Engineering Recommendation P28

Issue 2 2018

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Voltage fluctuations and the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom

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2	2018	Major technical revision

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Foreword

This Engineering Recommendation (EREC) is published by the Energy Networks Association (ENA) and comes into effect from date of publication. The approved abbreviated title of this Engineering Recommendation is “EREC P28”, which replaces the previously used abbreviation “ER P28”.

Revision of this EREC has been prepared under the authority of the Grid Code and Distribution Code Review Panels of Great Britain – being a qualifying standard and licence standard under these respective codes. The review and subsequent revision of EREC P28 has been overseen by the ENA P28 Working Group. Approval for publication has been granted by Ofgem.

This EREC supersedes ENA Engineering Recommendation P28 Issue 1 1989.

This EREC has been fully updated with reference to the United Kingdom implementation of the IEC 61000 series of Standards so far as they relate to voltage fluctuations and disturbance.

Harmonic voltage distortion and voltage unbalance aspects associated with the connection of disturbing equipment to transmission systems and distribution networks are covered in ENA Engineering Recommendation G5 and Engineering Recommendation P29 respectively.

This document constitutes a full technical revision of EREC P28 Issue 1. This issue [Issue 2] of EREC P28 has been extended to cover assessment and limits for rapid voltage changes (RVCs).

This EREC is intended to be read as a standalone document; references to other publications are intended to direct users to additional supporting information that could be useful but not essential to understanding requirements.

Engineering Report P28 [8] provides background, information and examples that support the requirements in this EREC.

This EREC should be used by those who propose to connect disturbing equipment with the potential for voltage fluctuation, being flicker and/or RVC, to public electricity supply systems. The document should also be used by those who carry out assessments concerning the suitability of connecting such equipment to these systems.

This document is not intended to replace or override requirements in BS EN 50160 for ensuring acceptable voltage quality.

The terms ‘this Engineering Recommendation’ and ‘this EREC’ refer to Engineering Recommendation P28 Issue 2 2018, as amended.

In this document, the term ‘shall’ relates to a statutory or mandatory requirement. The term ‘should’ expresses a recommendation and the term ‘may’ indicates a permission.

Commentary, explanation and general informative material is presented in smaller *italic* type, and does not constitute a normative element.

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The term ‘system/network operator’ in this EREC is intended to apply to owners and operators of transmission systems and distribution networks, in so far as the requirements are applicable to their statutory and regulatory duties and responsibilities.

The term ‘disturbing equipment’ is intended to refer to individual items of disturbing equipment, whereas the term ‘fluctuating installation’ is intended to refer to multiple items of disturbing equipment contained within an installation connected to the supply system.

The convention used for cross-referencing clauses within this EREC is the omission of the term ‘clause’ before the clause number and the placing within parenthesis. For example: “(see 5.3)” denotes a cross-reference to Clause 5.3 in this document.

Abbreviations used throughout this document are stated in ‘Terms and definitions’ (see 3).

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Introduction

Repetitive voltage fluctuations of sufficient frequency and/or magnitude in the supply system can cause the luminance of incandescent lamps, e.g. traditional tungsten filament light bulbs, to fluctuate with time. This creates an impression of unsteadiness of visual sensation in humans, who observe these fluctuations. This effect is known as flicker. If the flicker is of sufficient severity then this can be annoying to observers and can result in them complaining to the system/network operator.

Fast changes in supply system voltages can result from energising/de-energising certain types of electrical equipment. These are known as rapid voltage changes (RVCs) which, if of sufficient magnitude, duration and frequency, can cause maloperation of and damage to equipment and similar annoyance, as flicker, to those that observe changes in luminance of electric lighting. The process for assessment of RVCs is described in Clause 5.3.

EREC P28 was first published in 1989 to provide recommended planning limits for voltage fluctuations for connection of equipment to public electricity supply systems in the UK. Issue 1 was primarily concerned with assessment of voltage fluctuations and associated flicker produced by traditional domestic, commercial and industrial loads. Since EREC P28 was first published, the factors affecting development of transmission systems and distribution networks, and equipment connected to them have changed significantly. There has been a shift towards connection of distributed/embedded generation equipment powered by renewable energies and other low carbon technology equipment. These types of modern equipment are capable of causing flicker. As such, the impact of connecting modern equipment has been reviewed and EREC P28 has been updated accordingly.

Significant developments in Electromagnetic Compatibility (EMC) requirements have taken place, which are captured in the International Electrotechnical Commission (IEC) 61000 series of Standards and technical reports. United Kingdom implementation of these Standards is captured in the various parts of BS EN 61000. Consequently, EREC P28 Issue 2 has been revised in line with the requirements of these Standards, so far as they apply to the limitation of voltage fluctuations in public electricity supply systems and resultant flicker. Relevant considerations in IEC technical reports have been reviewed and, where appropriate, have been adopted.

The flickermeter algorithm is based on the perceived visual effects from traditional incandescent light bulbs, which are being phased out and replaced by new technology lamps including:

- halogen;
- compact fluorescent lamps (CFL);
- light emitting diodes (LED).

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Whilst most new technology lamps are less sensitive to applied voltage fluctuations, some are more sensitive at higher frequencies [of voltage fluctuation] than the traditional 60 W incandescent lamp, which is the reference lamp for the flicker curve[1].

For example: some types of high pressure discharge lighting might produce marginally higher levels of flicker severity than tungsten filament lamps at higher frequencies of the voltage fluctuation spectrum, however operating experience over many years has not found this to be problematic. The requirements in this EREC will need to be kept under review given on-going developments in lighting technology.

International Standards continue to use the existing flicker curve [P_{st} = 1 in Figure 2 of BS EN 61000-3-3] for assessing the disturbance to lighting and all other equipment connected to public electricity supply systems caused by voltage fluctuation. The limits for voltage fluctuation in EREC P28 Issue 2 are compatible with the existing flicker curve.

This EREC defines good engineering practice, which is applicable to the connection of customers' disturbing equipment and fluctuating installations, with respect to limiting voltage fluctuations on transmission systems and distribution networks in the United Kingdom.

The intention is that planning levels stated in this EREC will ensure emissions from new connections of customers' disturbing equipment and fluctuating installations are sufficiently below immunity levels of equipment connected to the system so as not to cause unacceptable disturbance to other customers and system users. Disturbance includes the effect of voltage fluctuations on flicker severity and/or the capability of equipment connected to the system to function correctly. The planning levels in this document should not be considered as targets and all reasonable steps should be taken to minimise voltage fluctuations.

A key principle in this EREC is that the visual discomfort due to light flicker is the most frequent reason to limit voltage changes due to fluctuating installations. Flicker, if particularly severe, can adversely affect the health of those people exposed. This is why minimising flicker, where possible, is important. System/network operators have to maintain the voltage magnitude within narrow limits and individual customers should not produce significant voltage fluctuations even if they are tolerable from a flicker perspective.

A three-stage approach is presented for assessing the acceptability of the connection of proposed disturbing equipment and/or fluctuating installations, in terms of flicker, to supply systems.

a) Stage 1

The intention is that individual equipment that conforms to relevant product standards can be connected to the system without further assessment under Stage 1 (see 6.3.2).

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[1] The term 'flicker curve' relates to the curve for P_{st} = 1 for rectangular equidistant voltage changes as illustrated in Figure 2 of BS EN 61000-3-3. The flicker curve is used to determine the amplitude of rectangular voltage changes that correspond to a flicker severity of P_{st} = 1 for a particular rate of repetition.

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b) Stage 2

Disturbing equipment that does not conform to Stage 1 requirements but conforms to limits and requirements in Stage 2 can be connected without detailed assessment or consideration of flicker background level (see 6.3.3).

c) Stage 3

All other disturbing equipment that does not conform to limits and requirements in Stage 2 will need detailed assessment against Stage 3 limits and requirements before it can be connected (see 6.3.4).

The characteristic of flicker means disturbances from independent sources are not directly additive. In practice, additional disturbing equipment/fluctuating installations can generally be connected to the electricity supply system even when the existing flicker background level is approaching the planning level[2]. The coincidence of RVCs from independent sources is considered to present a low enough probability that no summation laws are taken into account when assessing RVCs. Whilst it is recognised that particular network designs could result in coincident RVCs under certain circumstances, e.g. restoration of systems/networks following a G59 trip event, conformance to the limits in this EREC is still required.

Therefore, flicker from disturbing equipment/fluctuating installations should not be unnecessarily constrained by system/network operators, to allow for future unspecified emissions, subject to good engineering practice being followed in the design and installation of disturbing equipment.

If disturbing equipment fails to meet the stage limits following assessment, in exceptional circumstances the system operator or network operator may permit the connection of disturbing equipment even though flicker levels are likely to exceed planning levels. The final decision as to whether or not disturbing equipment exceeding the limits in this EREC may be connected to the public electricity supply system is at the discretion of the relevant system/network operator – subject to any other recourse that could be available to customers[3].

1 Scope

This EREC defines planning levels and compatibility levels for the assessment of voltage fluctuations from customer disturbing equipment and fluctuating installations to be connected to transmission systems and distribution networks in the United Kingdom.

This EREC only applies to the proposed connection of customer disturbing equipment and fluctuating installations. It is not intended to apply to the connection of equipment or installations operated by licensed distribution network operators or licensed transmission system operators.

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[2] A review of flicker background levels in the UK public electricity supply system has not found any evidence to support apportioning of remaining capacity to prevent planning levels being exceeded in future. See ENA Engineering Report P28 [8].

[3] Such as Regulation 26 of The Electricity Safety, Quality & Continuity Regulations 2002 [6] (as amended) for GB and Regulation 27 The Electricity Safety, Quality and Continuity Regulations (Northern Ireland) 2012 [7] (as amended) for Northern Ireland.

The scope of voltage fluctuations in this EREC applies to flicker or RVCs emitted onto the public electricity supply system by customer equipment, i.e. customer owned demand, generation, energy storage[4], or other types of disturbing equipment that may be connected.

This EREC is not intended to be applied retrospectively to existing connections that have been previously assessed under Issue 1 of EREC P28.

However, it is intended to be applied in the event of any change(s) to existing customer disturbing equipment/fluctuating installations that affect voltage fluctuation and to new connections.

This EREC neither replaces nor negates the United Kingdom implementation of EMC Standards, including relevant harmonised equipment Standards that are applicable to particular equipment, under the terms of the Electromagnetic Compatibility Regulations 2016 [1]. The intention is to assist customers to meet their obligations under these Regulations and to prevent interference.

The provisions in this EREC only apply to voltage fluctuations and connection of disturbing equipment. Other criteria, not stated in this document, apply to meeting current ratings, statutory voltage limits, harmonic distortion limits etc. such that, even if voltage fluctuation aspects are satisfied, the connection of disturbing equipment will be conditional on meeting other criteria.

Specific aspects not considered in this EREC include radiated interference, which might affect communications systems, and specific methods for mitigation of disturbances.

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2 Normative references

The following referenced documents, in whole or part, are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

IEC 60050, *International Electrotechnical Vocabulary*

IEC TR 61000-2-1, *Electromagnetic compatibility (EMC) - Part 2: Environment - Section 1: Description of the environment - Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems*

IEC 61851-21-1, *Electric vehicle conductive charging system - Part 21-1: Electric vehicle on-board charger EMC requirements for conductive connection to an AC/DC supply*

BS EN 61000-2-2, *Electromagnetic compatibility (EMC). Environment. Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*

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[4] Energy storage installations can operate flexibly as load or generation.

BS EN 61000-3-3, *Electromagnetic compatibility (EMC). Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection*

BS EN 61000-3-11, *Electromagnetic compatibility (EMC). Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems. Equipment with rated voltage current ≤ 75 A and subject to conditional connection*

BS EN 61000-4-15, *Electromagnetic compatibility (EMC). Testing and measurement techniques. Flickermeter. Functional and design specifications*

BS EN 61000-6-3, *Electromagnetic compatibility (EMC). Generic standards. Emission standard for residential, commercial and light-industrial environments*

BS EN 61000-6-4, *Electromagnetic compatibility (EMC). Generic standards. Emission standard for industrial environments*

BS EN 61000-4-30, *Electromagnetic compatibility (EMC). Testing and measurement techniques. Power quality measurement methods*

BS EN 61400-21, *Wind turbines. Measurement and assessment of power quality characteristics of grid connected wind turbines*

BS 7671:2008+A3:2015, *Requirements for Electrical Installations. IET Wiring Regulations*

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Other publications

[N1] ENA Engineering Recommendation G83, *Recommendations for the connection of type tested small-scale embedded generators (up to 16 A per phase) in parallel with low-voltage distribution systems*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
compatibility level
specified electromagnetic disturbance level used as a reference level in a specified environment for coordination in the setting of emission and immunity limits

NOTE: By convention, the compatibility level is chosen so that there is only a small probability, for example 5%, that it will be exceeded by the actual disturbance level.

[Equivalent to definition in Clause 3.6 of PD IEC/TR 61000-3-7:2008]

3.2
conditional connection
connection of equipment requiring the customer's supply at the connection point to have an impedance lower than the reference impedance Z_{ref} in order that the equipment emissions conform to the limits in BS EN 61000-3-3

NOTE 1: Meeting the voltage change limits might not be the only condition for connection; emission limits for other phenomena such as harmonics, might also have to be satisfied.

NOTE 2: The symbol Z_{ref} relates to the reference impedance referred to in BS EN 61000-3-3 and BS EN 61000-3-11.

3.3
customer
entity who is or is entitled to either supply or be supplied with electricity at any premises within the United Kingdom excepting the licensed transmission system operator or licensed network operator

NOTE 1: The definition of "customer" broadly aligns with the GB Distribution Code [2] but includes customer own generation by virtue of: "…to either supply or be supplied electricity…".

3.4
distribution network
part of a public electricity supply system that requires the owner or operator to hold a Distribution Licence in the United Kingdom

3.5
disturbance
electromagnetic phenomenon which, by being present in the electromagnetic environment, can cause electrical equipment to depart from its intended performance

3.6
disturbing equipment
equipment that when connected to the public electricity supply system has the potential to cause disturbance from voltage fluctuations

3.7
electricity supply system
lines, switchgear and transformers operating at various voltages which make up the transmission systems and distribution networks to which customers' installations are connected

NOTE 1: Sometimes abbreviated to "supply system" or "system".

NOTE 2: When preceded by the term "public", the wider use of the system is intended.

3.8
electromagnetic compatibility (EMC)
ability of equipment or a system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

NOTE 1: Electromagnetic compatibility is a condition of the electromagnetic environment such that, for every phenomenon, the disturbance emission level is sufficiently low and immunity levels are sufficiently high so that all devices, equipment and systems operate as intended.

NOTE 2: Electromagnetic compatibility is achieved only if emission and immunity levels are controlled such that the immunity levels of the devices, equipment and systems at any location are not exceeded by the disturbance level at that location resulting from the cumulative emissions of all sources and other factors such as circuit impedances. Conventionally, compatibility is said to exist if the probability of the departure from intended performance is sufficiently low. See Clause 4 of BS EN 61000-2-1.

NOTE 3: Where the context requires it, compatibility could be understood to refer to a single disturbance or class of disturbances.

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NOTE 4 Electromagnetic compatibility is a term used also to describe the field of study of the adverse electromagnetic effects which devices, equipment and systems undergo from each other or from electromagnetic phenomena.

3.9
emission
source of electromagnetic disturbance

3.10
emission level
level of a given electromagnetic disturbance emitted from a particular device, equipment, system or fluctuating installation as a whole, assessed and measured in a specified manner

3.11
emission limit
maximum emission level specified for a particular device, equipment, system or disturbing installation as a whole

3.12
ENA
Energy Networks Association

NOTE: ENA have responsibility for the review, publication and maintenance of EREC P28.

3.13
equipment
single apparatus or set of devices or apparatuses, or the set of main devices of an installation, or all devices necessary to perform a specific task

3.14
EREC
Engineering Recommendation

3.15
flicker
impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time

NOTE: Flicker is the effect on certain types of electric lamps, in particular incandescent lamps, while the electromagnetic phenomenon causing it is referred as voltage fluctuations.

[Equivalent to definition in Clause 3.6 of PD IEC/TR 61000-3-10:2008].

3.16
fluctuating installation
electrical installation as a whole, i.e. including disturbing equipment and non-disturbing equipment, which is characterized by repeated or sudden power fluctuations, or start-up or inrush currents which can produce flicker or rapid voltage changes on the electricity supply system to which it is connected

3.17
fundamental frequency
frequency in the spectrum obtained from a Fourier transform of a time function, to which all the frequencies of the spectrum are referred.

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NOTE: For the purpose of this EREC, the fundamental frequency is the same as the power supply frequency.

[Same as definition in PD IEC/TR 61000-3-7:2008].

3.18
high voltage (HV)
voltage exceeding 1 kV

NOTE: Equivalent to definition in the GB Distribution Code [2].

3.19
IEC
International Electrotechnical Commission

3.20
immunity level
maximum level of a given electromagnetic disturbance on a particular device, equipment or system for which it remains capable of operating with a declared degree of performance

3.21
interference
overlap of system disturbance levels and equipment immunity levels resulting in unwanted effects such as visual discomfort, degradation or maloperation of equipment

3.22
long-term flicker severity (P_{lt})
measure of the visual severity of flicker for a specified period derived from the summation of P_{st} values in accordance with the general formula stated in Clause 4 of PD IEC/TR 61000-3-7

NOTE: A 2 h period is specified in this EREC.

3.23
low voltage (LV)
in relation to alternating current, a voltage exceeding 50 V but not exceeding 1 kV

NOTE: Equivalent to definition in the GB Distribution Code [2].

3.24
network operator
owner or operator of a distribution network

NOTE: The term ‘network operator’ primarily applies to licensed Distribution Network Operators (DNOs) and Independent DNOs in the United Kingdom.

3.25
normal operating conditions
variation of generation/demand, the energisation/de-energisation of plant and equipment as a consequence of temporal, seasonal and operational variability, including credible outages, under which the supply system is designed to operate

NOTE: See Clause 6.1.6.

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3.26

planning level

level of a particular disturbance in a particular environment, adopted as a reference value for the limits to be set for the emissions from the installations in a particular system, in order to coordinate those limits with all the limits adopted for equipment and installations intended to be connected to the electricity supply system

[Equivalent to definition in Clause 3.19 of PD IEC/TR 61000-3-7:2008]

3.27

point of common coupling (PCC)

point in the public electricity supply system which is electrically closest to the installation concerned and to which other customers are or might be connected

NOTE: The PCC is generally upstream from the installation concerned.

3.28

protective multiple earthing (PME)

TN-C-S LV supply system

NOTE: The term ‘TN-C-S’ is defined in BS 7671.

3.29

rapid voltage change (RVC)

change in root mean square (r.m.s.) voltage over several cycles

NOTE 1: Rapid voltage changes can also be in the form of cyclic changes.

NOTE 2: See Clause 5.2.

[Similar to definition in PD IEC/TR 61000-3-7:2008].

3.30

service current capacity

the current per phase which can be taken continuously by the customer at their supply terminals without exceeding the plant ratings used by the system/network operator in the design of its system

NOTE: Each part of the LV service equipment that provides the customer connection has a rating, i.e. service cable, cut-out, meter and meter tails. The environment that service equipment is located within affects this rating. In the case of a looped service, the rating is also determined by the service equipment at the adjacent premise(s). Whichever part of the service equipment has the lowest rating defines the service current capacity. It is necessary to consult the network operator to establish the service current capacity. In cases where the network operator declares supply capacities in volt-amperes, the current per phase can be deduced for: single-phase supplies by dividing the volt-amperes by the declared phase-neutral voltage, and three-phase supplies by dividing the volt-amperes by √3 multiplied by the declared phase-phase voltage.

3.31

short-term flicker severity (P_{st})

measure of the visual severity of flicker derived from the time series output of a flickermeter over a 10-minute period

NOTE 1: P_{st} provides an indication of the risk of customer complaints arising from voltage fluctuations.

NOTE 2: P_{st} = 1 for any point on the curve in Figure 2 of BS EN 61000-3-3 (replicated in Annex B) for repetitive and periodic step voltage changes in the form of a square waveform.

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NOTE 3: The term ‘flickermeter’ refers to apparatus for measuring flicker conforming to the requirements of BS EN 61000-4-15.

3.32
step voltage change
change from the initial voltage level to the resulting voltage level after all generating unit automatic voltage regulator (AVR) and static VAR compensator (SVC) actions and transient decay (typically 5 seconds after the fault clearance or system switching) have taken place, but before any other automatic or manual tap-changing and switching actions have commenced

NOTE 1: Automatic voltage regulator also applies to other similar fast acting voltage control responses, e.g. associated with power park modules, HVDC voltage control responses.

