ENGINEERING RECOMMENDATION **P28**
SYSTEM UTILISATION CONSULTANCY GROUP
SEPTEMBER 1989 INC AMD 1.

THE ELECTRICITY COUNCIL

ENGINEERING MANAGEMENT CONFERENCE

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

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ADDENDA

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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effect from the date of issue of this Recommendation these Engineering Recommendations, with the exception of P16, are withdrawn.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.

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 syste 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.

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 referenc 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_o 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

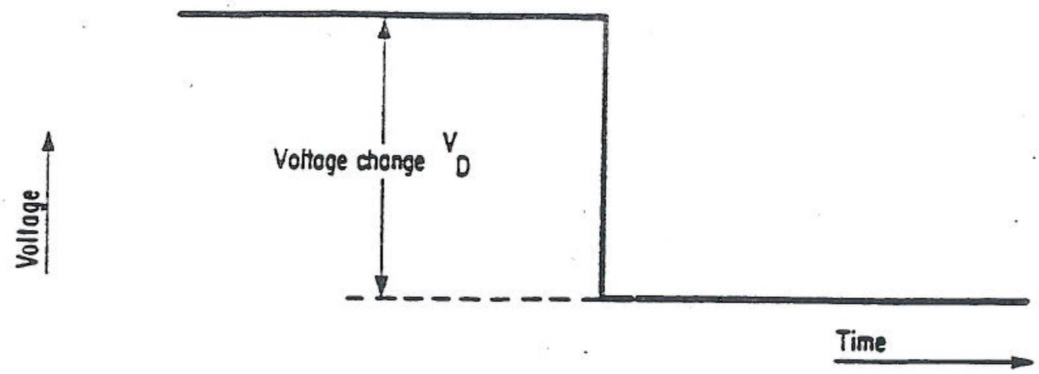


FIGURE 2 RAMP-TYPE VOLTAGE CHANGE

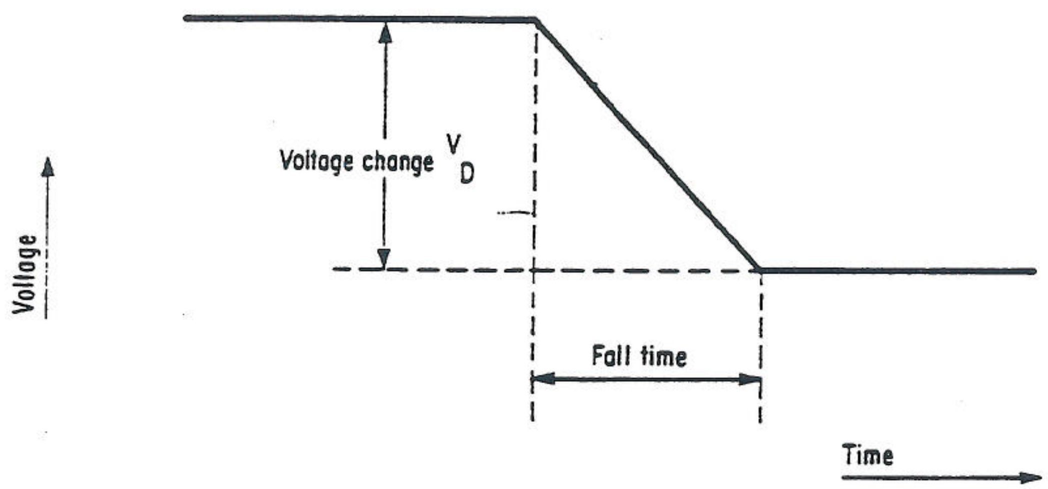
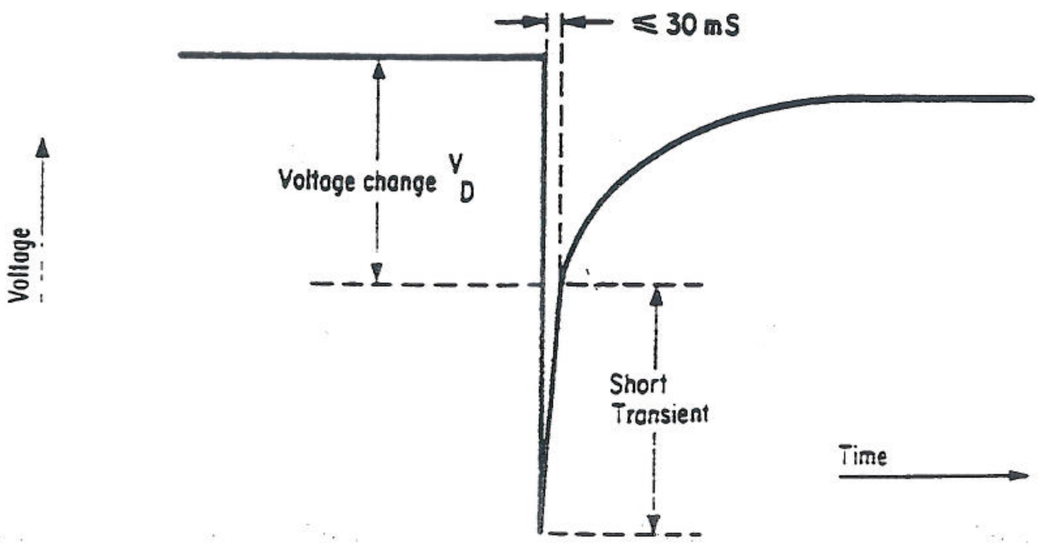


