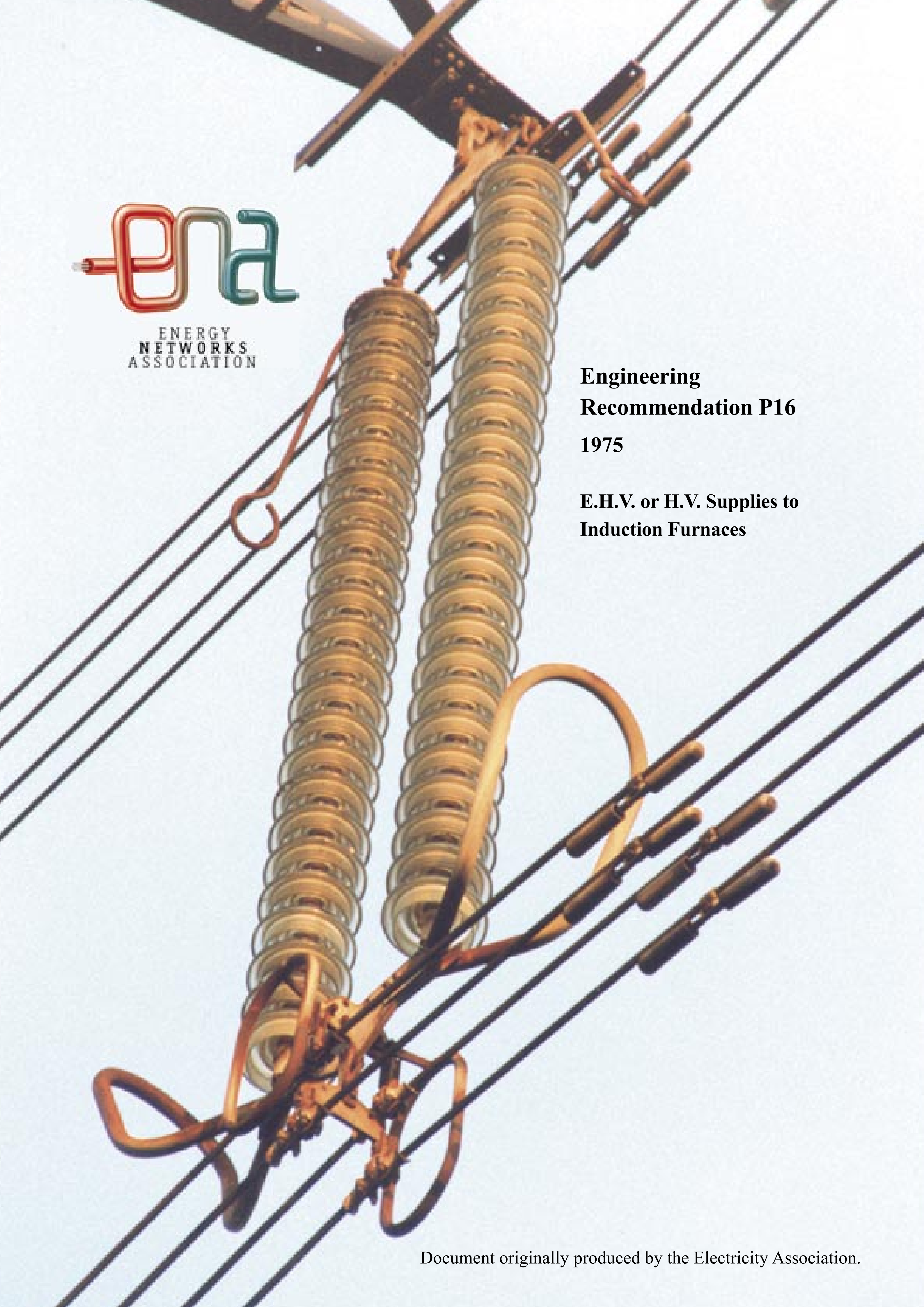

ENERGY NETWORKS ASSOCIATION

Engineering Recommendation P16

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E.H.V. or H.V. Supplies to Induction Furnaces