NOTE 2: For the purposes of this EREC, percentage step voltage change is the value of step voltage change in volts expressed as percentage change of the nominal system voltage (V_n).

NOTE 3: Step voltage change can be equivalent to the steady state voltage change ($\Delta V_{steadystate}$) (see 4.6).

NOTE 4: By virtue of this definition, a ramped voltage change can be a form of step voltage change and subject to the limit in Clause 5.4.

NOTE 5: Step voltage changes can occur as a result of switching on the system, a fault or operation of disturbing equipment that produces an instantaneous change in steady state voltage.

[Similar to definition in DPC4.2.3.3 of the GB Distribution Code [2]].

3.33
system operator
owner or operator of a transmission system

3.34
transfer coefficient
relative level of disturbance that can be transferred between two busbars or two parts of an electricity supply system for various operating conditions

NOTE: Identical to Clause 3.28 of PD IEC/TR 61000-3-7.

3.35
transmission system
part of a public electricity supply system that requires the owner or operator to hold a Transmission Licence in the United Kingdom

3.36
voltage change
single variation of the r.m.s. value or the peak value of the supply voltage unspecified with respect to form and duration

3.37
voltage dip
temporary reduction of the r.m.s. voltage at a point in the electricity supply system below a specified start threshold

NOTE: Identical to Clause 3.23 of BS EN 50160: 2010+A1: 2015.

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3.38
voltage fluctuation
series of voltage changes that can be regular or irregular

NOTE: Types of voltage fluctuation include: repetitive voltage change associated with flicker, rapid voltage change, step voltage change, etc.

3.39
voltage swell
temporary increase of the r.m.s. voltage at a point in the electricity supply system above a specified start threshold

NOTE: Identical to Clause 3.23 of BS EN 50160: 2010+A1: 2015.

3.40
worst case normal operating condition
the condition that results in the maximum short-circuit impedance when measured at the PCC for the various normal operating conditions considered

4 Basic EMC concepts related to voltage fluctuations

4.1 General

Fluctuations in the supply system voltage can result in excessive flicker and can adversely affect the performance, or even damage, electrical equipment. This can result in complaints from customers to the system/network operator.

To minimise the risk of equipment damage and complaints it is necessary to ensure that:

a) customer installations and associated equipment have a level of immunity to voltage fluctuations; and

b) the magnitude and frequency of voltage fluctuations in the supply system do not exceed recommended compatibility and/or planning levels.

EMC is achieved when the supply system disturbance level/emission level is sufficiently low and the equipment immunity level is sufficiently high to prevent interference.

System operators/network operators are responsible for overall coordination of permitted voltage fluctuations to ensure EMC in the supply system. Consequently, this EREC recommends:

a) planning levels for assessing disturbances and emissions from customer disturbing equipment and fluctuating installations to be connected to public electricity supply systems;

b) emission limits for customers' disturbing equipment and fluctuating installations that are or are proposed to be connected to public electricity supply systems.

Compatibility levels for LV public electricity supply systems in the UK are defined in BS EN 61000-2-2.

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Equipment immunity levels are specified in relevant Standards[5] or agreed upon between equipment manufacturers and customers; as such no recommendations are made in this document.

4.2 Compatibility levels

Compatibility levels are the reference level in the supply system for setting of emission and immunity limits to ensure the EMC in the whole system (including system and connected equipment).

Compatibility levels are specified for entire supply systems so that there is only a small probability, typically 5%[6], that actual disturbance levels in the entire system will exceed the specified compatibility level. Similarly, there is only a small probability that actual equipment immunity levels will be below the compatibility level.

Compatibility levels for representative transmission systems and distribution networks in the UK are specified in Clause 5.

4.3 Planning levels

Planning levels are used for determining emission limits for individual fluctuating installations and take into consideration emissions from other fluctuating installations, i.e. flicker background levels.

Planning levels are specified at each system voltage level and allow coordination of voltage fluctuations between voltage levels[7].

Planning levels for different voltage levels in transmission systems and distribution networks in the UK are specified in Clause 5.

The nature of planning levels means that voltage fluctuations in parts of the electricity supply system could be higher than these levels.

4.4 Emission limits

Emission limits are maximum emission levels determined for either particular disturbing equipment or fluctuating installations that need to be met as a whole. Emission limits for disturbing equipment connected to LV public electricity supply systems are defined in the BS EN 61000 series of product standards. Emission limits that need to be met as a whole are determined from planning levels specified for the system concerned.

Emission levels are assessed against specified emission limits at a defined point (see 6.1.2). The intention is that under normal operating conditions emission levels do not exceed emission limits at any time.

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[5] Immunity levels for products and equipment are specified in individual product standards or in BS EN 61000 Part 3 Standards insofar as they do not fall under the responsibility of product committees.

[6] 5% is a typical probability value, which may differ in real supply systems.

[7] Different planning levels are necessary to take into account transfer of flicker from higher to lower voltage systems/networks.

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Emission limits are specified in accordance with the approach in Clause 6 for assessing the connection of disturbing equipment and fluctuating installations to transmission systems and distribution networks.

4.5 Illustration of EMC concepts

Figure 1 and Figure 2[8] illustrate the concept of compatibility levels, planning levels and emission limits and how EMC, relating to voltage fluctuations in the supply system, is achieved.

Figure 1 shows how EMC is achieved on a supply system wide basis.

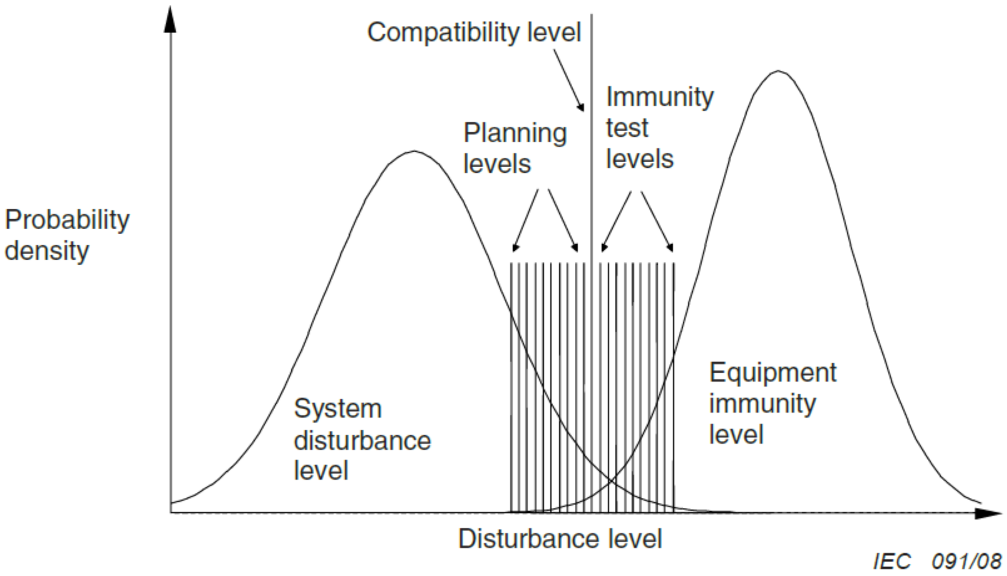

Figure 1 — Illustration of EMC concepts relevant to system

Figure 1 shows that there is a chance that interference might occur at certain times or certain locations in the system. This is recognition that the system operator/network operator cannot control all points of the system at all times.

[8] Figure 1 and Figure 2 are reproduced from PD IEC/TR 61000-3-7.

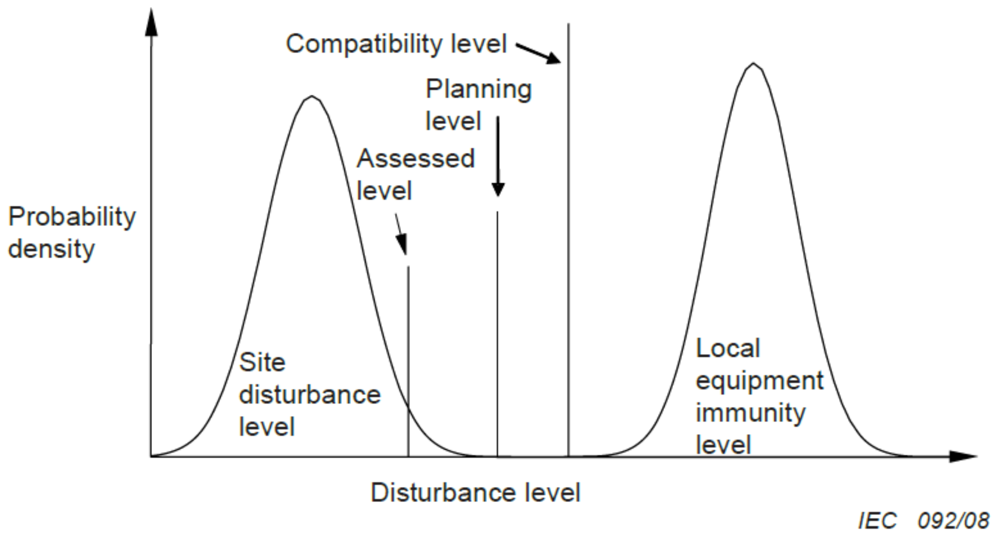

Figure 2 — Illustration of EMC concepts relevant to local site

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Figure 2 shows conceptually that, on a local site basis, specifying suitable planning levels should ensure there is no overlap of disturbance and immunity levels.

4.6 Flicker

Flicker is the result of repetitive voltage fluctuations, caused by disturbing equipment, in the supply system, which can be observed by changes in luminance of incandescent lamps.

The severity of flicker is dependent upon the magnitude and the frequency of the voltage fluctuations. High powered process type equipment which does not have a steady power demand and can draw frequently changing current is typically associated with flicker related voltage fluctuations.

The severity of flicker is quantified using flicker severity levels, P_{st} and P_{lt}, where P_{st} is the short-term flicker severity measured over a 10-minute interval and P_{lt} is long-term flicker severity measured over a 2-hour interval, typically. Values of P_{st} and P_{lt} are determined from voltage fluctuation data using a flickermeter algorithm which conforms to the requirements of BS EN 61000-4-15 (see 6.3.1).

4.7 Rapid Voltage Change (RVC)

RVC is a fast change in the r.m.s.[9] voltage between two steady state voltage conditions.

RVCs are generally caused by equipment start-up and shutdown including:

- motor starting/stopping;

[9] RMS is measured over one cycle refreshed every half-cycle in accordance with the method in BS EN 61000-4-30.

- energising transformers;
- switching capacitors/inductors, e.g. capacitor banks and reactors;
- switching in/out of large electrical loads;
- tap-changer operation;
- tripping of load/generation.

RVCs generally relate to infrequent or very infrequent events that can occur randomly on the system/network or events that need to be separated by time periods, which exceed the minimum intervals stated in this EREC.

The characteristics of a voltage dip and a voltage swell are shown in Figure 3 and Figure 4 respectively.

Limits for RVCs are shown in Table 4.

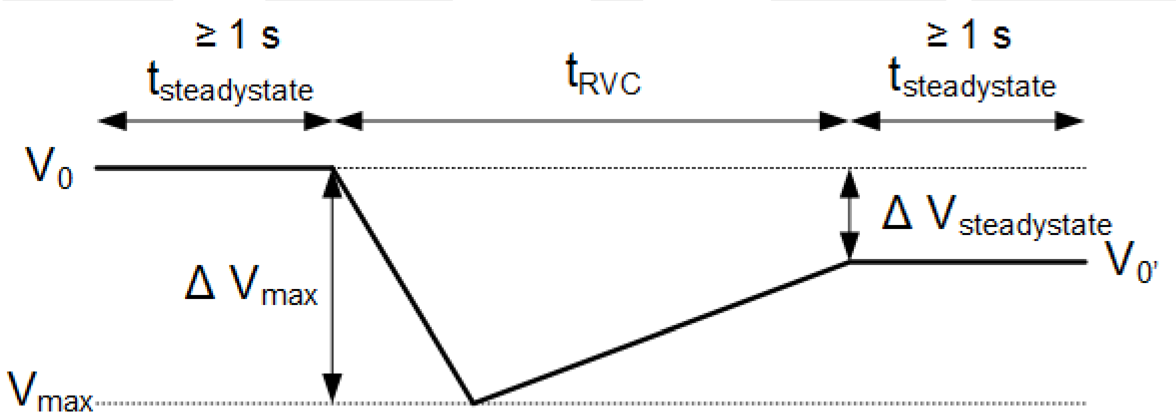

Figure 3 — Illustration of RVC characteristic for voltage dip

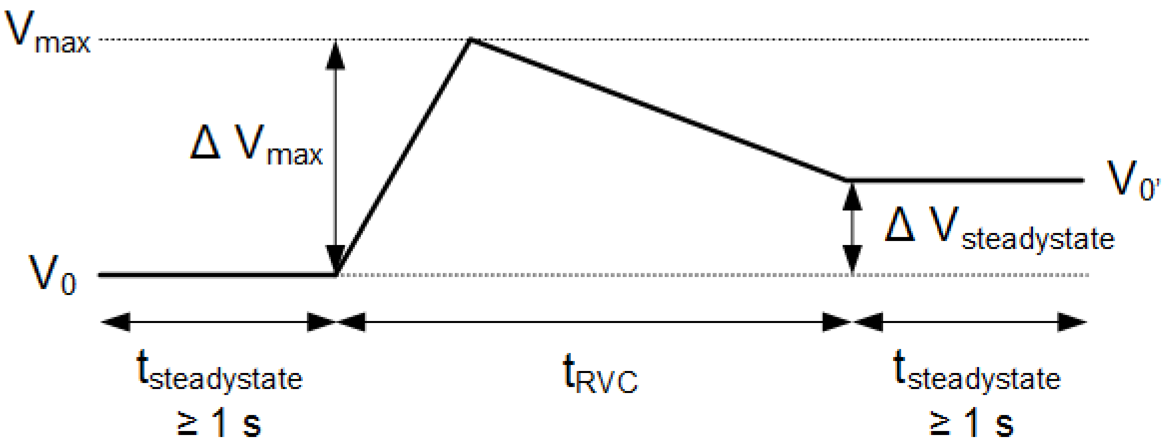

Figure 4 — Illustration of RVC characteristic for voltage swell

Where:

t_{RVC}	is the time duration of the RVC between steady state conditions
V_{max}	is the maximum voltage magnitude between two steady state voltage conditions
V_0	is the initial steady state voltage prior to the RVC
$V_{0'}$	is the final steady state voltage after the RVC
$V_{steadystate}$	is the voltage at the end of a period of 1 s during which the rate of change of system voltage over time is ≤ 0.5%.
ΔV_{max}	is the absolute value of the maximum change in the system voltage (V_{max}) relative to V_0
$\Delta V_{steadystate}$	is the difference in voltage between the initial steady state voltage prior to the RVC (V_0) and the final steady state voltage after the RVC ($V_{0'}$)
$\%\Delta V_{max}$	$= 100 \times \frac{\Delta V_{max}}{V_n}$
$\%\Delta V_{steadystate}$	$= 100 \times \frac{\Delta V_{steadystate}}{V_n}$
V_n	is the nominal system voltage

All voltages are the r.m.s. voltage measured over one cycle refreshed every half cycle in accordance with BS EN 61000-4-30.

For RVCs, $\Delta V_{steadystate}$ equates to the value of step voltage change.

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5 Compatibility levels, planning level and emission limits

5.1 General

Separate compatibility levels, planning levels and emission limits apply to different types of voltage fluctuations, i.e. flicker and RVC. Levels/limits for flicker and RVC are stated in Clause 5.2 and 5.3 respectively. Limits for step voltage change are stated in Clause 5.4.

5.2 Flicker

5.2.1 Compatibility levels

The following compatibility levels for flicker in Table 1 are specified for LV supply systems[10].

Table 1 — Compatibility levels for flicker in LV supply systems

Compatibility level	
P_{st}	P_{lt}
1.0	0.8

Compatibility levels are such that there is a 5% probability that measured disturbance in the wider area system could exceed the specified levels based on a statistical distribution of measurements varying in both time and location [on the supply system].

The magnitude of any frequently occurring voltage change should not exceed the limits of the voltage characteristic shown in Figure 5, other than for RVCs (see 4.6)[11].

Compatibility levels should only be used for evaluating system-wide disturbance by system/network operators; planning levels should be used for evaluating the acceptability of disturbance levels at a local site or specific location.

5.2.2 Planning levels

Planning levels for distribution networks and transmission systems in the United Kingdom are dependent upon the nominal voltage of the system.

Planning levels for flicker are specified in Table 2.

Planning levels specified in Table 2 should be used to derive flicker limits for disturbing equipment and fluctuating installations according to the staged approach outlined in Clause 6.3. In principle, disturbing equipment and fluctuating installations that do not meet the criteria for unconditional connection under Stage 1 are required to meet the flicker limit allocated under the Stage 2 assessment. Under special circumstances, remaining headroom may be allocated to the customer, on a ‘first come first served’ basis, under the Stage 3 assessment process for flicker (see 6.3.1).

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10 Compatibility levels for supply systems with nominal voltages greater than LV are not currently specified.

11 When measured at the PCC (see 6.1.2).

The planning levels in Table 2 are absolute values and should not be exceeded given the real risk of customer complaints occurring.

The planning levels in Table 2 allow for coordination of voltage fluctuations based on typical transfer coefficients for flicker that have been determined for transmission systems and distribution networks in the United Kingdom such that the likelihood of visual nuisance to LV customers is minimised. In some non-typical parts of a network[12], specific consideration may be required to ensure that flicker at higher voltage levels are co-ordinated to prevent interference.

Table 2 — Planning levels for flicker

Supply system Nominal voltage	Planning level	
	P_{st}	P_{lt}
LV	1.0	0.8
3.3 kV, 6.6 kV, 11 kV, 20 kV, 33 kV	0.9	0.7
66 kV, 110 kV, 132 kV, 150 kV, 200 kV, 220 kV, 275 kV, 400 kV	0.8	0.6
NOTE 1: Planning levels for LV connections are equal to compatibility levels. NOTE 2: The magnitude of P_{st} is linear with respect to the magnitude of the voltage changes giving rise to it. NOTE 3: Extreme caution is advised in allowing any excursions of P_{st} and P_{lt} above the planning level.		

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Table 3 — Typical transfer coefficients

System voltage level	T_{Pst} T_{Plt} [1]
400/275 kV to 132/110 kV	0.85
400/275 kV to 66 kV	0.85
400/275 kV to 33/22 kV	0.80
400/275 kV to 20/11/6.6 kV	0.70
132/110 kV to 66 kV	0.95
132/110 kV to 33/22 kV	0.90
132/110 kV to 20/11/6.6 kV	0.75
66 kV to 33/22 kV	0.95
66 kV to 20/11/6.6 kV	0.90
33/22 kV to 20/11/6/6 kV	0.90
11 kV to LV	1.0

12 For example: Where there are higher than standard impedances between voltage levels, or particularly weak supply systems/networks with long feeders and limited current capacities, which could have higher transfer coefficients.

NOTE 1: Transfer coefficients are typical of those measured in UK transmission systems / distribution networks.

NOTE 2: The transfer coefficients are based on the results of data and modelling by National Grid for the GB supply system.

NOTE 3: Transfer coefficients equally apply to assessment of RVC as well as flicker.

[1] The transfer coefficients apply to both P_{st} and P_{lt}.

The typical transfer coefficients in Table 3 should be used unless specific flicker propagation data exists (see 7.2.2).

In the absence of specific flicker propagation data or where flicker at the PCC needs to be specifically assessed, it should be assumed that flicker is not transferred from lower voltage systems to higher voltage systems due to the associated increase in short-circuit power.

5.2.3 Emission limits

Emission limits from a fluctuating installation should be such so as to ensure planning levels at the PCC (see 6.1.2) are not exceeded taking into account flicker background levels.

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5.3 Rapid voltage changes

5.3.1 Compatibility levels

Compatibility levels for RVC are common across transmission systems and distribution networks in the United Kingdom irrespective of the nominal voltage of the system.

Compatibility levels for RVC are the same as the planning levels specified in Table 4[13].

RVCs emanating from fluctuating installations that are thought likely to be coincident should be specifically assessed to ensure that the combined effect will not result in RVCs exceeding the compatibility level.

5.3.2 Planning levels

Planning levels for RVC are specified in Table 4.

The planning levels in Table 4 define absolute limits of maximum voltage change (ΔV_{max}) and steady state voltage change ($\Delta V_{steadystate}$) for RVCs according to the maximum number of occurrences permitted within a specified time period.

