ENGINEERING RECOMMENDATION G.5/3
System Design and Development Committee
September 1976
CLASSIFICATION 'C'

THE ELECTRICITY COUNCIL

CHIEF ENGINEERS' CONFERENCE

LIMITS FOR HARMONICS IN THE UNITED KINGDOM ELECTRICITY SUPPLY SYSTEM

CONTENTS

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1 SCOPE

This Engineering Recommendation supersedes Engineering Recommendations G.5/2 and G.11 which are hereby cancelled. It provides guidance as to the limits of harmonic currents that may be fed into the electricity supply system by consumers supplied from low or higher voltage systems and to the limits of harmonic voltage distortion caused thereby, but whether or not a proposed installation can be accepted on the system will rest with the Board concerned.

Other aspects of the connection of loads with non-linear characteristics, such as voltage flicker and unbalance, are discussed in the relevant Engineering Recommendations - for example Engineering Recommendation P.16 for Induction Furnaces. A frequent application of the harmonic current limits is to the connection of single and three-phase convertors or a.c. regulators, and guidance is therefore given as to the maximum sizes of these types of equipment that may be connected to an electricity supply system.

Household or similar equipment provided with electronic control devices and complying with British Standard 5406 (European Standard EN 50.006 : CENELEC) will automatically comply with this Recommendation.

2 REFERENCES

This Recommendation makes reference to the following documents:

BS 5406	: The Limitation of Disturbances in Electricity Supply Networks Caused by Domestic and Similar Appliances Equipped with Electronic Devices
IEC Standard 146	: Semiconductor Convertors
IEC Standard (In draft)	: Electronic A.C. Regulators and Switches
Engineering Recommendation P.16	: EHV and HV Supplies to Induction Furnaces
ACE Report No. 15	: Harmonic Distortion Caused by Inverter Equipment
ECRC Report No. R920	: The Development of a Harmonic Analyser

ECRC Report No. 962	: A Harmonic Alarm for the Supply Industry
ECRC Report No. 989	: A Harmonic Power Meter
ECRC Report No. 990	: A System for Measuring the Source Impedance of HV and LV Distribution Networks at Various Frequencies
EC (TR Branch) Publication	: Engineering Applications to Computers: Program Data Sheets
EC (TR Branch) Publication	: User's Guide to the Automatic Mains Harmonic Analyser CCL Type C 157A.

3 DEFINITIONS

3.1 Point of Common Coupling (pcc)

The point of common coupling with other consumers is the point in the public supply network, electrically nearest to the consumer for whom the new connection is proposed, at which other consumers' loads are, or may be, connected.

3.2 Harmonic Distortion

The departure of a waveform from sinusoidal shape, that is caused by the addition of one or more harmonics to the fundamental.

3.3 Harmonic Voltage Distortion, V_n

The rms amplitude of a harmonic voltage, of order n, expressed as a percentage of the rms amplitude of the fundamental.

3.4 Harmonic Current Distortion, I_n

The rms amplitude of a harmonic current, of order n, expressed as a percentage of the rms amplitude of the fundamental.

3.5 **Total Harmonic Voltage Distortion, V_T**, expressed as a percentage of the fundamental, and calculated using the expression:

$$V_T = \sqrt{\sum_{n=2}^{\infty} V_n^2}$$

Note: Generally, it is sufficient to use values of n up to 19.

3.6 Convertor Equipment (Convertor)

An operating unit for power conversion, comprising one or more diode or thyristor assemblies together with convertor transformers, essential switching devices and other auxiliaries.

3.7 Thyristor A.C. Power Controller (A.C. Regulator)

A power electronic equipment for the control or switching of a.c. power using circuits without forced commutation and where switching, multicycle control or phase control are included.

Definitions 3.6 and 3.7, for Convertor and A.C. Regulator, are from IEC Standard 146, "Semi-conductor Convertors", and Draft IEC Standard, "Electronic A.C. Regulators and Switches", respectively.

4 GENERAL

The method of approach enables the problem of acceptance of loads with non-linear characteristics to be dealt with in stages, according to the size and type of equipment. The first stage concerns the smaller types of equipment which are in general use and states the maximum sizes of convertor or a.c. regulator generally acceptable for connection to the normal 0.415, 6.6 or 11 kV system(s). No consideration of system details, other than the normal considerations which apply to all new loads, such as thermal rating of the circuit to supply the load, or voltage regulation, is necessary.

If the equipment size exceeds the Stage 1 limits then it should be considered under Stage 2. The Stage 2 limits comprise a table of maximum permitted values of harmonic currents that a consumer may feed into the system at the point of common coupling, provided that the existing values of individual harmonic and total harmonic voltage distortion on the system are within stated limits.

Finally, if the equipment cannot be accepted under Stage 2 limits because of its size or the existing levels of harmonic current and voltage, then it should be considered under Stage 3. This comprises a number of guide lines, including voltage distortion values, which should be considered in conjunction with a knowledge of the characteristics of the load, the system and existing background distortion levels.

5 STAGE 1 LIMITS

5.1 Three-phase Equipments

The maximum sizes of individual convertor or a.c. regulator equipments that may be connected to any 0.415, 6.6 or 11 kV system(s), without detailed consideration by the supply authority of the harmonic currents produced, are stated in Table 1.

TABLE 1
MAXIMUM SIZES OF INDIVIDUAL CONVERTOR AND A.C. REGULATOR EQUIPMENTS UNDER STAGE 1 LIMITS

Supply System Voltage (kV) at Point of Common Coupling	3-Phase Convertors			3-Phase A.C. Regulators	
	3-Pulse (kVA)	6-Pulse (kVA)	12-Pulse (kVA)	6-Thyristor (kVA)	3-Thyristor/ 3-Diode (kVA)
0.415	8	12	-	14	10
6.6 and 11	85	130	250*	150	100

*This limit applies to 12-pulse devices, and to combinations of 6-pulse devices always operated as 12-pulse devices, employing careful control of the firing angles and the d.c. ripple to minimise non-characteristic harmonics, eg 3rd, 5th and 7th.

5.2 Single-phase Equipments

Single phase electrical appliances equipped with electronic devices for supply or control and intended for household or similar applications should comply with British Standard 5406 (European Standard EN 50.006).

Single phase convertors or a.c. regulators, which theoretically produce no even harmonics, and which are intended for industrial type equipment and battery charging should not exceed 5 kVA capacity at 240 V, 7.5 kVA at 415 or 480 V. The use of single phase convertors or a.c. regulators, which do produce both odd and even harmonics, is deprecated.

When a number of single phase equipments are installed by a consumer at one location, an attempt should be made to connect them so as to balance the non-linear load equally between the three phases. The aggregate effect of the non-linear loads at an installation where there is more than one non-linear load per phase should comply with the requirements of Stage 2. Further information on the connection of single phase loads is given in Engineering Recommendation P.16.

5.3 Direct Current

The use of equipments which produce a d.c. component in the a.c. supply system is deprecated.

6 STAGE 2 LIMITS

6.1 Three-phase Loads

The connection of equipment whose size exceeds the Stage 1 limits may be agreed if

(a) the consumer's total installation does not produce, at the pcc, currents (in any phase) in excess of those listed in Table 2,

(b) the existing voltage distortion at the point of common coupling before the connection of the new load does not exceed 75% of the values in Table 3, and

(c) the short-circuit level is not unduly low.

For convenience of use, Tables A1 and A2 in the Appendix show the current limits of Table 2 in terms of equivalent convertor and a.c. regulator loads.

Examples of the procedures that may be adopted in dealing with a request by a new consumer for the connection of non-linear load, or by an existing consumer for the connection of additional non-linear load, are given in the Appendix, Section A3.

TABLE 2

PERMITTED HARMONIC CURRENTS FOR ANY ONE CONSUMER AT POINT OF COMMON COUPLING

UNDER STAGE 2 LIMITS Ø

Supply System Voltage (kV) at Point of Common Coupling	Harmonic Number and Current (A rms)																	
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0.415	48	34	22	56	11	40	9	8	7	19	6	16	5	5	5	6	4	6
6.6 and 11	13	8	6	10	4	8	3	3	3	7	2	6	2	2	2	2	1	1
33	11	7	5	9	4	6	3	2	2	6	2	5	2	1	1	2	1	1
132	5	4	3	4	2	3	1	1	1	3	1	3	1	1	1	1	1	1

Ø : A tolerance of +10% or 0.5 A (whichever is the greater) is permissible, provided it applies to not more than two harmonics.

6.2 Single-phase Loads

Harmonic-producing single-phase loads in excess of Stage 1 limits are deprecated because of the unbalance caused to the fundamental three-phase voltages as well as the increased penetration of unbalanced triplen harmonics to different voltage levels. If single-phase loads are installed, they should comply with the voltage unbalance limits of Engineering Recommendation P.16. Under unbalanced conditions the phase-to-neutral harmonic voltage levels, in per cent, may differ widely from the phase-to-phase values.

7 STAGE 3 LIMITS

When a non-linear load does not comply with the limits of Table 2 and/or when the voltage distortion at the points of common coupling already exceeds 75 per cent of the limits of Table 3, it may still be possible to connect the load after a detailed examination of existing harmonic current and voltage conditions and the conditions resulting from the new load.

Information should first be obtained about existing harmonic voltage distortion on the system to which the load is to be connected. This may be obtained from previous knowledge of the system or by a survey using the Automatic Mains Harmonic Analyser referred to in Section 10, "Site Measurements", or an equivalent device.

The voltage distortion expected on the distribution network, resulting from a combination of the existing distortion and that produced by the new load, should be estimated and should not exceed, at any point on the Supply Authority network, the values in Table 3. An example of the procedure that may be adopted in dealing with a request for a connection which comes within Stage 3, is given in Section A3 of the Appendix.

The values in Table 3 are only to be regarded as a guide to good practice, reducing the risks of damage or malfunctioning of other consumers', or of the Board's, equipment or overloading of a section of the network due to resonance.

TABLE 3

HARMONIC VOLTAGE DISTORTION LIMITS AT ANY POINT ON THE SYSTEM (INCLUDING BACKGROUND LEVELS)

Supply System Voltage (kV) at Point of Common Coupling	Total Harmonic Voltage Distortion V_T (%)	Individual Harmonic Voltage Distortion (%)	
		Odd	Even
0.415	5	4	2
6.6 and 11	4	3	1.75
33 and 66	3	2	1
132	1.5	1	0.5

In considering the connection of plant having a 132 kV point of common coupling, it may be necessary to make a harmonic penetration computer study. This should permit the level of distortion throughout a network to be estimated, including the effects of resonances, provided sufficient data are available on system and load parameters. The size and cost of plant likely to be connected at this voltage, and the potential area of distortion, will, in general, warrant this more detailed analysis. The lack of wound VT's may make site recordings difficult, but system data should be more readily available to permit analysis by computer studies (see the Electricity Council's "Engineering Applications of Computers").

It is expected that the use of the harmonic impedance meter mentioned in Section 10, "Site Measurements", may help to supply information about the system impedance as seen from the point of common coupling of a consumer's non-linear load.

8 ADDITION OF HARMONICS

There is no simple rule for the addition of varying harmonic currents produced by the equipment of a number of consumers connected to the same section of the distribution network. A research project is being conducted by the Electrical Research Association (ERA) with the object of formulating a guide for the addition of harmonic currents produced by two or more sources. Pending the outcome of this work, where a number of harmonic producing loads are, or are to be, connected to the network, the procedure described in Section A2 of the Appendix - Treatment of a Number of Harmonic Sources - may be followed as providing a reasonable guide.

9 SHORT-DURATION HARMONICS

Devices such as thyristor-controlled rolling mill drives may produce short-duration bursts of currents as a sheet or billet passes through the rollers. These bursts of current may include transients and also harmonics. Such short-duration transients and harmonics are tolerable provided the current bursts and related voltage distortions are of an intermittent nature, eg the burst duration does not exceed 2 seconds and the interval between bursts is not less than 30 seconds. The principal concern is to prevent damage to other plant, such as capacitors. Provided that the fundamental voltage at the metering point does not exceed the nominal system supply voltage plus 6 per cent, there should be no risk of damage.

The harmonic conditions likely to prevail pose problems of measurement and quantitative analysis. However, the controlling factor in such installations is frequently not the harmonic current content of the waveform but the rapid voltage changes caused by the nature of the process. In order to reduce these to an acceptable level, either the short-circuit level must be high, such as to make harmonic distortion a secondary consideration, or a voltage fluctuation compensator incorporating harmonic filtering can be provided.

