IEC/TR 61000-3-7

Edition 2.0 2008-02

TECHNICAL REPORT

BASIC EMC PUBLICATION

Electromagnetic compatibility (EMC) –
Part 3-7: Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems

IEC/TR 61000-3-7:2008(E)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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IEC/TR 61000-3-7, which is a technical report, has been prepared by subcommittee 77A: Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility.

This Technical Report forms Part 3-7 of IEC 61000. It has the status of a basic EMC publication in accordance with IEC Guide 107 [17].[1]

This second edition cancels and replaces the first edition published in 1996 and constitutes a technical revision.

1 Figures in square brackets refer to the bibliography.

This new edition is significantly more streamlined than the original technical report (Edition 1), and reflects the experiences gained in the application of the first edition. This technical report has also been harmonised with IEC/TR 61000-3-6 [18] and IEC/TR 61000-3-13 [19].

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
77A/576/DTR	77A/615/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

A list of all parts of the IEC 61000 series, under the general title *Electromagnetic compatibility (EMC)*, can be found on the IEC website.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

IEC 61000 is published in separate parts according to the following structure:

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits
(in so far as they do not fall under the responsibility of product committees)

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts published either as International Standards or as technical specifications or technical reports, some of which have already been published as sections. Others will be published with the part number followed by a dash and a second number identifying the subdivision (example: IEC 61000-6-1).

ACKNOWLEDGMENT

In 2002, the IEC subcommittee 77A made a request to CIGRE Study Committee C4 and CIRED Study Committee S2, to organize an appropriate technical forum (joint working group) whose scope was to prepare, among other tasks, the revision of the Technical Report IEC 61000-3-7 concerning emission limits for the connection of fluctuating installations to public supply systems at MV, HV and EHV.

To this effect, Joint Working Group CIGRE C4.103/ CIRED entitled ''*Emission Limits for Disturbing Installations*'' was appointed in 2003. Some previous work produced by CIGRE JWG C4.07-CIRED has been used as an input to the revision, in particular the planning levels and associated indices, along with the experience since the technical report IEC 61000-3-7 was initially published in 1996.

Subsequent endorsement of the document by IEC was the responsibility of SC 77A.

It may also be worthwhile mentioning that another CIGRE Working Group is currently preparing a Technical Report for reviewing the flicker measurement results available internationally along with the flicker propagation characteristics in systems and the related objectives (flicker levels).

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 3-7: Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems

1 Scope

This part of IEC 61000 provides guidance on principles which can be used as the basis for determining the requirements for the connection of fluctuating installations to MV, HV and EHV public power systems (LV installations are covered in other IEC documents). For the purposes of this report, a fluctuating installation means an installation (which may be a load or a generator) that produces voltage flicker and / or rapid voltage changes. The primary objective is to provide guidance to system operators or owners on engineering practices which will facilitate the provision of adequate service quality for all connected customers. In addressing installations, this document is not intended to replace equipment standards for emission limits.

This report addresses the allocation of the capacity of the system to absorb disturbances. It does not address how to mitigate disturbances, nor does it address how the capacity of the system can be increased.

Since the guidelines outlined in this report are necessarily based on certain simplifying assumptions, there is no guarantee that this approach will always provide the optimum solution for all flicker situations. The recommended approach should be used with flexibility and engineering judgment as far as engineering is concerned, when applying the given assessment procedures in full or in part.

The system operator or owner is responsible for specifying requirements for the connection of fluctuating installations to the system. The fluctuating installation is to be understood as the customer's complete installation (i.e. including fluctuating and non fluctuating parts).

Problems related to voltage fluctuations fall into two basic categories:

- Flicker effect from light sources as a result of voltage fluctuations;
- Rapid voltage changes even within the normal operational voltage tolerances are considered as a disturbing phenomenon.

The report gives guidance for the coordination of the flicker emissions between different voltage levels in order to meet the compatibility levels at the point of utilisation. This report primarily focuses on controlling or limiting flicker, but a clause is included to address the limitation of rapid voltage changes.

NOTE The boundaries between the various voltage levels may be different for different countries (see IEV 601-01-28) [16]. This report uses the following terms for system voltage:

- low voltage (LV) refers to $U_n \leq 1$ kV;
- medium voltage (MV) refers to 1 kV < $U_n \leq 35$ kV;
- high voltage (HV) refers to 35 kV < $U_n \leq 230$ kV;
- extra high voltage (EHV) refers to 230 kV < Un.

In the context of this report, the function of the system is more important than its nominal voltage. For example, a HV system used for distribution may be given a "planning level" which is situated between those of MV and HV systems.

2 Normative references

The following referenced documents 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.

IEC 60050(161), *International Electrotechnical Vocabulary – Chapter 161: Electromagnetic compatibility*

3 Terms and definitions

For the purpose of this part of IEC 61000, the following definitions apply as well as the definitions in IEC 60050(161).

3.1
agreed power
value of the apparent power of the disturbing installation on which the customer and the system operator or owner agree. In the case of several points of connection, a different value may be defined for each connection point

3.2
customer
a person, company or organization that operates an installation connected to, or entitled to be connected to, a supply system by a system operator or owner

3.3
(electromagnetic) disturbance
any electromagnetic phenomenon which, by being present in the electromagnetic environment, can cause electrical equipment to depart from its intended performance

3.4
disturbance level
the amount or magnitude of an electromagnetic disturbance measured and evaluated in a specified way

3.5
electromagnetic compatibility (EMC)
ability of an equipment or 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 IEC 61000-2-1 [20].

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

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.

3.6
(electromagnetic) 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.

3.7
emission
phenomenon by which electromagnetic energy emanates from a source of electromagnetic disturbance

[IEV 161-01-08 modified]

NOTE For the purpose of this report, emission refers to phenomena or conducted electromagnetic disturbances that can cause flicker or fluctuations of the supply voltage.

3.8
emission level
level of a given electromagnetic disturbance emitted from a particular device, equipment, system or disturbing installation as a whole, assessed and measured in a specified manner

3.9
emission limit
maximum emission level specified for a particular device, equipment, system or disturbing installation as a whole

3.10
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 the incandescent lamps while the electromagnetic phenomenon causing it is referred as voltage fluctuations.

3.11
fluctuating installation
an electrical installation as a whole (i.e. including fluctuating and non-fluctuating parts) 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 supply system to which it is connected

NOTE For the purpose of this report, all references to fluctuating installations not only include loads, but also generating plants.

3.12
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. For the purpose of this technical report, the fundamental frequency is the same as the power supply frequency

NOTE In the case of a periodic function, the fundamental frequency is generally equal to the frequency of the function itself.

3.13
generating plant
any equipment that produces electricity together with any directly connected or associated equipment such as a unit transformer or converter

3.14
immunity (to a disturbance)
ability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance

3.15
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

3.16
interharmonic frequency
any frequency which is not an integer multiple of the fundamental frequency

NOTE 1 By extension from harmonic order, the interharmonic order is the ratio of the interharmonic frequency to the fundamental frequency. This ratio is not an integer (recommended notation "m").

NOTE 2 In the case where m < 1 the term subharmonic frequency may be used.

3.17
interharmonic component
component having an interharmonic frequency. For brevity, such a component may be referred to simply as an "interharmonic"

3.18
normal operating conditions
operating conditions of the system or of the disturbing installation typically including all generation variations, load variations and reactive compensation or filter states (e.g. shunt capacitor states), planned outages and arrangements during maintenance and construction work, non-ideal operating conditions and normal contingencies under which the considered system or disturbing installation has been designed to operate

NOTE Normal system operating conditions typically exclude: conditions arising as a result of a fault or a combination of faults beyond that planned for under the system security standard, exceptional situations and unavoidable circumstances (for example: force majeure, exceptional weather conditions and other natural disasters, acts by public authorities, industrial actions), cases where system users significantly exceed their emission limits or do not comply with the connection requirements, and temporary generation or supply arrangements adopted to maintain supply to customers during maintenance or construction work, where otherwise supply would be interrupted

3.19
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 power supply system

NOTE Planning levels are considered internal quality objectives to be specified at a local level by those responsible for planning and operating the power supply system in the relevant area.

3.20
point of common coupling (PCC)
point in the public system which is electrically closest to the installation concerned and to which other installations are or may be connected. The PCC is a point located upstream of the considered installation

NOTE A supply system is considered as being public in relation to its use, and not its ownership.

3.21
point of connection (POC)
point on a public power supply system where the installation under consideration is, or can be connected

NOTE A supply system is considered as being public in relation to its use, and not its ownership.

3.22
point of evaluation (POE)
point on a public power supply system where the emission levels of a given installation are to be assessed against the emission limits. This point can be the point of common coupling (PCC) or the point of connection (POC) or any other point specified by the system operator or owner or agreed upon

NOTE A supply system is considered as being public in relation to its use, and not its ownership.

3.23
rapid voltage changes
changes in fundamental frequency r.m.s. voltages over several cycles; rapid voltage changes could also be in the form of cyclic changes

NOTE Rapid voltage changes are often caused by start-ups, inrush currents or switching operation of equipment.

3.24
short circuit power
theoretical value expressed in MVA of the initial symmetrical three-phase short-circuit power at a point on the supply system. It is defined as the product of the initial symmetrical short-circuit current, the nominal system voltage and the factor √3 with the aperiodic component (DC) being neglected

3.25
spur
a feeder branch off a main feeder (typically applied on MV and LV feeders)

3.26
supply system
all the lines, switchgear and transformers operating at various voltages which make up the transmission systems and distribution systems to which customers' installations are connected

3.27
system operator or owner
entity responsible for making technical connection agreements with customers who are seeking connection of load or generation to a distribution or transmission system

3.28
transfer coefficient (influence coefficient)
the relative level of disturbance that can be transferred between two busbars or two parts of a power system for various operating conditions

3.29
voltage fluctuations
a series of voltage changes or a cyclic variation of the voltage envelope

4 Basic EMC concepts related to voltage fluctuations

The international flickermeter (see IEC 61000-4-15 [1])[2] provides two quantities to characterize the flicker severity: P_{st} ("st" referring to "short term": one value is obtained for each 10 min period) and P_{lt} ("lt" referring to "long term": one value is obtained for each 2 h period). The flicker related voltage quality criteria are generally expressed in terms of P_{st} and/or P_{lt}, with P_{lt} typically being derived from groups of 12 consecutive P_{st} values.

2 Figures in square brackets refer to the bibliography.

$$P_{lt} = \sqrt[3]{\frac{1}{12} \cdot \sum_{j=1}^{12} P_{st\,j}^{\;3}} \qquad (1)$$

Flicker emission levels are assessed at the point of evaluation (POE) of a fluctuating installation (see Clause 6), at the MV, HV or EHV level in the context of this report. However, it should be remembered that the background for limits is the possible annoyance to LV customers, therefore flicker attenuation between LV, MV, HV and EHV should be considered in assessing the impact of emissions.

It is also assumed in this report that the flickermeter and the associated severity factors are adapted to the type of incandescent lamps in use (e.g.: 120 V or 230 V) so that the flicker limits remain the same irrespective of the voltage of the lamps. This is important because 120 V lamps are less sensitive to voltage fluctuations than 230 V lamps (see Annex A) and 100 V lamps are even less sensitive.

The development of emission limits for individual equipment or a customer's total installation should be based on the effect that these emissions will have on the quality of the voltage. Some basic concepts are used to evaluate voltage quality. In order for these concepts to be used for evaluation at specific locations, they are defined in terms of where they apply (locations), how they are measured (measurement duration, sample times, averaging durations, statistics), and how they are calculated. These concepts are described hereafter and illustrated in Figures 1 and 2. Definitions may be found in IEV 60050(161).

4.1 Compatibility levels

These are reference values (see Table 1) for coordinating the emission and immunity of equipment which is part of, or supplied by, a supply system in order to ensure the EMC in the whole system (including system and connected equipment). Compatibility levels are generally based on the 95 % probability levels of entire systems, using statistical distributions which represent both time and space variations of disturbances. There is allowance for the fact that the system operator or owner cannot control all points of a system at all times. Therefore, evaluation with respect to compatibility levels should be made on a system-wide basis and no assessment method is provided for evaluation at a specific location.

The compatibility levels for flicker in LV systems are reproduced in Table 1 from IEC 61000-2-2 [2]. In some cases, higher values have been reported without a correlation with complaints. In these cases, measurements were possibly made at EHV/HV levels, during daylight hours, or for other reasons. Additional information is available in reference [3].

Compatibility levels are not defined by IEC for MV, HV and EHV systems.

Table 1 – Compatibility levels for flicker in low voltage systems reproduced from IEC 61000-2-2

	Compatibility levels
P_{st}	1,0
P_{lt}	0,8

4.2 Planning levels

4.2.1 Indicative values of planning levels

These are voltage flicker levels that can be used for the purpose of determining emission limits, taking into consideration all fluctuating installations. Planning levels are specified by the system operator or owner for all system voltage levels and can be considered as internal quality objectives of the system operator or owner and may be made available to individual customers on request. Planning levels should allow coordination of voltage fluctuations between different voltage levels. It is worth noting that at HV and EHV, coordination of flicker levels can still be achieved while considering the attenuation of flicker due to motor loads and generators connected downstream which have a steadying influence on voltages and can reduce flicker perception.

Only indicative values may be given because planning levels will differ from case to case, depending on system structure and circumstances. Indicative values of planning levels for flicker are shown in Table 2.

Table 2 – Indicative values of planning levels for flicker in MV, HV and EHV power systems

	Planning levels (see NOTE 2)	
	MV	HV-EHV
P_{st}	0,9	0,8
P_{lt}	0,7	0,6

NOTE 1 These values were chosen on the assumption that the transfer coefficient between MV or HV systems and LV systems is unity.

NOTE 2 In practice, the transfer coefficients between different voltage levels are less than 1,0. This can be taken into account when establishing new planning levels. For example, a typical value for the transfer coefficient between HV and LV is T_{PstHL}= 0,8. In such a case, the indicative planning level for HV becomes L_{PstHV} = 0,8/0,8 = 1,0.

NOTE 3 In some countries, planning levels are defined in national standards or guidelines.

NOTE 4 Voltage characteristics that are quasi-guaranteed levels exist in some countries for MV and HV systems. Theses should be coordinated with the planning levels [3].

As stated in NOTE 2, for the purpose of setting emission limits, it is recommended to weight the given planning levels at MV and HV-EHV by taking into account the flicker transfer coefficient from the source of emissions to the POE at EHV, HV, MV and LV. In addition, planning levels must allow coordination between different voltage levels. To enable this, the system operator or owner has to evaluate the flicker transfer coefficients for various operating conditions of the system. Further discussion of the assessment of flicker transfer coefficients is given in Annex B of this report. Reallocation of planning levels is exemplified in Annex C.

Where national circumstances make it appropriate depending on system characteristics, intermediate values of planning levels may be needed between the MV and HV EHV values due to the possibly wide range of voltage levels included in HV-EHV (>35 kV). Additionally, an apportioning of planning levels between HV and EHV may also be necessary to take account of the impact on HV systems of disturbing installations connected at EHV.

The remainder of this report outlines procedures for using these planning levels to establish the emission limits for individual fluctuating installations.

4.2.2 Assessment procedure for evaluation against planning levels

The measurement methods to be used for flicker is the class A method specified in IEC 61000-4-30 [4] and the related IEC 61000-4-15 [1]. The data flagged in accordance with IEC 61000-4-30 should be removed from the assessment. For clarity, where data is flagged, the percentile used in calculating the indices defined below is calculated using only the valid (unflagged) data.

The minimum measurement period is one week with normal business activity. The monitoring period should include some part of the period of expected maximum flicker levels.

One or more of the following indices may be used to compare the actual flicker levels with the planning levels. More than one index may be needed for planning levels in order to assess the impact of higher emission levels allowed for shorter periods of time such as during bursts or start-up conditions.

– The 95 % probability weekly value of P_{st}.
– The 99 % probability weekly value of P_{st}.
– The 95 % probability weekly value of P_{lt}.

NOTE It is recommended that each new P_{st} value be incorporated in a revised P_{lt} calculation using a sliding window where the oldest P_{st} measurement is replaced by the newest P_{st} value at each 10 minute interval. This recommended P_{lt} calculation procedure results in 144 P_{lt} values each day. In some cases, this may require post-processing of P_{st} outputs from a flickermeter.

The 95 % probability value should not exceed the planning level. The 99 % probability value may exceed the planning level by a factor (for example: 1 to 1,5) to be specified by the system operator or owner, depending on the system and load characteristics.

NOTE Comparing 99 % to 95 % percentiles may be useful. If the ratio between them is greater than 1,3 (1,3 is typical of a single arc furnace installation) one should investigate the reason for the discrepancy. Possible abnormal results (e.g. due to voltage dips or other transients) should then be eliminated.

4.3 Illustration of EMC concepts

The basic concepts of planning and compatibility levels are illustrated in Figure 1 and Figure 2. They are intended to emphasize the most important relationships between the basic variables.

Within an entire power system it is inevitable that some level of interference will occur on some occasions, hence there is a risk of overlapping between the distributions of disturbance levels and immunity levels (see Figure 1). Planning levels are generally equal to or lower than the compatibility level (for flicker, the transfer characteristics between different voltage levels may allow planning levels at HV and EHV to be higher while still achieving coordination with the compatibility levels that apply at LV); they are specified by the system operator or owner. Immunity test levels are specified by relevant standards or agreed upon between manufacturers and customers.