These planning levels take into account the need to minimise disturbance to other customers connected to the system, associated with RVCs, whilst recognising that the visual disturbance caused by RVCs is not as severe or frequent as for flicker. The planning levels in Table 4 have been determined so as to avoid maloperation of electrical equipment connected to the system at the maximum voltage change permitted for RVCs.

[13] The assumption being that, in practice, there is no coincidence between RVCs in transmission systems or distribution networks.

Table 4 — Planning levels for RVC

Category	Title	Maximum number of occurrence	Limits $\%\Delta V_{max}$ & $\%\Delta V_{steadystate}$	Example Applicability
1	Frequent events	(see NOTE 1)	As per Figure 5	Any single or repetitive RVC that falls inside Figure 5
2	Infrequent events	4 events in 1 calendar month (see NOTE 2)	As per Figure 6 $\lvert \%\Delta V_{steadystate} \rvert \leq 3\%$ For decrease in voltage: $\lvert \%\Delta V_{max} \rvert \leq 10\%$ (see NOTE 3) For increase in voltage: $\lvert \%\Delta V_{max} \rvert \leq 6\%$ (see NOTE 4)	Infrequent motor starting, transformer energisation, G59 [4] re-energisation (see NOTE 7)
3	Very infrequent events	1 event in 3 calendar months (see NOTE 2)	As per Figure 7 $\lvert \%\Delta V_{steadystate} \rvert \leq 3\%$ For decrease in voltage: $\lvert \%\Delta V_{max} \rvert \leq 12\%$ (see NOTE 5) For increase in voltage: $\lvert \%\Delta V_{max} \rvert \leq 6\%$ (see NOTE 6)	Commissioning, maintenance & post fault switching (see NOTE 7)

NOTE 1: ±6% is permissible for 100 ms reduced to ±3% thereafter as per Figure 5.
If the profile of repetitive voltage change(s) falls within the envelope given in Figure 5, the assessment of such voltage change(s) shall be undertaken according to the recommendations for assessment of flicker and shall conform to the planning levels provided for flicker.
If any part of the voltage change(s) falls outside the envelope given in Figure 5, the assessment of such voltage changes, repetitive or not, shall be done according to the guidance and limits for RVCs.

NOTE 2: No more than 1 event is permitted per day, consisting of up to 4 RVCs, each separated by at least 10 minutes with all switching completed within a two-hour window.

NOTE 3: −10% is permissible for 100 ms reduced to -6% until 2 s then reduced to -3% thereafter as per Figure 6.

NOTE 4: +6% is permissible for 0.8 s from the instant the event begins then reduced to +3% thereafter as per Figure 6.

NOTE 5: −12% is permissible for 100 ms reduced to −10% until 2 s then reduced to -3% thereafter as per Figure 7.

NOTE 6: +6% is permissible for 0.8 s from the instant the event begins then reduced to +3% thereafter as per Figure 7.

NOTE 7: These are examples only. Customers may opt to conform to the limits of another category providing the frequency of occurrence does not exceed the ‘Maximum frequency of occurrence’ for the chosen category.

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Where:

a) $\%\Delta V_{steadystate} = 100\times\frac{\Delta V_{steadystate}}{V_n}$ and
$\%\Delta V_{max} = 100\times\frac{\Delta V_{max}}{V_n}$

b) V_n is the nominal system voltage.

c) $V_{steadystate}$ is the voltage at the end of a period of 1 s during which the rate of change of system voltage over time is ≤ 0.5%.

d) $\Delta V_{steadystate}$ is the difference in voltage between the initial steady state voltage prior to the RVC (V_0) and the final steady state voltage after the RVC ($V_{0'}$).

e) ΔV_{max} is the absolute change in the system voltage relative to the initial steady state system voltage (V_0).

f) All voltages are the r.m.s. of the voltage measured over one cycle refreshed every half a cycle as per BS EN 61000-4-30.

g) The applications in the ‘Example Applicability’ column are examples only and are not definitive.

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The limits for RVCs in Category 2 and Category 3 of Table 4 take into account differences in the perceptibility of RVC compared with flicker associated with continuously fluctuating loads. As such, conformance to flicker limits in Clause 5.1, although desirable, is not a requirement for RVCs in Category 2 and Category 3.

The voltage change limit is the absolute maximum allowed of either the phase-to-earth voltage change or the phase-to-phase voltage change, whichever is the highest. The limits do not apply to single phasor equivalent voltages, e.g. positive phase sequence (PPS) voltages. For high impedance earthed systems, the maximum phase-to-phase, i.e. line voltage, should be used for assessment.

Voltage changes in Category 1 should not only fall within the envelope in Figure 5 but should also meet the flicker limits as determined from assessment of flicker (see 6.3).

RVCs in Category 2 and 3 should not exceed the limits depicted in the time dependant characteristic shown in Figure 6 and Figure 7 respectively.

Any RVCs permitted in Category 2 and Category 3 should be at least 10 minutes apart.

The value of $V_{steadystate}$ should be established immediately prior to the start of a RVC. Following a RVC, the voltage should remain within the relevant envelope, as shown in Figures 5, Figure 6 or Figure 7, until a $V_{steadystate}$ condition has been satisfied.

The voltage change between two steady state voltage conditions should not exceed 3%[14].

[14] The limit is based on 3% of the nominal voltage of the system (V_n) as measured at the PCC. The step voltage change as measured at the customer’s supply terminals or equipment terminals could be greater. For

The limits apply to voltage changes measured at the PCC (see 6.1.2).

At transmission system voltage levels, Category 3 events that are planned should be notified to the relevant Transmission System Operator in advance. At distribution network voltage levels, the requirement to notify planned Category 3 events is at the discretion of the relevant Distribution Network Operator.

Category 2 events do not need to be notified to the system/network operator.

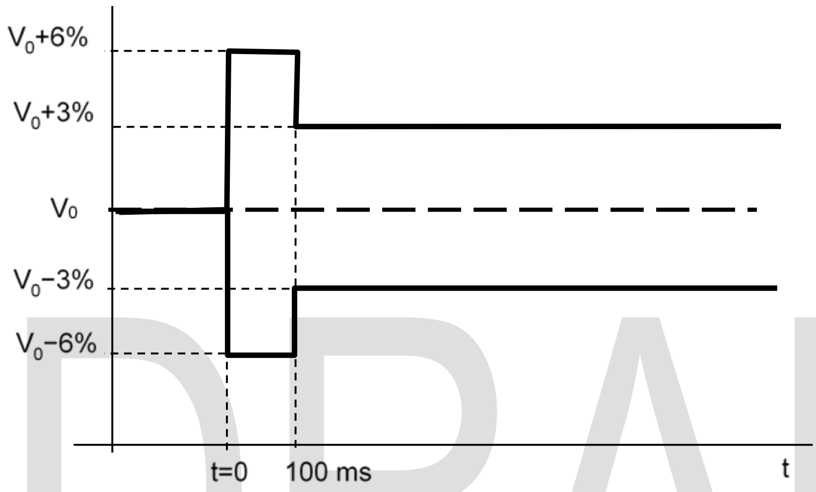
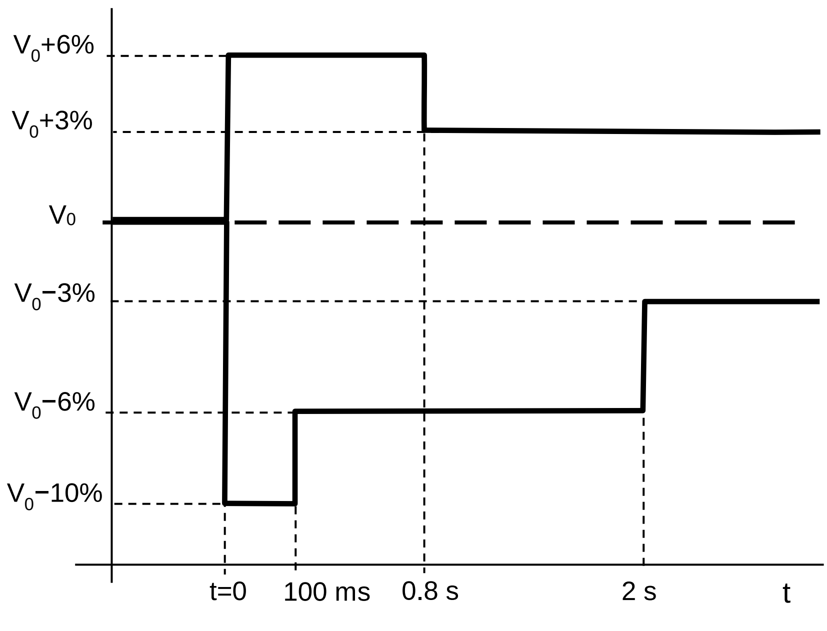


Figure 5 — Voltage characteristic for frequent events



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example: The step voltage change limit stated in BS EN 61000-3-3 and BS EN 61000-3-11 is 3.3% when measured at the equipment terminals.

Figure 6 — Voltage characteristic for infrequent events

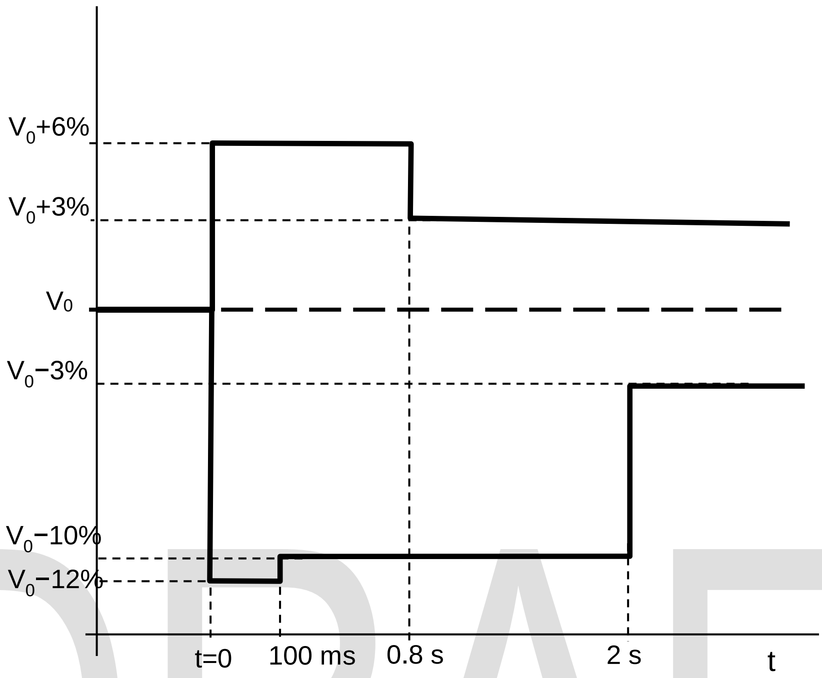

Figure 7 — Voltage characteristic for very infrequent events[15]

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5.3.3 Emission limits

RVCs from individual fluctuating installations should not exceed the relevant planning level(s) in Table 4.

Limits for individual fluctuating installations may need to be lower than those in Table 4 where there is likely to be co-incident RVCs from different installations, such that the combined effect of co-incident RVCs from fluctuating installations are within the limits set out in Table 4. Measures should be taken to prevent co-incident RVCs at the PCC, where reasonably practicable. This requires knowledge to be obtained about the potential for RVCs from existing fluctuating installations to coincide with those for proposed connections.

The requirement to prevent co-incident RVCs exceeding the limits in Table 4 at the PCC does not apply to: a) fault clearance operations; or b) immediate operations in response to fault conditions.

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[15] In Northern Ireland, lesser limits than those in Figure 7 apply for as long as Engineering Recommendation G59/1/NI is applied.

5.4 Step voltage change limit

A 3% general limit applies to the magnitude of percentage step voltage changes regardless of frequency of occurrence.

NOTE: For the purposes of this EREC, percentage step voltage change is the value of step voltage change in volts expressed as percentage change of the nominal system voltage (V_n).

Voltage fluctuations greater than 3% in magnitude should not cause interference where the shape of the voltage characteristic is equivalent to a step voltage change less than or equal to 3% (see 6.3.3.4) or is of sufficiently low frequency of occurrence (see 5.2.2).

6 Assessment of disturbing equipment and fluctuating installations

6.1 General guidelines for assessment

6.1.1 Assessment procedure

Assessment of step voltage change should follow the procedure in Clause 6.2.

Assessment of flicker should follow the procedure in Clause 6.3.

Assessment of RVCs should follow the procedure in Clause 6.4.

The flowchart in Figure 8 summarises the high-level assessment procedure to be followed.

Disturbing equipment and fluctuating installations that can be characterised as producing RVCs but could also result in flicker should be assessed for RVC (see 6.4) and flicker (see 6.3).

NOTE: The relevant clauses in this EREC are identified in parentheses.

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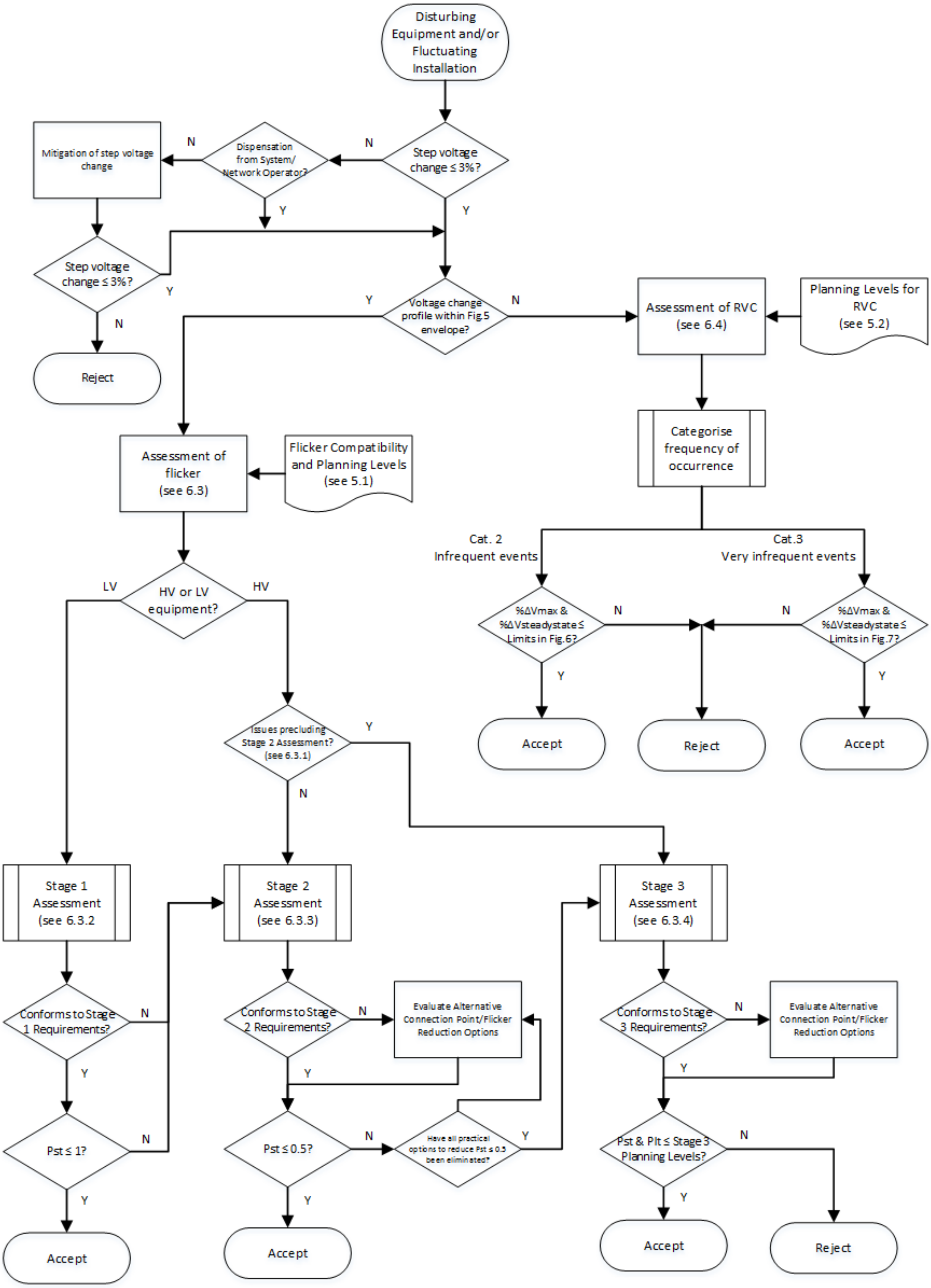

Figure 8 — Flowchart assessment procedure

6.1.2 Point of evaluation

The assessment of voltage fluctuation should be at the PCC unless otherwise specified by the system/network operator when evaluation at the PCC is not appropriate (see 6.3.4).

6.1.3 Capability of equipment to function correctly

Assessment in accordance with this EREC considers the effect of voltage fluctuations from disturbing equipment/fluctuating installations on the capability of other equipment connected to the public electricity supply system to function correctly.

6.1.4 Information requirements and responsibilities

The information to be provided and the responsibilities of the customer and system/network operator in the assessment process should be as those in Table 5.

The system/network operator shall declare maximum values of supply system impedance for networks with a nominal voltage greater than LV in accordance with the provisions of Clause 6.1.5 and Clause 6.1.6.

Details of disturbing equipment should be: provided in a timely manner; sufficiently detailed; and in a format that enables the system/network operator to accurately model it.

Where measured emission levels are found to exceed predicted emission levels in the compliance report and this has a material effect, the system/network operator may:

a) require the customer to take mitigating action, where such action is reasonable;

b) require the customer to disconnect the disturbing equipment until mitigating action can be taken;

c) consider the need to disconnect the fluctuating installation.

Where reasonably practicable, direct measurement of flicker severity should be carried out following connection of the disturbing equipment/fluctuating installation to validate the results of calculation and modelling.

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Table 5 — Information requirements and responsibilities *(1 of 2)*

Information	Requirement	Assessment Stage	Responsibility
Supply system impedance - LV only	For single-phase: Measurement of supply phase to neutral loop impedance at the customer supply terminals (see NOTE 1) or Calculation of supply phase to neutral loop impedance at the customer supply terminals for normal supply arrangement (see NOTE 2) For three-phase: Measurement of supply phase to phase supply impedance at the customer supply terminals (see NOTE 1) or Calculation of supply phase to phase impedance at the customer supply terminals for normal supply arrangement (see NOTE 2)	Stage 1	Customer Network Operator (on request) Customer Network Operator (on request)
Service current capacity	Check against Connection Agreement Check service records and/or inspection of cut-out (see NOTE 3)	Stage 1	Customer Network Operator (on request)
Disturbing equipment details:	Type of equipment Rated voltage, current, power Single-phase or three-phase connection Single-phase or three-phase impedance Starting/stopping current characteristics Operating cycle (periods of operation) Statement of EMC compliance with relevant product standards, e.g. BS EN 61000-3-3 (see NOTE 4)	Stage 1,2 & 3	Customer

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Table 5 — Information requirements and responsibilities *(2 of 2)*

Information	Requirement	Assessment Stage	Responsibility
P28 compliance assessment	Assess flicker/RVC emission against compatibility/planning levels in P28 Issue 2. Provide compliance report for Network Operator Assess compliance report from customer for acceptability	Stage 2 & 3	Customer (see NOTE 5) System/Network Operator
Emission measurements and validation	Measurement of customer's emission levels and validation against predicted levels in P28 compliance report	Stage 2 & 3	Customer & System/Network Operator (see NOTE 6)
Supply system impedance - except LV (see 6.1.5)	Declaration of maximum supply system impedance at the PCC	Stage 1, 2 & 3	System/Network Operator
Known future connections/ alterations (see 6.1.6)	Provide system/network information in Long Term Development Statements, where available, and similar documents Consider known future alterations to the supply system in supply system impedance information (see NOTE 7) Consider known future connection/alterations (supply system and disturbing equipment/fluctuating installation) in emissions assessment	Stage 1, 2 & 3	System/Network Operator System/Network Operator Customer
Flicker background level (see 7)	Measurement of existing flicker background level (pre-connection)	Stage 3	System/Network Operator

NOTE 1: This check is required to be carried out by a competent person/organisation to ensure the supply impedance is equal to or less than the manufacturer declared maximum supply impedance for the equipment to be installed. For further information see BS EN 61000-3-3 and BS EN 61000-3-11.

NOTE 2: The source impedance upstream of the distribution transformer can be excluded where it is insignificant compared to the impedance of the distribution transformer.

NOTE 3: There is a requirement under BS 7671 (IET Wiring Regulations), to assess supply adequacy. It is important to note that the current rating of the cut-out fuse holder by itself is not indicative of the service current capacity.