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E.H.V OR H.V. SUPPLIES TO INDUCTION FURNACES

1. SCOPE

Induction furnaces may disturb the supply system by producing voltage dips or rises, and/or voltage unbalance and/or harmonics. This Recommendation states the limits of disturbance which should be observed, and applies to induction furnaces (for heating with or without melting) of any size supplied from a point of common coupling which is on the H.V. or E.H.V. system. Reference is also made to the responsibility for costs of any special measures required, to measurement of voltage unbalance of the 3-phase supply system, and to the information required from the consumer.

The initial assessment covered by this Recommendation is intended as a guide as to whether a proposed furnace installation can be connected to the supply system without risk of undue interference to the equipment of other consumers. When a proposed installation is likely to exceed the proposed limits a more detailed investigation will be necessary.

The present Recommendation is an interim one - the intention is that the situation be reviewed when further information has been obtained. In the meantime close collaboration is to be maintained with the manufacturers and users of induction furnaces. Any problems arising in the application of this interim Recommendation should be referred to the Head of Engineering at the Electricity Council.

2. DEFINITIONS

2.1 The point of common coupling (p.c.c.) with other consumers is the point on the public supply network, electrically nearest to the induction furnace installation, at which other consumers' loads are, or may be, connected.

2.2 Inrush Current. When a reactance (inductive or capacitive) is switched onto an a.c. supply, initial transient currents greater than the sustained current may flow for a short time depending on the instant of switch-on. Their duration for an induction furnace installation may range from a few milliseconds to several cycles of the 50Hz supply. Likewise, a furnace transformer will draw an inrush current when it is switched on to the supply. For the purposes of this Recommendation inrush current is the maximum transient current taken when the furnace is switched for each melt cycle. This current will be required for calculating the voltage dip defined in the following paragraph, but see also Section 3.1.

2.3 The voltage dip at the p.c.c. is that occurring at switch-on or power change or other adjustment. It takes account of the effects of the sustained load current and also of transient inrush current when this occurs, by defining the dip to be that which is effective for more than 1 cycle of the 50Hz supply. A voltage rise measured at the same p.c.c. (at switch-on or off as appropriate) is also covered where the words "voltage dip" are used.

ΔV_1 = voltage dip effective for more than 1 cycle of 50Hz supply, based on the worst inrush condition.

ΔV_2 = steady voltage dip due to the sustained full load current.

ΔV_A = voltage dip (effective for more than 1 cycle of the 50Hz supply) for the average switch-on situation (allowing for the worst switch-on instant not occurring every time).

In principle these are R.M.S. values - see also Appendix 2.

2.4 The voltage dip will be either line/neutral or line/line for the worst phase(s) involved at the p.c.c. Pending issue of the ACE Report referred to in section 8 below, use should be made of the general methods of ACE Report No. 7 and Engineering Recommendation P.9 (Supply to Welding Plant) for calculating the effects of single phase loads and for any unbalanced component of the 3-phase currents taken by a nominally balanced furnace installation (in particular the inrush currents may not be balanced).

2.5 The voltage unbalance factor of a 3-phase system is:-

$$\frac{\text{Negative phase sequence component of voltage}}{\text{Positive phase sequence component of voltage}}$$

It may be shown that where there is only one single phase load, then for all practical purposes

$$\left.\begin{array}{l}\text{Voltage}\\ \text{unbalance}\\ \text{factor}\end{array}\right\} = \frac{\text{single phase load (kVA)}}{\text{three phase short circuit level (MVA) x 10}}\ \%$$

(as defined in Section 3.2)

2.6 Harmonic currents injected into the system will normally be those measured at the p.c.c. (often the supply metering point).

