are the reductions of the 5^{th} harmonic current amplitude (Fig 13) from 232 amperes to 11 amperes and the 7^{th} harmonic current amplitude from 72 amperes to 11 amperes as well.

During the commissioning of the drilling package, the 11kV supplies were monitored by a third party. They reported that without the 50% drilling package operating (i.e. 3 x 800HP DC drives) the background THDv at 11kV was 4.2%, rising to 4.8% when the 50% of drilling package DC drives were running. Once the active harmonic filter was switched on they reported the 11kV THDv dropped to 4.1%. The effect of the active harmonic filter was therefore to reduce the net contribution of the 3 x 800HP DC drives to around zero. Had the full drilling package been running (i.e. 6 x 800HP) the full contribution to the 11kV would have been in the order of 1.2%, which represents about 25% of all distortion on the 11kV supplies. The installation of the active harmonic filter reduced that to almost zero. In addition, due to the excellent response of these active harmonic filters (100uS), the line notching was almost eliminated as can be seen in Fig 8.

Conclusion

The active harmonic filters have achieved the intended result of greatly reducing the THDi (34% to 3.4%) and the resultant THDv (almost zero) due to the DC drives.

We look forward to installing AHF on the other drilling packages and on the 11kV supplies (via special transformers) in order to drive down voltage distortion for the generator and the rest of the ring main system. Only by doing so will the operator of the oil field have low voltage distortion in the 33kV subsea cables, thus reducing harmonics and the potential for resonance with the resulting problems associated with each.

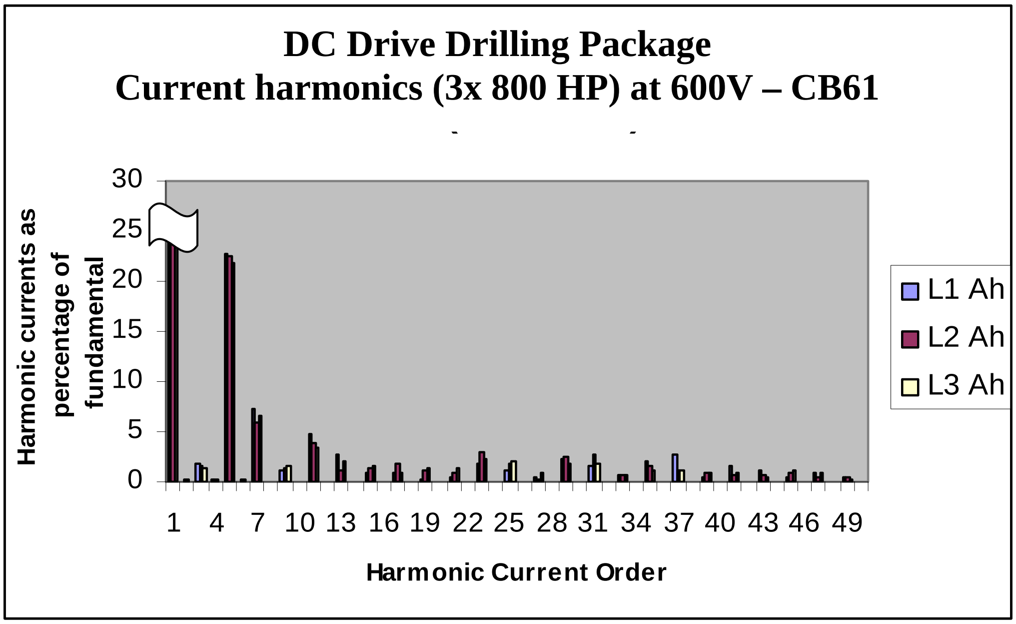

Fig 1– 3 x 800HP DC drives drilling system harmonic current distortion (relatively normal staircase shape). THDi are 24% (L1), 23.8% (L2) and 23.2% (L3) at the load captured
[Note that the fundamental current amplitude has been truncated in order to show better detail of the harmonic spectrum.]

