

**Engineering Recommendation No.1
of the Electricity Distribution Code**

**Limits for Harmonics
in the Electricity Supply System**

*Version 1.0
30th November 2005*

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1.0 PREFACE

1.1 Background

This document has been prepared to fulfill the technical requirements of the Distribution Code relating to limits for harmonics in the Electricity Supply System. The Distribution Code places obligations on Distribution Companies, Customers and other Users of the Distribution System in order to ensure the efficient planning, operation and development of the System.

This document has been prepared after a review of international practices and gives the requirements for the Electricity Distribution System in the Emirate of Abu Dhabi. Particular reference is made to UK and European standards which are listed in section 5.0.

1.2 Definitions

This document uses the same definitions as listed in the Electricity Distribution Code. Additional technical definitions are listed below which are used in ***bold italics*** in this document. Where there is any conflict or ambiguity between definitions given in the reference documents and those in the Distribution Code, then the latter shall be overriding.

<i>Harmonic current, I_n</i>	the RMS amplitude of a harmonic current, of order n, expressed in amperes
<i>Harmonic distortion</i>	the cyclic departure of a waveform from the sinusoidal shape (described by the addition of one or more harmonics to the fundamental frequency)
<i>Harmonic voltage, V_h</i>	the RMS amplitude of a harmonic voltage of order h, expressed as a percentage of the fundamental voltage.
<i>Total Harmonic Distortion:</i>	the RMS value of individual harmonic voltages expressed as a percentage of the fundamental RMS voltage, and calculated as:

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

PCC (Point of Common Coupling): the point on the Distribution System nearest to the Customer, as which other customers may be connected

1.3 Scope

This Engineering Recommendation is applicable to the Users of the Electricity Distribution Network as specified and defined by the latest edition of the Electricity Distribution Code.

1.4 Related Documents

This Engineering Recommendation should be read in conjunction with the latest version of the Electricity Distribution Code, the Electricity Supply Regulations and the Electricity Wiring Regulations, copies of which may be obtained from Distribution Companies.

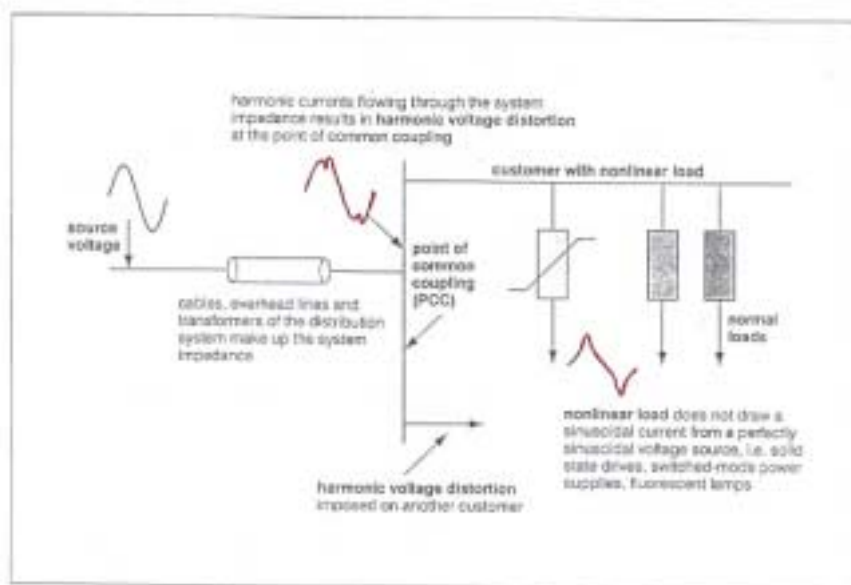
1.5 Description of harmonic disturbances

The majority of loads connected to the electricity supply system draw power which is a linear (or near linear) function of the voltage and current supplied to it. These 'linear' loads do not usually cause disturbance to other users of the supply system. Examples include lighting, heating, directly driven motors, pumps etc.

Some types of loads cause a distortion of the supply voltage / current waveform due to their non-linear impedance. The most common devices causing such problems are electronic controllers (such as motor drives) and AC to DC power supply convertors for equipment such as computers. The nature of these devices is that the waveform is switched or 'chopped' (commutated) very rapidly in order to control power flow or to convert to a DC output, typically using solid state components such as diodes and thyristors. Some types of florescent lighting or the controllers for such lighting can also cause these effects. Problems occur when such activity causes interference or permanent damage to equipment that is connected adjacent to the disturbing load (within the same building or in nearby premises).

