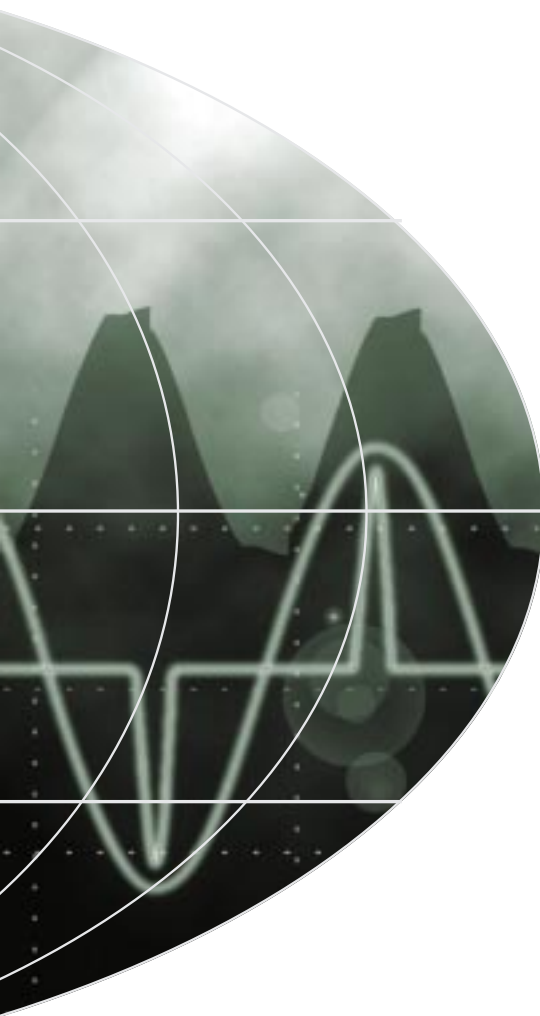




**CONTROL
TECHNIQUES**

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Harmonics Guide



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What is the problem?

Variable speed drives, like most other electronic equipment, do not draw their current as a smooth sinusoid. The supply current waveform is generally referred to in terms of the harmonics of the supply frequency which it contains. The harmonic current causes harmonic voltage to be experienced by other equipment connected to the same supply. Because harmonic voltage can cause disturbance or stress to other electrical equipment connected to the same supply system, there are regulations in place to control it. If installations contain a high proportion of variable speed drives and/or other power electronic equipment such as UPS, then they may have to be shown to satisfy the supply authorities' harmonic guidelines before permission to connect is granted. As well as obeying regulations, users of drives need to ensure that the harmonic levels within their own plant are not excessive.

Some of the practical problems which may arise from excessive harmonic levels are:

- Poor power factor, i.e. high current for a given power
- Interference to equipment which is sensitive to voltage waveform
- Excessive heating of neutral conductors (single-phase loads only)
- Excessive heating of induction motors
- High acoustic noise from transformers, busbars, switchgear etc.
- Abnormal heating of transformers and associated equipment
- Damage to power factor correction capacitors

An important property of harmonics is that they tend to be cumulative on a power system, i.e. the contributions of the various harmonic sources add up to some degree. This is different from other high-frequency electromagnetic compatibility (EMC) effects which are generally localised and not significantly cumulative. It is important to differentiate harmonics from high-frequency EMC effects which tend to cause interference to sensitive data and measuring circuits by stray coupling paths. With few exceptions, if harmonics cause disturbance it is through direct electrical connection and not through stray paths. Screening is rarely a remedial measure for harmonic problems*.

* Telephone interference is a possible exception

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What are the regulations?

There are two kinds of regulations which may need to be considered:

Regulations for installations

These are imposed by the electricity supply authority to protect other electricity consumers from the effects of excessive harmonics. They are usually based on an agreed level of voltage distortion which can be tolerated by correctly designed equipment. This is specified in terms of a total harmonic distortion (THD) (see definitions). The internationally accepted maximum THD "compatibility level" in a low voltage system is 8%, and to achieve this with a high degree of confidence it is usual to aim for a rather lower level as the "planning level", typically 5%. Individual harmonics are also subject to limits.

Some relevant standards and regulations are given in the references.

From the point of view of the supply authority, the relevant harmonic voltage is at the point of common coupling (PCC) with other power consumers. The harmonic levels within the consumer's premises may be higher because of the impedance of cables and transformers. In large installations measures may be necessary to prevent harmonic problems within a site. Since there are no statutory requirements, a relaxed version of the authority limits can be applied internally. It is not advisable to allow the 8% THD limit to be exceeded, because the majority of equipment will have been designed to be immune only up to this level.

Calculating the voltage distortion of a proposed installation can be an expensive matter, because it requires existing harmonics to be measured over a period of time, the system parameters such as source impedances to be derived, and the effect of the planned new load to be estimated. For a large installation with a high proportion of the load comprising electronic equipment, it is cost-effective to complete this exercise in order to avoid the application of unnecessary remedial measures. For simpler cases a full analysis would be burdensome. Regulations such as the UK G5/3** provide simplified "staged" procedures to permit connection based only on harmonic current data, which can be obtained readily from the manufacturers' technical data. This involves making simplifying assumptions biased in a cautious direction. If the simplified stage does not permit connection, the full calculation procedure has to be applied.

*** To be replaced by G5/4, probably during 2001*

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Standards for equipment

A further simplification can be made if a product conforms to a relevant harmonic standard, so that it can be connected without reference to the supply authority. The international standard for equipment rated at less than 16A is IEC61000-3-2, the corresponding CENELEC standard being EN61000-3-2. These are applied to consumer products and similar equipment used in very large numbers, where individual permission to connect would not be practical. Small variable speed drives rated at less than about 650W shaft power fall within the scope of this standard, and can be made to conform to it by the application of suitable measures. However where they are used in large quantities in a single installation it may be more cost-effective to assess their total current and obtain permission to connect from the supply authority. In future there will be a further standard, IEC61000-3-12 (EN61000-3-12) covering equipment rated up to 75A.