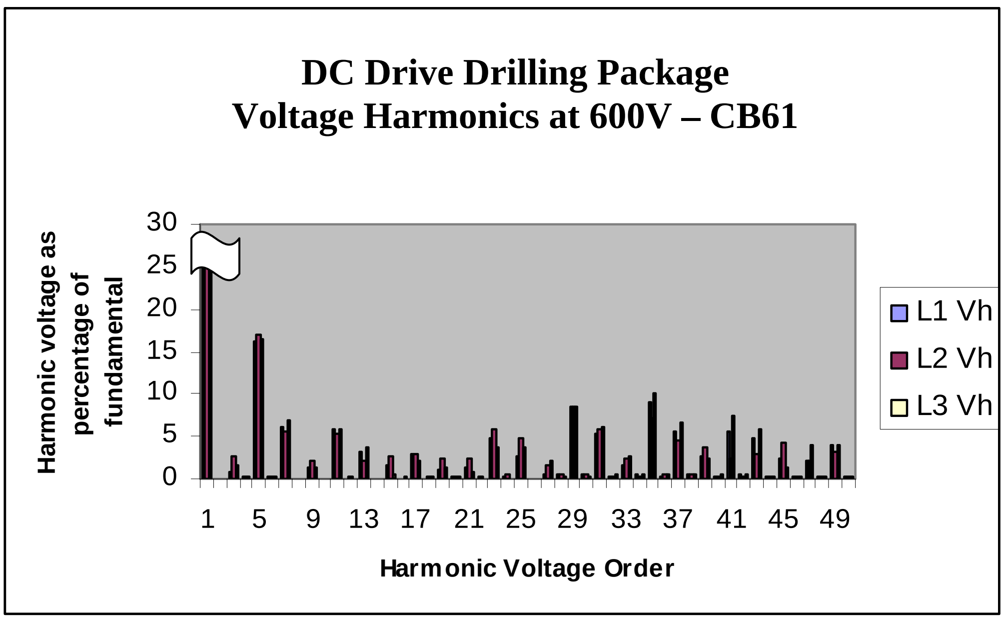

Fig 2 –Drilling system busbars - Harmonic voltage spectrum on 600 VAC.
THDv are 24.1% (L1), 24.7% (L2) and 25.3% (L3)
[Note that the fundamental voltage amplitude has been truncated in order to show better detail of the harmonic spectrum.]

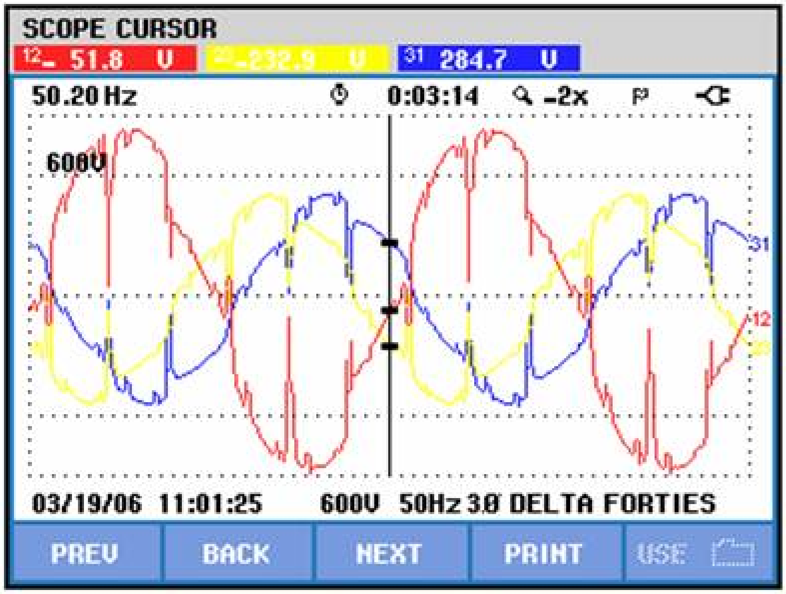

Fig 3 –DC drives drilling package – Line voltage notching due to SCR commutation with no AC line reactance

