Managing Harmonics

A guide to ENA Engineering Recommendation G5/4-1

6th Edition : 2011

GAMBICA

AUTOMATION
INSTRUMENTATION & CONTROL
LABORATORY TECHNOLOGY

MANAGING HARMONICS
A Guide to ENA Engineering Recommendation G5/4-1

Foreword

This Guide is a simple authoritative introduction to good practice in the application of variable speed drives, soft starters and load regulators in compliance with the requirements of the United Kingdom electricity supply utilities.

The Third Edition was published to accompany the issue of Energy Networks Association (ENA) Engineering Recommendation G5/4-1 in October 2005. This version contains improved guidance regarding filters.

It is the result of work undertaken by GAMBICA members, interpreting the appropriate documents.

The guide should be read in conjunction with the ENA Engineering Recommendation G5/4-1, which amends ENA Engineering Recommendation G5/4, which was originally published by the Electricity Association in February 2001. An extensive supporting guide, the Energy Networks Association Engineering Technical Report ETR 122, published December 2002, accompanies the Recommendation.

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Scope

The Guide considers the installation of single or multiple drive systems, and provides information on the manner in which applications for connection should be made with the appropriate utility.

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1 Basis

The intention of the Energy Networks Association Recommendation G5/4, first published in 2001, was to try to ensure that the levels of harmonics in the Public Electricity Supply do not constitute a problem for other users of that supply.

This is a primary function of Electromagnetic Compatibility (EMC) Management and Regulation, and it forms part of the Distribution Code which is a statutory requirement placed on the UK Electricity Supply Industry.

In addition, under EU legislation the supply industry has a duty to meet BS EN 50160, Voltage Characteristics of Electricity Supplied by Public Distribution Systems, which includes magnitudes of harmonic voltage distortion among other parameters.

To facilitate the connection of non-linear equipment, G5/4-1 specifies harmonic current emission limits with the intention of limiting the overall voltage distortion to no more than the network planning levels specified in ER G5/4-1, which in turn are set to achieve compatibility.

G5/4-1 identifies consumers by their point of common coupling (PCC) to the supply, and applies limits at that point. G5/4-1 therefore applies to every consumer connected to the Public Electricity Supply (PES), including:

- Domestic
- Commercial, shop and office consumers
- Industrial users.

It forms part of the consumer's agreement to connect, and it is the responsibility of the individual consumer to ensure that the appropriate procedures to agree connection of new loads are followed. It is also very important that the consumer understands the responsibilities placed on him by the supply utilities to avoid the possibility of having to implement costly remedial measures in the event of a problem.

It is important to understand that G5/4-1 is effectively an "Installation Standard" and applies to the total harmonic generating equipment installed by a consumer.

It is not a product or equipment standard, and no single items of equipment can be said to comply.

1.1 Why change?

Engineering Recommendation G5/4 replaced the former Electricity Council Engineering Recommendation G5/3, which had been in place since 1976, during which period the network has seen a vast expansion of the numbers of rectifiers used both industrially, in terms of drives and controls, rail traction supplies, in the office environment within IT and in domestic appliances.

There has been a tendency for distortion levels, especially the 5th harmonic, to increase, although it is generally considered that consumer equipment is the main source of this distortion. G5/4 also introduced areas new to regulation in the UK, including sub-harmonics, interharmonics, and voltage notching.

The original edition of G5/4 included certain limits which were to be applied from 1st January 2005. However, after discussion with industry it was agreed to modify this requirement, and this has resulted in G5/4-1:2005.

Specifically the changes in G5/4-1 allow for the application of a "Partial Weighted" methodology for higher frequency harmonics, which is described in Section 6.2.2, and "Conditional Connections", which are described in Section 6.2.4.

From the point of view of the user, a modern, well designed drive system will not normally produce significant levels of interharmonics or cause notching outside of the permitted levels and they are therefore not considered in further detail in this guide.

Since the publication of G5/3 the structure of the Electricity Supply Industry has changed dramatically, and European legislation, in particular the “EMC Directive”, has been implemented, adding mandatory product specific requirements.

In the United Kingdom, it is possible to purchase electricity from one company, the Public Electricity Supplier (PES), and to have it delivered by another company, the Network Operating Company (NOC).

It is the NOC who must agree connection for harmonic producing loads.

1.2 Who does it apply to?

The recommendations of G5/4-1 apply to each consumer at his point of connection to the Public Supply Network. It effectively forms part of each consumers’ agreement to connect with his NOC.

The harmonic levels within an individual consumer’s network are NOT covered by this guide, and must be judged solely by the influence they will have at the point of common coupling, and the ability of other equipment on that particular network to operate satisfactorily.

To this end the consumer should reference the applicable IEC standards, including IEC 61000-2-2 – Electromagnetic Compatibility, Environment, Compatibility levels for low frequency conducted disturbances and signaling in public low-voltage power supply systems, or IEC 61000-2-4 Electromagnetic compatibility (EMC), Environment, Compatibility levels in industrial plants for low-frequency conducted disturbances.

Any rectifier will generate harmonic currents on a network, although they will vary in magnitude according to the design of the specific circuit. It is important that all estimates, calculations, and limits assume a balanced voltage supply.

Even a small imbalance can cause large changes in drawn current, particularly with uncontrolled bridge rectifiers, and the harmonic performance of the drive equipment will deteriorate in such conditions. Discussion with the Network Operating Company (NOC) must emphasis this unbalanced situation, which could affect meeting predicted harmonic values.

Rectifiers are incorporated in the majority of domestic and office machines, ranging from TVs, through computers and washing machines to cordless telephones, as well as industrial PLCs and drive systems.

All supply systems also have ‘natural’ harmonics, introduced by the generators and transformers, and may also have resonant frequencies caused by a combination of the capacitances and inductances of the system.

2 Harmonic Current and Voltage

It is the harmonic voltage at a given point in the supply network that determines the risk of disturbance to the load at that point.

The part of that voltage which results from the harmonic producing load, is caused by the voltage drop from the supply impedance, due to the individual harmonic currents generated by the load.

Generally the harmonic currents generated by a load are controlled by its circuit design, and its manufacturer can predict these with a reasonable degree of confidence. They will be affected to some extent by the supply impedance, especially for small drives, which often use little or no inductance in the d.c. link.

The supply impedance is primarily a function of the electricity distribution network, and can normally be predicted by the network operator for the fundamental.

There are three levels of supply impedance that are of importance:

- The minimum level, which would allow the highest possible fault current to flow
- The normal running level
- The maximum level, which would allow the highest possible harmonic voltages to appear.

The minimum value is needed to enable the design of switch and control gear to be evaluated to withstand a potential fault occurrence. This level is frequently misquoted to correspond only to the standard capabilities of switch and control gear, but the correct values are needed to predict the maximum harmonic currents.

The other values represent the normal running range, which are needed to predict the harmonic distortion.

In practice, the system impedance will vary over the course of the day, and the network operator must predict the most appropriate figure as a basis for calculation.

While the system impedance or fault level can be predicted for the fundamental frequency, it is also probable that the impedance will vary relative to the frequency.

This variation can become a source of resonance at some point within the distribution network.

It is very important to try and identify potential sources of resonance, such as power factor correction and long MV supply cables, to ensure that these can be included in calculation models.

The method of representing the system impedance is often by the maximum power that can flow in a fault condition, this is the system fault level, and is usually quoted in MVA.

The higher the fault level the lower the source impedance, and therefore the lower the voltage resulting from a specific current.

G5/4-1 document uses fault level as the measure of source impedance for assessments in both Stages 1 & 2.

3 Power Factor

When harmonics are present in a power system the term “power factor” can be confusing. A strict definition of power factor is the ratio of the power to the product of the r.m.s. voltage and current in the circuit. This factor has a value less than one, and is influenced both by the phase angle between the fundamental current and voltage and also by the presence of harmonic current.

When no harmonics are present the power factor is affected only by the phase angle of the current and voltage, and is calculated by the well-known expression $\cos\phi$. Traditional power factor correction equipment (usually capacitor banks) is used to increase this factor and reduce peak demand or similar charges to the power consumer.

Within the field of power electronics the terms “displacement factor” or “displacement power factor” are widely used to distinguish the phase angle element of power factor ($\cos\phi$) from the harmonic element. In the remainder of this document we have used the common parlance, i.e. a reference to power factor or power factor correction relates to the traditional matter of current phase angle.

4 Drive Basics

Most a.c. variable frequency drives operate by using a bridge rectifier to convert the incoming a.c. voltage into a d.c. voltage.

The inverter part of the drive then converts the d.c. into a controlled voltage and frequency for speed control of the motor.

In addition d.c. drives generally use a controlled bridge rectifier to control the current flowing in the d.c. circuit.

4.1 Drive Topology

There are many drive topologies; the following gives a brief outline of some of the more commonly encountered types, with examples of typical waveforms and spectrum analyses:

4.1.1 Single Phase supplies

A typical single-phase input frequency converter will be provided with a 4-diode full wave rectifier, feeding an uncontrolled d.c. link, with capacitor energy storage.

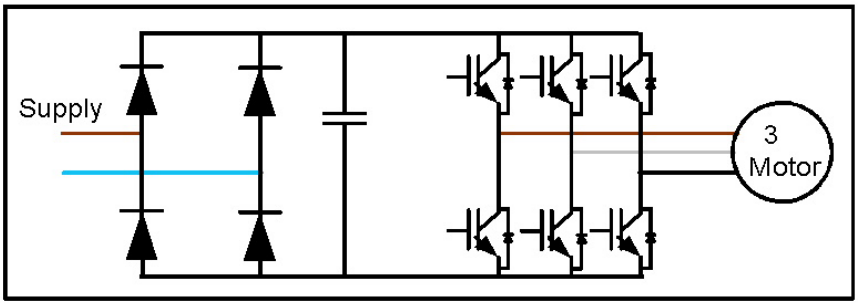

Figure 1

Basic single-phase frequency converter

This should generate no even harmonic currents but will produce odd harmonics from the 3rd upwards, the magnitude depending basically on internal impedances.