NOTE 4: The System/Network Operator may provide assumed data, where data is not provided by the customer and will advise the customer accordingly. The costs could be chargeable to the customer according to the Network Operator's charging statements and methodologies.

NOTE 5: The System/Network Operator may elect to carry out the assessment on behalf of the customer. In this case a summary of the assessment and any relevant data should be provided to the customer on request and subject to meeting any confidentiality requirements.

NOTE 6: Depending upon the extent of studies carried out and the results provided, the system/network operator may decide not to measure customer emission levels for Stage 2 assessments. Notwithstanding, it is incumbent on the customer to ensure that actual emission levels post connection conform to emission limits.

NOTE 7: The onus is on the system/network operator to determine what system developments are known and reasonably foreseeable and to advise these for the assessment of disturbing equipment/fluctuating installations.

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6.1.5 Supply system impedance

Where knowledge of supply system impedance is required for calculating the magnitude of voltage fluctuations, then credible maximum values should be used. These values should generally coincide with the worst case normal operating conditions (see 6.1.6). Where operation of disturbing equipment/fluctuating installations is seasonal then supply system impedances at coincident time(s) of year may be used.

When assessing the voltage fluctuation, which would be imposed on the supply to other customers, then only the supply system impedance up to the PCC should be taken into account. The effect on supply system impedance from customer owned local generation that can be relied upon to be in operation may be considered.

Information provided by the system/network operator regarding planned alterations to the public electricity supply system, which would increase or decrease the supply system impedance, should be taken into account[16].

Any local conditions that could increase the supply system impedance at the PCC should be considered (see 6.1.6).

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The effects of embedded generation on the supply system impedance should be ignored unless there is a long-term guarantee that this generation would be operating at the same time as the disturbing equipment and/or fluctuating installation. In this case, planned outages of such embedded generation should be considered.

In the absence of seasonal data, the supply system impedance in summer, with minimum generating plant[17] in operation and credible planned outages, should be used.

At LV, the source impedance upstream of HV/LV distribution transformers may be ignored where it is insignificant compared with the impedance of the distribution transformer. The source impedance upstream of 11 000/230 V pole mounted transformers with small rated powers should not be ignored.

For assessing voltage fluctuation caused by three-phase connected equipment, the initial symmetrical short-circuit impedance of the supply system, Z_k'' (R_k'' and X_k''), should be used.

NOTE: The short-circuit impedance Z_k'', corresponds to the initial symmetrical short-circuit current, I_k''.

Where the initial symmetrical short-circuit impedance of the supply system, Z_k'' is not available then the symmetrical short-circuit breaking current I_b may be used to calculate the short-circuit impedance of the supply system.

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[16] Planned system alterations and associated changes to fault levels can be obtained from Long Term Development Statements, where available, and similar documents prepared by system/network operators, noting that the fault levels in Long Term Development Statements are maximum fault levels.

[17] 'Minimum generation plant' equates to the expected minimum aggregated power output of generation connected to the system in any year, which is consistent with the lowest contribution from generation to system fault levels.

As the symmetrical short-circuit breaking current I_b is normally smaller than the initial symmetrical short-circuit current $I_k^{"}$, using I_b instead of $I_k^{"}$ for assessing voltage fluctuation would normally produce a more pessimistic result[18].

For assessing voltage fluctuation caused by single-phase connected equipment, the short-circuit loop impedance between the source and load should be used, whether that is between the phase and neutral or between two phases of the supply system.

For assessing RVC the appropriate subtransient reactance of the disturbing equipment should be used, where this information is available.

6.1.6 Normal operating conditions

Voltage fluctuations should be assessed under the worst case normal operating condition(s) unless specified otherwise by the system/network operator.

Normal operating conditions for the supply system include those operating conditions in Table 6, where the system/network is designed to remain within acceptable/statutory limits.

Voltage fluctuations during credible outage conditions should be considered, including planned and/or fault outages consistent with those where there is a requirement to secure demand as required by security of supply standards, i.e. ENA Engineering Recommendation P2 for HV distribution networks[19] and National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS) for transmission systems[20]. For generation, the most onerous condition(s) the generator(s) will be expected to normally operate should be considered.

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For an arrangement where there are two transformers in a system/network operator's substation that are normally operated in parallel, a planned outage of one transformer would generally result in the worst case normal operating condition.

Considerations of outages in the electricity supply system may be disregarded for assessment of LV disturbing equipment/fluctuating installations.

Voltage fluctuations are not expected to conform to planning levels under the following conditions.

a) Temporary/abnormal conditions or whilst steps are taken to maintain/restore supplies to customers, where otherwise supplies would be interrupted[21].

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18 Further information on short-circuit currents can be found in BS EN 60909-0.

19 For HV distribution networks, a first circuit outage condition generally only needs to be considered, where a 'first circuit outage' condition refers to a single outage (planned or fault) of a circuit or item of plant.

20 For transmission systems, a second circuit outage condition generally needs to be considered, where a 'second circuit outage' condition refers to a first circuit outage (planned or fault) with the additional consideration of a fault outage on a second circuit or item of plant within the same load group as the first.

21 For example: Most 6.6 kV, 11 kV, 20 kV and 33 kV networks are not designed to operate within acceptable limits for a second circuit outage condition.

b) Emergency conditions.

Particular care should be taken when considering the effect of local system outages given the following.

a) An outage of a local circuit might not give rise to the worst case normal operating condition.

b) An outage of a local circuit needs to be considered together with wider system outage scenarios so minimum acceptable security of supply standards are still met.

Table 6 — System/network conditions - Normal operating conditions

System/network operating condition	Description
Normal network configuration	Normal running arrangement with normal open point(s). No network assets out-of-service for construction, maintenance or faults
Alternative network configuration(s)	Alternative running arrangement(s) with substitute open point(s). No network assets out-of-service for construction, maintenance or repair
Planned outages (see NOTE)	Planned outages of specific network assets for construction, maintenance or repair activities
Fault outages (see NOTE)	Running arrangement taking into account credible fault outage scenario(s) for normal/alternative network configuration(s). Compliant with network design limits before fault outage and within a short time after fault outage, where reconfiguration of network is required
Switching operations (including reactive compensation)	Energisation and de-energisation of network assets. Reactive compensation. Reconfiguration of network
Protection operation (including G59 [4] protection operation)	Operation of protection and disconnection of load/generation for which the network is designed to cater for
Demand / generation variations	Variations in demand/generation within rating of network under normal and alternative network configurations
Local embedded/distributed generation	Generally, can be ignored unless there is a long-term guarantee that this generation would be operating at the same time as the disturbing equipment and/or fluctuating installation (see 6.1.5)
NOTE: For various credible planned/fault outage scenarios the scenario that results in the maximum supply system impedance should be generally chosen.	

Where operation of the disturbing equipment/fluctuating installation can be assured so as not to coincide with a particular network operating condition then assessment of that particular network operating condition can be discounted.

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6.1.7 Exceeding planning levels

Where emission levels are assessed to exceed the planning levels in this EREC, options for reducing emission levels to acceptable levels should be evaluated. These include but are not limited to:

a) a change in the supply system arrangement including new proposed connection point that would reduce the maximum supply system impedance and/or reduce the disturbance at the PCC;

b) modification to the disturbing equipment or fluctuating installation to reduce voltage fluctuations including use of compensation equipment/techniques[22].

Any cost of taking remedial action to conform to planning levels should be borne by the customer.

Further information on mitigation actions can be found in Part 5 of the BS EN 61000 series of EMC Standards.

Emission levels higher than specified emission limits may be permitted by system/network operators under certain circumstances. Guidance can be found in ENA Engineering Report P28 [8].

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6.2 Assessment of step voltage change

Conformance to the 3% step voltage change limit should be assessed as a first step.

In certain cases, where special circumstances apply, the system/network operator may, at its discretion, allow larger step voltage changes to occur, e.g. continuous process plant where larger motors are only started once in several months. The system/network operator may also give special limited approval for the use of some types of equipment that result in step voltage changes in excess of 3% without the need for individual consideration.

6.3 Assessment of flicker

6.3.1 General

Assessment of flicker severity is based on the long established and reliable measures P_{st} and P_{lt}. These measures should be used for assessing disturbance to all other equipment connected not just lighting.

Flicker severity shall be characterised according to a flickermeter conforming to the requirements of BS EN 61000-4-15.

The 95th percentile value of P_{st} and P_{lt} measured over 1 week should be used to assess flicker against flicker planning levels in Table 2. Where measurements are made over several weeks then the value of flicker severity for each weekly measurement period should not exceed the applicable planning limits.

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[22] For example: point-on-wave switching for energising transformers.

NOTE: Where flicker severity is measured over a number of weekly measurement periods, the values in each week of measurement need to conform to the applicable planning limit, not the flicker severity over the whole measurement period.

It is generally acceptable for customers to connect disturbing equipment to LV public electricity supply systems without any reference to the network operator or specific assessment of flicker providing:

a) the disturbing equipment is declared as conforming to that part of BS EN 61000 appropriate to the product; and

b) the LV supply system source impedance at the customer supply terminals is equal to or less than:

   i. the reference impedance (Z_{test})[23] stated in that part of BS EN 61000 appropriate to the product; or

   ii. the maximum value of the supply impedance at which equipment would meet required limits (Z_{max}), as declared by the equipment manufacturer.

The LV public electricity supply system impedance can be determined by one or more of the following approaches.

a) Use of generic supply system impedance values for metered connections (see Table 7).

b) Measurements of supply system impedance.

c) Specific supply system impedance values provided by the network operator.

The following supply system impedances, based on generic values of supply impedance for LV public electricity supply systems in the United Kingdom, may be used for approximate calculations in the absence of measurements or specific LV supply system impedance data.

Table 7 — Generic supply impedance for LV metered connections

Supply	Service capacity (per phase)	Supply impedance (single-phase connections)	Supply impedance (three-phase connections)
230 V single-phase PME supply	< 100 A	0.34 Ω	-
230 V single-phase non PME supply	<100 A	0.47 Ω[A]	-
400 V three-phase supply	150 A	0.42 Ω	0.25 Ω
400 V three-phase supply	200 A	0.31 Ω	0.19 Ω
400 V three-phase supply	300 A	0.21 Ω	0.13 Ω
400 V three-phase supply	400 A	0.16 Ω	0.10 Ω
400 V three-phase supply	600 A	0.10 Ω	0.06 Ω

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23 Z_{ref} represents a maximum value of source impedance, which is used for testing the appliance or disturbing equipment.

NOTES:

1 The values of supply impedance are derived from values in Table 1, Table 5 and Table 6 of PD IEC/TR 60725, which have been deemed most appropriate to the United Kingdom.

2. For three-phase supplies the supply impedance to be used will depend upon whether disturbing equipment is connected single-phase or three-phase.

[A] Derived from survey data for the UK published in PD IEC/TR 60725, where 98% of 230 V single-phase supplies with <100 A capacity had a supply system impedance, measured at the supply terminals, less than or equal to 0.4 + j0.25 Ω.

NOTE: Actual LV supply system impedances might be higher than the typical values stated. For example, where supplied from pole mounted transformers with low rated power and LV mains cables or service cables with small cross-sectional area.

For LV supplies with a declared supply capacity ≥ 100 A then specific data provided by the network operator should be used for assessment of flicker.

Where individual items of disturbing equipment within a fluctuating installation work together as a system,[24] flicker from the system, as well as those from the individual items of disturbing equipment, should be assessed against the relevant requirements in this EREC.

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Assessments should follow a three-stage procedure summarised in Figure 9.

Stage 1 (see 6.3.2) is a simplified assessment for assessing discrete items of LV equipment based on equipment standards; it is not applicable to HV connections or to the assessment of disturbing equipment that work together as a system, which should be assessed under Stage 2. LV disturbing equipment and/or fluctuating installations that meet the Stage 1 assessment criteria can be connected without specific assessment or reference to the network operator. The assessment criteria are such that individual LV equipment conforming to relevant BS EN 61000 product standards or the connection of multiple items of similar LV equipment with limited fluctuating power can be connected under Stage 1 with no prospect of interference.

Stage 2 (see 6.3.3) is an assessment of flicker levels from disturbing equipment and/or fluctuating installations against a specified planning level. The assessment does not require the existing flicker background level to be taken into account. Disturbing equipment and/or fluctuating installations can be connected under Stage 2 without reference to the network operator or further assessment providing emission levels do not exceed the emission limits of P_{st} ≤ 0.5 (see Figure B.1.2) for the system voltage level concerned. Where expected flicker severity exceeds the limit in Stage 2, then subject to addressing the particular requirements of the system/network operator, the disturbing equipment and/or fluctuating installation may be eligible for Stage 3 assessment.

Stage 3 assessment (see 6.3.4) applies where:

a) emission levels exceed the specified emission limit in Stage 2 despite:

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[24] For example: Individual micro inverters that form part of a larger PV system or indoor and outdoor parts of a heat pump installation that work together to form a system.

i. good engineering practice having been followed in the design of the disturbing equipment and/or fluctuating installation; and

ii. reasonably practicable alternative connection points and flicker reduction options having been evaluated and discounted.

b) there is a possibility, based on the system/network operator's knowledge of flicker background levels and any other proposed connection(s), that additional flicker with a $P_{st} > 0.5$ would result in planning levels being exceeded.

The assessment is such that existing flicker background level and emission levels from the disturbing equipment and/or fluctuating installation at the PCC need to be taken into account. Disturbing equipment and/or fluctuating installations can be connected under Stage 3 providing the available headroom allocated under Stage 3 assessment is not exceeded.

Disturbing equipment connected to the HV system and/or fluctuating installations connected to the HV system should be assessed under Stage 2 and should not be permitted to be assessed under Stage 3 unless the agreement of the system/network operator is obtained.

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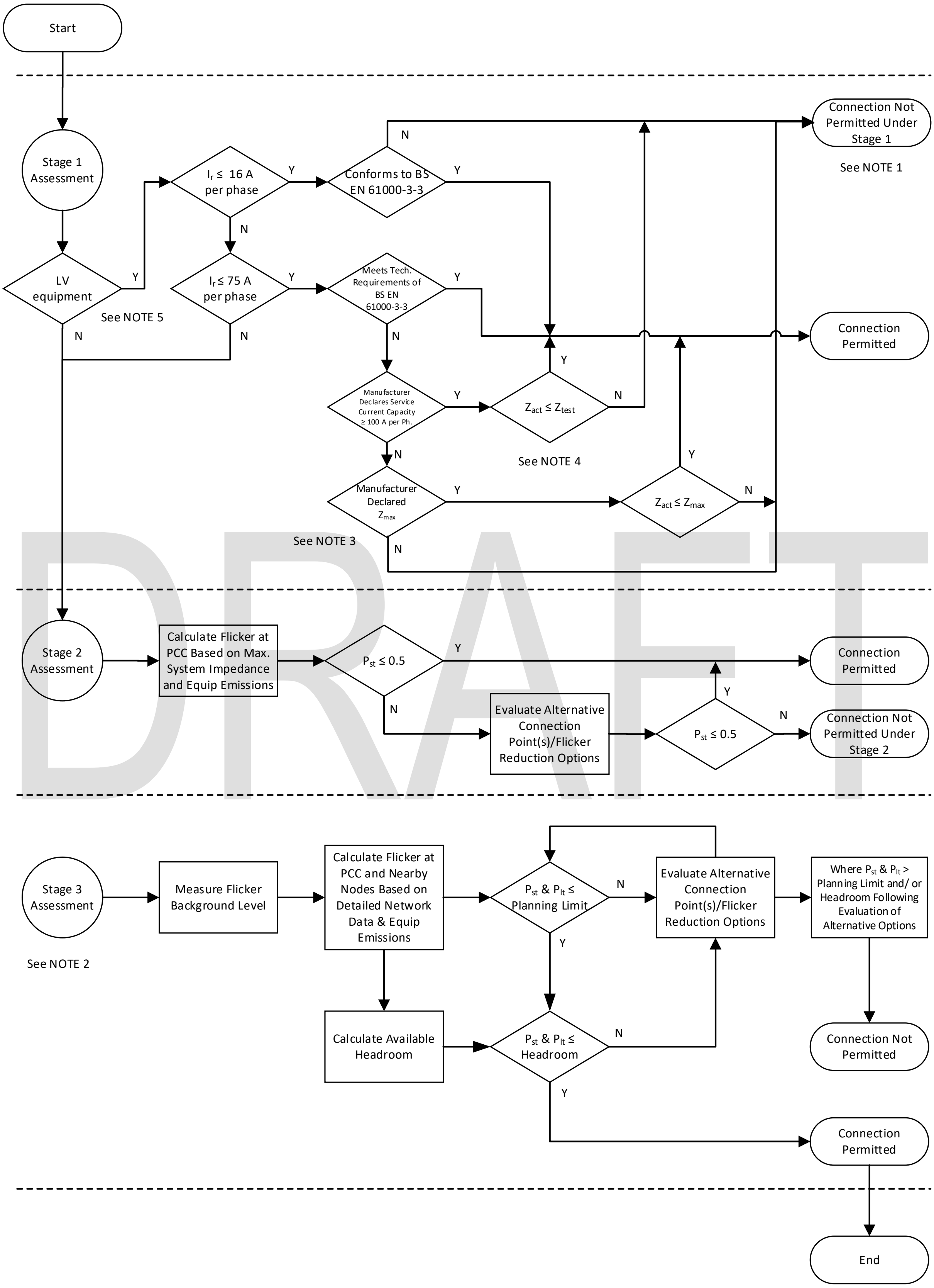

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Figure 9 — Three-stage flicker assessment approach

NOTE 1: LV equipment with a rated current (I_r) ≤ 16 A that does not conform to the limits in BS EN 61000-3-3 may be retested and evaluated to show conformance with BS EN 61000-3-11.

NOTE 2: See 6.3.1 concerning the criteria for assessment and connection under Stage 3.

NOTE 3: Zact is the modulus of the actual supply impedance at the customer supply terminals.

NOTE 4: Ztest = 0.15 + j015 Ω for three-phase equipment & Ztest = 0.25 + j0.25 Ω for single-phase equipment.

NOTE 5: Where the PCC is at HV not LV, Stage 1 assessment of LV equipment is not appropriate.

6.3.2 Stage 1 assessment

6.3.2.1 Household appliances and similar electrical equipment

Household appliances and similar electrical equipment with a rated current ≤ 16 A per phase and conforming to BS EN 61000-3-3 are not subject to conditional connection and can be connected to LV public electricity supply systems under this stage without reference to the network operator or further assessment based on LV supply impedance not exceeding the following typical maximum values at the customer supply terminals.

a) Phase-neutral loop impedance of 0.4 + j0.25 Ω (|*Z*| = 0.472 Ω) for single-phase 230 V connections.

b) Three-phase impedance of 0.24 + j0.15 Ω (|*Z*| = 0.283 Ω) for three-phase connections.

Interference is very unlikely given network operators design their LV networks to have significantly lower source impedances than those stated in a) and b)[25]. However, it should be recognised that the LV supply impedance of service connections installed pre-1950[26] could be higher than the typical maximum values stated. Where there is doubt whether the impedance at the customer supply terminals is less than the typical maximum values stated then the LV supply impedance should be measured.

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Household appliances and similar electrical equipment with a rated current ≤ 16 A per phase but not conforming to emission limits in BS EN 61000-3-3 are subject to conditional connection and can be connected to LV public electricity supply systems under this stage providing they conform to BS EN 61000-3-11 (see 6.3.2.2).

6.3.2.2 Equipment with a rated current ≤ 75 A

Equipment with a rated current ≤ 75 A can be connected to LV public electricity supply systems under this stage without reference to the network operator providing it conforms to the technical requirements in BS EN 61000-3-3 and the service current capacity is confirmed as being adequate for connection of the equipment.

NOTE: Regulation 132-16 of BS 7671 (The Wiring Regulations) requires that the rating and condition of any existing equipment, including that of the network operator, is ascertained as being adequate before any additional or altered equipment is connected.

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[25] LV public electricity systems that are TN-C-S (PME) will typically have a supply impedance ≤ 0.35 Ω.

[26] Services installed pre-World War II and those installed in some council housing estates in the late 1940’s and early 1950’s could exceed the typical maximum values of LV supply impedance for modern day networks.

Equipment with a rated current > 16 A per phase and ≤ 75 A per phase, not conforming to the technical requirements in BS EN 61000-3-3, is subject to conditional connection and can be connected to LV public electricity supply systems under this stage providing it conforms to the technical requirements in BS EN 61000-3-11.