The measurement of such interferences has been established by the parameter known as harmonic current/voltage. This is simply a measure of the extent of distortion of the normal AC sinusoidal voltage/current supplied by the power system, caused by the disturbing load. The distortion may be exhibited by a change in the sinusoid shape or by short 'notches' in the waveform. The method of measurement is based on disaggregating the distorted waveform into a normal 50Hz waveform plus smaller, superimposed waveforms taken at integer multiples (or sub-multiples) of the fundamental frequency. The 'total harmonic distortion' is expressed as the sum of the harmonic waveforms (rms values) operating at the 1st, 2nd, 3rd etc multiples of the fundamental frequency.

Figure 1. Illustration of harmonics caused by a non-linear load



Further useful information on the nature of harmonics is given in a tutorial paper published by Power Engineering Journal, April 2002 (see ref. 1).

2.0 LIMITS FOR HARMONICS

2.1 Planning limits and assessment process

In order to prevent disturbance and damage¹ to Users of the electricity distribution system, caused by other Users, this document sets limits for the maximum harmonic voltage/current that may be imposed by equipment. Distribution Companies will be expected to undertake a 3 stage assessment process to determine the suitability of connection of a new potentially disturbing load. This is intended to simplify the procedure for small loads which are unlikely to cause problems, whilst requiring more rigorous assessment, including on-site measurement before and after connection, for large loads. The 3 stage assessment process is described in the following sections and is summarised in Figure 2.

Before making an assessment of the harmonic impact of a new load the DISCO must take into account the background levels or harmonics that may already exist on the system. The maximum level of background harmonics, to be adopted as a standard for planning, development and connections on the distribution system are given in tables 1 – 3 below.

¹ **Note:** IEC standards 61000-2-2 and 6100-2-1 define harmonic compatibility levels to which manufacturers' equipment should be designed, and which will minimise the likelihood of damage as long as the planning levels described above are maintained.

Table 1: THD (total harmonic distortion) planning limits

System Voltage	THD limit
400V	5%
6.6kV, 11kV and 20kV	4%
22kV to 400kV	3%

Table 2: Planning limits for harmonics at 400V

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)				

Table 3: Planning limits for harmonics at 6.6kV – 20kV

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)				

Table 4: Planning limits for harmonics at >20kV and <145kV

Odd harmonics (Non-multiple of 3)		Odd harmonics (multiple of 3)		Even Harmonics	
Order 'h'	Harmonic voltage (%)	Order 'h'	Harmoni c 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(25/h)				

Note: see G5/4 Table 5 for voltages above 145kV

2.2 Stage 1 assessment

2.2.1 Loads below 16A per phase

Where a potentially disturbing load or non-linear equipment is to be supplied at low voltage and it has a rating of less than 16A per phase it may be connected without any further assessment if it conforms to BS EN 61000 (part 3-2) or other relevant European Standard which defines harmonic limits.

Where there is no European Standard for the equipment or it is not shown to conform to the relevant BS-EN document then the equipment can still be connected if it meets the limits given in table 7 below.

In addition, single or three phase convertors and AC regulators intended only for industrial applications or for over-night battery charging and which by design have negligible even harmonic emissions, may be connected without assessment.

If the above conditions cannot be met then mitigation measures, such as the use of harmonic filters, may be required, in which case the DISCO will provide advice.

2.2.2 Loads above 16A per phase

For LV equipment rated >16A per phase connection may be given if it complies with BS EN 6100-3-4 or the values given in table 7 below.

Single phase convertors and AC regulators intended only for industrial applications or for over-night battery charging and which by design have negligible even harmonic emissions, may be connected without assessment if their aggregate load does not exceed 5 kVA per installation. Three phase regulators or convertors may be connected without further assessment if they are rated less than the values given in table 6 below.

If these conditions cannot be met then an assessment under stage 2 can be made in which case the emission characteristic data for the load should be provided to the DISCO.

Table 6: Maximum Aggregate Value of Three Phase Convertors 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)
400 V	12	50	14

Table 7: Maximum allowable harmonic current for aggregate loads / equipment rated >16A per phase at 400V (stage 1 assessment).