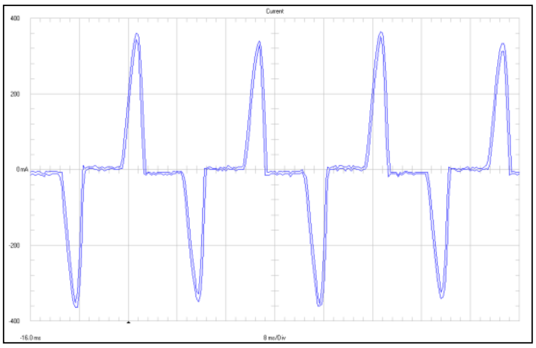

Figure 2

Typical measured current waveform for single phase rectifier

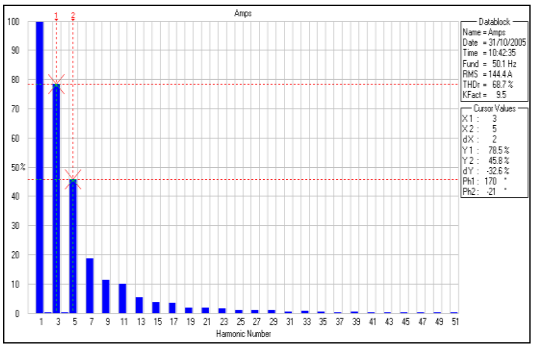

Figure 3

Typical measured harmonic current spectrum for single phase rectifier

The actual magnitude of both the current and voltage harmonics will depend on the impedances of the system.

4.1.2 Three Phase supplies

Three phase supplies will normally be used for industrial power solutions, and use at least six semiconductors connected in the rectifier bridge.

In general the following paragraphs refer to three phase networks.

4.2 Drive Types

Very often the rectifier arrangement is used as the description of the type of drive.

4.2.1 6 pulse

A typical voltage source a.c. drive fitted with a 6-diode full wave rectifier, feeding an uncontrolled d.c. link, with capacitor energy storage, will generate no even harmonics, no triplen (multiples of 3rd) harmonics, and only odd harmonics from the 5th upwards.

The magnitude will depend on the internal impedances of the system. The basic diagram shown in Figure 4 ignores the chokes, which would normally be used in the a.c. or d.c. lines.

In practice imbalances in the supply and in components will give rise to some minimal levels of non-characteristic harmonic currents.

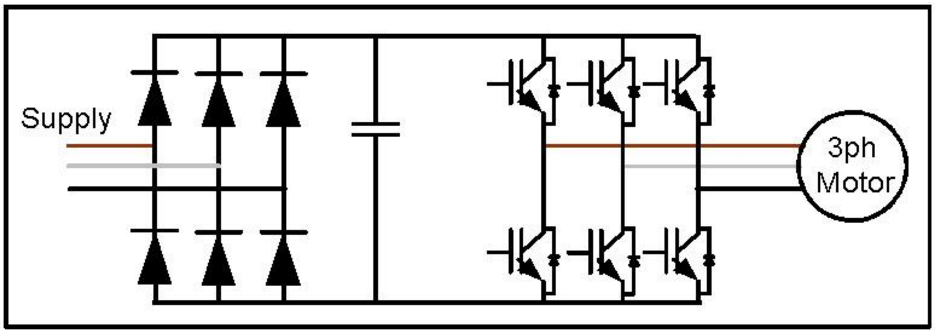

Figure 4

Basic 6-pulse rectifier frequency converter

Typical d.c. drives (and some 4 quadrant a.c. drives based on thyristor technology) also use a full wave 6 pulse thyristor rectifier, although for regenerative solutions there will be 12 semiconductors.

These will generate no even or triplen harmonics, only odd harmonics from 5th upwards, the magnitude again depending on internal impedances.

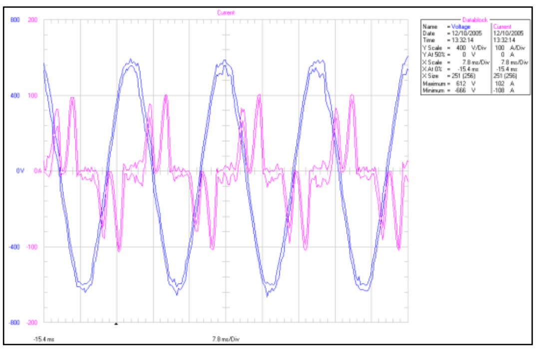

Figure 5

Typical current and voltage waveform for 6 pulse rectifier

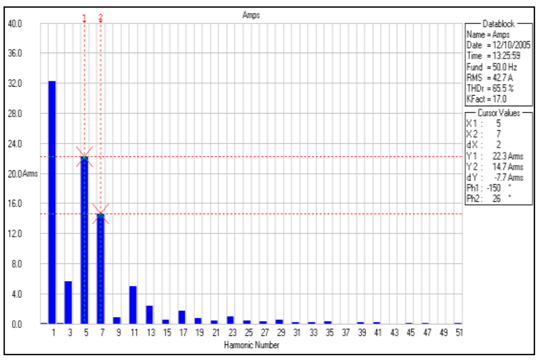

Figure 6

Typical current spectrum analysis for 6 pulse rectifier

4.2.2 Multi-pulse Rectifiers

12, (or 18 or 24) pulse full wave rectifier, supplied from a phase-shifting transformer (see Table 1).

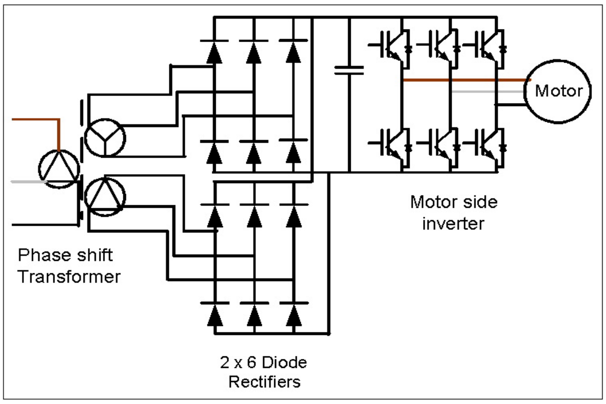

Figure 7

Basic 12-pulse parallel-connected rectifier frequency converter

As with 6 pulse rectifiers multi-pulse rectifiers theoretically generate no even or triplen harmonics, only odd harmonics from the (n – 1) (where n is the pulse number) upward, the magnitude again depends on internal impedances.

Therefore an ideal 12 pulse drive eliminates the 5th, 7th, 17th and 19th harmonics. In practice, as shown in Figure 8 and Figure 9, a residual level of these harmonics is present due to imbalance in the transformer and the supplying network.

This effect becomes more marked with lower ratings, and there is a practical limit for the minimum rating of the wound components for multi pulse systems.

Multi-pulse rectifiers always require some wound components (transformers, reactors, etc) to obtain the phase shifts required in the supplies to the rectifiers. It must be noted that designing suitable transformers is a skilled process, as the impedances of each limb must match, despite the differences inherent in the length of windings. For example the star secondary winding in Figure 7 requires $\sqrt{3}$ times the number of turns of the delta winding to maintain the same voltage. Some imperfection is inevitable.

Pulse number	Phase shift
12	2 outputs 30^0 apart
18	3 outputs 20^0 apart
24	4 outputs 15^0 apart

Table 1

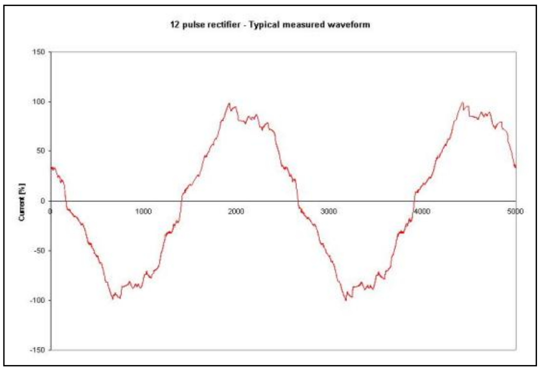

Figure 8

Typical measured current waveform for 12 pulse rectifier

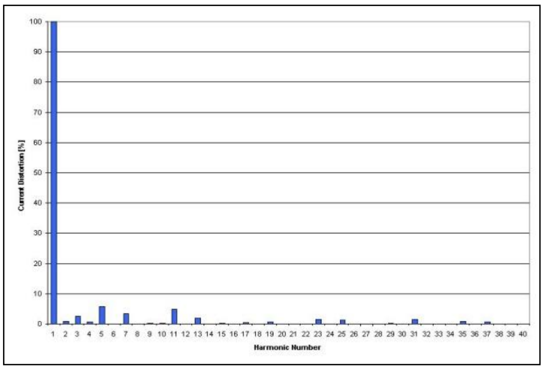

Figure 9

Typical measured spectrum analysis for 12 pulse rectifier

4.2.3 Active Rectification

Most active rectifiers are based on an inverter working in reverse, with enhanced d.c. link voltage.

These are also sometimes known as “harmonicless rectifiers”, “regenerative rectifiers” or “unity power factor rectifiers”.

Small amplitude residual low frequency harmonics and inter-harmonics will occur. In all cases, some residual even and lower order odd harmonics may also occur due to supply imbalances, and manufacturing tolerances in the individual components used.

These are difficult to predict, and are generally so small as to be insignificant.