Equipment that is subject to conditional connection [as required by this clause] can only be connected to the LV public electricity supply system without reference to the network operator providing either:

a) the LV supply impedance at the customer supply terminals is confirmed by measurement (see 7) or from calculated values provided by the network operator as being equal or less than the value (Z_{max}) declared by the equipment manufacturer in the equipment instruction manual; or

b) at the customer supply terminals:

   i. the service current capacity is confirmed as being ≥ 100 A per phase, as required by the equipment manufacturer in the equipment instruction manual, and the equipment has been clearly marked to this effect by the manufacturer; and

   ii. the LV supply impedance is confirmed by measurement as being equal or less than 0.25 + j0.25 Ω (|Z| = 0.35 Ω) for single-phase connections or 0.15 + j0.15 Ω (|Z| = 0.212 Ω) for three-phase connections[27].

The presence of a fuse carrier rated for 100 A per phase does not necessarily mean that the service has a current capacity ≥ 100 A per phase. Where there is doubt regarding the service current capacity at the customer supply terminals or the actual value of LV supply impedance, the installer should contact the relevant network operator for information.

Equipment to be connected to the LV supply system that does not conform to emission limits in both BS EN 61000-3-3 and BS EN 61000-3-11 may be assessed under Stage 2.

NOTE: It is unlikely that disturbing equipment that does not conform to emission limits in both BS EN 61000-3-3 and BS EN 61000-3-11 would meet the limits in Stage 2.

When assessing the suitability of high rated power equipment, i.e. > 16 A per phase, for connection to the public electricity supply system, consideration should be given to: whether the equipment is normally switched infrequently; whether it is designed to avoid unnecessary rapid cycling by control systems; and the magnitude of steady state voltage change to ensure that flicker problems do not arise.

The connection of multiple items of similar LV equipment is addressed in Clause 6.3.2 of BS EN 61000-3-11.

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[27] The LV supply impedance for single-phase connections is the phase-neutral loop impedance not the earth fault loop impedance.

6.3.3 Stage 2 assessment

6.3.3.1 General

LV connections that do not come under the Stage 1 assessment process (See Figure 9) and all HV connections should be assessed under the Stage 2 assessment process described in this clause.

Under the Stage 2 assessment process, individual disturbing equipment that is assessed to result in flicker with $P_{st} \leq 0.5$ under the worst case normal operating condition at the PCC can be connected without further detailed assessment[28]. No measurement of existing flicker background level is required for Stage 2 assessment.

An assessment of the P_{st} resulting from connection of the disturbing equipment/fluctuating installation should be conducted. This should be done by simulation, calculation or measurement. Rules to simplify the waveforms generated by particular types of equipment are given in Clause 6.3.3.4.

Simulation of flicker severity from the voltage change characteristics of the disturbing equipment/fluctuating installation being assessed may be carried out using a flicker simulation program providing this accurately simulates the flickermeter in BS EN 61000-4-15[29]. The use of a flickermeter is the preferred method of evaluating flicker severity.

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For simple step voltage change patterns or ramp voltage change patterns, or combinations of the two, a simple approximation of P_{st} may be calculated using the ‘memory time’ technique. The method and examples for calculating P_{st} can be found in Annex G of PD IEC/TR 61000-3-7. Flicker severity should be assessed by simulation if:

a) there is any doubt regarding the values calculated; or

b) the calculated flicker severity is within ±10% of the Stage 2 limit.

Where flicker measurements exist elsewhere for similar disturbing equipment/fluctuating installations to that being assessed, then these measurements may be scaled for the proposed PCC and supply system impedance. The method should follow that in Annex G of PD IEC/TR 61000-3-7, where the ratio of the voltage change is directly proportional to the ratio of the supply system impedance for the worst case normal operating condition at the respective PCCs.

6.3.3.2 Simplified assessment of step voltage changes

The following simplified assessment approach may be applied to most disturbing equipment that causes step voltage changes, ramp voltage changes or simple combinations of these two types of voltage change. Recommendations for assessing other types of voltage change are described in Clause 6.3.3.4.

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[28] Connection of 8 individual disturbing loads each with $P_{st} = 0.5$ and an exponent of $\alpha = 3$ summate to a resultant $P_{st} = 1$. Further information about flicker summation exponents can be found in Table 8.

[29] This Engineering Recommendation does not recommend any particular flickermeter simulation program. However, any party carrying out assessments using flickermeter simulation programs could be required to demonstrate its suitability and accuracy.

The limit of P_{st} = 0.5 for the maximum allowable magnitude of step voltage change with respect to the time between each change is shown by the line in Figure B.1.2.

This limit does not represent the maximum tolerable P_{st} at the PCC but is a value that generally allows individual items of disturbing equipment, which conform to this limit at the PCC, to be connected without any significant probability that the planning level would be exceeded.

Disturbing equipment that results in a flicker severity at any point on or below the line in Figure B.1.2a) can be connected without further detailed assessment.

Figure B.1.2b) is the inverse characteristic of Figure B.1.2a) and shows the maximum number of voltage changes per minute for a given % voltage change.

A step up in voltage followed by a step down in voltage constitutes two separate voltage changes.

Such voltage changes, where the duration between step up and step down are ≤ 1 s are known as 'pulse changes'. Pulse changes can be equated to a single step voltage change for use in Figure B.1.2 using Figure E.1 in PD IEC/TR 61000-3-7.

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6.3.3.3 Simplified assessment of ramp voltage changes

Ramp voltage changes are less noticeable in terms of flicker than step voltage changes of the same size.

Figure B.2.5 provides a simplified method for deriving an equivalent step voltage change from ramp voltage changes with different rise/fall times, where the equivalent relative step voltage change is equal to the shape factor (*F*), determined from the characteristic in Figure B.2.5, multiplied by the maximum voltage change (d_{max}).

NOTE: The term d_{max} used in BS EN 61000-3-3 is equivalent to ΔV_{max} used in this EREC.

The acceptability of the voltage change, in terms of flicker, may then be considered as an assessment of simplified step voltage change (see 6.3.3.2).

6.3.3.4 Shape factors

Shape factors may be used for simplified P_{st} assessments for both periodic and non-repetitive voltage fluctuations. Voltage fluctuations of a more random nature, such as those produced by electric arcs, require more advanced techniques for accurate prediction.

In many cases, voltage fluctuations produced by disturbing equipment follow known shapes and predictable patterns. In these cases, the flicker severity that would be produced for a given magnitude of voltage change and shape may be determined using shape factors. These shape factors have been determined from flickermeter simulation programs and can be used in conjunction with the P_{st} = 1 curve to predict P_{st} for known shapes (other than square waveforms).

NOTE: The magnitude of voltage change can be determined from simplified calculations, flickermeter simulation programs or historical data for similar disturbing equipment whereas some knowledge of the operational pattern produced by the disturbing equipment is necessary to evaluate the overall shape of the voltage fluctuation.

The shape factor curves in Annex B may be used for the following fluctuation shapes/patterns.

a) Shape factor curve for pulse and ramp changes.

b) Shape factor curves for double-step and double-ramp changes.

c) Shape factor curves for sinusoidal and triangular changes.

d) Shape factor curve for motor-start voltage characteristics.

6.3.4 Stage 3 assessment

Disturbing equipment that is not permitted to be connected under Stage 2 (see 6.3.3) should be subject to Stage 3 assessment, where agreed by the system/network operator, where a detailed assessment of existing flicker background levels and projected flicker severity should be carried out with the addition of the proposed disturbing equipment/fluctuating installation. In this case the customer should provide all the necessary data to the system/network operator for study purposes (see 6.1.4).

Disturbing equipment and/or fluctuating installations with stochastic voltage fluctuations, such as arc furnaces, should generally be subject to Stage 3 assessment[30].

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The flicker background level should, where practicable, be measured at the PCC (see 7.2) during periods the proposed disturbing equipment and/or fluctuating installation is likely to be in operation. Where this is not practicable, the flicker background level may be determined by extrapolation of measurements taken at nearby nodes.

Although the highest flicker level will normally be at the connection point, it could be at another location between the connection point of the proposed disturbing equipment/fluctuating installation and the main source of existing flicker background levels, where existing flicker background levels are high, i.e. $P_{st} > 0.5$. The method in Annex C of PD IEC/TR 61000-3-7 may be used in conjunction with the flicker transfer co-efficient in Table 3 [of EREC P28] to transfer flicker measured at remote nodes to the PCC under consideration.

Where there is doubt about the location of the highest flicker levels then further measurements of flicker background levels should be taken at other locations. In addition, further modelling should be carried out by the customer to determine the location and magnitude of the highest flicker level. Particular consideration should be given to whether the highest flicker levels can be found on the LV network as a result of:

a) existing high flicker background levels on the LV network; and

b) the additional flicker transferred from proposed disturbing equipment/fluctuating installations to be connected to the higher voltage supply system.

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[30] This recommendation does not preclude assessment under Stage 2, where flicker is expected to conform to the limits in Stage 2.

Where there is reason to believe the flicker background level might be relatively high, P_{st} > 0.5 then a direct measurement of the flicker background level at the PCC should be carried out at the pre-connection study stage. A more detailed evaluation of flicker background level may be carried out to identify any scope to reduce flicker levels.

The short-term flicker severity (P_{st}) for the proposed disturbing equipment and/or fluctuating installation should be determined from either:

a) previous measurements of P_{st} for identical disturbing equipment (see NOTE);

b) scaling characteristics of similar disturbing equipment with known P_{st} values;

c) flickermeter simulation[31].

NOTE: A change in network characteristics, e.g. fault level, can affect P_{st} levels even when identical equipment is used elsewhere. The fact that equipment used elsewhere has not resulted in flicker issues does not mean it will continue not to when moved or used at a new network location without assessment.

The effects of any known future connections or system changes, including use of previous measurements of P_{st} for identical equipment used elsewhere, should be assessed[32].

The P_{st} values of the proposed disturbing equipment and/or fluctuating installation, the P_{st} values of any known future connections or system changes and the P_{st} values of flicker background should be summated using the general summation law (see Equation 1).

$$P_{st} = \sqrt[\alpha]{\sum_{i=1}^{i=n} {P_{sti}}^{\alpha}}$$ Equation 1

where:

P_{st} is the magnitude of the resulting short-term flicker level for the considered aggregation of flicker sources (probabilistic value)

P_{sti} is the magnitude of the various flicker sources or emission levels to be combined

α is an exponent that depends on various factors (see Table 8)

Where the summated P_{st} values exceed the P_{st} planning levels in Table 2, connection of the proposed disturbing equipment and/or fluctuating installation should not be permitted.

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31 Computer programs that simulate flicker severity are commercially available.

32 Information about known future connections and system changes can be obtained from Long Term Development Statements (LTDS) published by system/network operators, where available, or on request from system/network operators. This includes the Electricity Ten Year Statement (ETYS) for transmission systems in GB.

The long-term flicker level should be calculated from short-term flicker levels using Equation 2.

$$P_{lt} = \sqrt[3]{\frac{1}{n} \sum_{j=1}^{j=n} {P_{stj}}^3} \qquad \text{Equation 2}$$

where:

P_{lt} is the magnitude of the resulting long-term flicker level for the aggregation of short-term flicker levels over the time which P_{lt} is required to be measured (see NOTE)

n is the number of P_{st} values in the time over which P_{lt} is required to be measured

P_{st} is the magnitude of the resulting short-term flicker level for the considered aggregation of flicker sources (probabilistic value)

NOTE: P_{lt} is normally evaluated over a 2 h period, where n = 12.

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Where relevant, multiple values of P_{lt} should be summated using the general summation law (see Equation 1) as for P_{st} values. Where the P_{lt} value or the summated P_{lt} values exceed the P_{lt} planning levels in Table 2, connection of the proposed disturbing equipment and/or fluctuating installation should not be permitted.

Where consent is given to connect disturbing equipment or a fluctuating installation following Stage 3 assessment, the system/network operator should measure flicker severity at the PCC following commissioning to verify that the actual measured values are consistent with the assessment and, in the worst case, do not exceed the Stage 3 planning levels. If measurements are made at some other point then the results should be transposed to the PCC, with consideration to using the actual compared with the minimum supply system impedance declared by the system/network operator.

Where two or more applications are received to connect new disturbing equipment/fluctuating installations on the same part of the existing electricity supply system, the extent of interaction and their cumulative effect should be considered. If it is not practicable to connect all of the affected parties without exceeding planning limits, it may be permissible to connect all parties by carrying out mitigating measures. However, following connection of the first party and on-site measurement of the resultant flicker severity levels it might be permissible to connect additional disturbing equipment/fluctuating installations. In such circumstances, the system / network operator will inform all affected parties of the situation and will determine the terms of their connection offers.

Flicker levels should be measured at the PCC, with the disturbing equipment/fluctuating installation:

a) connected to the system/network, i.e. to measure the overall flicker level; and

b) disconnected from the system/network, i.e. to measure the flicker background level.

If the disturbing equipment/fluctuating installation is not connected to a "clean" flicker free system/network, the flicker level should be determined by subtracting the flicker background level from the overall flicker level using the summation law equation (see Equation 1).

Table 8 — Flicker summation exponents

Exponent	Application
α = 4	Should be used for the summation of flicker when simultaneous voltage fluctuations are very unlikely to occur (e.g. specific equipment controls are installed so as to prevent simultaneous fluctuations and arc furnaces are specifically run to avoid coincident melts).
α = 3	Should be used for the summation of flicker for most types of flicker sources where the risk of coincident voltage fluctuations is small. The majority of studies combining unrelated disturbances fall into this category and it is recommended for general use and when where there is any doubt over the magnitude of the risk of coincident voltage fluctuations occurring.
α = 2	Should be used for the summation of flicker when coincident voltage fluctuations are likely to occur (e.g. coincident melts on arc furnaces).
α = 1	Should be used for the summation of flicker when there is a very high occurrence of coincident voltage fluctuations (e.g. when multiple motors are started at the same time).

NOTE 1: Applies to the addition of either P_{st} or P_{lt} from various sources.

NOTE 2: The lower value of α equates to higher coincidence of voltage changes, where α = 1 is the lowest.

An exponent of α = 3 should be used for summation of flicker unless there is information/justification to support the application of another exponent.

There might be applications where using an exponent of α = 3 is too conservative, particularly where the risk of coincident voltage fluctuations is very low.

Where the measured flicker background level is $P_{st} > 0.5$ then a more refined method should be used to validate how voltage changes from the fluctuating installation correlate with measured voltage changes.

6.3.5 Simplified voltage change evaluation

For balanced three-phase a.c. electricity supply systems the percentage voltage change caused by disturbing equipment can be derived as follows.

Where the supply system impedance is stated as per unit resistance and per unit reactance values on a base MVA:

$$\frac{\Delta V}{V} = \frac{S}{S_{base}} \left(\cos\varphi \,.\, R_{p.u.} + \sin\varphi \,.\, X_{p.u.}\right) \qquad \text{Equation 3}$$

Where:

ΔV/V Voltage change per unit (p.u.)

S Apparent power change in MVA of the disturbing equipment

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S_{base} Base MVA of the supply system impedance

φ Power factor of the disturbing equipment

$R_{p.u.}$ Supply system resistance per unit

$X_{p.u.}$ Supply system reactance per unit

NOTE: Voltage change percent (%) is equivalent to $\Delta V/V$ x 100.

Where the supply system short-circuit power (see 6.1.5) is stated in MVA and the power factor of the load is assumed to be the same as the ratio of supply system resistance to supply system impedance[33]:

$$\frac{\Delta V}{V} = \frac{S}{S_k^{"}} \times 100 \qquad \text{Equation 4}$$

Where:

$\Delta V/V$ Voltage change percent (%)

S Apparent power change in MVA of the disturbing equipment

$S_k^{"}$ Supply system initial symmetrical short-circuit power MVA

Examples of more detailed calculations of voltage changes can be found in Annex G of PD IEC/TR 61000-3-7.

6.3.6 Assessment of equipment against EMC generic standards

Where a dedicated product EMC standard does not exist, then disturbing equipment may be connected to the supply system subject to meeting the requirements and levels for flicker in BS EN 61000 Part 6 Generic standards and with the specific consent of the system/network operator.

Equipment intended to be directly connected to the LV public electricity supply system conforming to BS EN 61000-6-3 shall be subject to Stage 1 assessment (see 6.3.2) as BS EN 61000-3-3 and BS EN 61000-3-11 are normative references in this standard [BS EN 61000-6-3].

Equipment that is supplied from a HV transformer, which is dedicated to the supply of an installation feeding manufacturing or similar plant and is intended to operate in or in proximity to industrial locations, can be connected subject to conformance to BS EN 61000-6-4 and meeting the requirements and levels for flicker stated by the system/network operator.

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[33] This is the worst-case condition.

Where conformance to EMC requirements in harmonised product standards or BS EN 61000 Part 6 Generic standards is not applicable or not appropriate then equipment can be connected to public electricity supply systems via the 'Technical File' path, where it can be shown to conform to the requirements of The Electromagnetic Compatibility Regulations 2016 [1] [34].

NOTE: The 'Technical File' path is a route that manufacturers can opt to follow when declaring conformance to the Electromagnetic Compatibility Regulations 2016. This route is based on relying on evidence assembled within a Technical File by the manufacturer, as opposed to relying on conformance to some or all relevant harmonised standards.

6.4 Assessment of rapid voltage change

6.4.1 General

As a minimum requirement, an assessment to determine the maximum RVC should be carried out:

a) at the minimum fault level for normal operating conditions (see 6.1.6);

b) assuming 0.5 p.u. of remanent flux in transformers[35];

c) assuming the pre-event initial steady state voltage, V_{0}, occurs at the upper and lower statutory voltage limits;

d) at the voltage zero crossing or other point on the voltage waveform, where this results in the maximum magnitude of RVC; and

e) including sympathetic inrush currents between transformers connected in the vicinity unless it can be demonstrated that these currents are insignificant[36].

The assessment procedure should be based on measured changes in r.m.s. voltage refreshed each half cycle starting with the first full cycle of measurements following commencement of the RVC (see 7.3). The first incomplete half cycle measurement following commencement of the RVC should be disregarded.

The maximum RVC should not exceed the relevant limit(s) in Table 4[37].

NOTE: The relevant limits in Table 4 define an envelope for categories of occurrence, which the maximum r.m.s. RVC is required to fit within. The acceptability of voltage change is now assessed over a time period from the start of the RVC event and not just after 30 ms from the start of the event, as was the case in Engineering Recommendation P28 Issue 1.

The magnitude of remanence flux can vary for different types and designs of transformers.

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[34] The Electromagnetic Compatibility Regulations 2016 are the UK implementation of Directive 2014/30/EU of the European Parliament and of the Council relating to electromagnetic compatibility.

[35] In the absence of specific data, a value of 0.5 p.u. remanent flux can be assumed given a value between 0.4 and 0.6 p.u. is typical of measured results.

[36] Sympathetic inrush currents can affect voltage recovery especially in systems/networks with lower fault levels.

[37] Assessment of emission levels is based on the absolute maximum voltage change measured and not the probability the limit could be exceeded for a small period of time.

Where the magnitude of the calculated maximum RVC is marginal, with respect to the limits in this EREC, then the validity of any typical values used, including those for remanence, together with any assumptions should be checked for the particular transformer being studied[38].

6.4.2 Transformer energisation

6.4.2.1 General

Transformer inrush current is asymmetrical with a harmonic content that can last for tens of cycles after transformer energisation. Asymmetry of the inrush current is the result of a d.c. component that can be a significant proportion of the peak current magnitude. For three-phase transformers, at the instant of transformer energisation, the voltage will be different in each phase. Invariably the RVC will be of greater magnitude in one of the phases depending upon the point-on-wave energisation. The maximum voltage change, of the three-phases, should be taken to be ΔV_{max} and used for assessment against the RVC limits in Table 4.

The magnitude of RVC depends on the relative short-circuit capacity of the upstream electricity supply system to the transformer rated power and the inrush characteristic of the transformer. The inrush current characteristic, in terms of the proportion of 50 Hz fundamental frequency current and the initial magnitude and time constant of the d.c. component can vary for different types of transformers.

The study of transformer inrush current is complex and is best done through electromagnetic transient analysis using an appropriate software program. Careful consideration should be given to assigning values to parameters in such software programs.

For example: Magnetising impedance parameters have an important effect on the linear reactance and the decaying time constant related to the magnetic circuit used for estimating the magnetic flux in the core of the transformer.

Studies involving transformer inrush current should consider energisation at a switching angle corresponding to zero volts in one phase[39].

Where the resultant voltage change is marginal, i.e. within 10% of the relevant RVC limit, then energisation at a switching angle corresponding to 5% of the peak rated voltage in that phase should be evaluated[40]. The studies will be acceptable if the resultant voltage change for the latter case is less than 90% of the relevant RVC limit.

Empirical studies show that significant variations can occur in the calculated magnitude of voltage dip depending upon the value of assumed parameters. The sensitivity of the calculated magnitude of voltage dip to changes in parameter values should be understood to ensure the calculated values accurately represent expected measured values.