10 SITE MEASUREMENTS

Measurements should be carried out from time to time to diagnose system behaviour and to provide background information so that consideration may be given to the connection of new loads in accordance with Stage 2 and 3 procedures. Site measurements are also required before and after the connection of large new loads to verify compliance with the agreed levels of harmonic current production. Instruments have been developed to facilitate this work and to assist in maintaining a uniform interpretation of this Engineering Recommendation.

10.1 Harmonic Alarm Indicator

A Harmonic Alarm Indicator has been developed (see Electricity Council Research Centre (ECRC) Report No. R 962) and will give an approximate indication of the total voltage distortion at any point on the system by means of a coloured flag which moves across an opening. If the total voltage distortion exceeds 5 per cent, the flag locks in the fully displayed position. This is a low cost instrument that can be installed at points where high levels of distortion are suspected. It may help to determine where harmonic surveys are required and also to give warning of points at which it may no longer be possible to accept loads, in accordance with Stage 2 limits, without a harmonic survey.

10.2 Automatic Mains Harmonic Analyser

An instrument has been developed (see ECRC Report No. R 920) under the direction of the Electricity Council and is designed to facilitate the carrying out of harmonic surveys. Its use is described in the Electricity Council (Technical Research Branch) publication entitled "User's Guide to the Automatic Mains Harmonic Analyser, CCL - Type C157A". A new version of this instrument is now available.

This analyser can be used to measure harmonic voltages as percentages of the fundamental 50 Hz voltage at the time of measurement, or by use of a suitable shunt, harmonic currents as percentages of the fundamental 50 Hz current at the time of measurement. It also measures phase angle of the harmonic relative to the fundamental. The instrument will measure all the harmonics selected in the range 2nd to 25th (or to 39th in a special version). It can be set to measure each harmonic for 5, 10 or 20 seconds and to make the selected sequence of harmonic measurements continuously, or at intervals of 7.5, 15, 30 or 60 minutes. The measured quantities are recorded on a built-in printer and, if required, can be punched onto paper tape by a separate paper tape punch. Computer programs are available to analyse the paper tape output. Further details of these instruments and of the paper tape data analysis, can be obtained from the Technical Research Branch of the Engineering Division, Electricity Council.

Harmonic current and voltage magnitudes frequently vary erratically, and occasionally give rise to uncharacteristic high values. There is also the possibility of occasional spurious high values being recorded by the instrument; these readings should be ignored. It is recommended that, over a 24 hour recording period, the highest three rms readings of a harmonic be identified and, if they are not equal, the lowest one is taken and compared with the limit of the same harmonic number in Table 2. A shorter recording period may be used if there is justification for believing that this will include a number of occasions of maximum harmonic current generation.

10.3 Direction of Flow of Harmonics

The convention adopted in the supply industry concerning the connection of thyristor/diode or other non-linear loads to the system is to consider the direction of flow of harmonic current resulting from their connection as being from the device into the source of supply. However it is evident that when there are other non-linear loads connected to the system the net harmonic current flowing in the new connection at the point of common coupling will be dependent on the magnitude and phase angle of both the existing and new harmonic currents and the ability of the new load to absorb harmonics. This may be an important consideration if the installation includes power factor correction capacitors or a filter since either may draw harmonic currents from the supply system as well as from the new non-linear load.

The direction of flow of the net harmonic current in the new connection can be determined by site measurements using an instrument developed (see ECRC Report No. R 989) for the purpose by the Electricity Council. Details of this instrument can be obtained from the Technical Research Branch.

10.4 Impedance Measurement

A recurring problem, when considering the connection of new loads, is the conversion of harmonic currents, injected into the system, into their corresponding harmonic voltages, because the values of system impedance at harmonic frequencies are not known with confidence. A survey is being made of system harmonic impedance with a technique (see ECRC Report No. R 990) developed by the Electricity Council. The harmonic impedance measurement system comprises a variable-frequency current-injection unit and an automatic harmonic analyser modified to measure the injected frequencies. Current amplitude and phase-angle are monitored via a system current transformer whilst the voltage drop across the system impedance is monitored in amplitude and phase via a system voltage transformer. Vectorial division gives the system impedance at the injection frequency.

11 APPLICATION

This Recommendation in no way overrides good engineering practice for establishing firm supplies and acceptable regulation.

It is suggested that in accepting harmonic producing loads within the limits of this Recommendation, the following approach should be adopted:-

All such installations larger than 1 MW or beyond the limits of Stage 2 should have commissioning tests carried out by the Electricity Board to determine:-

i   prior to commissioning - the magnitude of existing current and voltage harmonics in the network.

ii   following commissioning - that the agreed values of harmonic current and voltage distortion have not been exceeded.

The consumer should be advised to check:-

i   that power factor correction capacitors are not being overloaded by excessive harmonic current absorption, or overstressed by excessive peak voltage.

ii   that a harmful degree of series or parallel resonance is not occurring.

As there is no guarantee that adherence to the recommended limits of harmonic current and voltage will prevent trouble arising, particularly when the limits are approached, and as it is prudent to consider that system changes will sometime justify re-examination, measurements should be carried out from time to time to diagnose system behaviour and equipment performance. The use of the Harmonic Alarm Indicator, already mentioned, on the system at points where high levels of distortion are suspected, may help to determine where harmonic surveys are required.

Bearing in mind that the limits imposed are necessarily based on certain simplifying assumptions and in order to enable as flexible an interpretation of the Recommendation as possible, attention is drawn to the use of filters for limiting the harmonic currents passed to the network and also to the use of protective inductors with capacitor installations to eliminate possible resonance and overloading, and to the use of alternative transformer connections to produce phase shifts between currents from a number of equipments.

An ACE Report will describe the relevant methods of measurement and study procedures, and will explain the theory and assumptions on which the present Engineering Recommendation is based.

APPENDIX

A1 GUIDE TO MAXIMUM SIZES OF CONVERTOR INSTALLATIONS - STAGE 2

Tables A1 and A2 of this Appendix have been prepared as a guide to the sizes of equipment which will normally be acceptable on supply systems and which will comply with the criteria laid down for Stage 2.

TABLE A1

MAXIMUM LOAD OF SINGLE-CONVERTOR INSTALLATIONS CORRESPONDING TO HARMONIC CURRENT LIMITS OF TABLE 2

Supply System Voltage (kV) at Point of Common Coupling	Type of Convertor	Permissible kVA Capacity and Corresponding Effective Pulse Number of 3-Phase Installations		
		3-pulse	6-pulse	12-pulse
0.415	Uncontrolled	-	150	300
	Half-controlled	-	65*	-
	Controlled	-	100	150
6.6 and 11	Uncontrolled	400	1000	3000
	Half-controlled	-	500*	-
	Controlled	-	800	1500
33	Uncontrolled	1200	3000	7600
	Half-controlled	-	1200*	-
	Controlled	-	2400	3800
132	Uncontrolled	1800	5200	15000
	Half-controlled	-	2200*	-
	Controlled	-	4700	7500

* See Note iii

Notes

i **Multi-Convertor Installations**

The total installed capacity of convertors, at an installation comprising a number of separate convertors, may be greater than the figures shown if there is diversity in use and/or control. See Section A2.1, "Coincidence Factor", and Table A3.

ii **3-Pulse Convertors**

These are not acceptable at 415 V because they produce direct current in the low voltage network.

iii **Half-Controlled Convertors**

The capacities shown in Table A1 for 6-pulse half-controlled convertors, refer to three-thyristor/three-diode half-controlled bridges.

iv Uncontrolled Convertors

The capacities shown for uncontrolled, that is, free firing, convertors take advantage of the effect of transformer impedance in reducing the harmonic currents to values below the theoretical, infinite load inductance values.

v Accuracy of Control

The maximum loads permitted assume that the accuracy in the timing of the firing pulses is such that they are symmetrically displaced on the three phases, and the commutating voltages at the instant of firing are all identical.

TABLE A2

MAXIMUM LOAD OF SINGLE A.C. REGULATOR INSTALLATIONS CORRESPONDING TO HARMONIC CURRENT LIMITS OF TABLE 2

Supply System Voltage (kV) at Point of Common Coupling	3 Phase		1 Phase
	*6 Thyristor Type (kVA)	3 Diode/3 Thyristor Type (kVA)	*2 Thyristor Full Wave Type (kVA)
0.415	100	85	25 (240 V) 45 (415 V)
6.6 and 11	900	600	-

* Note that these devices may be described as 3-phase or 1-phase Triacs. A Triac simulates a single assembly of two thyristors with a common gate.

A2 TREATMENT OF A NUMBER OF HARMONIC SOURCES

Statistical methods have been proposed for the addition of harmonic currents produced by several non-linear loads connected to the same supply system. Investigations are being made to determine the relation between these calculations and the results of site investigations. Pending the outcome of these investigations, Table A3 may be used to assess the cumulative effects of a number of convertors supplied from the same or different points of common coupling on the same voltage network.

If, however, one source provides more than 60% of the arithmetic total harmonic current, the arithmetic total should be used.

A2.1 Coincidence Factor

Types of equipment and operating conditions are numerous; however present information regarding summation effects only justifies the use of the three broad categories shown in Table A3.

COINCIDENCE FACTORS FOR USE IN SUMMATION OF HARMONIC CURRENTS*

Category	Type and Operating Conditions of a Number of Convertors	Coincidence Factor
1	Uncontrolled convertors (therefore a high probability of phase coincidence at times of peak harmonic production)	0.9
2	Convertors with control of firing angle, operating on daily duty cycles likely to produce maximum rms harmonic currents on numerous occasions each day (therefore a fair probability of coincidence of peak harmonic production of a number of units).	0.75
3	Convertors with control of firing angle, operating independently, intermittently throughout the day, or once started operating continuously for a shift and only producing maximum rms harmonic currents during starting (therefore low probability of coincidence of peak harmonic production and then only for a short time).	0.6 for up to 3 convertors 0.5 for 4 or more convertors

* Note: As stated in Section A2 above, this guide can only be used when no convertor provides more than 60% of the arithmetic total of the harmonic currents being considered. If a convertor does provide more than 60% of the arithmetic total then the arithmetic sum must be used and the Coincidence Factor is therefore 1.

The Coincidence Factors shown in Table A3 for each category may be applied to the arithmetic sum of the maximum rms values of harmonic currents produced by a number of equipments - if Table 2 is being used, or to the maximum loads of the equipments in kVA - if Tables A1 or A2 are being used.

A3 COMPLIANCE WITH STAGE 2 AND STAGE 3 RECOMMENDATIONS

A3.1 Site Measurements

Site measurements may be required before agreeing to the connection of a new consumer with a non-linear load or the connection of additional non-linear loads by an existing consumer. They should be made under the conditions likely to produce the greatest distortion. This will normally be at times of minimum demand on the supply system, with no local generation connected. The types of measurement required depend upon whether a new consumer's application is being considered or an existing consumer wishes to install additional non-linear load. The measurements required are as follows:-

Stage 2 Cases

(a) New Consumer	Voltage distortion measurements to determine that the voltage distortion at the proposed pcc does not exceed 75% of the values of Table 3 and that the consumer may therefore be considered under Stage 2.
(b) Existing Consumer	Voltage distortion measurements as in (a) above. Harmonic current measurements at the pcc to provide information on which to base an estimate of the additional load that can be accepted under Stage 2. (See Section A3.5 "Estimating Harmonic Currents for Stage 2").

Stage 3 Cases

(c) New Consumer	Voltage distortion measurements at the proposed pcc to determine what increase in voltage distortion may be allowed to appear due to the connection of a new non-linear load. Harmonic current measurements may also be required to determine the magnitude and pattern of hourly variation in magnitude and phase of existing harmonic currents in feeders at the proposed pcc (see section A3.6.1, "Estimating Harmonic Voltages and Currents for Stage 3").
(d) Existing Consumer	Voltage distortion measurements and harmonic current measurements in the consumer's feeder or feeders, at the pcc to provide information on which to base an estimate of the additional load that can be accepted under Stage 3 (see Section A3.6.2, "Estimating Harmonic Currents and Voltages for Stage 3").

A3.2 Information Required from Consumer, For Stage 2 and 3 Cases

The consumer should be asked to provide, as appropriate, the following information, some of which he may have to obtain from his equipment supplier:

a New Consumers

i Type and rating of the proposed plant.

ii Rating and point of connection of any power factor correction capacitor or filter bank.

iii Pulse number of convertors, type of a.c. regulators, method of connection (ie type of bridge, full or half-controlled etc) and details of any transformer connections providing phase displacement between individual convertor equipments.

iv Harmonic current production for the whole installation in the form of a table giving:-

maximum rms values of each harmonic current produced at any time, and

the rms values of the harmonic currents produced simultaneously, corresponding to the highest value of total voltage distortion - normally at rated full load.

v Type and duty cycle of plant, in particular the time of day, duration and number of times per hour or day that maximum production of harmonics occurs.

vi Details of any short bursts of harmonics (See Section 9, "Short Duration Harmonics").

b <u>Consumers with Existing Non-Linear Load</u>

i to vi as in (a) for both new and existing plant plus

vii The relative phase displacement of the harmonics produced by the new and existing plant. If this is not possible a statement of the categories into which the sections of the plant fall according to Table A3; alternatively a table of maximum harmonic currents for the complete installation which the consumer undertakes not to exceed and which can be checked by site measuremnets using the Automatic Mains Harmonic Analyser.