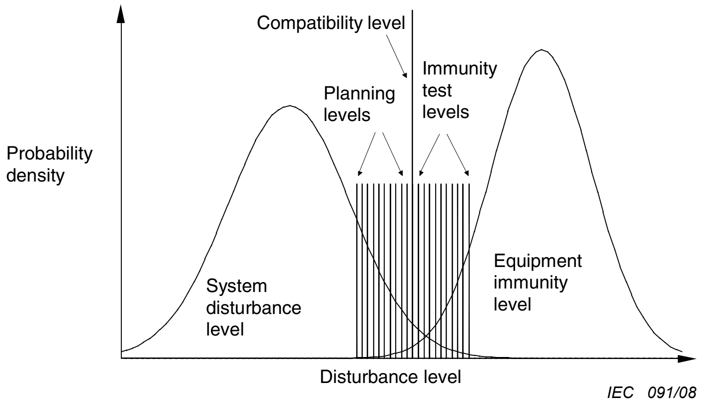

Figure 1 – Illustration of basic voltage quality concepts with time/ location statistics covering the whole system

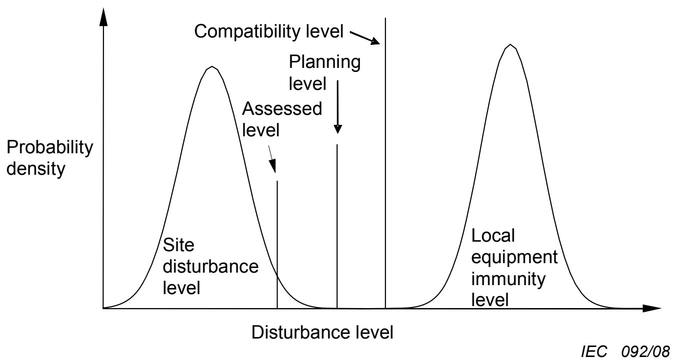

Figure 2 – Illustration of basic voltage quality concepts with time statistics relevant to one site within the whole system

As illustrated in Figure 2, the probability distributions of disturbance and immunity levels at any one site are normally narrower than those in the whole power system, so that at most locations there is little or no overlap of disturbance and immunity level distributions. Interference is therefore not generally a major concern, and equipment is anticipated to function satisfactorily. Electromagnetic compatibility is therefore more probable than Figure 1 appears to suggest.

4.4 Emission levels

The coordination approach recommended in this report relies on individual emission levels being derived from the planning levels. For this reason, the same indices are applied both when evaluating actual measurements against the emission limits and against the planning levels as described in the following text.

One or more of the following indices can be used to compare the actual emission level with the customer's emission limit. More than one index may be needed in order to assess the impact of higher emission levels allowed for short periods of time such as during bursts or start-up conditions.

– The 95 % probability weekly value of P_{sti} should not exceed the emission limit E_{Psti}.
– The 99 % probability weekly value of P_{sti} may exceed the emission limit E_{Psti} by a factor (for example: 1 to 1,5) to be specified by the system operator or owner, depending on the system and load characteristics.
– The 95 % probability weekly value of P_{lti} should not exceed the emission limit E_{Plti}.

In order to compare the level of flicker emissions from a customer's installation with the emission limits, the minimum measurement period should be one week. However, shorter measurement periods might be needed for assessing emissions under specific conditions. Such shorter periods should represent the expected operation over the longer assessment period (i.e. a week). In any case, the measurement period must be of sufficient duration to capture the highest level of flicker emissions which is expected to occur. If the flicker level is dominated by one large item of equipment, the period should be sufficient to capture at least two complete operating cycles of this equipment. If the flicker level is caused by the summation of several items of equipment, the period should be at least one operating shift.

Where significant the following factors should also be taken into account:

- effect of compensating equipment;
- capacitor banks within the installation with possible amplification of low order interharmonics that can cause flicker.

The measurement methods to be used are IEC 61000-4-15 [1] and the Class A measurement method defined in IEC 61000-4-30 [4] for flicker (for rapid voltage changes see Clause 10). The data flagged in accordance with the latter standard should be removed from the assessment. For clarity, where data is flagged the percentile used in calculating the indices defined in this report is calculated using only the valid (unflagged) data.

The emission level from a fluctuating installation is the flicker level assessed according to the subclauses of Clause 6.

5 General principles

The proposed approach for setting emission limits of fluctuating installations depends on the agreed power of the customer, the power of the flicker-generating equipment, and the system characteristics. The objective is to limit the flicker injection from the total of all fluctuating installations to levels that will not result in flicker levels that exceed the planning levels (taking into consideration the transfer coefficient, where applicable). Three stages of evaluation are defined, which may be used in sequence or independently.

5.1 Stage 1: simplified evaluation of disturbance emission

It is generally acceptable for customers to install small appliances without specific evaluation of flicker emission by the system operator or owner. Manufacturers of such appliances are generally responsible for limiting the emissions. For instance, IEC 61000-3-3 [5], IEC 61000-3-5 [6] and 61000-3-11 [7] are product family standards which define flicker emission limits for equipment connected to public LV systems. There are currently no emission standards for MV equipment for the following reasons:

- medium voltage varies between 1 kV and 35 kV;
- no reference impedance has been internationally defined for medium-voltage systems.

Even without a reference impedance, it is possible to define criteria for quasi-automatic acceptance of customers on the MV system (and even HV system). If the total fluctuating power of the installation, or the customer's agreed power, is small relative to the short-circuit power at the point of evaluation, it should not be necessary to carry out detailed evaluation of flicker emission levels.

In 8.1 and 9.1, specific criteria are developed for applying stage 1 evaluation.

5.2 Stage 2: emission limits relative to actual system characteristics

If an installation does not meet stage 1 criteria, the specific characteristics of the flicker generating equipment within the customer's installation should be evaluated together with the absorption capacity of the system. The absorption capacity of the system is derived from the planning levels and is apportioned to individual customers according to their demand with respect to the total system supply capacity. The disturbance level transferred from upstream voltage systems should also be considered when apportioning the planning levels to individual customers.

The principle of this approach is that, if the system is fully utilised to its designed capacity and all customers are injecting up to their individual limits, the total disturbance levels will be equal to the planning levels taking into account transfer factors between different voltage levels and the summation effect of various flicker producing equipment. The procedure for apportioning the planning levels to individual customers is outlined in 8.2 and 9.2.

NOTE If the capacity of the system increases in future the emission levels of individual customers should become lower. It is important therefore, where possible, to consider future expansions of the system.

5.3 Stage 3: acceptance of higher emission levels on a conditional basis

Under some circumstances, a customer may require acceptance to emit disturbances beyond the basic limits allowed in stage 2. In such a situation, the customer and the system operator or owner may agree on special conditions that facilitate the connection of the fluctuating installation. A careful study of the actual and future system characteristics will need to be carried out in order to determine these special conditions.

NOTE Emission limits obtained from the application of the methods recommended in Clauses 8 and 9 are intended to keep flicker levels below the planning levels. The application of other methods recommended in Clause 10 is intended to limit the magnitude of rapid voltage changes.

5.4 Responsibilities

In the context of this report from the EMC point of view, the following responsibilities are defined.

– The customer is responsible for maintaining his emissions at the specified point of evaluation below the limits specified by the system operator or owner.
– The system operator or owner is responsible for the overall coordination of emission levels under normal operating conditions in accordance with regional or national requirements. For evaluation purposes the system operator or owner should, where required, provide relevant system data such as the system short-circuit power or impedance and existing flicker levels. The evaluation procedure is designed in such a way that the flicker emissions from all fluctuating installations do not cause the overall system flicker levels to exceed the planning and compatibility levels. However, given local conditions and the assumptions that are necessary in this evaluation procedure there is no guarantee that the recommended approach will always avoid exceeding the levels.
– Finally, the system operator or owner and customers should cooperate when necessary in the identification of the optimum method to reduce emissions. The design and choice of method for such reduction are the responsibility of the customer.

6 General guidelines for the assessment of emission levels

6.1 Point of evaluation

The point of evaluation (POE) is the point where the emission levels of a given customer's installation are assessed for compliance with the emission limits. This is also a point within the considered power system at which the planning levels are defined. This point could be the point of connection (POC) or the point of common coupling (PCC) of the disturbing installation or any other point specified by the system operator or owner or agreed upon. More than one point of evaluation may also be specified for a given customer's installation depending on the system structure and characteristics of the installation; in this case, the evaluation should be made considering the system characteristics and agreed powers applicable to the different points of evaluation.

NOTE 1 It should be noted, however, that for the determination of the emission limits and for the evaluation of the emission levels it is often necessary to take account of system parameters beyond the point of evaluation.

NOTE 2 Depending on the location of the point of common coupling compared to the point of connection of the fluctuating installation, the flicker level might be higher at the latter.

NOTE 3 It should be remembered that as voltage characteristics or contracted limits generally apply at the point of connection, these should be taken into account in discussions between parties.

6.2 Definition of flicker emission level

The emission level from an installation into the power system is the magnitude of flicker which the considered installation gives rise at the point of evaluation (POE). The emission level is required to be less than the emission limit assessed according to the relevant clauses in this document.

6.3 Assessment of flicker emission levels

It is recommended that the emission levels be assessed under normal operating conditions, unless otherwise specified. The assessment of flicker emission levels from fluctuating installations should consider the worst normal operating conditions including contingencies for which the system or the customer's installation is designed to operate and that may last for a specified percentage of the time, e.g. more than 5 % of time based on a statistical average. Additionally, for large installations compared to the system size (ex.: S_{sc}/S_i <30; note that the ratio of 30 can be adjusted to meet particular conditions), it may also be necessary to assess emission levels for occasional operating conditions lasting less than 5 % of the time. However, higher emission limits may be allowed under such occasional conditions or during start-up or burst conditions (for example: 1 to 1,5 times, to be specified by the system operator or owner, depending on the system and installation characteristics).

Other details on the assessment of the emission levels in the power supply of industrial plants may be found in another IEC publication [8].

Measurement of flicker emission level is also possible. For situations where the flicker background level is relatively low (Pst < 0,5), two sets of measurement should be performed in the following conditions:

– with the fluctuating installation and any compensating equipment of the customer connected;
– with the fluctuating installation and any compensating equipment of the customer disconnected.

The second measured flicker value should be subtracted from the first one by using the recommended summation law (see Clause 7).

For situations where the existing P_{st} level at the POE is higher than 0,5, a more refined method should be used. Correlation between the fluctuating current and the observed voltage fluctuations may be used to determine the emission level of a particular fluctuation equipment or installation. Other methods are possible and some applications are discussed in Annex E.

In practice, the emission levels are generally predicted by making a pre-connection study from the available data concerning the installation and the system. Simplified and advanced methods for predicting flicker severity are given in this report in Annex E. Simplified methods which may be used for easily-defined fluctuations (e.g., step changes, ramp changes, etc.) are based on the "P_{st} = 1 curve" in Annex A and shape factor curves given in Annex E. Advanced techniques which are more suitable for arcing and randomly-fluctuating installations are based on system and end-use equipment characteristics (including compensation and mitigation equipment) and flickermeter simulation.

For post-connection assessments, direct measurements of flicker are often sufficient but might not be in full agreement with predictions made during the pre-connection assessment. If measurements are made at some other point, it is necessary to transpose measurement results to the point of evaluation (POE) carefully considering the possible influence of the actual system impedance compared to the declared impedance.

6.4 Declared system short circuit power or impedance

Information on the system short-circuit power or the declared impedance is a prerequisite both for the system operator or owner for assessing emission limits and for the customer in order to assess the emission levels of the considered installation. The declared short-circuit power or impedance is used in two different ways:

6.4.1 Short-circuit power or impedance for pre-connection assessment of emission levels

For enabling a pre-connection assessment of the flicker emission levels for large fluctuating installations in particular, the short-circuit power or the impedance at the point of evaluation can be obtained by simulation for various system operating conditions (including future conditions). It is important that the phase angle information is provided, as the fluctuating component of an installation may be different combinations of real and reactive power.

6.4.2 Short-circuit power or impedance for assessing actual emission levels

For assessing the actual emission levels from a given fluctuating installation, the actual impedance can be measured or calculated for use in combination with other measured parameters in order to assess the actual emission levels.

6.5 General guidelines for assessing the declared system impedance

It is important to consider that the impedance of the system may vary significantly with time and that it may be frequency dependent. As for the assessment of emission levels (see first paragraph of 6.3), the determination of the system impedance should consider the different normal operating conditions including system abnormal operating conditions where these situations may last for a specified portion of the time, e.g. more than 5 % of time based on a statistical average. Known or foreseeable future system changes should be included. For more details, see Annex E, E.3.1.

7 General summation law

A general combination relationship for short-term flicker severity caused by various installations has been found in the following form, where P_{stj} are the various individual levels of flicker severity to be combined:

$$P_{st} = \sqrt[\alpha]{\sum_i P_{st_i}^{\ \alpha}} \quad (2)$$

NOTE The same equation can be used for the long term flicker index P_{lt}.

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 discussed below.

In general, a value of α = 3 (“cubic summation law”) has been largely used for years and is recommended for P_{st} (or P_{lt}) summation provided that additional information is not available to justify a different value. See Annex D for a discussion of an equivalent severity factor which may simplify the calculations in some cases.

$$P_{st} = \sqrt[3]{\sum_i P_{st_i}^{\ 3}} \qquad (3)$$

$$P_{lt} = \sqrt[3]{\sum_i P_{lt_i}^{\ 3}} \qquad (4)$$

Early studies based on multiple arc furnaces and using weekly P_{st} values showed that the value of the exponent α depends on the characteristics of the main source of fluctuation. In general, the exponent decreases as the likelihood of simultaneous fluctuations increases and the following recommendations can be made when additional information is available:

– $\alpha = 4$: should be used for the summation of flicker when simultaneous fluctuations are very unlikely (e.g., specific equipment controls are installed so as to prevent simultaneous fluctuations);
– $\alpha = 3$: should be used for most types of flicker sources where the risk of coincident voltage changes is small. The majority of studies combining unrelated disturbances fall into this category and it is recommended for general use;
– $\alpha = 2$: should be used where coincident fluctuations are likely to occur (e.g., coincident melts on arc furnaces);
– $\alpha = 1$: should be used when there is a very high occurrence of coincident voltage changes (e.g., when multiple motors are started at the same time).

Recent studies have shown that the summation law which best fits measurement results depends on both the degree of coincidence in the voltage changes and the P_{st} percentile which is used for the evaluation and also on the equipment technologies involved in producing the voltage fluctuations. For additional information, see [15].

8 Emission limits for fluctuating installations connected to MV systems

8.1 Stage 1: simplified evaluation of disturbance emission

In stage 1, the connection of small installations with only a limited amount of fluctuating power can be accepted without detailed evaluation of the emission characteristics or the supply system response.

NOTE For LV equipment, see IEC 61000-3-3 [5] (input current ≤ 16A/phase) or IEC 61000-3-11 [7] (input current ≤ 75A/phase).

The connection of a fluctuating installation can be accepted without further analysis if the ratio of apparent power variations ΔS to the system short circuit power S_{sc}, expressed as percentages, are within the following limits at the POE. These limits depend on the number r of voltage changes per minute (a voltage drop followed by a recovery means two voltage changes).

Table 3 – Stage 1 limits for the relative changes in power as a function of the number of changes per minute

r min^{-1}	$K=(\Delta S / S_{sc})_{max}$ %
r > 200	0,1
10 ≤ r ≤ 200	0,2
r < 10	0,4

NOTE The apparent power variations ΔS may be lower, equal or higher than the rated power S_N of the considered equipment (e.g. for a motor, account should be taken of the apparent power at starting and it may be $\Delta S \approx$ 3-8 S_N). S_{sc} may be calculated (or measured) for the specific point of evaluation, or may be estimated for typical MV system with similar characteristics to that under consideration.

8.2 Stage 2: emission limits relative to actual system characteristics

Considering the actual absorption capacity of the system, in particular taking into account the transfer factor, higher emissions than those according to stage 1 criteria may be granted.

In this stage, the allowable global contribution to the overall level of disturbance is apportioned to each individual installation in accordance with its share of the total capacity of the supply system (S_t) to which this installation is connected. This ensures that the disturbance level due to the emissions of all customers connected to the system will not exceed the planning level.

NOTE The following procedure may be completed using real power, P, in place of apparent power, S.

The approach presented hereafter assumes that propagation of flicker disturbances in a radial power system follows quite simple laws.

– The approach is based on the general summation law given in Clause 7.
– The flicker values present at a given voltage level will be transferred downstream with some attenuation (transfer coefficient somewhat lower than 1, e.g. 0,8).
– Due to the increase of short circuit power with that of voltage level and to the low coincidence of voltage changes, flicker contributions from lower to higher voltage systems can be considered practically negligible in most situations.

8.2.1 Global emission to be shared between the customers

Consider a typical MV system as illustrated in Figure 3. The aim is to set emission limits at MV.

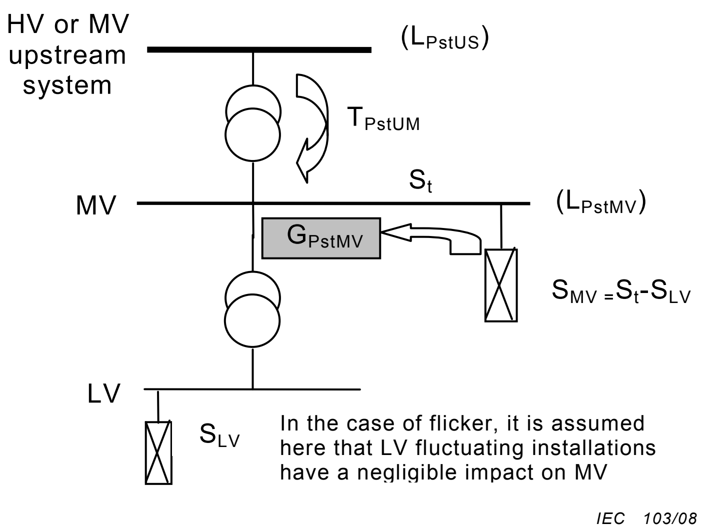

Figure 3 – Example of a system for sharing global contributions at MV

Firstly, an application of Equation (2) is necessary to determine the global contribution of all flicker sources present in a particular system. Indeed, the actual flicker level in a MV system results from the combination of the flicker level coming from the upstream (note that upstream system may be a HV or another MV system for which intermediate planning levels have been set before) with the flicker level produced by all fluctuating installations connected to the considered MV system, including LV fluctuating installations. However, as already mentioned in 8.2, it can generally be assumed that LV fluctuating installations only have a negligible impact on MV systems flicker levels. So the flicker level should not exceed the planning level of the MV system given by:

$$L_{PstMV} = \sqrt[\alpha]{G^{\alpha}_{PstMV} + T^{\alpha}_{PstUM} \cdot L^{\alpha}_{PstUS}} \qquad (5)$$

where

G_{PstMV} is the maximum global contribution to the flicker level of all the MV fluctuating installations that can be connected to the considered system (expressed in terms of P_{st} or P_{lt});

L_{PstMV} is the planning level for flicker (indices P_{st} or P_{lt}) in the MV system;

L_{PstUS} is the planning level for flicker in the upstream system (for reasons explained before, different planning levels may be needed for intermediate voltage levels between MV and HV-EHV; this is why the general term of upstream system planning level is used);

T_{PstUM} is the transfer coefficient of flicker (P_{st} or P_{lt}) from the upstream system to the MV system (it could be determined by simulation or measurements, see Annex B);

α is the summation law exponent, commonly equal to 3 (see Clause 7).