FIGURE 3 USUAL FORM OF VOLTAGE CHANGES CAUSED BY MOTOR STARTING



WITH RESPECT TO THE TIME BETWEEN EACH CHANGE

$P_{ST} = 0{\cdot}5$

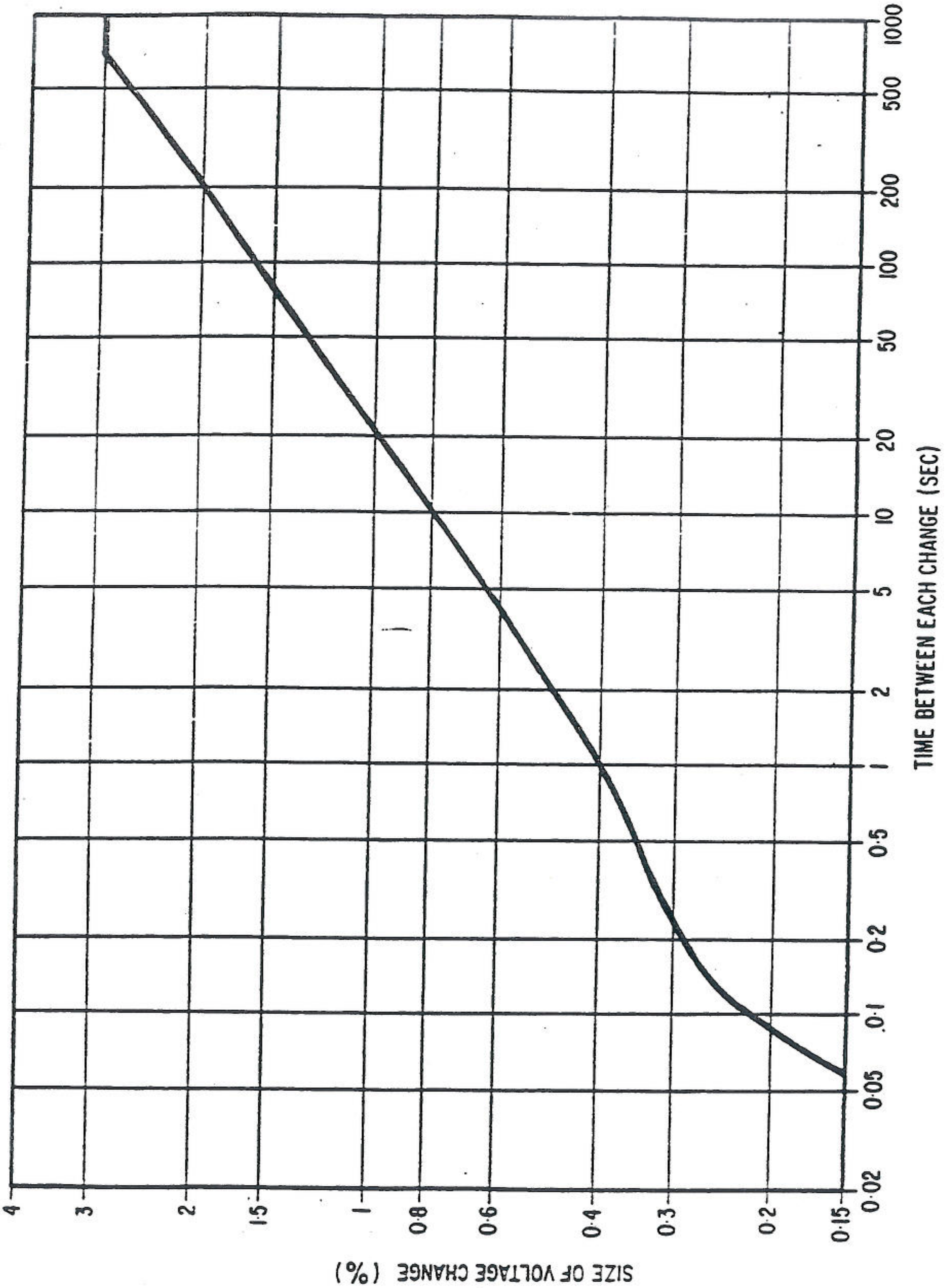
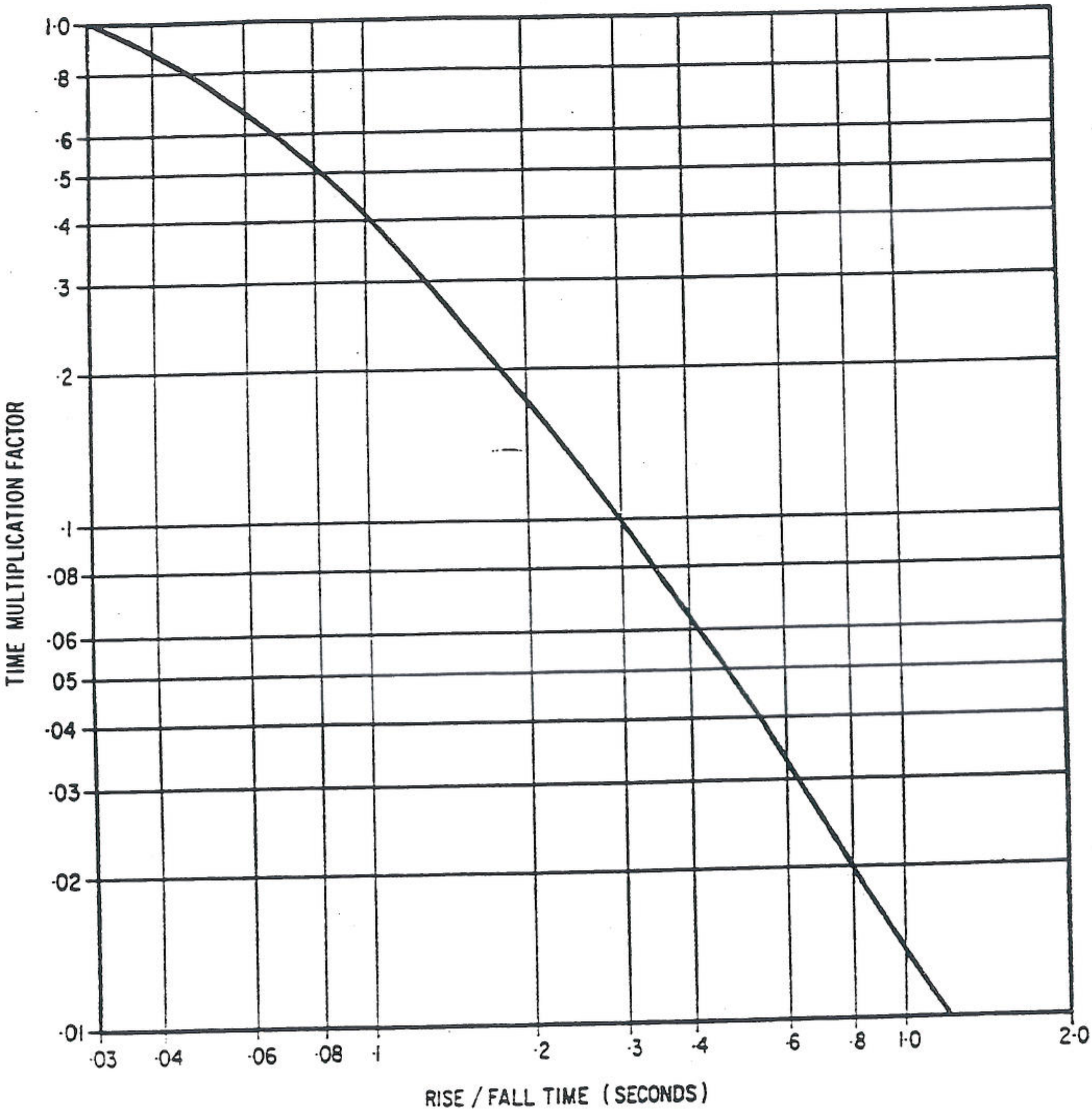


FIGURE 5 MULTIPLICATION FACTOR FOR DERIVING THE MINIMUM TIME BETWEEN RAMP-TYPE VOLTAGE CHANGES FROM THE STEP CHANGE LIMIT OF FIGURE 4



Minimum time between voltage changes = TIME (from figure 4) x TIME MULTIPLICATION FACTOR 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 shredder 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. non-ferrous 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.

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 (≤ 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 Vm 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 $Pst \leq 0.5$, 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} $\sqrt[3]{\frac{1}{12}\Sigma (P_{st}^3)}$
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