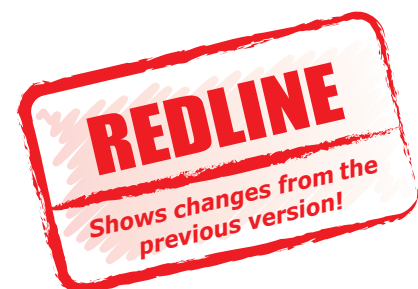


IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems

IEEE Power and Energy Society

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IEEE Std 1453™-2015
(Revision of
IEEE Std 1453-2011)

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IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems

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Transmission and Distribution Committee
of the
IEEE Power and Energy Society

Approved 3 September 2015

IEEE-SA Standards Board

Abstract: Background on light flicker caused by fluctuations in power demands of variable loads is presented in this recommended practice. A flicker measurement method is presented using a meter that is completely described in IEC 61000-4-15. The short-term (P_{st}) and long-term (P_{lt}) flicker indices used for the analysis of flicker data are defined. Flicker limits for various voltage levels are presented. An assessment procedure for evaluating flicker compliance against emission limits is described. Methodologies to analyze background flicker to identify the flicker contribution of single loads are also presented.

Keywords: flicker, fluctuating loads, IEEE 1453™, power systems

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Introduction

This introduction is not part of IEEE Std 1453-2015, IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems.

Voltage fluctuations on electric power systems sometimes give rise to noticeable illumination changes from lighting equipment. The frequency of these voltage fluctuations is much less than the 50 Hz or 60 Hz supply frequency. However, they may occur with enough frequency and magnitude to cause irritation for people observing the illumination changes. This phenomenon is often referred to as flicker, lamp flicker, and sometimes voltage flicker. Often times, the terms have been used interchangeably. IEEE Std 141TM-1993 [B14] and IEEE Std 519TM-1992 [B15] contain charts showing allowable voltage fluctuations. The advent of high-power electronic utilization equipment and mitigation equipment has given rise to some very complex voltage fluctuations that are not easily handled by IEEE Std 141-1993 [B14] and IEEE Std 519-1992 [B15]. For this reason, the IEEE has worked in close cooperation with the International Union for Electroheat (UIE) and the International Electrotechnical Commission (IEC) to enhance existing standards to include a broader part of the world community. In 2004, IEEE Std 1453-2004 was published, adopting the IEC flickermeter standard and providing recommended levels. IEEE Std 1453-2011 adopted the 2010 edition of the IEC 61000-4-15, moving the recommended acceptable flicker levels to its annex, facilitating the adoption of the IEC/TR 61000-3-7 in IEEE Std 1453.1TM-2012. This present version of IEEE Std 1453 replaces both IEEE Std 1453-2011 and IEEE Std 1453.1-2012. This edition uses the IEC flicker methodology while providing additional information.

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IEEE Recommended Practice for the Analysis of
Fluctuating Installations on Power Systems

~~ELECTROMAGNETIC COMPATIBILITY (EMC)—~~

~~Part 4-15: Testing and measurement techniques—~~

~~Flickermeter—Functional and design specifications~~

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1. Overview

1.1 Scope ~~and object~~

This recommended practice provides background on light flicker caused by fluctuations in power demands of variable loads. A flicker measurement method is presented using a meter that is completely described in IEC 61000-4-15. The short-term (P_{st}) and long-term (P_{lt}) flicker indices used for the analysis of flicker data are defined. Flicker limits for various voltage levels are presented. An assessment procedure for evaluating flicker compliance against emission limits is described. Methodologies to analyze background flicker to identify the flicker contribution of single loads are also presented.

The document provides ways to estimate flicker levels at the Point of Common Coupling (PCC) depending on the type of the load. This document includes example terms and language that can be the basis for defining relative responsibilities and assessment methods for customer installations that may cause flicker.

~~This part of IEC 61000 gives a functional and design specification for flicker measuring apparatus intended to indicate the correct flicker perception level for all practical voltage fluctuation waveforms. Information is presented to enable such an instrument to be constructed. A method is given for the evaluation of flicker severity on the basis of the output of flickermeters complying with this standard.~~

~~The flicker meter specifications in this part of IEC 61000 relate only to measurements of 120 V and 230 V, 50 Hz and 60 Hz inputs. Characteristics of some incandescent lamps for other voltages are sufficiently similar to the values in Table 1 and Table 2, that the use of a correction factor can be applied for those other voltages. Some of these correction factors are provided in the Annex B. Detailed specifications for voltages and frequencies other than those given above, remain under consideration.~~

~~The object of this part of IEC 61000 is to provide basic information for the design and the instrumentation of an analogue or digital flicker measuring apparatus. It does not give tolerance limit values of flicker severity.~~