A3.3 <u>Information Required by Consumers</u>

The consumer may require the following information:

i The short-circuit level of the Board's system, as seen from the pcc for winter minimum generation conditions. If there is a large variation in the short-circuit level between winter and summer conditions due to the operation of local generation, it is advisable to use the summer minimum plant condition.

ii Details of the existing harmonic voltage distortion at the pcc.

iii In Stage 3 cases, for a new connection, the estimated values of harmonic currents which the new consumer may be allowed to produce at the pcc; or, where an existing consumer wishes to increase his non-linear load, the maximum value of the harmonic currents that he may be allowed to produce with the combination of new and existing loads.

A3.4 <u>System Impedance</u>

The impedance of a supply system as seen from a pcc will depend upon the frequency of the current flowing, the resistance, inductance and capacitance of the system and its connected loads. When considering the effects of harmonic currents produced by a consumer it is seldom possible to obtain sufficient information of the system and load characteristics to carry out an accurate harmonic penetration study. For the purpose of this Recommendation, in the absence of more detailed hence proportional to frequency, and that there are no resonance effects. At 132 kV, sufficient information should be available to permit estimates to be made using computer programs. Particular care is required in dealing with higher order and triplen harmonics. In the latter case transformer winding connections have a major effect and must be carefully represented.

A3.5 Estimating Harmonic Currents for Stage 2

When considering an application by an existing consumer to install additional non-linear load under the Stage 2 procedure it is necessary to estimate jointly with the consumer the harmonic currents that the new load may produce, without the combined existing and new harmonic currents exceeding the permitted values of Table 2. It is then possible for the consumer or his equipment supplier to estimate the permissible harmonic characteristics of the new plant.

This estimate may be made in the following manner, using the results of the site measurements mentioned in Section A3.1 (b) and described in Section A4:-

For each harmonic let:-

I_m = the measured values of harmonic current, (item (b) of Section A3.1)

I_p = the permitted total harmonic current in accordance with Table 2

I_a = the harmonic current that could be accepted under Stage 2 from the new load

k_1 = factor from Table A3 taking account of the consumer's existing and new load

then,

$$I_a = \frac{I_p}{k_1} - I_m \quad \text{A rms}$$

The consumer can then be advised that the combined operation of his new and existing load will be acceptable provided that his total installation does not produce harmonic currents in excess of I_p (from Table 2) of which it is estimated that I_a may be produced by the new load. Measurements should be made during commissioning to ascertain that the value I_p is not exceeded.

Using the above approach to calculate values for I_a which must not be exceeded, use is made of the coincidence factor k_1. Consequently there is a finite probability that the value of I_p will occasionally be exceeded (See Section 10.2, "Automatic Mains Harmonic Analyser". When measurements are made to check the actual values of the currents being produced, it is necessary to bear this possibility in mind, and hence avoid the expense of providing remedial measures dictated by abnormal measurement conditions.

A3.6 Estimating harmonic [illegible]

There are two types of problem under Stage 3, as indicated in Section A3.1 (c) and (d), namely the connection of a new consumer or the consideration of an increase in non-linear load at an existing consumer's installation. The fact that the additional load is being considered under Stage 3 implies that the harmonic currents expected to be produced exceed the Table 2 recommended limits or the voltage distortion at the pcc exceeds 75% of the values in Table 3. An estimate of the effect of the additional load on the system should therefore be made using the best available information and methods of analysis taking account of the actual system impedance/frequency characteristic. However sufficient information may not be available to permit of rigorous calculations and the following approximate method is suggested as a guide. For each harmonic let:-

kV = system voltage at pcc in kV (phase to phase)

n = harmonic number

V_p = permitted harmonic voltage distortion in accordance with Table 3

V_m = measured harmonic voltage distortion - Sections A3.1 (c), A3.1 (d) and A4

V_a = harmonic voltage distortion which could be accepted under Stage 3 due to new load

k_2 = factor from Table A3 taking account of new load and existing distorting loads around the pcc.

F = system short-circuit level at pcc in MVA, see Section A3.3 (i)

then,

$$V_a = \frac{V_p}{k_2} - V_m \quad \%$$

A3.6.1 New Consumer

Firstly, the case of the connection of a new Stage 3 consumer when it is desired to estimate the permissible values of harmonic currents.

In order to convert the values of V_a into harmonic currents let I_a = harmonic current that could be accepted if produced by the new load,

then,

$$I_a = \frac{V_a . 10 . F}{\sqrt{3} . kV . n} \quad \text{A rms}$$

The consumer can then be advised that the new load is acceptable, provided that it does not produce harmonic currents in excess of the caulculated values of I_a and provided that measurements are made after commissioning to show that these values are not exceeded.

A3.6.2 <u>Existing Consumer</u>

In the second case, the connection of additional non-linear load by an existing consumer, it is necessary to estimate the harmonic currents that can be accepted if produced by the combination of new and existing loads. First determine, as in Section A3.6, the harmonic voltage distortion, V_a, which could be accepted under Stage 3 due to the consumer's new load. For this part of the calculation, the factor to be used from Table A3 is that relating to the diversity between the consumer's installation and other installations around the pcc, that is k_2 of Section A3.6.

Then for each harmonic let:

I_c = harmonic current that could be accepted from the combined new and existing load

I_m = measured value of existing harmonic current at pcc (item (d) of Section A3.1)

I_a = harmonic current that could be accepted, under Stage 3, from the new load

k_1 = coincidence factor between the consumer's new load and his existing load - Table A3

then,

$$I_a = \frac{V_a.10.F}{\sqrt{3}.kV.n} \text{ A rms}$$

where V_a has been determined as in A3.6

and,

$$I_c = k_1 (I_m + I_a) \text{ A rms}$$

The consumer can then be advised that the combined operation of his new and existing load will be acceptable provided that his total installation does not produce harmonic currents in excess of this value of I_c. He may also be advised that these values include harmonics of values I_a attributable to the new load. The agreement should be to limit the combined harmonic current production from the whole installation to the values of I_c and measurements should be made after commissioning to ascertain that these values are not exceeded.

In a similar manner to the measurements of I_a and I_p (see last paragraph of Section A 3.5) there is a finite probability that the calculated values of I_c will occasionally be exceeded.

The same caution should be exercised in this case as in the previous one.

A4 MEASUREMENT PROCEDURES

The recording of voltage distortion and current harmonics at an existing or at the position of a future, pcc should preferably be made with the Automatic Mains Harmonic Analyser. There may be instances where this is not suitable because of the very rapid bursts of harmonic current caused by other plant connected near the pcc.

The Automatic Mains Harmonic Analyser or equivalent instrument should be connected to make recordings as follows:-

Measurement Points	Point of Common Coupling a Busbar or equivalent, for voltage b Current transformer in the supply feeder or feeders to the consumer, for currents.
Measurement Duration	At least 24 hours, at a time of the week when the proposed plant would be in operation. System conditions may vary widely during a week; tests should be made under worst conditions. (See Notes 1 and 2 below).
Measurement Time	10 seconds per harmonic
Measurement Repetition	Every 15 min
Measured Harmonics	2, 3, 4, 5, 7, 11, 13, 17, 19th current and voltage. (See Note 3 below).

Note:

1 A knowledge of the method of operation of the new and existing plant and of existing voltage distortion levels may justify recording only during certain hours of the day.

2 Harmonic voltage distortion effects and resonance conditions are usually most pronounced at times of light load.

3 The harmonic currents or voltages recorded may be modified if information is available to indicate which harmonics may be significant. A trial run may assist in selection of harmonics to be recorded.

APPENDIX A

FLICKER SEVERITY MEASUREMENT AND ASSESSMENT

A1 FLICKERMETER OPERATION AND DERIVATION OF P_{st}

Voltage fluctuations can be regarded as an envelope modulating the 50 Hz supply voltage wave, the envelope itself varying in a manner determined by the operation of connected loads. A typical modulated supply voltage for an arc-furnace is shown in Figure A1. The envelope may be conceived as a separate fluctuating voltage which produces the subjective effect of flicker on human subjects.

The flickermeter developed by ECRC was designed to comply with IEC publication 868 which was prepared by an international group of experts, including UK members, under the auspices of the UIE (International Union for Electroheat).

This flickermeter (and simulator) is now commercially available. Its algorithm is designed to accurately model the response of the lamp, eye and brain to voltage fluctuations based on the flicker produced by a 60 watt tungsten filament lamp as a result of these voltage fluctuations. Experience has shown that low wattage tungsten lamps are most likely to cause flicker annoyance problems.

The flickermeter is designed to monitor the supply voltage for a period of up to approximately one week and gives a continuous time series output, which is a measure of flicker visibility. This output is scaled such that one per unit represents marginal flicker visibility to 50% of observers.

In order to convert this time series flicker visibility into a value representing visual severity, the term P_{st} is used based on the analysis of 10 minutes of time series flickermeter data output. This conversion from 10 minutes of time series data to P_{st} is such that a P_{st} value of 1 is obtained for any repeated step disturbance defined by the limit curve given in BS 5406 (for voltage changes less than 3% in magnitude).

The conversion from time series data to P_{st} is a procedure which involves the classification of the 10 minutes of time series data into a cumulative distribution function. The values of $P_{0.1}$, P_1, P_3, P_{10}, and P_{50} are then evaluated which are the time series output levels which are exceeded 0.1%, 1%, 3%, 10% and 50% of the time respectively as shown in Figure A2.

P_{st} is then derived from the following formula:

$$P_{st} = \sqrt{(0.0314\ P_{0.1} + 0.0525\ P_1, + 0.0657\ P_3 + 0.28\ P_{10} + 0.08\ P_{50})}$$

The accuracy of this formula is improved by taking smoothed values of the percentile points as follows:

$$P_{50} = (P_{30} + P_{50} + P_{80})/3$$
$$P_{10} = (P_6 + P_8 + P_{10} + P_{13} + P_{17})/5$$
$$P_3 = (P_{2.2} + P_3 + P_4)/3$$
$$P_1 = (P_{0.7} + P_1 + P_{1.5})/3$$

The 0.3 second memory time constant incorporated in the flickermeter circuit ensures that $P_{0.1}$ cannot change abruptly and no further smoothing is needed.