By algebraic manipulation, the global contribution for MV fluctuating installations can be determined for P_{st} or similarly for P_{lt} from Equation 5.

$$G_{PstMV} = \sqrt[\alpha]{L^{\alpha}_{PstMV} - T^{\alpha}_{PstUM} \cdot L^{\alpha}_{PstUS}} \qquad (6)$$

Examples are given in Annex C for reallocating global contributions considering transfer coefficients.

8.2.2 Individual emission limits

For each customer, only a fraction of the global emission limit G_{PstMV} will be allowed. A reasonable approach is to take the ratio between the agreed power S_i and the total supply capacity S_t of the MV system, where S_t may be taken as the capacity of the HV-MV transformer or as the total downstream load, with a provision for possible future load growth. Such a criterion is related to the fact that the agreed power of a customer is often linked with the customer's share in the investment costs of the power system.

Using the recommended summation laws (Equations (3) and (4)), the individual emission limits (E_{Psti} and E_{Plti}) are then given by (7) and (8) where α = 3 is commonly used:

$$E_{Psti} = G_{PstMV} \cdot \sqrt[\alpha]{\frac{S_i}{(S_t - S_{LV})}} \qquad (7)$$

$$E_{Plti} = G_{PltMV} \cdot \sqrt[\alpha]{\frac{S_i}{(S_t - S_{LV})}} \qquad (8)$$

where

E_{Psti} , E_{Plti} are the flicker emission limits for the customer's installation i directly supplied at MV,

G_{PstMV}, G_{PltMV} are the maximum global contributions to the flicker levels of all the MV fluctuating installations that can be connected to the considered system as given by Equations 5 and 6 (expressed in terms of P_{st} or P_{lt}.),

S_i = (P_i /cos φ_i) is the agreed power of the customer's installation i, or the MVA rating of the considered fluctuating installation (either load or generation),

S_t is the total supply capacity of the considered system including provision for future load growth (in principle, S_t is the sum of the capacity allocations of all installations including that of downstream installations that are or can be connected to the considered system, taking diversity into consideration). S_t might also include the contribution from dispersed generation, however, more detailed consideration will be required to determine its firm contribution to S_t and its effective contribution to the short-circuit power as well,

S_{LV} is the total power of the installations supplied directly at LV in the considered system including provision for future load growth,

α is the summation law exponent (see Clause 7).

NOTE In some cases, dispersed generation may actually be a source of voltage fluctuations and should be accounted for accordingly.

It may happen at some locations that the pre-existing flicker level is higher than the normal share for existing installations. In this case, the emission limits for new installations could be reduced or a reallocation of the planning levels between the different voltage levels could be considered, or the system flicker absorption capacity could be increased.

For customers having a low agreed power, this approach may yield impractically low limitations. Emission limits shall then be set at values given in Table 4.

Table 4 – Minimum emission limits at MV

E_{Psti}	E_{Plti}
0,35	0,25

8.3 Stage 3: acceptance of higher emission levels on a conditional basis

Under some circumstances, the system operator or owner may accept a fluctuating installation to emit disturbances beyond the basic limits allowed in stage 2. This is especially the case when stage 2 limits are generic limits derived using typical but conservative system characteristics. The following factors may leave a margin on the system for allowing higher emission limits, for example:

- Some customer installations do not produce significant flicker because they do not have fluctuating equipment of significant size. Therefore some of the available flicker absorption capacity of the system may not be utilized for a period of time.
- The general summation law may be too conservative, for instance, it may happen that some fluctuating installations never operate simultaneously, due to system or load constraints.
- In some cases, higher global contributions may be defined after reallocation of the planning levels between MV and HV-EHV systems (see Annex C), to take account of local phenomena such as special attenuation effects or the absence of fluctuating installations at a certain voltage level.
- In some cases, a disturbing installation may comply with its emission limits in normal system configurations, while exceeding the stage 2 emission limits only occasionally under degraded configurations (e.g., when a nearby generation plant is out of service).

In all the cases, when appropriate the system operator or owner may decide to allocate higher emission limits under stage 3. A careful study of the connection should always be carried out, taking account of the pre-existing flicker level and of the expected contribution from the considered installation for different possible operating conditions. Acceptance of higher than normal emission limits may be given to customers only on a conditional basis and limitations may be specified by the system operator or owner, for instance:

- Temporary stage 3 limits apply for

  - As long as spare supply capacity remains available in the system for allowing more emissions;
  - As long as most other customers do not make full use of their normal stage 2 emission limits;
  - The time needed for a new installation, in order to implement additional corrective measures whenever needed.
- Reduced or non-operation of the fluctuating installations for some supply system or customer configurations.

8.4 Summary diagram of the evaluation procedure

An overview of the evaluation procedure presented so far in this report is given in Figure 4. The evaluation procedure is equally applicable to P_{st} and P_{lt}.

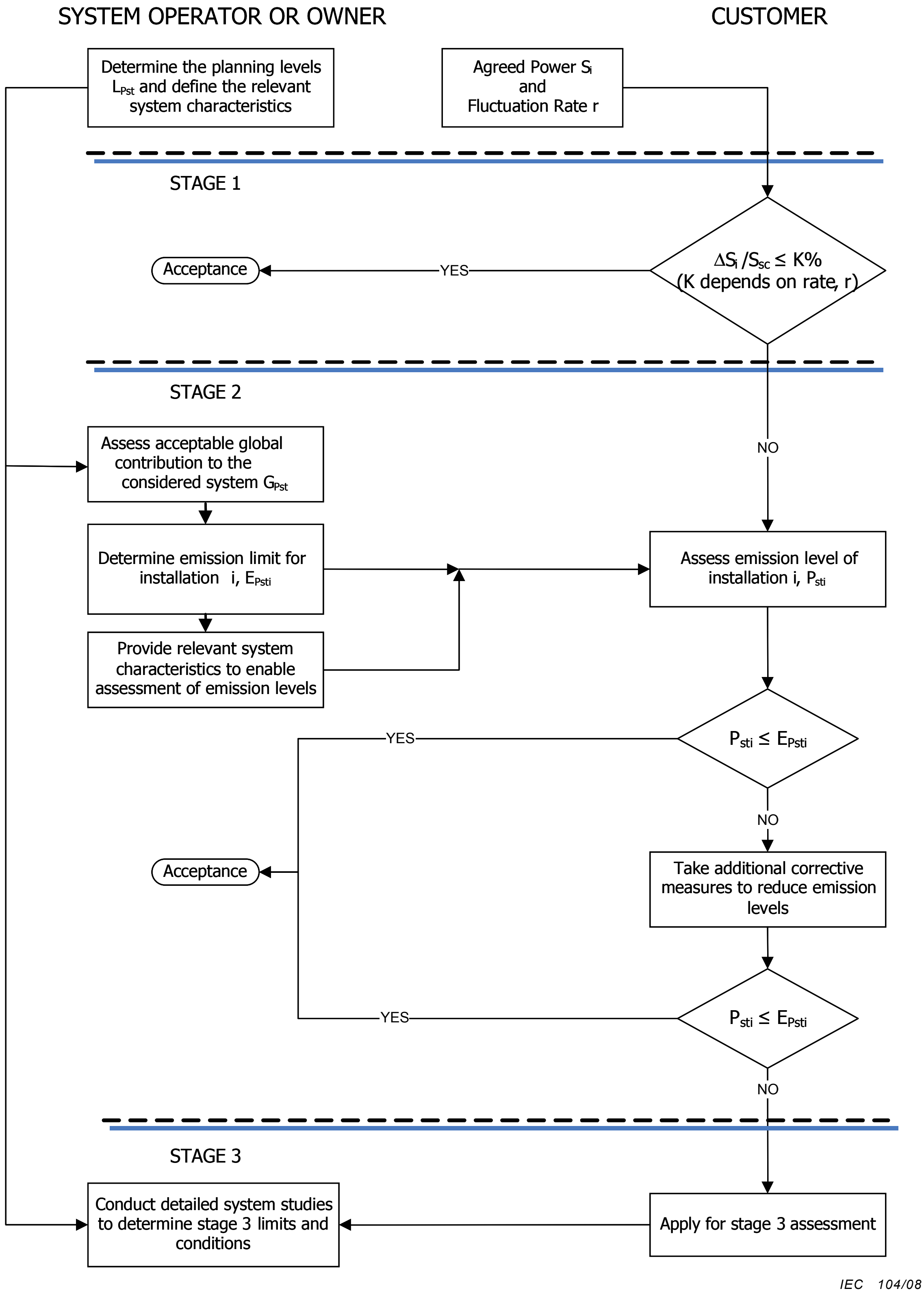

Figure 4 – Diagram of evaluation procedure

9 Emission limits for fluctuating installations connected to HV or EHV systems

9.1 Stage 1: simplified evaluation of disturbance emission

The same criteria for connection at stage 1 given in 8.1 can be used at HV-EHV.

9.2 Stage 2: emission limits relative to actual system characteristics

The approach is basically the same as for MV users (see 8.2). However, in the particular case of HV or EHV fluctuating installations, the share of the global disturbance level between each user should be based on the total power available for all HV or EHV fluctuating installations and not to the total supply capacity of the system. Indeed, it has been mentioned previously that the contribution of MV and LV fluctuating installations to the flicker level at HV or EHV can be neglected; therefore MV and LV installations need not be included in the determination of the total supply capacity for allowing flicker emissions at HV-EHV.

9.2.1 Assessment of the total available power

Calling S_i the apparent power of installation i and S_{tHV} (S_{tEHV}) the total power available for HV (EHV) users at the point of evaluation (POE), the S_i/S_{tHV} (S_i/S_{tEHV}) ratio is the basic quantity for the determination of the emission limits following the stage 2 procedure.

9.2.1.1 First approximation

Assessing S_t is much more difficult in HV and EHV systems than for the MV case. The suggested approach is the following: when considering the case of an installation connected at a given HV or EHV substation, the basic information is the forecast of power flows taking account of the system evolution in the future:

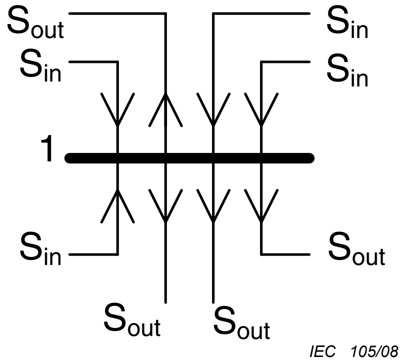

Figure 5 – Determination of S_t for a simple HV or EHV system

The assessment is simply:

$$S_t = \Sigma\, S_{out} \tag{9}$$

where

S_t in this case is an approximation of the total power of all installations for which emission limits are to be allocated to in the foreseeable future. In this case it is estimated as the sum of the power flows (in MVA) leaving the considered HV-EHV busbar (including provision for future load growth).

This first approximation of S_t is intended to remain conservative. The more detailed second approximation is recommended where such conservative assumptions lead to unrealistic emission limits.

NOTE This first approximation assumes that flicker emissions caused by installations connected at other connected busbars directly impact the considered busbar (i.e. the influence factors used in the second approximation is unity).

9.2.1.2 Second approximation

The simple first approach may not be correct if important fluctuating installations are present or are likely to be connected in the vicinity of the considered substation. In case of doubt, it is recommended to proceed as follows:

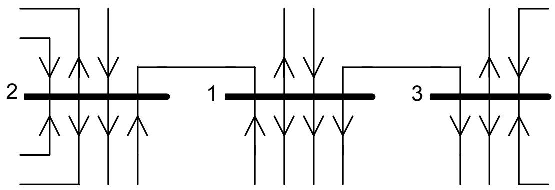

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Figure 6 – Determination of S_t for a meshed HV or EHV system

Calling "1" the considered node and "2", "3" , etc. the other nodes located in the vicinity of the first one, the values of S_{tHV1}, S_{tHV2}, S_{tHV3} . . . will be calculated according to Equation (9), while ignoring all power flows S_{out} between two of these nodes.

At the power frequency, the influence coefficients K_{2-1}, K_{3-1}, ... will be calculated (the influence coefficient K_{n-m} is the voltage change which is caused at node m when a 1 p.u. (per unit) voltage change is applied at node n; the calculation of K_{n-m} usually requires the use of a computer program).

An alternative approach is based on applying a load (or a three-phase short-circuit through some impedance) at bus n and noting the voltages at buses m and n. The influence coefficient can then be defined between buses m and n as $K_{n-m}=(U_m-U_m^0)/(U_n-U_n^0)$ where U_m and U_n are the voltages at buses m and n with the applied load present at n and U_m^0 and U_n^0 are the corresponding voltages without the applied load present.

NOTE The influence coefficients obtained in this manner may be sensitive to the power factor of the load or short-circuit applied and the load connected in the simulation should closely represent the characteristics of the load being assessed. Also note that influence coefficients are frequency dependent and in some cases, particularly near generating plants, the dependencies may become significant for frequencies below the fundamental.

A more rigorous method, based on typical short-circuit analysis data and techniques, is given in Annex F.

For this second approximation, Equation (9) will be replaced by (or similarly for S_{tEHV}):

$$S_{tHV} = S_{tHV1} + (K_{2-1})^{\alpha} S_{tHV2} + (K_{3-1})^{\alpha} S_{tHV3} + \ldots \qquad (9')$$

adding $(K_{n-m})^{\alpha} S_{tHVn}$ terms (α=3 is commonly used) as long as they remain significant as compared to S_{tHV1}.

9.2.2 Individual emission limits

Taking account of the recommended summation law (Equations (3) and (4)) the individual emission limits (E_{Psti} and E_{Plti}) are then given by (10) through (13):

$$E_{Psti} = G_{PstHV} \cdot \sqrt[\alpha]{\frac{S_i}{S_{tHV}}} \qquad (10)$$

$$E_{Psti} = G_{PstEHV} \cdot \sqrt[\alpha]{\frac{S_i}{S_{tEHV}}} \qquad (11)$$

$$E_{Plti} = G_{PltHV} \cdot \sqrt[\alpha]{\frac{S_i}{S_{tHV}}} \tag{12}$$

$$E_{Plti} = G_{PltEHV} \cdot \sqrt[\alpha]{\frac{S_i}{S_{tEHV}}} \tag{13}$$

where

E_{Psti} , E_{Plti}	are the flicker emission limits for installation i,
$G_{PstHV(EHV)}$ or $G_{PltHV(EHV)}$	is the maximum global contribution to the flicker level (P_{st} or P_{lt}) of all fluctuating installations that can be connected to the considered HV (or EHV) system (see Equation 14),
$S_i = P_i / \cos\varphi_i$	is the agreed apparent power of installation i,
S_{tHV} or S_{tEHV}	is the part of the total supply capacity of the HV or EHV considered system which is devoted to the HV or EHV installations (see Equation 9 or 9').
α	is the summation law exponent, commonly equal to 3 (see Clause 7).

The determination of the global contributions ($G_{PstHV\ or\ EHV}$) and the share of planning levels between different parts of a HV or EHV system requires a classical study to be carried out for evaluating the effects of the different fluctuating installations taking into account the evolution of the EHV/HV system configuration, load distribution and expected percentage of fluctuating installations. In any case, the combined flicker contributions allocated to HV and EHV fluctuating installations should be such as to meet the planning levels taking into consideration the transfer coefficient from EHV to HV ($T_{PstEHV\text{-}HV}$). That is to say (14) applies where α = 3 is commonly used.

$$\sqrt[\alpha]{G^{\alpha}_{PstHV} + T^{\alpha}_{PstEHV-HV} G^{\alpha}_{PstEHV}} \le L_{Pst\ HV} \tag{14}$$

It may happen that at some locations the pre-existing flicker level is higher than the normal share for existing installations. In this case, the emission limits for new installations could be reduced or a reallocation of the planning levels between the different voltage levels could be considered, or the system flicker absorption capacity could be increased.

For customers having a low agreed power, this approach may yield impractically low limitations. Emission limits shall then be set at values given in Table 5.

Table 5 – Minimum emission limits at HV-EHV

E_{Psti}	E_{Plti}
0,35	0,25

9.3 Stage 3: acceptance of higher emission levels on a conditional basis

The considerations presented in 8.3 apply equally to stage 3 at HV-EHV.

10 Rapid voltage changes

10.1 General considerations

The visual discomfort due to light flicker is the most frequent reason to limit voltage changes due to fluctuating installations. However, system operators or owners have to maintain the voltage magnitude within narrow limits and individual customers should not produce significant voltage variations even if they are tolerable from the flicker point of view. In the context of this report, rapid voltage changes are considered to be changes in fundamental frequency r.m.s. voltages over several cycles.

