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Planning Limits for Voltage Fluctuations Caused by Industrial, Commercial and Domestic Equipment in the United Kingdom

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ENGINEERING RECONMENDATION P.28

PLANNING LIMITS FOR VOLTAGE FLUCTUATIONS CAUSED BY INDUSTRIAL, COMMERCIAL AND DOMESTIC EQUIPMENT IN THE UNITED KINGDOM

1 SCOPE

This Engineering Recommendation supersedes the planning limits for flicker-producing voltage fluctuations which were contained in the following Engineering Recommendations:

P7/2	Supply to Arc Furnaces
P8	Supply to Colliery Winders and Rolling Mills
P9	Supply to Welding Plant
P13/1	Electric Motors - Starting Conditions
P16	EHV or HV Supplies to Induction Furnaces

With effect from the date of issue of this Recommendation these Engineering Recommendations, with the exception of P16, are withdrawn. An amendment to P16 has been prepared which covers other aspects of the operation of Induction Furnaces but which refers to this Engineering Recommendation as far as voltage fluctuation limits are concerned.

This Engineering Recommendation covers all devices and equipment not specifically covered in British Standard BS 5406 (1988) -"Disturbances in supply systems caused by household appliances and similar equipment". Engineering Technical Report ET 117* offers further information and background to this Engineering Recommendation.

The assessment of flicker severity by means of a flickermeter to IEC Publication 868 is introduced as one means of determining the acceptability of a proposed installation. Recommended limits for the short term severity values, P_{st}, at different points of the supply system are given.

For high powered equipment, where the disturbance level is dependent on the supply conditions, the stated limits must not be used in isolation as these relate only to acceptable flicker levels. In general, if the flicker severity level is not relevant, a 3% voltage change limit applies. This Recommendation is complementary to good engineering practice for establishing firm supplies and acceptable voltage regulation.

Other aspects of the connection of disturbing loads are discussed in the relevant Engineering Recommendations, e.g Harmonics, in Engineering Recommendation G5/3.

* In preparation

2 DEFINITIONS

(a) *Automatically Controlled Household Appliance*

Any electrical appliance within the scope of BS 5406.

(b) *Voltage Change*

A single variation of the rms value or the peak value of the supply voltage unspecified with respect to form and duration.

(c) *Voltage Fluctuation*

A series of voltage changes which may be regular or irregular.
Note: Single variations or a series of variations of 10% or more of the rms voltage are termed voltage dips.

(d) *Flicker*

Impression of fluctuating luminance occurring when the supply to an electrically powered lighting source is subjected to voltage fluctuation.

(e) *Flickermeter*

An instrument meeting the specification of IEC Publication 868. It gives a measure of the visual severity of the flicker that would be caused by voltage fluctuation applied to a 60W 240V tungsten filament lamp.

(f) *Short Term Severity Value* P_{st}

A measure of the visual severity of flicker derived from the time series output of a flickermeter over a 10 minute period and as such provides an indication of the risk of customer complaints.

Its calibration is such that $P_{st} = 1$ for any point on the limit curve of BS 5406 Part 3 Figure 4A, for rectangular voltage changes of magnitude less than 3%.

Appendix A gives the derivation of P_{st}

(g) *Long Term Severity Value P_{lt}*

A value derived from the short term severity values, P_{st}, in accordance with the following general formula:

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

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

In this Recommendation a period of 2 hours is used, i.e. n = 12.

(h) *Point of Common Coupling (p.c.c)*

The point on an Electricity Board's system electrically nearest to a customer's installation at which other customers' loads are, or may be connected.

3 FORM OF RECOMMENDATION

A three stage approach, increasing in complexity, is adopted to minimise the cost and time of the investigations needed by the supply authority to determine the acceptability of a proposed installation.

Stage 1 assessment and limits relate to smaller sizes of equipment which can be connected to defined parts of the supply system without individual consideration of flicker effects.

Stage 2 assessment and limits relate to the acceptance of new disturbing loads which are likely to cause a short term flicker severity, $P_{st} \leq 0.5$. There is no requirement to check existing background flicker severity at the p.c.c.

Stage 3 assessment and limits apply to new disturbing loads where limits under Stage 2 are exceeded. A full assessment of existing and projected flicker severity is required. Background levels are included in the assessment and the resulting flicker severity must be less than the Stage 3 limits.

4 INTRODUCTION

4.1 Basis of Limits

The limits in the Recommendation are based on both laboratory tests and field experience of the risks of customers complaining of excessive flicker. The laboratory tests were used to define the magnitude/frequency characteristics of allowable step and ramp voltage changes and to validate the use of P_{st} as a reliable measure of flicker severity. P_{st} and P_{lt} limits were derived from field measurements of customers' reaction to flicker.

The limits have been set to allow the maximum utilisation of the supply system's capacity to accept fluctuating loads without an excessive risk of provoking customer complaints.

Tungsten filament lamps are the most sensitive lighting source in widespread use at the time of issue of the recommendation and hence all the limits in the recommendation are based on this factor. It is known that some types of high pressure discharge lighting produce marginally higher levels of flicker than tungsten filament lamps at the high frequency end of the flicker-producing voltage fluctuation spectrum. This is not considered significant at present, but the limits will have to be reviewed if the use of this type of lighting becomes more widespread in areas where critical visual tasks are undertaken.

A 3% general limit on the allowable magnitude of voltage changes, regardless of shape, caused by fluctuating loads has been the accepted practice for many years to control the risk of excessively low system voltages. For this reason this general limit is retained even though voltage changes in excess of 3%, if of sufficiently low frequency, may not give rise to flicker severity levels (P_{st}) in excess of the limits in this Recommendation.

In addition to the need to avoid excessive voltage changes at the p.c.c, it may be necessary for the customer to give consideration to the capability of equipment to function correctly (e.g motor starting) and the effect of the disturbing equipment on other parts of the customer's installation. These aspects can be particularly significant when dealing with rural supplies fed from small capacity pole mounted transformers, but can occasionally arise in other locations.

In certain cases where special circumstances apply, a Supply Authority may, at its discretion, allow larger voltage changes to occur, e.g continuous process plant where the larger motors are only started once in several months. It may also be possible to give special limited approval for the use of some types of equipment which cause voltage changes in excess of 3% without the need for individual consideration. Such approvals will be issued as addenda to this Recommendation.

4.2 Influence of System Impedance on Magnitude of Voltage Changes

Some parts of this Recommendation require a knowledge of the system impedance in order to calculate the magnitude of voltage changes or the severity values at the p.c.c.

The impedance value to be used is that which gives a realistic maximum value of flicker severity which may occur at the times when lighting is in widespread use over the useful lifetime of the disturbing load. This is very much dictated by local conditions but the following are factors which may need considering:

a	Local Generation	Unless there are long term guarantees that this will be running at the time of operation of the disturbing load it should be ignored.
b	Routine Switching	This is usually employed for fault level control and reactive compensation purposes. The condition which gives the highest system impedance should be used

unless it is tied-in directly with the operation of local generation. In this case the condition with the generation running should be used if this has the higher impedance.

c	System Outage	Outages due to faults or maintenance should in general be disregarded as they will normally occur for short periods. Major maintenance can usually be undertaken during the summer months when the use of lighting is at a minimum.
d	Future System Changes	Planned system alterations which will increase the system impedance during the lifetime of the disturbing load should always be taken into account.
e	Supergrid Impedance	At 132kV and above the impedance on the supergrid system may be significant. The impedance corresponding to the generation levels that typically occur during spring and autumn evenings have been found to be the most appropriate for flicker calculations. However, in the absence of this data being available, the summer minimum plant level should be used.

The fault level provides a readily available measure of the system impedance through which the fluctuating load is supplied and enables an estimate to be made of the voltage fluctuation resulting from load variations. In estimating the voltage fluctuation which will be imposed on the supply to other customers, only the conditions from the supply source up to the p.c.c. need be taken into account.

For balanced 3-phase systems the volt drop at the p.c.c. can be defined as

$$\frac{m}{1000\,S} \times 100\%$$

i.e. $$\frac{m}{10\,S}\%$$

Where S is the short circuit level in MVA and m is the load change in kVA.

It will be noted that this expression implicitly assumes that the power factor of the load is equal to the resistance/impedance ratio of the source impedance up to the p.c.c. This is the worst possible condition.

Appendices B and C give examples of more accurate calculations of voltage changes.

4.3 The Combination of Disturbances from Various Sources

Historically, supply authorities have adopted a "first come first served" policy in relation to mains interference and distortion. This means that the interference or distortion accepted from a consumer is not specifically constrained to allow for further unspecified interference or distortion which might be imposed on the mains in the future.