FIGURE A1 RMS SUPPLY VOLTAGE TO AN ARC - FURNACE

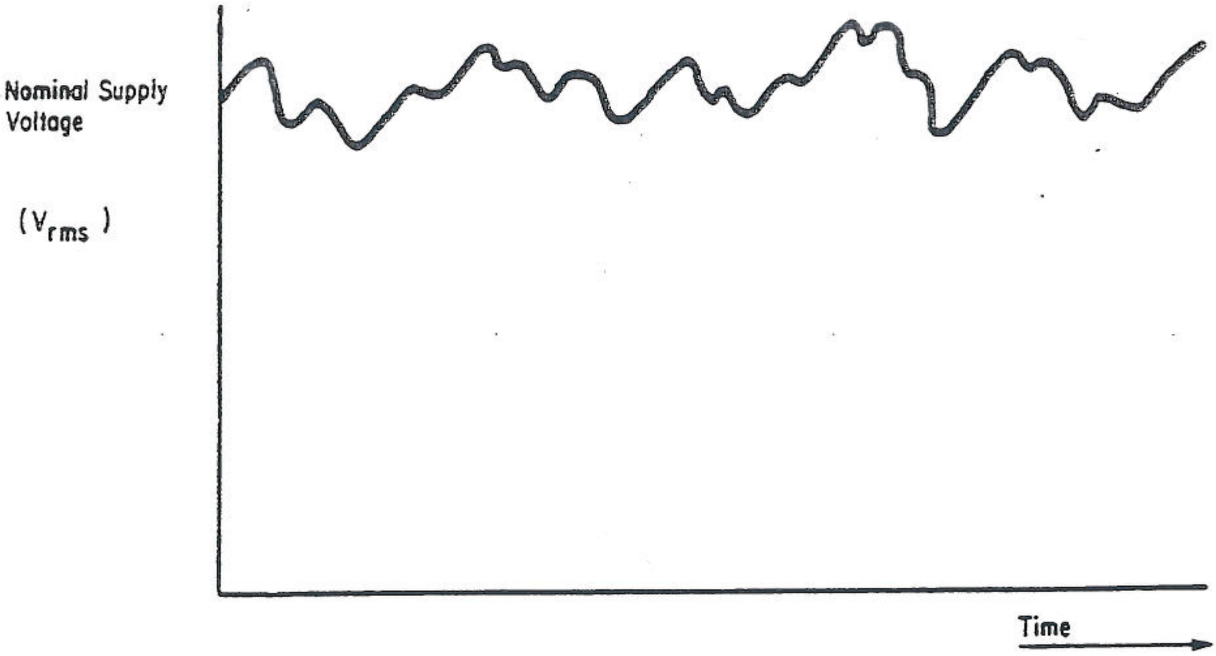
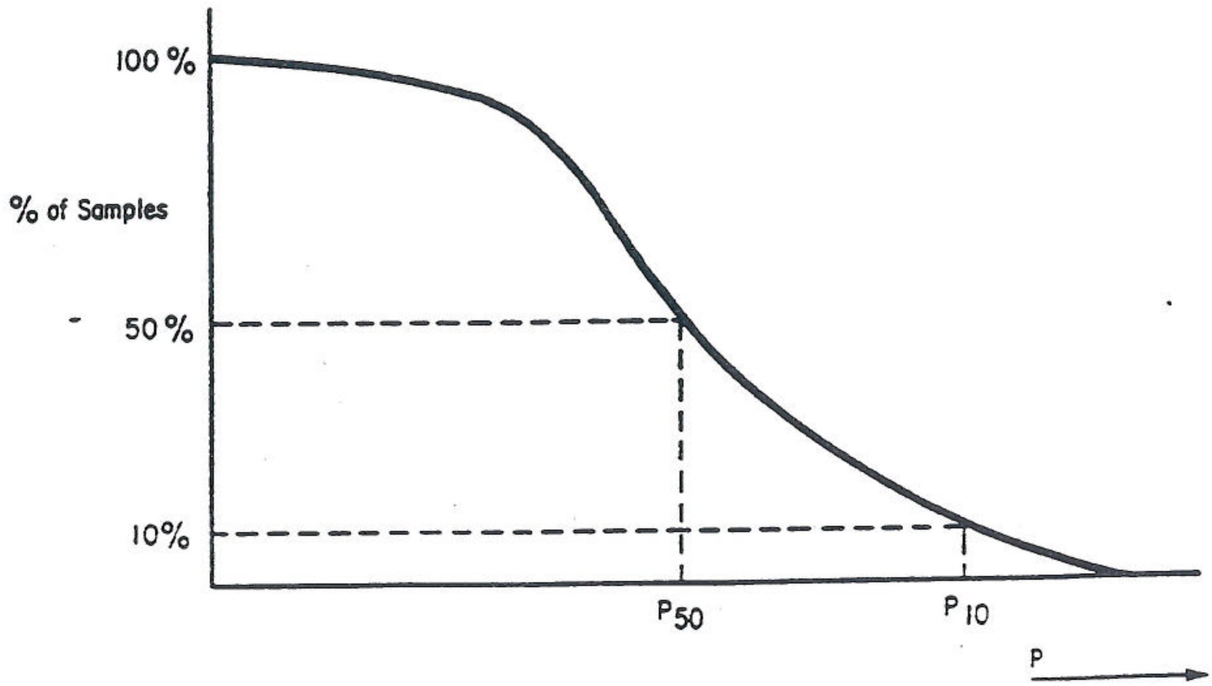


FIGURE A2 CUMULATIVE DISTRIBUTION FUNCTION OF TIME SERIES OUTPUT EVALUATION OF P_{50}, P_{10}, P_3, P_1, $P_{0\cdot1}$



A2 COMBINATION RULES FOR TEN MINUTE SEVERITY VALUES (P_{st})

A2.1 Scaling

P_{st} is a linear quantity with respect to the magnitude of the voltage changes which give rise to it. Thus where P_{st} is known for a piece of equipment at one system location and it is required at another, then the resultant value is given by:

$$P_{st_1} = P_{st_0} \times \frac{V_{D1}}{V_{D0}} \quad \text{(See Figures 1 and 2)}$$

where V_{D0} = magnitude of voltage changes at location where P_{st0} was measured.

V_{D1} = magnitude of the voltage changes caused by the same piece of equipment at the location where P_{st1} is required.

A2.2 Addition of P_{st} from Several Sources

Where full data is available, a simulation of the resultant voltage changes pattern should be undertaken. Where this is not possible, then the following approximate methods may be used.

The general formula for the resultant value of P_{st} for n disturbance sources is.

$$P_{st} = \sqrt[m]{[(P_{st_1})^m + (P_{st_2})^m + \ldots\ldots + (P_{st_n})^m]}$$

The value of m to use depends on the characteristics of the main source of the fluctuation:

m = 4 Used only for the summation of voltage changes due to arc furnaces specifically run to avoid coincident melts.

m = 3 This is used for most types of voltage changes where the risk of coincident voltage changes occurring is small. The vast majority of studies combining unrelated disturbances will fall into this category and it should be used where there is any doubt over the magnitude of the risk of coincident voltage changes occurring.

m = 2 This is used where coincident stochastic noise is likely to occur, e.g coincident melts on arc furnaces.

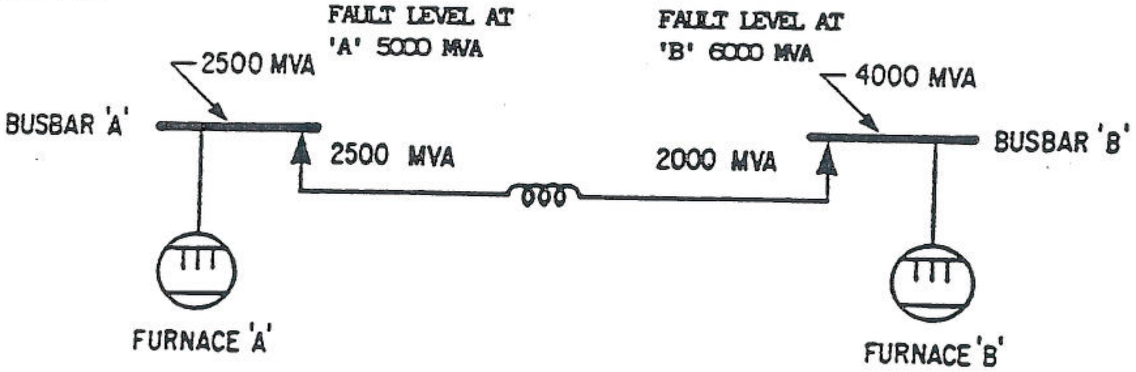
m = 1 The resultant P_{st} will approach the value given by this when there is a very high incidence of coincident voltage changes.

A2.3 Addition of P_{st} from Electrically Distant Busbars.

In cases where it is required to assess the fluctuation effect of a source upon another installation fed from another point on the supply network, it is necessary to allow for the effect of the electrical interconnection before combining the P_{st} values of the separate sources at their own p.c.cs.

An example is given below for 2 arc furnaces located at different busbars:

FIGURE A3



The individual fluctuation-voltage caused at Busbar A by Furnace A is simply based on a local fault level of 5000 MVA. Similarly, the individual fluctuation-voltage caused at Busbar B by Furnace B is based on a local fault level of 6000 MVA.

We shall first assume that we are interested only in Busbar A. We therefore wish to assess the increase in voltage fluctuation caused at A by Furnace B.

Let us assume that the values of P_{st} measured for the two furnaces are:

Caused at Busbar A by Furnace A acting alone:	$P_{st}A$
Caused at Busbar B by Furnace B acting alone:	$P_{st}B$

The procedure is to replace furnace B by an "equivalent furnace" B^1 of a suitably reduced size placed at A.

Then the P_{st} measured at A by B^1 will be:

$$P_{st}B^1 = P_{st}B \times \left[\frac{\text{Fault infeed at B from A}}{\text{Fault level at A - Fault infeed at A from B}}\right]$$

$$= P_{st}B \times \left[\frac{2{,}000}{5{,}000 - 2{,}500}\right]$$

$$= 0.8\ P_{st}B$$

$P_{st}A$ and $P_{st}B^1$ may then be summated as shown in Section A2.2 to give the total effects at A.

The total at B can be similarly calculated.

A2.4 Long Term Severity Value P_{lt}

This is derived from the appropriate values of P_{st} as follows:

$$P_{lt} = \sqrt[3]{\frac{1}{n} \sum_{j=1}^{j=n} P_{st_j}^{3}}$$

Where n = number of short term P_{st} values in the time over which P_{lt} is required.

Two hours (n = 12) is the time over which P_{lt} is normally evaluated.

Note that normally P_{lt} will be measured using the flickermeter although calculation is possible. (See Appendix B, Example 2).

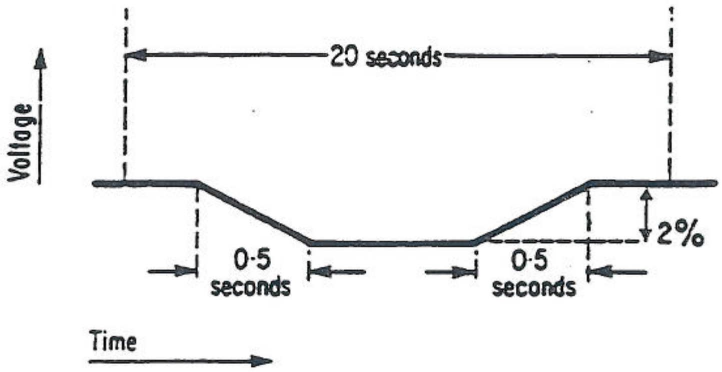
APPENDIX B

EXAMPLES OF STAGE 2 ASSESSMENTS

EXAMPLE 1 - ROLLING MILL LOAD

It is proposed to connect a rolling mill equipped with a Ward-Leonard drive to a supply point where the following voltage change pattern is expected to occur at the point of common coupling with other consumers:

FIGURE B1



As a first step, acceptability is assessed in terms of Stage 2.

From Figure 4, a 2% step change is acceptable every 210 seconds. From Figure 5, a 0.5 second ramp has a multiplication factor of 0.044.

Therefore the minimum allowable time between changes = 210 x 0.044
= 9.2 seconds

The proposed mill will produce, on average, only one voltage change in 10 seconds so it is just acceptable.

An existing 11 kV supply point supplies a large 900 kW induction motor driving a car shredder. The customer has requested the connection of an additional 1500 kW induction motor to drive an additional car shredder.

(a) Characteristics of Existing Supply

Impedance at p.c.c : 37.5 + j82 % on 100 MVA.

(b) Characteristics of Existing Motor

Starting	:	Direct on line, 3.3 MVA at 0.3 power factor once per day.
Running	:	No load to full load power change at 0.9 power factor.

(c) Characteristics of Proposed Motor

This is a scaled version of the existing 900 kW motor. Complex voltage changes occur during running caused by the fluctuating loading of the driving motor so a flickermeter approach has to be used to assess the severity of the flicker likely to be caused. But first, regardless of the flicker severity, it is necessary to check that with normal system connections the voltage changes on starting are within the 3% limit. This initial assessment is done by scaling the characteristics of the existing motor, so:

the starting voltage change for the existing motor is calculated:

$$\text{Voltage Change (\%)} = \frac{3.3}{100}(37.5 \times 0.3 + 82 \times 0.95)$$

$$= 2.94\%$$

In order to calculate the starting voltage change of the proposed motor, the value is scaled from the calculated value of the existing one; therefore:

$$\text{Voltage Change (\%)} = 2.94 \times \frac{1500}{900} = 4.90\%$$

This is unacceptable so the machine cannot be connected to the existing supply without relaxing the normal 3% limit.

(d) Action Taken

With some minor system rearrangements the point of common coupling can be moved to the 11 kV busbar of a two transformer 33/11 kV substation. The normal system impedance at this busbar is:

1.3 + j48.8 % on 100 MVA.

With this supply the proposed motor's starting voltage change becomes:

$$\text{Voltage Change (\%)} = \frac{3.3}{100} \times \frac{1500}{900} \times (1.3 \times 0.3 + 48.8 \times 0.95)$$

$$= 2.57\%$$

(e) Flicker Measurements (see Table 2)

Flickermeter readings were taken for the following conditions:

Test (i) Existing location with 900 kW motor not running (background) (P_{st2}).

Test (ii) Existing location with 900 kW motor starting.