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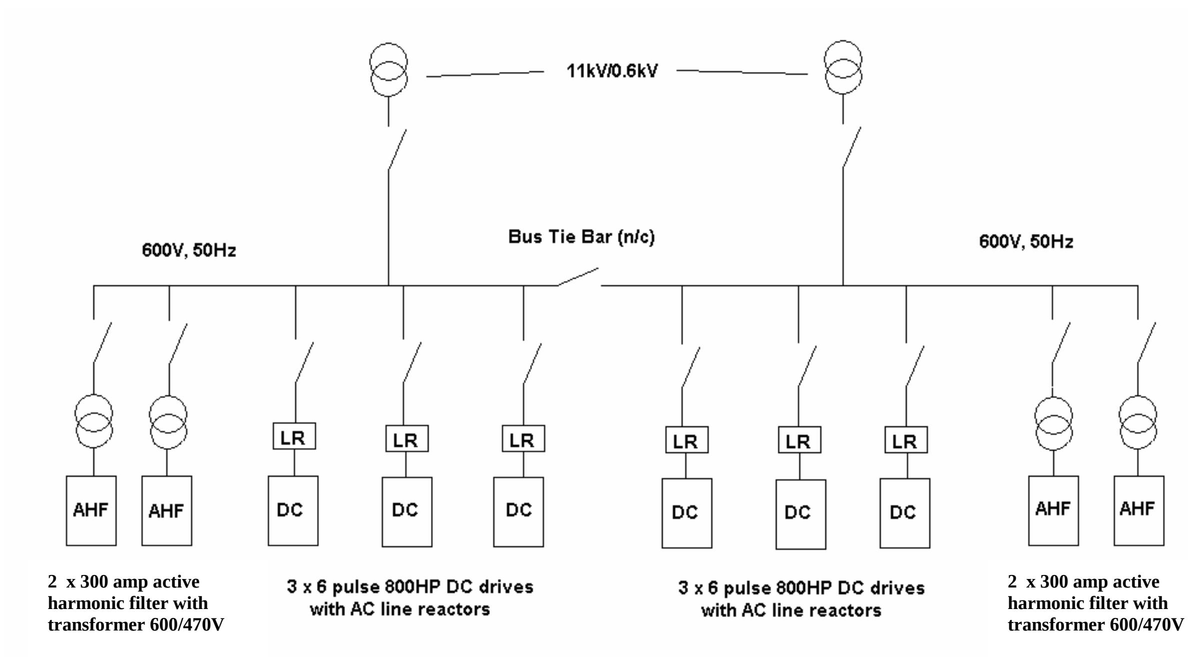

Fig 4 – Full DC drives drilling package with 6 x 800HP DC drives and 1200A of active harmonic filters

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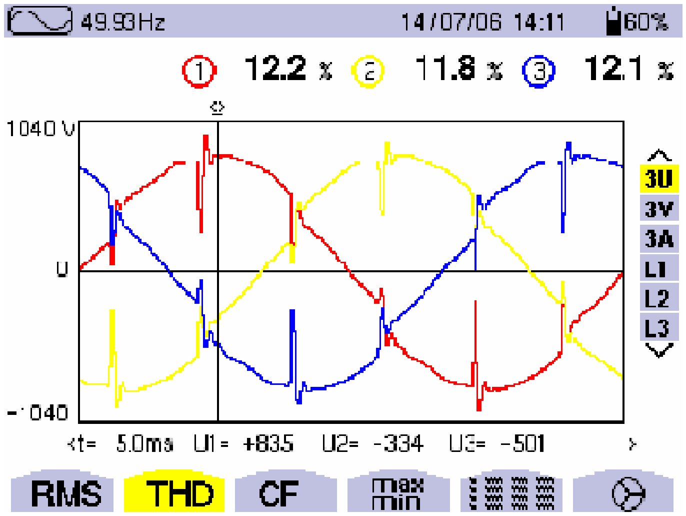

Fig 5 – 3 x 800HP DC drives voltage waveforms and THDv without active harmonic filter (THDv 12.2%) but with 3% AC line reactors.
Note that line notching is less than illustrated in Fig 3 with line reactors now installed.