2.7 Sub-harmonic instability is a phenomenon sometimes occurring with magnetic frequency convertors (e.g. triplers) or saturable reactors and is more fully explained in Section 4.4 below.

2.8 A "soft start" refers to a method of limiting inrush currents at switch-on. It involves connection of the load to the supply via short time rated series resistors which are subsequently shorted out.

One or more resistors may be connected in series thereby providing two or more steps in the soft start.

3. BASIS OF SHORT CIRCUIT LEVELS AND LIMITS SPECIFIED IN THIS RECOMMENDATION

3.1 Voltage Fluctuations

In considering voltage fluctuations, the short circuit level corresponding to normal system operating conditions should be assumed (some increases in fluctuation during single outage conditions - fault or maintenance - would be tolerated).

The limit for voltage dip is set by the visible effect on tungsten lighting, for which it is already the practice to limit step voltage changes (repeated with a cycle time of between 33 seconds and 2 hours) to 1% and for which it has also been ascertained (int.al. by the ERA) that a short rectangular voltage dip (e.g. due to transient inrush currents), if it lasts for more than about 30 milliseconds, has the same visibility as a step voltage change of equal magnitude.

The allowance for each switching operation not causing the worst inrush condition every time is assumed to be sufficiently represented by:-

$$\Delta V_A = \frac{2}{3} (\Delta V_1 - \Delta V_2) + \Delta V_2$$

The relatively frequent voltage dips resulting from the furnace melting cycle are expected to be the most likely to cause annoyance and, therefore, are used as the criterion for acceptance in section 4.1. When the furnace transformer normally remains energised - see section 4.1 - transformer magnetising inrush current will not flow when the furnace is switched and hence would not come into the calculation.

3.2 Voltage Unbalance

In view of the possibility of damage to motors (see following paragraph), the short circuit level corresponding to single outage conditions - fault or maintenance - should be assumed when applying the voltage unbalance limit. See also section 3.4 regarding minimum generation.

The limit to system voltage unbalance factor is set by the sensitivity of ac motors - the figure of 2% which is quoted in BS 2613 should be regarded as the limit of an exceptional, rather than a normal operating condition. The limits quoted in section 4.2 are intended to allow for a measure of voltage unbalance from other causes at the p.c.c. (and/or on the system fed from it), and for a possibly lower short circuit level during summer generation conditions.

3.3 Harmonics

In considering harmonics, normal system operating conditions should usually be assumed. In some instances single outage conditions may also need to be studied.

The limits for harmonic currents injected into the supply system have:-

(a) for the 5th, 7th, 11th and 13th been set the same as Engineering Recommendation G.5/2 and

(b) for the 2nd, 3rd and 4th been set no higher than the 5th (in view of the possibility of resonance on the higher voltage system) pending revision of Engineering Recommendation G.5/2.

See also section 4.3 below.

3.4 Generation Conditions

In all the above cases, if generation forms a significant contribution to the relevant short circuit level, the readily available figure for winter minimum generation should be used. This approximates to the level of generation obtaining for substantial periods at other times of the year. Generation which would become time-expired during the period under review should be ignored.

4. LIMITS TO BE OBSERVED

A prospective induction furnace installation should comply with the following:-

4.1 Voltage Fluctuations (normal operating conditions)

The voltage dip at the p.c.c. (at switch-on or power change or other adjustment) which is effective for more than 1 cycle of the 50Hz supply, i.e. the highest value of ΔV_A for the average switch-on situation defined above, should comply with the following (see also Appendix 2):-

(a) Counting each switching operation and each step of the soft start as separate cycles of fluctuation, the combined number of operations in the one minute period which contains the largest number of fluctuations, should be assessed. The permitted voltage dip should then be determined from Fig. 1 (which is based on Fig. 11 of Engineering Recommendation P.9 - Supply to Welding Plant).

(b) Where there is a "soft start" the time between the steps of the soft start should be assessed and Fig. 2 should also be complied with - i.e. the permitted voltage dip will be the lower of those determined from Figs. 1 and 2.