Test (iii) Existing location with 900 kW motor operating normally (P_{st1}).

Test (iv) 33/11 kV substation 11 kV busbar (background) (P_{st6}).

(f) Choice of System Impedance to use in Study

The impedance given in (d) of 1.3 + j48.8 % on 100 MVA is with both 33/11 kV transformers in circuit. An outage of one of these transformers will increase the 11 kV busbar's impedance to 2.5 + j85.6 % on 100 MVA, i.e almost twice that of the normal operating condition. Major transformer faults can take several months to repair and consequently represent a risk of causing extended running with a high system impedance. However, in this case, as operation of the car shredders is mainly during the day when there is no significant use of tungsten filament lighting it was decided to ignore the outage situation and use the normal operating system impedance. However, it should be noted that under these outage conditions the voltage step change on motor starting is about 5.2%.

(g) Choice of Value to Use for "m" in the Summation Formula of Appendix A Section 2

Both the existing motor and the proposed one will operate independently of each other and so the general value, m = 3, is used for the summation of flicker effects. The two motors are not expected to start at exactly the same time, so again, m = 3 can be used for this.

(h) Flicker Effects, Starting

The following ten minute severity values, P_{st}, were obtained for the starting of the existing 900 kW motor on the existing supply (see Table 2):

Starting (including background) $P_{st} = 0.56$ (test (ii))
Typical background readings $P_{st} = 0.3$ (mean value, test (i))

$\therefore$ Starting, 900 kW motor only, $P_{st} = \sqrt[3]{(0.56^3 - 0.3^3)}$
$= 0.53$

To transfer this value to the 11 kV busbar given in (d) it is necessary to determine the ratio of voltage change magnitudes between the two locations.

Existing location, starting voltage changes for existing motor is 2.94% (see (c))

11 kV busbar starting voltage change would be

$$\text{Voltage Change (\%)} = \frac{3.3}{100}(1.3 \times 0.3 + 48.8 \times 0.95) = 1.54$$

Therefore at the 11 kV busbar, on starting, the 900 kW motor would cause a severity of:

$$0.53 \times \frac{1.54}{2.94} = 0.28 \quad (P_{st}\ 7)\ \text{Table 2)}$$

The proposed 1500 kW motor is a scaled version of the existing 900 kW one, so this will cause a severity value of:

$$0.28 \times \frac{1500}{900} = 0.47 \quad (P_{st}\ 8)\ \text{Table 2)}$$

(i) <u>Flicker Effects, Normal Running (see Table 2)</u>

(A) <u>900 kW motor</u>

To determine the flicker effects of the 900 kW motor on its own it is necessary to subtract the effects of background disturbances (test a) from the combined reading of motor and background (test c).

This result gives the effects of the 900 kW motor only at the existing location. To translate the effects to the 11 kV busbar proposed in (d) it is necessary to scale the severity values for the ratio of the magnitude of the voltage changes at the two locations. As power swings during running occur at 0.9 power factor then this ratio is:

$$\text{Ratio} = \frac{(1.3 \times 0.9 + 48.8 \times 0.44)}{(37.5 \times 0.9 + 82 \times 0.44)} = 0.32$$

(B) <u>Proposed 1500 kW motor</u>

This is a scaled version of the 900 kW motor so its likely severity values are those of the smaller motor multiplied by (1500/900).

(C) <u>Summation of effects at the 11 kV busbar</u>

The total severity is obtained by summating the background severity at the 11 kV busbar (test d) and that from the two motors. In addition, to cover for the motors starting at the beginning of a day, the first severity value should also include the starting severity values of the two motors.

The long term severity value, P_{lt}, is derived from the summated P_{st} values using the formula in Appendix A2.4.

(j) <u>Summary</u>

(a) The starting voltage change of the proposed 1500 kW motor at the 11 kV busbar of the 33/11 kV substation of 2.6% is acceptable.

(b) The transfer of the existing motor and the connection of the proposed 1500 kW motor to this 11 kV busbar will lead to the following flicker severity values:

$$P_{st} \text{ (MAXIMUM)} = 0.75$$
$$P_{lt} = 0.59$$

Both of these values are within the limits of Table 1 and so this proposal is acceptable.

TABLE 2. FLICKER MEASUREMENTS FOR EXAMPLE 2
FLICKER EFFECTS, NORMAL RUNNING

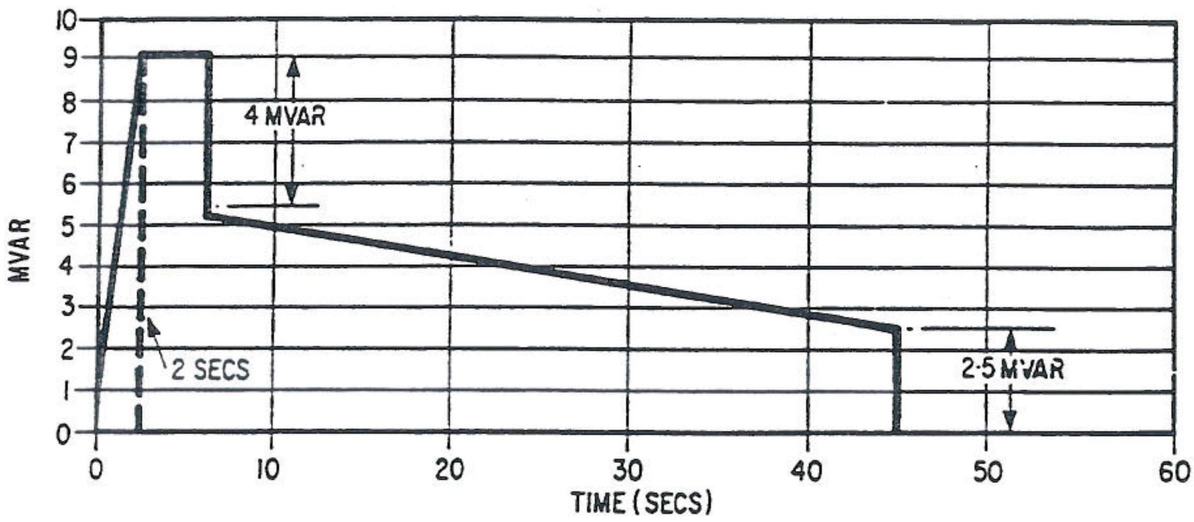
	CONSECUTIVE SHORT TERM SEVERITY VALUES, P_{st} TAKEN OVER 2 HOURS											
Test (iii), 900 kW motor & background (P_{st_1})	.54	.78	.81	.84	.87	.84	.81	.75	.75	.81	.81	.66
Test (i), background (P_{st_2})	.27	.27	.24	.48	.48	.27	.24	.27	.27	.24	.27	.30
900 kW motor, $\sqrt[3]{(P_{st_1}^3 - P_{st_2}^3)}$, ($P_{st_3}$)	.52	.77	.80	.78	.82	.83	.80	.74	.74	.80	.80	.64
900 kW motor scaled for alternative location, P_{st_3} x 0.32 (P_{st_4})	.17	.25	.26	.25	.26	.27	.26	.24	.24	.26	.26	.21
1500 kW motor, P_{st_4} x (1500/900) (P_{st_5})	.28	.41	.43	.42	.44	.45	.43	.40	.40	.43	.43	.34
Test (iv), background (P_{st_6})	.24	.24	.69	.69	.45	.48	.36	.24	.36	.36	.21	.66
900 kW motor starting (P_{st_7})	.28											
1500 kW motor starting (P_{st_8})	.47											
SUMMATION, $\sqrt[3]{\sum_{n=4}^{n=8} P_{st_n}^3}$ (P_{st_9})	.55	.46	.75	.75	.58	.60	.53	.45	.50	.53	.47	.70

$$P_{1t} = \sqrt[3]{\frac{1}{12} \sum_{1}^{12} (P_{st})^3} = 0.59$$

EXAMPLE 3 - STUDY OF PROPOSED MULTIPLE MINE WINDER LOAD

In this example there was a proposal to install three 5 MW mine winders connected to a supply with a 400 MVA fault level at the p.c.c. The profile of the winder reactive power levels is given in Figure B2 below. The question was how the operation of the three winders together with similar but not identical cycle times of approximately 60 seconds affected the flicker.

FIGURE B2



The voltage changes are approximately proportional to the reactive power profile with 4 MVAr equal to 1% volt change. It is seen from Figure B2 that ramp times greater than about 1 second have a small effect compared to step changes of a similar size. The flicker from the winders will therefore be predominately caused by the 4 MVAr change at 6 seconds after switch on and to a lesser extent by the smaller step reactive power change of 2.5 MVAr at switch off.

Thus, if there is only one mine winder the P_{st} (assuming that the largest step causes a 1% voltage change at the point of common coupling) for a repetition rate of 60 seconds can be derived from Figure 4.

From Figure 4 for a 60 second repetition rate, $P_{st} = 0.5$, the maximum voltage change is 1.35%.

Therefore for a 1% voltage change $P_{st} = 0.5 \times \frac{1}{1.35} = 0.37$

and for a .63% voltage change $P_{st} = 0.37 \times 0.63 = 0.23$

The combined P_{st} for both step changes $= \sqrt[3]{.37^3 + .23^3}$

$= .40$

(As P_{st} is directly proportional to the size of the voltage change, then it is easily calculated for other p.c.c with different voltage changes.)

If it is assumed that the operation of the winders is uncorrelated the flicker effects from more than one winder can also be obtained by application of the cube root law, i.e for 3 winders, $P_{st} = \sqrt[3]{(3 \times 0.40^3)} = 0.58$. This ignores the more severe flicker which would result from the coincidence of steps from different winders. Studies have shown that the coincidence of the step changes would have to be closer than 0.1 seconds to have a pronounced flicker effect. The frequency of two steps coinciding within 0.1 seconds with three winders in operation having a cycle time of sixty seconds each is about one an hour and the coincidence of three winder steps is about once a fortnight.

It is also interesting to note that if the steps do not occur within say half to one second of each other then a flicker meter assessment would give a result for P_{st} based on mean frequency of occurrence regardless of whether the step changes are regular or random.

It is seen from this analysis that the proposed winder installation would not be acceptable with a P_{st} maximum of 0.58 under Stage 2 and a Stage 3 approach would be necessary.

Another method to assess this problem is to use the "memory time" technique of 6.2.2. Again the two ramp type changes have a negligible effect on flicker since both rise (or fall) times exceed 1 second.

From Figure 4, the step change of 4 MVar at 6 seconds into the cycle and with a magnitude of 1% would be allowed every 23 seconds for a P_{st} of 0.5. The step change of 2.5 MVar at 45 seconds into the cycle with a magnitude of 1% x 2.5/4 = 0.63% would be allowed every 5 seconds. The total "memory time" is therefore 23 + 5 = 28 seconds.

For three such machines with a mean cycle time of 63 seconds, the memory time will be 3 x 28 = 84 seconds. This is in excess of the 63 seconds cycle time and so the connection of these machines is not acceptable under Stage 2.