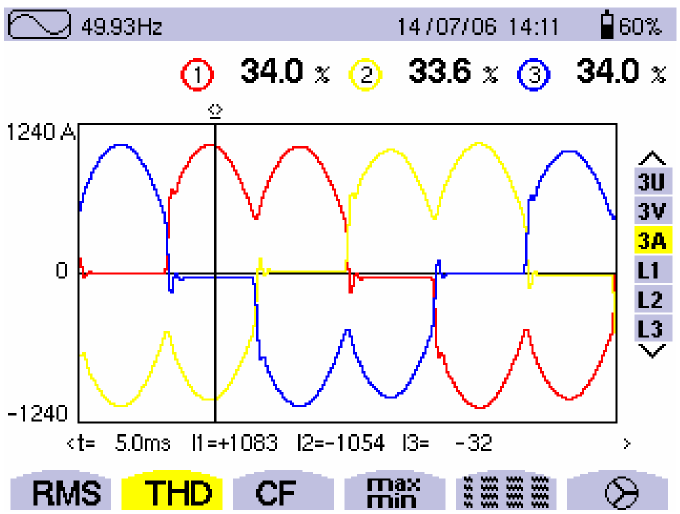

Fig 6 – 3 x 800HP DC drives current waveforms and THDi without active harmonic filter (34% THDi)

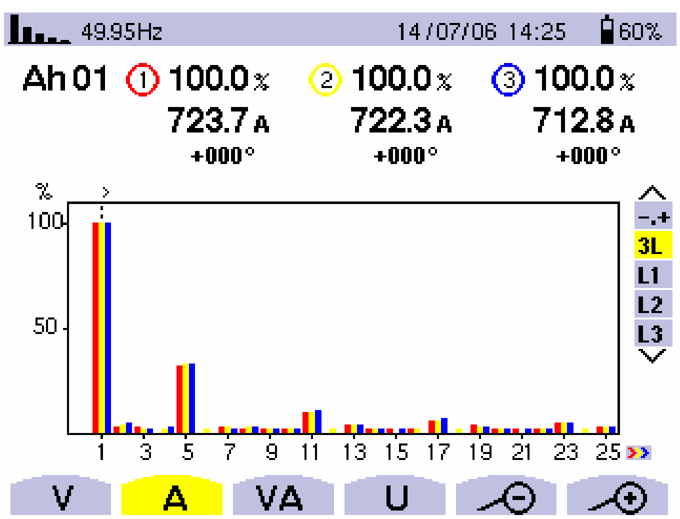

Fig 7 – 3 x 800HP DC drives harmonic current spectrum without active harmonic filter (34% THDi)

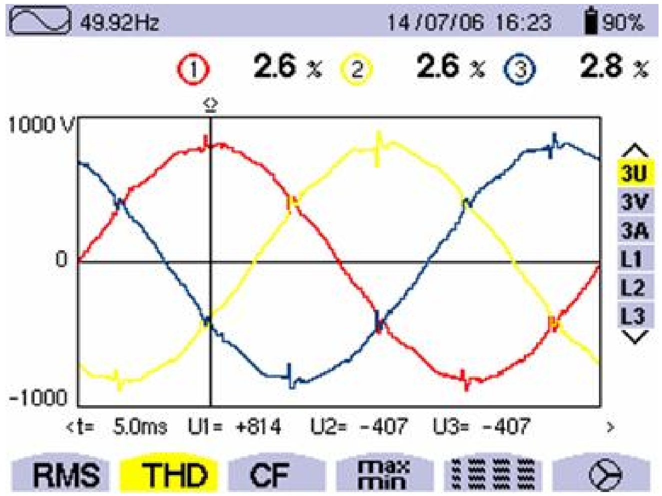

Fig 8 – 3 x 800HP DC drives voltage waveforms and THDv with active harmonic filter (2.6% THDv)
Note vast improvement in line notching due to active harmonic filter 100uS response.