How are harmonics caused?

Harmonics are caused by any process whereby the current drawn by equipment does not faithfully follow the sinusoidal supply voltage waveform. Most electronic circuits use DC internally, so they have a rectifier to convert the incoming AC to DC. Unless it has special additional active features, the rectifier draws its current in a series of short pulses.

Figure 1 shows the essential circuit for a typical AC variable speed drive (VSD). The input is rectified by the diode bridge, and the resulting DC is smoothed by the capacitor and, for drives rated typically at over 2.2kW, the inductor. It is then chopped up in the inverter stage which uses PWM to create a sinusoidal output voltage of adjustable voltage and frequency. Supply harmonics do not however originate in the inverter stage or its controller, but in the input rectifier.

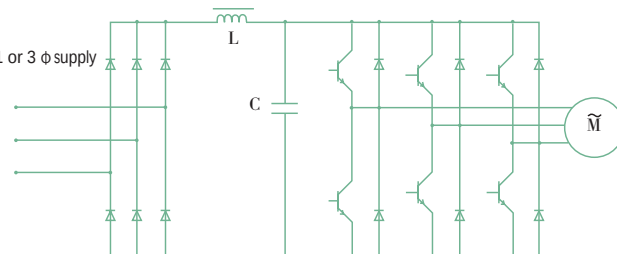


Figure 1: Essential features of AC variable speed drive

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The input can be single or three phase. For simplicity the single phase case is covered first. Current flows into the rectifier in pulses at the peaks of the supply voltage as shown in figure 2.

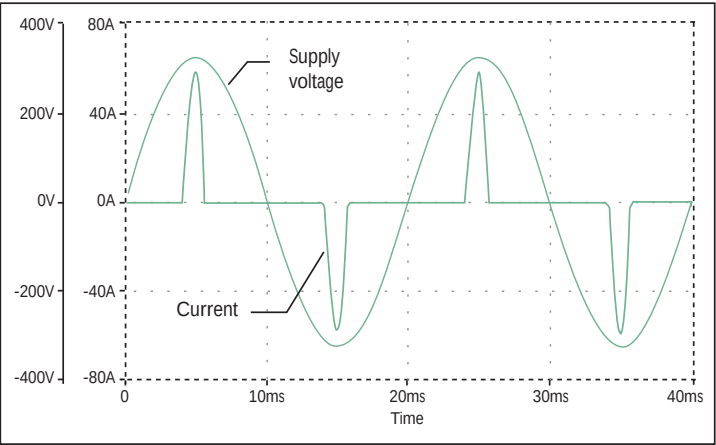


Figure 2: Typical input current waveform for a 1.5kW single phase drive (with supply voltage)

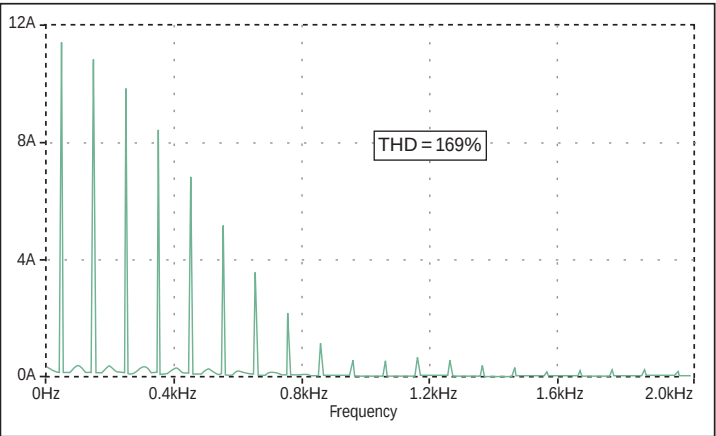


Figure 3: Corresponding spectrum for figure 2

Note that all currents shown in spectra are in peak values, i.e. $\sqrt{2}$ times their r.m.s. values.

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Figure 3 shows the Fourier analysis of the waveform in figure 2. It comprises lines at multiples of 50Hz. Because the waveform is symmetrical in the positive and negative half-cycles, apart from imperfections, only very low level even-order harmonics are present. The odd-order harmonics are quite high, but they diminish with increasing harmonic order. By the 25th harmonic the level is negligible. The frequency of this harmonic for a 50Hz supply is 1250Hz which is in the audio frequency part of the electromagnetic spectrum and well below the radio frequency part which is generally considered to begin at 150kHz. This is important, because it shows that supply harmonics are low frequency effects which are quite different from radio frequency EMC effects. They are not sensitive to fine details of layout and screening of circuits, and any remedial measures which are required use conventional electrical power techniques such as tuned power factor capacitors and phase-shifting transformers. This should not be confused with the various techniques used to control electrical interference from fast switching devices, sparking electrical contacts etc.

Three-phase-input drives cause less harmonic current for a given power than single-phase drives. Figure 4 shows the input current waveform for a 1.5kW three-phase drive. The line current is less in any case, and there are two peaks in each mains cycle each of about 20% of the peaks in the single phase drive.