It is assumed in formulating this Recommendation that this policy will apply to voltage fluctuation limits. Fortunately, flicker has a characteristic which is similar to harmonic interference in that disturbances from different sources are not directly additive (see Appendix A). Additional disturbing loads can often be connected to the supply even though the existing severity level approaches the recommended limit.

Where calculations show that the severity level due to the connection of a new load will exceed the recommended upper limits, remedial action can take the form of a change in the system arrangement so as to vary the relevant short circuit level, or the p.c.c. Alternatively, for some types of equipment, compensation equipment can be installed so as to limit the resultant voltage fluctuations to an agreed acceptable value. The extra costs of such remedial action should be borne by the customer owning the new load concerned.

5 STAGE 1 - ASSESSMENT AND LIMITS

5.1 Household Appliances and Similar Electrical Equipment

a) Most household appliances are connected without reference to the supply authority and having regard to the multiplicity of customers and the level of appliance ownership, effective control to prevent excessive voltage fluctuations can only be obtained at the manufacturing stage. BS 5406 Part 3 defines a limit curve of the magnitude of step voltage changes against time between occurrences for automatically controlled household and similar appliances when measured against a phase-neutral loop impedance of 0.4 + j 0.25 ohm or 3-phase impedance of 0.24 + j 0.15 ohm per phase. All appliances which comply with this standard are acceptable for connection anywhere in the UK.

b) BS 5406 allows a supply authority to declare a "general consent" for high power appliances which are intended only to be used in systems having an impedance considerably lower than the reference impedance.

   Any such general consents will be issued as addenda to this Engineering Recommendation.

c) Other equipment which is outside the scope of BS 5406 such as electric storage heaters, water boilers, heat pumps, direct water heaters and manually switched shower units are often of a capacity high enough to necessitate notification of proposed connection to the supply authority. These equipments will, in many cases, be the subject of discussions at the manufacturing design stage. General consents and recommendations will be issued from time to time which explain the operating characteristics and the limits to the size of equipment acceptable for connection to lv networks. Again, these general consents will also be issued as addenda to this Recommendation.

d) High power appliances such as electric boilers and storage radiators are subject to the individual consent of the supply authority. Such equipment is normally switched infrequently and should be designed to avoid unnecessary rapid cycling by control systems. In consenting to the installation, account will be taken of statutory voltage regulation requirements and the normal frequency of switching to ensure that flicker problems do not arise. In the development of load control systems it is desirable to avoid the synchronised switching of such loads in adjacent installations.

5.2 Electric Motors

Previous experience has shown that relatively small direct-on-line lv motors can be connected without detailed consideration. These are listed in Addendum 1.

5.3 Other Equipment with Rated Input Current ≤ 16A

Although the scope of BS 5406 (EN 60.555) is limited to household and similar equipment it is recommended that all equipment with rated input current of ≤16A should be assessed using the procedure from that Standard.

6 STAGE 2 - ASSESSMENT AND LIMITS

6.1 General

It is anticipated that the majority of applications to connect loads which do not come under the Stage 1 procedure will be evaluated using the procedures explained in this section. The procedure is applicable to most equipment which causes step voltage changes (Figure 1) or ramp voltage changes (Figure 2), or simple combinations of these two types of voltage change.

Under the Stage 2 procedure, individual loads which cause a short term flicker severity $P_{st} \leq 0.5$ when assessed using the applicable supply impedance at the p.c.c. can be connected without further assessment. Figure 4 gives limits for the size and time between step voltage changes such that all points on or below the curve have a short term severity value, $P_{st} \leq 0.5$. Ramp voltage changes are less noticeable in terms of flicker than step voltage changes of the same size, and Figure 5 provides a simple means of converting the time between ramp voltage changes into the equivalent time between step voltage changes of the same size.

The limit set for Stage 2 does not represent the maximum tolerable flicker severity for the supply system but is a value which generally allows individual items of equipment which comply with this limit at the p.c.c to be connected without the need to carry out site measurements of flicker severity. The additional effect of such loads is generally very unlikely to cause the flicker severity for the supply system to reach intolerable levels if it was previously acceptable, because of the way in which flicker from different sources is summated (see Appendix A).

6.2 Assessment Techniques

Under the Stage 2 procedure no measurements of the flicker severity at the p.c.c. are necessary. However, an assessment of the flicker severity resulting from connection of the load has to be made. This can be done by simulation, calculation or measurement. Rules to simplify the waveforms generated by particular types of equipment are given in sections 6.3 to 6.6.

6.2.1 Assessment by Simulation of the Disturbing Load

The pattern of voltage changes caused by the load has to be calculated using details of the characteristics of the load and the relevant value of system impedance at the p.c.c. Then a flickermeter simulator program can be used to convert the voltage change pattern into corresponding values of flicker severity P_{st}. The UIE report 'Connection of Fluctuating Loads' contains details of two such programs. The Electricity Council has available programs including one suitable for an IBM PC or compatible personal computer. This program enables a variety of disturbance waveforms to be input including those arising from welders, arc furnaces and motors starting. The Head of Distribution Engineering at the Electricity Council should be contacted for details and availability of the program.

6.2.2 Assessment by Calculation – Memory time technique

For certain simple combinations of step or ramp voltage change patterns, the short term flicker severity can be calculated using the memory time technique. The method is applicable to voltage change patterns consisting of step or ramp changes of different size or irregular spacing or combinations of step and ramp voltage changes.

The method is to calculate:

- the minimum time between changes, read from Figure 4 or the combination of Figures 4 and 5 for each of the n th voltage changes (t_n seconds);
- the duration of the operating cycle of the equipment (t_o secs). This is the typical minimum time between successive commencements of the operating cycle;
- where the operating cycle (t_o secs) is 600 sec (10 minutes) or less the sum of the n individual times, $\sum_n t_n$,is calculated;
- where the operating cycle (t_0 secs) is longer than 600 sec, the 600 sec period with the maximum sum of the individual minimum times, t_n, should be found; t_o being taken as 600 sec;

- the equipment complies with the Stage 2 limits in either case if $\sum t_n \leq t_o$.
  Examples of this technique are contained in Appendix B, Examples 1 and 3.

The accuracy of this method is usually within ±10%. If there is any doubt about the values calculated then the simulation method should be used instead.

6.2.3 Use of Flickermeter

If a piece of equipment already exists, it is possible to make flicker measurements on the equipment using a flickermeter to IEC 868. A method to scale the measured flicker severity to another location with a different supply impedance is illustrated in Example 2 of Appendix B. In order to comply with the Stage 2 procedure the value of flicker severity, P_{st}, should be less than or equal to 0.5 at the proposed location for the equipment.

6.3 Electric Motors

Motors can cause changes in the system voltage on starting, when running and on stopping. All three conditions need to be considered in determining the acceptability of a motor.

(a) Starting

In most cases starting produces the most severe fluctuation due both to the magnitude and power factor of the current taken. Two types of change are normally produced as shown in. Figures 2 and 3.