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[38] In practice, remanence values have been found to be lower than 0.8 p.u.

[39] Theoretically this represents the worst-case condition.

[40] This approach recognises that before the poles of a circuit breaker actually close and touch each other an arc strikes across the poles and current starts flowing in the phase (through the arc). The striking of the arc and flow of current is due to the fact that there is a voltage difference between the circuit breaker poles at that point. Empirically, this voltage is about 5% of the peak rated voltage in the phase when current starts to flow.

6.4.2.2 Simplified assessment

Where detailed information needed to carry out transformer magnetising inrush simulation studies is not available then a simplified assessment may be carried out as a first step to determine whether the magnitude of the voltage dip during energisation is sufficiently close to the RVC limits as to warrant detailed electromagnetic transient analysis.

Simplified assessment can include the following.

- Application of generic curves that relate system fault level to the magnitude of voltage dip for typical distribution type transformers[41].
- Simple modelling of the inrush current from the peak inrush current provided by the manufacturer / supplier and typical constants for different transformer types based on the fundamental frequency component of rated current [42].
- Simple calculation of the magnitude of the initial voltage dip based on the ratio of the peak inrush current to the peak rated current (see Annex C).

It should be noted that using the manufacturer's/supplier's stated peak inrush current as a multiple of rated current might result in an unduly pessimistic magnitude of voltage dip compared with measured results.

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The following points should be considered when carrying out simplified assessment.

a) Simplified modelling of the inrush current could underestimate the magnitude of the peak voltage dip by up to 30%, where default values are used and subtransient effects are omitted.

b) The modelling of inrush current decay may differ from that measured in practice given the inrush current decay envelope could be more complex than can be represented by an exponential decay curve and single time constant.

c) The ratio of the peak inrush current and peak rated current can differ appreciably for different types of transformer, therefore it is important to use data that is specific to the transformer being modelled.

d) Dry type distribution transformers will generally result in a greater magnitude of voltage dip on the first energisation than equivalent oil-filled distribution transformers.

e) RVCs are characterised by true r.m.s. voltages not just the power frequency component.

It should be noted that empirically, the magnitude of inrush current and hence voltage dip is generally lower for transformers that comply with BS EN 50588-1, due to lower fixed iron losses.

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[41] Such as the Paper 'Assessing P28 Guidelines for Renewable Generation Connections' by R.A. Turner and K.S. Smith [10].

[42] Such as the Paper 'A Simplified Method For Estimating Voltage Dips Due To Transformer Inrush', CIRED 20th International Conference on Electricity Distribution, 2009 by Graeme Bathurst [11].

7 Measurements

7.1 General guidelines for measurements

The measurement period should be chosen to include the expected maximum disturbance (flicker severity or RVC) caused by the disturbing equipment/fluctuating installation being assessed.

The measurement period should be generally not less than one week to capture any daily variations in background levels. A shorter measurement period may be used providing this is representative of the measurements that would be expected if measured over one week or would capture the most severe two-hour period of voltage fluctuations (see 7.2.1). In any case, the measurement period should be of sufficient duration to cover at least two full operating cycles of single disturbing equipment and/or at least one full operating cycle for a fluctuating installation with several items of disturbing equipment.

The decision as to whether the limits apply to phase-phase or phase-neutral voltage should be consistent with relevant measurement standards.

Where measurements are taken from systems/networks through a voltage transformer, it is important to give due regard to the phase relationship between measured voltages and LV system/network voltages[43]. This is particularly important for voltage fluctuations which are not symmetrical to all three phases.

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Where it is not possible to take measurements under the worst case normal operating condition, the measured values obtained for the particular system/network condition should be analysed to ensure they are consistent with those expected for that condition.

7.2 Flicker measurements

7.2.1 Measurement of flicker severity for an item of disturbing equipment

Direct measurement of all types of voltage fluctuations should be assessed using a flickermeter conforming to the requirements to BS EN 61000-4-15.

Flicker should be measured using the Class A method specified in BS EN 61000-4-30 and BS EN 61000-4-15, except the measurement uncertainty requirement for P_{st} at low modulation rates, i.e. < 40 changes per minute, need only be met for voltage fluctuations ≤ 10% in amplitude over an input voltage in the range of nominal voltage ± 10%. Alternatively, where agreed with the system/network operator, flicker may be assessed using the Class S method for specific applications where the measurement uncertainty requirement is not critical for P_{st} outside the range of 0.4 to 4.

Data should be flagged in accordance with BS EN 61000-4-30 such that abnormal voltage fluctuations[44], e.g. associated with faults or switching events on the network, can be omitted to ensure the measurement is representative of the flicker being assessed.

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[43] This is important as lighting equipment, which is most sensitive to voltage fluctuation, is connected between phase and neutral at LV.

[44] Abnormal voltage fluctuations include those from unintended sources, such as faults etc.

Measurements of P_{st} and P_{lt} should be 95% probability values over a normal measurement period of one week. For shorter measurement periods, 99% probability values for measurements of P_{st} should be used[45].

NOTE: Comparison of 99% and 95% probability values can be useful as ratios > 1.3 can indicate abnormal results caused by voltage dips and transients.

The calculation of P_{lt} should be based on a sliding window of P_{st} values, where the oldest P_{st} value is replaced by the newest P_{st} value at each 10-minute interval.

A check should be made when starting measurements and when interpreting measurement results that step voltage changes are not exceeding 3% between steady state conditions and/or that P_{st} is not exceeding planning levels (see Table 2).

If the disturbing equipment/fluctuating installation is not connected to a "clean" flicker free supply then the measured flicker background level (see 7.2.2), without the disturbing equipment/fluctuating installation in operation, should be subtracted from the result using the general summation law equation (see 6.3.4).

7.2.2 Flicker background levels

Flicker background levels in each phase should be measured without the disturbing equipment/fluctuating installation in operation. The measurement period should be of sufficient duration to obtain typical flicker background levels that coincide with the operation of the proposed disturbing equipment/fluctuating installation. Measurements in the phase with the highest measured flicker background levels should be used for assessment.

A flicker background level of $P_{st} < 0.35$ is negligible and may be discounted in any simplified flicker assessment approach referenced in this EREC.

In the absence of any measured data, the flicker background level should be assumed to be $P_{st} = 0.5$. If there is reason to believe the flicker background level might be greater than $P_{st} = 0.5$, a direct site measurement should be carried out for the purposes of assessment.

Flicker background levels for new substations may be estimated from measurements at other locations in the electricity supply system by applying relevant transfer coefficients from adjacent nodes (see Table 3 for typical transfer coefficients). Examples of how to apply transfer coefficients between different nodes can be found in Annex B of PD IEC/TR 61000-3-7.

7.3 RVC measurements

RVC measurements should be based on measured changes in the r.m.s. voltage.

The worst case RVC measured over the measurement period should be used to determine the emission level, not probability values.

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[45] 99% probability values of P_{st} and P_{lt} are not permitted to exceed planning levels.

Instruments used for power quality measurements should conform to BS EN 61000-4-30 and should be capable of Class A measurements, where r.m.s. voltage measurements are refreshed each half-cycle.

It is likely that the actual RVC measured during the measurement period could differ from the value(s) calculated during studies. The difference between actual measured values and calculated values could be explained by one or more of the following.

a) The actual supply system impedance present during the measurement period might be significantly less than for the worst case normal operating condition used for study.

b) Power quality measurement instruments that measure true r.m.s. voltage will include the additional voltage fluctuation caused by harmonic currents; some studies could consider the 50 Hz fundamental frequency only.

c) Switching during the measurement period will not necessarily take place at the worst case condition(s) as studied, e.g. the worst case point on the voltage waveform and/or the worst case remanence flux.

Given actual measured values are dependent on the point on the voltage waveform that a fluctuating installation is energised then a number of repeat energisations should be carried out, where practicable, to validate emission values.

The effect of actual conditions present during the measurement period should be considered when validating measurement results against calculated results and limits in this EREC.

Where possible, measurements should be conducted when the system is fully intact with no outages of equipment and validated against calculated values of RVC for the same system arrangement.

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8 Guidance on application

8.1 General

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

When assessing several sources of flicker the resultant value of P_{st} should be determined by application of the general summation law equation (see 6.3.4).

8.2 Supply system considerations

For connected disturbing equipment or fluctuating installations with $P_{st} > 0.5$, the system/network operator should carefully control the connection of further disturbing equipment/fluctuating installations to affected supply systems. This is to prevent planning levels being exceeded in future.

The system/operator should have an effective system in place to identify, record and monitor these affected supply systems.

As it is not practicable to control the connection of certain LV disturbing equipment, in particular, household appliances and similar electrical equipment, the network operator should only consent to the connection of disturbing equipment or a fluctuating installation under Stage 3 if satisfied that other significant loads cannot be connected without their consent.

Where system alterations are contemplated that could change the realistic maximum impedance at the PCCs used for Stage 3 assessments then the system/network operator should re-assess the flicker severity at these PCCs to ensure planning levels are not exceeded.

8.3 Electric motors

As motors can cause voltage changes on starting, during running and on stopping, all these conditions need to be considered when assessing the acceptability of connecting a motor to the supply system.

8.3.1 Starting

In most cases, starting produces the most severe voltage change in terms of both the magnitude and power factor of the current taken. In the majority of cases for motors with direct-on-line starting, the duration of the magnetising inrush current is several seconds.

Where the voltage change characteristic of the starting event fits within the envelope in Figure 5, the acceptability of the minimum time between occurrences may be assessed from Figure B.1.2 and should conform to the recommendations for planning levels and assessment of flicker stated in this EREC.

Where the voltage change characteristic of the starting event does not fit within the envelope in Figure 5, the acceptability of the magnitude of the voltage change should be assessed against the limits in Table 4.

Where a motor is only started at intervals of several months (very infrequent starting event), the voltage change characteristic should fit within the envelope in Figure 7. The system/network operator may insist on special conditions being put in place. These special conditions may include one or more of the following.

a) Restriction of starting to times when the associated system is fully intact with no outages of equipment.

b) Restriction of starting to certain hours, e.g. 0100 hrs - 0700 hrs, to minimise the likelihood of disturbance to other customers.

c) Liaison with the system/network control engineer prior to starting.

d) Consideration of inhibiting tap-changer operation.

Special consideration may be given to other scenarios, where motors will usually only be started over a limited period of the year, generally when there is no lighting load on the system. In these scenarios, although a very limited number of customers might experience the full voltage depression at the PCC, the probability of resultant voltage complaints will be low. Whilst these and similar cases require judgement to be exercised, voltage depressions within the limits of Figure 7 are acceptable.

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For motors where the front time associated with starting is short, e.g. ≤ 30 ms, and the tail time is comparatively longer, then the maximum voltage change, d_{max}, can be substituted as the step voltage change in Figure B.1.2.

Example 1: For a motor with a starting and stopping characteristic lying within the envelope of Figure 5 would need to have a minimum time between starting events of 475 s if the voltage change was 3%.

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 B.1.2.

Use of reduced voltage starters, such as star-delta and reactor types, normally causes a second voltage change at the changeover point. This second voltage fluctuation is similar to that in Figure 5 and should be considered equivalent to a further single step voltage change.

For LV motors, where the maximum voltage change (d_{max}), the front time (T_f) and the tail time (T_t) are known then a shape factor (F) can be determined from Figure 5 in BS EN 61000-3-3. The equivalent step voltage change for use in Figure B.1.2 can be obtained by multiplying F and d_{max} (see Figure 10).

For motors with normal magnetising inrush current characteristics the magnitude of the largest r.m.s. voltage change for starting events can be assessed from either:

a) measurement of the motor current with the rotor locked when supplied at the intended operating voltage of the motor; or

b) reference to the manufacturer’s published information.

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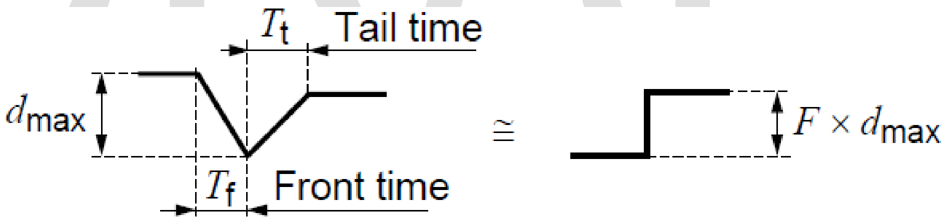

NOTE: The same convention as BS EN Standards has been followed, where a reduction in voltage is represented as a positive value of d_{max}.

Figure 10 — Application of shape factor (F) for motor starting

For motors with abnormal magnetising inrush characteristics then the voltage fluctuation should be determined from either measurement of similar motor installations or flickermeter simulation programs.

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

8.4 Furnaces

At the design stage and for single furnace installations, which are effectively electrically isolated from other furnaces, the following simplified assessment may be adopted, generally for connections to 11 kV and 33 kV networks, which involves the calculation of the short-circuit voltage depression at the PCC.

Assuming 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 (S_t) and the system short-circuit power in MVA at the PCC (S_c) (see Equation 4).

The apparent short-circuit power of a furnace (S_t) 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. The value of S_t may be taken to be twice the furnace rated power if no other information is available.

In order to meet the Stage 2 limit for flicker severity, the value of short-circuit voltage depression calculated from Equation 4 should be less than 1%[46].

Where the effect of source impedance on the short-circuit power drawn by the furnace is not negligible, a more accurate assessment should be conducted.

For induction furnaces, additional aspects of operation, including consideration of voltage fluctuations, are described in Engineering Recommendation P16 [3].

However, the voltage fluctuation limits in EREC P28 supersede any limits in Engineering Recommendation P16 [3].

The cubic summation law in the case of the summation effects of two arc furnaces (at the 95th & 99th percentile) could be too pessimistic for realistic estimation of summation effects and an exponent of $\alpha = 4$ could be considered.

8.5 Heat pumps

Assessment of domestic heat pumps for connection to LV public electricity supply systems should follow the connection/notification process published by the ENA[47]. The voltage fluctuation requirements of that process for connection of a single heat pump/system are equivalent to the Stage 1 assessment process in this EREC (see 6.3.2).

Multiple heat pumps/systems, each with a rated power ≤75 A per phase including any boost or back-up function, for connection to the LV public electricity supply systems, shall be subject to conditional assessment in accordance with Stage 1 of this EREC.

The short-term flicker severity (P_{st}) of fluctuating installations with multiple heat pumps can be summated according to the summation law and exponents in Equation 1 (see 6.3.4) providing that heat pumps start 30 s apart.

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[46] This equates to a step voltage change of 1% not more than every 20 s.

[47] The notification process for connecting heat pumps can be found on the ENA website.

The general flicker summation exponent α = 3 may be used to calculate how many heat pumps can be connected to the same PCC without exceeding the flicker planning level. The flicker summation law and exponents are not valid for multiple heat pumps within a fluctuating installation that are centrally controlled to switch at the same time.

The boost function on multiple heat pumps in the same fluctuating installation should be controlled, where unacceptable voltage fluctuations would occur otherwise if the heat pumps were to switch on/off simultaneously[48].

The indoor and outdoor parts of a heat pump system should be tested as a whole integrated system as well as individual items of equipment. The whole integrated system is required to conform to the emission limits in this EREC.

Special consideration should be given to heat pumps with direct-on-line connection as these could result in excessive voltage fluctuations unless steps are taken to reduce the initial starting current, e.g. using soft-start technology.

8.6 Electric vehicles (EVs)

8.6.1 General

Equipment and systems for charging EVs whether installed in an EV or in a fixed installation should conform to BS EN 61851.

General guidance on the notification process for connecting EV charging infrastructure to LV public electricity supply systems is published by the ENA[49].

The following specific recommendations relate to the assessment of flicker from EV charging equipment.

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8.6.2 Fixed charging installations

Fixed charging equipment is not subject to conditional connection and can be connected to LV public electricity supply systems under Stage 1 without reference to the network operator where:

a) the equipment has a rated current ≤ 16 A and it conforms to BS EN 61000-3-3;

b) the equipment is connected at a domestic residence has a rated current ≤ 32 A and it conforms to the technical requirements of BS EN 61000-3-3.

Fixed charging equipment ≤75 A per phase not conforming to BS EN 61000-3-3 should be subject to conditional connection in accordance with BS EN 61000-3-11 and can only be connected to the LV public electricity supply system under Stage 1 if the actual impedance of the supply system the equipment is connected to meets the required value (see 6.3.2).

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[48] Some heat pumps are fitted with a boost function that is programmed to operate at specific times. Multiple heat pumps from the same manufacturer, which are fitted with this function, could operate simultaneously if the default time of the programmed boost is not changed.

[49] The notification process for connecting EV charging infrastructure can be found on the ENA website.

Network operators should give special consideration to assessment of installations where multiple EV charging connections are proposed to be connected to a PCC. This may include taking steps to prevent simultaneous switching of multiple active chargers to prevent breaching the 3% step voltage change limit.

Where conformance to flicker limits depends upon minimum control cycle time(s) being applied to fixed charging equipment then these should be declared by the manufacturer/supplier and applied to the charging equipment.

The severity of flicker from fixed charging equipment depends, inter alia, on the characteristics of the charger. Where the charging characteristic resembles a stable load with long control cycle times then meeting the 3% step voltage change limit will most probably be the overriding consideration not flicker. Small variations of load whilst charging an EV, even when frequent, are unlikely to result in flicker as opposed to large infrequent step voltage changes when multiple chargers are simultaneously switched on/off.

Special consideration should be given to fixed charging equipment where the main charge has a pulsed current characteristic, given this equipment could significantly increase P_{st} values. This recommendation also applies to chargers that have a maintenance charge function, where the charge is delivered periodically to keep the vehicle battery ‘topped-up’ after the main charge but whilst it is still connected to the charger.

8.6.3 EV on-board chargers

There is no particular requirement to assess flicker from EVs with on-board charging equipment for plug-in connections ≤ 13 A given connections of individual equipment to LV public electrical supply systems with typical supply impedances (see Table 7) have little effect on flicker background levels.

Where the connection of individual EV on-board charging equipment to the LV system results in flicker limits being exceeded, the network operator may require the customer to take steps to prevent interference to other customers.

8.7 Wind turbine generators

Voltage fluctuations from wind turbines connected to the supply system, where the PCC is at HV, should be measured and assessed using the methods in BS EN 61400-21. The measurement procedures in BS EN 61400-21 are valid and may be used for wind turbines connected via three-phases to the LV supply system.

The assessment should consider voltage fluctuations that would arise in continuous operation and during switching operations. Calculations should be based on the power quality information and type test data provided by the wind turbine manufacturer.

For assessing continuous operation of multiple wind turbines within a fluctuating installation, an exponent of $\alpha = 2$ may be used for summation of flicker severity. An exponent of $\alpha = 3.2$ should be used for summation of flicker severity when assessing the effects of switching operations of multiple wind turbines.

When assessing the connection of additional wind turbines to the PCC, steps should be taken to avoid two wind farms performing switching operations at the same time.

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Where simultaneous switching operations can be avoided, no summation effects need to be taken into account. Where the risk of simultaneous switching operations cannot be avoided then the resultant voltage fluctuations should be studied and assessed.

Flicker caused by turbulence, wind gusts, tower shadow and oscillation during continuous operation of wind turbines should be assessed, however, these are not expected to be significant for modern Doubly-Fed Induction Generator (DFIG)/full converter connected wind turbines.

When assessing voltage fluctuations caused by wind turbines, particular consideration should be given to switching operations involving fixed speed wind turbine generators and to the energisation of step-up transformers between the wind farm and the supply system.

The connection of the latest wind turbines, with rated powers > 3 MW are unlikely to result in significant flicker when the resultant reduction in local supply system impedance is taken into account. Where the rated apparent power of the wind turbine(s) (S_n) is large compared with the supply system initial symmetrical short-circuit power (S''_k), i.e. S_n / S''_k ≤ 3, flicker from the wind turbine(s) may have a significant impact on flicker background levels.

In these cases, an emission limit of P_{st} ≤ 0.35 applies to calculated emissions, where the actual flicker background level is unknown. Where the calculated emission limit is P_{st} > 0.35 but ≤ 0.5, more detailed assessments that take into account actual flicker background levels should be carried out.

8.8 Photovoltaic (PV) installations

Inverter connected PV ≤16 A per phase should conform to the test requirements and limits in BS EN 61000-3-3 and relevant recommendations in ENA Engineering Recommendation G83 [N1].

When assessing flicker from PV installations, flicker severity should be evaluated for various generation outputs from 0% to 100% at power factor conditions that are representative of those likely to be encountered during operation. It is acceptable to assess flicker severity at a constant power factor for PV installations that do not have reactive power control.