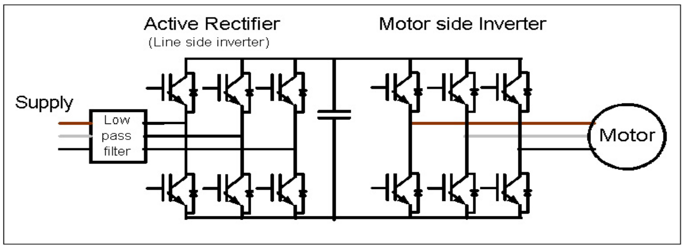

Figure 10 Basic active rectifier voltage source inverter

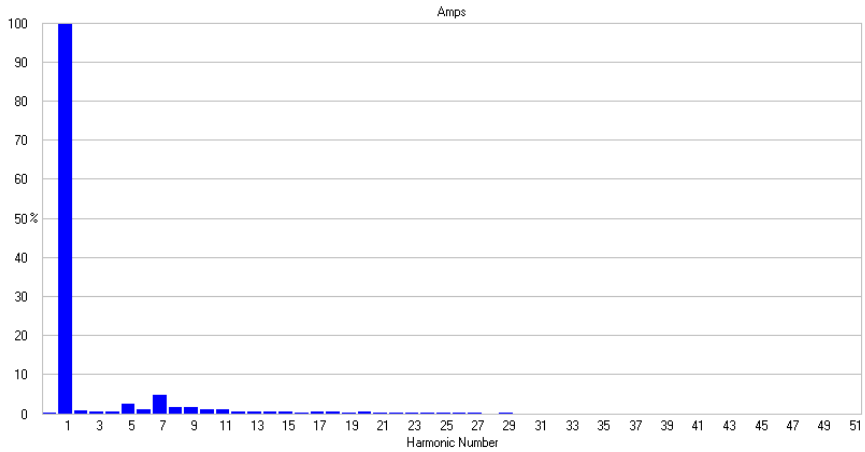

Figure 11 Typical measured current harmonic spectrum for active rectifier drive (THDi = 3.5%)

4.2.4 Filter

In addition to connecting rectifiers to a network, it is possible to fit filters, and the application of active and passive harmonic filtering as an independent means of attenuation or as part of a power factor correction scheme may provide a cost effective solution to meeting the planning levels.

4.2.4.1 Passive Filters

Passive filters are generally tuned circuits using capacitors and inductors. They may be either shunt or series connected.

4.2.4.1.1 Shunt Filters

Shunt filters are generally used where some degree of power factor correction is also required. They will provide reactive compensation, and may be used to improve the network power factor where reactive loads such as motors, or phase controlled rectifiers are present.

Generally shunt filters are tuned to attenuate a specific harmonic frequency or group of frequencies. Their shunt connection means that they are affected by all harmonics in the system, regardless of source. Their application requires skill and experience, because it is possible for the filter to be overloaded by existing harmonics, in which case its protection device will disconnect it and it will fail to work.

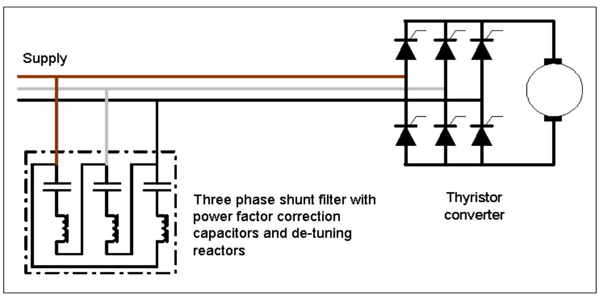

Figure 12 d.c. converter with shunt filter

4.2.4.1.2 Series Filters

Series filters are dedicated to a single drive or group of drives. When correctly designed they are not significantly affected by existing supply harmonics, and they maintain their performance well in the presence of phase unbalance. They have the benefit of simplicity, giving a low failure rate, and they can be a cost-effective solution. Some possible drawbacks which should be taken into account are that they may affect the d.c. link voltage regulation, causing a voltage reduction at high load power or an increase at light load, and also possibly affecting motor control stability in open loop applications. Also at light load the power factor becomes leading, which in most applications is of no consequence, but might be unacceptable where the power source is a local generator.

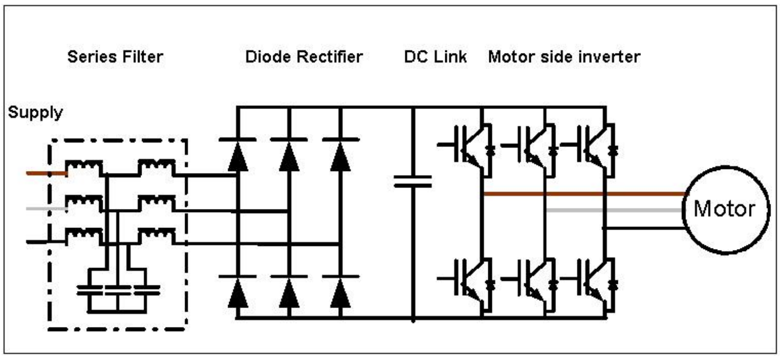

Figure 13 Voltage source inverter with series filter

4.2.4.2 Active Filters

Active filters are semiconductor converters, which are specifically designed to generate anti-phase harmonics, and may be of open or closed loop design.

Active filters react very rapidly to changing network conditions, and can add stability to a system.

The effects of network impedance variation, especially if standby generation is present, must also be taken into account when designing any filter installation.

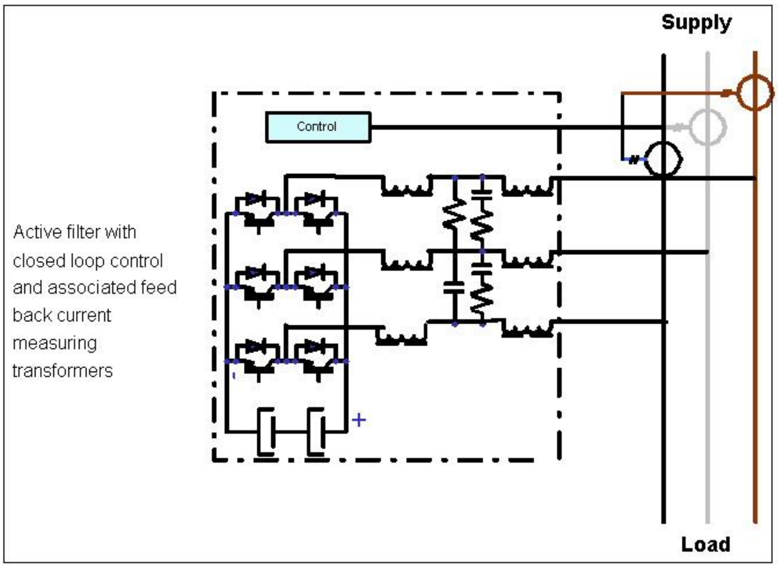

Figure 14 Typical closed loop active filter

4.2.4.3 Power Factor Correction

Diode rectifier voltage source frequency converters operate at very high power factors, and are extremely unlikely to require any power factor correction. Active rectifiers are often capable of operating at a preset power factor. Where reactive loads such as fixed speed motors and thyristor rectifiers are connected to a network, it is usual to fit power factor correction.

Important Limitation

Power factor correction capacitors can cause increased harmonic current in a power network unless provided with de-tuning reactors. It is important that any system with equipment which generates harmonics, including both drives and active rectifiers, together with power factor correction or shunt filters, should be designed as part of an integrated system. This should include de-tuning of capacitors and preferably should be designed with a single point of connection rather than distributed around individual loads, due to the possibility of undesirable interaction.

5 Soft starters and Load controllers

For the purposes of G5/4-1, semiconductor motor controllers (soft starters) and load controllers, which comply with EN 60947-4-2 and EN 60947-4-3, can be considered as a.c. regulators and the limits for these devices given in G5/4-1 will apply.

Motor and load controllers rated at more than 16 A will have to be considered under the same stages of assessment as for drives.

Motor and load controllers rated at less than 16 A that comply with the requirements of EN 61000-3-2 are exempt from assessment and can be used without restriction.

However, devices rated at less than 16 A that do not comply with EN 61000-3-2 will be classified as professional equipment and will need to be assessed as for controllers rated greater than 16 A. In practice, non-optimising motor controllers rated less than 16 A will probably comply with EN 61000-3-2, whereas load controllers rated up to 16 A, and optimising motor controllers rated at more than 5 A are unlikely to meet the harmonic emissions requirements of EN 61000-3-2 and will require assessment.

5.1 Controller Basics

There are a number of controller topologies, but all employ self-commutating semiconductor switches, either as a single element or, more usually, as an anti-parallel pair inserted in each phase connection to the controlled motor or load.

Controllers having switches controlling each half-wave of the power wave are said to be fully-controlled, whereas those controlling only one half-wave of the power wave with a single switch element paralleled by an uncontrolled diode for the other half-wave in the phase connections are known as half controlled types.

Because they do not produce even harmonics, fully controlled versions will have a less severe harmonic spectrum than their half-controlled variants. A brief outline of some of the more commonly encountered types is given:

5.1.1 Single Phase

A typical fully controlled single-phase input controller will be provided with a single semiconductor switch in the line connection to a single-phase load. This should generate no even harmonic currents; only with odd harmonics from 3rd upwards, the magnitude depending on internal impedances.

5.1.2 Three Phase

Three phase supplies will normally be used for industrial power applications and will use semiconductor switches either in two or three phases.

Optimising motor controllers, which use phase control techniques to reduce the voltage supplied to a running motor, will always employ full control to all three phases.

A typical three-phase, fully controlled, a.c. semiconductor motor or load controller, fitted with a 6-pulse thyristor bridge will not generate even or triplen (multiples of 3rd) harmonics, but only odd harmonics from the 5th upwards. Again the magnitude will depend on the internal impedances of the system.

In all cases, some residual even and lower order odd harmonics may occur due to supply imbalances and manufacturing tolerances in the individual components used. These are difficult to predict, but are generally so small as to be insignificant.

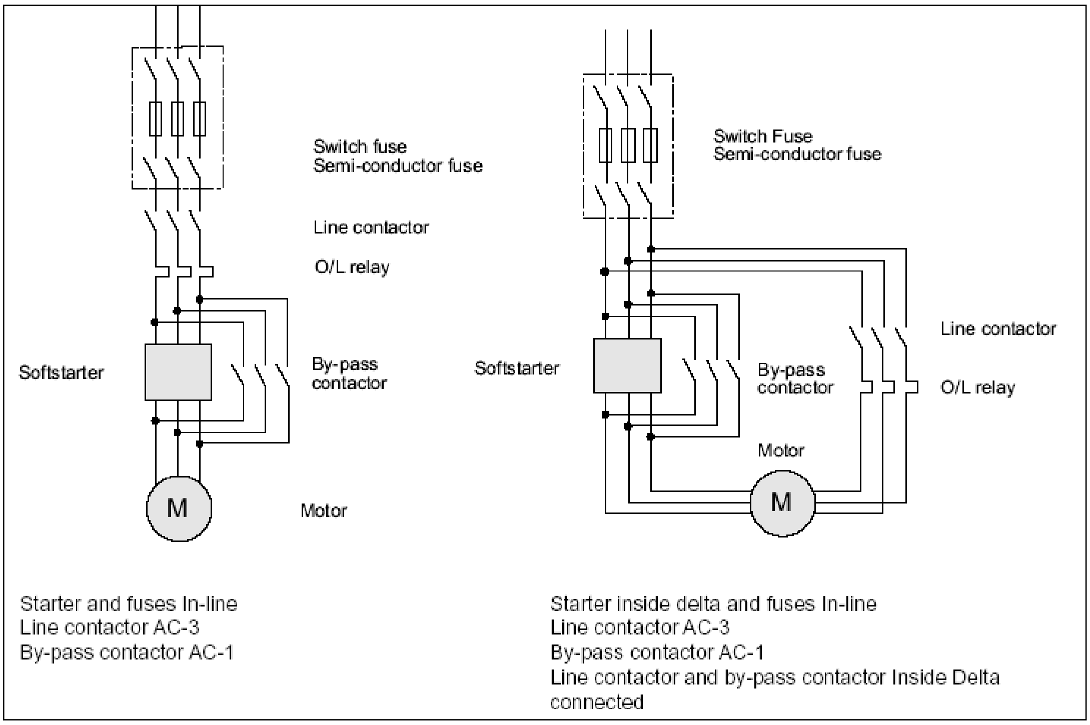

Figure 15 - Typical soft starter connections

5.2 Controller Types

5.2.1 Motor Controllers

Because motor starting currents are measured in multiples of motor full-load current, the harmonic effects of motor controllers are at their greatest during the motor starting and accelerating phase.

However, provided the controller ramp-time is set at three seconds or less, the effects can be ignored. When longer ramp-times are necessary due to higher inertia loads, or where motors with larger inertia rotors are involved, G5/4-1 accepts the use of soft starting 'infrequently' on a 'conditional' basis.

With this concession, most soft starter installations will not need special considerations. However, if a challenge arises, consumers will need specific information regarding the levels and harmonic spectrum of the type of controller being used.

5.2.2 Optimising Motor Controllers

Optimising motor controllers operate on the basis of reducing the motor terminal voltage, and deliberately running a motor under fluxed. This results in an improved power factor, and reduced current thus giving energy savings. As the controller is operating continuously they will introduce odd harmonics (5^{th} and higher) while the optimising function is active during normal running.

However, the harmonic effects are greatest at the lightest loads of the motor, and since the harmonic currents are related to a line current which may be significantly less than the motor full-load current, this device should be designed to meet the requirements of G5/4-1. The manufacturers prediction should be sought in order to implement this.

5.2.3 Load Controllers

Load controllers are used to regulate the energy supplied to a wide variety of non-motor loads, ranging from control of resistive loads such as lighting arrays, furnaces, etc to non-resistive loads such as capacitor banks.

The harmonic effects of load controllers are present all the time that the load is being controlled and depend on the degree and nature of the control. Broadly speaking, there are two types of control method:

a) 'Burst firing' where energy is supplied to the load in a sequence of very short periods of a variable number of full cycles and,

b) 'Phase control', where energy is passed continuously to the load through semiconductor switches with variable delays applied to the turn-on of the devices.

Burst firing is most frequently used for the regulation of resistive loads such as furnaces, and usually involves firing the semiconductor devices at the corresponding voltage zero crossings of the supply. In this type of controller, the harmonic effects are relatively benign, however, flicker and voltage drop effects can be significant.

Where phase controlled controllers are employed, the harmonic spectrum is directly related to the firing angle of the semiconductor switches in the main circuits.

Fully controlled systems will only generate odd harmonics. If there is no neutral connection, there will be no triplen harmonics with only the 5th and higher harmonics being of concern. Before any assessment of the distortion effects of this type of controller can be made, detailed knowledge of the application and the anticipated range of control are required.

Half-controlled systems have a wider harmonic spectrum and will include even harmonics. For this reason, half-controlled systems are usually limited to low-power applications. Provided the application will allow the harmonics to be restricted to the requirements of IEC 61000-3-2, they can be installed without reference to the network operator. If this is not the case, then detailed knowledge of the application and the anticipated range of control are required before the processes outlined in G5/4-1 can be applied.

6 Point of Common Coupling

The implementation of G5/4-1 depends on defining the 'point of common coupling'. This is not necessarily the voltage level at which the equipment is connected.

The Point of Common Coupling (PCC) is the point at which the consumer is connected to other consumers on the Public Electricity Supply.

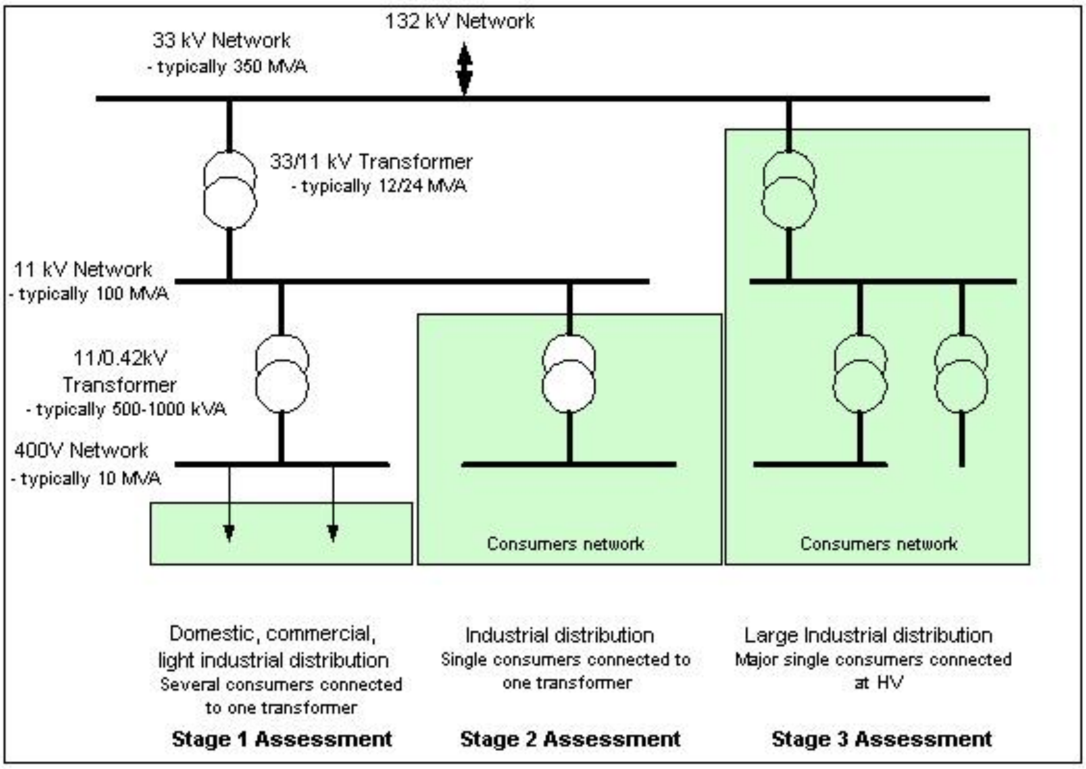

Figure 16 - Network model

Note that transformer ratios are normally detailed off load; therefore with distribution systems the current standard is 420 V for a 400 V network, compared to the former standard 433 V for a 415 V network. Generally in the United Kingdom, a consumer with a connected load of less than around 15 kVA will normally be connected at 230 V single phase and up to 300 kVA at 400 V. They constitute the main base of Domestic, light industrial and commercial connections.

Consumers, with higher power demands, will normally be connected to the medium[1] voltage network by a dedicated transformer, in which case this medium voltage level will be their point of common coupling, e.g. if a site is fed by a dedicated distribution transformer with nominal ratio 11 kV/420 V and no other consumers are fed by the 400 V system, then the PCC is at 11 kV. Larger consumers may well be connected to higher voltage levels.

The NOC will only apply G5/4-1 at the point of common coupling (PCC).

The levels of harmonic current and voltage at intermediate points in a consumer's own networks are solely at the discretion of the consumer, who may wish to consider the immunity limits for various categories of installations defined in IEC 61000-3-12.

7 Stages of assessment

G5/4-1 defines three stages of assessment, which increase in complexity.