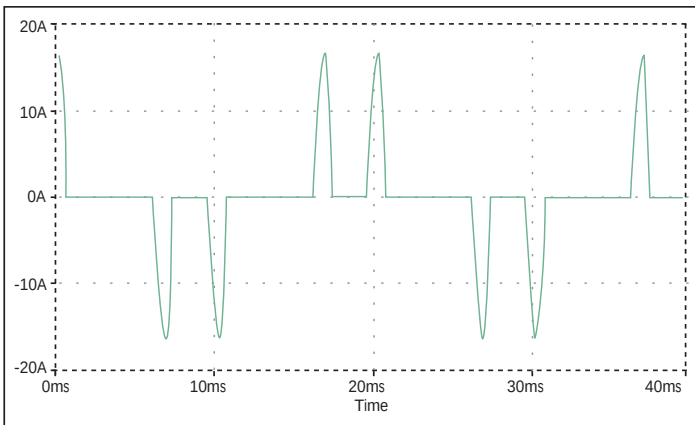


Figure 4: Typical input current waveform for a 1.5kW three phase drive

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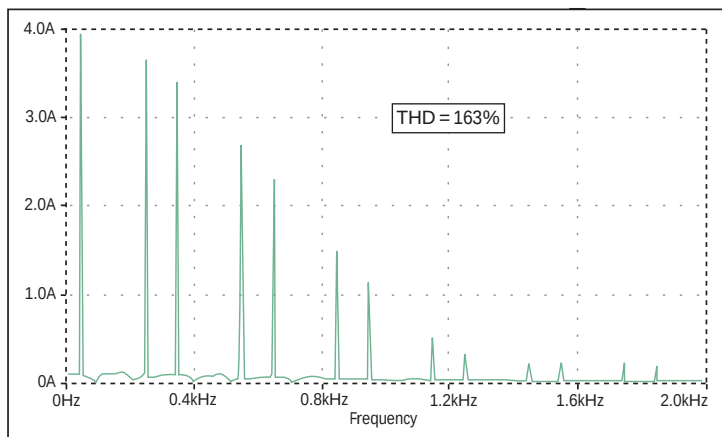


Figure 5: Spectrum corresponding to figure 4

Figure 5 shows the corresponding spectrum. Compared with the single phase case the levels are generally lower, and the triplens (multiples of three) are absent.

All of the above examples have referred to AC drives which have capacitor-input rectifiers. DC drives have detail differences although the principles are the same. Their harmonic levels are generally rather lower than those of AC drives. They are affected by the motor armature inductance as well as loading and AC inductance, so they are difficult to give as hard data, but they are quite easy to calculate. Calculation techniques are given in textbooks, and a particularly clear account is given in IEEE 519.

Effects of harmonics

Some of the effects of harmonics were summarised above.

Figure 6 shows a voltage waveform where a distribution transformer is loaded to 50% of its capacity with single-phase rectifiers. It shows the characteristic flat-top effect.

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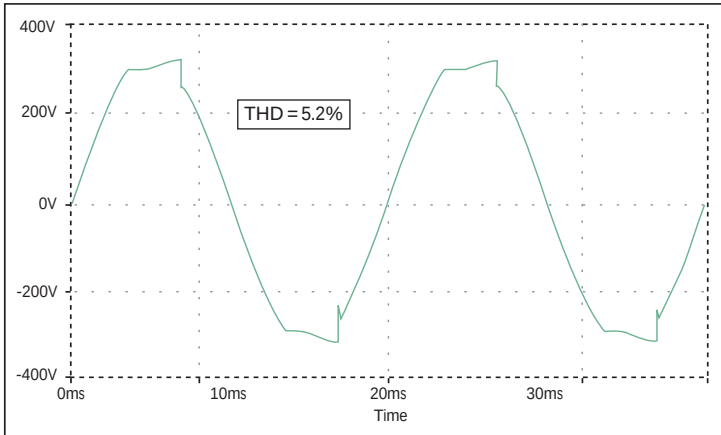


Figure 6: Supply voltage waveform with single phase loads of 50% supply capacity

Although this waveform looks alarming, in fact most modern electronic equipment is unaffected by it. However the harmonic content can cause excessive stress in components, especially capacitors, connected directly to the supply.

The diode bridge input circuit in a single phase AC drive is the same as used in a very wide range of electronic equipment such as personal computers and domestic appliances. All of these cause similar current harmonics. Their effect is cumulative if they are all connected at the same low voltage (e.g. 230V) supply system. This means that to estimate the total harmonic current in an installation of single-phase units, the harmonics have to be added directly. Phase-controlled equipment such as lamp dimmers and regulated battery chargers cause phase-shifted harmonics which can be added by root-sum-squares to allow for their diverse phase angles.

In a mixture of single- and three-phase loads, some of the important harmonics such as the fifth and seventh are 180° out of phase and actually mutually cancel. Sometimes this information can be very helpful even if there is no certainty that the loads will be operated simultaneously – for example, in an office building which is near to its limit for fifth and seventh harmonic because of the large number of single-phase computer loads, the installation of three-phase variable speed drives will certainly not worsen the fifth and seventh harmonics and may well reduce them.

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How is the problem solved?

The first point to make is that harmonics problems are unusual, although with the steady increase in use of electronic equipment, problems may be more common in future. The most frequent situations where problems have occurred are in office buildings with a very high density of personal computers, and in cases where most of the supply capacity is used by electronic equipment such as drives, converters and UPS.

As a general rule, if the total rectifier loading (i.e. variable speed drives, UPS, PC etc.) on a power system comprises less than 20% of its current capacity then harmonics are unlikely to be a limiting factor. In most industrial installations, the capacity of the supply considerably exceeds the installed load, and a large proportion of the load is not a significant generator of harmonics – uncontrolled AC induction motors and resistive heating elements generate minimal harmonics.

If rectifier loading exceeds 20% then a harmonic control plan should be in place. This requires that existing levels be assessed, and a harmonic budget allocated to new equipment.