NOTE: Generally, residential small scale commercial PV installations export power at unity power factor.

Calculations of flicker should consider those requirements in BS EN 61400-21, for assessing flicker severity from wind turbine generators, that can be applied to assessment of flicker from PV installations. For example, the applicability of the method for assessing the impact of changes to wind speed to assessing the impact of changes in solar energy.

For installations where multiple inverters are proposed, the acceptability of voltage fluctuations arising from variations in generation output caused by changes in solar energy levels should be assessed using a flickermeter simulation program.

Voltage fluctuations caused by the effect of moving clouds on generation output generally result in ramp voltage changes, as opposed to step voltage changes. The effects of moving clouds may be studied but they are unlikely to result in high flicker levels unless the supply impedance at the PCC is untypically high.

The contribution of the customer’s own PV installation to the fault level at the PCC may be considered, where calculated flicker is marginal with respect to flicker limits.

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8.9 Energy storage

The ability of energy storage to change rapidly between importing and exporting electrical power has the potential to cause significant voltage fluctuations on the supply system.

Particular consideration should be given to energy storage providing a frequency response function for the supply system as these schemes are designed to produce rapid power swings, which could result in step voltage changes of significant magnitude. There is also a very high probability of coincident power swings between such installations.

Energy storage which provides voltage control/reactive power support can result in small frequent voltage fluctuations that could result in flicker.

Ramping of power changes will assist with meeting step voltage change limits and flicker limits, where significant changes in power occur frequently such as energy storage with low energy rating to power rating. Ramping of power changes is recommended to minimise voltage fluctuations at the PCC.

Where necessary, charging and discharging rates should be limited so as to conform to the voltage fluctuation limits in this EREC.

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Energy storage used to balance load to generation can result in increased flicker levels due to its response to a change in customer load and/or generation output. Systems that could significantly increase flicker severity through large step voltage changes following step changes in load or generation should be assessed as a complete system of generation, load and energy storage. Further guidance can be found in ENA EREC G100 [9].

8.10 Household equipment

8.10.1 High power household cooking appliances

Household cooking appliances with rated power > 2 kW but ≤ 4.5 kW may be connected without individual consideration providing that they meet the technical requirements of BS EN 61000-3-3 and/or BS EN 61000-3-11, as appropriate (see 6.3.2.1).

8.10.2 Electrically heated instantaneous shower units

Although electric shower units have high rated powers, compared with most household appliances, their load factor is so small that large numbers can often be accommodated within the supply capacity of an LV network. However, large numbers of electric shower units with the same PCC can cause unacceptable voltage fluctuations on LV networks and it is necessary to regulate their rated power and/or operating characteristics. Electric shower units which conform to the requirements of BS EN 61000-3-11 may be connected without individual consideration (see 6.3.2.2).

8.11 Welding equipment

8.11.1 General

Welding equipment with a rated current ≤ 16 A per phase can be connected to the LV supply system without further consideration providing it meets the requirements of BS EN 61000-3-3.

Welding equipment with a rated current > 16 A and ≤ 75 A per phase, not conforming to the technical requirements in BS EN 61000-3-3, is subject to conditional connection in accordance with BS EN 61000-3-11 and can only be connected to the LV public electricity supply system under Stage 1 if the actual impedance of the supply system the equipment is connected to meets the required value (see 6.3.2).

The following arc-welding and metal-heating plant applications are unlikely to cause appreciable flicker problems on supply systems.

a) Welding equipment with a small rated power compared with that of the supply system impedance, where any additional flicker caused by the welding equipment would be insignificant with that of other large disturbing loads already connected to the PCC. For example: argon-arc machines, atomic-hydrogen machines, wire welders, and miscellaneous small metal-heating machines, such as rivet heaters, installed in moderately large factories.

b) Welding equipment that presents a steady three-phase balanced load on the system for long periods. For example: three-phase a.c./d.c. automatic wire-fed machines and three-phase a.c./d.c. nonferrous welders.

c) Welding equipment fed from motor generators which do not pose any appreciable flicker problems for inherent physical reasons.

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The following characteristics of welding equipment are relevant to flicker severity and should be considered in flicker assessments.

a) The magnitude of the sudden steps in welding current that can be imposed on the supply system.

b) Whether the steps in welding current are two-level or multi-level.

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

d) Distribution of the welding current in the phase conductors on the HV supply system.

e) The frequency of the resultant voltage changes.

Where welding equipment is connected directly phase-phase at LV, the resultant phase-neutral voltage change[50] can be calculated from the following equation.

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[50] The phase-neutral voltage is more appropriate since lighting is usually connected phase-neutral.

$$\%\Delta V\ (per\ kVA\ of\ welding\ load) = 0.74\ R_s + 0.68\ X_s \qquad \text{Equation 5}$$

Where:

R_s is the resistance of the LV supply system in ohms

X_s is the reactance of the LV supply system in ohms

kVA refers to the manufacturer's stated rated power

$\%\Delta V$ is in the normal range, i.e. 3%

Load power factor is 0.3 p.u. lagging

Each burst of welding current involves two voltage changes

Where welder equipment has a load power factor greater than 0.3 p.u. lagging, the voltage drop on both the lagging phase and the leading phase should be calculated[51].

Generally electric welding equipment is of the arc or resistance type.

8.11.2 Arc welding equipment

Arc welders are, generally, relatively low powered equipment which produce a step change in the system voltage when the arc is struck and another step change when the arc is broken.

Times between the striking and extinguishing of the arc can vary but are usually in the range of several seconds to a few minutes. Problems with flicker severity are only likely to occur when arc welding equipment is connected to a PCC on a 'weak' LV supply system.

8.11.3 Resistance welding equipment

Resistance welders, both due to their size and operating characteristics, can cause severe voltage fluctuations over a wide area of the supply system. Consequently, every effort should be made to check the full range of a resistance welder's likely operating patterns. The voltage changes that each of the pulse size/frequency patterns can cause should be checked using a suitable assessment procedure (see 6.3). Where complex multi-level voltage changes are involved, they should be assessed using a flickermeter or flickermeter simulation program.

Where resistance welding equipment does not incorporate point-on-wave switching control, the voltage change (%ΔV) should be increased by V_m (see Equation 6) to allow for magnetising in-rush.

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[51] Further information on the flicker effects of welding plant, including frequency-changing transformer, d.c. and stored energy types, which are not dealt with by simplified assessment in Equation 5, can be found in ACE Report No 7.

$$\%V_m(per\ kVA\ of\ welding\ load) = 0.50\ R_s + 0.87\ X_s$$ Equation 6

Where:

R_s is the resistance of the LV supply system in ohms

X_s is the reactance of the LV supply system in ohms

kVA refers to the manufacturer’s stated rated power

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Annex A

Connection of LV electric motors

A.1 Motors that can be connected without reference to the network operator

Previous experience has shown that certain relatively small motors detailed in Table A.1 starting direct-on-line can be connected without consideration of flicker or RVC.

Table A.1.1 — Motors started very frequently[1]

Type	Rated Power Output (kW)	Rated Power Input (kVA)
Single-phase 230 V	≤ 0.37	≤ 1.0
Single-phase 460 V	≤ 1.50	≤ 3.0
Three-phase 400 V	≤ 2.25	≤ 4.0

NOTES:

1. Rated power output and rated power input relates to normal running.
2. Motor rated power can be expressed as rated power output (kW) and/or rated power input (kVA)

[1] Very frequent means started at intervals less than one minute.

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Table A.1.2 — Three-phase motors with the PCC not covered by (a) or (c)

Type	Rated Power Output (kW)	Rated Power Input (kVA)
Single-phase 230 V	≤ 0.75	≤ 1.7
Single-phase 460 V	≤ 3.00	≤ 4.5
Three-phase 400 V	≤ 4.50	≤ 6.00

NOTES:

1. Rated power output and rated power input relates to normal running.
2. Motor rated power can be expressed as rated power output (kW) and/or rated power input (kVA)

[1] Very frequent means started at intervals less than one minute.

Table A.1.3 — Three-phase motors with the PCC at the LV busbar of a distribution substation

Distribution Transformer Rated Power (kVA)	Rated Power Output (kW)
200	22.5
300/315	30.0
500	45.0
750/800	50.0
1 000	75.0

NOTES:

1. Rated power output relates to normal running.
2. Applies to motors started at intervals of 10 minutes or longer.

A.2 Three-phase motors with star-delta starting

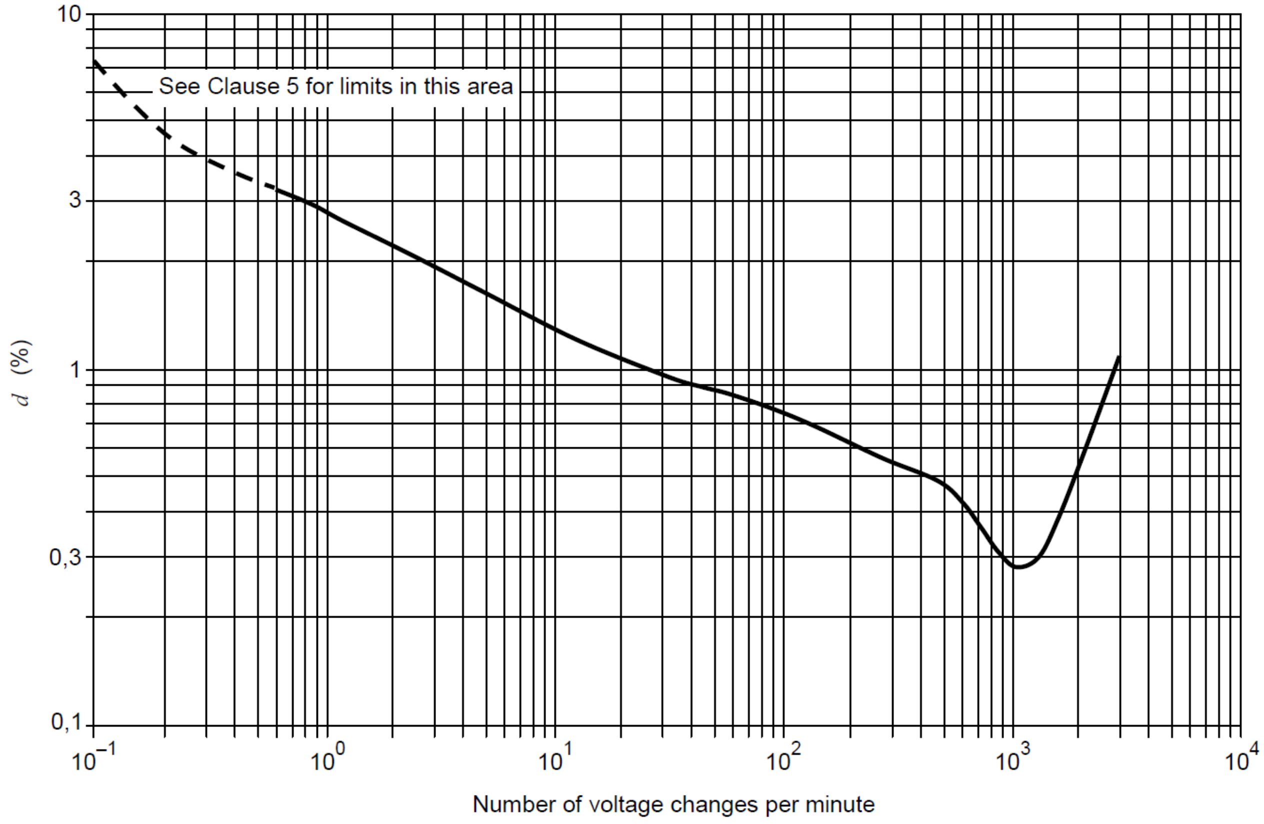
Where star-delta starting is employed, LV motors of up to 1.5 times the rated powers given in Table A.1.1, Table A.1.2 and Table A.1.3 may be accepted without consideration of flicker or RVC.

Annex B

P_{st} curves and shape factor curves

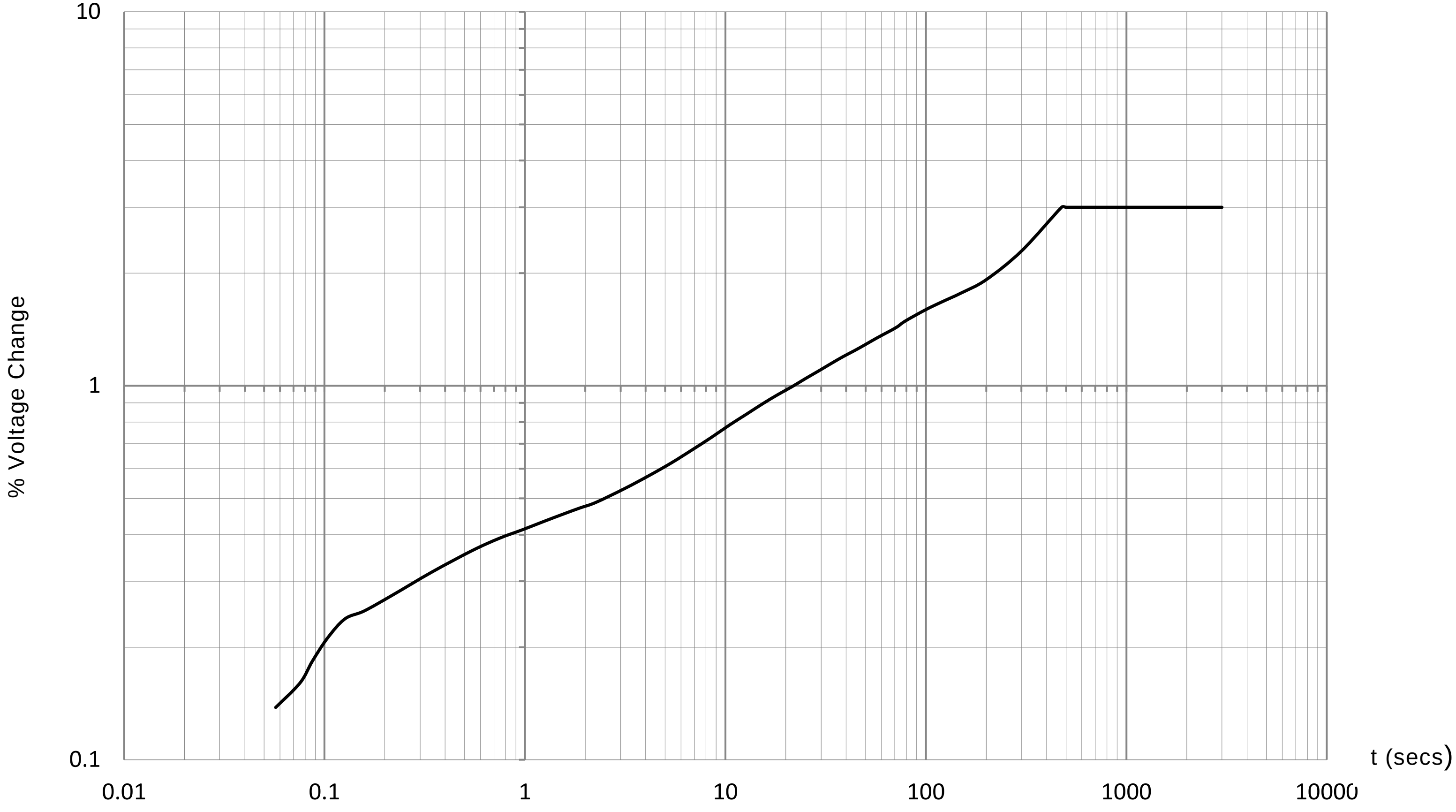
B.1 P_{st} curves

The following P_{st} = 1 curve has been replicated from Figure 2 of BS EN 61000-3-3.



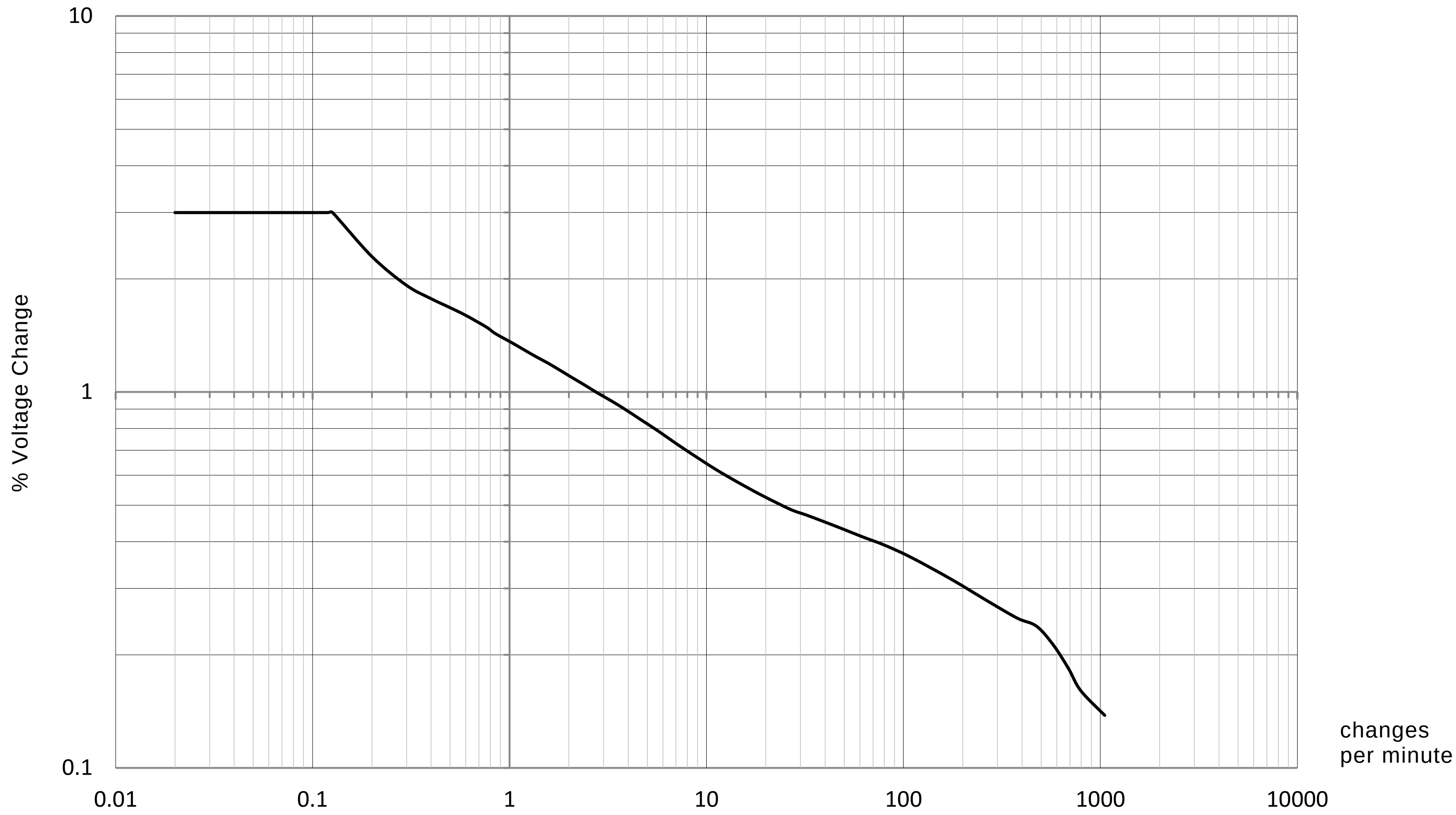
NOTE: ‘Clause 5’ in this figure refers to Clause 5 of BS EN 61000-3-3.

Figure B.1.1 — Curve for P_{st} = 1 for rectangular equidistant voltage changes



a) Minimum time interval between voltage changes

Figure B.1.2 — P_{st} = 0.5 curve for rectangular voltage changes



b) Maximum number of voltage changes per minute

Figure B.1.2 — Pst = 0.5 curve for rectangular voltage changes

Notes for Figure B.1.2

NOTE 1: The P_{st} = 0.5 curve is derived from the P_{st} = 1 curve in Figure A.1 of PD IEC/TR 61000-3-7, given the linear relationship between the value of P_{st} and the magnitude of voltage change. For example: a 2% step voltage change that would give P_{st} = 1 equates to a 1% step voltage change at P_{st} = 0.5 at the same frequency of occurrence.