Harmonic order 'h'	Emission current I _h	Harmonic order 'h'	Emission current I _h	Harmonic order 'h'	Emission current I _h
2	28.9	19	9.1	36	0.4
3	48.1	20	1.4	37	2.1
4	9.0	21	0.7	38	0.8
5	28.9	22	1.3	39	0.4
6	3.0	23	7.5	40	0.7
7	41.2	24	0.6	41	1.8
8	7.2	25	4.0	42	0.3
9	9.6	26	1.1	43	1.6
10	5.8	27	0.5	44	0.7
11	39.4	28	1.0	45	0.3
12	1.2	29	3.1	46	0.6
13	27.8	30	0.5	47	1.4
14	2.1	31	2.8	48	0.3
15	1.4	32	0.9	49	1.3
16	1.8	33	0.4	50	0.6
17	13.6	34	0.8		
18	0.8	35	2.3		

Note: these values may be increased if the system fault level is greater than 10MVA (see table 9 and section 3.1)

2.3 Stage 2 assessment

Stage 2 assessment covers the connection of loads to systems less than 33kV, including LV equipment that cannot be dealt with under stage 1. The maximum permissible harmonic currents emitted from equipment are specified in table 12 over leaf, on the assumption that existing background levels of harmonics are less than 75% of the planning limits given in tables 2 to 4.

If these requirements are met then further assessment is not necessary. If the background levels are above 75% but less than 100% of the planning limits then the DISCO will be required to make a simple assessment of the predicted affect of the new load, summated with the existing harmonic levels. If the result is less than 100% of the planning limits, the load can be connected.

[Stage 2 also defines certain sizes of AC-DC convertors and regulators which may be connected without further assessment, given in table 10 over leaf].

The method of assessing the predicted harmonic voltage is as follows:

Method for assessment of predicted harmonic voltage

(a) first assess the calculated harmonic voltage distortion caused by the load for each harmonic order using the formula:

$$V_{hc} = \frac{I_h k h \sqrt{3} V_s 100\%}{F 10^6}$$

where:

V_{hc}	is the calculated harmonic voltage
I_h	is the harmonic current of the load
h	is the harmonic order (number)
V_s	is the supply line voltage (volts)
F	is the system short circuit level in MVA
k	is a factor which allows for low order parallel resonance and is given the values in table 8 below

(b) calculate the predicted voltage distortion by the sum of the measured harmonic voltage (from the DISCO site measurements) and the calculated values in (a) as follows:

- for each harmonic order up to and including the 5th, and for all triplens and for the harmonic order having the highest value, it should be assumed that the background measured values and the calculated value of the load may be in phase and therefore add arithmetically as follows:

$$V_{hp} = V_{hm} + V_{hc}$$

- For all other harmonics and to allow for diversity it is assumed that the phase angle between the background and new load harmonics is 90° and therefore the RMS total can be used:

$$V_{hp} = \sqrt{V_{hm}^2 + V_{hc}^2}$$

The total harmonic distortion is then given by:

$$THD = \sqrt{\sum_{n=2}^{n=50} V_{hp}^2}$$

Table 8: Values of ‘k’

Supply voltage	Harmonic order			
	$h \leq 7$	$h \leq 8$	$h > 7$	$h > 8$
$\leq 400V$	1		0.5	
11kV – 22kV		2		1

Table 9: Assumed fault levels used for tables 7 and 11

System Voltage	Assumed fault level, F (MVA)
≤ 400V	10
6.6kV	60
11kV	100
20kV	182
22kV	200

Table 10: maximum aggregate rating of convertors or regulators that can be connected under stage 2

Supply voltage	Three phase convertor rating (kVA)		Three phase AC regulator rating (kVA)
	6 pulse	12 pulse	6 pulse thyristor
6.6kV to 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 the 3rd, 5th and 7th.

If the prospective load is to be connected at low voltage and the requirements of stage 2 assessment described above cannot be satisfied then mitigation measures will be required. If the prospective load is to be connected above 400V then a further assessment under stage 3 may be carried out.

Table 11: stage 2 THD and 5th harmonic limits

Supply voltage	Stage 2 THD voltage limit	Stage 2 5th harmonic distortion limit
≤ 400V	5%	4%
6.6kV – 20kV	4%	3%
22kV	3%	2%

Table 12: Maximum allowable harmonic current per customer
at HV in amps RMS per phase (stage 2 assessment).