Calculations may be required to predict the effect on harmonic voltage from connecting additional equipment. Appendix 1 gives a guide to calculation methods.

The following measures can be used to reduce the harmonic level. Further details are given in the next section.

1. Connect the equipment to a point with a high fault level (low impedance)

When planning a new installation, there is often a choice of connection point. The harmonic voltage caused by a given harmonic current is proportional to the system source impedance (inversely proportional to fault level). For example, distorting loads can be connected to main busbars rather than downstream of long cables shared with other equipment.

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2. Use three-phase drives where possible

As shown above, harmonic current for a three-phase drive of given power rating is about 30% of that for a single-phase drive; and there is no neutral current. If the existing harmonics are primarily caused by single-phase loads, the dominant fifth and seventh harmonics are also reduced by three-phase drives.

3. Use additional inductance

Series inductance at the drive input gives a useful reduction in harmonic current. The benefit is greatest for small drives where there is no DC inductance internally, but useful reductions can also be obtained with large drives.

4. Use a higher pulse number (12-pulse or higher)

Standard three-phase drives rated up to about 200kW use 6-pulse rectifiers. A 12-pulse rectifier eliminates the crucial fifth and seventh harmonics (except for a small residue caused by imperfect balance of the rectifier groups). Higher pulse numbers are possible if necessary, the lowest harmonic for a pulse number N being $(N-1)$. Individual drives may be supplied with DC from a single bulk 12-pulse rectifier, or where the loading on drives is known to be reasonably well balanced individual 6-pulse drives may be supplied from the two phase-shifted supplies. If the transformer rating matches the total drive rating reasonably closely then its inductance gives a very useful additional reduction of the higher order harmonics. For ratings up to about 1MW it is unusual to require pulse numbers greater than 12.

5. Use a drive with an active input stage

The Control Techniques Regenerative Unidrive has an active input stage which generates negligible harmonic current, as well as permitting the return of braking power to the supply.

6. Use a harmonic filter

Harmonic filters are available to attenuate specific harmonics. Most commonly they are passive circuits based on the tuning of power factor compensation capacitors by series inductors. They can be very effective, but there are potential difficulties, and a specialist supplier should be consulted. Active harmonic filters are also available, and avoid many of the difficulties of passive filters. They are generally rather expensive, but their increased use can be expected to lead to a price reduction in future.

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Further information on remedial measures

3. Additional inductance

The addition of AC input inductance to the single phase drive improves the current waveform and spectrum from those shown in Figures 2 and 3 to those shown in Figures 7 and 8. It is particularly beneficial for the higher order harmonics, but the fifth and seventh are reduced by a useful degree. Only the third harmonic is little improved.

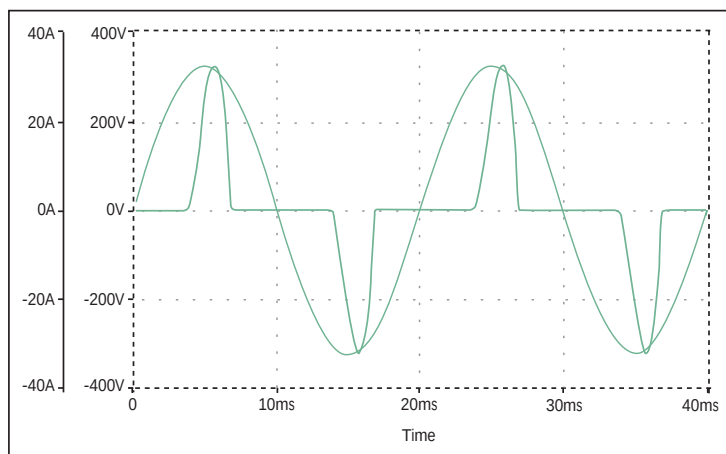


Figure 7: Input current waveform as figure 2 but with 2% input inductor

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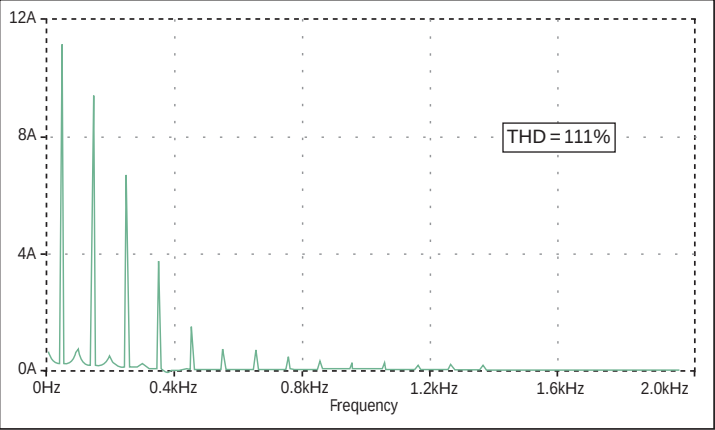


Figure 8: Input current spectrum for figure 7

Since the three-phase rectifier has no third harmonic current, the AC inductor is even more beneficial, as shown in Figures 9 and 10.