Exceptionally, if the equipment is so designed that a current change is gradual and cannot take less than 2 seconds, up to 3% voltage dip may be permitted, provided that this can be accommodated within the required overall voltage regulation of the section of system concerned.

Exceptionally, if switching events occur less frequently than one in 2 hours, up to 3% voltage dip may be permitted, provided that this can be accommodated within the required overall voltage regulation of the section of system concerned.

Some installations are arranged with the contactor (or other switching device), which is operated each melt cycle, connected on the secondary side of the furnace transformer. In these cases the furnace transformer should be energised with the secondary off load and preferably not more than about once per day.

4.2 Voltage Unbalance (single outage conditions)

The voltage unbalance factor at the point of common coupling with other consumers, based on the consumer's worst sustained negative phase sequence component of current (assuming an initially symmetrical system at this point and based on supply system single outage conditions and winter minimum generation) should not exceed:-

1% at 33kV and above, or 1.3% below 33kV.

For a furnace equipped with a balancer, these voltage unbalance limits may be exceeded for not more than 5 minutes in every 30 minutes in order to accommodate some mismatch of the balancer (e.g. due to the changing nature of the melt as it heats up) during the operating cycle.

4.3 Harmonics (normal operating conditions)

Harmonic currents should not exceed the values in the following Table at any point in a system:-

TOTAL PERMISSIBLE HARMONIC CURRENT

NETWORK VOLTAGE AT THE POINT OF COMMON COUPLING	HARMONIC CURRENT IN AMPS						
	2nd	3rd	4th	5th	7th	11th	13th
6,600/11,000	9.7	9.7	9.7	9.7	6.3	10.0	8.5
33,000	9.6	9.6	9.6	9.6	6.3	7.0	6.0
66,000	4.8	4.8	4.8	4.8	3.2	3.5	3.0
132,000	3.0	3.0	3.0	3.0	2.5	3.3	2.8

In view of the possibility of resonance on the higher voltage systems, the limits for the 2nd, 3rd and 4th harmonics have been set no higher than the limit for the 5th harmonic until work for the revision of Engineering Recommendation G.5/2 has been completed. Installations exceeding the limits set out in the above Table may receive special study to examine the harmonic current distribution throughout the network using, if necessary, computer programmes developed for the purpose (see Index of Engineering Applications of Computers).

Bearing in mind that the limits imposed are necessarily based on certain simplifying assumptions and in order to permit as flexible an interpretation of the Recommendation as possible, attention is drawn to the use of filters for limiting the harmonic currents passed to the network and also to the use of protective chokes with capacitor installations to eliminate possible resonances and overloading.

4.4 Sub- harmonics

Sub-harmonic instability (an unbalanced variation at a sub-harmonic or irregular frequency of the 3-phase currents, usually with waveform distortion) may occur with magnetic frequency convertors (e.g. triplers) or saturable reactor controlled furnaces. This phenomenon, if it occurs, can cause serious trouble and it must not therefore be allowed to remain on the system. Although some installations of these types have been connected without trouble, it is not possible at the present time to predict in advance of the connection of a proposed furnace whether instability will occur. Therefore the consumer's assurance should be obtained that suitable facilities (e.g. filters) are to be provided, or will be provided, to eliminate such instability if it occurs.

5 COST OF SPECIAL MEASURES

Where compliance with the above recommendations requires the provision of special supply system arrangements, the extra costs (over and above the cost of the new works which would be required to supply a non-disturbing load of the same magnitude) should be borne by the consumer owning the furnace(s).

Where the furnace installation is specially designed or modified (e.g. as a result of supply authority acceptance tests) in order to comply with the above recommendations, the total cost of these refinements should be borne by the consumer.

6 MEASUREMENT OF VOLTAGE UNBALANCE FACTOR

The Electricity Council is arranging to hold a number of instruments for measurement of the negative phase sequence component of voltage. These will be made available on application to the Engineering Division (Technical Research Branch), The Electricity Council, 30 Millbank, London SW1P 4RD.