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

Note: the above limits are based on assumed fault levels shown in table 9; the above values may be proportionally increased for networks with higher fault levels.

2.4 Stage 3 assessment

The stage 3 procedure covers detailed assessment of a prospective new load if the requirements under stage 2 are not satisfied, and for all connections at 33kV and above. Measurements of the existing (background) levels of harmonics are required before and after connection. The cumulative effect of the existing and predicted new harmonic emissions is calculated by the DISCO using the customer's detailed harmonic load characteristic and a harmonic impedance model (not the simple impedance model used in stage 2), for which a harmonic analysis programme will normally be required. Alternatively, the DISCO may provide the customer with the system harmonic impedance values in order for the customer to calculate the cumulative harmonics. The resulting values should be less than the planning guidelines given in tables 1 to 4 discussed earlier.

The stage 3 procedure also requires consideration of capacitance effects of the local supply network, potential resonance, and transfer of harmonics to lower voltages on the supply system. Documents G5/4 and ETR122 published by the Energy Networks Association (UK) provide further guidance in these issues (see references).

2.5 Cases of high background harmonics

Stage 2 and stage 3 require the existing background level of harmonics to be assessed prior to the connection of new customers². Where this is found to be above 100% of the planning levels shown in tables 1 to 4 the DISCO will need to undertake mitigation measures to reduce the background levels to below 75% which will then allow new customers to be accommodated. Mitigation measures that may be taken by the DISCO can include:

- a. identifying existing sources of high harmonic emission; if any existing customers are identified to be a main contributor to harmonics being above the planning limits these customers may be requested by the DISCO to reduce their harmonic emissions;
- b. where no individual customers can be identified as significant contributors to the high background harmonic levels, then the DISCO will need to consider other mitigating measures. These may include splitting areas of the network into smaller isolated zones or installing harmonic filters at distribution or primary substations.

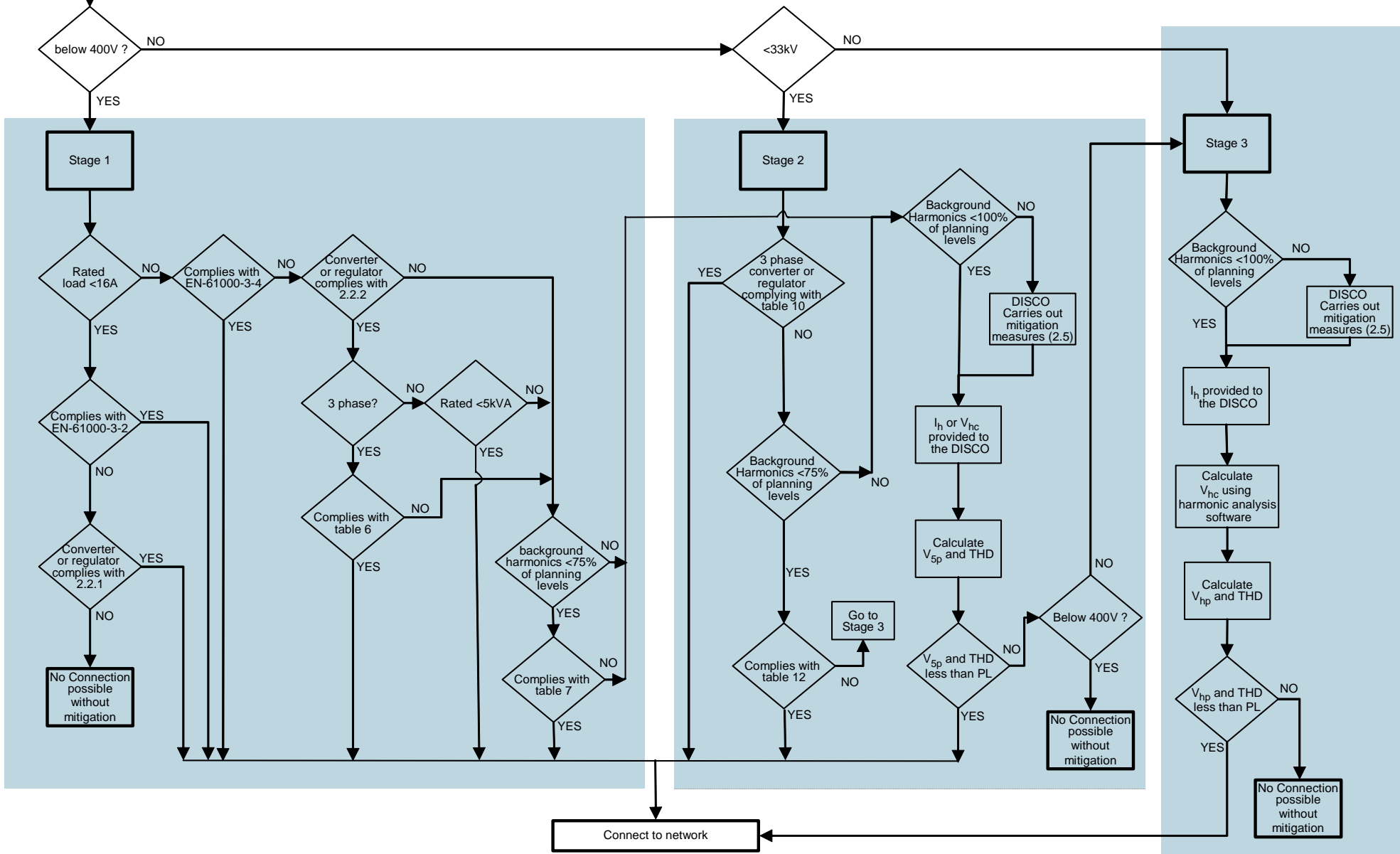
² Assessment of background harmonics would normally be carried out the point of common coupling between existing and potential new customers, such as a feeder pillar or distribution substation.