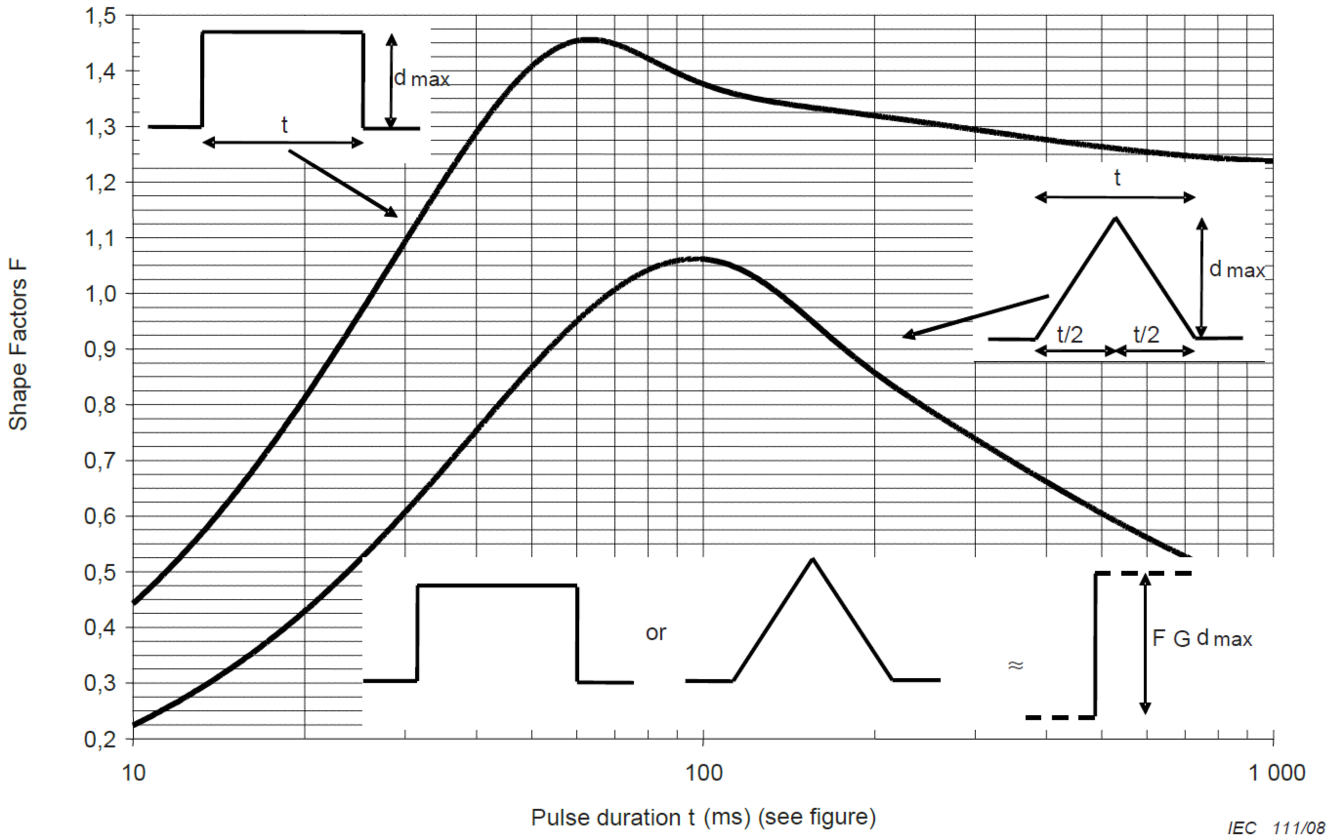
NOTE 2: The P_{st} = 0.5 curve has been deliberately capped at a maximum symmetrical step voltage change of 3% once every 475 secs given the simplified nature of assessment.

NOTE 3: % voltage change represents the magnitude of a relative voltage change with a rectangular (step) voltage characteristic expressed as a percentage of the nominal system voltage (V_n).

NOTE 4: Figure B.1.2 replaces Figure 4 in P28 Issue 1.

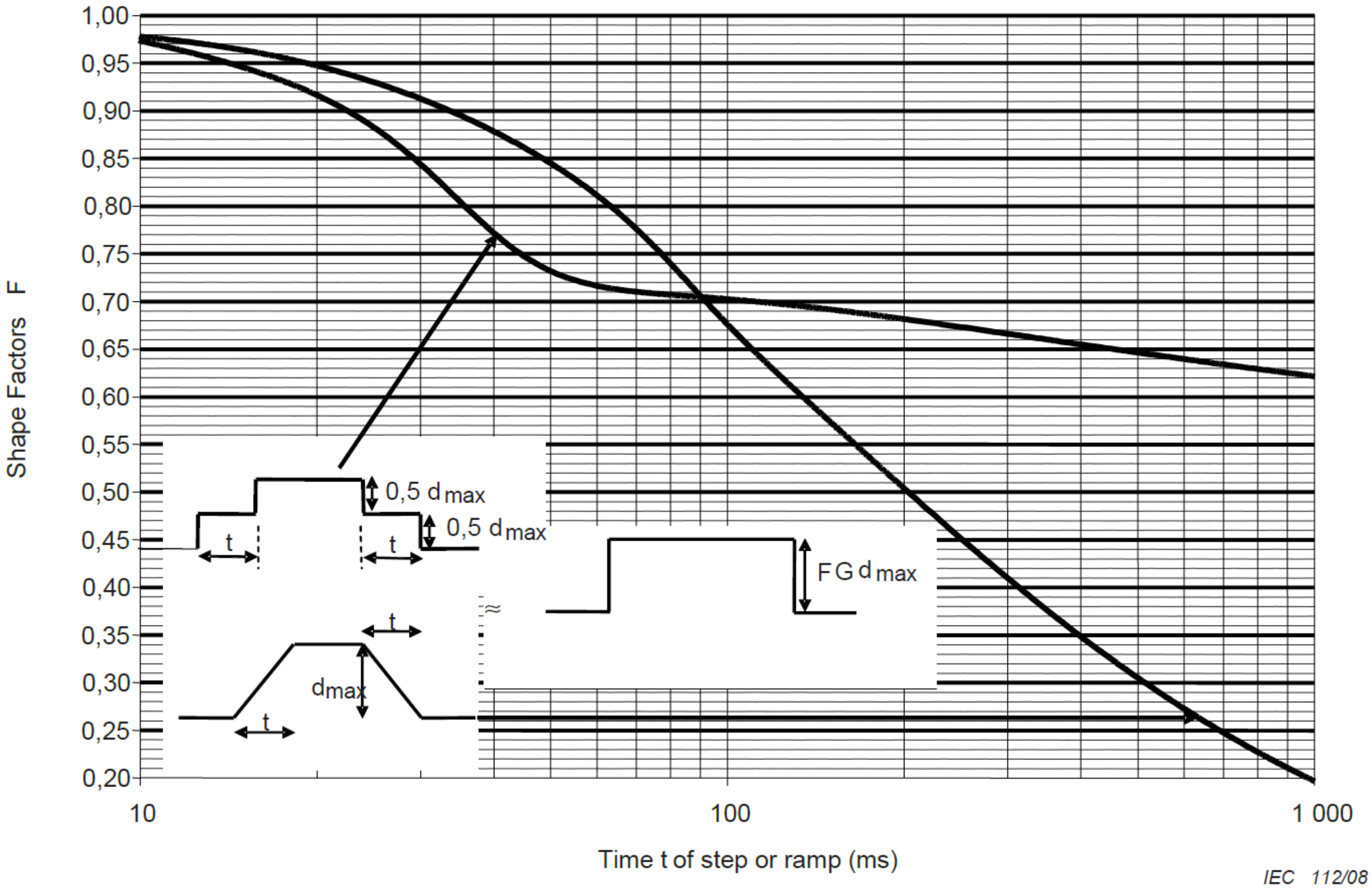
1950 B.2 Shape factor curves

1951 The following shape factor curves have been replicated from Annex E of PD IEC/TR 61000-3-7 and Clause 6 of BS EN 61000-3-3.



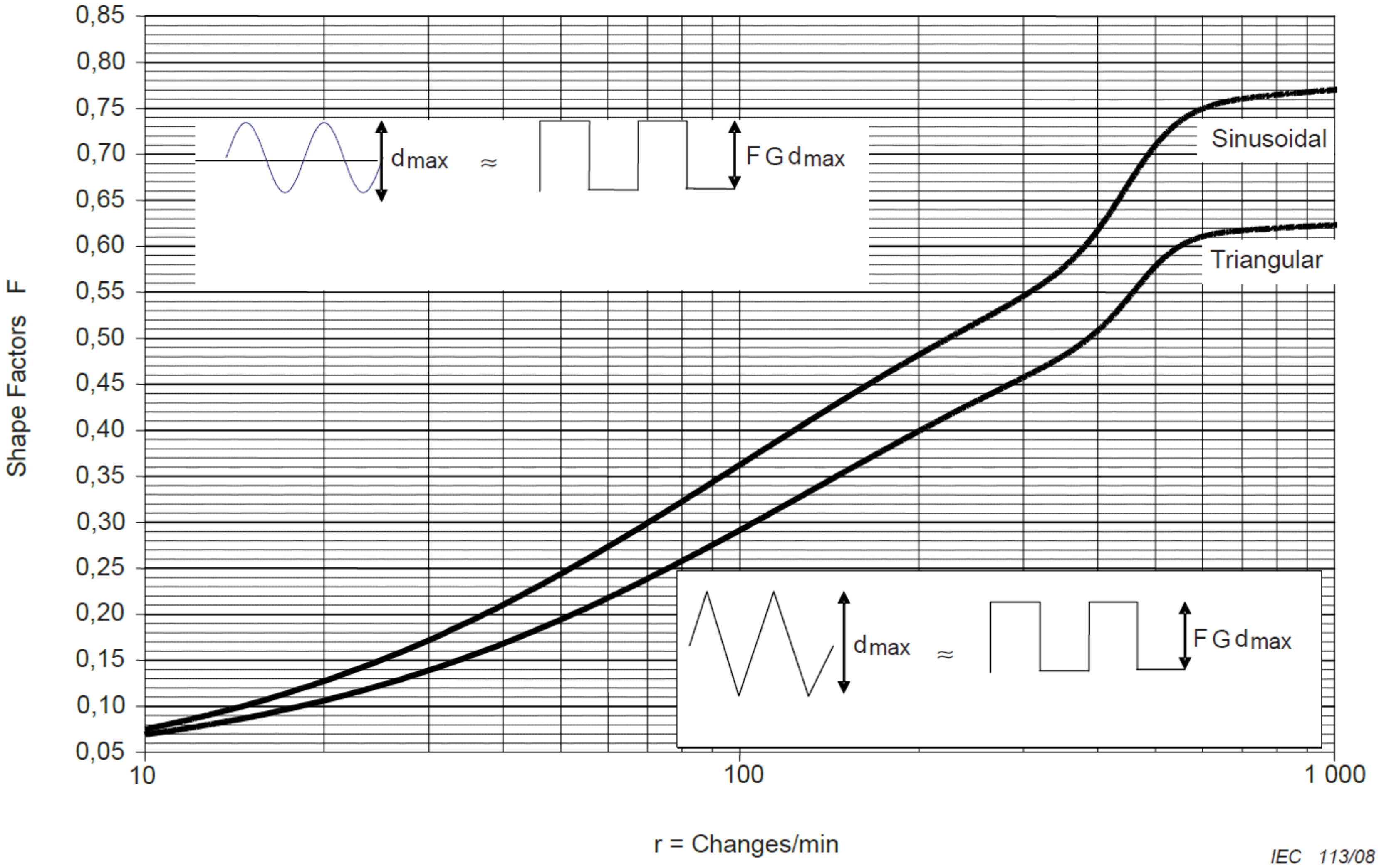
1952

1953 **Figure B.2.1 — Shape factor curve for pulse and ramp changes**



1954

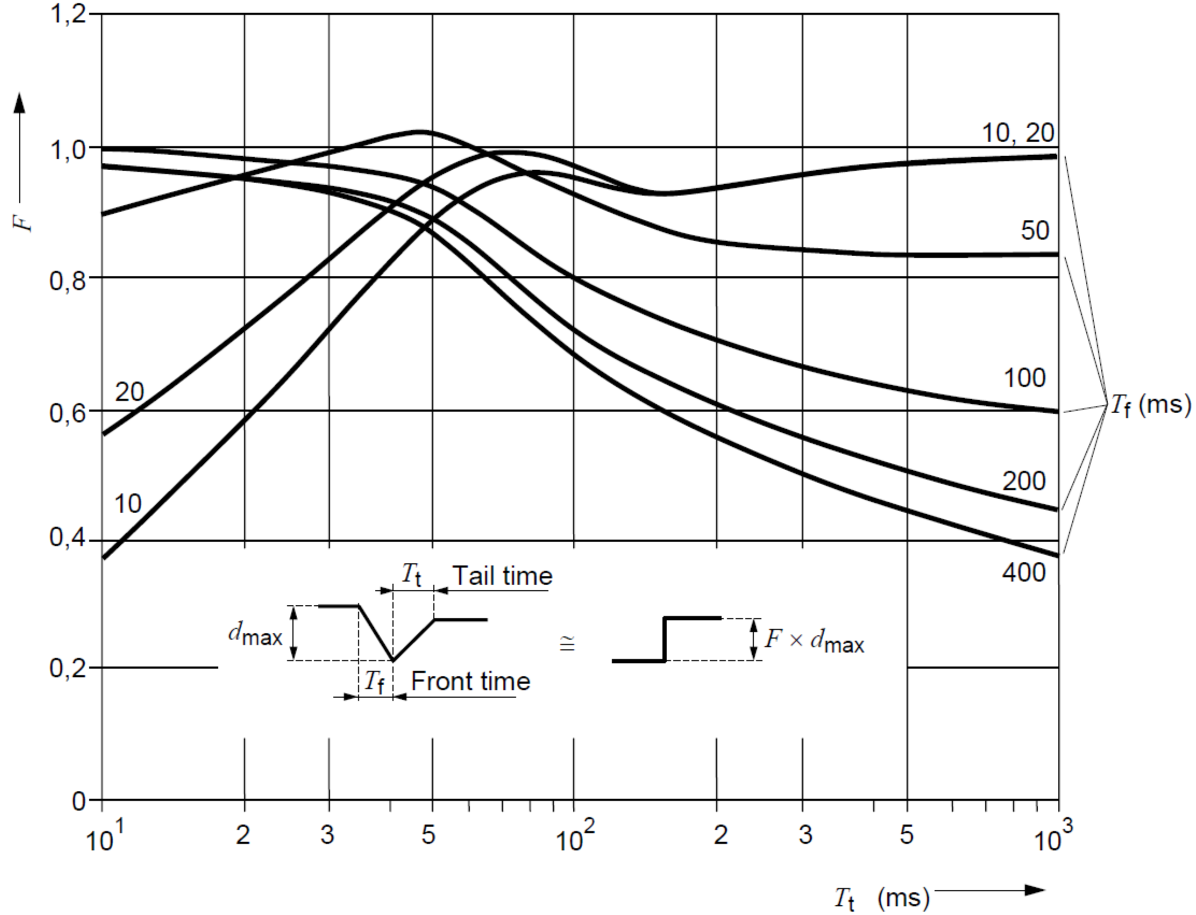
1955 **Figure B.2.2 — Shape factor curve for double-step and double-ramp changes**



1956

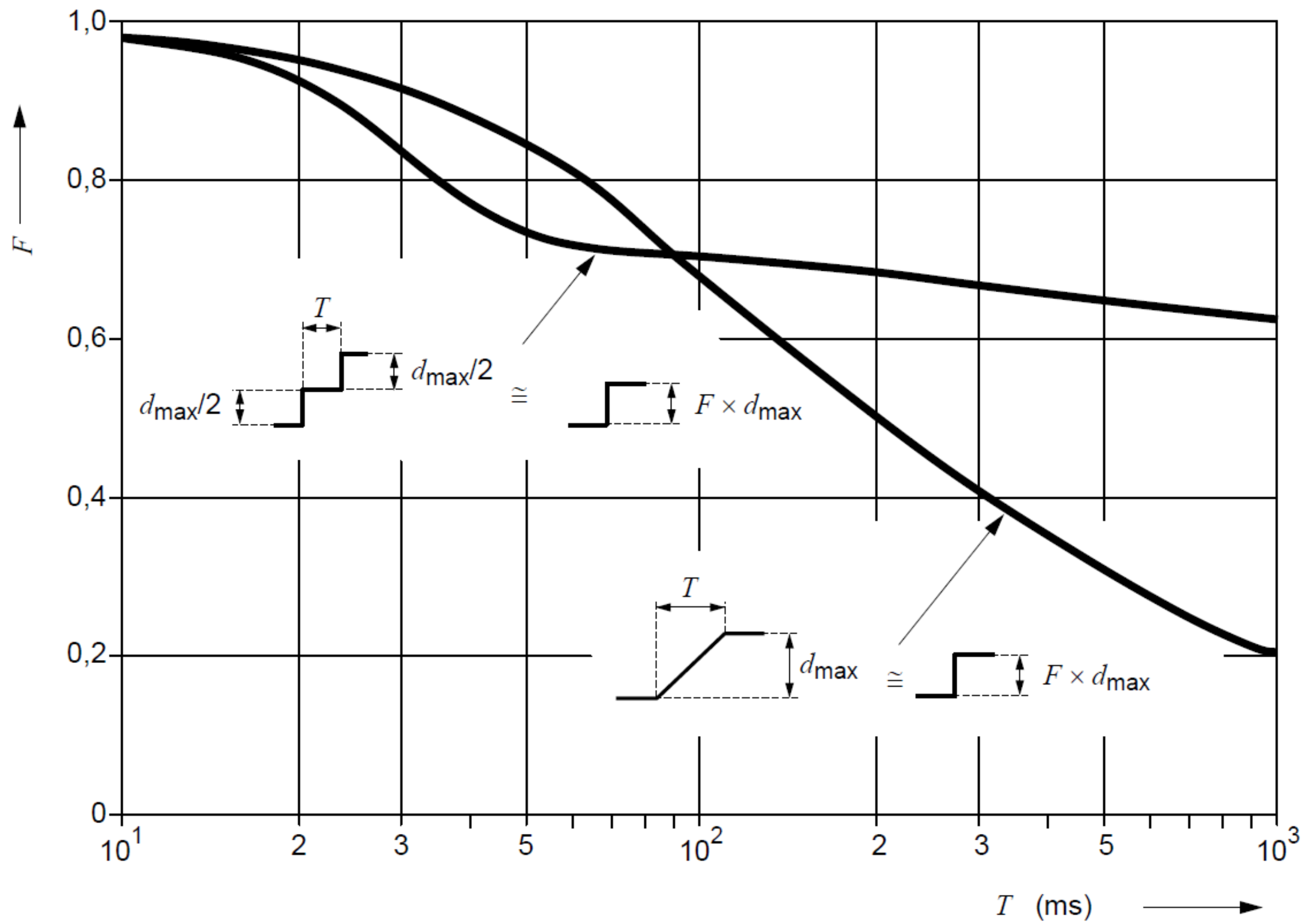
1957 **Figure B.2.3 — Shape factor curve for sinusoidal and triangular changes**

1958



1959

1960 **Figure B.2.4 — Shape Factor curves for motor-start characteristics having various front times**



1961

1962 NOTE: Equivalent to Figure 3 in BS EN 61000-3-3.

1963 **Figure B.2.5 — Shape factor (*F*) for ramp type voltage characteristic**

Annex C

Simplified calculation to estimate voltage change due to inrush current

C.1 Introduction

Where it is necessary to estimate the approximate voltage change due to magnetising inrush current, a simplified calculation (Equation C.1 in this Annex) can be carried out as a first step.

This calculation is not a substitute for detailed electromagnetic transient analysis but can help to determine whether the magnitude of the initial voltage dip during energisation is sufficiently close to the RVC limits as to warrant detailed electromagnetic transient analysis.

This calculation estimates the initial voltage change (decrease) only and does not give any indication of the voltage characteristic of the voltage recovery.

If the estimated voltage change is well within the RVC envelopes (see 5.3.2), it is likely that the energisation would be compliant with limits for RVC in this EREC.

This calculation is applicable to transformer energisation, motor start, and other inrush currents with similar behaviour.

C.2 Simplified calculation

$$\%\Delta V = m \times k \times \frac{S}{S_{sc}} \times 100 \qquad \text{Equation C.1}$$

Where:

$\%\Delta V$ is the percentage voltage change

m is the ratio of peak inrush current to peak rated current

k is a factor to convert the peak value of the inrush current to a r.m.s. value

S is the rated power of the transformer or motor

S_{sc} is the short-circuit power of the supply system

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[6] Statutory Instrument 2002 No. 2665, *The Electricity Safety, Quality and Continuity Regulations 2002*: http://www.legislation.gov.uk/uksi/2002/2665/made

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[12] Commission Regulation (EU) No 548/2014 of 21 May 2014 on implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers