

# Engineering Recommendation **G5/4-1**

**Issue 4 Amendment 1 – October 2005**



energynetworks  
association

**Planning Levels For Harmonic Voltage Distortion And The Connection Of Non-Linear Equipment To Transmission Systems And Distribution Networks In The United Kingdom**



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## **PLANNING LEVELS FOR HARMONIC VOLTAGE DISTORTION AND THE CONNECTION OF NON-LINEAR EQUIPMENT TO TRANSMISSION SYSTEMS AND DISTRIBUTION NETWORKS IN THE UNITED KINGDOM**

### **1 SCOPE**

Engineering Recommendation G5/4-1 contains five amendments from ER G5/4 that was published in February 2001. These amendments may be purchased separately from the Energy Networks Association (ENA).

Engineering Recommendation G5/4 supersedes Engineering Recommendation G5/3 on 1<sup>st</sup> March 2001. Engineering Recommendation G5/3 will be withdrawn on that date, but for practical reasons non-linear equipment subject to contract specifications based on G5/3 entered into before 1<sup>st</sup> March 2001 may be connected in accordance with that recommendation after 1<sup>st</sup> March 2001.

Engineering Recommendation G5/4 sets the planning levels for harmonic voltage distortion to be used in the process for the connection of non-linear equipment. These planning levels are set with respect to harmonic voltage distortion compatibility levels. For systems less than 35kV these are set by International Standards. For systems above 35kV by the compatibility levels appropriate to the UK. A process for establishing individual customer emission limits based on these planning levels is described. The planning levels of harmonic voltage distortion should not normally be exceeded when considering the connection of non-linear loads and generating plant to Transmission Systems under the Grid Codes, or to Distribution Networks under the Distribution Codes.

The emission phenomena considered in this Recommendation are:

- continuous harmonic, sub-harmonic and interharmonic voltage distortion within the range of 0 to 2500Hz,
- short bursts of harmonic voltage distortion, and
- voltage notching.

Voltage distortion associated with switching transients is not considered in this Recommendation.

This Recommendation provides a standard basis of assessment for use by Network Operating Companies and their customers. Notwithstanding this, the final decision regarding the connection of any load is at the discretion of the Network Operating Company (NOC).

Other aspects of voltage distortion relevant to the connection of disturbing loads are considered in Engineering Recommendations P28 for flicker and P29 for unbalance.

### **2 INTRODUCTION**

Satisfactory operation of the electricity supply system and users' equipment is only obtained where electromagnetic compatibility (EMC) between them exists. By limiting the harmonic emissions of customers' non-linear loads and generating plant, this Recommendation helps to fulfil the technical objective of the UK EMC Regulations (which implement the EU EMC Directive). These Regulations seek to limit the voltage distortion present in distribution networks to levels below the immunity levels at which equipment function and performance are likely to be

impaired. Equipment immunity levels are based on the compatibility levels specified in Appendix A.

As harmonic distortion limits are not governed by statute, the enforcing document is the connection agreement reached between the NOC and the customer. This agreement must use the connection conditions laid down in the Grid or Distribution Code under which the NOC operates. This Recommendation forms part of these connection conditions.

This Recommendation uses a three-stage assessment procedure, which enables non-linear load and generating plant to be connected to supply systems in a pragmatic manner. Emission limits and any necessary mitigation measures should be part of the connection agreement reached between the NOC and the customer.

There may be exceptional circumstances that can enable a NOC to permit the connection of a customer's non-linear equipment which exceeds the Stage 1, 2, or 3 limits and is likely to cause levels of system voltage distortion to exceed planning levels (see Section 10). However, the final decision as to whether or not particular equipment can be connected to a supply system rests with the Network Operating Company responsible for the connection.

This Engineering Recommendation has a companion Application Guide, Engineering Technical Report ETR 122. This gives the technical background to the Recommendation and provides application guidance to current best practice in the connection of non-linear equipment.

### **3 DEFINITIONS**

For the purposes of this Engineering Recommendation the following definitions apply.

NOTE 1: Defined terms are capitalised where they are used in the main text of this report.

NOTE 2: Values denoted with an uppercase letter are absolute electrical values; those with lower case are percentages.

#### **Aggregate Load**

A term denoting that items of non-linear load and generation connected to a Customer's installation are being considered as an item of equipment with a rating equal to the sum of the individual non-linear equipment ratings.

#### **Convertor Equipment (Convertor)**

An operating unit in the connection between the supply system and a load or generator for the conversion of power from one frequency to another, including AC/DC and DC/AC conversion. It usually comprises one or more diode or thyristor assemblies, together with convertor transformers, essential switching devices, and other auxiliaries.

#### **Customer**

A person, company, or organisation connected to, or entitled to be connected to, a Supply System by a Network Operating Company.

#### **Distribution Code**

The code produced by each holder of a Public Electricity Supply Licence.

#### **Distribution Network**

All the lines, switchgear, and transformer windings connected together and energised at or over a range of voltages, other than a Transmission System.

#### **Distribution Network Operator, DNO**

The Company responsible for making technical connection agreements with Customers who are seeking connection of load or generation to a Distribution Network.

#### **Electromagnetic Compatibility Level**

The specified disturbance level in a system which is expected to be exceeded only with small probability, this level being such that electromagnetic compatibility should exist for most equipment within the system.

#### **Emission Level (of a disturbing source)**

The level of a given electromagnetic disturbance emitted from a particular device, equipment or system, measured in a specified manner.

#### **Emission Limit (of a disturbing source)**

The specified maximum emission level of a source of electromagnetic disturbance.

### **Fault Level**

A fictive or notional value expressed in MVA of the initial symmetrical short-circuit power at a point on the Supply System. It is defined as the product of the initial symmetrical short-circuit current, the nominal system voltage and the factor  $\sqrt{3}$  with the aperiodic component (DC) being neglected.

### **Generating Plant**

Any equipment that produces electricity together with any directly connected or associated equipment such as a unit transformer or convertor.

### **Grid Code**

The code required under the terms of a Transmission Licence to be produced and maintained by each Grid Operating Company.

### **Grid Operating Company**

The holder of a Transmission Licence granted under section 6(1)(b) of the Electricity Act 1989 or article 10(i) b of the Electricity (Northern Ireland) Order 1992, and for the purpose of this Recommendation also a member of the Electricity Association.

### **Harmonic Current, $I_h$**

The RMS amplitude of a harmonic current, of order h, expressed in Amperes.

### **Harmonic Distortion**

The cyclic departure of a waveform from the sinusoidal shape. This can be described by the addition of one or more harmonics to the fundamental.

### **Harmonic Voltage, $v_h$**

The RMS amplitude of a harmonic voltage, of order h, expressed as a percentage of the RMS amplitude of the fundamental voltage. An additional suffix 'p' denotes that it is a predicted value; 'c' that it is a calculated value, and 'm' that it is a measured value.

### **Immunity Level**

The maximum level of a given electromagnetic disturbance on a particular device, equipment or system for which it remains capable of operating with a declared degree of performance.

### **Immunity (from disturbance)**

The ability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance.

### **Interharmonic Voltage, $v_{\mu}$**

A periodic voltage disturbance having a frequency which is a non-integer multiple,  $\mu$ , of the fundamental 50 Hz system frequency. If  $\mu$  is less than 1, then the term sub-harmonic voltage disturbance is used.

### **Load**

The active, reactive or apparent power taken from a Supply System by either a Customer or by all the Customers connected to a Supply System according to the context.

### **Network Operating Company, NOC**

A generic term embracing Grid Operating Companies and Distribution Network Operators.

### **Non-Linear Load or Equipment**

A load or equipment that draws a non-sinusoidal current when energised by a sinusoidal voltage. For the purpose of this Recommendation, all references to non-linear load also includes Generating Plant, and any source of non-sinusoidal current emissions such as regenerative braking systems.

### **Partial weighted harmonic distortion (PWHHD)**

Ratio of the r.m.s. value of a selected group of higher order harmonics (in this Engineering Recommendation the PWHHD spectrum covers the range 23<sup>rd</sup> – 50<sup>th</sup> harmonic inclusive), weighted with the harmonic order  $h$ , to the r.m.s. value of the short circuit current  $I_{Ssc}$ :

$$PWHHD = V \sqrt{\sum_{h=23}^{50} h \left( \frac{I_h}{I_{Ssc}} \right)^2}$$

Where:

$V$  = Line voltage

$h$  = Harmonic order

$I_h$  = Harmonic emission current

$I_{Ssc}$  = Short circuit current

NOTE: The partial weighted harmonic distortion (PWHHD) is employed to provide a margin for some high order harmonics to exceed specified limits whilst still ensuring that the overall heating effect of high order harmonics does not exceed acceptable limits. The PWHHD used in ER G5/4-1 is based on the equation used in IEC 61000-3-12.

### **Point of Common Coupling, PCC**

The point in the public Supply System, electrically nearest to a Customer's installation, at which other Customers' loads are, or may be, connected.

### **Supply System**

All the lines, switchgear and transformers operating at various voltages which make up the transmission systems and distribution systems to which Customers' installations are connected.

### **Switch Mode Power Supply, SMPS**

A simple single phase AC/DC power supply used in most small electronic equipment and which is designed to operate over a wide input voltage range. An SMPS device is composed basically of a full wave rectifier with a capacitor connected across the output. The current taken from the AC system is very 'spiky' and is a significant source of fifth order harmonic distortion in Supply Systems and also of third harmonic distortion in low-voltage Supply Systems.

### **Total Harmonic Voltage Distortion, THD**

The RMS value of individual harmonic voltages expressed as a percentage of the fundamental RMS voltage, and calculated using the following expression:

$$\text{THD} = \sqrt{\sum_{h=2}^{h=50} V_h^2}$$

The increasing use of variable frequency control techniques has made it necessary to consider integer values of 'h' up to 50.

### **Thyristor AC Power Controller, AC Regulator**

An item of power electronic equipment for the control or switching of AC power using circuits without forced commutation and where switching, multicycle control or phase control are included.

### **Transmission System**

The system of 110, 132, 275 and 400 kV lines and plant owned and operated by a Grid Operating Company.

### **Voltage Notching**

A severe voltage change, generally of very short duration, caused by the commutating action of a rectifier.

## 4 SYSTEM PLANNING LEVELS FOR HARMONIC DISTORTION

Planning levels for the various voltage levels are given in Tables 1 to 5. The THD harmonic voltage planning levels for all supply systems operating at and below 66 kV remain unchanged from those established in the previous Recommendation G5/3. The individual harmonic levels are closely related to the indicative values given in IEC Technical Report 61000-3-6, and this has led to a reduction in planning levels above the 7<sup>th</sup> order.

This Engineering Recommendation does not contain provisions for DC current emissions because of their deleterious effects on the supply system. All DC emissions are deprecated.

Information on compatibility levels and their relationship to the system planning levels is given in Appendix A.

### 4.1 Index of Planning Level Tables

**Table 1: Summary of THD Planning Levels**

**Table 2: Planning Levels for Harmonic Voltage Distortion in 400V systems**

**Table 3: Planning Levels for Harmonic Voltage Distortion in 6.6, 11, and 20kV systems**

Tables 2 and 3 are applicable to all final distribution systems except 33kV. A final distribution system is one whose transformers have a lower voltage winding operating at low-voltage.

**Table 4: Planning Levels for Harmonic Voltage Distortion in Systems >20kV and <145 kV**

Table 4 is applicable to the majority of primary distribution and sub-transmission systems. (A primary distribution system is generally one whose transformers have a lower voltage winding operating at nominal voltages greater than 400V.)

**Table 5: Planning Levels for Harmonic Voltage Distortion in 275 and 400 kV systems**

Table 5 is applicable to transmission systems.

### Table 1: Summary of THD Planning Levels

System Voltage at the PCC	THD Limit
400V	5%
6.6, 11 and 20kV	4%
22kV to 400kV	3%

**Table 2: Planning Levels for Harmonic Voltages in 400V Systems**

Odd harmonics (Non-multiple of 3)		Odd harmonics (Multiple of 3)		Even harmonics	
Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)
5	4.0	3	4.0	2	1.6
7	4.0	9	1.2	4	1.0
11	3.0	15	0.3	6	0.5
13	2.5	21	0.2	8	0.4
17	1.6	>21	0.2	10	0.4
19	1.2			12	0.2
23	1.2			>12	0.2
25	0.7				
>25	$0.2 + 0.5(25/h)$				

The Total Harmonic Distortion (THD) level is 5%.

**Table 3: Planning Levels for Harmonic Voltages in 6.6kV, 11kV, and 20kV Systems**

Odd harmonics (Non-multiple of 3)		Odd harmonics (Multiple of 3)		Even harmonics	
Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)
5	3.0	3	3.0	2	1.5
7	3.0	9	1.2	4	1.0
11	2.0	15	0.3	6	0.5
13	2.0	21	0.2	8	0.4
17	1.6	>21	0.2	10	0.4
19	1.2			12	0.2
23	1.2			>12	0.2
25	0.7				
>25	$0.2 + 0.5(25/h)$				

The Total Harmonic Distortion (THD) level is 4%

**Table 4: Planning Levels for Harmonic Voltages in Systems >20kV and <145 kV**

Odd harmonics (Non-multiple of 3)		Odd harmonics (Multiple of 3)		Even harmonics	
Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)
5	2.0	3	2.0	2	1.0
7	2.0	9	1.0	4	0.8
11	1.5	15	0.3	6	0.5
13	1.5	21	0.2	8	0.4
17	1.0	>21	0.2	10	0.4
19	1.0			12	0.2
23	0.7			>12	0.2
25	0.7				
>25	0.2 + 0.5 ( <sup>25</sup> / <sub>h</sub> )				

The Total Harmonic Distortion (THD) level is 3%

**Table 5: Planning Levels for Harmonic Voltages in 275 and 400 kV Systems**

Odd harmonics (Non-multiple of 3)		Odd harmonics (Multiple of 3)		Even harmonics	
Order 'h'	Harmonic Voltage (%)	Order 'h'	Harmonic Voltage (%)	Order 'h'	Harmonic Voltage (%)
5	2.0	3	1.5	2	1.0
7	1.5	9	0.5	4	0.8
11	1.0	15	0.3	6	0.5
13	1.0	21	0.2	8	0.4
17	0.5	>21	0.2	10	0.4
19	0.5			12	0.2
23	0.5			>12	0.2
25	0.5				
>25	0.2 + 0.3 ( <sup>25</sup> / <sub>h</sub> )				

The Total Harmonic Distortion (THD) level is 3%

## **5 ASSESSMENT PROCEDURE FOR THE CONNECTION OF NON-LINEAR EQUIPMENT**

This assessment procedure is intended to be generally applicable to any non-linear equipment that has a harmonic current emission into the electricity supply system irrespective of the direction of the fundamental frequency power flow. Therefore, there is no differentiation between loads and generation as far as this procedure is concerned. Any specific references to load or generation should therefore be treated as implying the general case of non-linear equipment.

The assessment procedure for non-linear equipment follows three stages. The objective of this three stage approach is to balance the degree of detail required by the assessment process with the degree of risk that the connection of the particular equipment will result in unacceptable harmonic voltage levels occurring on the supply system if it is connected without any mitigation measures.

Stage 1 facilitates the connection of equipment to low-voltage networks without individual assessment. It specifies the maximum sizes of convertors and regulators that can be connected without assessment.

Stage 2 facilitates the connection of equipment to all systems less than 33 kV including low-voltage equipment which is too large for consideration under Stage 1 or cannot meet the emission limits of Stage 1. Measurements of the existing network harmonic distortion may be required before a simplified assessment is made of the predicted harmonic voltage distortion at the PCC that may result from the connection of the new non-linear equipment. The predicted harmonic voltage distortion is required to be less than or equal to the specified limits. At voltages above low-voltage, the predicted values in this assessment Stage are intended to be an indicator of acceptability or of a need for a more detailed calculation under Stage 3.

Stage 3 is the final assessment at the planning stage. It applies to the connection of equipment that is not found to be acceptable under Stage 2 assessment, and for equipment which is outside the scope of Stages 1 and 2. It applies to any non-linear equipment that has a PCC on a system at 33 kV or above.

This three stage process is illustrated in summary form in Figure 1: Flow Diagram of the Assessment Procedure before Connection at the end of Section 5. The following paragraphs give an overview. Details of the methods of assessment for the three stages are given in Sections 6, 7 and 8 respectively. Section 9 considers short duration harmonics, sub-harmonics, interharmonics and notching. Section 10 considers situations where planning levels may be exceeded.

## **5.1 Summary Description of the Connection Process**

### **5.1.1 Stage 1**

If there are no International Standards governing the emissions of the low-voltage non-linear equipment to be connected, Stage 1 gives maximum equipment ratings and harmonic current emission limits for an installation. These current emissions are based on a typical supply network with a fault level of 10MVA and are usually acceptable unless connection to a system with a much lower fault level is being proposed. Where a DNO is providing a connection to a distribution network with a minimum fault level higher than 10 MVA, the current limits may be linearly scaled up for the particular connection. Where the harmonic current emissions are higher than the limits and there is a risk that the resulting increase in the harmonic voltage may not be acceptable, a more detailed Stage 2 assessment is required.

The Stage 1 assessment procedure and limits are given in Section 6.

### **5.1.2 Stage 2**

For a Stage 2 connection assessment, small convertor loads may be connected on the basis of their aggregate capacity. For loads where a more detailed assessment is required, a measurement of the existing background harmonic voltages is necessary. Where the existing harmonic voltages are less than 75% of the planning levels, the equipment may be assessed against the harmonic current emission limits. These harmonic current limits are based on fault levels typical for the voltage levels at the point of connection and are indicative of the current emissions that would raise an existing harmonic voltage distortion level of 75% up to the planning level after connection of additional non-linear equipment.

As in Stage 1, where a DNO is providing a connection to a network with a minimum fault level higher than the typical value, the current limits may be linearly increased for that connection. Where the harmonic current emissions are higher than the limits and there is a risk that the harmonic voltage levels may exceed the planning limits, a more detailed assessment is required based on the calculation of harmonic voltages.

This calculation is based on a simple reactance model for the source with a multiplying factor to allow for any low order harmonic resonance. The assessment concentrates on the dominant 5th harmonic and the THD. Where assessed levels exceed the Stage 2 limits, mitigation measures are indicated for low-voltage connections. For higher voltage connections, a more detailed Stage 3 assessment against the individual voltage planning limits is required.

The Stage 2 assessment procedure and limits are given in Section 7.

Where the assessment has indicated that mitigation measures may be necessary, a conditional connection may be made where the margin outside the limits is low and considered to be within the uncertainty in the assessment process. Further guidance on conditional connections is provided under clause 5.1.6 and in ETR 122.

### **5.1.3 Stage 3**

For Stage 3 assessment, a determination of the harmonic voltages at the PCC based on a harmonic impedance model of the network is required in order to take account of any resonance that may occur. For connections at 33kV and above, the assessment should also take into consideration the effect of such new emissions on connected lower voltage networks since the emissions can exacerbate any potential resonance conditions.

The Stage 3 assessment procedure and limits are given in Section 8

### **5.1.4 Interconnection of supply systems**

This assessment procedure will facilitate the interconnection of supply systems and the connection of customers' systems to supply systems by maintaining uniform compatibility levels. On this basis, assessment at the interface between two NOC networks is not required before interconnection provided that the NOC seeking interconnection has undertaken to comply with the network planning levels, connection procedures, and emission limits for non-linear equipment that are contained in this Recommendation.

### **5.1.5 Measurements**

Measurements of background harmonic levels are generally needed for Stage 2 and always needed for Stage 3 assessments. The responsibility for making these measurements lies with the NOC, but the customer may be required to assist by providing information on the operation of non-linear equipment during the testing period, or by ensuring other non-linear equipment is not operating during this period. In general, the background harmonics should be assessed over at least a 7 day period when the PCC fault levels are representative of post-connection conditions. If this is not the case, scaling of the measured levels may need to be carried out in making the assessment. The Application Guide ETR 122 considers measurements in more detail.

### **5.1.6 Uncertainty in the assessment**

Network data used in the assessment may have a degree of uncertainty, and measurements themselves will have an inherent error. Due to location of voltage transformers, it may not be possible to make measurements at the proposed connection point.

The variation of the low-voltage system capacitance in the 'average load model' described in the Application Guide ETR 122 may help in addressing this uncertainty, particularly in relation to resonance effects.

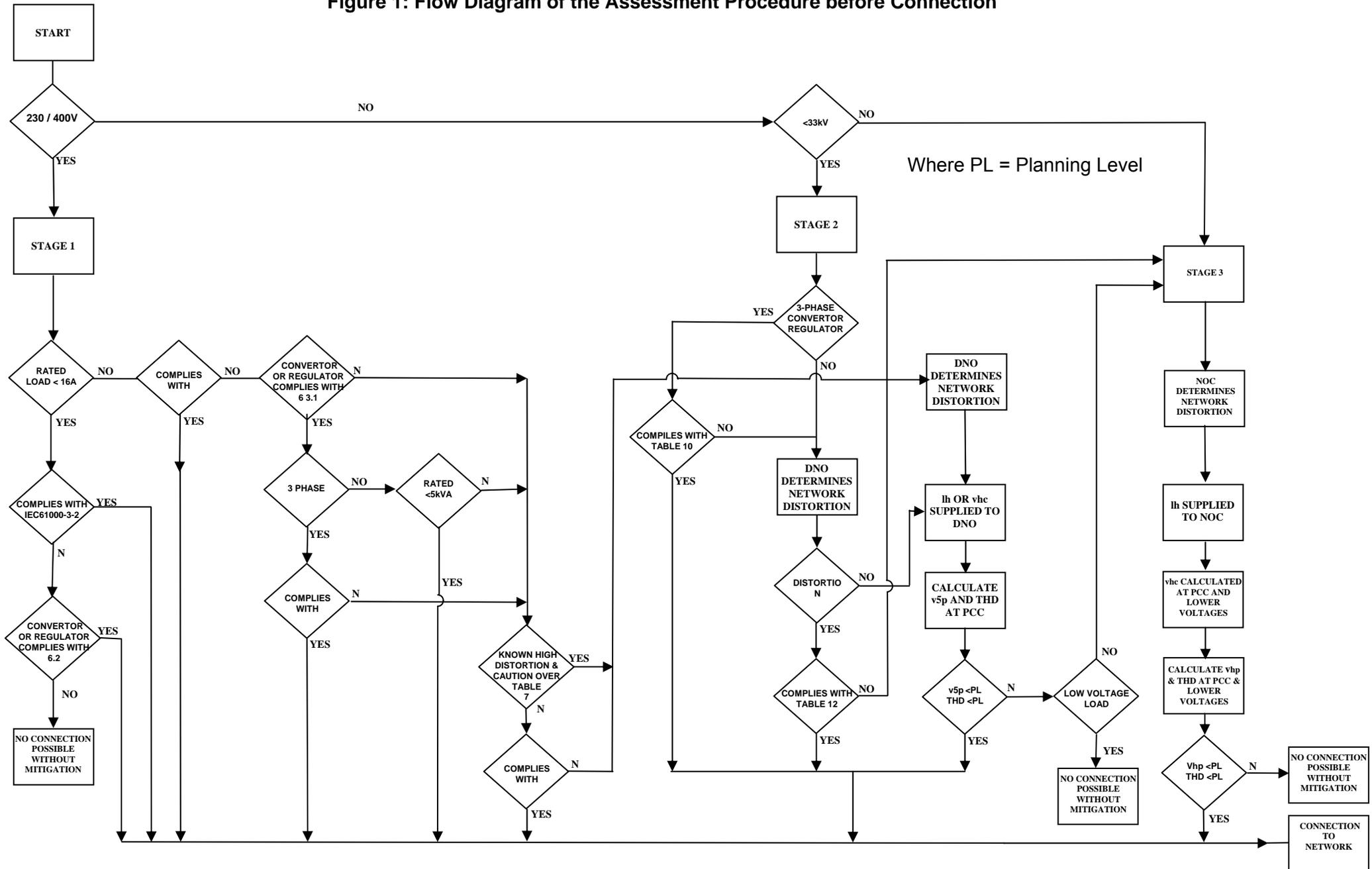
In the assessment and compliance process of the assessed load, the current emission limits are given in Stages 1 and 2, and are intended as a basis for initial acceptance of the connection. Final acceptance will be judged by the contribution of the particular equipment to the total harmonic voltage levels. For larger loads, where fault levels are low, and for Stage 3 assessments where uncertainty over the data used for the study is an issue, a post-connection measurement is required to ensure that network levels are being adequately controlled.

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

However, conditional connections involve a risk that acceptable limits of distortion may still actually be exceeded and such connections should therefore have regard to the practicality, timescale and costs of remedial measures after the connection is made. A combination of load restrictions with time-of-day and system operating configuration restrictions may need to be applied to the operation of the new non-linear equipment until the mitigation measures are in place. The post connection measurements can be used to determine the extent of any mitigation measures that are required.

However, the final decision as to whether or not particular equipment can be connected to a supply system rests with the NOC responsible for the connection.

Figure 1: Flow Diagram of the Assessment Procedure before Connection



## **6 STAGE 1 ASSESSMENT PROCEDURE AND LIMITS**

### **6.1 General**

Stage 1 assessment applies to all 230/400V individual items of equipment, generating plant, and groups of non-linear equipment that are intended for connection to low-voltage networks not known to have excessive background levels of harmonic voltage distortion.

Applications for the connection of all loads should be treated with caution at locations where existing background levels of voltage distortion are known to be approaching the planning levels given in Table 2.

A customer's non-linear equipment can be connected under a Stage 1 assessment provided at least one of the relevant conditions contained in 6.2 and 6.3 is met.

Aggregate load or equipment emissions which do not meet the Stage 1 criteria or where caution is required because of high background levels of distortion shall be assessed in accordance with the procedures given in 7.2 and 7.3 of Stage 2. The Stage 2 voltage assessment shall be made at low-voltage. If the predicted 5<sup>th</sup> harmonic and THD distortion levels exceed the Table 2 low-voltage planning levels, mitigation measures will normally be required.

All the values in Table 7 for harmonic orders exceeding the 25<sup>th</sup> are indicative values until 2005 when they will automatically become limit values unless experience in the meantime shows them to be unrealistic. They have been included in Table 7 at this time for the guidance of purchasers and manufacturers of equipment and to indicate future trends and levels of emission that may cause problems and require mitigation. Nevertheless, where the harmonic currents at these higher harmonic orders cause the harmonic voltages to exceed the voltage compatibility levels and this is a cause of disturbance to other customers, then mitigation measures will have to be undertaken.

However, the prediction of THD for comparison with the Stage 2 limits requires all harmonics up to and including the 50<sup>th</sup> to be taken into account in calculations.

### **6.2 Customer's Non-linear Equipment having an Aggregate Load or Rated Current less than or equal to 16 A per phase**

All equipment and generating plant used by one customer and rated less than or equal to 16A per phase, and which complies with BS EN61000-3-2, or any other European product standard for equipment rated up to 16 A per phase that includes limits for harmonic emissions and has been harmonised under the EMC Directive, may be connected without further consideration. For a group of non-linear equipment, the aggregate of rated currents must be less than or equal to 16A and each individual piece of equipment must comply with BS EN61000-3-2.

A customer may connect without assessment individual single and three-phase converters and AC regulators intended only for industrial applications or overnight battery charging and which by design have negligible even harmonic emissions.

When a number of single phase devices are installed by a customer at one location with a three phase supply, an attempt should be made to balance the non-linear equipment equally between the three phases.

### 6.3 Customer's Equipment having an Aggregate Load or Rated Current greater than 16 A per phase

Aggregate load or a single item of non-linear low-voltage equipment complying with the emission limits of Stages 1 or 2 of IEC Technical Report 61000-3-4 may be connected without assessment, subject to the fault level at the point of common coupling being at least equal to the minimum value required in that Technical Report.

#### 6.3.1 Convertors and AC Regulators

##### 6.3.1.1 Single Phase Equipment

Single phase convertors and AC regulators intended only for industrial applications or for overnight battery charging and which by design have negligible even harmonic emissions, may be connected without assessment if the aggregate load does not exceed 5 kVA per installation.

##### 6.3.1.2 Three Phase Equipment

Table 6 sets out the maximum value of aggregate ratings of three-phase convertor or AC regulator equipment, which may be connected to any low-voltage system without, further assessment.

**Table 6: Maximum Aggregate Value of Three Phase Convertor and AC Regulator Equipment, which may be connected under Stage 1**

Supply system voltage at the PCC	Three phase convertors		Three phase AC regulators
	6 pulse (kVA)	12 pulse (kVA)	6 pulse thyristor (kVA)
400V	12	50	14

#### 6.3.2 Aggregate Loads and other Equipment Rated >16A per phase

For all installations where there are concentrations of non-linear equipment, the aggregate emissions per phase should not exceed the values given in Table 7. A single item of equipment greater than 16A per phase that does not meet the current emission values of IEC Technical Report 61000-3-4, when assessed for a fault level of 10MVA, can be connected if the emissions per phase do not exceed the values given in Table 7. Where necessary, the actual fault level at the point of connection shall be used to scale the values in Table 7. (See the discussion on Table 9 in Section 7.3.1.) The harmonic emissions from aggregate loads should be determined in accordance with IEC 61000-3-6, details of which are discussed in the Application Guide ETR 122

Aggregate loads and individual items of equipment not meeting Table 7 limits shall be assessed under Stage 2 (see section 7.3) which requires emission characteristic data to be provided to the DNO so that a harmonic assessment can be completed.



## **7 STAGE 2 ASSESSMENT PROCEDURE AND LIMITS**

### **7.1 General**

A Stage 2 assessment is applicable to:

- low-voltage connections where a Stage 1 assessment is not appropriate because of the aggregate size of the equipment, emission levels or network characteristics,
- customers whose PCCs are above low-voltage and below 33kV.

For a low-voltage connection, the only part of Stage 2 which is applicable is the assessment by voltage prediction of Section 7.3.

A customer whose aggregate of three-phase convertor and regulator equipment ratings are less than those given in Table 10 in Section 7.4.1 may be connected without further assessment.

Connections of customers' equipment which in aggregate comply with Table 12 emission limits may be made without a voltage assessment provided that the levels of network distortion, measured before the connection is made, are less than 75% of the planning levels given in Tables 2 and 3.

All the values in Table 12 for harmonic orders exceeding the 25th are indicative until 2005 when they will automatically become limit values unless experience in the meantime shows them to be unrealistic. They have been included in Table 12 at this time for the guidance of purchasers and manufacturers of equipment and to indicate future trends and levels of emission that may cause problems and require mitigation. Nevertheless, where the harmonic currents at these higher harmonic orders cause the harmonic voltages to exceed the voltage compatibility levels and this is a cause of disturbance to other customers, then mitigation measures will have to be undertaken.

The prediction of THD for comparison with the Stage 2 limits requires all harmonics up to and including the 50th to be taken into account in calculations.

### **7.2 Procedure for Assessment of New Non-linear Equipment**

In order to assess a new non-linear load or equipment because the rating is more than Table 10 or the existing voltage distortion is greater than 75% of the planning levels given in Tables 2 and 3, the DNO making the connection must:

- (a) assess the distortion, which will be caused by the new non-linear equipment,
- (b) predict the possible effect on harmonic levels by an addition of the results of (a) to the existing levels of distortion.

If the prediction of voltage distortion is less than the planning levels for THD and 5<sup>th</sup> harmonic that are appropriate to the PCC, the load is acceptable.

To enable the assessment of distortion due to the new non-linear load, the customer or his agent must provide comprehensive data to the DNO relating to its harmonic current emission characteristics. Similarly, manufacturers should provide the data to purchasers of their equipment. The Application Guide ETR 122 gives details of the type of data that is required and

examples of its use.

### 7.3 Prediction of System Distortion relating to the Connection of New Non-linear Load

#### 7.3.1 Calculation of Voltage Distortion due only to the New Non-linear Load

The voltage distortion caused by the load at the PCC, at a particular harmonic frequency, will be the harmonic current multiplied by the system impedance at that frequency. The study of supply systems in the United Kingdom that culminated in the publication of Engineering Technical Report ETR 112 showed that for typical supply systems, the system impedance,  $Z_h$ , at harmonic frequencies is related to the fundamental impedance,  $Z_1$ , and to the harmonic order by the expression:

$$Z_h = k h Z_1 \quad (1)$$

Experience has shown that adoption of the 'k' values given in Table 8 will make an appropriate allowance for low-order parallel resonance that might occur in this frequency range.

**Table 8: Values of 'k'**

Supply system voltage at the PCC	Harmonic order			
	$h \leq 7$	$h \leq 8$	$h > 7$	$h > 8$
400V	1		0.5	
6.6, 11, 20 and 22 kV		2		1

The calculated voltage distortion,  $v_{hc}$ , for each order of harmonic current,  $I_h$ , is expressed as a percentage of the system phase voltage and is given by

$$v_{hc} = I_h Z_h \left( \frac{\sqrt{3}}{V_s} \right) 100 \% \quad (2)$$

Substituting  $k h V_s^2 / F 10^6$  for  $Z_h$ , the following expression for  $v_{hc}$  is obtained:

$$v_{hc} = \frac{I_h k h \sqrt{3} V_s 100}{F 10^6} \% \quad (3)$$

where:  $I_h$  = the harmonic current in amperes (RMS) drawn by the new load at the PCC.

$V_s$  = the nominal system line voltage at the PCC in volts.

$F$  = the system short-circuit level at the PCC in MVA.

$h$  = the harmonic order.

$v_{hc}$  = the calculated harmonic voltage distortion associated with the new load expressed as a percentage of the phase voltage at the PCC.

The typical values of  $F$  relevant to system voltages given in Table 9 have been used in the

calculation of Table 7 and Table 11 emission currents. These values facilitate a consistent approach to the prediction of voltage distortion,  $v_{hc}$  for a Stage 2 assessment.

Different values of F shall be used in place of the typical values for specific assessments. The effect of using a different fault level value at the PCC higher than the typical value will reduce the level of predicted voltage distortion and using a lower value will increase the predicted distortion. Advice on factors to be taken into account in establishing a fault level value different from the typical value is given in the Application Guide ETR 122

The customer or his agent shall supply either  $v_{hc}$  or  $I_h$  to the DNO. The DNO shall use this information to estimate the supply system distortion with the new load connected. The DNO shall then compare the predicted supply system distortion with the appropriate planning levels and decide whether the load is acceptable for connection under Stage 2. If connection under Stage 2 is not acceptable, a Stage 3 assessment should be made with the predicted voltage distortion being calculated based on the actual harmonic impedance characteristic at the PCC.

**Table 9: The Typical Values of ‘F’ relevant to nominal System Voltage**

Nominal system voltage (kV)	Fault level F (MVA)
0.4	10
6.6	60
11	100
20	182
22	200

### 7.3.2 Summation of Calculated and Measured Voltage Distortion

For each harmonic order the DNO shall predict the summated voltage distortion,  $v_{hp}$ , from the measured value,  $v_{hm}$ , and the total emission from the customer’s new load,  $v_{hc}$ , as calculated and provided in accordance with Section 7.3.1. All these voltages should be expressed as percentages of the system phase voltage.

The prediction process allows for the similarity in the phase angles of the dominant harmonic emissions from existing loads and of the emissions from the additional equipment.

- For each harmonic order up to and including the fifth, for all triplens and for the harmonic order having the highest measured value (if not so included), it must be assumed that on some occasions the background and load related emissions will be in phase, and therefore they will add arithmetically:

$$V_{hp} = V_{hm} + V_{hc} \quad (4)$$

- For all other harmonics and to allow for diversity, it is assumed that the phase angle between the background distortion and the new non-linear load emissions is 90°. The

RMS value of the background and load related emissions are used for these harmonics.

$$V_{hp} = \sqrt{V_{hm}^2 + V_{hc}^2} \quad (5)$$

The THD is then given by:

$$THD = \sqrt{\sum_{h=2}^{h=50} V_{hp}^2} \quad (6)$$

## 7.4 Stage 2 Limits

### 7.4.1 Three-Phase Convertor and Regulator Equipment

Table 10 gives the maximum ratings of a single convertor or regulator, or aggregate values which may be connected to 6.6kV, 11kV, 20kV and 22kV supply networks without assessment by the DNO

**Table 10: Maximum Aggregate of Convertor and Regulator Ratings**

Supply system voltage at the PCC	Three phase convertor ratings in kVA		Three phase AC regulator ratings in kVA
	6 pulse	12 pulse	6 pulse thyristor
6.6 , 11, 20 and 22kV	130	250*	150

- \* This limit applies to 12 pulse devices, and to combinations of 6 pulse devices always operated as 12 pulse devices that employ careful control of the firing angles and the DC ripple so as to minimise non-characteristic harmonics, such as 3rd, 5th and 7th.

The sizes of equipment detailed in Table 10 are derived from Section 5 of ACE Report No 73.

## 7.4.2 Connections to Networks having Low Levels of Background Harmonic Distortion

When the existing background levels of harmonic distortion are less than 75% of the individual harmonic order planning levels, the customer's equipment may be connected without detailed consideration by the DNO if the total current emissions from all non-linear equipment comply with the limits given in Table 12. Where necessary, the actual fault level at the point of connection shall be used to scale the values in Table 7. (See the discussion on Table 9 in Section 7.3.1.)

## 7.4.3 Stage 2 Total Harmonic Distortion Limit

Where the existing background levels of harmonic distortion exceed 75% of the individual planning levels, the customer's equipment may be connected by the DNO if the predicted THD is less than or equal to the planning levels which are repeated in Table 11 as limits for the system distortion.

In addition, the predicted 5<sup>th</sup> harmonic distortion must be less than or equal to the relevant planning level for connection to be allowed to proceed.

It is likely that the measurements of background distortion will have shown a strong diurnal variation with the highest levels in the evening (particularly Sundays). In the event that the predicted levels are in the region of the limits, the times at which the new non-linear load is adding to the THD can be considered in the assessment. The probabilistic nature of the levels of distortion can also be taken into consideration by using values of background distortion that are not exceeded for 95% of the time. However, care is needed in the assessment if network resonance is likely to occur. For further detail, see the Application Guide ETR 122.

**Table 11: Stage 2 THD and 5<sup>th</sup> harmonic limits**

<b>System system voltage at the PCC</b>	<b>Stage 2 THD voltage limit</b>	<b>Stage 2 5th harmonic voltage limit</b>
400V	5%	4%
6.6, 11 and 20kV	4%	3%
22kV	3%	2%

**Table 12: Stage 2, Maximum Permissible Harmonic Current Emissions per Customer in Amperes, RMS per phase**

Harmonic Order, h	PCC on 6.6, 11 or 20 kV systems	PCC on 22kV systems	Harmonic Order, h	PCC on 6.6, 11 or 20 kV systems	PCC on 22kV systems
2	4.9	3.3	26	0.3	0.3
3	6.6	4.4	27	0.1	0.1
4	1.6	1.3	28	0.2	0.2
5	3.9	2.6	29	0.8	0.8
6	0.6	0.6	30	0.1	0.1
7	7.4	5.0	31	0.7	0.7
8	0.9	0.9	32	0.2	0.2
9	1.8	1.5	33	0.1	0.1
10	1.4	1.4	34	0.2	0.2
11	6.3	4.7	35	0.6	0.6
12	0.2	0.2	36	0.1	0.1
13	5.3	4.0	37	0.5	0.5
14	0.5	0.5	38	0.2	0.2
15	0.3	0.3	39	0.1	0.1
16	0.4	0.4	40	0.2	0.2
17	3.3	2.0	41	0.4	0.4
18	0.2	0.3	42	0.1	0.1
19	2.2	1.8	43	0.4	0.4
20	0.3	0.3	44	0.2	0.2
21	0.1	0.1	45	0.1	0.1
22	0.3	0.3	46	0.2	0.2
23	1.8	1.1	47	0.3	0.3
24	0.1	0.1	48	0.1	0.1
25	1.0	1.0	49	0.3	0.3
26	0.3	0.3	50	0.1	0.1

NOTE: The 6.6, 11, or 20kV column is relevant to final distribution systems; the 22kV column is relevant to primary distribution

These limits are based on the typical fault levels given in Table 9 (and see the Application Guide ETR 122).

For equipment where the harmonic current emissions of orders  $23 \leq h \leq 50$  marginally exceed the limits shown in Table 12 the connection could still be acceptable if the PWHd value does not exceed 29.2V. The use of the PWHd approach does not remove the requirement to comply with the 4% planning level for THD.

With the exception of the third and fifth harmonic orders any two emission currents up to and

including the nineteenth order may exceed the limit values by 10% or 0.5A, whichever is the greater. For harmonic orders greater than the nineteenth any four emission currents may exceed the given values by 10% or 0.1A, whichever is the greater. However where the PWHD approach is used the harmonic current emissions shall not exceed the following limits:

Odd order harmonics (non multiple of 3)	120% of limits in Table 12
Odd order harmonics (multiple of 3)	100% of limits in Table 12
Even order harmonics	150% of limits in Table 12

## **8 STAGE 3 ASSESSMENT PROCEDURE AND LIMITS**

### **8.1 General**

A Stage 3 assessment is applicable to the connection of all non-linear equipment to supply systems having PCCs at 33kV and above. Stage 3 is also the final planning stage assessment for the connection of loads with PCCs above low-voltage and below 33kV, which are not found acceptable when assessed under Stage 2.

The Stage 3 assessment will be made by the NOC with the characteristics of the non-linear equipment being provided by the customer. Where the customer is connecting a system containing non-linear equipment, the NOC will be required either to provide the customer with the system harmonic impedance values at the PCC which will enable the customer to evaluate his system harmonic performance, or to model part of the customer's system within the Stage 3 assessment. For an example of this procedure, see the Application Guide ETR 122.

The prediction of THD for comparison with the Stage 3 limits requires all harmonics up to and including the 50<sup>th</sup> to be taken into account in calculations.

A NOC need not apply a Stage 3 assessment where the connection of a supply system containing non-linear equipment is being requested by another NOC or customer who can demonstrate that the planning and operational conditions relating to the supply system to be connected is in accordance with this Recommendation.

### **8.2 Procedure for Assessment of New Non-linear Equipment**

The assessment of the connection of new non-linear equipment consists of:

- (a) measuring the levels of distortion already existing on the system,
- (b) calculating the distortion which will be caused by the new equipment, and
- (c) predicting the possible effect on harmonic levels by an addition of the results of (a) and (b)

Connection of the equipment is acceptable if the results of (c) are less than the THD and harmonic voltage planning levels for all individual harmonic orders and the.

All the individual voltage planning levels for harmonic orders exceeding the 25<sup>th</sup> in Tables 2 to 5 are indicative until 2005 when they will automatically become limit values unless experience in

the meantime shows them to be unrealistic. However, the prediction of THD for comparison with the limits requires all harmonics up to and including the 50<sup>th</sup> to be taken into account in calculations. Additionally, where harmonic voltages caused by the connection of non-linear equipment exceed any of these values and are a potential cause of EMC problems, mitigation will be required.

In Stage 3, it is recommended that in addition to an assessment based on conditions at the PCC, assessment at other locations is undertaken to establish directly the possibility of resonance effects and in particular the effects on equipment connected to lower voltage systems. It is possible that the harmonic voltage levels at the PCC will have to be set below the planning limits to take account of equipment at other locations within the same supply system, which is susceptible to the resulting voltage distortion.