TABLE A: Harmonic assessment procedure for new connections – summary of cases which can be accepted

Stage I (230/400V) Connection to Network Accepted		Transfer from Stage I to Stage 2 and Accepted	Stage II (<33kV) Connection to Network Accepted	Transfer from Stage 2 to Stage 3 for Action	Stage III Connection to Network Accepted
Rated Load < 16A	Rated Load > 16A	Load > 16A and doesn't comply with any of the acceptance criteria in stage 1: <ul style="list-style-type: none"> ■ DISCO Determines Network Distortion ■ I_h or V_{hc} supplied to DISCO ■ Calculate V_{5p} and THD at PCC ■ $V_{5p} < PL$ and $THD < PL$ <u>Note:</u> I_h - harmonic current V_{hc} - calculated harmonic voltage THD - total harmonic distortion PCC - point of common coupling PL - planning level	1. 3 phase convertor or regulator which complies with limits given in table 10	Calculated V_{5p} and THD at PCC are not both < PL Doesn't comply with table 12	<ul style="list-style-type: none"> ■ DISCO determines background network distortion ■ I_h supplied to DISCO ■ V_{hc}, V_{hp} & THD calculated at PCC and lower voltages ■ $V_{hc} < PL$ and $THD < PL$
1. All appliances comply with emission limits in BS-EN61000-3-2	1. All appliances comply with emission limits in BS-EN61000-3-4		2. DISCO determines existing network distortion is <75% of planning levels and the new load complies with table 12		
2. Convertor or regulator that is only used for industrial applications or overnight charging	3. Convertor or regulator less than 5kVA used only for industrial applications or overnight charging		3.		
	4. Three phase convertor or regulator which complies with emission limits given in table 6		<ul style="list-style-type: none"> ■ DISCO determines existing network distortion is >75% of planning levels: ■ I_h or V_{hc} supplied to DISCO ■ Calculated V_{5p} and THD are both < PL 		
	5. New load complies with table 7				

Figure 2: flow diagram of harmonics assessment procedure

KEY:
 I_h - harmonic current
 V_{hc} - calculated harmonic voltage
 THD - total harmonic distortion
 PCC - point of common coupling
 PL - planning level



3.0 SPECIAL CONSIDERATIONS

3.1 Fault levels

The harmonic current limits specified under tables 7 and 11 in the preceding sections are based on assumed fault levels on the supply system. In Abu Dhabi Emirate the system faults levels are often higher than these assumed values and G5/4 states that the harmonic current limits can be linearly scaled up where this is the case (for all orders of harmonics).