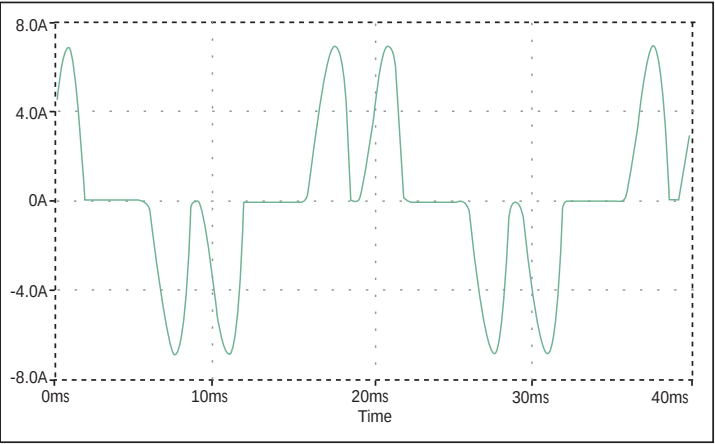


Figure 9 Input current waveform as figure 4 but with 2% input inductors

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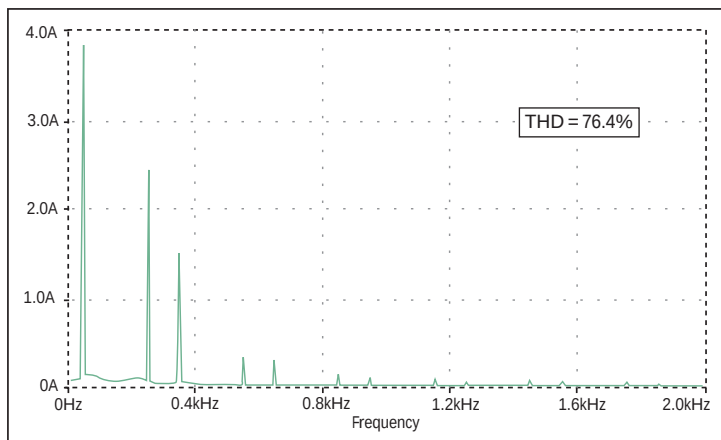


Figure 10: Input current spectrum for figure 9

In these examples the value of the AC inductor is 2% (i.e. 0.02 p.u.). This is the highest value recommended where full torque at base speed is required, since the drive output voltage at full load begins to be reduced significantly for higher values.

DC inductance

Drives rated at 4kW or more usually have three-phase input and include inductance in the DC link. This gives the improved waveform and spectrum shown in Figures 11 and 12, which are for a hypothetical 1.5kW drive for ease of comparison with the previous illustrations.

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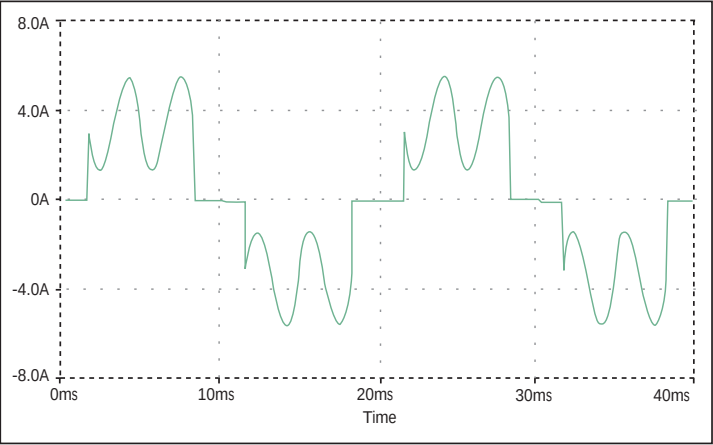


Figure 11: Input current waveform for 1.5kW drive with DC inductance

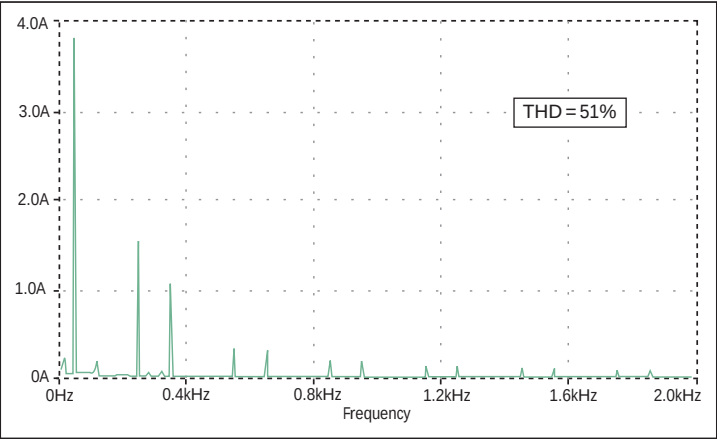


Figure 12: Spectrum for figure 11

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Further improvement is possible by adding AC inductance as well as DC, as shown in Figures 13 and 14. This represents the limit of what can be practically achieved by very simple low-cost measures.

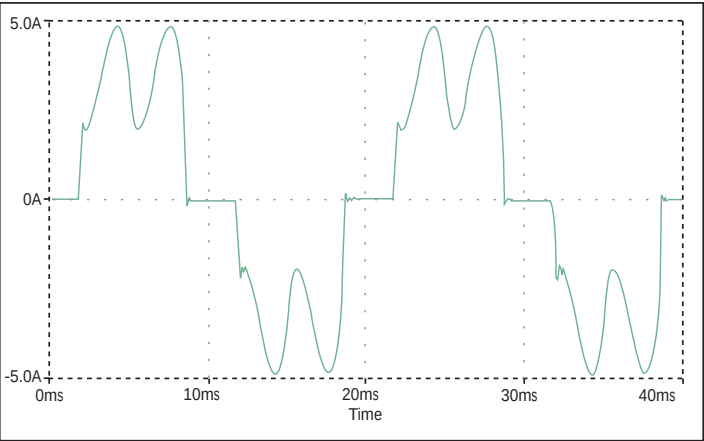


Figure 13: Input current waveform for 1.5kW drive with DC and input inductors

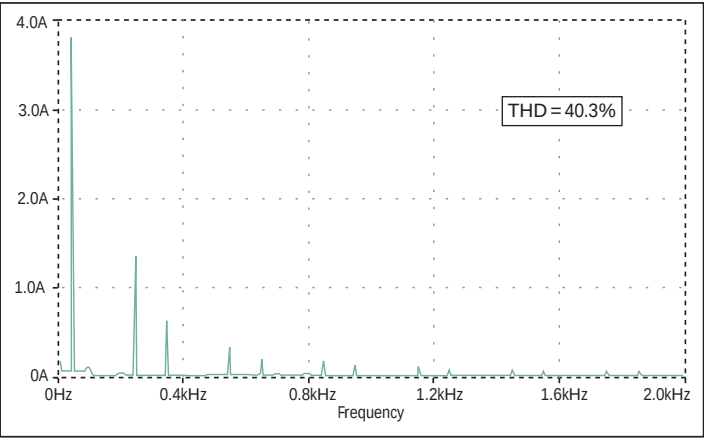


Figure 14: Spectrum for figure 13

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4. Higher pulse numbers

The 12-pulse system is illustrated in Figure 15. The star and delta windings (or zig-zag windings) have a relative 30° phase shift which translates to 180° at the fifth and seventh harmonics (as well as 17,19,29,31 etc.), so that current at these harmonics cancels in the transformer.

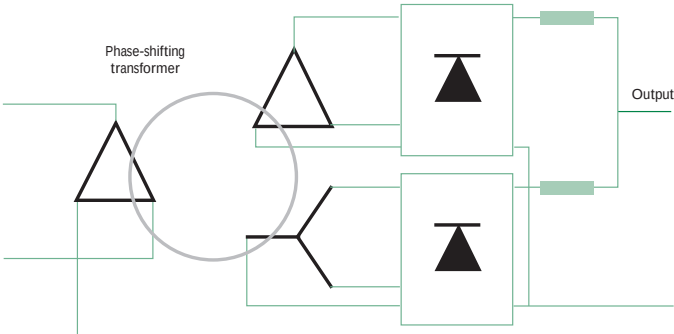


Figure 15: Basic twelve-pulse rectifier arrangement

The transformer input current waveform and spectrum are shown in figures 16 and 17 respectively.

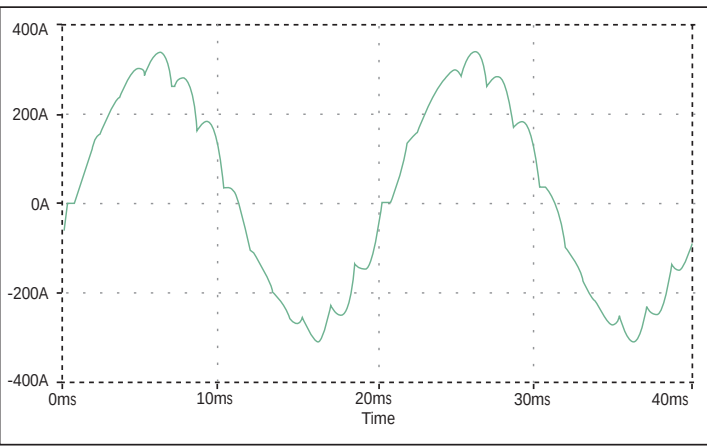


Figure 16: Input current waveform for 150kW drive with 12-pulse rectifier

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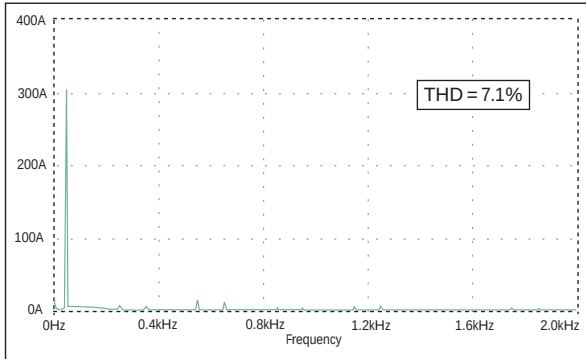


Figure 17:
Spectrum for
figure 16

5. Active input stages

The input current for an active input stage contains negligible harmonic current if the supply voltage is sinusoidal. There are two side-effects which must be considered:

- The input stage PWM frequency causes input current which may have to be filtered.
This is an optional extra in addition to the radio frequency filter.
- Existing voltage harmonics in the supply will cause some harmonic current to flow in to the drive.
This should not be mistaken for harmonic emission.

6. Harmonic filters

The simplest harmonic filter is a power factor correction capacitor tuned by series inductance to the harmonic of interest so that the impedance is a minimum at that frequency. There are potential disadvantages to this arrangement:

- The filter will absorb harmonics existing on the power system, and must be rated for this duty.
If inadequately rated it will trip and refuse to operate.
- The filter has a leading phase angle. With DC and similar thyristor drives this provides useful power factor compensation, but with AC drives having negligible phase angle the leading current may have to be cancelled by a parallel inductance.
- The filter will have at least one resonant frequency where it magnifies harmonics. This has to be adjusted to avoid any odd harmonic frequencies. Multiple filters on a single supply system may interact and cause troublesome resonances. For these reasons advice should be taken from an experienced supplier.

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How can Control Techniques help?

Control Techniques provides comprehensive EMC data sheets for all of its AC drive products. These are available on request from drive centres and distributors, and give harmonic currents at full load, with and without 2% AC line reactors.

Control Techniques have also produced a spreadsheet running under Microsoft™ Excel™, which estimates the harmonics produced by any combination of Control Techniques AC drives, and tabulates the results with the G5/3 limits for ease of assessment. It includes the effect of variation in load, the use of AC line reactors, and the operation of some or all drives in 12-pulse configuration.