It is important to note that these stages do not correspond totally to those in the previous document, the EA Engineering Recommendation G5/3, or to those in the various EN and IEC standards.

In addition, while the Planning Levels for voltage distortion have remained the same for low and medium voltage, and have even increased at high voltage, the limits for

[1] Low Voltage U_n <1000V, medium voltage 1000 < U_n <35000V, high voltage 35000 < U_n.

some specific harmonic currents have reduced substantially, especially for the 5th harmonic. There is no change between G5/4 and G5/4-1.

Where a user wishes to install new equipment to extend an existing installation, and where agreement to connect has already been established under previous rules, it is possible that the connection of additional equipment could involve a new and lower limit being applied to the whole installation under the terms of a new agreement.

This would be retrospective, and therefore difficult to enforce.

In these circumstances agreement to connect without increase in the aggregate harmonic current loading should be forthcoming, although the overall connection may be for a higher power.

Where a user wishes to replace existing equipment with new equipment of similar functionality, there should be no need to repeat the application procedure, if documentary evidence exists that the levels of harmonic currents generated by the new equipment do not exceed the existing levels.

7.1 Stage 1

Under G5/4-1 Stage 1, only connections to 230 V single phase and 400 V three phase supplies are considered, therefore this applies to the majority of domestic, commercial and light industrial consumers.

G5/4-1 assumes that there will be no more than four harmonic producers connected to a single supply source (distribution transformer) when considering Stage 1 connections.

The ‘available’ levels of harmonic current for each point of connection have then been split in accordance with this assumption.

7.1.1 $I_n \leq 16$ A [2]

Under the EU EMC Directive, any equipment designed for use in a domestic environment, with nominal current less than or equal to 16 A RMS (per phase), and which meets Harmonised European Standard EN 61000–3-2, will carry a ‘CE mark’ to this directive. It may then be connected without further assessment.[3]

Where a number of items of equipment are installed, the aggregate of the rated currents must be less than or equal to 16 A, and each individual piece of equipment must also comply with EN 61000-3-2.[4]

Basically, this standard covers domestic equipment such as televisions, washing machines, etc. and it is these devices that are responsible for the bulk of harmonic voltage distortion throughout the UK network.

Under this standard, drives are considered to be professional equipment, and with a total rated input over 1 kW they are at present accepted with no limits under this standard.

If the equipment is a conventional inverter load, and the combined total rating is under 5 kVA for a single-phase supply, it may again be connected without further assessment.[5]

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[2] Rated current drawn

[3] G5/4-1 Clause 6.2

[4] EN 61000-3-2:2000

[5] See G5/4-1 Clause 6.3.1.1

7.1.2 16 A < I_n ≤ 75 A

For three phase supplies, a maximum total of 12 kVA of standard 6-pulse diode rectifier loads can be connected without further assessment.[6]

Alternatively any single piece of equipment between 16 A and 75 A nominal current, which meets Stages 1 or 2 of EN 61000-3-12:2004 may also be connected without further assessment.[7]

The procedures detailed refer to a single consumer having single items of harmonic generating equipment installed to a single point of common coupling.

7.1.3 I_n > 75 A, or Multiple Equipments

The sum of the harmonic currents generated by all the equipment connected to a single point of common coupling can be calculated and checked to be below G5/4-1 Table 7.

This restricts the total amount of equipment that can be installed by a single consumer under the Stage 1 procedure, and includes multiple equipments meeting the harmonized standard EN 61000-3-2 and EN 61000-3-12.

One possible problem area in this procedure is where the standing voltage distortion level is already close to or above the planning level (5%).

In this case, the Network Operator reserves the right to examine any additional load under the Stage 2 procedure.

If a Table 7 assessment needs to be made, the drive supplier will normally provide the appropriate data for individual drives

It must also be remembered that G5/4-1 Table 7 is based on a system fault level of 10 MVA at 400 V.

This is fairly typical for an urban supply system. However, this must be confirmed by the supply utility.

If the fault level varies from this base level the figures in Table 7 may be varied pro-rata, as will the powers that can be connected.

It is the responsibility of the supply utility to advise the effective peak, normal running and minimum running fault levels.

This information also has implications to the electrical safety of the consumer's equipment.

It is critically important for electrical safety that all equipment connected to a network is designed to cope with the peak fault level likely to be encountered, while the harmonic calculations should be based on the normal running fault level.

7.1.4 Stage 1 Differences between G5/4 and G5/4-1

Table 7 of G5/4-1 covers all harmonics up to the 50th. If there is a problem in meeting the levels of the higher orders, a new concession has been incorporated to allow the higher order harmonics (23rd. upwards) to be lumped together as a partially weighted sum (PWHD), as set out in BS EN 61000-3-12.

This is a useful assistance when using multi-pulse and active rectifiers, which can have relatively a relatively large high order harmonic content

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6 See G5/4-1 Table 6

7 See G5/4-1 Clause 6.3

7.1.5 Stage 1 – Typical Drive Loads

When the levels of harmonics generated by different types of drive rectifiers are considered, at the base fault level for the system, we may expect to be able to connect the following powers:

- 6 pulse diode – 30 kW limited by the 5^{th} harmonic
- 12 pulse diode – 300 kW limited by the 23^{rd} harmonic (but could be slightly higher using the PWHD rule)
- Active Rectifier – possibly up to 500 kW.

To calculate the resulting level, the arithmetic sum of all the harmonics for a number of drives is taken. A typical calculation example is shown in Table 2.

In practice, there will be a co-incidence factor, depending on the relative loading and method of connection of each specific rectifier, giving a small safety margin in the calculation.

This co-incidence factor may need to be more carefully considered as phase shifting and consequent summation or subtraction can occur between industrial and domestic loads.

With an uncontrolled rectifier, the 5th, 11th, and 17th (6n – 1) harmonics, on a three phase system, will always be in phase, whilst the 7th, 13th, and (6n + 1) harmonics will vary in phase with the relative loading of the rectifier.

In addition, the harmonics generated on a single-phase (phase/neutral) network will also be phase displaced to the harmonics generated by a three phase (phase/phase) system.

Specifically, the harmonics generated by single phase loads are related to the phase – neutral vector, while those generated by three phase loads relate to the phase to phase vector, and so are approximately 30^0 apart electrically. Thus in a mixed system some 5^{th} and 7^{th} harmonics will partially cancel.

Guidance to harmonic co-incidence factors was given in G5/3 Table A3. However, G5/4-1 now refers to IEC 61000-3-6.

Practical experience suggests for a number of unequally loaded uncontrolled 6 pulse (diode) rectifiers, the (6n – 1) harmonics will always be in phase and currents should be summed arithmetically.

The (6n + 1) harmonics, however, will vary in phase and current cancellation will allow a reduction from the arithmetic sum by a factor of up to 10%.

Application Example of G5/4-1 Table 7

Table 2 shows the summation of harmonics for a number of different loads in a typical small installation, without the use of co-incidence factors.

It should be noted that the current limit tables are based on nominal system fault levels, and will vary pro-rata if the actual running fault level varies substantially from the nominal.

Load / Equipment Rating [kVA] / Harmonic order	f [Hz]	7.5 kW 6 pulse diode 11 Current [A]	20 kW 6 pulse diode 30 Current [A]	Domestic load (Lights, PCs, etc) Current [A]	Sum Current [A]	G5/4-1 Table 7 (10 MVA fault level) Current [A]	Margin Current [A]
Fund.	50	11.1	29.4	12.4	52.9		
3	150	Negligible	Negligible	11.0	11.0	48.1	37.1
5	250	3.9	12.1	8.0	24.0	28.9	4.9
7	350	2.4	7.7	4.8	14.9	41.2	26.3
9	450	Negligible	Negligible	2.2	2.2	9.6	7.4
11	550	1.2	2.6	1.0	4.8	39.4	34.6
13	650	0.9	2.1	0.9	3.9	27.8	23.9
17	850	0.7	1.5	0.8	3.0	13.6	10.6
19	950	0.6	1.2	0.5	2.3	9.1	6.8
23	1150	0.5	1.1	0.4	2.0	7.5	5.5
25	1250	0.4	0.9	0.3	1.6	4.0	2.4
29	1450	0.4	0.8	0.1	1.3	3.1	1.8
31	1550	0.4	0.7	0.1	1.2	2.8	1.6
35	1750	0.3	0.6	Negligible	0.9	2.3	1.4
37	1850	0.3	0.6	0.1	1.0	2.1	1.1
41	2050	0.3	0.5	Negligible	0.8	1.8	1.0
43	2150	0.2	0.5	Negligible	0.7	1.6	0.9
47	2350	0.2	0.4	0.1	0.7	1.4	0.7
49	2450	0.2	0.4	Negligible	0.6	1.3	0.7

Table 2

Example of typical Table 7 Calculation

Because of uncertainties in system data and measurements it is misleading to calculate values to better than 1% of fundamental. This should always be considered when calculating the margin.

For even harmonics and triplens, due to three phase loads, the values will normally be negligible and therefore need not be recorded.

3rd harmonic and other triplens will occur on most three phase networks due to voltage imbalance and phase sequence effects of the supply system at the rectifier terminals. These cannot be readily quantified by calculation. In addition, single-phase loads may result in some triplen contribution.

G5/4-1 permits any two harmonics between 6th and 19th to exceed the limit by 10% or 0.5 A, whichever is the greater.

G5/4-1 also permits any four harmonics above the 19th to exceed the limit by 10% or 0.1 A, whichever is the greater.

In each case, the uncertainty of the measurement may well be greater than these values.

The higher order currents are also significantly attenuated by the distribution system, and do not normally cause problems with the exception of a possibility of interference with older analogue telephone installations.

The example in Table 2, which consists of 27.5 kW of converter fed motor loads, meets the current limits for each harmonic and should therefore be acceptable for connection at Stage 1.

Table 2, which is based on a simple spreadsheet model, provides a ready means of presenting the appropriate data.

7.1.6 Filtering

If alternative means of harmonic attenuation are being utilised, such as a closed loop active harmonic filter, which will inject anti phase harmonics, the attenuation of this device can be shown as a negative value in this table.

When calculating a suitable filter the harmonic generation of the rectifier against a true sinusoid should be considered, as the measured harmonic currents from a rectifier will be lower when a standing distortion exists on a network. As the filter will result in an improved network distortion the actual absorption may be higher than measurements predict.

The same principle may also be applied to open loop active and tuned filters if the load is non-dynamic. However, tuned filters may also import harmonic load.

The addition of tuned shunt filters must be very carefully considered, especially with conventional voltage source PWM drives. These filters consist of an LC (inductor and capacitor) network, tuned close to a harmonic frequency (typically 225 – 235 Hz on a 50 Hz network) to provide a low impedance path to allow controlled harmonic current flow.

The filter is therefore inherently capacitive below the tuned frequency and reactive above. The low impedance at the tuned point may also allow harmonic currents to be imported from other parts of a network.

As a diode rectifier presents very little fundamental reactive load to compensate, it is relatively easy to create a system that can achieve a leading power factor, which in turn may set up a resonant condition with the d.c. link components and result in premature drive or filter failure.

The use of this type of filter with a d.c. or CSI drive provides a convenient and cost-effective means of controlling both power factor and harmonic load.

The use of power factor correction capacitors without de-tuning is not recommended on any circuits that may have a harmonic content, as they will appear as a low impedance path for any harmonics on that network.

Some manufacturers will also offer “series” filters, which will reduce the harmonics due to a single or multiple drive rectifier combination. In these cases the residual harmonics are generally all 5^{th} harmonic.

If the connection is not acceptable at Stage 1 or is at Medium Voltage, it is possible to consider a Stage 2 assessment.

7.2 Stage 2

If the levels of harmonics exceed those for Stage 1, the standing distortion is already close to the planning level, or the point of common coupling is at medium voltage (6.6 kV to 22 kV), then a different procedure is called for.

Firstly, for an MV PCC, if the total of converter loads is lower than 130 kVA of 6 pulse or 250 kVA of 12 pulse diode rectifier, there is no need for further assessment.

Otherwise the Network Operator will require to determine the network background voltage distortion.

This should be a measured value, and for a balanced load application should record as a very minimum the primary odd distorting harmonics, up to the 50th, plus the total harmonic distortion (THD) from 2nd to 50th harmonic.

The peak values of voltage harmonic distortion on the UK network will usually occur on a Saturday or Sunday evening, when very high levels of domestic television viewing co-incide with low levels of generation.

The measurements should therefore be taken over a period of seven days, to allow the results to be assessed realistically. Under G5/4-1, if the measured distortion on a network is less than 75% of the planning level for voltage distortion, then a summation of currents can be used and compared with G5/4-1 Table 12.

Within the scope of G5/4-1, there is the provision to allow the background level to be assessed on the basis of the level that is not exceeded for 95% of the time.

If the equipment will not be in continuous operation, the background should only be considered for the hours and days of the week that the equipment will be operated.

As an example, taking an 11 kV point of common coupling, if the measured THD is less than 3% - that is less than 75% of the planning level at 4%, and the 5th harmonic distortion is less than 2.25% (75% of 3%), then we can apply G5/4-1 Table 12, as shown in Table 2.

The planning levels for THD are the same as the former G5/3 levels for 400 V and 11 kV networks (5% and 4%), however, maximum 5th harmonic content is now introduced (4% and 3%).

The values of current permitted in G5/4-1 Table 12 are substantially lower than the previous G5/3 Stage 2 limits.

7.2.1 Stage 2 Typical Drive Loads

The current levels in Table 12 of G5/4-1 may typically correspond to the following levels of load, depending on the manufacturer, and the specific components:

- 6 pulse diode – 185 kW
- 12 pulse diode – 2500 kW
- 24 pulse diode – 2500 kW
- Active Rectifier –up to 3500 kW.

Typical harmonic spectra are given in Table 3.

		G5/4-1 Table 12 100 MVA fault level	**Drive 1** **185 kW 6 pulse**	**Drive 2** **2500 kW 12 pulse**
n	f [Hz]	Current [A]	Current [A]	Current [A]
1	50		10.8	151.6
5	250	3.9	3.8	2.9
7	350	7.4	1.5	1.2
11	550	6.3	0.8	4.7
13	650	5.3	0.5	3.9
17	850	3.3	0.4	0.2
19	950	2.2	0.2	0.1
23	1150	1.8	0.2	1.1

25	1250	1.0	0.1	1.0
29	1450	0.8	0.1	0.0
31	1550	0.7	0.1	0.0
35	1750	0.6	0.0	0.5
37	1850	0.5	0.1	0.5
41	2050	0.4	0.0	0.0
43	2150	0.4	0.0	0.0
47	2350	0.3	0.0	0.3
49	2450	0.3	0.0	0.3

Table 3

Comparison of typical rectifier harmonic loads at 11 kV with G5/4-1 Table 12[8]

7.2.2 Application of the PWHD method

Many drives will have some relatively high levels of current distortion at a relatively high harmonic number, possibly associated with the switching frequencies. In this case the PWHD method may be applied.

The example shown in Table 4 shows a 3500 kW active rectifier system, connected to an 11 kV network, with a fault level of 100 MVA (5.25 kA), and the calculation is based on the formula:

$$PWHD = V\sqrt{\sum_{h=23}^{h=50} h\left\{\frac{I_h}{I_{SSC}}\right\}^2}$$

Where: V = Line voltage; h = Harmonic order; I_h = Harmonic current; I_{Ssc} = Short circuit current

[8] Measured values against a dedicated supply

h n	f [Hz]	**G5/4-1 Table 12** 100 MVA fault level Current [A]	**Drive 1** **3500 kW active rectifier** I_h Current [A]	I_h/I_{Ssc}
1	50		216.8	
5	250	3.9	2.6	
7	350	7.4	1.4	
11	550	6.3	4.0	
13	650	5.3	3.0	
17	850	3.3	1.9	
19	950	2.2	1.3	
23	1150	1.8	2.2	4.039E-06
25	1250	1	1.2	1.306E-06
29	1450	0.8	0.8	6.865E-07
31	1550	0.7	0.6	4.068E-07
35	1750	0.6	0.4	2.269E-07
37	1850	0.5	0.2	4.339E-08
41	2050	0.4	0.3	1.019E-07
43	2150	0.4	0.1	2.295E-08
47	2350	0.3	0.2	8.274E-08
49	2450	0.3	0.1	5.898E-09
			Σh	6.922E-06
			Result	28.9 V

Table 4

Calculation by PWHD method

This results in an acceptable installation

7.2.3 Application of the Voltage Distortion Calculation

If the distortion, present before the new load is connected, exceeds 75% of the appropriate voltage planning level or the currents exceed the Table 12 limits, then, it is necessary to determine the voltage distortion that is likely to be generated by the new load, and to predict the overall levels of voltage distortion that will result.

In this case the predicted harmonic currents for the load as calculated by the manufacturer should be submitted to the supply utility for them to calculate the effect of the proposed new load.

The harmonic currents are used to calculate the resultant voltage distortion, however, G5/4-1 uses some correction factors to allow for possible system resonances in making this calculation.

At 400 V the voltages generated by harmonic currents of the 7th order and above are reduced by 50%, and for 6.6 kV, 11 kV, and 22 kV systems voltages generated by harmonic currents up to the 7th order are doubled.

If the resultant THD and the level of 5^{th} harmonic remain within the planning levels, then connection should be agreed.

Typical examples of a voltage distortion calculation are given in Table 5, based on the 6 pulse drive shown in Figure 4 rated to deliver 185 kW with the system impedances typical in a 10/100 MVA fault level system.

n	LV Current [A]	Uncorrected Voltage	Correction factor "k" G5/4-1 Table 8	Corrected Voltage	HV Current [A]	Uncorrected Voltage	Correction factor "k" G5/4-1 Table 8	Corrected Voltage
Fund	286.81	400.00	1	400.00	10.43	11000	1	11000.00
5	100.67	13.72	1	13.72	3.66	34.08	2	68.17
7	39.58	7.55	0.5	3.78	1.44	18.71	2	37.42
11	22.08	6.62	0.5	3.31	0.80	16.38	1	16.38
13	12.91	4.57	0.5	2.29	0.47	11.31	1	11.31
17	9.75	4.52	0.5	2.26	0.35	11.17	1	11.17
19	6.31	3.27	0.5	1.63	0.23	8.08	1	8.08
23	4.30	2.70	0.5	1.35	0.16	6.66	1	6.66
25	3.15	2.15	0.5	1.07	0.11	5.31	1	5.31
29	2.01	1.59	0.5	0.79	0.07	3.92	1	3.92
31	2.01	1.70	0.5	0.85	0.07	4.19	1	4.19
35	1.15	1.09	0.5	0.55	0.04	2.70	1	2.70
37	1.43	1.45	0.5	0.72	0.05	3.57	1	3.57
41	1.15	1.28	0.5	0.64	0.04	3.17	1	3.17
43	1.15	1.34	0.5	0.67	0.04	3.32	1	3.32
47	1.15	1.47	0.5	0.73	0.04	3.63	1	3.63
49	0.86	1.15	0.5	0.57	0.03	2.84	1	2.84
THDv		4.80%		3.82%		0.43%		0.75%

Table 5

Typical voltage distortion calculation

A clear exchange of information is needed in order that the drive supplier should be able to offer the most cost-effective solution.

The drive supplier is only indirectly a party to the application of G5/4-1, however, in practice to achieve the optimal solution the end user, who is the electricity consumer should encourage direct involvement and good communication between the utility and the supplier.

There are a number of techniques available to minimise harmonics and potential supply problems.

These consist of modifications of the network or the drive, and range from phase shifting, through multi-pulse rectifiers, to filters.

The sequence for exchange of information should preferably be as shown in the Appendices. It must always be remembered that the time scale for this exchange is critical to avoid unreasonable delays in implementation of a project.

7.2.4 Conditional connection

Under G5/4-1, it is possible to undertake a "conditional Installation":

Where the assessment has indicated that mitigation measures may be necessary, a conditional connection (of the uncompensated equipment) may be made where the margin outside the limits is low and considered to be within the uncertainty in the assessment process.

A post installation survey must then be used to confirm the actual requirements.

The equipment to be connected parameters and performance must be known and clearly defined. The supply network parameters are time variable. The supply network parameters are thereby significantly more complex to analyse.

Incompatibility issues will inevitably occur, therefore this method should be used with care, but it does allow the flexibility to optimise any necessary mitigation measures to the specific installation requirements.

The responsibilities of the parties to undertake this work should be fully detailed at the outset.

The method allows the flexibility to optimise any necessary mitigation measures to the specific installation requirements. It is particularly useful where there is reason to believe that the additional effect of the proposed load will be much less than suggested by the Stage 2 procedure – for example, where it is likely that the 5^{th}. Harmonic contribution from a three phase rectifier will reduce, or at least not increase, the contribution from existing single phase rectifiers.

Conditional connections may involve a risk that high levels of distortion may occur temporarily, and such connections should have regard to the practicality and risk of this alternative and with due regard to the cost and timescale of post installation harmonic mitigation measures.

7.3 Stage 3

If the levels of harmonics exceed those for Stage 2, or if the point of common coupling is at 33 kV or over, then a different and substantially more complex procedure is called for.

In this case, measurements to determine the distortion of the local network, at least up to the 33 kV level are needed, together with detailed information on the system impedances.

This information is then used in constructing a computer model, showing the interrelationship of the consumers' network and the local supply network, to enable the effects of the new harmonic sources to be computer modeled.

Currently there is little standardized methodology for undertaking this type of study, and this needs to be established between the NOC, the consumer, and the drive supplier.

A number of proprietary programs are available for network studies; most were developed to enable the safety of a system to be established by calculating worst case fault levels, and establishing the protective equipment co-ordination. Each of these programs has both strengths and limitations.

It is therefore important that the most effective software and correct form of study is selected and undertaken.

Within the model, account may be taken of the variation of existing and predicted harmonic levels with time of day, and/or day of the week. This may be useful if a clear correlation can be established between the existing levels and the effect of the proposed load.[9]

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[9] See G5/4-1 Para 8.3.2

According to G5/4-1, it is the responsibility of the network operating company (NOC) to carry out these calculations, and to determine whether the proposed load is acceptable for connection.

In practice, even with the most precise software, the validity of the model will depend absolutely on the accuracy of information input.

In practice, the user will need to plan the installation in advance to be sure that it will be accepted. This means that the information, which will be used by the NOC to carry out the estimation, must be made available during the planning phase.

These studies are inevitably time consuming and costly, and the apportionment of these costs must also be established.

7.3.1 General

If a drive installation is to be run for less than 24 hours daily, it is quite possible to consider only the standing distortion during the proposed operating period.

8 Measurements

Measurements can be taken of supply impedances and both harmonic currents and voltages using proprietary equipment.

The most common form of measurement is of the voltage distortion over a period of time, and while G5/3 accepted measurements over 24 hours, G5/4-1 now looks to a seven-day record in order to establish the worst case operating conditions.

While seemingly simple, obtaining and interpreting measurements of power quality including harmonics is a skilled task. The accuracy of any measurement is limited by the measuring equipment, and the method of measurement.

At low voltage, it is normal to take direct voltage measurements, but current measurements are normally made indirectly, by a current transformer, Hall effect transducer or Rogowski coil connected to the secondary..

At medium and high voltage, the measurement voltage and current transformers forming the switchgear protection or metering provisions are normally the only facilities available to be utilised, adding their inaccuracies. They may also place limitations in terms of the phase shift between current and voltage transformers, and the numbers of CTs and VTs fitted.

Limitations in measuring transformers also exist, which are outlined in IEC 60044 Parts 1 & 2.

The harmonic current measurement tolerances may be greater than the actual values in G5/4-1 Tables 7 and 12 especially at higher frequencies when measuring larger loads. This may limit the validity of measurements to show compliance with Table 7 or Table 12 for higher power levels.

G5/4-1 currently references two standards for making measurements, namely the harmonised European Standards EN 61000-4-7 Ed. 2:2002, and EN 61000-4-30:2003, which should be implemented.

8.1 Report

G5/4-1 also adds a format for the information to be provided in a site survey, to enable an assessment to be readily undertaken.

The report should show basic site details in the following format (see Table 6).

It is also important to record the details of the transducer and instrumentation, including any interposing transformers.

1	Company (submitting report)	
2	Contact Name & Address	
3	Site Address	
4	MPAN (Metering Point Administration Number_	
5	Network connection (where known)	*e.g.: A single 11 kV overhead feeder enters site with a transformer fed by a fused isolator*
6	Transformer details (where relevant)	*e.g.: 500 kVA, 11000+/-2x2.5%: 420 V, 4.5%*
7	Reason for survey	*e.g.: Preinstallation survey, to accompany application to connect a new 110 kW 6-pulse motor drive*
8	Existing non linear load	*e.g.: No existing long term harmonic producing load. A number of electronic soft starters are installed.*
9	Details of new non linear load	*e.g.: As* Table 10
10	Point of measurement	*e.g.: Multifunction metering on LV MCC incoming*
11	Measurements	
12	Connection arrangements	*e.g.: 3 phase 4 wire voltage connection* *single phase current measurement from existing xxx:x CT*
13	Measuring Instrument	*Manufacturer, type , serial number,*
14	Measurement Start Time	
15	Measurement Finish Time	*Measurements are usually for at least 7 days at 10 minute intervals*

Table 6

This should result in a summary of results in the following format (see Table 7).

	Channel 1	Channel 2	Channel 3	G5/4-1 Planning Levels
Measured voltage maximum and minimum values				
Peak Voltage Harmonic Distortion (THD) [%]				
Time of peak voltage distortion				
Value of THD not exceeded for 95% of the time [%]				
Peak 5th. Harmonic voltage distortion [%]				
Value of 5th harmonic not exceeded for 95% of the time [%]				

Table 7

In addition a number of graphical trends and spectra are required to allow a reasoned decision.

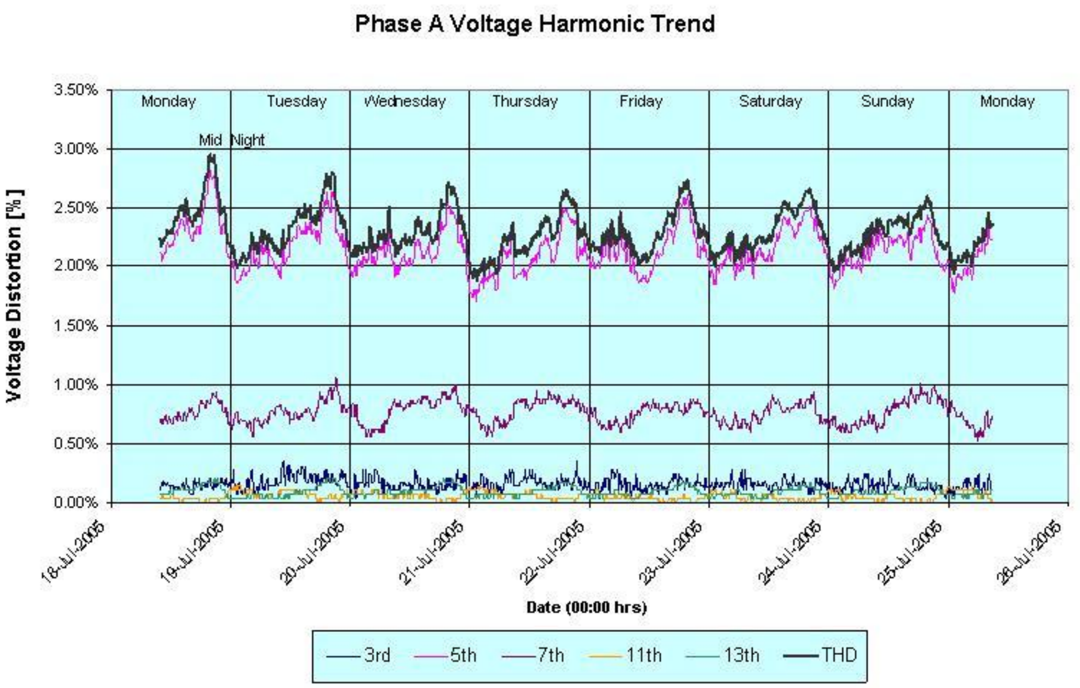

Figure 17

Typical Harmonic Voltage Trend

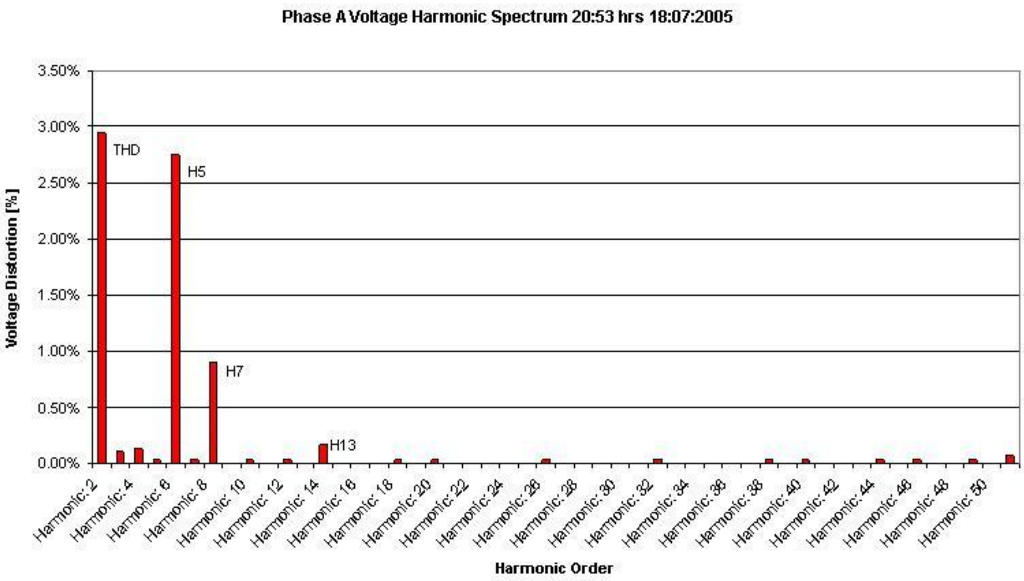

Figure 18

Typical Voltage Harmonic Spectrum

9 Resolution of Problems

G5/4-1 is a process for permitting connection of new non-linear loads to the public electricity supply.

If it is applied consistently, it is unlikely that problems will arise after installation and commissioning.

Firstly, it is critically important that adequate and sufficient information is available at the outset of a project, and that this information is provided in a timely manner.

Drives up to 250 kW generally available ex-stock, or a short delivery and even drives above 1 MW, are available within eight or ten weeks. Therefore, any delay in the provision of information could be critical to the implementation of a project.

Exact calculation of harmonics for drives is a difficult procedure, as the supply impedance and existing harmonic voltages will influence the magnitude and direction of harmonic current flow in a rectifier.

This is especially true where there are several rectifier combinations, variations in the supply source fault level, tap-changer settings, and installed power factor correction.

If the supply utility is unable to complete the calculations for a Stage 2 or Stage 3 connection, within a reasonable time[10], the consumer should be permitted to undertake the measurements and to submit calculations.

Normally the equipment manufacturer will be best placed to carry out the calculations and simulations. The NOC should provide such data as is available, including confirmation of the fault levels for Stage 1 or Stage 2, and the supply impedance model for Stage 3.

If a problem does occur, it is most likely to be where a measurement is made after installation, and the levels of voltage distortion are shown to be excessive.

[10] A maximum time of one month would seem reasonable

To avoid post installation disputes it would be helpful to include a digitally recorded waveform as part of the measurements. The waveform shape will generally show whether the equipment and its transducers were properly connected and measuring correctly.

If the current harmonics are within the levels predicted at the time of approval, it would be unreasonable to ask the consumer to contribute to remedial measures.

It is therefore incumbent on the parties to an agreement to connect to have a procedure for arbitration in the event of a problem.

10 Summary

The use of intelligent power controllers, such as variable speed drives and soft starters is well accepted both in industry and by Government as one of the major means available to improve energy efficiency and productivity. It is also essential to many industries to achieve process control, so it is in the interests of all parties to co-operate to facilitate their use.

This leads to an examination of the responsibilities of the different parties involved in the use of a drive system.

10.1 The Equipment Supplier

The responsibility of the equipment supplier is to identify the harmonic currents generated by the equipment under defined conditions.

10.2 The Supply Utility

The responsibility of the Supply Utility is to provide appropriate details of the network, including the appropriate fault levels in normal and emergency operating conditions, and to identify any known limitations, including existing harmonic levels.

10.3 The User

The responsibility of the user is to ensure that the compatibility of his network, and compliance with the appropriate requirements.

10.4 Competence

Understanding the propagation of harmonics is a complex problem, and in general, the drive manufacturers have the greatest experience in the application of their products.

GAMBICA drive manufacturers have many years of experience at meeting all sorts of harmonic limitations. However, it can often be time consuming to provide associated information and other assistance.

The manufacturers' basic responsibility is to provide the detail as shown in Appendix 2. However, most manufacturers are able to offer additional services including system studies, and to make appropriate measurements at a reasonable cost.

Appendix 1

Request to Connect Non linear Load			
To		Network Operating Company	
From		The consumer	
Contact			
Phone No		Fax No	
E_mail			
Installation site			
Metering Point Administration Number			
Voltage at point of common coupling (if known)			kV
Connection substation (if known)			
Site line diagram showing connection		Enclosed	Not available
Description of load			
	Motor rating		kW
	Motor voltage		V
	Converter		kVA
	Converter rectifier type		
Interposing transformer			
	Ratio (no load)		
	Rating		KVA
	Impedance		%
	No load loss		W
	Load loss		W
Proposed Stage of Connection			
Proposed method of compliance		Power within Table 6 of G5/4-1	
		Compliance with Table 7 of G5/4-1	
		Compliance with Table 12 of G5/4	
		Compliance with Stage 3 limits	
		Conditional connection to Stage Facility for remedial work	
Enclosures		Manufacturers prediction	

Table 8

Suggested Format for Application to Connect to Supply

NOC Response to Request to Connect Non linear Load			
From		Network Operating Company	
To		The consumer	
Contact			
Phone No		Fax No	
E_mail			
Installation site			
Agreed Voltage at point of common coupling			kV
Connection substation (if known)			
Site Fault level (Peak for equipment design)			MVA at PCC
Site Fault level (Running for harmonic calculation)			MVA at PCC
Stage of Connection according to G5/4-1			
For Stage 2/Stage 3 connection			
Existing worst case distortion (THD)			%
95 percentile value for THD			%
Existing worst case 5th. Harmonic			%
95 percentile value for 5th. Harmonic			%
For Stage 3 connection			
Supply impedance values			
Special conditions			

Table 9

Anticipated detail in Response to Application to Connect

The following information is also anticipated:

a) Any available information regarding major sources of harmonics in the neighborhood

b) Details of any large consumer in the same network who may be affected

c) Details of any filter networks in the same network

d) Transient or emergency conditions that may apply additional stress to the system network - eg: likelihood of lightning strikes, large DOL motor starting loads, etc.

e) Details of any suspected resonant conditions within the local network.

In the case of large power installations and a penetration/load flow study being required, full details of each of these will be required.

Appendix 2

Harmonic Prediction			
Supplier	*XYZ*		
Type reference	*123*		
Rating [kVA]	*40*	Rated current [A]	*56*
Load Power [kW]	*30*	Motor power[kW] [kW]	*30*
Rectifier type	*6 pulse diode*		
Network Data			
Primary Voltage [V]	*11000*	Secondary Voltage [V]	*400*
Network Sk [MVA]	*100*	Transformer Sn {kVA]	*500*
Transformer Pk [kW]	*4.9*	Transformer Zk [%]	*4.5*

n	f [Hz]	Current [A]	In/I1
1	50	*48.7*	*100.0 %*
5	250	*16.3*	*33.5 %*
7	350	*9.3*	*19.1 %*
11	550	*4.0*	*8.2 %*
13	650	*2.9*	*6.0 %*
17	850	*2.3*	*4.8 %*
19	950	*1.8*	*3.7 %*
23	1150	*1.6*	*3.3 %*
25	1250	*1.3*	*2.7 %*
29	1450	*1.2*	*2.5 %*
31	1550	*1.0*	*2.1 %*
35	1750	*0.9*	*1.9 %*
37	1850	*0.8*	*1.7 %*
41	2050	*0.7*	*1.5 %*
43	2150	*0.7*	*1.4 %*
47	2350	*0.6*	*1.2 %*
49	2450	*0.6*	*1.1 %*

Table 10

Suggested Format for Drive Suppliers Response with data for typical 30 kW load

11 Glossary of Terms and Abbreviations

a.c.	Alternating current	
BS	British Standard	Published by the British Standards Institute
CENELEC	European Committee for Electrotechnical Standardization	Publishers and maintainers of harmonised Electrotechnical standards. These standards generally follow the equivalent IEC standard text.
CSI	Current source inverter	
d.c.	Direct current	
DNO	Distribution Network Operator	Term formerly used to describe operator of medium voltage networks – now generally superseded by NOC.
EA	Electricity Association	Trade association of the private successor companies in the electricity supply sector, which took over many of the Electricity Council responsibilities
EC	Electricity Council	Committee of the former state electricity providers, original publishers of the industry standards, including the “G” series.
EMC	Electromagnetic Compatibility	The ability of one piece of equipment to operate satisfactorily within an electromagnetic environment. Subject of an EU Directive, implemented by the application of certain harmonised standards
EN	European Norm	Harmonised standards published by national standards organisations under the auspices of CENELEC
ENA	Energy Networks Association	One of the successors to the Electricity Association, which has responsibility for maintenance of the former EC and EA standards.
EU	European Union	
GAMBICA		Trade association of the variable speed drive manufacturers
IEC	International Electrotechnical Committee	Publishers of international standards
MPAN	Metering Point Administration Number	Unique number (appears on electricity billing) which identifies the consumer to the NOC
NOC	Network Operating Company	Organisation running the public electricity network
PCC	Point of common coupling	Point where one electricity consumer is connected to other consumers on the public electricity supply.
PES	Public Electricity Supplier	Organisation selling electrical energy
Pk	Load loss (of transformer)	
Sk	Fault level (of network)	
Sn	Nominal rating (of transformer)	
THD	Total harmonic distortion	
Zk	Impedance (of transformer)	

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