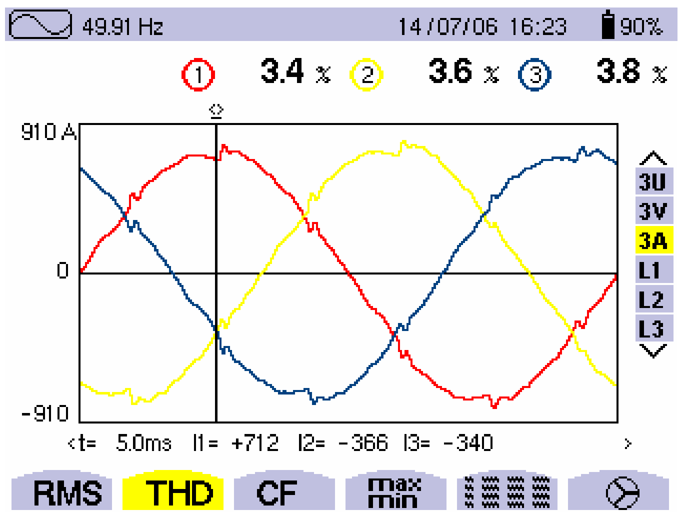

Fig 9 – 3 x 800HP DC drives current waveforms and THDi with active harmonic filter (3.6% THDi)

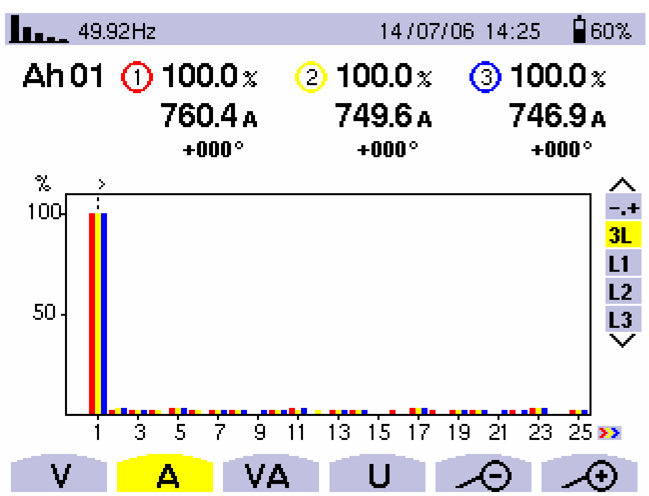

Fig 10 – 3 x 800HP DC drives harmonic current spectrum with active harmonic filter (3.4% THDi)

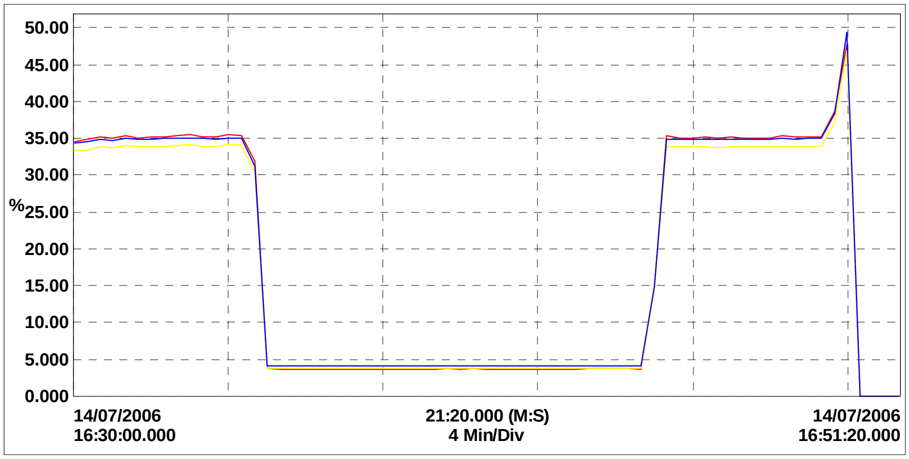

Fig 11 – THDi on 3 x 800HP DC drives without/with/without active harmonic filter. THDi - 35% to 3.7%.