### **8.3 Prediction of System Distortion relating to the Connection of New Non-linear Equipment**

#### **8.3.1 Calculation of Voltage Distortion due only to the New Non-linear Equipment**

The use of a harmonic analysis program is recommended for even simple network calculations.

In the detailed system modelling to facilitate the harmonic analysis it is required that:

- capacitance effects of the local supply network and equivalent models to represent the system load are included,
- for connections at 66kV and above, the local supply network should be modelled together with the connections to the lower voltage networks. Equivalent models to represent load on the local supply network should be used for 33kV or lower voltages.
- specific busbars at which compliance with the harmonic voltage limits applicable to that voltage level are represented. Alternatively, where the load is represented by an equivalent model connected above low-voltage, the model can have a 400V equivalent bar within it, and an assessment against the 400V planning levels may be made. In the latter case, the measurement of the existing background will be made at a 400V bar near to the PCC. However, in this case, the calculation does not relate to this specific 400V busbar and sensitivity to the load model should be investigated by varying the 400V capacitance. In both cases, secured outage conditions for higher voltage connections and variations in load level will need to be investigated.

#### **8.3.2 Summation of Measured and Calculated Distortion**

The calculation in 8.3.1 will have provided a harmonic voltage distortion,  $v_{hc}$ , for each harmonic at the PCC and at other selected busbars for the evaluation of limits. To this has to be added the measured distortion,  $v_{hm}$ , for each harmonic. The summation basis for the assessment against planning levels should be based upon the criteria given below.

Maximum calculated values and the highest measured background value using a time-at-level method as described in ETR 122 should be used as the basis of the assessment unless specific factors determine otherwise; e.g. maximum individual calculated or measured values being associated with incompatible system operating conditions or times of day or that the operating times for the non-linear load are being restricted to specific time-of-day periods.

Separate assessments may therefore be appropriate for different system conditions or time of day operations. A non-linear equipment that produces fluctuating levels of harmonics of low amplitude relative to the background will not greatly alter the harmonic magnitude as assessed from a time-duration characteristic, particularly if they are of random phase relative to the background.

The total triplen harmonic content of the current being taken by the non-linear load needs to be considered when assessing the effect on the distortion on the network to which the customer is to be directly connected. The transformer interconnection arrangements generally do not transfer the zero sequence component of any triplen harmonic to low-voltage systems. Therefore, for higher voltage connections where an assessment of the transfer of triplen harmonics to a lower voltage system is being assessed, only the positive and negative triplen components associated with a lack of balance between the three phases needs to be considered.

The process to be used for the harmonic addition to establish the THD of a continuous non-linear load is: -

- for unbalanced harmonic conditions, the phase with the highest distortion (THD) should be used for comparison with the limits.
- for the particular single harmonic which will have the largest summated magnitude and hence will indicate the greatest THD, the measured and calculated values of voltage distortion are assumed to peak at the same time and to be in phase:

$$V_{hp} = V_{hm} + V_{hc} \quad (7)$$

- for the other harmonics, an average phase difference of 90° is assumed at the time of maximum THD:

$$V_{hp} = \sqrt{V_{hm}^2 + V_{hc}^2} \quad (8)$$

The THD is then given by:

$$THD = \sqrt{\sum_{h=2}^{h=50} V_{hp}^2} \quad (9)$$

### 8.3.3 Special Considerations for Fluctuating Non-linear Loads

The harmonic assessment for a fluctuating non-linear load should be assessed taking account of its particular time-duration characteristic. Engineering Recommendation P24 for AC Traction Supplies indicates that account for such fluctuations should be similar to that for unbalance considerations with single-phase supply points where the peak one-minute average value is used.

If more than one traction supply point is involved it is likely that different phase pairs will be used for unbalance mitigation. Before summation of the harmonics with the relatively stable background level, the assessed contribution from each should be made taking into account both the degree of co-ordination between the respective traction load currents and the phase

differences between the harmonic components.

Where there is an existing fluctuating harmonic source, separation of the fluctuating component from the relatively stable component from the continuous load, for example due to a traction supply, will require a suitable short interval between measurements.

#### **8.4 Stage 3 Limits**

The values of  $v_{hp}$  for all harmonic orders and the THD which have been assessed in accordance with 8.3, both at the PCC and at other selected locations, should not exceed the individual and the THD harmonic voltage planning levels for the relevant supply network voltage contained in Tables 1 to 5. At least one of the selected locations should be a low-voltage system downstream of the PCC under consideration; see Section 8.3.1.

### **9 LIMITS FOR NON-CONTINUOUS HARMONIC DISTORTION**

#### **9.1 Bursts of Short-Duration Harmonic Distortion**

The thyristor drives of motors which are subjected to random and sudden shock loads (including starting) generate bursts of harmonic distortion which frequently last less than 3 seconds and are therefore classed as being of very short-duration or time.

IEC 61000-2-2 and 61000-2-12 give compatibility levels for very short-term harmonic voltage distortion. The change in the fundamental load current associated with a shock load will produce a change in the RMS voltage, and where this is frequent, the effect of the relative change in harmonic content will be less significant than the change in voltage. Therefore, for a load producing frequent bursts of harmonic, provided that the voltage change characteristics comply with the voltage change and flicker limits in Engineering Recommendation P28, it is unlikely that the additional contribution from such bursts of harmonic distortion needs to be considered at the time of connection.

Very infrequent bursts of harmonic distortion from motor starting, including those which incorporate a soft start facility, will have a negligible effect on system harmonic performance assessed using the 95% cumulative value as described in ETR122 and so may be effectively discounted. Very large bursts may interfere with other equipment and this issue of interference is discussed in ETR122. Such interference may well be connection point specific, and not as readily identified at the connection assessment stage.

Connections where as a result of such bursts the compatibility levels may be exceeded should be accepted on a conditional basis as discussed in Section 10 below as long as the very short-term compatibility levels quoted in the IEC Standards mentioned above are not exceeded.

#### **9.2 Sub-Harmonic and Interharmonic Distortion**

If the predicted sub-harmonic and interharmonic voltage emissions from an item of equipment or customer's aggregate load are less than 0.1% of the fundamental voltage, connections may be made without any further assessment.

In the United Kingdom, it is assumed that ripple control systems are not being used and therefore a customer's load, having individual interharmonic emissions less than the following Table 13 limit values, may be connected without assessment.

**Table 13: Sub-harmonic and Interharmonic Emission Limits**

<b>Sub-harmonic or interharmonic frequency in Hz</b>	<b>&lt;80</b>	<b>80</b>	<b>90</b>	<b>&gt;90 and &lt; 500</b>
<b>Voltage distortion as % of the fundamental</b>	0.2	0.2	0.5	0.5

Limits for particular interharmonic frequencies between 80 and 90 Hz may be interpolated linearly from the limits given in Table 13.

### **9.3 Notching**

Voltage notching occurs during rectifier commutation when two phases of the supply are effectively short-circuited. Figure 2 (a) shows a typical voltage characteristic and Figure 2 (b) shows the method of measuring notch parameters from an oscillographic display. Commutation notches, in so far as they contribute to harmonic levels, are covered by the compatibility levels for very short-term effects given in IEC 61000-2-2 and 61000-2-12.

Notching is a high frequency event and as such there are measurement issues. The use of direct oscillographic measurement is only appropriate to low-voltage systems.

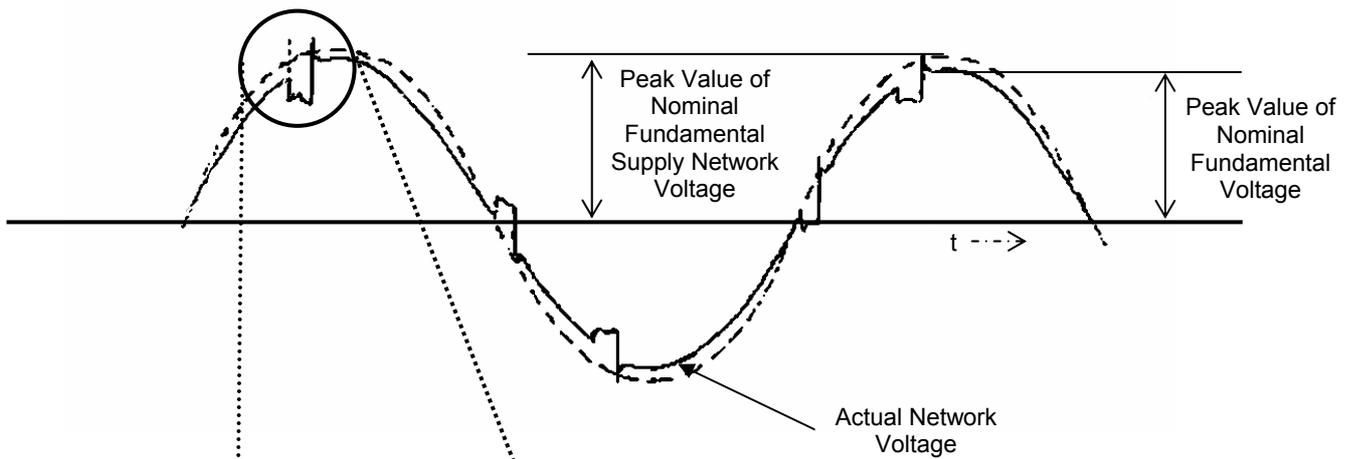
Equipment that results in voltage notching can only be connected if the level of harmonic distortion present at the PCC on the supply system is less than the appropriate planning level. The additional requirements at the PCC will be:

- the notch depth, 'd' , shall not exceed 15% of the nominal fundamental peak voltage,
- the peak amplitude of oscillations, due to commutation at the start and at the end of the notch, shall not exceed 10% of the nominal fundamental peak voltage.