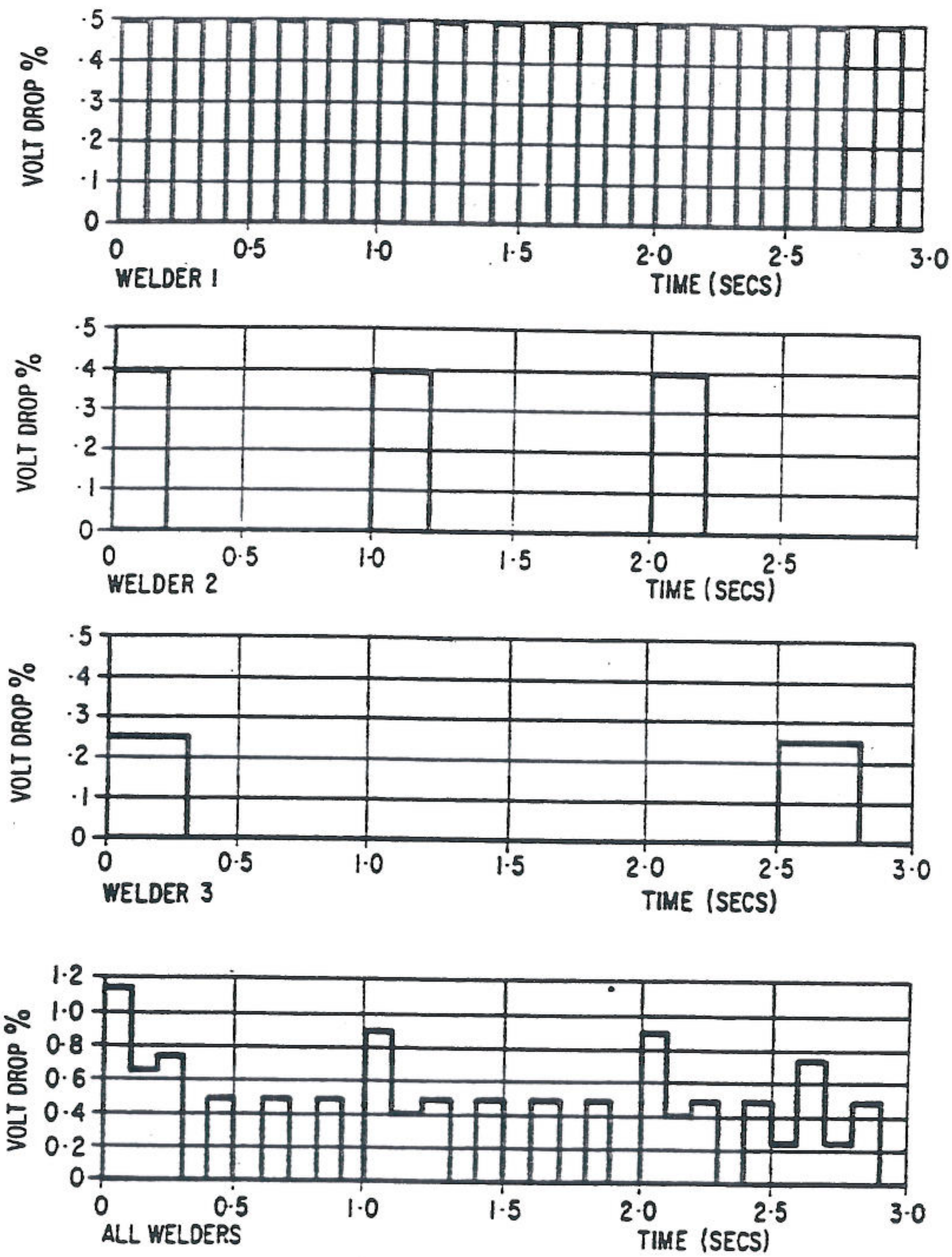
EXAMPLE 4 - MULTIPLE SPOT WELDER LOAD

A manufacturer wishes to install a spot welder load. This load consists of three spot welders having cycle repetition time of 0.2, 1 and 2.5 seconds respectively. The welders give voltage drops of 0.5, 0.4 and 0.25 volts respectively at the p.c.c and have dwell times of 0.1, 0.2 and 0.3 seconds. The waveforms of the three welders are shown in Figure B3.

The severity value of each welder on its own could be evaluated using Figure 4, as shown in Example 3, and then summated using the techniques of Appendix A. However, as voltage changes are occurring at less than .1 second intervals the risk of co-incident voltage changes is very high and it is not clear which value of "m" to use in the summation formula. It is much better in this case to use the flickermeter simulator program to evaluate all three welders working together.

The waveform analysed assumed maximum co-incidence of voltage changes and had a severity value $P_{st} = 1.48$. A slightly lower value would be obtained if the voltage changes were not exactly co-incident (minimum 1.42).

FIGURE B3



VOLT DROP %
·5
·4
·3
·2
·1
0
0
0·5
1·0
1·5
2·0
2·5
3·0
WELDER 1
TIME (SECS)
VOLT DROP %
·5
·4
·3
·2
·1
0
0
0·5
1·0
1·5
2·0
2·5
WELDER 2
TIME (SECS)
VOLT DROP %
·5
·4
·3
·2
·1
0
0
0·5
1·0
1·5
2·0
2·5
3·0
WELDER 3
TIME (SECS)
VOLT DROP %
1·2
1·0
0·8
0·6
0·4
0·2
0
0
0·5
1·0
1·5
2·0
2·5
3·0
ALL WELDERS
TIME (SECS)

APPENDIX C

EXAMPLES OF THE CALCULATIONS REQUIRED TO DETERMINE THE VOLTAGE FLUCTUATIONS CAUSED BY LOADS WITH P.C.C AT LV

C1 INTRODUCTION

The worked examples contained in this section demonstrate how the system data contained in Appendix D may be used to calculate a voltage drop or alternately the maximum current for a particular load connected to the l.v. system.

C2 CALCULATION OF SYSTEM IMPEDANCES

C2.1 3-Phase 415 V Equipment

The maximum permissible load can be calculated directly from the data in Appendix D as shown in Example 5.

C2.2 240 Volts Equipment

Care must be taken when assessing the impedance seen by the load in this case. As current will flow in 2-phases of the hv system, an impedance must be inserted for the "return" path as well as the "go" path as shown in Example 6. The hv impedance data given in Appendix D are based on a lv system voltage of 415 volts and this must be corrected to a 240 volt system as shown in Example 6.

No correction is needed for the transformer data given in Appendix D since this will already be in the correct system voltage.

The lv path must also include an impedance for the "return" neutral path as well as the "go" phase path. The impedance of this netural path is usually taken as the same as the "go" phase path.

However, because the neutral is concentric in CNE cables, the equivalent neutral impedance is significantly different from that of a phase conductor. Table D8(b) gives an "equivalent for neutral conductor" impedance for the common CNE cables.

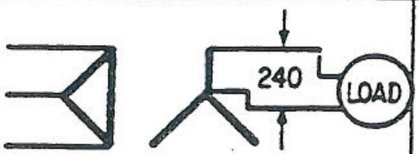
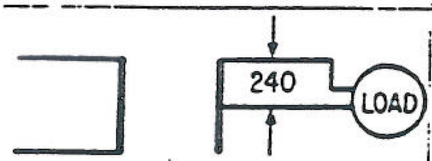
C2.3 480 Volts Loads

The assessment of impedance is subject to similar corrections to that of 240 volts loads with regard to "go" and "return" paths as shown in Example 7.

The hv impedance must be corrected to a 480 volts system as shown in Example 7.

The above are exemplified in tabular form (Table C1).

CALCULATION OF SYSTEM IMPEDANCES FOR USE IN VOLTAGE FLUCTUATION STUDIES

System	Correction for H.V. System Impedance	Transformer Impedance To Use	Correction for L.V. System Impedance
	None	3-phase in 415 V system and 240 V system	None
	x $(240/415)^2$ "Go" and "Return" paths required	3-phase in 415 V system and 240 V system	"Go" and "Return" paths required *
	x $(480/415)^2$ "Go" and "Return" paths required	Single-phase 3-wire in 480-V system	"Go" and "Return" paths required
	x $(240/415)^2$ "Go" and "Return" paths required	Single-phase 3-wire in 240-V system	"Go" and "Return" paths required
	x $(240/415)^2$ "Go" and "Return" paths required	Single-phase 2-wire in 240 V system 3-wire transformer with links arranged for 2-wire output	"Go" and "Return" paths required
	x $(240/415)^2$ "Go" and "Return" paths required	Single-phase 2-wire in 240 V system	"Go" and "Return" paths required

* When C.N.E. lv cables are involved, for the concentric "return" neutral conductor use the impedances given in Table D8(b) "Equivalent for neutral conductor".

C3. EXAMPLES

EXAMPLE 5: 3-phase 415 V Load

(a)	Fault level at primary substation	150 MVA
(b)	Primary substation to distribution substation	1000 metres 185 mm^2 11 kV cable (aluminium conductor)
(c)	Distribution substation transformer	11 000/433V 500 kVA
(d)	Distribution substation to the point of common coupling	500 metres 185 mm^2 WAVEFORM l.v. cable

	415 V Equivalent Resistance (ohms)	415 V Equivalent Reactance (ohms)
Source to 11 kV busbar of primary substation (Appendix D: Table D1)	-	0.0013
11 kV cable (Appendix D: Table D2)	0.00025	0.00012
Transformer (Appendix D: Table D6)	0.00509	0.0171
L.V. cable (Appendix D: Table D8(a)	0.082	0.037
TOTAL	0.08734	0.05552

Assume a load power factor of 0.3 lag, the voltage drop per ampere of load current will be:

$$(0.3 * 0.0873) + (0.954 * 0.0555)$$

$$= 0.0262 + 0.0529$$

= 0.0791 volts per ampere of load current

(a)	Fault level at primary substation	100 MVA
(b)	Primary substation to distribution substation	1000 metres 70 mm^2 11 kV overhead line (copper conductors)
(c)	Distribution substation transformer	2-wire, 11 000/250V 15 kVA
(d)	Distribution substation to the point of common coupling	100 metres 70 mm^2 overhead line (copper conductor)

	415 V Equivalent Resistance (ohms)	415 V Equivalent Reactance (ohms)	Adjustment Factor For Voltage $(240/415)^2$	240 V Equivalent Resistance (ohms)	240 V Equivalent Reactance (ohms)
Source to busbar of primary substation (Appendix D: Table D1) "go" path "return" path	 0 0	 0.0019 0.0019	 x 0.33 x 0.33	 0 0	 0.00063 0.00063
11 kV line (Appendix D: Table D4) "go" path "return" path	 0.0004 0.0004	 0.00057 0.00057	 x 0.33 x 0.33	 0.00013 0.00013	 0.00019 0.00019
Transformer (Appendix D: Table D6)	-	-	-	0.118	0.146
L.V. overhead line (Appendix D: Table D9) **"go" path** **"return" path**	 0.0259 0.0259	 0.0289 0.0289	 - -	 0.0259 0.0259	 0.0289 0.0289
TOTAL				0.17006	0.20544

Assume a load power factor of 0.3 the voltage drop per ampere of starting current will be:

$$(0.3 * 0.170) + (0.954 * 0.205) \quad \text{volts}$$

$$= 0.051 + 0.196$$

= 0.246 volts per ampere of load current

(a)	Fault level at primary substation	200 MVA
(b)	Primary substation to distribution substation	1000 metres 100 mm^2 ACSRV overhead line
(c)	Distribution substation transformer	11000/500V 25 kVA
(d)	Distribution substation to the point of common coupling	100 metres 70 mm^2 CONSAC cable

	415 V Equivalent Resistance (ohms)	415 V Equivalent Reactance (ohms)	Adjustment Factor of Voltage $(480/415)^2$	480 V Equivalent Resistance (ohms)	480 V Equivalent Reactance (ohms)
Source to busbar of primary substation (Appendix D: Table D1)					
"go" path	0	0.00094	x 1.34	0	0.0013
"return" path	0	0.00094	x 1.34	0	0.0013
11 kV line (Appendix D: Table D4)					
"go"	0.00042	0.00059	x 1.34	0.00056	0.00079
"return"	0.00042	0.00059	x 1.34	0.00056	0.00079
Transformer (Appendix D: Table D6)	-	-	-	0.233	0.365
L.V. cable (Appendix D: Table D8(a))					
"go" phase path	0.0443	0.00705	-	0.0443	0.00705
"return" phase path	0.0443	0.00705	-	0.0443	0.00705
TOTAL				0.32272	0.38328

Assume a load power factor of 0.3 the voltage drop per ampere of load current will be:

$$(0.3 * 0.323) + (0.954 * 0.383) \quad \text{volts}$$

$$= 0.0962 + 0.3654$$

$$= 0.462 \text{ volts per ampere of load current}$$

APPENDIX D

SYSTEM DATA IN THE FORM OF OHMIC VALUES TO AN LV BASE

S Sources of System Data contained in Tables D1 to D9.

D1 H.V. OVERHEAD LINES

D1.1 Resistance values are at 20°C derived from BS 125 (1970) and BS 215 (1970).

D1.2 Reactance is given for a BS 1320 type of construction with 3 feet 6 inch conductor spacing. However, the values are sufficiently accurate in this context for 2 feet 6 inch spacing BS 1320 lines, light lines to ESI Standard 43-10 and heavy lines to ESI Standard 43-20.

D1.3 The transformer ratio used for referring values to a 415 v system was 11 000/433 or 6600/433.

D2 H.V. CABLES

D2.1 Resistance values are at 20°C.

D2.2 Equivalent star reactances are derived from the following:

(a) CE Specification C2 (1955)

(b) BEB Specification C6 (1960)

(c) Engineering Recommendation C67 (1970).

D2.3 The transformer ratio used for referring values to a 415 v system was 11 000/433 or 6600/433.

D3 L.V. OVERHEAD LINES

D3.1 Resistance values are at 20°C derived from BS 125 (1970) and BS 215 (1970).

D3.2 Reactance values are given for a BEB Specification L1 (1962) construction with 12 inch conductor spacing and are equivalent star reactances for a 3-phase load. For this application, these values are still sufficiently accurate for lines with 9 inch conductor spacing.

D3.3 When carrying single-phase loads and for single-phase lines, the reactance varies depending on the spacing of the conductors in use. However, for the application of motor starting calculations the 3-phase values are considered sufficiently accurate.

D4 L.V. CABLES

D4.1 Resistance values are at 20°C.

D4.2 Equivalent star reactances were derived from the following:

(a) CE Specification C2 (1955)

(b) BEB Specification C6 (1960)

(c) Engineering Recommendation C67 (1970)

(d) ESI Standard 09-8

(e) ESI Standard 09-9

D4.3 "Districable" impedances were derived from manufacturers' data.

D4.4 Neutral characteristics of "CONSAC" and "WAVEFORM" were derived from manufacturers' data.

D5 TRANSFORMERS

D5.1 All values have been referred to the nominal secondary voltages of 433, 500 or 250 as appropriate.

D5.2 Impedances are those applicable to typical transformers which comply with BEB Specification T1 (1958) at nominal tap. Although losses are no longer specified in ESI Standard 35-1 (1970) manufacturers have little scope to deviate significantly from the losses of BEB Specification T1 (1958) and the given values are considered sufficiently accurate to also apply to these.

D5.3 The impedances given for 3-wire transformers are measured values of typical units.

TABLE D1

IMPEDANCE BETWEEN SUPPLY SOURCE AND
LOWER VOLTAGE BUSBARS OF PRIMARY SUBSTATION

Fault Level at 6.6 kV or 11 kV Busbar of Primary Substation (MVA)	Equivalent Impedance Per Phase in 415 V System	
	Resistance (ohms)	Reactance (ohms)
250	0	0.00075
200	0	0.00094
150	0	0.0013
100	0	0.0019
75	0	0.0025
50	0	0.0038
25	0	0.0075

TABLE D2

IMPEDANCE OF 11 kV CABLES REFERRED TO 415 V SYSTEM

Size Imperial - ($inch^2$) Metric - (mm^2)	Resistance Per Phase Conductor (ohms/1000 m) — Conductor Material: Copper	Resistance Per Phase Conductor (ohms/1000 m) — Conductor Material: Aluminium	Reactance Per Phase Conductor (ohms/1000 m)
Imperial			
0.0225	0.0019	0.0032	0.00018
0.04	0.0011	0.0018	0.00016
0.06	0.00072	0.0012	0.00015
0.1	0.00043	0.0071	0.00014
0.15	0.00029	0.00048	0.00013
0.2	0.00022	0.00036	0.00013
0.25	0.00018	0.00029	0.00012
0.3	0.00014	0.00024	0.00012
0.4	0.00011	0.00018	0.00012
0.5	0.000086	0.00014	0.00012
Metric			
95	0.00031	0.00050	0.00014
150	0.00019	0.00032	0.00013
185	0.00015	0.00025	0.00012
240	0.00012	0.00019	0.00012
300	0.000093	0.00016	0.00012

TABLE D3

IMPEDANCE OF 6.6 kV CABLES REFERRED TO 415 V SYSTEM

Size Imperial - ($inch^2$) Metric - (mm^2)	Resistance Per Phase Conductor (ohms/1000 m)		Reactance Per Phase Conductor (ohms/1000 m)
	Conductor Material		
	Copper	Aluminium	
Imperial			
0.0225	0.0054	0.0089	0.00049
0.04	0.0030	0.0050	0.00054
0.06	0.0020	0.0033	0.00041
0.1	0.0012	0.0020	0.00039
0.15	0.00081	0.0013	0.00036
0.2	0.00061	0.0010	0.00035
0.25	0.00049	0.00080	0.00034
0.3	0.00040	0.00066	0.00033
0.4	0.00030	0.00049	0.00033
0.5	0.00024	0.00040	0.00032
Metric			
95	0.00086	0.0014	0.00037
150	0.00053	0.00087	0.00036
185	0.00043	0.00071	0.00035
240	0.00033	0.00054	0.00034
300	0.00026	0.00043	0.00033

TABLE D4

IMPEDANCE OF 11 kV OVERHEAD LINES
REFERRED TO 415 V SYSTEM

Size mm^2 ($inch^2$ Copper Equivalent)		Resistance per Phase Conductor (ohms/1000 m)	Reactance per Phase Conductor (ohms/1000 m)
12 (0.017)	Cadmium Copper	0.0027	0.00067
16 (0.025)	Copper	0.0015	0.00066
32 (0.05)	Copper	0.00084	0.00063
50 (0.075)	Copper	0.00053	0.00059
70 (0.1)	Copper	0.00040	0.00057
100 (0.15)	Copper	0.00027	0.00055
50 (0.05)	Al. Alloy	0.00085	0.00058
25 (0.025)	ACSR	0.0017	0.00067
40 (0.04)	ACSR	0.0010	0.00063
50 (0.05)	ACSR	0.00084	0.00061
100 (0.1)	ACSR	0.00042	0.00059
150 (0.15)	ACSR	0.00028	0.00052
175 (0.175)	ACSR	0.00024	0.00051
200 (0.2)	ACSR	0.00021	0.00051

TABLE D5

IMPEDANCE OF 6.6 kV OVERHEAD LINES
REFERRED TO 415 V SYSTEM

Size mm^2 ($inch^2$ Copper Equivalent)		Resistance per Phase Conductor (ohms/1000 m)	Reactance per Phase Conductor (ohms/1000 m)
12 (0.017)	Cadmium Copper	0.0075	0.0019
16 (0.025)	Copper	0.0043	0.0018
32 (0.05)	Copper	0.0023	0.0017
50 (0.075)	Copper	0.0015	0.0016
70 (0.1)	Copper	0.0011	0.0016
100 (0.15)	Copper	0.00076	0.0015
50 (0.05)	Al. Alloy	0.0024	0.0016
25 (0.025)	ACSR	0.0047	0.0019
40 (0.04)	ACSR	0.0029	0.0018
50 (0.05)	ACSR	0.0023	0.0017
100 (0.1)	ACSR	0.0012	0.0016
150 (0.15)	ACSR	0.00078	0.0014
175 (0.175)	ACSR	0.00067	0.0014
200 (0.2)	ACSR	0.00059	0.0014

IMPEDANCE OF DISTRIBUTION TRANSFORMERS REFERRED TO 415 V, 480 V or 240 V SYSTEMS AS APPROPRIATE

Transformer		Resistance per Phase	Reactance per Phase
Type	Rating (kVA)	(ohms)	(ohms)
Single phase 2-wire in 240 V System	5	0.430	0.362
	10	0.191	0.206
	15	0.118	0.146
	16	0.108	0.139
	25	0.0612	0.0944
	25*	0.0570	0.0920
	50	0.0266	0.0496
	50*	0.0270	0.0497
Single-phase 3-wire in 240 V System	25	0.0853	0.0943
	50	0.0393	0.0513
	100	0.0165	0.0255
Single-phase 3-wire in 480 V System	25	0.233	0.365
	50	0.109	0.195
	100	0.0445	0.102
3-phase in 415 V System and 240 V System	25	0.208	0.266
	50	0.0876	0.144
	100	0.0371	0.0810
	200	0.0158	0.0406
	300	0.00948	0.0281
	315	0.00901	0.0268
	500	0.00509	0.0171
	750	0.00313	0.0115
	800	0.00291	0.0107
	1000	0.00219	0.00863

* 3-wire Transformer with links arranged for 2-wire output.

TABLE D7

IMPEDANCE OF PAPER INSULATED LEAD COVERED L.V. CABLES

Size Imperial - ($inch^2$) Metric - (mm^2)	Resistance Per Phase Conductor (ohms/1000 m)		Reactance Per Phase Conductor (ohms/1000 m)
	Conductor Material		
	Copper	Aluminium	
Imperial			
0.0225	1.26	2.08	0.0864
0.04	0.702	1.16	0.0787
0.06	0.464	0.767	0.0755
0.1	0.276	0.456	0.0733
0.15	0.188	0.312	0.0700
0.2	0.142	0.234	0.0689
0.25	0.113	0.187	0.0689
0.3	0.0920	0.152	0.0678
0.4	0.0684	0.113	0.0678
0.5	0.0558	0.0923	0.0667
Metric			
16	1.15	1.91	0.0805
25	0.673	1.20	0.0790
35	0.524	0.868	0.0745
70	0.268	0.443	0.0710
95	0.199	0.320	0.0700
120	0.153	0.253	0.0680
185	0.0991	0.164	0.0680
300	0.0601	0.100	0.0670

TABLE D8(a)

IMPEDANCE OF ALUMINIUM C.N.E. L.V. CABLES - PHASE CONDUCTORS

Cable Size mm^2	Resistance per Phase Conductor (ohms/1000 m)	Reactance per Phase Conductor (ohms/1000 m)		
		Consac	Waveform	Districable
70	0.443	0.0705	0.0755	0.0755
95	0.320	0.0690	0.0735	0.0735
120	0.253	0.0685	0.0730	0.0730
150	0.206	0.0685	0.0740	0.0740
185	0.164	0.0685	0.0740	0.0740
240	0.125	0.0680	0.0730	0.0730
300	0.100	0.0675	0.0725	0.0725

TABLE D8(b)

IMPEDANCE OF ALUMINIUM C.N.E. L.V. CABLES - EQUIVALENT FOR NEUTRAL CONDUCTOR

Cable Size mm^2	Consac		Waveform		Districable	
	R (ohms/1000m)	X (ohms/1000m)	R (ohms/1000m)	X (ohms/1000m)	R (ohms/1000m)	X (ohms/1000m)
70	0.386	0.0105	0.443	0.0152	0.443	0.0755
95	0.310	0.0093	0.320	0.0155	0.320	0.0735
120	0.242	0.0088	0.253	0.0153	0.253	0.0730
150	0.206	0.0085	0.206	0.0150	0.206	0.0740
185	0.164	0.0078	0.164	0.0140	0.164	0.0740
240	0.125	0.0086	0.164	0.0123	0.164	0.0730
300	0.100	0.0082	0.164	0.0108	0.164	0.0725

TABLE D9

IMPEDANCE OF L.V. OVERHEAD LINES

Size mm^2 ($inch^2$ Copper Equivalent)		Resistance (ohms/1000 m)	Reactance (ohms/1000 m)
16 (0.025)	Copper	1.08	0.347
32 (0.05)	"	0.541	0.325
70 (0.1)	"	0.259	0.289
100 (0.15)	"	0.176	0.278
22 (0.0225	Aluminium	1.23	0.323
50 (0.05)	"	0.542	0.297
100 (0.1)	"	0.270	0.276
150 (0.15)	"	0.183	0.260

REFERENCES

1.	BS 125	:	Specification for Hard-drawn Copper and Copper-cadmium Conductors for Overhead Power Transmission Purposes.
2.	BS 215	:	Specification for Aluminium Conductors and Aluminium Conductors, Steel-reinforced, for Overhead Power Transmission.
3.	BS 1320	:	High Voltage Overhead Lines on Wood Poles for Line Voltages up to and including 11 kV with Conductors Not Exceeding 0.05 sq in. (Withdrawn November 1977)
4.	ESI Standard 09-8	:	Impregnated Paper Insulated 600/1000 V Cable with Three Solid Aluminium Phase Conductors and Aluminium Sheath/Neutral Conductor (CONSAC).
5.	ESI Standard 09-9	:	Polymeric Insulated, Combined Neutral/Earth (CNE) Cables with Solid Aluminium Phase Conductors and Concentric Aluminium Wire Waveform Neutral/Earth Conductor.
6.	ESI Standard 35-1	:	Distribution Transformers (from 16 kVA to 1000 kVA).
7.	ESI Standard 43-10	:	11 kV Single Circuit Overhead Lines of Light Construction on Wood Poles. (Withdrawn November 1988)
8.	ESI Standard 43-20	:	11 kV and 33 kV Single Circuit Overhead Lines of Heavy Construction on Wood Poles. (Withdrawn November 1988)
9.	CE Specification C2 (1955)	:	Impregnated Paper Insulated solid Type Lead or Lead Alloy Sheathed Power Cables for Voltages up to and including 22 kV. (Withdrawn 1973)
10.	BEB Specification C6 (1960)	:	Impregnated Paper Insulated Solid Type Lead or Lead Alloy Sheathed Power Cables having Aluminium Conductors for Voltages up to and including 22 kV. (Withdrawn 1973).
11.	BEB Specification L1 (1962)	:	Medium and Low Voltage Overhead Lines on Wood Poles. (Withdrawn June 1978)
12.	BEB Specification T.1 (1958)	:	Transformers from 5 kVA to 1000 kVA for Use on Standard 415 V and 240 V Systems. (Withdrawn 1973)

REFERENCES (Cont'd)

13	UIE (1986) Disturbances Working Group	:	Flicker Measurement and Evaluation.
14	UIE (1988) Disturbances Working Group	:	Connection of Fluctuating Loads
15	IEC 725 (1981)	:	Considerations on reference impedances for use in determining the disturbance characteristics of household and similar electrical equipment.
16	IEC 868 (1985)	:	Flickermeter Functional and Design Specifications.
17	IEC 555 (1982) (in three parts)	:	Disturbances in supply systems caused by household appliances and similar equipment.
18	CENELEC EN 60.555	:	Equivalent to IEC 555.
19	BSI, BS5406 (1988) (in three parts)	:	Equivalent to EN 60.555. Disturbances in supply systems caused by household appliances and similar equipment.
20	The Electricity Council Report ACE 7 1963	:	Supply to Welding Plant (Associated with ER P9)
21	The Electricity Council Report ACE 4 (1961)	:	Supply to Collier Winders and Rolling Mills (Associated with ER P8)
22	The Electricity Council Report ACE 26 (1970)	:	Supply to Arc Furnaces (Associated with ER 7/2)
23	The Electricity Council Report ACE 48 (1977)	:	EHV on HV Supplies to Induction Furnaces (Associated with ER P16)
24	The Electricity Council Report ACE 58 (1977)	:	Report on Compensators for Arc Furnaces (Associated with ER 7/2)
25	The Electricity Council Report ET 117 (in preparation)	:	Limits for Voltage Fluctuations Caused by Industrial, Commercial and Domestic Equipment in the UK
26	The Electricity Council Engineering Recommendation P 7/2	:	Supply to Arc Furnaces

27 The Electricity Council Engineering Recommendation P 8 : Supply to Colliery Winders and Rolling Mills

28 The Electricity Council Engineering Recommendation P 9 : Supply to Welding Plant

29 The Electricity Council Engineering Recommendation P 13/1 : Electric Motors - Starting Conditions

30 The Electricity Council Engineering Recommendation P 16 : EHV or HV Supplies to Induction Furnaces

Note: The voltage fluctuation limits in Engineering Recommendations P7/2, P8. P9, P13/1 and P16 are superseded by this document. The remaining background information may be of interest.

APPENDIX F

DECISION TREE FOR ACCEPTING FLUCTUATING LOADS

Does equipment comply with Stage 1 limits for small equipment? — YES ------ **ACCEPT**

NO

Are voltage changes at the p.c.c. 3% or less? — YES

NO

Can the voltage changes be reduced by equipment modification? — YES

NO

REJECT

Does equipment comply with Stage 2 assuming step or ramp type voltage changes? — YES ------ **ACCEPT**

NO

Does equipment comply with Stage 2 when assessed by simulation or calculation — YES ------ **ACCEPT**

NO

Measure background flicker and add to the disturbance caused by the equipment. Does total estimated flicker severity comply with Stage 3? — YES ------ **ACCEPT** (subject to review if complaints arise)

NO

Identify most significant voltage changes. Can frequency of voltage changes be reduced or ramp type changes substituted for steps? Can system impedance at the p.c.c. be reduced? — YES ------ ASSESS AT STAGE 2 OR 3 AGAIN

NO

REJECT

1. MOTORS WHICH CAN BE CONNECTED WITHOUT PRIOR AGREEMENT

Previous practice has shown that certain relatively small motors starting direct-on-line can be connected without consideration of flicker effects. These are detailed below:

(a) Motors which are intended to be started very frequently, i.e at less than one minute intervals:

TYPE	NORMAL RUNNING RATING EXPRESSED IN TERMS OF EITHER:	
	OUTPUT (kW)	INPUT (kVA)
Single-phase 240 V	0.37	1.0
Single-phase 480 V	1.50	3.0
3-phase 415 V	2.25	4.0

(b) All other motors with an lv point of common coupling not covered by (a) or (c).

TYPE	NORMAL RUNNING RATING EXPRESSED IN TERMS OF EITHER:	
	OUTPUT (kW)	INPUT (kVA)
Single-phase 240 V	0.75	1.7
Single-phase 480 V	3.00	4.5
3-phase 415 V	4.50	6.0

(c) 3-phase motors with the point of common coupling at the lv busbar of a hv/lv substation where the interval between starts is 10 minutes or longer.

TRANSFORMER RATING (kVA)	NORMAL OUTPUT RATING (kW)
200	22.5
300/315	30.0
500	45.0
750/800	50.0
1000	75.0

2. 3 PHASE MOTORS WITH STAR-DELTA STARTING

Where star-delta starting is employed motors of up to 1.5 times the sizes given in tables (a), (b) and (c) may be accepted without consideration of flicker effects.

3. SPECIAL CASES OF VERY INFREQUENT STARTING

From time to time, cases arise (usually in connection with continuous process plant) where a motor is only started at intervals of several months. In these cases of "very infrequent starting" it may be possible for a Board to agree to voltage depression in excess of 3%, (taking account of the associated starting equipment), subject to special conditions. These special conditions could include:

(i) Restriction of starting to times when system connections are normal.

(ii) Restriction of starting to certain hours (for example 0100-0700 hours) to minimise the likelihood of disturbance to other customers. In this case care should be taken to use the source impedance appropriate to the starting hours.

(iii) Liaison with Board Control Engineer prior to starting.

(iv) In certain cases consideration may have to be given to inhibiting tap changer operation.

In no case should the voltage depression at the point of common coupling on starting exceed 6%.

Another category of motor where special consideration may be warranted is grain drying installations. Here motors will usually only be started over a limited period of the year, generally when there is no lighting load on the system. Additionally, a very limited number of consumers may experience the full volt drop at the p.c.c. These and similar cases require the exercise of judgement but a volt drop of up to 4½% at the p.c.c may be acceptable in some cases.

ADDENDUM 2 - HIGH POWER HOUSEHOLD COOKING APPLIANCES

It is RECOMMENDED that household cooking appliances with ratings exceeding 2 kW up to and including 4.5 kW should be regarded as suitable for connection provided that:

(a) they present a resistive load;

(b) the characteristics of load and switching rate lie below the curve in Figure AD1;

(c) they conform in other respects to BS 5406;

(d) the supply is otherwise suitable.

Notes:

1. The definition of an appliance for the purpose of BS 5406 is:

Appliance

One appliance may have several separately controlled circuits. Each circuit is considered as a single appliance if it is intended to be used independently, provided that the controls are not synchronised to switch at the same instant, other than where:

(i) this occurs at random,

(ii) this occurs through the use of a timeswitch,

(iii) the synchronisation is arranged to switch one load off at the same time as another is switched on.

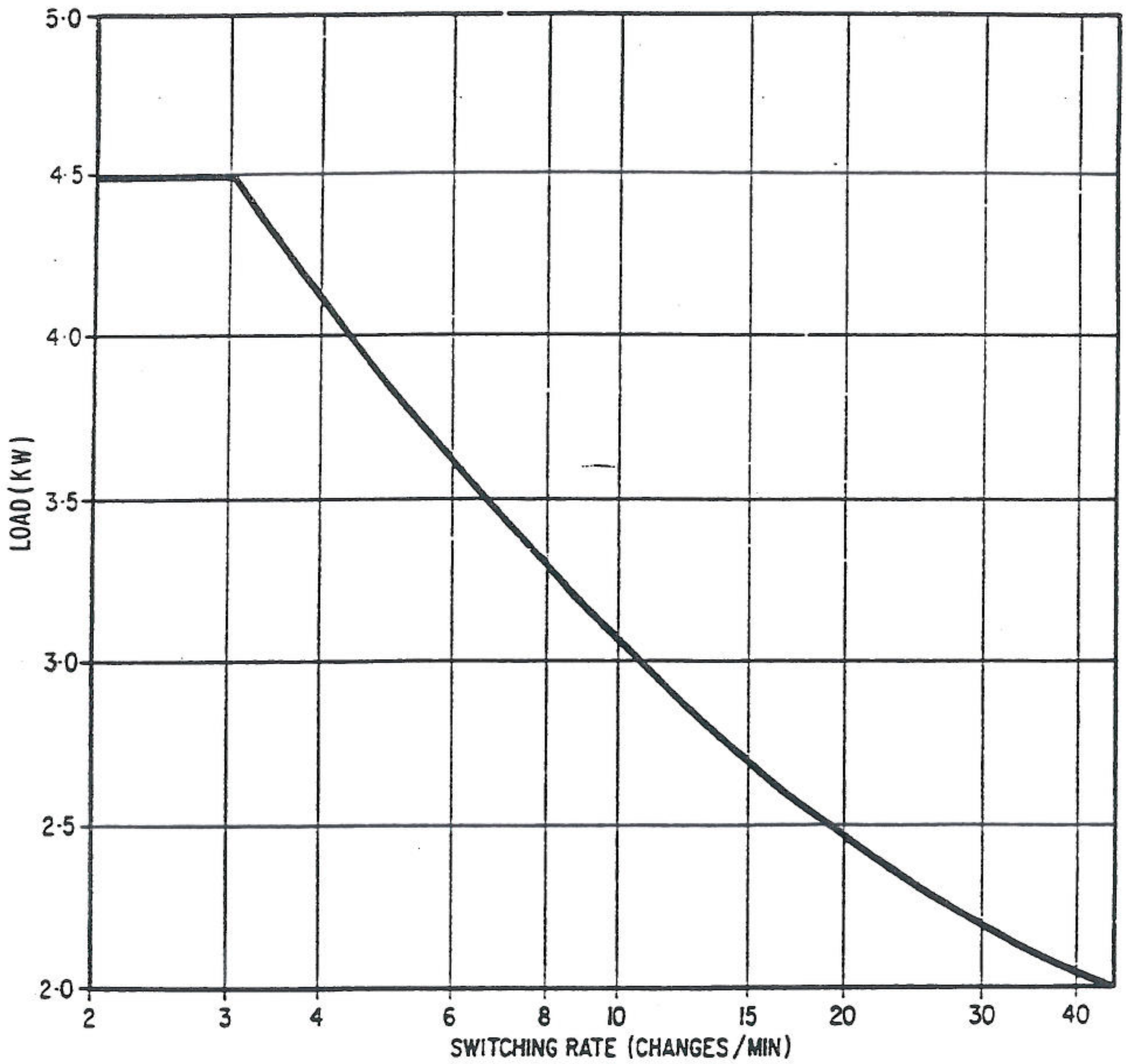
Several circuits intended to be used independently may be controlled by automatic synchronised switching, provided that the combined load does not produce voltage fluctuations exceeding the limits given in Fig 1 of BS 5406.

2. The Association of Manufacturers of Domestic Electrical Appliances (AMDEA) are aware of this Recommendation.

3. In applying Figure AD1, where the switching rate of controls is subject to production tolerances, at the worst setting not more than 5% of the controls may have switching rates exceeding the appropriate point on the limit curve. Where tolerances do not apply, for instance digital devices, the curve shall be regarded as an upper limit. The switching rate is the total number of changes occurring in one minute.

FIGURE AD1 CONNECTION OF HIGH POWER HOUSEHOLD COOKING APPLIANCES

Limits for acceptance of load switching rates



Though these units are very highly powered compared with most household appliances their load factor is so small that large numbers can often be accommodated within the capacity of an lv network.

Consequently their increasingly widespread use presents a potential threat of causing unacceptable flicker levels on lv networks making some regulation of their operating characteristics necessary.

Shower units which comply with the following requirements may be connected without individual consideration subject to item 2.

1. (a) the characteristics lie below the curve of load and switching rate defined in Figure 4a of BS 5406 (1988) Part 3. The definitions and reference impedance being in accordance with the Standard;

   or (b) the rating does not exceed 7.2 kW single-phase and the device is manually switched in one step;

   or (c) the rating does not exceed 10.8 kW and the device is manually switched both on and off in stages. The manual switching shall be arranged so that the loads switched do not result in flicker severity, $P_{st} > 1.0$ when assessed against the reference impedance of BS 5406 and assuming that the shower is switched on and off once in a ten minute period; compliance with this limit being assessed by means of ~~a~~ flickermeter, flickermeter simulator or by an appropriate analytical method.

   A tolerance in the value of P_{st} of up to 5% is permissible in accordance with IEC 868.

2. Each instantaneous shower unit with a rating in excess of 7.2 kW should have the following notice incorporated in the installation instructions:

   "As this is a high power unit it is essential to contact your Electricity Board to ensure that the electricity supply is adequate for the purpose".

   Note: (a) The requirements for staged switching under items 1(a) and 1(c) do not apply in respect of any emergency arrangements for switching off the shower under abnormal conditions.

   (b) Power ratings quoted are subject to the normal manfacturing tolerance in BS 3456.