7 PROCEDURE FOR INVESTIGATION OF AN INQUIRY, AND INFORMATION REQUIRED

The steps necessary for consideration of an inquiry from a consumer are outlined in Appendix 1. This also indicates the information the consumer is likely to required from the Electricity Board for either a limited study (where the disturbance limits are unlikely to be exceeded) or a detailed study.

8 ACE REPORT

An ACE Report is in preparation covering the properties of various furnaces, the basis of the above figures and the special measures which may be necessary to comply with the recommendation.

Note:
For an induction furnace, a switch-on or a switch-off operation may produce (due to the transient effects) a complete cycle of fluctuation (down and up or up and down) but this should be taken as one operation (as defined in Section 4.1(a)).

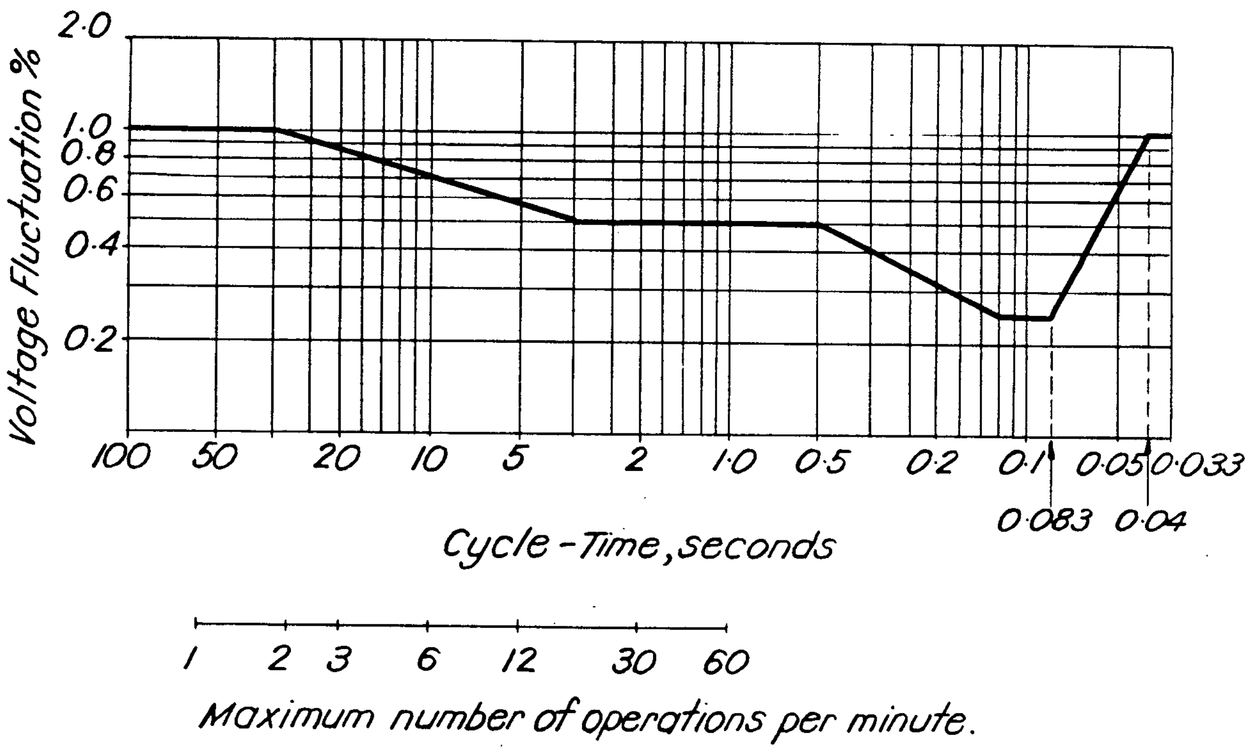

FIG 1. MAXIMUM ALLOWABLE VOLTAGE FLUCTUATION TO BE CAUSED BY INDUCTION FURNACES

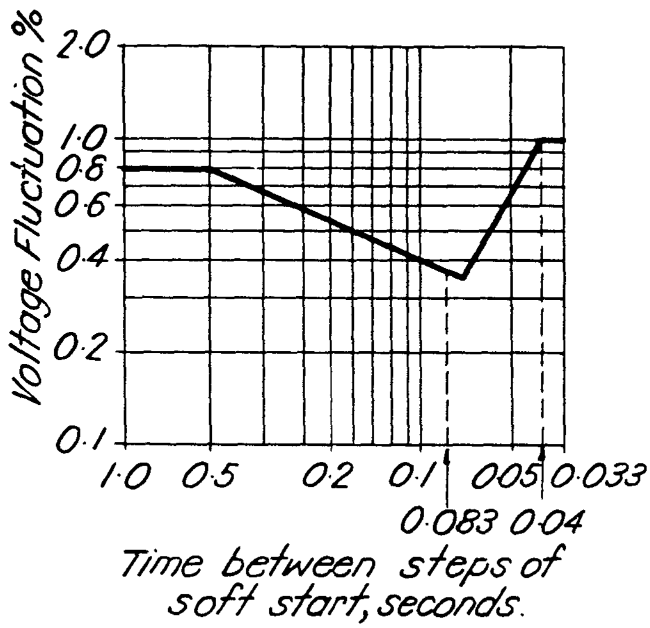

FIG. 2. MAXIMUM ALLOWABLE VOLTAGE FLUCTUATION TO BE CAUSED BY A SOFT START

PROCEDURE FOR INVESTIGATION OF AN INQUIRY FOR A PROPOSED INDUCTION FURNACE

1. Information to be provided with initial inquiry by consumer for supply to Induction Furnace

1(a) Rating(s) of proposed furnace(s).

(b) Type of furnace under consideration.

(c) Envisaged operating frequency (Hertz) of furnace load.

(d) Proposed type of power control (e.g. transformer taps, saturable reactor or thyristors etc).

(e) Draft outline of furnace operations (kVA/time), including the probable duration of heating or melting cycle and number of melts per day.

2. Initial information to be provided by Electricity Board to enable consumer to formulate inquiry to Manufacturers

2(a) System Impedance (R + j X) and short circuit level at supply terminals for expected normal and single outage conditions.

(b) Ditto at point of common coupling if significantly different.

(c) Estimated present harmonic voltage distortion.

(d) Tentative initial indication of probable design limits, particularly any arrangements which will obviously not be acceptable.

3. Assessment where no detailed study is needed

Following confirmation of the furnace parameters and where the envisaged disturbance to the system is obviously within the limits of this Recommendation, it is envisaged that a decision can be given to the consumer without the detail specified in the next Section.

4. Detailed items to be assessed as appropriate where a full study is necessary

(Only those items necessary for the depth of study required, and appropriate to the type of furnace installation, need be requested).

4.1 All Types

4.1.1 Where appropriate, an estimate of the number of switching operations per melt. (Some types create the equivalent of a further switching operation each time the power factor or balance is adjusted).

4.1.2 Works distribution diagram showing consumer's H.V. system where there is a possibility of supplying the works load or a portion of the works load from two or more injection points.

4.2 <u>50Hz Furnaces</u>

4.2.1 Position in circuit of contactor or switching device which is operated each melt cycle.

4.2.2 "Soft start" arrangements (if any) and time between steps of soft start.

4.2.3 Transient inrush currents (magnitude and duration) when furnace is switched as for each melt cycle and whether quoted figures are "worst" or "average" - to enable voltage dips ΔV_1 and ΔV_A to be calculated.

4.2.4 For saturable reactor or thyristor controlled types, the method of complying with the rate of rise of power specified by the Supply Authority.