The Application Guide ETR 122 provides further information on the measurement and the levels of notching

**Figure 2: Explanatory Diagram of Voltage Notching and Oscillation Depth**

**(a) Voltage Notching**



End Notch  
Oscillation Depth

Start Notch  
Depth

Notch Depth (d)

Starting Notch  
Oscillation Depth

**(b) Oscillation Depth**

## **10 SITUATIONS WHERE PLANNING LEVELS MAY BE EXCEEDED**

Where existing harmonic voltage levels are more than the planning levels, the risk of disturbance to other customers is increased. This concern should be reflected in a conditional connection agreement, which should require mitigation measures if the risk is realised.

The final decision as to whether or not a particular load can be connected to a transmission system or a public electricity supply system rests with the NOC responsible for the connection.

As harmonic distortion limits are not governed by statute, the enforcing document is the connection agreement reached between the NOC and the customer. This agreement must use the connection conditions laid down in the Grid or Distribution Code under which the NOC operates. This Recommendation forms part of these connection conditions

Where it is apparent that connection of new load would impose harmonic voltage distortion on the supply system greater than the planning levels given in this document, the NOC can refuse connection until agreement is reached on a solution.

In a marginal situation or for large loads that may trigger unpredicted system resonance, a conditional connection may be agreed where any necessary remedial measures can be effected within a reasonable timescale after connection.

If needed, the NOC, the equipment installer and the customer should consider remedial action and the most effective measure or measures agreed, as described in the Application Guide ETR 122.

In exceptional circumstances, where for example a customer is located in an area remote from other customers and it is certain that only that customer's equipment will be connected to the local network, the DNO may assess new load under Stage 2 using compatibility levels appropriate to the network voltage, instead of planning levels. In these circumstances, the DNO should establish procedures to ensure that no other load is connected to that part of the network that has harmonic levels more than the planning levels unless mitigation measures are adopted.

## REFERENCES

NOTE: The "Electricity Association" documentation listed below is available from the ENA.

**Electricity Association: ACE Report No.73 (1979):** Limits for harmonics in the UK Electricity Supply Industry

**Electricity Association: Engineering Recommendation P28 (1989):** Planning limits for voltage fluctuations caused by industrial, commercial and domestic equipment in the United Kingdom

**Electricity Association: Engineering Recommendation P29 (1990):** Planning limits for voltage unbalance in the UK

**Electricity Association: Engineering Technical Report 112 (1988):** Report on the harmonic impedance of supply systems

**Electricity Association: Engineering Technical Report 122 (2001):** Guide to the application of Engineering Recommendation G5/4 in the assessment of harmonic voltage distortion and connection of non-linear equipment to the Electricity Supply System in the UK

**ENV 61000-2-2 (Ed 2, 2002):** Electromagnetic compatibility (EMC). Environment - Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems.

**IEC 61000-2-12 (2003):** Compatibility levels for low frequency conducted disturbances and signalling in public medium-voltage supply systems.

**IEC 61000-3-2 (Ed 2.2, 2004):** Electromagnetic compatibility (EMC). Limits - Limits for harmonic current emissions (equipment input current  $\leq 16$  A per phase)

**BS IEC 61000-3-4 (1998):** Electromagnetic compatibility (EMC). Limits - Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A.

**IEC/TR3 61000-3-6 (1996):** Electromagnetic compatibility (EMC) - Part 3: Limits - Section 6: Assessment of emission limits for distorting loads in MV and HV power systems - Basic EMC publication

**IEC 61000-3-12 (2004):** Electromagnetic compatibility (EMC) Part 3-12: Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current  $>16$ A and  $\leq 75$  A per phase.

**IEC 61000-4-7 (Ed 2, 2002),** Electromagnetic compatibility (EMC) Part 4-7: Testing and measurement techniques - General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto.

**IEC 61000-4-30 (2003),** Electromagnetic compatibility (EMC) Part 4-30: Testing and measurement techniques - Power quality measurement methods.

## **APPENDIX A            COMPATIBILITY LEVELS**

### **A1       Relationship between Planning Levels and Compatibility Levels**

The planning levels in this Recommendation are to be used by NOCs as reference levels against which they assess the suitability for connection to their systems of large loads and equipment which are rated over 16A and are subject to their consent. They are specific to UK supply systems but are based on IEC Technical Report 61000-3-6.

Compatibility levels for public supply system harmonics are specified in IEC Basic Standards 61000-2-2 and 61000-2-12. The immunity test levels for equipment are higher levels based on the specified compatibility levels. If network distortion exceeds the relevant compatibility level, experience has shown that there will be a sudden increase in equipment failures and customer complaints.

The precise relationship between specified compatibility levels and planning levels depends on the disturbance phenomenon being considered and whether or not they are load related. Figure A1 demonstrates that planning levels control the emissions of large loads and are lower than or equal to compatibility levels. The margins between planning levels and compatibility levels depend on the electrical characteristics of the supply network, the background levels of distortion, the nature of the disturbance (continuous or random), load profiles, and load density of the supply system area.

Planning levels stipulated by NOCs are therefore subject to national and local supply system conditions. The basis of compatibility levels for harmonic, interharmonic and sub-harmonic voltage distortion is shown below:

Harmonic                      For this continuous phenomenon, there is generally a larger margin between medium voltage planning levels and compatibility levels than for other voltages. Margins are necessary in order to make allowances for system resonance which may amplify equipment emissions, and for the background levels of distortion due to 400V residential load which is connected without the specific consent of DNOs and is present on all supply systems..

Margins for total harmonic distortions in the United Kingdom are: 3% for 400V, 4% for 6.6 and 11kV 5% for 22 and 33kV, 2% for 66 and 132kV, and 0.5% for 275 and 400kV systems. Compatibility levels for 66, 132, 275, and 400kV systems have not been specified internationally

The compatibility levels specified in IEC Standards 61000-2-2 and 61000-2-12, for 400V and 6.6kVto33kV systems respectively are based on the immunity of capacitors as these components are susceptible to harmonic voltage distortion and are in common use.

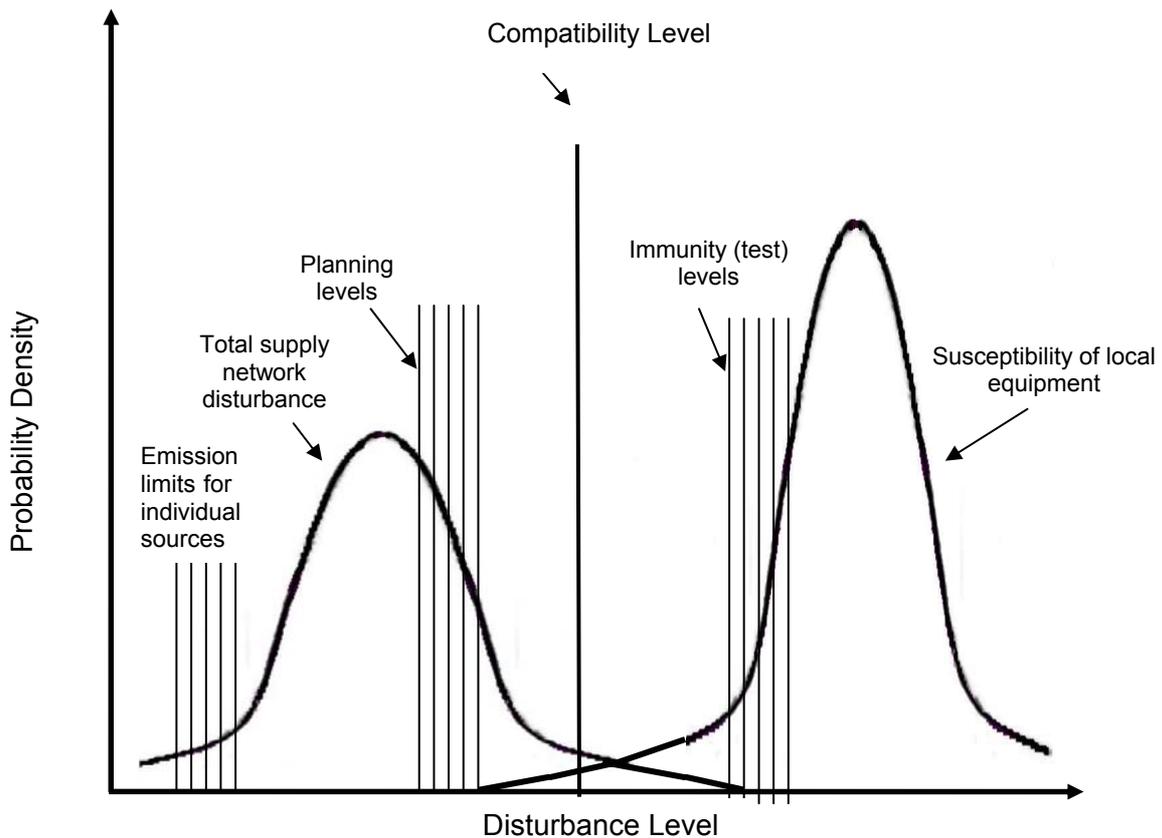
The total harmonic distortion level specified for 400V and 6.6 to 33kV supply systems is 8%, for 66 and 132kV systems it is 5%, and for 275 and 400kV systems is 3.5%. Breakdowns of these figures for individual harmonic orders are given in Tables A1 to A4