A simple assessment of the relative voltage change may be done as follows (see

Figure 7, Figure 8 and Figure 9):

$$I = I_p - jI_q \tag{15}$$

$$Z_L = R_L + jX_L \tag{16}$$

(a) Equivalent circuit (b) Vector diagram

Figure 7 – Equivalent circuit and vector diagram for simple assessments

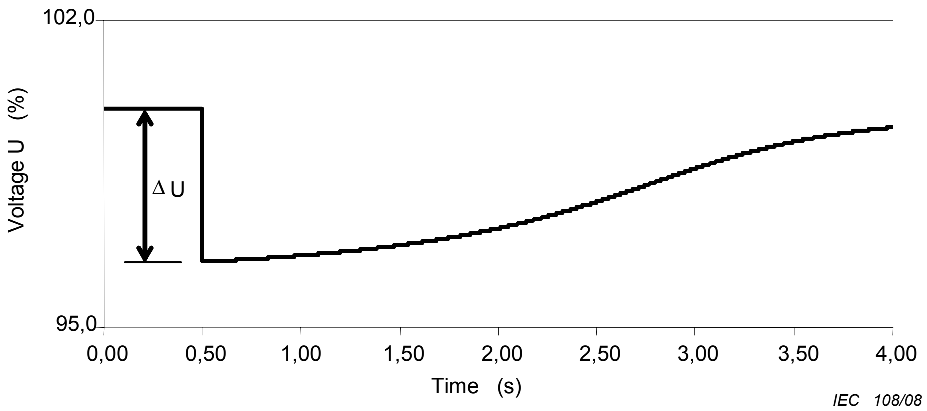

Figure 8 – Example rapid voltage change associated with motor starting

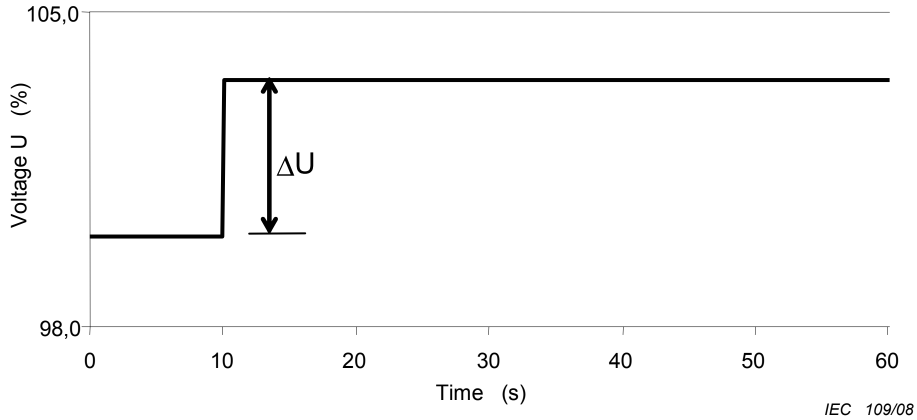

Figure 9 – Example rapid voltage change associated with capacitor switching

For single-phase and symmetrical three-phase loads:

$$\Delta U \approx \Delta I_p \cdot R_L + \Delta I_q \cdot X_L \qquad (17)$$

10.2 Compatibility level

Under normal circumstances, the value of rapid voltage changes is limited to 3 % of nominal supply voltage in MV systems. However, rapid voltage changes exceeding 3 % can occur infrequently on MV public supply systems, see IEC 61000-2-12 [9].

NOTE Current practice in many companies is that the value of 3 % corresponds in general to rapid voltage changes that may occur twice per hour or more.

Practically, the coincidence of occurrence of several rapid voltage changes presents a very low probability. For this reason no summation laws are taken into account. Because of the low frequency of occurrence, statistical indices are not considered.

10.3 Planning levels

These are disturbance levels that can be used for the purpose of determining emission limits, taking into consideration all installations which may cause rapid voltage changes. Planning levels are specified by the system operator or owner for all system voltage levels and can be considered as internal quality objectives of the system operator or owner and may be made available to individual customers on request. Only indicative values may be given because planning levels will differ from case to case, depending on system structure and circumstances.

Planning levels for MV are suggested based on the compatibility level. For HV-EHV, no established compatibility levels exist and suggested levels are provided based on

a) existing HV-EHV practices regarding rapid voltage changes and

b) the need to provide margin between MV and HV-EHV for the purposes for overall EMC coordination.

In Table 6 are given indicative planning levels for rapid voltage changes $\Delta U/U_N$ for infrequent events (expressed in per cent of the nominal voltage). These limits depend on the number of such changes in a given time period. Less frequent voltage changes are not covered here; however, they may also be of importance on some systems.

Table 6 – Indicative planning levels for rapid voltage changes as a function of the number of such changes in a given period

Number of changes n	**$\Delta U/U_N$** %	
	MV	HV/EHV
n ≤ 4 per day	5-6	3-5
n ≤ 2 per hour and > 4 per day	4	3
2 < n ≤ 10 per hour	3	2,5

NOTE 1 At HV/EHV, the permissible voltage change has a wide range due to the significant range of voltage levels covered (e.g., >35 kV to 500 kV).

NOTE 2 Higher values may be permissible under abnormal system conditions.

NOTE 3 The permissible voltage change $\Delta U/U_N$ (%) and number of changes in a given period should be applied so that the number of changes of magnitude $\Delta U/U_N$ does not exceed the number specified within the total time period corresponding to the rate (e.g. no more than 4 changes of 6 % are permitted at MV during any one 24 hour period).

NOTE 4 Note that in addition to the above planning levels, engineering assessment is required in the case of motor starting.

10.4 Emission limits

The coordination approach recommended in this report relies on individual emission levels being derived from the planning levels so that overall EMC is maintained. Because the indicative planning levels are defined in terms of numbers of occurrences of a specific rapid voltage change level permitted during a specific interval, emission limits for individual installations shall be defined by the system operator or owner on a case by case basis taking into account the particular operation and impact of each installation that may cause rapid voltage changes in the system of interest. The combined effect of all installations should not result in rapid voltage changes exceeding the planning levels set by the system operator or owner.

NOTE It may be necessary to coordinate the emissions from installations at MV and HV-EHV depending on the specific system and location of installations under consideration.

10.5 Assessment procedure for evaluation against planning levels & emission limits

No standardized measurement method exists for rapid voltage changes. For this reason, it is recommended that the assessment procedure used be based on measured changes in r.m.s. voltage considering only the power frequency component with transients removed. In practice, the shortest possible multi-cycle window should be used to avoid artificially smoothing the desired r.m.s. fundamental frequency voltage change.

The minimum measurement period is one week of normal business activity. The monitoring period should include the period of expected maximum rapid voltage change levels.

In the case of rapid voltage changes the worst case of rapid voltage changes of the fluctuating installation is considered when assessing the emission level (i.e. the assessment of emission level is not based on 95 % of time).

Annex A
(informative)

P_{st} = 1 curves and numerical data for 230 V and 120 V applications

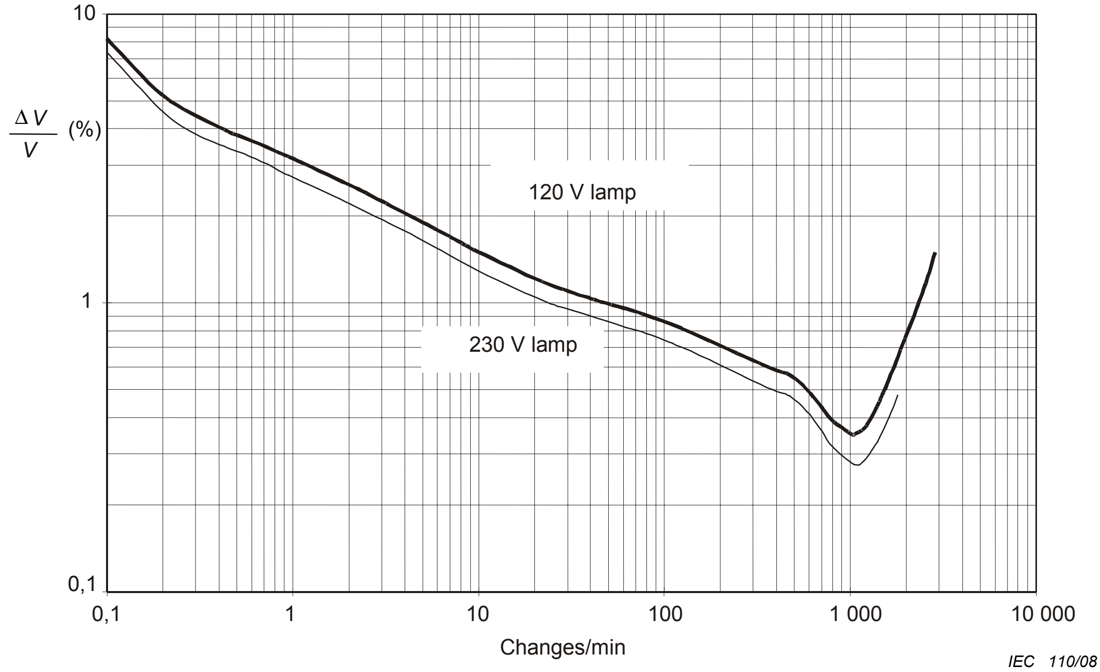

Figure A.1 – P_{st} = 1 curve for regular rectangular voltage changes [13]

Table A.1 – Input relative voltage fluctuation ΔV/V for P_{st}=1,0 at output [13]

Fluctuation Rate (r) changes/min	Voltage fluctuation %		Fluctuation Rate (r) changes/min	Voltage fluctuation %	
	120 V lamp 60 Hz system	230 V lamp 50 Hz System		120 V lamp 60 Hz system	230 V lamp 50 Hz system
0,1	8,202	7,4	176	0,739	0,64
0,2	5,232	4,58	273	0,65	0,56
0,4	4,062	3,54	375	0,594	0,5
0,6	3,645	3,2	480	0,559	0,48
1	3,166	2,724	585	0,501	0,42
2	2,568	2,211	682	0,445	0,37
3	2,25	1,95	796	0,393	0,32
5	1,899	1,64	1 020	0,35	0,28
7	1,695	1,459	1 055	0,351	0,28
10	1,499	1,29	1 200	0,371	0,29
22	1,186	1,02	1 390	0,438	0,34
39	1,044	0,906	1 620	0,547	0,402
48	1	0,87	2 400	1,051	0,77
68	0,939	0,81	2 875	1,498	1,04
110	0,841	0,725			

NOTE 1 Two consecutive voltage changes (one positive and one negative) constitute one “cycle”, i.e. two voltage changes per second correspond to a 1 Hz fluctuation.

NOTE 2 These curves are based on 60 W incandescent lighting. While other lighting equipment may give different results, these curves are adopted as reference to allow consistent evaluations across a wide variety of situations.

NOTE 3 Different versions of Table A.1 exist in the literature with some differences.

Annex B
(informative)

Guidelines on the assessment of flicker transfer coefficient

The transfer coefficient of flicker between two points A and B where a dominant flicker source is located at point A is defined as the ratio of the P_{st} values, measured at the same time in both locations [3]:

$$T_{PstAB} = P_{st}\,(B) / P_{st}\,(A)$$

Measurement results from various campaigns showed that the flicker produced by fluctuating installations connected at EHV or HV can significantly attenuate when it propagates into the MV or LV systems. This reduction is mainly due to the compensation effect due to rotating machines connected at utilization voltages.

Example of measurement results

Simultaneous flicker measurements were conducted in order to obtain experimental values for transfer coefficients between various voltage levels. Measurements were carried out at 220 kV, 70 kV and 15 kV where a 220/70 kV substation and a 70/15 kV substation are connected through a 13 km, 70 kV overhead line. The 220 kV point is the point of common coupling with several large arc furnaces. No permanent fluctuating installation was connected to the downstream systems. Only cases where a good correlation existed between the voltage fluctuations at different voltage levels should be considered for the assessment of the transfer coefficients.

Table B.1 – Example of flicker transfer coefficients

Voltage level	T_{PstAB}
220 kV towards 70 kV	0,82
70 kV towards 15 kV	0,91
15 kV towards 230 V	0,98 – 1,0

General observations

The following observations can be made.

– A significant flicker reduction is observed between 220 kV and 70 kV (about 0,8) and to a lesser extent between 70 kV and 15 kV (about 0,9), giving a total transfer coefficient from 220 kV to 15 kV of about 0,72.

– Similar results were also observed for the P_{lt} index.

– The assessment of the transfer coefficient from statistical measurement results (such as 99 % or 95 % percentiles) is valid only when good correlation exists between the measured voltage fluctuations at different voltage levels. When significant flicker sources are also connected at lower voltage levels, it is then preferable to estimate the transfer coefficient during periods of low flicker at LV so that the effects of flicker sources at higher voltage levels can be clearly observed at LV. Alternatively, a system analysis method can be used.

– There was no significant reduction from 15 kV to 230 V. A number of other measurement results also showed transfer coefficients between MV and LV to be near unity.

Annex C
(informative)

Example of reallocation of global contributions and planning levels considering transfer coefficients

For the purposes coordinating EMC at LV, MV, HV, and EHV, it is necessary to consider the impact of upstream fluctuations on downstream systems using flicker transfer coefficients. As described in Clauses 8 and 9, a global contribution can be established at each voltage level using the planning level at the voltage level under consideration, the planning level of the upstream system, and the transfer coefficient between them.

C.1 Including transfer coefficients in the allocation procedure

Using the indicative planning levels in Table 2 and assuming a transfer coefficient between HV and MV of 0,9 (see Table B.1), the global contribution of all MV installations can be given as:

$$G_{PstMV} = \sqrt[3]{L_{PstMV}{}^3 - T_{PstUM}{}^3 \cdot L_{PstHV}{}^3} = \sqrt[3]{0{,}90^3 - 0{,}9^3 \cdot 0{,}8^3} = 0{,}71$$

Similarly for LV, assuming that the planning level at LV is equal to the compatibility level (i.e. P_{st} = 1) and the transfer coefficient between MV and LV is unity, the global contribution of all LV installations can be given as:

$$G_{PstLV} = \sqrt[3]{L_{PstLV}{}^3 - T_{PstUL}{}^3 \cdot L_{PstMV}{}^3} = \sqrt[3]{1{,}0^3 - 1{,}0^3 \cdot 0{,}9^3} = 0{,}65$$

C.2 Using transfer coefficients to recover and re-allocate unused emission contributions

Let us consider that transfer coefficients equal to unity have been used for the determination of the global contribution at MV. Following the same calculation as before gives:

$$G_{PstMV} = \sqrt[3]{L_{PstMV}{}^3 - T_{PstUM}{}^3 \cdot L_{PstHV}{}^3} = \sqrt[3]{0{,}90^3 - 1{,}0^3 \cdot 0{,}8^3} = 0{,}60$$

Comparing the above value of 0,60 with the previous result of G_{PstMV} equal to 0,71 shows that considering a transfer coefficient of 0,9 would allow an additional global contribution of 0.11 at MV while still meeting the overall EMC coordination objective. Assuming that the MV planning level was satisfied based on G_{PstMV} = 0,60, the unused contribution at MV can be reallocated to HV by increasing the planning level at HV as follows :

$$G_{PstMV} = 0{,}6 = \sqrt[3]{L_{PstMV}{}^3 - T_{PstUM}{}^3 \cdot L_{PstHV}{}^3}$$
$$0{,}6^3 = 0{,}9^3 - 0{,}9^3 \cdot L_{PstHV}{}^3$$
$$0{,}89 = L_{PstHV}$$

When needed, such an increased planning level may allow more emission at HV.

C.3 Re-allocating unused emission contributions between voltage levels

Let us consider the special case where potential fluctuating installations that can be connected are not capable of creating the value of G_{Pst} at a given voltage level. It should then be possible to reallocate the unused emissions and revise planning levels at other voltage levels. For example, consider a case where no significant fluctuating installations are connected to LV so that it is possible not to exceed a value of G_{PstLV}=0,5. Considering a transfer coefficient between MV and LV of unity (see Table B.1), the allowable upstream MV planning level could be increased as follows:

$$G_{PstLV} = 0{,}5 = \sqrt[3]{L_{PstLV}{}^3 - T_{PstUL}{}^3 \cdot L_{PstMV}{}^3}$$
$$0{,}5^3 - L_{PstLV}{}^3 = -T_{PstUL}{}^3 \cdot L_{PstMV}{}^3$$
$$0{,}5^3 - 1^3 = -1^3 \cdot L_{PstMV}{}^3$$
$$0{,}96 = L_{PstMV}$$

Additionally, if it happens that the global contribution of all MV installations cannot exceed a value of G_{PstMV}=0,5, the upstream HV planning level could then be increased (transfer coefficient HV to MV of 0,9 per Table B.1) as follows:

$$G_{PstMV} = 0{,}5 = \sqrt[3]{L_{PstMV}{}^3 - T_{PstUM}{}^3 \cdot L_{PstHV}{}^3}$$
$$0{,}5^3 = 0{,}96^3 - 0{,}9^3 \cdot L_{PstHV}{}^3$$
$$1{,}01 = L_{PstHV}$$

If this reallocation process is further continued by assuming the global contribution of all HV installations cannot exceed a value of G_{PstHV}=0,5, an increased planning level at EHV could be found using an EHV to HV transfer coefficient of 0,8 (see Table B.1):

$$G_{PstHV} = 0{,}5 = \sqrt[3]{L_{PstHV}{}^3 - T_{PstUH}{}^3 \cdot L_{PstEHV}{}^3}$$
$$0{,}5^3 = 1{,}01^3 - 0{,}8^3 \cdot L_{PstHV}{}^3$$
$$1{,}21 = L_{PstEHV}$$

The obtained planning level in this example at EHV is significantly greater than the indicative value of Table 2. This was made possible by reallocating emissions based on the location (and possible impacts) of fluctuating installations and by considering the effect of transfer coefficients between different voltage levels. Global contributions to emissions may be reduced at some voltage levels and these reductions may be reallocated to other voltage levels while still maintaining EMC coordination from EHV to LV. Of course, this approach needs regular checks to account for possible changes.

Annex D
(informative)

The use of the severity indicators A_{st} and A_{lt} to simplify calculations

As the summation law is accepted, it is often convenient to replace P_{st} by the equivalent severity indicator A_{st}, such that: $A_{st} = P_{st}^{\alpha}$ in order to simplify the calculations where the exponent α = 3 is generally accepted. Some countries systematically use A_{st} instead of P_{st} for the sake of simplicity. This substitution gives a linear relationship for the evaluation of the total disturbance A_{stt} generated by multiple flicker sources:

$$A_{st} = \sum_i A_{sti}$$

Moreover, taking into account the fact that the long-term flicker severity P_{lt} is obtained as the α root of the average of the cube P_{st} values occurring during the observation period, the long-term severity can also be expressed by an equivalent indicator A_{lt} by placing:

$$A_{lt} = P_{lt}^{\alpha} = \frac{1}{N}\sum_i P_{sti}^{\alpha} = \frac{1}{N}\sum_i A_{sti}$$

The use of the equivalent severity indicators thus also simplifies the calculation of the long-term severity, which becomes a simple average of the short-term values. The linear summation also applies for the evaluation of the long-term equivalent severity A_{ltt} caused by several sources:

$$A_{lt} = \sum_i A_{lti}$$

It should be remembered that A_{st} is not linearly related to a relative voltage change, as P_{st} is, so that the usefulness of the two severity indicators changes according to the problem considered.

Expressing the compatibility levels and the planning levels in terms of A_{st} and A_{lt} gives:

Table D.1 – Compatibility levels for A_{st} and A_{lt} in LV and MV power systems

	Compatibility levels
A_{st}	1,0
A_{lt}	0,5

Table D.2 – Indicative values of planning levels for A_{st} and A_{lt} in MV, HV and EHV power systems

	Planning levels	
	MV	HV-EHV
A_{st}	0,73	0,5
A_{lt}	0,3	0,2

NOTE These values were chosen with the assumption that the transfer coefficients between HV and MV and MV and LV are about unity.

Should the reader prefer the use of the equivalent severity indicator A_{st} instead of P_{st}, the methods presented in the body of this report can similarly be converted into A_{st} indices.

Annex E
(informative)

Pre-connection and post-connection assessment of emission for P_{st}

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

E.1 Simplified pre-connection assessments for common periodic and aperiodic fluctuations

In many cases, the voltage fluctuations produced by equipment follows known and predictable patterns. In these cases, it is possible to pre-determine the flicker level that will be produced for a given shape and total voltage change. Note that simplified calculations, computer studies or historical data may be used to predict the total voltage change whereas some knowledge of the equipment operational pattern is necessary to evaluate the overall shape of the fluctuation.

E.1.1 Simplified assessment procedure for periodic voltage changes

The P_{st}=1,0 curves in Annex A are based on repetitive and periodic step changes in the form of a square wave. From the P_{st} = 1,0 curves, it is possible to determine the value of the relative voltage change d that will give P_{st} = 1,0 for a given frequency of square-wave modulation. Because the flickermeter is linear, a relative voltage change of 2d at the same frequency will produce a P_{st} = 2,0.

In practice, most voltage changes are not stepwise in nature. Flickermeter simulations have been used to develop results for other (not square wave) periodic modulation shapes and these results can be used in conjunction with the P_{st} = 1,0 curves to predict P_{st} values for non-square wave changes. Results are available for sinusoidal, triangular, ramp, double-step, and other common shapes as shown in Figure E.1 through Figure E.3. Because these results are a function of the frequency of the changes, curves called “shape factor curves” are used to display the results over a range of frequencies of interest.

Using the P_{st} = 1,0 curves, the shape factor curves, and a known relative voltage change d, it is possible to predict P_{st} using

$$P_{st} = \left(\frac{d}{d_{P_{st}=1}} \right) * F \qquad \text{(E.1)}$$

where $d_{P_{st}=1}$ is the required value of relative voltage change to produce P_{st}=1 for a given frequency as read from Figure A.1 and F is the shape factor value as read from the appropriate curve in Figures E.1 through E.3.

E.1.2 Simplified calculation of the relative voltage change d

The relative voltage change d can be evaluated as the ratio of the load power change (ΔS_i) and the short-circuit power S_{sc}. For balanced three-phase loads, the relative changes of the phase-to-neutral voltages (U_Y) and of the phase-to-phase voltages are equal to

$$d = \frac{\Delta U_Y}{U_{NY}} = \frac{\Delta U}{U_N} \approx \frac{\Delta S_i}{S_{sc}} \qquad \text{(E.2)}$$

NOTE 1 For example ΔS_i for motor starting is the change from $S_i = 0$ to $S_i = S_{i.max}$ (maximum apparent power during start), and therefore $\Delta S_i = S_{i.max}$.

If the system X/R ratio of the system is low (e.g., less than 5), the relative voltage change should be calculated in a more precise way using the resistive and inductive part of the system impedance:

$$d = \frac{R_L \cdot \Delta P_i + X_L \cdot \Delta Q_i}{U_N^2} \tag{E.3}$$

Voltage changes caused by a two-phase load (for example a welding machine) can be evaluated by:

$$d = \frac{\Delta U_Y}{U_{NY}} = \frac{\sqrt{3} \cdot \Delta S_i}{S_{sc}} \tag{E.4}$$

In many cases, advanced calculations are used in place of the simplified formulas. It is common to use computer simulations to determine the relative voltage change d so as to take into account all relevant aspects of the assessment.

E.1.3 Shape factor curves

The relationship between $P_{st} = 1,0$ curves for square-wave periodic changes and other periodic changes are tabulated in graphical form as shape factor curves. In these curves, voltage increases are usually shown. Note that these are equivalent to voltage drops with respect to flicker prediction.

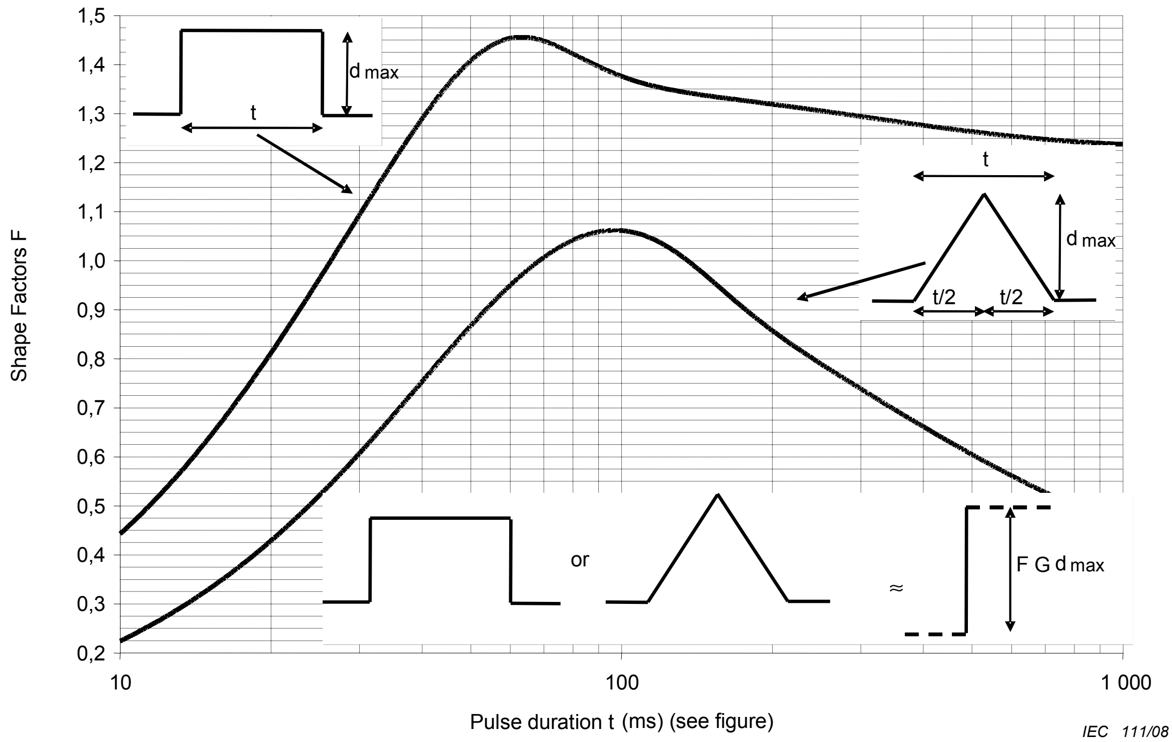

Figure E.1 – Shape factor curve for pulse and ramp changes

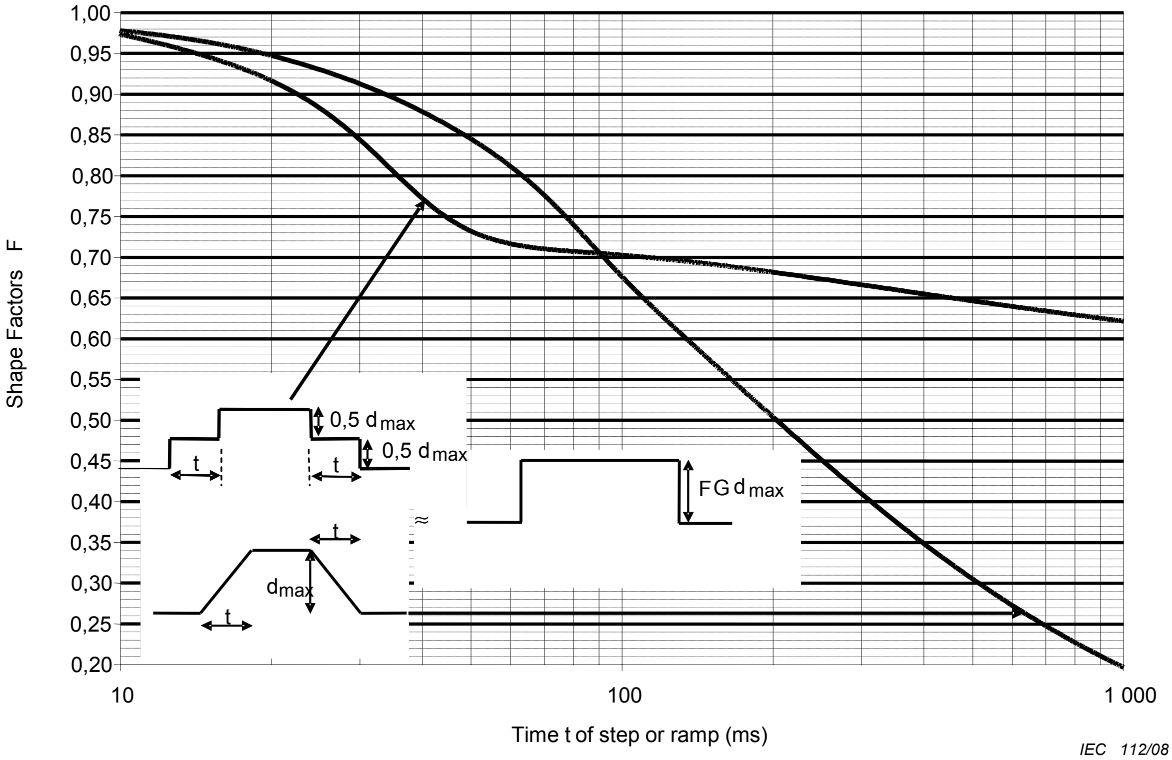

Figure E.2 – Shape factor curves for double-step and double-ramp changes

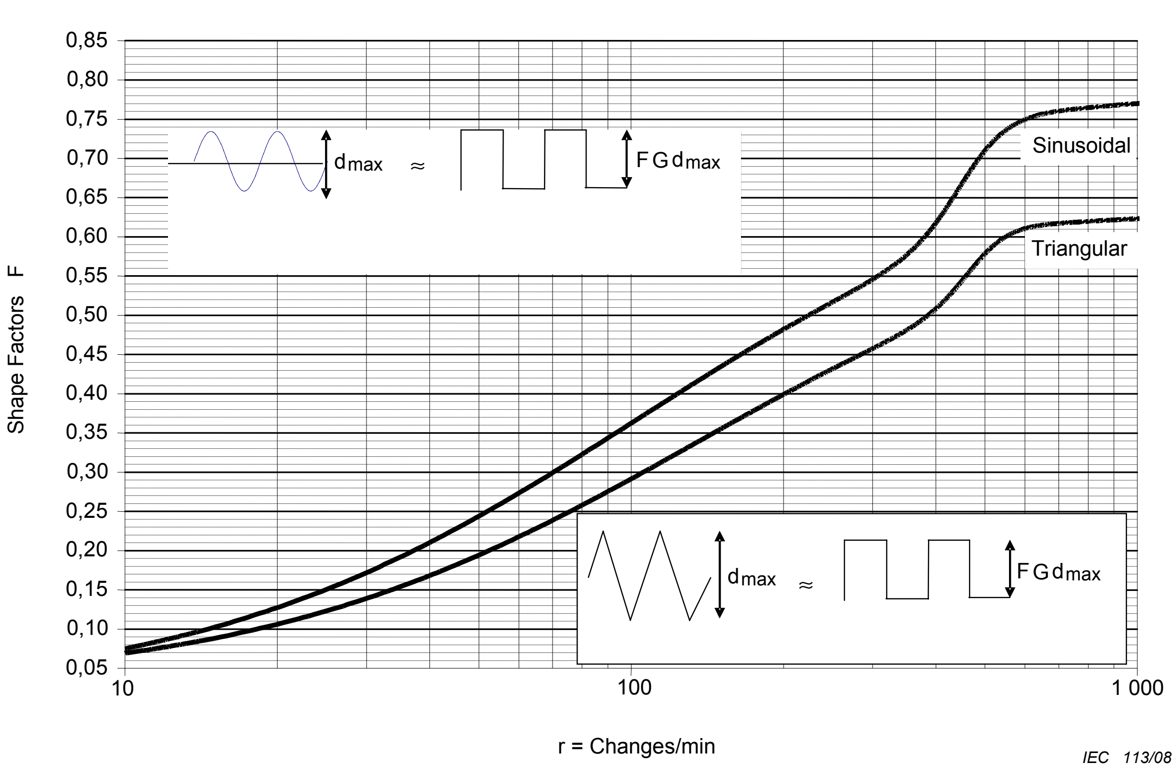

Figure E.3 – Shape factor curves for sinusoidal and triangular changes

E.1.4 Simplified assessment procedure for aperiodic voltage changes

In many cases, voltage changes do not occur on a continuously repetitive basis or on a periodic basis over the 10 minute interval for which P_{st} assessments are made. A common situation would have a load fluctuate during startup, operate for some time, shut down for some time, then restart. This type of operation is not continuously repetitive and may not be periodic during any particular 10 minute interval.

An additional set of shape factor curves shown in Figure E.4 has been developed for these types of aperiodic voltage change situations.

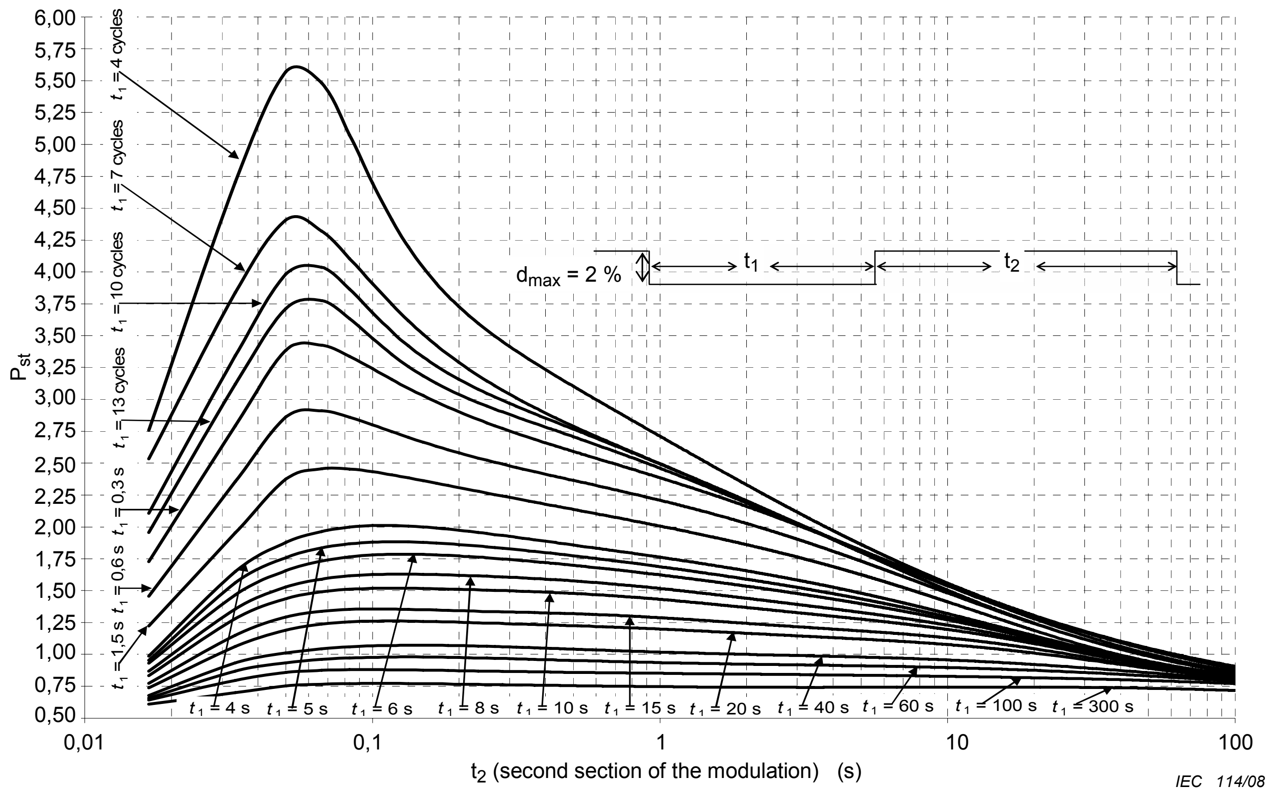

Figure E.4 – Shape factor curves for aperiodic changes

Note that the results of Figure E.4 are based on an assumed unequal duty cycle square wave shape and a relative voltage change of 2 %. For relative voltage changes that can be described by an unequal duty cycle square wave with times t_1 and t_2 as shown in Figure E.4, P_{st} can be estimated using

$$P_{st} = \left(\frac{d}{2}\right) * P_{st,2\%} \tag{E.5}$$

where d is the actual relative voltage change in percent and $P_{st,2\%}$ is the value read from Figure E.4 for a particular voltage change described by t_1 and t_2.

It is important to recognize that the approach of Equation (E.5) can be combined with that of Equation (E.1) so as to allow for fluctuations of various shapes which are either not continuously repetitive or are not periodic. The combined approach is

$$P_{st} = F * \left(\frac{d}{2}\right) * P_{st,2\%} \tag{E.6}$$

where all variables are as previously defined.

E.2 Pre-assessment of the connection in case of AC or DC arc furnaces with or without SVC (Static Var Compensator)

The pre-assessment or predetermination of flicker produced by an AC or DC arc furnace (before the equipment is put into operation) is a difficult but important exercise. The pre-assessment is necessary to evaluate the place of connection of the arc furnace and the need to install compensation.

Flicker measurements carried out in the past have enabled the development of an empirical equation for estimating the flicker produced by an arc furnace:

$$P_{st95\%} = K_{st} \frac{S_{scf}}{S_{sc}}$$

where

S_{scf} = the short-circuit power of the furnace (short circuited electrodes test),

S_{sc} = the short-circuit power of the system at the POE,

K_{st} = characteristic flicker emission factor of the arc furnace.

It follows that if the short circuit power is increased, the flicker produced decreases by the same proportion. However, in the case of a very low level of short-circuit, the amount of flicker can be higher than predicted by a linear relation with the short-circuit level. This can be explained by the fact that the instability of the arc is increasing when the furnace is operated from a weak system.

The K_{st} factor can be determined by a flicker emission measurement on an arc furnace of similar size and technology that is already in operation. From the literature The K_{st} factor for AC arc furnaces ranges from 52 to 135 for systems supplying 230 V lighting load at LV. K_{st} values ranging from 64 to 75 are generally recommended for systems supplying 230 V lighting load, while values ranging from 58 to 70 are recommended for systems supplying lower voltage (110 V-127 V) lighting load [15].

If the $P_{st,95\%}$ calculated exceeds the emission limit, compensation has to be installed.

The effectiveness of the compensation can be evaluated by determining the flicker reduction coefficient R_{comp}. This is the ratio between the flicker level measured without and with the compensation equipment in service. This reduction coefficient can be determined by flicker emission measurements on existing arc furnaces with the same kind of compensation. The coefficient R_{comp} is between 1,5 and 2,0 for a properly sized SVC and between 3 and 6 for STATCOM compensation.

E.3 Post-connection assessment of a fluctuating installation

E.3.1 The concept of the short-circuit power

The concept of the short-circuit power is basic for the assessment of the connection of fluctuating installations.

The short-circuit power of the system can vary due to

– periods of low and high generation
– changes in the operation of the system due to maintenance or incidents on the system.

This is especially the case in a meshed system where the short-circuit power might be continuously changing due to generation dispatch changes or system contingencies.

It is the responsibility of the system owner or operator to specify the short-circuit power that should be used for the assessment of the fluctuating installation. This so-called 'declared short-circuit power' is not as such a minimum value, but a low value accounting for variations in the operating conditions that should be used for the assessment of the flicker emission. It can be obtained by using one of the following approximations. Note that the short-circuit power will vary with the time, so even at the time of commissioning it is likely to be different from the declared value.

a) Short-circuit power for rating of equipment

   The basic definitions of short-circuit conditions are given in the IEC 60909-0 [10]. This standard is based on the calculation of symmetrical initial short-circuit current (I''_{sc}), for unloaded networks, i.e., in the absence of passive loads and any shunt capacitance. In order to calculate I''_{sc}, Thévenin's Theorem is applied.

   IEC specifies two standard values for a multiplying factor to be used depending on the purpose for which the calculations are to be used. The 'maximum value' is to be used for apparatus rating purposes and it is fixed at 1,1 for HV systems. The 'minimum value' is to be used for other purposes such as the control of motor starting conditions which typically appear as fast voltage fluctuation problems as discussed in Clause 10. The minimum value of c is fixed at 1,0 for HV systems. The (IEC standard) short-circuit power is then defined with c=1 as:

$$S''_{sc} = \sqrt{3} \cdot U_n \cdot I''_{sc}$$

   As calculated in this way, the short-circuit power is suitable for either equipment rating purposes or for non-critical voltage fluctuations problems.

b) Short-circuit power considering the loading of the system and the actual voltage level at the supply substation

   This approximation enables further calculations following the theoretical definition of physical short-circuit power and is based on taking the actual voltage and the shunt elements into account.

   In normal operating conditions (see Figure E.5), the network is loaded. A supply substation to a customer (STo) is considered where the substation voltage is at least equal to the nominal value. To get Un at the substation, the value of the source emf needs to be set at Un/μ (in most cases μ < 1). Because of the increase in voltage, the physical short-circuit current also increases by the same factor. The physical short-circuit power therefore increases by 1/μ² in compliance with theory.

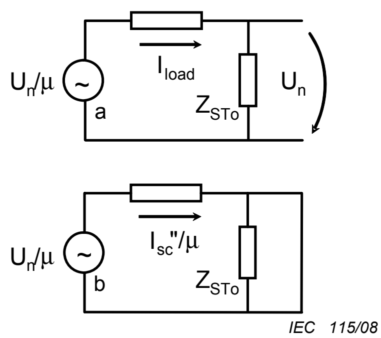

Figure E.5 – Accounting for network loading

c) Short-circuit power including the non-linear effects of the loads in the system

In the preceding analysis, the loads are taken into account as linear elements, i.e. assumed to be represented by constant impedances. However, it has been established in the past that loads do not usually behave as constant impedances during voltage disturbances. They might exhibit voltage dependent characteristics leading to reactive power versus voltage functions very different from the classical second-degree relationship associated to a constant impedance. The general form is as follows:

$$\frac{Q}{Q_0} = \left(\frac{U}{U_0}\right)^{\gamma}$$

Exponents γ between 0,5 and 12 are given in the literature, depending on the type of loads. Similar effects with different exponents have been reported for real power as well [12].

This non-linear behaviour may influence significantly the voltage fluctuations. The effect usually measured is a decrease in the severity of the voltage variations. In terms of short-circuit power, this decreasing effect can be captured as an "apparent" short-circuit power which is effectively larger than the short-circuit power calculated in approximation 1 or 2.

E.3.2 Simplified assessment of the flicker emission level: simple voltage measurement at the point of evaluation

In some cases, the flicker emission level of a fluctuating installation can be determined from a simple voltage measurement at the POE (point of evaluation). The condition is that the fluctuating installation is the only important source of flicker in the system during the period of measurement. A background level for P_{st} below 0,35 can generally be neglected.

If the 'declared short-circuit power' for the assessment of the installation is not the same as the 'actual short-circuit power' at the time of the measurement, the measured flicker emission level of the installation may be referenced back to the 'declared short-circuit power' using

$$Pst_{referenced,95\%} = Pst_{measured,95\%} \cdot \frac{S_{SC,actual}}{S_{SC,declared}}$$

where

$S_{SC,actual}$ = the actual short-circuit power at the point of evaluation during the measurements,

$S_{SC,declared}$ = the declared short-circuit power which has been specified by the system operator for the assessment of the flicker emission of the fluctuating installation,

$P_{st,measured,95\%}$ = the measured flicker level at the point of evaluation,

$P_{st,referenced,95\%}$ = the flicker level at the point of evaluation referenced to the declared short-circuit power.

To determine the emission level with respect to the 'declared short-circuit power,' the 'actual short circuit power' during the measurement should be determined; it should not vary significantly over the whole measurement period.

E.3.3 Simplified assessment of the flicker emission for arc furnaces

As illustrated in Figure E.6, the installation to be assessed (arc furnace and compensator) is connected at point A, at the secondary side of the step down transformer (with impedance Z_T). The transformer on its HV side is connected at point B of the HV-system. The short-circuit power at points A and B are respectively S_{SCA} and S_{SCB}.

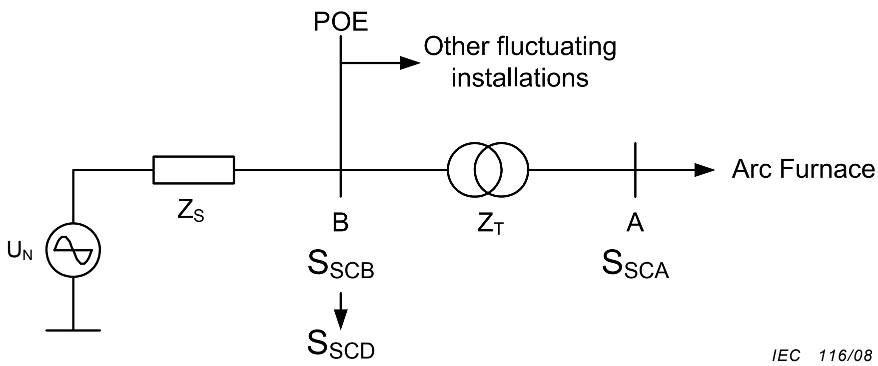

Figure E.6 – System for flicker emission assessment

In the case of an arc furnace, S_{SCA} will be much smaller than S_{SCB}; this will result in an important flicker level at point A when the arc furnace is operating. In most cases, the influence of other fluctuating installations connected to the system will be completely negligible at point A, even if this is not the case at point B.

The flicker level is measured at point A and can be converted to the 'actual short-circuit power' at the point of evaluation (S_{SCB}) or the 'declared short-circuit power' (S_{SCD}) to determine the emission level of the arc furnace at the point of evaluation (point B):

$$Pst_B \cong \frac{S_{SCA}}{S_{SCD}} \cdot Pst_A$$

To obtain good results, the angle of the impedances Z_S and Z_T should be similar (the ratio X/R should be approximately the same). In general, the impedance of the transformer Z_T is predominantly inductive, and the short-circuit impedance of the HV or EHV systems is also almost inductive (angle of Z_S between 80° and 85°). If this is not the case, the impact of the active power variations on the flicker emission level will not be estimated correctly.

E.3.4 Assessment of the flicker emission level by measurement of the voltage drop in the step-down transformer

This approach is applicable to any fluctuating installation. The transformer impedance, obtained from tests, is used to assess the emission level of the fluctuating installations.

The voltage waveforms $U_A(t)$ and $U_B(t)$ are measured at points A and B. The measured voltages on the primary and secondary side of the transformer should be in phase (for Dy or Yd transformers, the phase-to-ground voltage on one side should be compared to the corresponding phase-to-phase voltage on the other side).

In the next step, the voltage waveforms $U_A(t)$ and $U_B(t)$ are divided by the 10 minute r.m.s. fundamental frequency voltage so that their amplitude can be expressed as normalized quantities: $u_A(t)$ and $u_B(t)$.

The voltage drop due to the transformer impedance can then be calculated:

$$\Delta u_{BA}(t) = u_B(t) - u_A(t)$$

A signal $\sqrt{2} \cdot \sin[\omega t + \phi(t)] - \Delta u_{BA}(t)$ can then be applied to the flickermeter to obtain the flicker level, where $\phi(t)$ is the angle of the phasor of the voltage $u_B(t)$ with respect to point A.

That is to say, the instantaneous voltage drop $\Delta u_{BA}(t)$ is subtracted from a sinusoidal voltage source whose amplitude is 1 per unit with the same phase angle as the signal $u_B(t)$.

The so obtained P_{ste} value is the emission level of the installation at the secondary of the transformer Z_T. This result can then be converted to the actual short-circuit power at point B or the declared short-circuit power (S_{SCD}) as below where S_{SCT} is $1/Z_T$:

$$Pst_e(\text{at point B}) \cong \frac{|Z_S|}{|Z_T|} P_{ste} \cong \frac{S_{SCT}}{S_{SCD}} Pst_e$$

The discussion at the end of E.3.3 concerning phase angles is also valid in this case.

E.3.5 Assessment of the flicker emission level by measurement of both voltage and current of the installation at the POE

This approach is also applicable to any fluctuating installations. To apply the method, the voltage waveform $u_M(t)$ at the point of evaluation and the current waveform $i_M(t)$ drawn by the customer's installation should be measured.

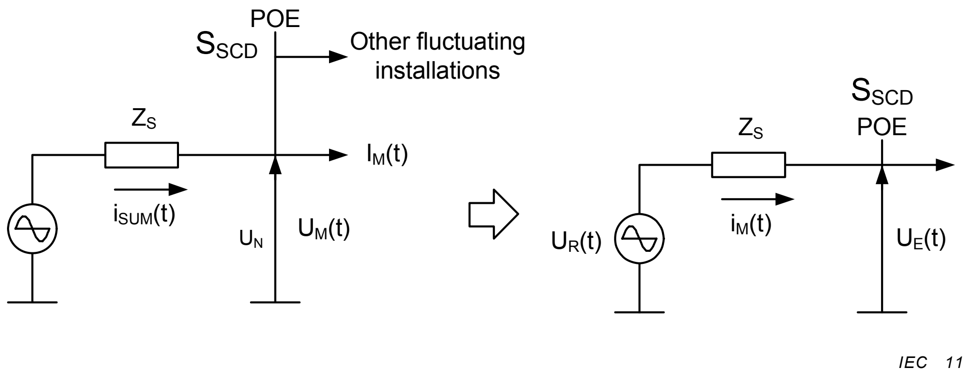

Figure E.7 – Assessment of emission level using current measurements

The voltage waveform $u_E(t)$ is to be determined. This is the voltage that would appear at the POE if the customer's installation was the only disturbing installation in the system. To obtain the voltage waveform, a Thévenin equivalent is used with a sinusoidal voltage source $U_R(t)$. The voltage $u_R(t)$ represents the voltage at the POE if the system was unloaded. The angle of the voltage waveform should be the same as the angle of the voltage u(t) where

$$u(t) = u_M(t) + R_S \cdot i_M(t) + L_S \frac{di_M(t)}{dt}$$

with $Z_S = R_S + j\omega L_S$ corresponding to the declared short circuit power.

Finally, the emission voltage $u_E(t)$ is calculated and applied to the flickermeter to obtain the flicker emission level for P_{st} or P_{lt} for the declared short-circuit power:

$$u_E(t) = u_R(t) - R_S \cdot i_M(t) - L_S \cdot \frac{di_M(t)}{dt}$$

This method can take into account both the resistive component of the system impedance and the impact of the active power variations of the customer's installation.

Annex F
(informative)

Addition of P_{st} from different busbars

In cases where it is required to assess the fluctuation effect of a source upon another point on the supply system, the following cases may occur:

– the point to be assessed may be located far from the location of the source of the fluctuation (from the electrical point of view) so as to be considered as not mutually influencing;

– the point to be assessed may be located sufficiently close to the location of the source of the fluctuation so as to be grouped together in a single equivalent;

– the two locations may be at some distance not so far apart, electrically speaking, so that they can be considered to be mutually influencing. It is necessary to allow for the effect of this influence before combining P_{st} values of separate sources at any particular POE. This case is considered hereafter.

An example is given below for two loads located at different busbars m and n in a networked system.

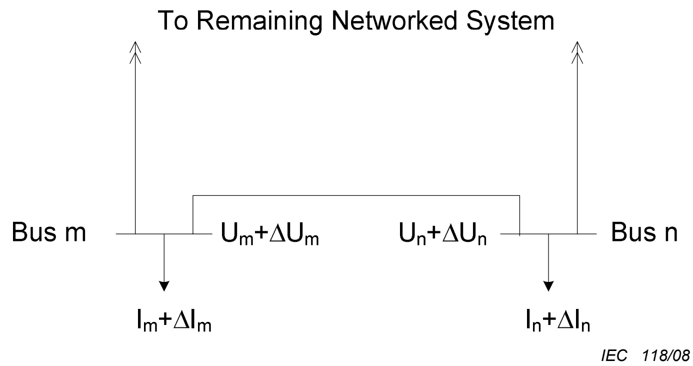

Figure F.1 – Example of two loads fed from different busbars

The following simplified approach based on short-circuit modelling is correct if the X/R ratios of all system components is approximately equal and if frequency dependence, over the range of interest for voltage fluctuations, is not considered. For more information, see [11].

A system impedance model can be constructed using standard short-circuit modelling techniques and used to relate the change in load currents and buses m and n to the associated voltage changes at the same buses.

$$\begin{bmatrix} \cdots \\ U_m + \Delta U_m \\ U_n + \Delta U_n \\ \cdots \end{bmatrix} = \begin{bmatrix} \cdots & \cdots & \cdots & \cdots \\ \cdots & Z_{mm} & Z_{mn} & \cdots \\ \cdots & Z_{nm} & Z_{nn} & \cdots \\ \cdots & \cdots & \cdots & \cdots \end{bmatrix} \begin{bmatrix} \cdots \\ I_m + \Delta I_m \\ I_n + \Delta I_n \\ \cdots \end{bmatrix} \qquad \text{(F.1)}$$

From Equation F.1, it is clear that the voltage fluctuation at bus m produced by the load (current) fluctuation ΔI_m is equal to Z_{mm}. The effect of the fluctuating (current) ΔI_m on bus n is similarly seen to be equal to Z_{mn}. Recalling the linearity of the flickermeter, a P_{st} measurement at bus m can be similarly translated to an approximate P_{st} measurement at bus n based on the following equation:

$$P_{st,n} = P_{st,m}\left(\frac{Z_{mn}}{Z_{mm}}\right) \tag{F.2}$$

Application of Equation F.2 is common in cases where measurements are made at the location of a particular fluctuating installation, possibly at the POC, whereas emission limits are assessed at another location, the POE. It is also common to apply Equation F.2 in cases where multiple fluctuating installations are present. In these cases, measurements or pre-assessments may be made at multiple locations, translated to a single point of interest, and combined at that single point using the summation law with an exponent appropriate for the nature of the fluctuations.

In cases where the simplified assumptions of Equation F.1 do not hold, it is possible to use the approach as outlined except that calculations may be performed using complex values for system impedances and phase angles for fluctuating load (current) changes. In this case, only the magnitude of the voltage changes as calculated by Equation F.1 are used to relate voltage changes at one bus to those at another bus because the flicker phenomena is not strongly dependent on phase angle changes. In the case where it is necessary to consider frequency dependence of system components, most notably near rotating generators, the approach can be applied as described except the impedance values in Equation F.1 should include appropriate values for machine impedances for the fluctuating frequency (or frequencies) of interest.

Annex G
(informative)

Examples of case studies

G.1 Rolling mill load

It is proposed to connect a rolling mill to a MV supply point where the following voltage change pattern is expected to occur at the point of common coupling with other customers:

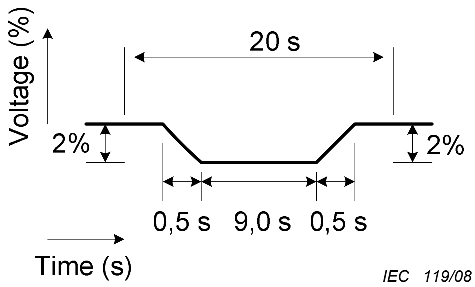

Figure G.1 – Example of effect from a rolling mill

Because the average number of voltage changes (r/min) is 6 (2/20 s) and ΔV ($\approx \Delta S/S_{sc}$) = 2 % the load will not meet the stage 1 limits given in Table 3.

Therefore acceptability is assessed using the stage 2 procedures of Clause 8. Using a maximum global contribution of local loads to the MV system flicker level of G_{PstMV} = 0,78, a system capacity of 20 MVA, and a user's agreed power of 3 MVA, a customer emission limit of P_{st} = 0,41 is derived by the application of Equation (7) if the total load supplied directly at LV, S_{LV}, is zero. Note that a summation law exponent α = 3 is used in this general case. The calculations are as follows:

$$G_{PstMV} = \sqrt[\alpha]{L^{\alpha}_{PstMV} - T^{\alpha}_{PstUM} \cdot L^{\alpha}_{PstUS}} = \sqrt[3]{0{,}9^3 - 0{,}8^3 \cdot 0{,}8^3} = 0{,}78$$

$$E_{Psti} = G_{PstMV} \cdot \sqrt[\alpha]{\frac{S_i}{(S_t - S_{LV})}} = 0{,}78 \cdot \sqrt[3]{\frac{3}{20}} = 0{,}41$$

For a rectangular voltage change with 6 changes/min, the value of voltage change required to produce P_{st} = 1,0 from Figure A.1 is approximately 1,6 (230 V applications). For ramp shape changes, the shape factor for a ramp time of 0,5 s is approximately 0,31 from Figure E.2. Using Equation (E.1), the P_{st} produced by the proposed rolling mill load will be

$$P_{st} = \left(\frac{d}{d_{P_{st}=1}}\right) * F = \left(\frac{2}{1{,}6}\right) * 0{,}31 = 0{,}39$$

This estimated P_{st} value is less than the emission limit of 0,41 and the load can be connected.

G.2 Multiple spot welder load

A manufacturer wishes to install a spot welder load. This load consists of three spot welders having cycle repetition times of 0,2 s, 1 s and 2,5 s respectively. The welders give voltage drops of 0,5 %, 0,4 % and 0,25 % respectively at the PCC and have dwell times of 0,1 s, 0,2 s and 0,3 s.

The waveforms of the three welders are shown in Figure G.2.

One approach is to evaluate the severity value of each welder on its own using Figure E.4 and then using the flicker summation law of Clause 7. For the first welder, with reference to Figure E.4, t_1 = 0,1 s and t_2 = 0,1 s and interpolation between the 4 cycle and 7 cycle curves of Figure E.4 is necessary to obtain an approximate $P_{st,2\%}$ = 4,43. Application of Equation E.5 gives for the first welder

$$P_{st} = \left(\frac{d}{2}\right) P_{st,2\%} = \left(\frac{0,5}{2}\right) 4,43 = 1,10$$

For the second welder, t_1 = 0,2 s and t_2 = 0,8s. No interpolation is required to obtain an approximate value of $P_{st,2\%}$ = 2,58 from Figure E.4. Application of Equation E.5 gives for the second welder

$$P_{st} = \left(\frac{d}{2}\right) P_{st,2\%} = \left(\frac{0,4}{2}\right) 2,58 = 0,52$$

Similarly, for the third welder, t_1 = 0,3 s and t_2 = 2,2 s and no interpolation is required to obtain the approximate value of $P_{st,2\%}$ = 2.1 from Figure E.4. Application of Equation E.5 gives for the third welder

$$P_{st} = \left(\frac{d}{2}\right) P_{st,2\%} = \left(\frac{0,25}{2}\right) 2,1 = 0,26$$

Because the voltage changes occur at less than 0,1 s intervals, the risk of coincident voltage changes is very high and it is not clear which value of α to use in the summation law formula. Assuming a maximum coincidence of voltage changes (α = 1) gives a worst-case value of P_{st} = 1,88. Regardless of the value of α used, the total P_{st} will exceed 1,0 and the installation should be denied unless specific action has been taken to increase the planning levels in the affected area or mitigate the severity of the disturbance.

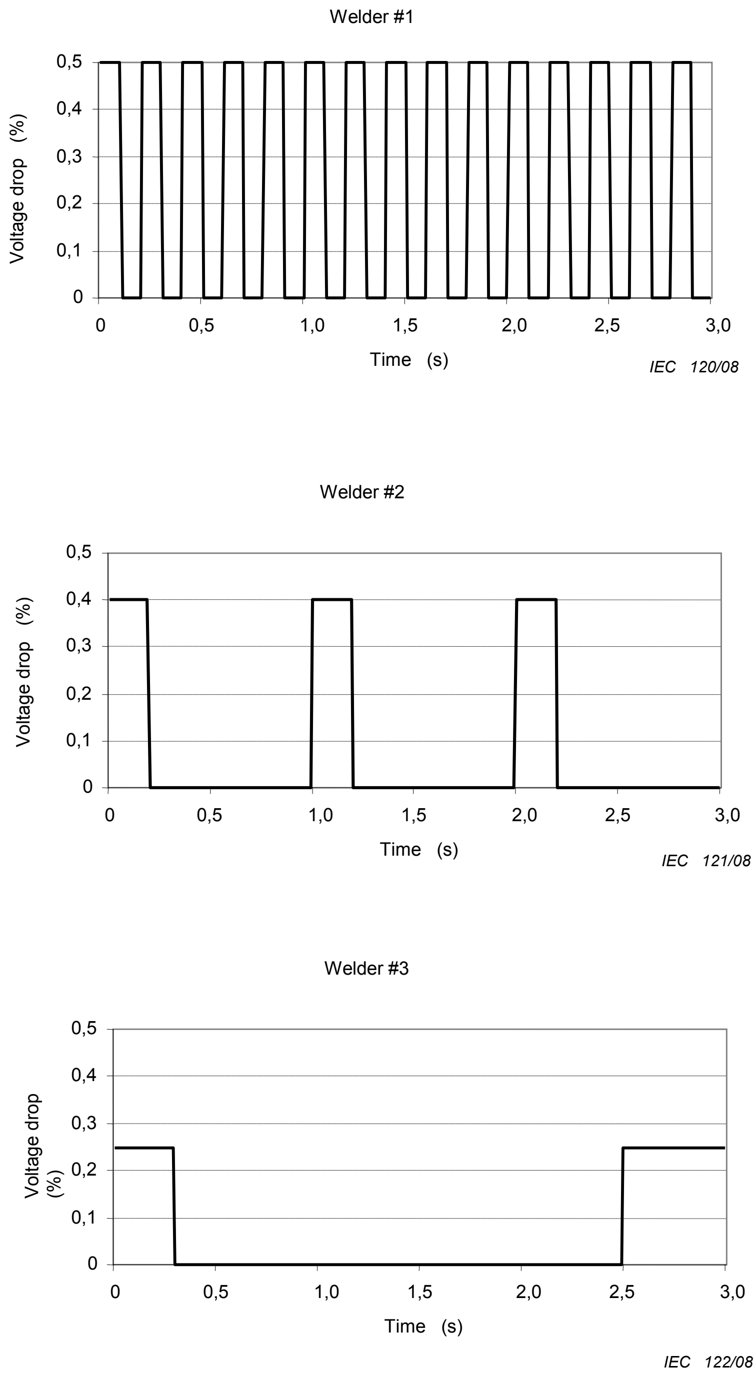

Figure G.2 – Example of effect of multiple spot welder load

G.3 Car shredder load

An existing 11 kV supply point supplies a large 900 kW induction motor driving a car shredder. The customer has requested the connection of an additional 1 500 kW induction motor to drive an additional car shredder.

a) Characteristics of existing supply at the point of connection

Impedance at POC: 37,5 + j · 82 % on a base of 100 MVA.

b) Characteristics of existing motor

Starting: direct on line, 3,3 MVA at 0,3 power factor once a day.

Running: no load to full load power change at 0,9 power factor.

c) Characteristics of proposed motor evaluated at the point of connection

This is a scaled version of the existing 900 kW motor. Complex voltage changes occur during running caused by the fluctuating installation of the driving motor; therefore, a flickermeter approach has to be used to assess the severity of the flicker likely to be caused. But first, regardless of the flicker severity, it is necessary to check that with normal system connections the voltage changes on starting are within the 6 % limit (see Table 6) assuming the entire MV planning level is allocated to this installation. This initial assessment at the POC is done by scaling the characteristics of the existing motor, thus the starting voltage change for the existing motor is calculated:

$$\frac{\Delta U}{U} = \frac{S}{S_{base}}(\cos\varphi \cdot R_{p.u.} + \sin\varphi \cdot X_{p.u.}) = \frac{3{,}3}{100} \cdot (37{,}5 \cdot 0{,}3 + 82 \cdot 0{,}95) = 2{,}94\%$$

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

$$\text{Voltage change} = 2{,}94 \cdot \frac{1\,500}{900} = 4{,}90\ \%$$

While this 4,9 % value is acceptable considering the 6 % emission limit (based on full allocation of the planning level in Table 6) to be applied at the point of evaluation, action should be considered which can minimize problems (e.g., the possible future connection of an additional fluctuating installation in the immediate area) in the future.

d) Action taken

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

1,3 + j48,8 % on 100 MVA.

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

$$\text{Voltage change} = \frac{3{,}3}{100} \cdot \frac{1\,500}{900} \cdot (1{,}3 \cdot 0{,}3 + 48{,}8 \cdot 0{,}95) = 2{,}57\ \%$$

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

e) Flicker measurements (see Table G.1)

Flickermeter readings were taken for the following conditions:

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

Test ii) existing location with 900 kW motor starting.

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

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

f) Choice of system impedance to use in study

The impedance, given in d), of 1,3 + j·48,8 % on 100 MVA is with both 33 kV/11 kV transformers in circuit. An outage of one of these transformers will increase the 11 kV busbar impedance to 2,5 + j·85,6 % on 100 MVA, i.e., almost twice that of the normal operating condition. Major transformer faults can take several months to repair and consequently represent a risk of causing extended running with a high system impedance. However, in this case, as the operation of car shredders takes place mainly during the day when there is no significant use of tungsten filament lighting, it was decided to ignore the outage situation and use the normal operating system impedance. However, it should be noted that under these outage conditions the voltage step change on motor starting is about 4,51 %.

g) Choice of value to use for α in the summation formula (2)

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

h) Flicker effects, starting

The following 10 min severity values, P_{st}, were obtained at the point of connection identified in c) for the starting of the existing 900 kW motor on the existing supply (see Table G.1):

Starting (including background): P_{st} = 0,56 (test ii – note that this value is not given in Table G.1)

Typical background readings: P_{st} = 0,3 (mean value, test i)

Starting, 900 kW motor only: $P_{st} = \sqrt[3]{\left(0{,}56^3 - 0{,}3^3\right)} = 0{,}53$

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

At the existing location, starting voltage changes for the existing motor are 2,94 % (see c)).

At the 11 kV busbar, the starting voltage change would be

$$\text{Voltage change} = \frac{3{,}3}{100} \cdot \left(1{,}3 \cdot 0{,}3 + 48{,}8 \cdot 0{,}95\right) = 1{,}54\ \%.$$

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

$$0{,}53 \cdot \frac{1{,}54}{2{,}94} = 0{,}28 \ (P_{st7}, \text{ see Table G.1}).$$

The proposed 1 500 kW motor is a scaled version of the existing 900 kW motor, so this will cause a severity value of

$$0{,}28 \cdot \frac{1\,500}{900} = 0{,}47 \ (P_{st8}, \text{ see Table G.1}).$$

i) Flicker effects, normal running (see Table G.1).

1) 900 kW motor.

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

The result gives the effects of the 900 kW motor only at the existing location. To translate the effects to the 11 kV busbar proposed in d), it is necessary to scale the severity values for the ratio of the magnitude of the voltage changes at the two locations. Because power swings during running occur at 0,9 power factor, then this ratio is:

$$\text{Ratio} = \frac{(\cos\varphi \cdot R'_{p.u.} + \sin\varphi \cdot X'_{p.u.})}{(\cos\varphi \cdot R_{p.u.} + \sin\varphi \cdot X_{p.u.})} = \frac{1{,}3 \cdot 0{,}9 + 48{,}8 \cdot 0{,}44}{37{,}5 \cdot 0{,}9 + 82 \cdot 0{,}44} = 0{,}32$$

2) Proposed 1 500 kW motor

This is a scaled version of the 900 kW motor so it's likely severity values are those of the smaller motor multiplied by (1 500/900).

3) Summation of effects at the 11 kV busbar

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

The long-term severity value, P_{lt}, is derived from the summated P_{st} values using formula (1).

j) Summary

1) The starting voltage change of 2,6 % of the proposed 1 500 kW motor at the 11 kV busbar of the 33 kV/11 kV substation is acceptable.

2) The transfer of the existing motor and the connection of the proposed 1 500 kW motor to this 11 kV busbar will lead to the following flicker severity values:

P_{st} (maximum) = 0,75

P_{lt} = 0,59

In this stage 3 evaluation, it is assumed that the load in question is allocated the global MV emission level. Based on a transfer coefficient of 0,8 from the upstream HV to the MV system and the planning levels in Table 2, both of these values are within the limits (G_{PstMV}=0,78 and G_{PltMV}=0,61) and so this proposal is acceptable.

Table G.1 – Flicker measurements for example G.3, flicker effects, normal operation

		Consecutive short-term severity values, P_{st} taken over 2 h											
Test ii), 900 kW motor + background	(P_{st1})	0,54	0,78	0,81	0,84	0,87	0,84	0,81	0,75	0,75	0,81	0,81	0,66
Test i),background	(P_{st2})	0,27	0,27	0,24	0,48	0,48	0,27	0,24	0,27	0,27	0,24	0,27	0,30
900 kW motor, $\sqrt[3]{P_{st1}{}^3 - P_{st2}{}^3}$	(P_{st3})	0,52	0,77	0,80	0,78	0,82	0,83	0,80	0,74	0,74	0,80	0,80	0,64
900 kW motor scaled for alternative location, P_{st3} x 0,32	(P_{st4})	0,17	0,25	0,26	0,25	0,26	0,27	0,26	0,24	0,24	0,26	0,26	0,21
1500 kW motor, P_{st4} x (1500/900)	(P_{st5})	0,28	0,41	0,43	0,42	0,44	0,45	0,43	0,40	0,40	0,43	0,43	0,34
Test iv), background	(P_{st6})	0,24	0,24	0,69	0,69	0,45	0,48	0,36	0,24	0,36	0,36	0,21	0,66
900 kW motor starting	(P_{st7})	0,28	0	0	0	0	0	0	0	0	0	0	0
1500 kW motor starting	(P_{st8})	0,47	0	0	0	0	0	0	0	0	0	0	0
Summation, $\sqrt[3]{\sum_{n=4}^{n=8} (P_{st_n})^3}$	(P_{st9})	0,55	0,44	0,74	0,74	0,56	0,59	0,50	0,42	0,48	0,50	0,45	0,69
$P_{lt} = \sqrt[3]{\frac{1}{12} \cdot \sum_{1}^{12} (P_{st})^3}$		0,58											

G.4 Study of proposed multiple mine winder load

In this example there is a proposal to install three 5 MW mine winders connected to a supply with a 400 MVA short circuit power at the PCC. The profile of the winder reactive power levels is given in Figure G.3. The question is how the operation of the three winders together, with similar but not identical cycle times of approximately 60 s, affects the flicker level.