4.2.5 For saturable reactor or thyristor or other harmonic generating controls, details of the harmonic currents which will be injected into the supply system at the worst condition of operation with any harmonic filters in circuit.

4.2.6 Frequency of switching on primary of furnace transformer (e.g. once per day).

4.2.7 Method of adjustment of power factor (manual/auto/bolted links; off load/on load with/without individual "soft start") and envisaged range of variation.

4.2.8 Where fitted with balancing equipment, the method of adjustment, if any (manual/auto/bolted links; off load/on load with/without individual "soft start") and envisaged range of residual negative phase sequence components of current.

4.3 <u>Furnace Supplied bv Magnetic Frequency Convertors (150, 250 or 450Hz)</u>

4.3.1 Method of switching and "soft start" arrangements, if provided, including time between steps of soft start.

4.3.2 Transient inrush currents (magnitude and duration) when furnace is switched as for each melt cycle and whether quoted figures are "worst" or "average" to enable the voltage dips ΔV_1 and ΔV_A to be calculated.

4.3.3 Details of the harmonic currents which will be injected into the supply system at the worst condition of operation with the harmonic filters in circuit.

4.3.4 Method of adjustment of load control capacitors (manual/auto/bolted links; off load/on load with/without individual "soft start").

4.3.5 Type of facility for use in elimination of sub-harmonic instability should it occur.

4.3.6 Arrangements for limiting sensitivity of equipment to variation of H .V. system voltage (e.g. use of current limiting reactances).

4.3.7 Power factor of 50Hz side.

4.3.8 Frequency of switching on primary side of installation (e.g. once per day).

4.4 Furnace supplied by Convertor/Invertor equipment

4.4.1 The number of pulses of the convertor

4.4.2 Details of the harmonic currents which will be injected into the supply system at the worst condition of operation (with harmonic filters - if any - in circuit).

4.4.3 The method of complying with the rate of rise of power as specified by the Supply Authority (alternatively, "soft start" data as for items 4.3.1 and 4.3.2 above).

4.4.4 Frequency of switching on primary side of convertor/invertor equipment (e.g. once per day).

4.5 Furnace supplied by Motor/generator

4.5.1 The motor starting arrangement, starting currents and frequency of starting.

INRUSH CURRENT
CALCULATION OF VOLTAGE DIP

1. As part of the information provided by the manufacturer:-

   (i) The peak inrush current may be stated as a multiple of the peak of the fundamental full load current.

   (ii) The decay time may be stated, or alternatively, the duration of the first lobe of current may be stated, together with the magnitude of a few subsequent cycles of current.

2. The basic problem is to convert this information into voltage dip at the p.c.c. and to interpret this in terms of visibility on lighting or other equipment.

3. A full analysis is not available at the present time, but the following example outlines one approach using the knowledge available.

4. A 1.5 MW furnace equipped with balancer and operating at 0.993 P.F. ($\sin \emptyset = 0.12$) is to be supplied from a p.c.c. of 180 MVA normal short circuit level with an $\frac{X}{R}$ ratio of 11 and with 10% mis-match in the balancer.

   The "Vector" voltage regulation for a balanced load of 1.5 MVA and 180 MVA fault level would be $\frac{1.5}{180} \times 100\% = 0.83\%$

   Hence, the full load voltage drop in the worst phase =

   (Vector Regulation) $\left(\frac{R}{X} \cos \emptyset + \sin \emptyset + \text{Unbalance} \right)$ =

   $$\Delta V_2 = \frac{1.5}{180} \times 100 \left(\frac{1}{11} \times 0.993 + 0.12 + 0.10\right) = 0.26\%$$

5. At first examination an inrush current of three times full load might be thought to produce maximum voltage dip ΔV_1 of 3 x 0.26% = 0.78% and hence

   $$\Delta V_A = \frac{2}{3} \left(\Delta V_1 - \Delta V_2 \right) + \Delta V_2 = \frac{2}{3} (0.78 - 0.26) + 0.26 = 0.61\%$$