Copies are available from Customer Technical Support at your local Drive Centre.

Definitions

Total Harmonic distortion (THD) (%) (applied to voltage or current):

$$\frac{\text{r.m.s. value of all harmonics considered (typically orders 2 to 50)} \times 100}{\text{r.m.s. value of fundamental}}$$

Distortion factor (D) (%) (applied to current):

$$\frac{\text{r.m.s. value of fundamental component of current} \times 100}{\text{r.m.s. value of current}}$$

Displacement Factor (cos Ø):

$$\frac{\text{r.m.s. value of fundamental component of current in phase with voltage} \times 100}{\text{r.m.s. value of fundamental component of current}}$$

Power Factor:

$$\frac{\text{r.m.s. value of fundamental component of current in phase with voltage} \times 100}{\text{r.m.s. value of current}}$$

So: Power Factor = Distortion factor x Displacement Factor

For example: An induction motor may have a power factor of 0.8 comprising distortion factor 1.0 and displacement factor 0.8

An AC VSD may have power factor of 0.8 comprising distortion factor 0.84 and displacement factor 0.95

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References

Harmonic regulations for installations and supply systems:

Electricity Association Engineering Recommendation G5/3 – Limits for harmonics in the United Kingdom electricity supply system

Electricity Association Engineering Recommendation G5/4 (draft) – Planning levels for harmonic voltage distortion and the connection of non-linear loads to transmission systems and PES systems in the UK (to replace G5/3 in 2001)

IEC61000-2-2 Electromagnetic compatibility (EMC) – Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems

EN50160 Voltage characteristics of electricity supplied by public distribution systems

IEEE519-1992 IEEE recommended practices and requirements for harmonic control in electrical power systems

Standards for individual equipment:

IEC61000-3-2 (and EN61000-3-2) Limits for harmonic current emissions
(equipment input current $\leq 16\text{A}$ per phase)

IEC61000-3-4 EMC: limits - limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16A

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Appendix 1:

Harmonic calculations

The impact of a harmonic current on the power system can be estimated by calculating the resulting harmonic voltage at a point in the supply system shared with other equipment. The power supply companies have a duty to control the quality of the power delivered to consumers, so their interest is at the point where the supply is shared with another consumer – the point of common coupling (PCC). The basic equivalent circuit for this calculation is shown in Figure 18.

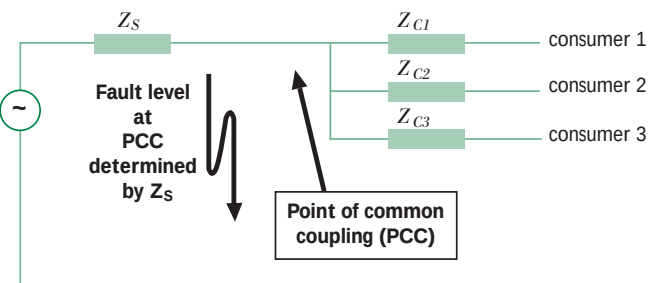


Figure 18: Supply system, showing point of common coupling with fault level

For the study of harmonics, the principle of superposition is used which means that the mains source is turned off and the consumer being studied is considered as a source of harmonic current, as shown in figure 19

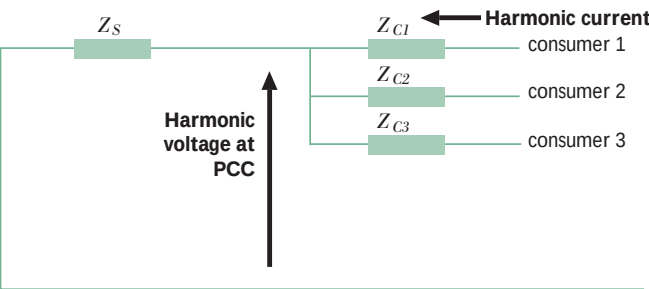


Figure 19: Supply system arranged for harmonic analysis

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Each harmonic is considered in turn. The voltage is simply the product of the current and the impedance of the supply system upstream of the PCC. The impedance at 50Hz (or other mains frequency) can be found from the declared fault level of the supply, which should be available from the supply company. If it is expressed in MVA then the impedance in ohms at mains frequency can be calculated as follows:

$$Z_s = \frac{V^2}{MVA \times 10^6} \quad \text{where } V \text{ is the voltage between lines and } Z_s \text{ is the source impedance of one line}$$

The impedance is assumed to be predominantly inductive – as is the case with high power circuits – so that for a harmonic of order n the impedance is nZ_s .

This calculation is required for assessment against stage 3 of the UK Electricity Association recommendation G5/3. It is widely accepted as giving a reliable basis for assessment of harmonic penetration. The presence of power-factor correction capacitors causes a more complex situation where resonance causes the impedance to rise at certain frequencies. If these coincide with odd harmonics where substantial currents exist, a higher harmonic voltage than estimated can occur. Fortunately this is an unusual situation, which can be expensive to cure.

Note that in Figure 19 the harmonic voltage within the premises of consumer 1 will be higher than that at the PCC, because of the voltage drop in Z_{CL} . Meeting G5/3 at the PCC is no guarantee of tolerable harmonic levels within the system of the consumer generating the harmonics.

In order to analyse a practical system, the known harmonic data for all the rectifiers and other distorting loads must be combined to predict a total current. In general, each harmonic from each unit is a vector quantity which can only be added to the others through vector addition. Usually the phase angle is unknown, and in the case of phase angle controllers it varies with the operating condition.

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For uncontrolled rectifiers, the phase angles of the dominant harmonics will be similar, and the amplitudes add directly. G5/3 permits the application of a coincidence factor of 0.9 to reflect the fact that perfect addition is not possible.