Sub-harmonic and interharmonic

System resonance effects due to interharmonics are not common and planning levels may be set equal to the 6.6 to 33kV supply system international compatibility level of 0.2% of the nominal supply voltage for individual harmonics which is published in IEC 61000-2-12. This compatibility level is based on the immunity response level of 0.3% of ripple control receivers. As ripple control are not used in the UK, planning levels have been based on the risk of disturbance to other susceptible equipment. This is described in the Application Guide ETR 122

A comprehensive explanation of the application of compatibility levels and planning levels and their relationships with emission and immunity limits and levels is to be found in IEC Standard 61000-2-12. Figure A1 has been taken from IEC 61000-2-12 and it illustrates the relationships between the EMC levels and limits.

**Figure A1: Typical Relationships between Planning Levels, Network Disturbance Levels, and Equipment Immunity Levels**



## A2 Supply System Compatibility Levels

**Table A1: Harmonic Voltage Compatibility Levels for 400V Systems – from IEC 61000-2-2**

Odd harmonics Non-multiple of 3		Odd harmonics Multiple of 3		Even harmonics	
Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.3	6	0.5
13	3	21	0.3	8	0.5
17	2	21<h≤45	0.2	10	0.5
17<h≤49	2.27 ( $^{17}/_h$ ) - 0.27			10<h≤50	0.25 ( $^{10}/_h$ ) + 0.25

Total Harmonic Distortion (THD) level is 8%

**Table A2: Harmonic Voltage Compatibility Levels for Systems up to 36.5kV – from IEC Standard 61000-2-12**

Odd harmonics (Non-multiple of 3)		Odd harmonics (Multiple of 3)		Even harmonics	
Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)
5	6.0	3	5.0	2	2.0
7	5.0	9	1.5	4	1.0
11	3.5	15	0.4	6	0.5
13	3.0	21	0.3	8	0.5
17	2.0	21<h≤45	0.2	10	0.5
17<h≤49	2.27 ( $^{17}/_h$ ) - 0.27			10<h≤50	0.25 ( $^{10}/_h$ ) + 0.25

Total Harmonic Distortion (THD) level is 8%

**Table A3: Harmonic Voltage Compatibility Levels for 66 and 132 kV Systems**

Odd harmonics (Non multiple of 3)		Odd harmonics (Multiple of 3)		Even harmonics	
Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)
5	4.0	3	2.0	2	1.0
7	2.0	9	1.0	4	0.8
11	1.5	15	0.3	6	0.5
13	1.5	21	0.2	8	0.4
17	1.0	>21	0.2	10	0.4
19	1.0			12	0.2
23	0.7			>12	0.2
25	0.7				
>25	$0.2 + 0.5^{(25/h)}$				

Total Harmonic Distortion (THD) level is 5%

**Table A4: Harmonic Voltage Compatibility Levels for 275 and 400kV Systems**

Odd harmonics (Non Multiples of 3)		Odd harmonics (Multiples of 3)		Even harmonics	
Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)
5	3.0	3	1.7	2	1.0
7	1.5	9	0.5	4	0.8
11	1.0	15	0.3	6	0.5
13	1.0	21	0.2	8	0.4
17	0.5	>21	0.2	10	0.4
19	0.5			12	0.2
23	0.5			>12	0.2
25	0.5				
>25	$0.2 + 0.3^{(25/h)}$				

The Total Harmonic Distortion (THD) level is 3.5 %

**APPENDIX B            DATA EXCHANGE PROFORMA**

NOTE 1:    This proforma is available to be used where considered appropriate by either the NOC or person seeking a network connection, however this does not preclude the submission of information on an alternative proforma.

NOTE 2:    Example text is shown in italics



**ENGINEERING RECOMMENDATION G5/4-1**

**Appendix B**

**HARMONIC MEASUREMENT SURVEY REPORT**

***SITE NAME AND DATE OF SURVEY***

Report prepared by: *Name and contact details*

**Contents:**

- Table B1: Survey details
- Table B2: Summary of results
- Additional Information

Report reference number XXXX

**Table B1. Survey Details**

1.	<b>Company (submitting the report)</b>	
2.	<b>Contact Name and Address</b>	
3.	<b>Site address</b>	
4.	<b>MPAN</b>	
5.	<b>Network connection (where known)</b>	<i>e.g. - A single 11kV overhead feeder enters the site, and feeds a pole mounted transformer</i>
6.	<b>Transformer details (where relevant)</b>	<i>e.g. xx kVA, ratio xxx:xxx, impedance xx%</i>
7.	<b>Reason for the survey</b>	<i>e.g.: This report is of the pre-installation survey and is to accompany the application to connect a new 200kVA six pulse drive</i>
8.	<b>Existing non linear load</b>	<i>e.g.: There is no existing long term harmonic producing load, however, a number of electronic "soft starters" are installed on site</i>
9.	<b>Details of new non linear load<sup>1</sup></b>	<i>e.g. The harmonic current spectrum for the new non linear load</i>
10.	<b>Point of measurement<sup>2</sup></b>	
11.	<b>Measurements<sup>3</sup></b>	
12.	<b>Connection Arrangements<sup>4</sup></b>	
13.	<b>Measuring instrument<sup>5</sup></b>	
14.	<b>Start time for measurements</b>	
15.	<b>Finish time for measurements<sup>6</sup></b>	

1 The completed proforma should include details of the prospective harmonic current emissions for the spectrum  $h = 2$  to  $h = 50$   
2 Measurements should either be carried out on the customer's equipment or it will be necessary to make arrangements with the DNO for the measurements to be carried out.  
3 The measurements should be made over a minimum of one week and should be measured in accordance with IEC 61000-4-30.  
4 To include the phases monitored and any VT details: connection arrangements and VT type.  
5 Manufacturer, Model number etc  
6 The duration of the measurement survey should cover a minimum of 7 days.

**Table B2 Summary of Results**

	<b>Channel 1</b>	<b>Channel 2</b>	<b>Channel 3</b>	<b>G5/4 Planning Levels 11 kV</b>
<b>Measured voltage max and min values</b>	222.0/ 239.1	223.7/ 241.7	223.3/ 240.8	
<b>Peak Voltage Distortion (THD) (%)</b>	2.90	2.88	2.88	4
<b>Time of peak voltage distortion</b>	16:10hrs 12 <sup>th</sup> . October 2003	16:10hrs 12 <sup>th</sup> . October 2003	16:10hrs 12 <sup>th</sup> . October 2003	
<b>Value of THD not exceeded for 95% time (%)</b>	2.71	2.67	2.67	3
<b>Peak 5<sup>th</sup> harmonic voltage distortion (%)</b>	2.67	2.68	2.68	3
<b>Value of 5<sup>th</sup> harmonic not exceeded for 95% time (%)</b>	2.47	2.44	2.44	2.25

**Additional Information**

- Table showing voltage (and current when available) distortion measurements plotted against time for the principal harmonics, with typical spectrum analysis and angular trend.

NOTE: If significant variation occurs between phases these should be shown separately.

- Figure 1: L1 Voltage harmonic trend – principal harmonics
- Figure 2: L1 Voltage harmonic spectrum – odd harmonics to 50<sup>th</sup>
- Figure 3: L1 Harmonic angular displacement – odd harmonics 3<sup>rd</sup> to 7<sup>th</sup>
- Figure 4: L1 Current harmonic trend – principal harmonics
- Figure 5: Digitally recorded waveforms showing the dominant harmonics recorded on the highest day during the survey.

NOTE: The figures should show the phase on which the maximum values of principal harmonics were measured