   However, the different transient characteristics of the components of the furnace circuit and the balancer are likely to result in the inrush currents being unbalanced. Thus, the voltage rise on one phase (or the voltage dip on another) may approach the "vector" regulation corresponding to the inrush. In the above example ΔV_1 = 3 x 0.83 = 2.5% and thus

   $$\Delta V_A = \frac{2}{3} \left(\Delta V_1 - \Delta V_2 \right) + \Delta V_2 = \frac{2}{3} (2.5 - 0.26) + 0.26$$

   $$= \frac{2}{3} \times 2.24 + 0.26 = 1.75\% \text{ for the above assumptions.}$$

   In practice, the voltage dip may lie between these estimates of 0.61% and 1.75%.

6. Where it can be shown that the inrush is only of very short duration (a few milliseconds - as may be the transient associated with a capacitor) the effect may be assessed as follows. Since the system impedance is largely inductive the major part of the voltage dip will be reflected in the differentiation of the current wave. The relationship of this dip to the supply voltage wave is dependent on the duration of the current wave and its phase position. For the very short pulse of a few milliseconds, the net effect would be as in the following diagrams:-

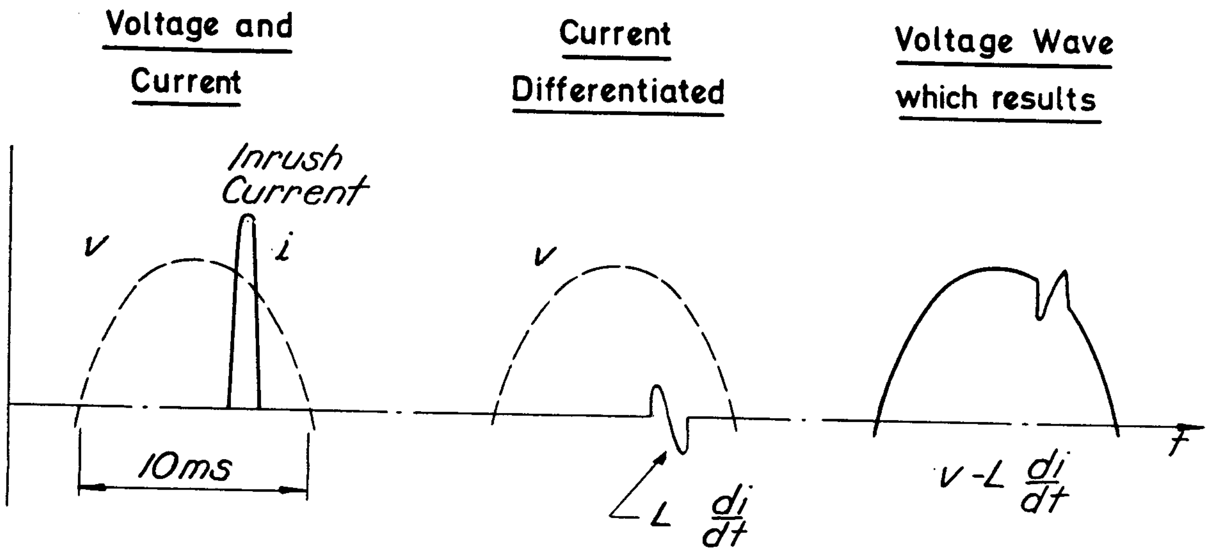

FIG. 3

7. Thus, an inrush component with a duration of only a few milliseconds, may have only a small effect.

8. Insufficient information is available to provide a more precise example at the present time.

9. Item 4.1 of the Recommendation should therefore be regarded as describing in principle the limits of voltage fluctuation which it is believed will need to be complied with in order to avoid complaints. It is recognised that the manner of application of these limits involves, for the time being, a qualitative interpretation of some of the information relating to inrush current.