1.2 Purpose

The purpose of this document is to provide guidance to system operators, owners, and engineers who are responsible for providing electrical service to installations that cause voltage fluctuations. It provides guidance on the principles and methodology that can be used to determine requirements for connecting fluctuating loads to both radial and network systems. Methods for determining appropriate flicker planning levels and emission limits for fluctuating loads as well as those that create rapid voltage changes are provided.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 61000-4-15, ~~Edition 2-08-2010~~—Electromagnetic compatibility (EMC)—Part 4-15: Testing and measurement techniques—Flickermeter—Functional and design specifications.¹

IEC 61000-3-7, ~~Edition 2-0~~ Electromagnetic compatibility (EMC) — ~~Part 3: Limits— Section 7:~~ Assessment of emission limits for the connection of fluctuating installations to ~~loads in~~ MV, HV and EHV power systems —~~Basic EMC publication.~~

¹ IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

~~IEC 60068 (all parts), Environmental testing~~

~~IEC 61000-3-3, Electromagnetic compatibility (EMC) — Part 3-3: Limits — Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current 16 A per phase and not subject to conditional connection~~

~~IEC 61000-3-11, Electromagnetic compatibility (EMC) — Part 3-11: Limits — Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems — Equipment with rated current 75 A and subject to conditional connection~~

~~IEC 61010-1, Safety requirements for electrical equipment for measurement, control, and laboratory use — Part 1: General requirements~~

~~IEC 61326-1, Electrical equipment for measurement, control and laboratory use — EMC requirements — Part 1: General requirements~~

3. Definitions

For the purposes of this [document](#) ~~recommended practice~~, the following terms and definitions apply. The ~~Authoritative~~ IEEE Standards Dictionary [Online Terms](#) should be [consulted](#) ~~referenced~~ for terms not defined in this clause.² ~~Note specifically that definitions D.2 through D.5 are adopted within this document for consistency with the IEC 61000 series upon which this document is based; thus they may conflict with ANSI C84.1 [B1]¹ and The Authoritative Dictionary of IEEE Standards Terms accepted definitions.²~~

² [IEEE Standards Dictionary Online subscription is available at: http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.](http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html)

¹ ~~The numbers in brackets correspond to those of the bibliography in Annex G.~~

² ~~The IEEE Standards Dictionary: Glossary of Terms & Definitions is available at http://shop.ieee.org/.~~

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.

disturbance level: The magnitude of an electromagnetic disturbance measured and evaluated in a specified way.

electromagnetic compatibility (EMC): The ability of a device, equipment, or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances 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.³

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.

NOTE 3—Where the context requires it, electromagnetic 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 that devices, equipment, and systems undergo from each other or from electromagnetic phenomena.

³ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

(electromagnetic) compatibility level: The specified [electromagnetic](#) disturbance level used as a reference level in a specified environment for coordination in the setting of emission and immunity limits. ~~This is normally taken as the level of P_{st} or P_{it} above which LV customers are likely to perceive flicker. These levels are not used for assessing individual load compliance.~~

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.

electromagnetic disturbance: Any electromagnetic phenomenon that may degrade the performance of a device, equipment, or system, or adversely affect living or inert matter.

emission: The phenomenon by which electromagnetic energy emanates from a source of electromagnetic disturbance.

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

emission level (of a disturbing source): The level of a specified electromagnetic disturbance type emitted from a particular device, equipment or system.

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

flicker: The subjective impression of fluctuating luminance caused by voltage fluctuations.

NOTE—Above a certain threshold, flicker becomes annoying. The annoyance grows very rapidly with the amplitude of the fluctuation. At certain repetition rates even very small amplitudes can be annoying.

flicker severity: The intensity of flicker annoyance defined by the UIE IEC flicker measuring method and evaluated by the following quantities:

- Short-term severity (P_{st}) measured over a period of ten minutes
- Long-term severity (P_{lt}) calculated from a sequence of 12 consecutive P_{st} values (i.e., over a two hour interval)

fluctuating installation: An electrical installation as a whole (i.e., including fluctuating and non-fluctuating parts) that is characterized by repeated or sudden power fluctuations, or start-up or inrush currents that can produce voltage fluctuations or rapid voltage changes on the supply system to which it is connected.

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

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

NOTE 1—For the purpose of this document, the fundamental frequency is the same as the power supply frequency (definition 3.12 in IEC 61000-3-7).

NOTE 2—In the case of a periodic function, the fundamental frequency is generally equal to the frequency of the function itself.

generating plant: Any equipment that is a source of electric power together with any directly connected or associated equipment such as a unit transformer or converter.

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

immunity level: The 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.

interharmonic frequency: Any frequency that 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.

interharmonic component: A component that has an interharmonic frequency. For brevity, such a component may be referred to simply as an “interharmonic”.

interharmonic voltage: A sinusoidal voltage with a frequency not equal to an integer multiple of the fundamental.

normal operating conditions: The 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.

P_{inst} : The instantaneous flicker sensation.

$P_{\text{inst,max}}$: The peak value of the instantaneous flicker sensation P_{inst} measured during the observation period.