FIGURE 1 STEP VOLTAGE CHANGE

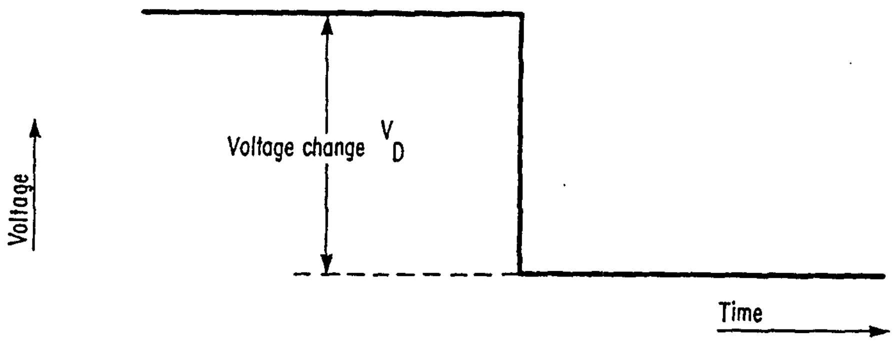


FIGURE 2 RAMP-TYPE VOLTAGE CHANGE

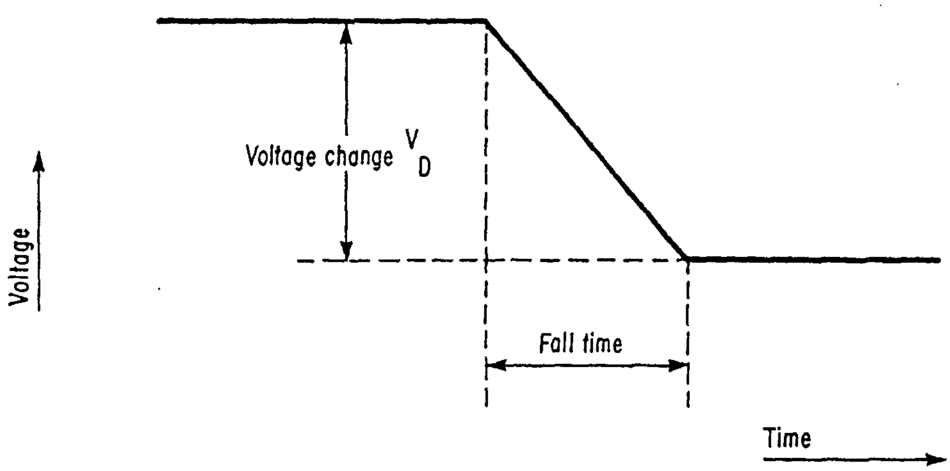


FIGURE 3 USUAL FORM OF VOLTAGE CHANGES CAUSED BY MOTOR STARTING

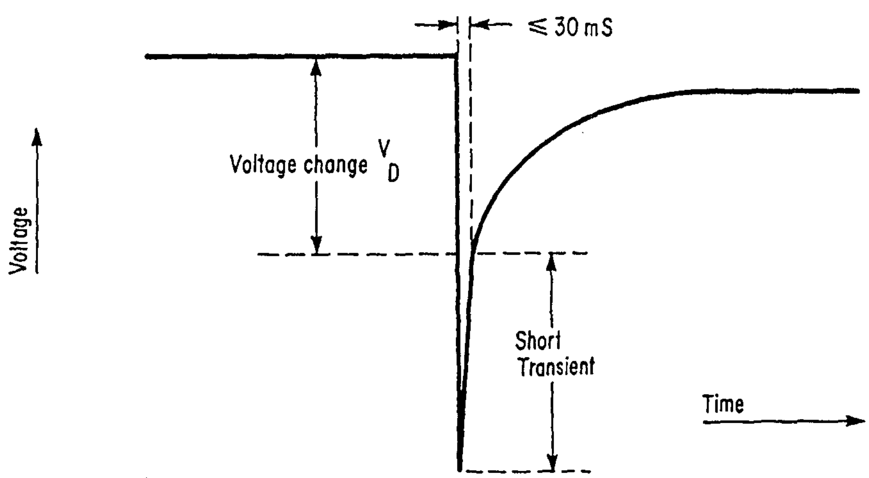


FIGURE 4 RECOMMENDED LIMIT FOR THE SIZE OF STEP VOLTAGE CHANGES WITH RESPECT TO THE TIME BETWEEN EACH CHANGE

$P_{ST} = 0.5$

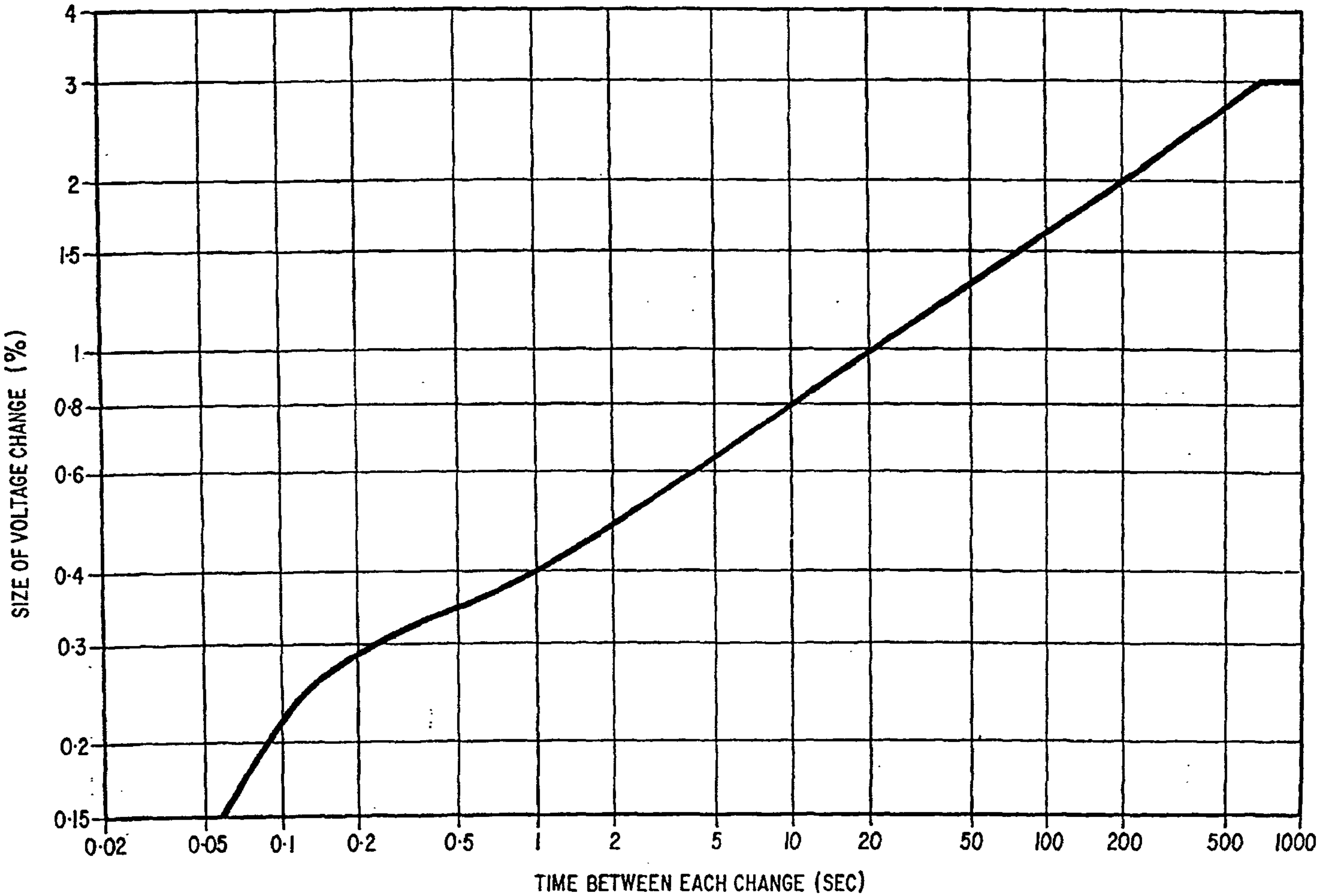
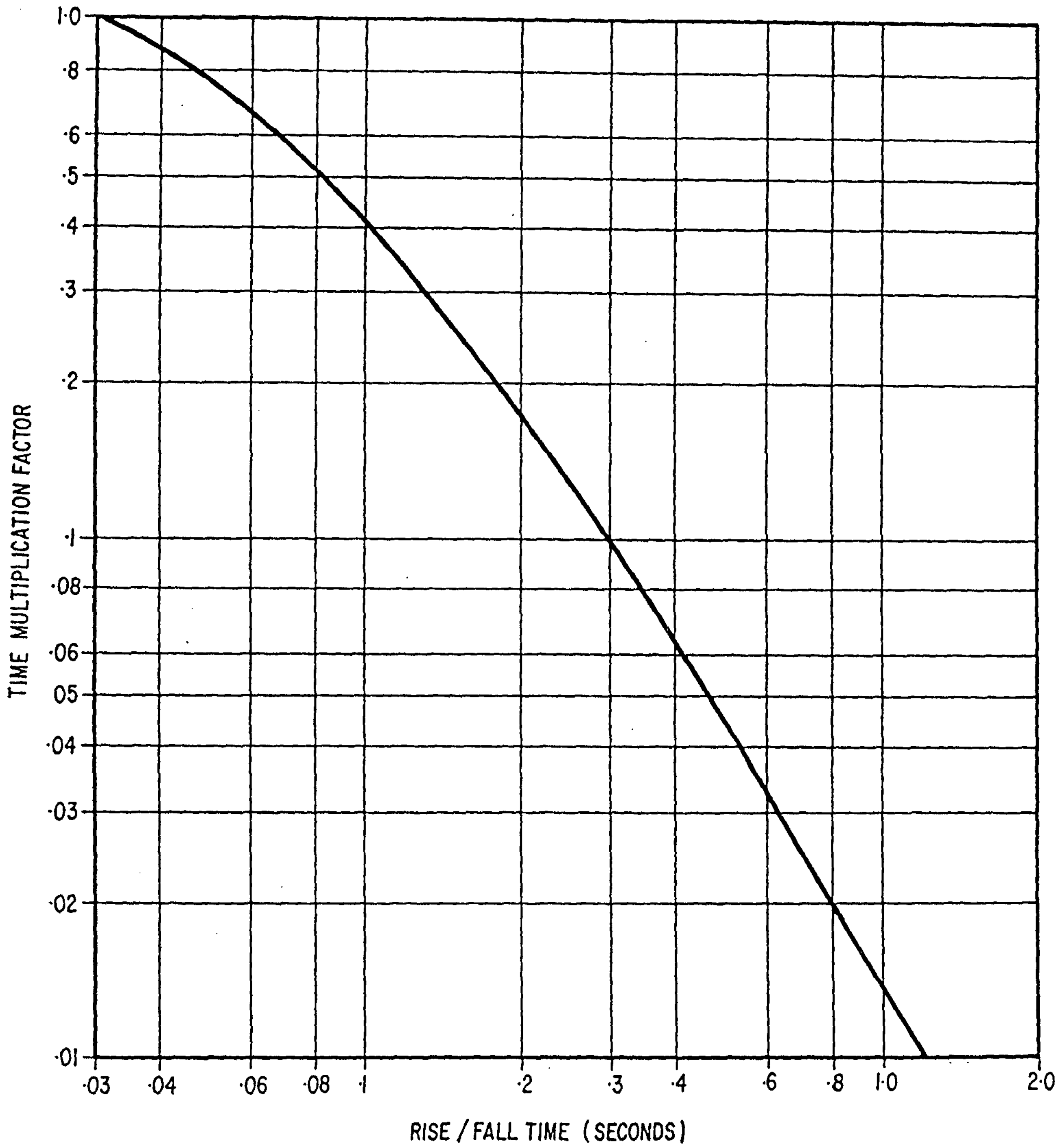


FIGURE 5 MULTIPLICATION FACTOR FOR DERIVING THE MINIMUM TIME BETWEEN RAMP-TYPE VOLTAGE CHANGES FROM THE STEP CHANGE LIMIT OF FIGURE 4



Minimum time between voltage changes = TIME (from figure 4) x TIME MULTIPLICATION FACTOR

Figure 3 is typical of the majority of motors in service with direct on line starting. In the majority of cases, the duration of magnetising in-rush is 30 ms or, less. The recommended limit for the magnitude of the change, V_D, with respect to the minimum time between occurrences is derived from the step change limits of Figure 4. For direct on line starting the whole cycle may be considered as being equivalent to one step change with the limit taken directly from Figure 4. Reduced voltage starters such as Star-delta and reactor types normally cause a second voltage change at the changeover point. This second voltage fluctuation is similar in form to Figure 3 and should be considered equivalent to a further single step voltage change of magnitude V_D Methods of assessment of these equivalent voltage changes are described in Section 6.2.

Where magnetising in-rush currents are in the normal range previously described, the magnitude of the voltage change, V_D, may be assessed by means of measurement of the current in a locked rotor test carried out at the intended working voltage of the equipment concerned, or by reference to manufacturer's published information. In other cases it is necessary to assess the flicker severity as described in 6.2.1 or 6.2.3.

Where motors are used which employ methods of providing more than one speed from an induction motor by reconnecting the stator windings (e.g pole changing and pole amplitude modulation), it is necessary to check that the starting voltage changes are within acceptable limits in all modes of operation. Additionally high transients at speed change should be avoided by the provision of a time delay in the changeover control scheme; this time delay must be adequate to allow the decay of the motor magnetic field.

In addition to supply system requirements it may be desirable to avoid too high a transient to avoid over stressing the motor(s) involved.

Figure 2 is typical of the type of voltage change produced when an electronic soft start is employed or when some types of DC motor drive systems are employed. The method of assessment of these voltage changes is given in Section 6.2. Minor deviations of the shape of the actual voltage change from a true ramp can be ignored.

(b) Running

Certain industrial applications of motor drives can give rise to significant voltage changes during normal running. Car shredders and rolling mills are examples of this (see ACE Report No 4). Normally these changes approximate to step functions but flywheels, fluid couplings and intervening motor generator sets can soften the changes to the less onerous ramp function. Predictable voltage change patterns can be assessed using the methods in Section 6.2. For more complex or irregular voltage change patterns direct measurements by a flickermeter, or calculation using a flicker simulation program will be necessary.

Variable speed motors which generate currents at non-synchronous frequencies, such as cycloconverter driven induction motors, also need careful consideration. In addition to the voltage fluctuations caused by load switching, non-synchronous currents can interact with the fundamental and produce a "beat" frequency disturbance in the flicker producing part of the frequency spectrum. For example, a 40 Hz current might give rise to flicker at 10 Hz. Such motors should be evaluated by a flickermeter or simulator program.

Appendix B, Example 3 indicates how only the largest disturbances may be significant in the analysis of the flicker severity produced by loads causing complex voltage changes.

(c) Stopping

Generally voltage changes produced on stopping should not cause flicker problems. However, when electronic soft starting equipment is involved then a step change on stopping may be more onerous than the starting ramp type change.

An example of assessment of a motor installation is given in Appendix B, Example 2.

6.4 Welding Equipment

There are many types of arc-welding and metal-heating plant in use which are unlikely to cause appreciable flicker problems on distribution networks. Some have very small ratings and are likely to be found only in moderately large factories where the additional flicker is not significant compared to ordinary factory loads; examples of these are argon-arc machines, atomic-hydrogen machines, wire welders, and miscellaneous small metal-heating machines like rivet heaters. Other classes of machine impose steady 3-phase balanced loads on the system for long periods; examples of these are 3-phase/d.c. automatic wire-fed machines and three-phase/d.c. nonferrous welders. There is also welding plant fed from motor generators which does not pose any appreciable flicker problems for inherent physical reasons.

The five characteristics of welding plant that are relevant to flicker problems are:

(a) The magnitude of the sudden "steps" of welding current that can be imposed on the distribution system;

(b) Whether the steps are two-level or multi-level;

(c) The power factor of the load increments constituting these steps;

(d) The distribution of the current in the phase conductors on the medium-voltage and high-voltage systems;

(e) The frequency of the voltage changes.

Generally electric welding equipment can be divided into two categories for flicker evaluation - arc and resistance.

(i) Arc welders are generally relatively low powered devices which produce a step change on the system voltage when the arc is struck and another when the arc is broken. Times between the striking and extinguishing of the arc are very variable but are usually in the range of several seconds to a few minutes. Problems are only likely to occur when connected to a weak lv p.c.c. and, where applicable, a procedure from Section 6.2 should be applied.

(ii) Resistance welders, both due to their size and operating characteristics may cause severe voltage fluctuations over a wide area of the supply system and consequently every effort should be made to check the full range of a machine's likely operating patterns. The voltage changes that each of the pulse size/frequency patterns can cause should be checked using a procedure from Section 6.2. Where complex multi-level voltage changes are involved it may be necessary to evaluate the acceptability with a flickermeter or flickermeter simulator program.

Where welding plant is connected directly phase-phase at lv the resultant phase-neutral voltage change (which is the voltage change related to the level of flicker since lighting is usually connected phase-neutral) may be calculated from the following equation:

$$V\% = 0.74\ Rs + 0.68\ Xs \text{ per actual kVA of welding load}$$

Assuming V is within the normal range for voltage ($\leq$ 3%) and the power factor of the voltage step is 0.3 lagging. It must not be forgotten that each burst of welding current involves two voltage changes.

Where resistance welding equipment does not incorporate point-on-wave switching control the voltage change should be increased by V_m to allow for magnetising in-rush where

$$V_m\% = 0.50\ Rs + 0.\ 87\ Xs \text{ per actual kVA of welding load}$$

(In both equations Rs, Xs refer to the impedance of the lv supply system in ohms and the actual kVA refers to the manufacturer's rating of the welder.)

Note that where welders with a power factor higher than 0.3 lag are encountered the voltage drop on both the lagging phase (as above) and the leading phase will need to be calculated as described in ACE Report No 7, eg d.c. welders connected phase-phase at lv.

ACE Report No 7 provides more detailed information on the flicker effects of welding plant, including frequency-changing transformer, d.c and stored energy types which are not dealt with by the simplified assessment above.

An example of assessment of a welding installation is given in Appendix B, Example 4.

6.5 Mains Frequency Induction Furnaces

Mains Frequency Induction Furnaces can produce voltage disturbances both at switch-on (in-rush current) and during normal operation. The duration of in-rush currents for induction furnaces may range from a few milliseconds to several cycles of the 50 Hz supply.

This is only relevant for flicker evaluation under Stage 2 if the duration exceeds 30 ms in which case it should be considered as being equivalent to a single step change with a magnitude the same as the maximum voltage change occurring. Note that some furnace designs require that the transformer is switched at every tap change of the operating cycle and hence this inrush transient can occur many times in a cycle. Even when the transformer is not switched the frequent tap and capacitor switching which occurs during an operating cycle could cause flicker problems and should be considered.

Detailed discussion on the common types of induction furnace and methods of calculating voltage fluctuations for single-phase loads are given in ACE Report 48. Once the Voltage change size/frequency pattern has been established one of the techniques given in 6.2 should be used to determine the acceptability of the furnace.

6.6 Arc Furnaces

The following refer particularly to standard metal melting and refining arc furnaces with an unprocessed scrap charge. There are other types of furnace which have either a processed charge or miss out the initial melt down stage e.g. ladle furnaces which can be much less onerous on the supply system. These will have special characteristics for which the flickermeter assessment route is likely to be the only viable path to follow.

6.6.1 Load Cycle

The typical load cycle produced by an arc furnace has a total duration of three to eight hours depending on the size of the furnace and the metallurgical requirements. The melting period occupies the first half to one and a half hours, during which the solid charge is melted and the main energy input is required. During the subsequent refining period the energy supplied has only to make good the heat losses in order to maintain the temperature, so that the power required is much reduced. The earlier part of the melting period is characterised by somewhat unstable arc conditions, while the arcs are formed between the electrodes and the solid charge. The arc conditions become steadier as the electrodes bore their way into the charge and pools of molten metal are formed, but heavy peaks of load appear from time to time as portions of the charge collapse on to the electrodes, or when additional scrap is added.

6.6.2 Limitation of Current

In order to limit heavy short-circuit currents which are particularly likely to occur during the melting period, and in order to stabilise the arcs, it is usual in the smaller furnaces to add reactance in series with the furnace transformer hv connections, thus bringing the total reactance, including that of the furnace electrodes and connections, up to 40% or 50% on the furnace rating. For furnace ratings of 10 MVA or larger, the inherent reactance of the furnace with its transformer may reach 50%, so that an additional reactor may be unnecessary.

6.6.3 Fluctuation of Current

Experience shows that an arc furnace during its melting period produces irregular fluctuations, many of which are equal to, or even greater than the nominal rated current of the furnace. The maximum possible furnace current (which does not occur frequently during operation but which is important for certain calculations specified later) occurs when the three electrodes are immersed in the molten steel. This current can be called the furnace short-circuit current. The maximum possible current swing obviously occurs when the furnace passes from this condition to a complete open circuit or vice versa.

It has been found that, apart from amplitude, the frequency spectrum of the current fluctuations produced by one uncompensated arc furnace is much the same as that produced by any other. The flicker effect caused by a given furnace when refining is much less than that caused when melting.

6.6.4 Assessment

Arc furnaces produce very complex voltage fluctuations such that a Stage 3 approach should almost always be used. However, at the design stage and for single furnace installations which are effectively electrically isolated from other furnaces, a simplified assessment can be adopted. It relates usually to 11kV and 33kV networks and involves the calculation of the short-circuit voltage depression at the p.c.c.

Assuming that the source impedance has a negligible effect on the short-circuit power drawn by the furnace, the short-circuit voltage depression may be calculated with sufficient accuracy from the ratio of the furnace steady state apparent short-circuit power in MVA (St) and the network short-circuit power in MVA at the p.c.c. (Sc); i.e.

$$\text{short circuit voltage depression} = \frac{St}{Sc} \times 100\%$$

The apparent short-circuit power of a furnace (St) is that power which would be drawn by the furnace if all three electrodes were immersed in molten steel with the furnace-transformer tap set to that corresponding to the highest furnace-voltage available. St may be taken as twice the furnace rating if no other information is available.

In order to meet the Stage 2 limit of $P_{st} \leq 0.5$, the value calculated above should be less than 1%.

Where the assumption relating to the effect of source impedance on the short-circuit power is not appropriate, a more accurate assessment may be made by reference to ACE Report No 26.

7 STAGE 3 - ASSESSMENT AND LIMITS

Where expected voltage fluctuations exceed Stages 1 and 2 levels, it may still be possible to connect the load after a detailed analysis of existing severity levels and an assessment of the additional effects of the new and future load.

Information should first be obtained of the level of background flicker using a flickermeter during the times the proposed load is likely to be in operation.

The short term severity values (P_{st}) of the new load should be found either from known values derived from previous tests, from scaled characteristics of similar loads or by using a flickermeter simulation program which can derive P_{st} from given theoretical or measured voltage change patterns. (See Section 6.2)

The P_{st} values of the new load (and any known future load) should then be superimposed on the background P_{st} values using the method given in Appendix A. The resultant long term severity values, P_{lt}, may then be calculated. The limits for both P_{st} and P_{lt} in Table 1 should not be exceeded.

Note: P_{st} is linear with respect to the magnitude of the voltage changes giving rise to it. At the threshold of causing flicker complaints, the risk of complaints increases at between the 6th and 8th power of the change in magnitude of the voltage changes. Extreme caution is therefore advised in allowing any excursions of P_{st} and P_{lt} above the limits in Table 1.

Attention is drawn to Section 4.2 which gives advice on the system impedance to use in determining P_{st} and P_{lt} for compliance with Table 1. In particular due consideration should be given to supply arrangements where the supply impedance can increase significantly for some outages. Such outage conditions may give rise to a significant risk of flicker complaints if the normal supply flicker levels are close to the Table 1 limits and in these cases extreme caution should be taken in accepting additional fluctuating loads.

TABLE 1

LIMITS OF SHORT TERM SEVERITY VALUES P_{st} AND LONG TERM SEVERITY VALUES P_{lt} AT ANY POINT ON THE SYSTEM (FROM ALL SOURCES)

SUPPLY SYSTEM VOLTAGE (kV) AT POINT OF COMMON COUPLING	P_{st} ABSOLUTE MAXIMUM VALUE	INTEGRATED VALUE IN ANY TWO HOURS, P_{lt} $\sqrt[3]{\frac{1}{12}(P_{st}^{\,3})}$
132 kV and below	1.0	0.8
Above 132 kV	0.8	0.6

7.1 Application of Table 1

The limits of Table 1 apply to any point on the supply system (subject to sub-section 7.2 for lv systems). When assessing the acceptability of a proposed new load, local knowledge and tests should be used to determine the location where the highest flicker levels resulting from the connection of the new load will occur. This would normally be at the p.c.c of the new load with other customers but, if existing flicker levels are high, it could well be at some other point between the new load and the main source of this existing flicker. In particular where the p.c.c of the new load is on an hv or ehv system, there is a possibility that the highest flicker levels may occur on a lower voltage network fed from this system.

7.2 Fluctuating Loads Connected with an LV Point of Common Coupling

The application of the full Stage 3 limits requires a knowledge of existing flicker levels which have a long term validity. To guarantee this, the supply authority must have effective control over the connection of further disturbing loads. This does not normally apply to lv networks since domestic equipment, in particular, is connected without reference to the supply authority. Consequently, loads should not be connected under the Stage 3 procedure unless the supply authority is satisfied that other significant disturbing loads cannot be connected without prior consent. Individual loads or groups of loads with $P_{st} < 0.5$ at their p.c.c may be connected under Stage 2 without the need to check background levels.

8 SITE MEASUREMENTS

The flickermeter, see Appendix A, will measure the flicker severity value of the voltage presented to it regardless of the source and magnitude of the voltage fluctuations present. Care should be taken when setting up the test and when interpreting results that voltage changes from unintended sources such as system faults are excluded and that voltage changes in excess of 3% are not occurring.

It is important to remember that lighting, which is the type of equipment most sensitive to voltage fluctuations, is always connected phase-neutral at lv. Where measurements are taken from high voltage systems through a voltage transformer it is important to give due regard to the phase relationship between measured voltages and lv system voltages. This is particularly important for voltage changes which are not symmetrical to all three phases.

8.1 Background Levels

It is necessary to check all phases in turn to determine which phase has the highest background levels.

The meter should be installed for a sufficient length of time on the phase with the highest background to obtain typical background values applicable to the times when the equipment under consideration is likely to be used.

8.2 Measurement of P_{st} and P_{lt} for an Item of Equipment

The flickermeter should be installed for a sufficient length of time to cover at least one full operating cycle of the equipment or to find the most severe two hours of voltage fluctuations. If the equipment is not connected to a "clean" flicker free supply then the level of background flicker should be subtracted from the result as shown in Appendix A.

In assessing compliance with the limits of Table 1 it may be appropriate to disregard values of P_{st} in excess of the limits when they occur due to unusual circumstances, such as faults or operating difficulties.

9 APPLICATION

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

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

All installations exceeding the limits of Stage 2 should have tests carried out by the supply authority to determine:-

(i) *prior to commissioning* - the magnitude of existing flicker severity in the network,

(ii) *following commissioning* - that the flicker severity does not exceed the Stage 3 limits or any other limits agreed with the supply authority.

In view of the real risk of customer complaints if the limits of Table 1 are exceeded, it is recommended that supply authorities keep a register of all HV and EHV connected loads which exceed the Stage 2 limit ie $P_{st} > 0.5$. From time to time, and particularly when system alterations which significantly change the fault level at the p.c.c. are contemplated, the flicker severity levels should be re-assessed and compared with Table 1.

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 compensators to limit excessive voltage changes and flicker severity.

The situation regarding flicker from high pressure discharge lighting is being kept under review and further guidance will be produced after investigations and discussions with the lighting industry.

This Engineering Recommendation should be read in conjunction with ET 117*, UIE Reports and the relevant National and European Standards. It is a planning document and the limits quoted are not necessarily the highest values that may be found on the power system.

A summary of the procedure for assessing acceptability of fluctuating loads is given in Appendix F.

* In preparation

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 Al. 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_l, 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:

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

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

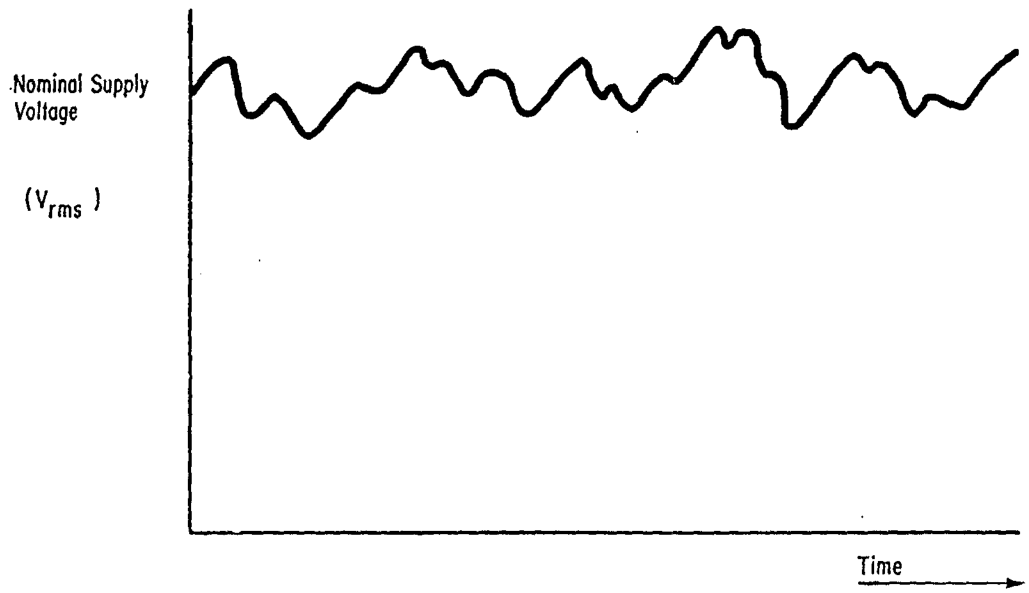
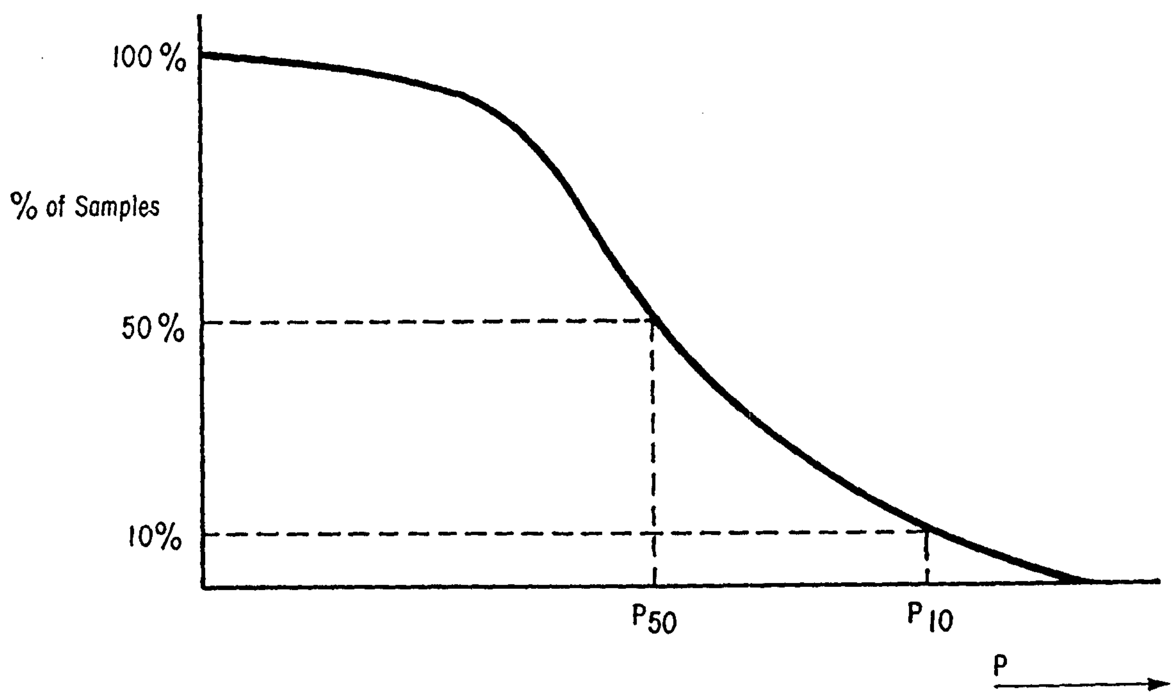


FIGURE A2 CUMULATIVE DISTRIBUTION FUNCTION OF TIME SERIES OUTPUT EVALUATION OF P_{50}, P_{10}, P_3, P_1, $P_{0.1}$



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:

$$P_{st_1} = P_{st_0} \times \frac{V_{D_1}}{V_{D_0}}$$ (See Figures 1 and 2)

where V_{D_0} = magnitude of voltage changes at location where P_{st_0} was measured.

V_{D_1} = magnitude of the voltage changes caused by the same piece of equipment at the location where P_{st_1} 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.

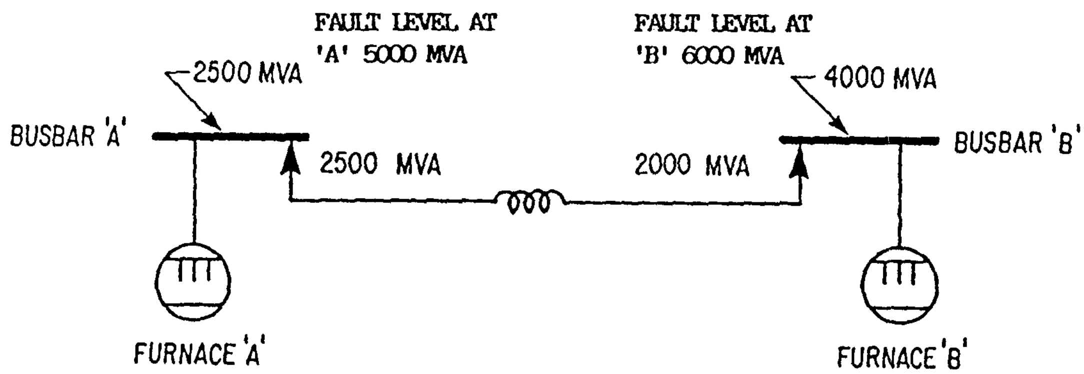
m = 1 The resultant P_{st} will approach the value given by this when there is a very high incidence of coincident voltage changes.

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 MA.

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).

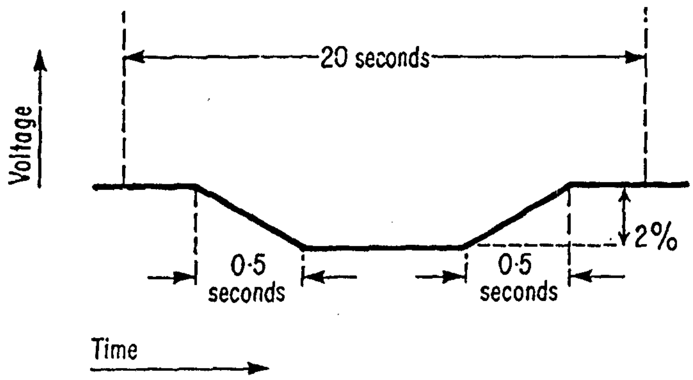
APPENDIX B

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 BI



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.

EXAMPLE 2 - CAR SHREDDER LOAD

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:

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

$$= 2.57\ \%$$

This is acceptable so the starting and running flicker effects at this alternative location now need to be assessed.

(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:

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

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

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

(i) Flicker Effects, Normal Running (see Table 2)

(A) *900 kW motor*

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) *Proposed 1500 kW motor*

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) *Summation of effects at the 11 kV busbar*

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) Summary

(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:

$$P_{st}\ (\text{MAXIMUM}) = 0.75$$
$$P_{lt} = 0.519$$

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

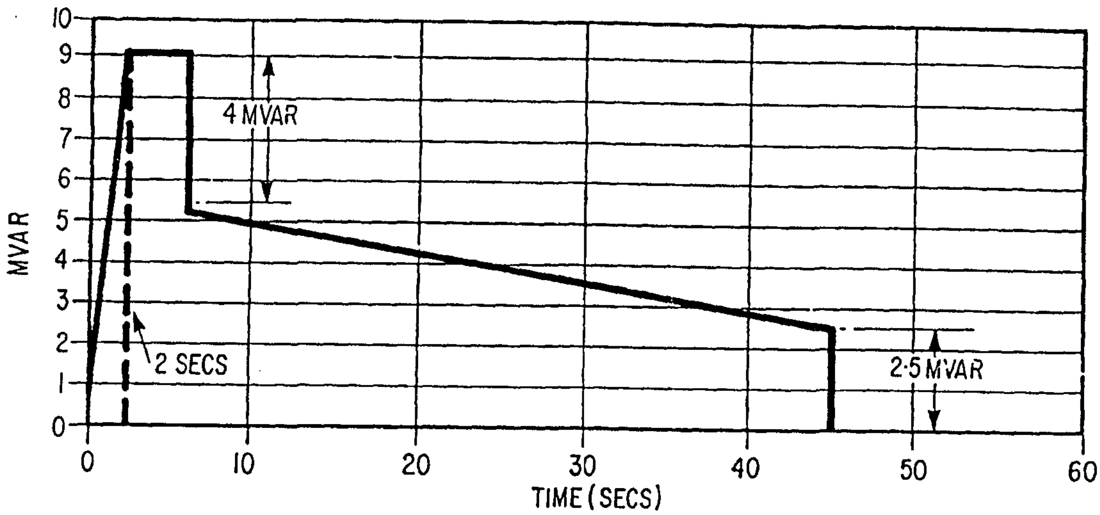
TABLE 2 FLICKER MEASUREMENTS FOR EXAMPLE 2 FLICKER EFFECTS, NORMAL RUNNING

	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
$P_{lt} = \sqrt[3]{\frac{1}{12} \sum_{1}^{12} (P_{st})^3}$	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, $P_{st} = 3/(3 \times 0.40^3) = 0.58$. 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.

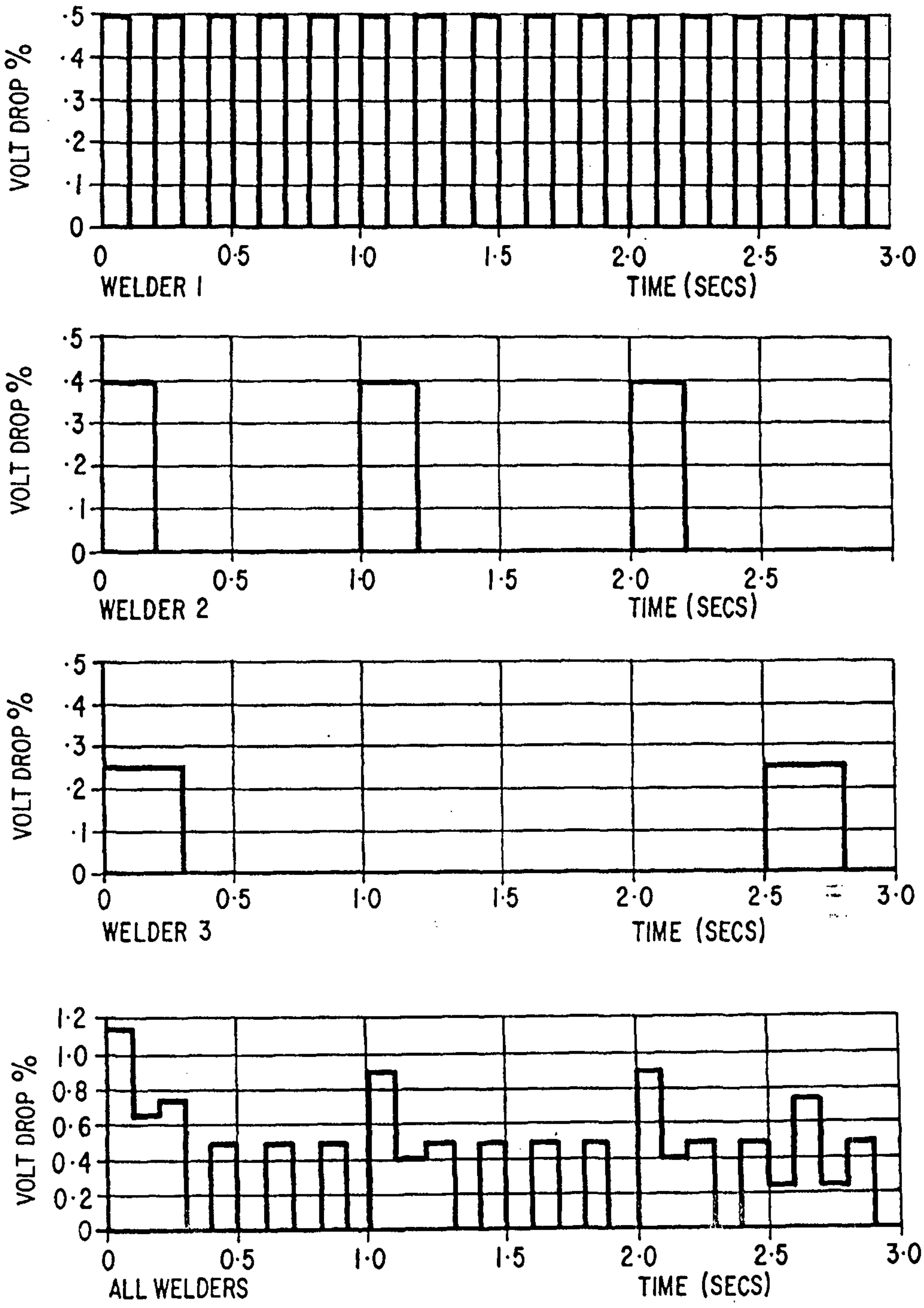
EXAMPLE 4 - MULTIPLE SPOT WELDER LOAD

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

Cl 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 CALCUTATION 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 neutral 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.

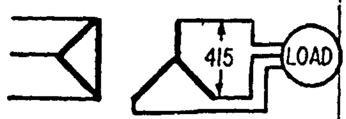
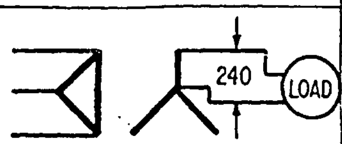
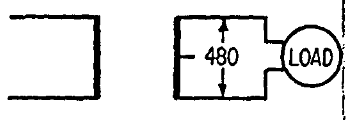
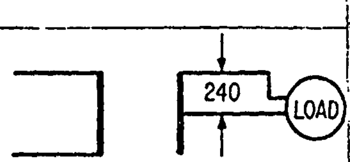
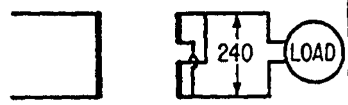
C2.3 480 Volts Loads

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 Cl).

TABLE C1 CALCULATION OF SYSTEM IMPEDENCES 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:

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

$$= 0.0262 + 0.0529$$

$$= 0.0791 \text{ volts per ampere of load current}$$

EXAMPLE 6: Single-phase 240 V Load

(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:

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

$$= 0.051 + 0.196$$

$$= 0.246 \text{ volts per ampere of load current}$$

EXAMPLE 7: Single-phase 480 V Load

(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 overhead line 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 "return" path	0 0	0.00094 0.00094	x 1.34 x 1.34	0 0	0.0013 0.0013
11 kV line (Appendix D: Table D4) "go" "return"	0.00042 0.00042	0.00059 0.00059	x 1.34 x 1.34	0.00056 0.00056	0.00079 0.00079
Transformer (Appendix D: Table D6)	-	-	-	0.233	0.365
L.V. cable (Appendix D: Table D8(a)) "go" phase path "return" phase path	0.0443 0.0443	0.00705 0.00705	- -	0.0443 0.0443	0.00705 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 Dl 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 11000/433 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 11000/433 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 Ll (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 3phase 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 Tl (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 Tl (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 DI

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)		Reactance Per Phase Conductor (ohms/1000 m)
	Conductor Material		
	Copper	Aluminium	
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

TABLE D6

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

Transformer		Resistance per Phase (ohms)	Reactance per Phase (ohms)
Type	Rating (kVA)		
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		Districtable	
	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

APPENDIX E

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).

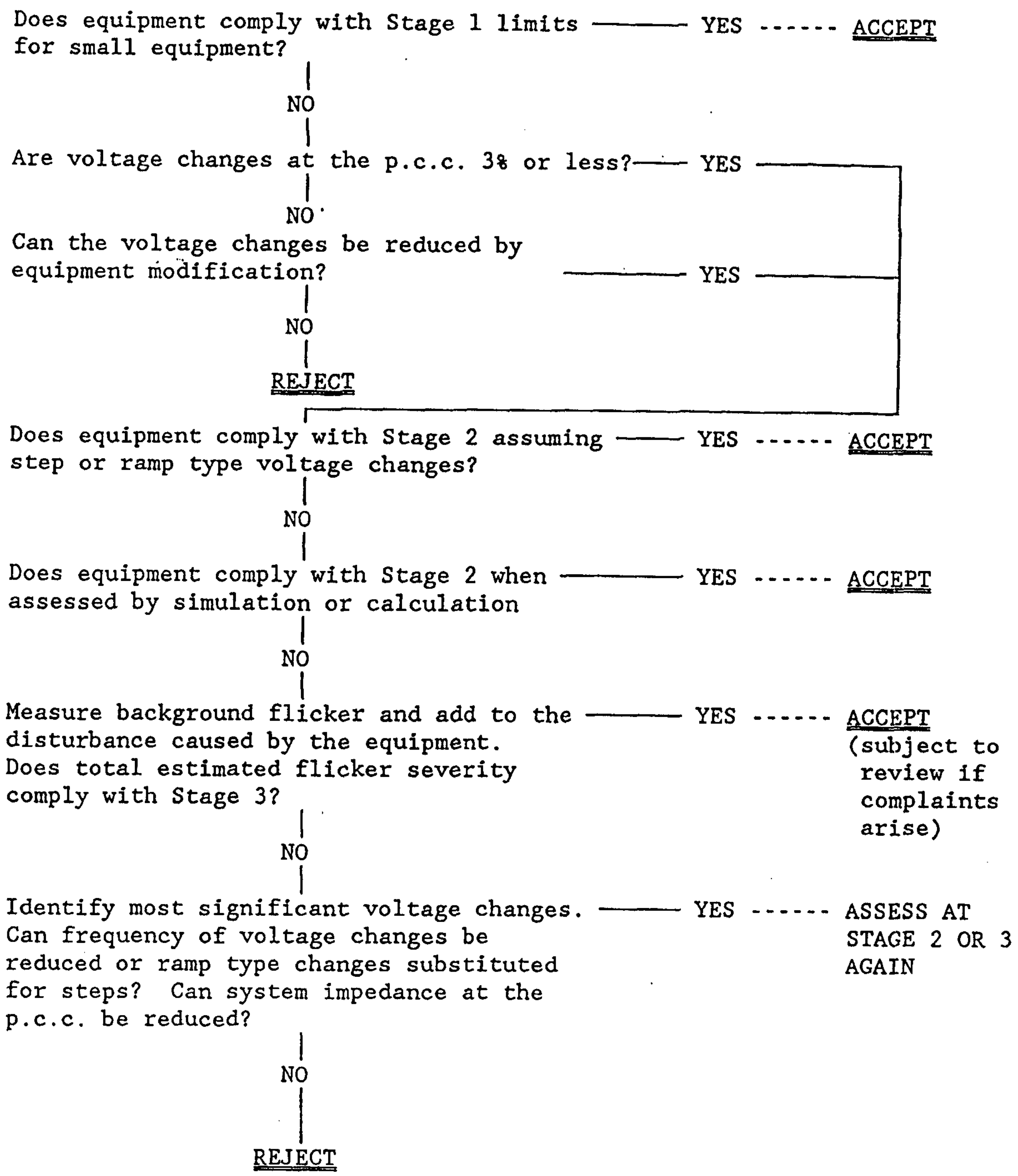
11.	BEB Specification Ll (1962)	Medium and Low Voltage Overhead Lines on Wood Poles. (Withdrawn June 1978)
12.	BEB Specification T.1 (1958)	Transformers from 5 kVA to 1000 kVA for Use on Standard 415 V and 240 V Systems. (Withdrawn 1973)
13	UIE (1986) Disturbances Working Group	Flicker Measurement and 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



ADDENDUM 1 - ELECTRIC MOTORS

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,

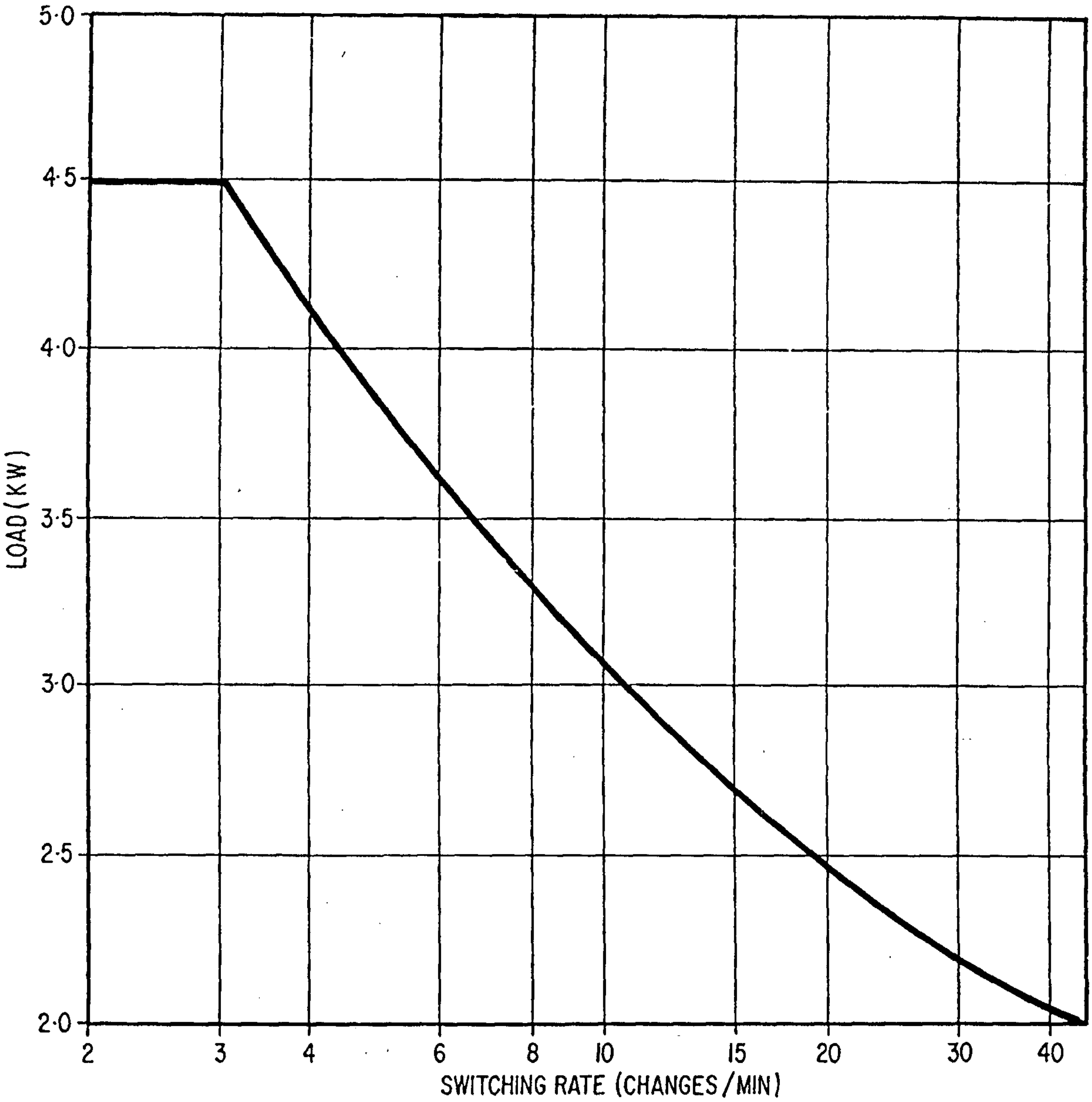
   (iii) the synchronisation is arranged to switch one load off at the same time as another is switched on.

   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 food switching rates



ADDENDUM 3 - ELECTRICALLY HEATED INSTANTANEOUS SHOWER UNITS

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 l(a) and l(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 manufacturing tolerance in BS 3456.