Table B: comparison of fault levels assumed in G5/4 with maximum Abu Dhabi fault levels

System Voltage	G5/4 Fault level (MVA)	Maximum Abu Dhabi Fault levels
400V	10	32MVA (46kA)
6.6kV	60	
11kV	100	475MVA (25kA)
20kV	182	
33kV		1800MVA (31.5kA)

Note: the above table shows maximum values for Abu Dhabi faults levels. However, the actual (lower) values at the location in question should be used in calculating the allowed harmonic levels.

3.2 Capacitor banks

Capacitor banks installed at LV or 11kV loads, which are used for power factor correction, are major contributors to potential resonance affects. Such resonance conditions can magnify harmonic levels. Parallel resonance gives rise to a high impedance across the network and can cause voltage and current amplification. Network studies should be carried out to ensure the correct rating of capacitors and their operation without causing resonance. It may be necessary to take mitigation measures such as installing suitable harmonic filters or reactors.

4.0 NOTES FOR USERS / CUSTOMERS OF THE DISTRIBUTION SYSTEM

4.1 Applications for connection of new loads

Customers / Users of the Distribution System will be required to submit an application for connection of new loads according to current procedures published by the DISCO. In addition to information required to be submitted under such procedures Customers / Users will be required to submit information on potentially disturbing loads which may require assessment by the DISCO before connection. Customers / Users may also be required, at the request of the DISCO, to provide information on other similar equipment installed at previous sites from which measurements can be taken, if required, for harmonic assessment.

Where mitigation measure are required for a particular new load the DISCO may give a 'conditional connection' in order to allow the installation and testing of the necessary equipment such as harmonic filters and for real time measurement to be taken. Consideration may be given for the installation of harmonic meters.

4.2 Assessment of harmonics and disturbing loads

The assessment of harmonic loads and other disturbing loads will be the responsibility of the DISCO. However, this will be dependant on the provision of adequate information by the customer / user for such an assessment to be made. The terms and duration of such an assessment will be as mutually agreed by the DISCO and the Customer / User.

4.3 Cost of on site measurements

The cost of on site measurements requirement to determine compliance with harmonic limits, will be borne by the customer / user making an application for connection. On site measurements may be carried out by the DISCO or an appointed contractor. Alternatively, the customer may provide on site measurements in a format approved by the DISCO. The DISCO may request re-measurement at some time after connection (e.g. after 1 year) to determine if the installation is still compliant with respect to harmonics emissions.

5.0 REFERENCES

1. **Connecting Non-linear Loads to Public Electricity Systems - a Guide to G5/4**
By Geoffrey Hensman, Power Engineering Journal, April 2002
2. **ETR 122 Guide to the Application of G5/4**
Energy Networks Association³, UK, June 2002
3. **G5/4: Planning Levels for Harmonic Voltage Distortion and the Connection of Non-Linear Equipment to Transmission and Distribution Networks**
Energy Networks Association, February 2001
4. **BS EN 61000-3-2 (2000)**
Limits for Harmonic Emission for Equipment up to 16A per phase
5. **BS EN 6100-3-4 (1998)**
Limits for Harmonic Emissions in LV Supply Systems rated greater than 16A.
6. **ENV 61000-2-2 (1993)**
Electromagnetic Compatibility levels for low frequency conducted disturbances and signaling in public LV supply systems
7. **IEC 61000-2-12 (2001)**
Compatibility levels for low frequency conducted disturbances and signaling in public LV supply systems (Consultation/Design Document)

³ Note: the Energy Network Association was previously known as the Electricity Association. All documents issued by EA have now been re-labeled under the ENA, but keeping the same document number. These can be purchased online from www.energynetworks.org.

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Directory: Y:\TARIQ\documents for pdf
Template: C:\Documents and Settings\rjeraissi\Application
Data\Microsoft\Templates\Normal.dot
Title: Engineering Recommendation No
Subject:
Author: user
Keywords:
Comments:
Creation Date: 11/21/2005 10:28 AM
Change Number: 7
Last Saved On: 4/17/2006 8:38 AM
Last Saved By: rjeraissi
Total Editing Time: 50 Minutes
Last Printed On: 4/17/2006 8:47 AM
As of Last Complete Printing
Number of Pages: 19
Number of Words: 4,420 (approx.)
Number of Characters: 21,661 (approx.)