Where phase angle controlled loads are added to one another or to a group of uncontrolled loads, the random phase angles mean that addition by square root of sum of squares is appropriate, whereas G5/3 suggests a coincidence factor of 0.75.

Diversity of loading is also an important issue. In some installations only a small part of the possible load on each drive can occur simultaneously. This must be considered to avoid an over-estimate of the harmonic loading.

The effect of load is very different for AC and DC drives. Although AC drives at full load generally generate rather higher levels of harmonic than DC drives, the input current and all the important harmonics fall with reduced load power whether this is caused by falling torque or speed or both. With DC drives the current is proportional to shaft torque but does not fall with reducing speed.

Isolated generators

If the system is supplied by isolated generators not connected to a grid, the impedance of the generators must be determined. The relevant parameter is the direct-axis sub-transient reactance, x_d'' *. Typical values are between 14% and 20%, compared with the 5% of a typical distribution transformer, so generators are less able to tolerate harmonic current than the public supply network.

**Strictly the quadrature axis impedance should also be considered, depending on the load angle. In practice they are usually similar.*

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Appendix 2:

Applying UK Electricity Association Engineering Recommendation G5/3

IMPORTANT NOTE

This information is given to help those unfamiliar with the recommendations. It is based on experience within Control Techniques Ltd of assisting customers in meeting G5/3, and is believed to be correct, but the reader is strongly advised to refer to the original document. Control Techniques accepts no liability for the consequences of following the advice given here. The electricity supply utility has the discretion to refuse to connect any consumer if they have reason to believe that unacceptable disturbance could result to the power system, or to other electricity users.

G5/3 is copyright by the Electricity Association. Therefore this guide quotes only restricted specific information from it, by permission of the EA. Copies of G5/3 are available from:

The Electricity Association
30 Millbank
London SW1P 4RD
Telephone 0207-9635700

At the time of writing a draft version of a new recommendation G5/4 is in circulation. This will eventually replace G5/3. G5/3 was written for UK supply voltages before European voltage harmonisation, so voltages for the LV supply are 240V and 415V.

Principles of G5/3

G5/3 provides a staged mechanism for assessing a proposed installation, whereby successive stages provide more scope for installing distorting loads but at the price of deeper analysis and calculation. Therefore we can consider the stages in succession.

The term "convertor" is used to represent any power electronic equipment which uses semiconductor switching devices so that the supply current departs from the sinusoidal. When G5/3 was published in 1976 this was most commonly thyristor controlled rectifiers and AC regulators. The increased use of simple diode rectifiers associated with PWM inverters, UPS and SMPS had not yet begun.

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Stage 1

Converters which meet stage 1 criteria may be connected without further consideration.

Single phase converters for connection at 240V should not exceed 5kVA capacity. Several loads may be connected to a three-phase system distributed evenly around the phases, but if there is more than one per phase then consideration under Stage 2 is required.

Individual three-phase converters rated less than 12kVA may be connected to the 415V system and less than 130kVA to the 11kV system without further consideration.

Stage 2

Stage 2 gives limits to harmonic current at the PCC at 415V, 11kV and higher voltage levels.

No calculation is required beyond the estimation of the total harmonic current for the installation as discussed above. For a number of uncontrolled rectifier loads the coincidence factor of 0.9 can be applied. Any knowledge about the limits to total loading (ie if not all drives can be fully loaded simultaneously) should be incorporated.

The Control Techniques harmonic calculator can be used directly to compare the effect of any combination of CT drives with the stage 2 limits. Note that the effect of other distorting loads within the same installation must be added, using the appropriate coincidence factor and any allowance for loading diversity.

A condition for applying stage 2 is that the existing voltage distortion should not exceed 75% of the permitted levels under stage 3. It is our experience that utilities do not generally require the consumer to verify this, but if existing distortion is known to be high they may notify the consumer of reduced permitted harmonic currents under stage 2.

Stage 3

For stage 3 the harmonic voltages resulting from the harmonic currents have to be estimated. This requires a knowledge of the system impedance, and requires more data and more computation than stage 2.

The first requirement is for harmonic survey data. In some cases this is available from the utility, but if not then the consumer must arrange with a suitable test organisation for a survey to be carried out.

Harmonics Guide

Next the harmonic voltage resulting from the proposed load must be estimated. This requires a knowledge of the supply impedance (fault level) at the PCC. This data should be available from the utility. It should allow for the possibility of a lower fault level during summer when less generating and distribution plant is operating. The Control Techniques harmonic calculator provides the harmonic voltage data, given the fault level at the PCC. Note that the calculator allows the resulting voltages to be compared with the G5/3 limits, but this is for indication only since it does not incorporate the effect of existing harmonic voltages.

For a preliminary calculation, if the fault level is not known, the following best estimates can be used to obtain a first impression of how close to the limit is a given proposed installation:

400V	10MVA
11kV	100MVA

However it is common in heavy industrial installations for the 11kV fault level to be considerably higher.

The Control Techniques calculator does not apply a coincidence factor to individual drives. Therefore a multiplier of 0.9 may be applied to its predictions.

The individual voltage predictions must then be added to the existing distortion levels. Issues to be considered are:

- What coincidence factor to be applied – given that the source of the existing harmonic voltage is unknown.
- How to handle time variations – whether the maximum or average existing distortion should be taken depends on any possible correlation with the operation of the proposed plant.

The individual harmonic voltages should be determined, and then the total harmonic distortion (THD) calculated from the square root of the sum of the squares of these voltages. THD figures cannot be added directly.

In any case where the installed distorting load exceeds 1MVA the utility may require tests to be carried out to verify the calculations.



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