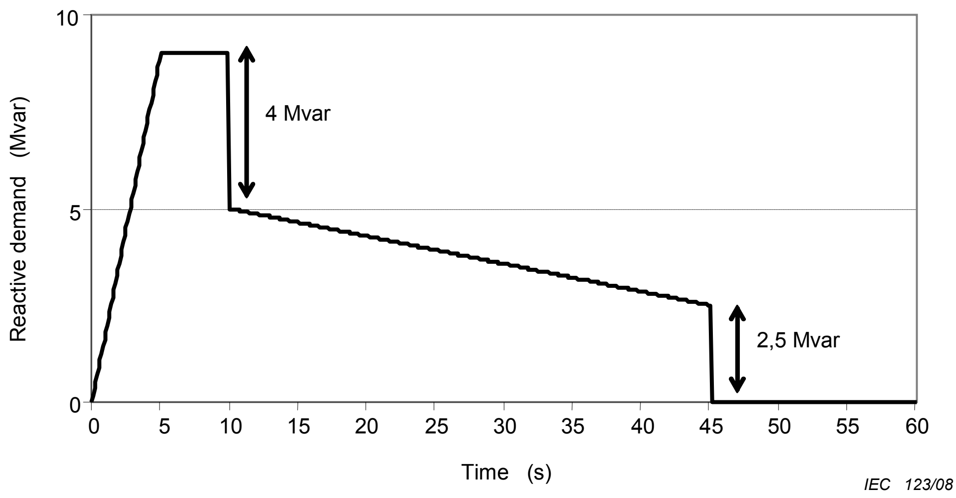

Figure G.3 – Example profile of winder reactive power levels

The voltage changes are approximately proportional to the reactive power profile with 4 Mvar equal to 1 % voltage change and 2,5 Mvar equal to 0,63 %. It is seen from Figure E.1 that ramp times greater than about 1 s have a small effect compared to step changes of a similar size. The flicker from the winders will therefore be predominately caused by the 4 Mvar change at 10 s after switch-on and to a lesser extent by the smaller step reactive power change of 2,5 MVar at switch-off.

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

From Figure A.1 (230 V) for a 1 per min repetition rate, P_{st} = 1,0, the maximum voltage change is 2,7 %.

Therefore, for a 1 % voltage change, $P_{st} = \frac{1}{2{,}7} = 0{,}37$ and for a 0,63 % voltage change P_{st} = 0,37*0,63 = 0,23, the combined P_{st} for both step changes = $\sqrt[3]{0{,}37^3 + 0{,}23^3}$ = 0,40 where α = 3 is chosen for this general application of the summation law.

If it is assumed that the operation of the winders is uncorrelated the flicker effects from more than one winder can also be determined by application of the summation law formula (2), again with α = 3, for three winders to be $P_{st} = \sqrt[3]{\left(3 \cdot 0{,}4^3\right)}$ = 0,58. This ignores the more severe flicker which would result from the coincidence of steps from different winders. Studies have shown that the coincidence of the step changes would have to be closer than 0,1 s to have a pronounced flicker effect. The frequency of two steps coinciding within 0,1 s with three winders in operation having a cycle time of 60 s each is about one an hour and the coincidence of three winder steps is about once a fortnight so the likelihood of coincidence is small enough to be ignored.

G.5 Connection of a 60 ton a.c. arc furnace

The 63 kV station comprises two HV busbars:

– the first one feeds an MV distribution system;
– the second one feeds a steel plant. The agreed power S_i of the customer is 47 MVA.

Three 63 kV lines come to this station, from the 225/63 kV stations named station 1, station 2 and station 3.

a) Normal system configuration

The normal system configuration is defined by the following characteristics (see Figure G.4):

- the bus coupler circuit-breaker is open;
- the steel plant is fed by station 1;
- the distribution system is fed by station 2 and station 3 in parallel;
- the static compensator (SVC) is in operation.

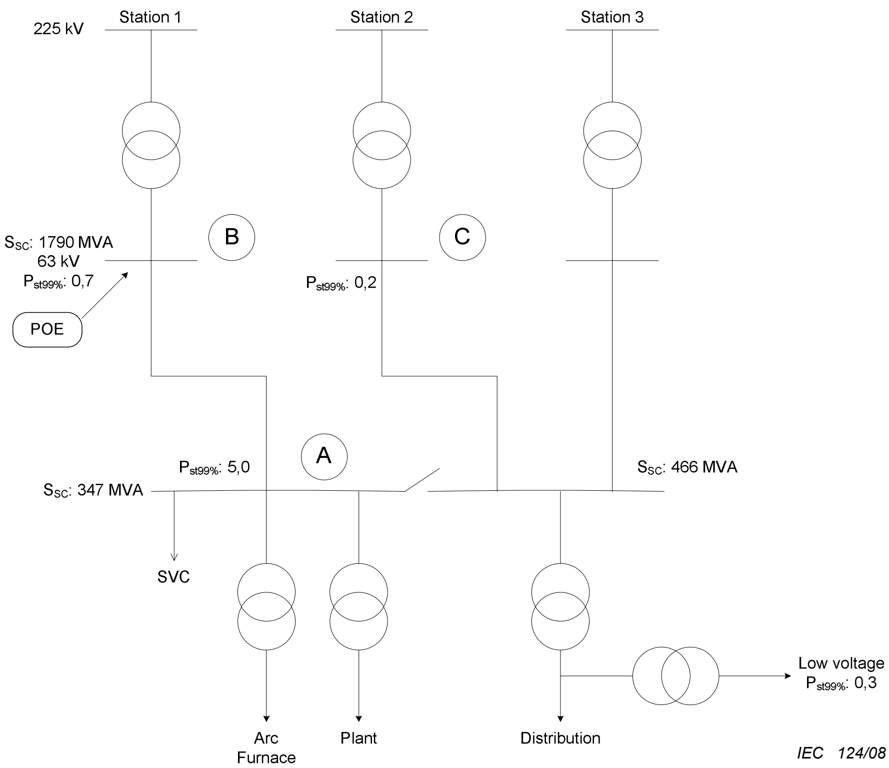

Figure G.4 – Normal system configuration

In Figure G.4, the POE is marked on the 63 kV busbar of station 1. The short-circuit power is 1 790 MVA and $\Delta S/S_{sc}$ = 2,6%. Stage 1 does not apply due to the size of the fluctuating to short-circuit power ratio.

Considering stage 2, the chosen planning level is L_{PstHV} = 1. The customer is the only load served from the 63 kV bus in station 1, so S_{tHV} = 47 MVA by default. Consequently:

$$E_{Psti} = L_{PstHV} \cdot \sqrt[3]{\frac{47}{47}} = 1$$

The measured $P_{st95\%}$ values are:

- 5 at the steel plant HV busbar (point A);
- 0,7 at station 1, in HV (63 kV) (point B);
- 0,2 at station 2, in HV (63 kV) (point C);
- 0,3 in the LV distribution system.

The normal system configuration is therefore acceptable under stage 2.

Three other system configurations are studied.

The attenuation of P_{st} between HV, MV and LV has been measured for stations 2 and 3 and found equal to T_{PstHM} = 0,97 from HV to MV and T_{PstML}=0,95 from MV to LV. These values are high because the area around the steel plant is rural and there are very few industrial loads that contribute to short-circuit power at the MV level. Attenuation has not been measured at station 1. The environment being similar, the attenuation coefficient for station 1 will be assumed to be T_{PstHL}= 0,92 (=T_{FPstHM} * T_{FPstML}) between HV and LV. The limits for P_{st} are then applied to HV values.

b) Coupling of the two busbars

The system configuration shown in Figure G.5 contains measurement results:

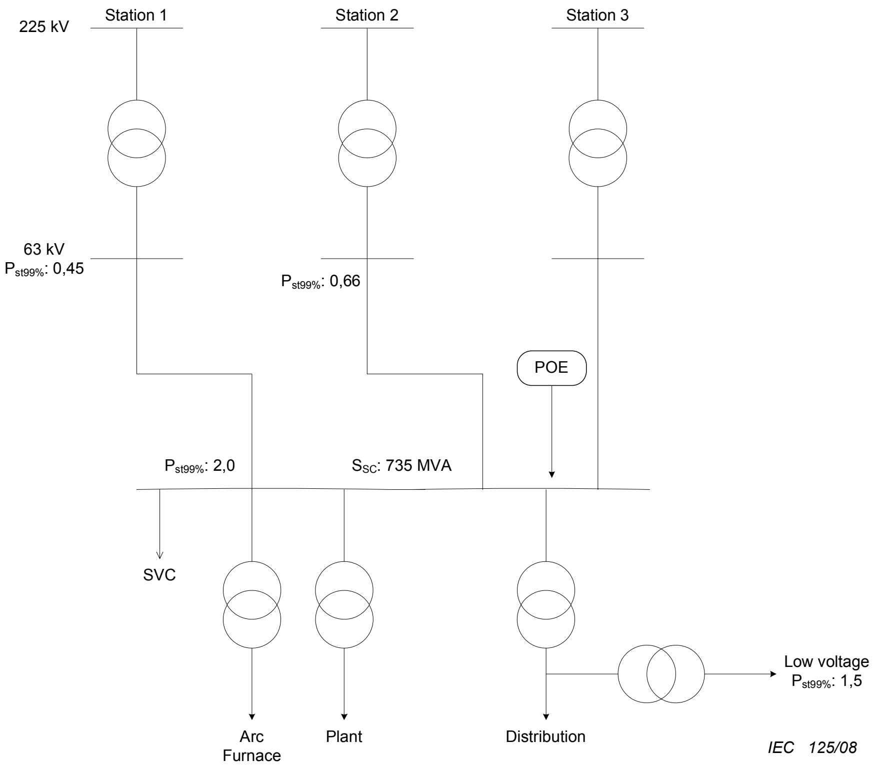

Figure G.5 – Busbars coupled

This system configuration leads to unacceptably high values of P_{st} at the new POE. The main reason for this is that the change of the POE reduces the electrical distance between the steel plant and the distribution system.

c) Loss of the station 1 line

If the line between the steel plant and station 1 is disconnected, the "n-1" system configuration is as shown in Figure G.6:

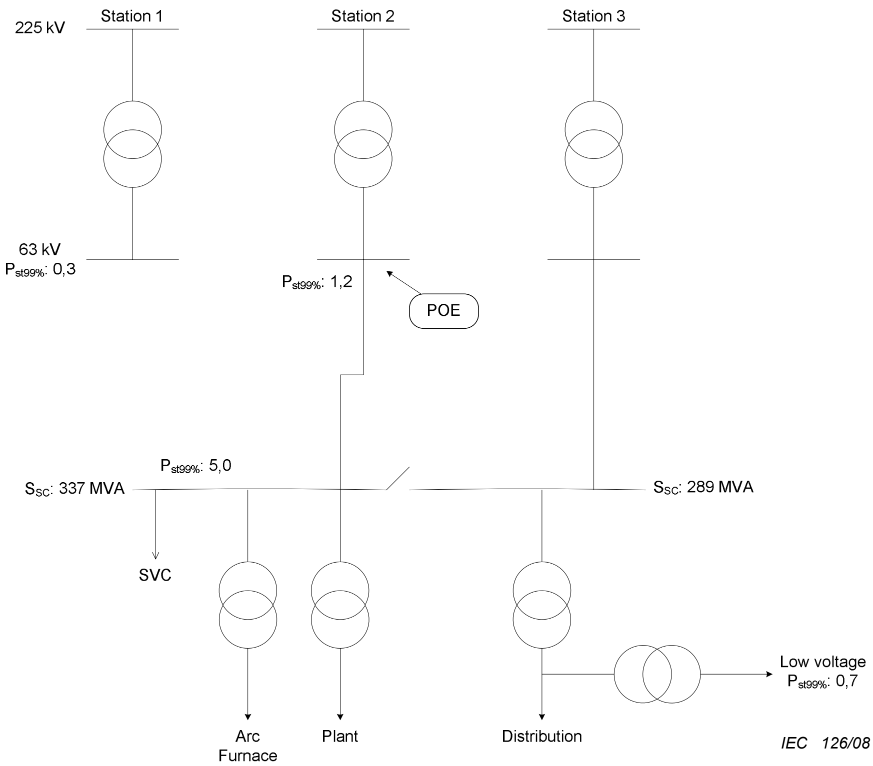

Figure G.6 – "n-1" system configuration

The value at station 2 is too high but this system configuration cannot be considered as a normal system configuration. However, due to the possibility of the transfer coefficient T_{PstHL} being less than 0,92, a predicted P_{st} value of 1,1 in the LV system connected to the busbar of station 2 may be acceptable for short periods during abnormal system configuration. Consequently, the probability of this situation has to be taken into account. In this case, the probability is very low. The customer is then accepted under stage 2 conditions without restriction.

d) Loss of the SVC

If the SVC is not in operation, the P_{st} values are multiplied by a factor between 1,5 and 2, depending on the system configuration. Considering the normal system configuration, the measured P_{st} values are given in Figure G.7.

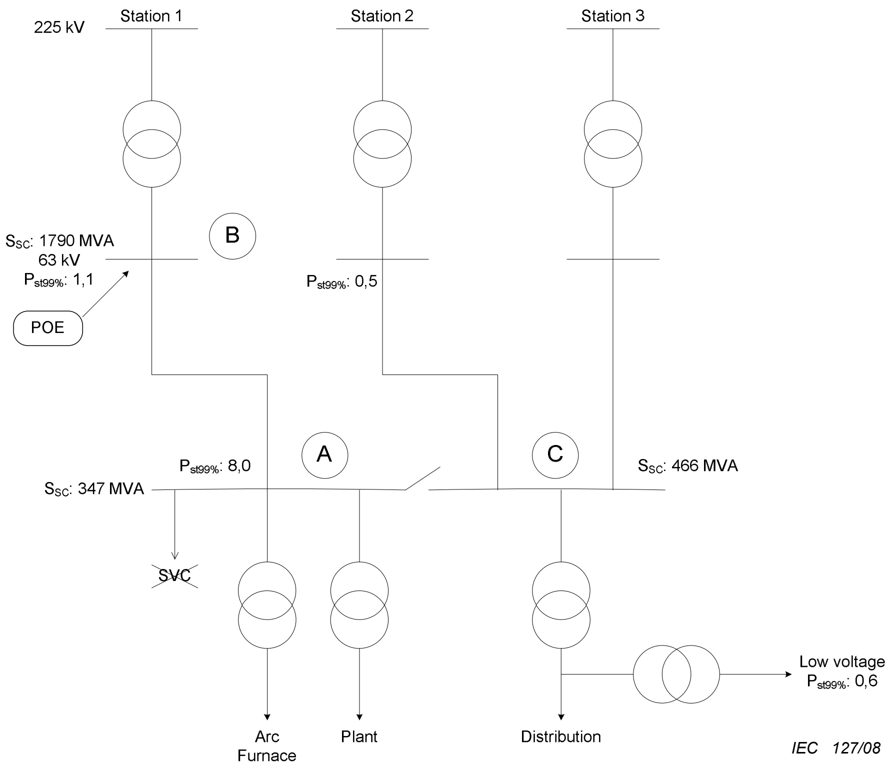

Figure G.7 – Operation without SVC

The value at station 1 is too high. However, as in the previous case, this system configuration is acceptable as a non-normal system configuration for short periods of time. Paralleling line 2 or line 3 from the distribution busbar with the steel plant busbar would increase the short-circuit power at the steel plant point of connection. The P_{st} in station 1 would then become acceptable, but the P_{st} level would also increase on the distribution system. As a consequence, the customer cannot be accepted without the SVC, neither under stage 2 nor under stage 3 conditions, if parallel operation of the plant and the distribution system buses is considered.

Annex H
(informative)

List of symbols and subscripts

H.1 Letter symbols

α	exponent of the summation law
B	Pre-existing disturbance level on a system (background level)
C	compatibility level
E	emission limit
G	Acceptable global contribution of emissions in a specified part of a system
i	single customer or load
I	current
j	single device within the installation of customer i
K	coefficient or ratio between two values (general meaning)
L	planning level
N	number of loads of the considered distribution system
n	number (of voltage changes) in a given period
PCC	Point of Common Coupling
POC	Point of connection of a customer's installation
POE	Point of evaluation
P	active power
S	apparent power
ΔS	apparent power variation of a fluctuating installation
T	transfer coefficient
U	voltage
Z	impedance

H.2 List of subscripts

i	customer or customer's installation (i)
j	device (j)
LM	between LV and MV systems
LV	LV systems or installations
ML	between MV and LV systems
MV	MV systems or installations

H.3 List of principal symbols

NOTE Obvious symbols are not listed.

C_{PstLV}	short-term flicker compatibility level for LV
E_{Psti}	allowed short-term flicker emission limit for the customer (i)
$G_{PstMV(HV\ or\ EHV)}$	maximum global contribution to the short term flicker level of all the fluctuating installations that can be connected to the considered (MV, HV or EHV) system (p.u.)

$G_{PltMV(HV\ or\ EHV)}$	maximum global contribution to the long term flicker level of all the fluctuating installations that can be connected to the considered (MV, HV or EHV) system (p.u.)
$L_{PstHV\text{-}EHV}$	short-term flicker planning level for HV-EHV
L_{PstMV}	short-term flicker planning level for MV (p.u.)
N	assumed number of MV loads of the considered MV distribution system (number of loads supplied from the same busbar)

P_i	active agreed power of the individual customer (i) (kW)
P_{stHV}	short-term flicker on HV
P_{stiMV}	short-term flicker emission level of customer (i) on MV
P_{stMV}	short-term flicker on MV
Q_c	capacitive reactive power
S_i	(P_i /cos φ) agreed apparent power of the customer's installation i, or the MVA rating of the considered installation (either load or generation)
S_{LV}	the total power of the loads supplied directly at LV in the considered system including provision for future load growth
S_{SC}	short-circuit power
S_t	the total supply capacity of the considered system including provision for future load growth (in principle, S_t is the sum of all installations including downstream loads that can be supplied from the considered system)
S_{tHV} or S_{tEHV}	is the part of the total supply capacity of the HV or EHV system considered which is devoted to the HV or EHV users
T_{PUM}	Upstream to MV flicker transfer coefficient; value depends on system and load characteristics
T_{PML}	MV/LV flicker transfer coefficient; value depends on system and load characteristics
U_N	nominal voltage of the distribution system (kV)
Z_i	impedance at POE of customer (i)

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