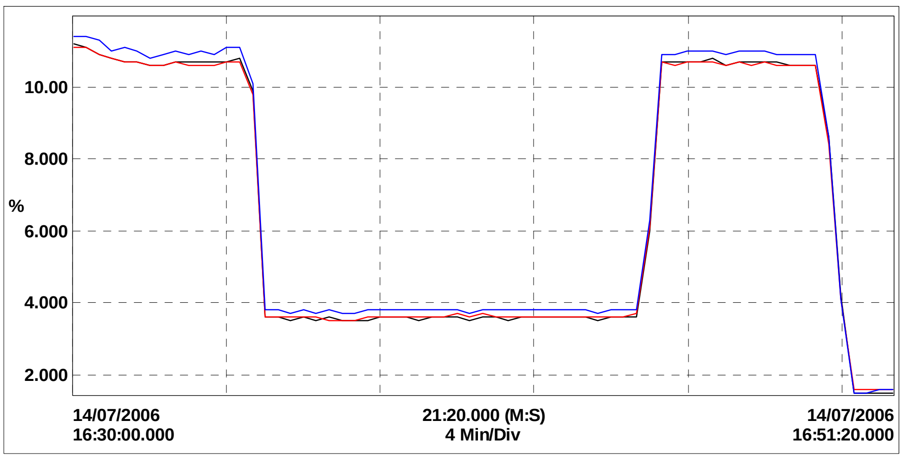

Fig 12 - THDv on 3 x 800HP DC drives without/with/without active harmonic filter.
THDv - 11.2% to 3.7%.

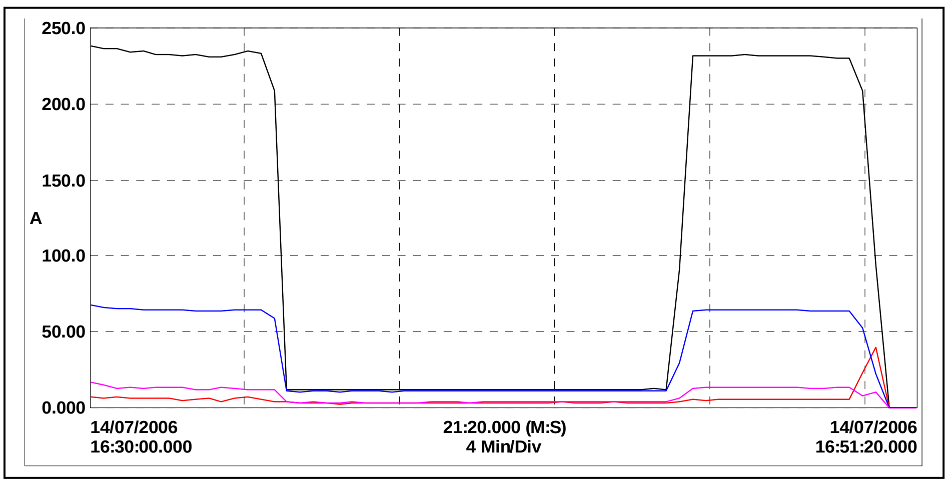

Fig 13- Salient harmonics: -- 5th, 7th, --- 11th, --- 13th on 3 x 800HP DC drives without/with/without active harmonic filter. Note - 5th harmonic reduced from 232A to 11A.

Fig 14 – 4 x 300A active harmonic filters on offshore oil platform

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Authors:

Ian C Evans
Following a background in marine and offshore electrical engineering and thirteen years in the drives industry as founder of both Elektrotek Drives Limited and Managing Partner of Howieson & Evans, Drive Consultants, Mr. Evans has been heavily involved in harmonic mitigation following his early 1997 introduction of active filters into the European marketplace.

Mr. Evans currently heads up Harmonic Solutions Co.Uk, a specialist company providing both passive and active harmonic mitigation, specialist technical training and harmonic consultancy services around the world.

He has written numerous editorials and papers on AC drives, explosion proof motor/VFD interaction, electric propulsion, harmonics and associated issues and has recently written the 240 page harmonics guidance notes for a major international marine classification body.

James R. Johnson is a 1972 graduate of the University of Pittsburgh with a Bachelor of Science degree in Electrical Engineering. His experience includes 21 years of selling, applying, and servicing AC & DC motor speed controls with several companies including Robicon and Emerson Industrial Controls/ControlTechniques. Beginning in 1983, Jim worked extensively in providing harmonic mitigation equipment in conjunction with motor speed controls. Since 1993, he has worked exclusively in the power quality market specializing in power factor correction and harmonic mitigation equipment, with major emphasis on active harmonic filters. Jim has lead two companies into the active harmonic filter market via company start-ups. Jim is presently Product Marketing Manager for AccuSine products for the PQ Correction Group of Schneider Electric – North America. Jim is a member of IEEE.