~~D.2 extra high voltage (EHV): Voltage levels that are greater than 230 kV.~~

~~D.3 high voltage (HV): Voltage levels that are greater than 35 kV, but less than or equal to 230 kV.~~

~~D.4 low voltage (LV): Voltage levels that are less than or equal to 1 kV.~~

~~D.5 medium voltage (MV): Voltage levels that are greater than 1 kV, but less than or equal to 35 kV.~~

P_{lt} : The long-term flicker severity ~~A measure of long-term perception of flicker obtained for a two-hour period. This value is made up of 12 consecutive P_{st} values per the following formula:~~

$$P_{\text{lt}} = \sqrt[3]{\frac{1}{12} \sum_{i=1}^{12} P_{\text{st}_i}^3}$$

(New)

$$P_{\text{lt}} = \sqrt[3]{\frac{1}{12} \sum_{j=1}^{12} P_{\text{st}_j}^3} \quad (\text{D.1})$$

~~(Deleted)~~

where

($i = 1, 2, 3, \dots$) are consecutive readings of the short-term severity P_{st}

P_{st} : The short-term flicker severity. If not specified differently, the P_{st} evaluation time is 10 minutes. For the purpose of power quality surveys and studies, other time intervals may be used, and have to be defined in the index. For example a 1 minute interval should be written as $P_{\text{st},1\text{m}}$.

NOTE—See Equation (1) and related discussion.

planning level: The 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 large loads and 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. ~~In planning studies, this is the level of P_{st} or P_{lt} used to assess the impact of adding fluctuating loads to the electric power 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.

point of common coupling (PCC): The point in the public system that 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. ~~The point on the LV, MV, HV, or EHV bus on the electric power system electrically closest to a particular fluctuating load, at which point other loads are or could be connected.~~

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

point of connection (POC): The 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.

point of evaluation (POE): The 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.

rapid voltage changes (RVC): Changes in fundamental frequency rms 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.

rms voltage refreshed each half-cycle, $V_{rms(1/2)}$: Value of the rms voltage measured over 1 cycle, commencing at a fundamental zero crossing, and refreshed each half-cycle (definition 3.22 in IEC 61000-4-30).

NOTE 1—This technique is independent for each channel and will produce rms values at successive times on different channels for polyphase systems.

NOTE 2—This value is used only for voltage dip, voltage swell, interruption, and RVC detection and evaluation, in Class A.

NOTE 3—This rms voltage value may be a phase-to-phase value or a phase-to-neutral value.

short-circuit power: The 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 $\sqrt{3}$ with the aperiodic component (dc) being neglected.

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

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

T_{long} : The long-term time interval for the P_{lt} evaluation, which is always an integer multiple of the short term flicker severity evaluation P_{st} . If not specified differently the long-term interval T_{long} is 12×10 minutes, i.e., 2 hours. For the purpose of power quality surveys and studies, other time intervals may be used.

T_{short} : The short-term time interval for the P_{st} evaluation. If not specified differently, the short-term interval T_{short} is 10 minutes.

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.

voltage fluctuations: A series of voltage changes or a cyclic variation of the voltage envelope.

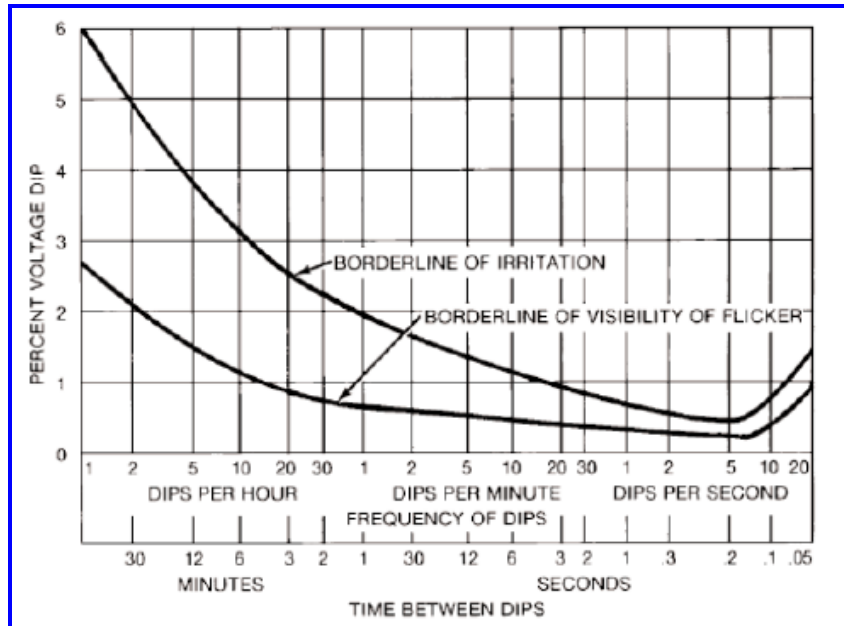
~~**D.9 P_{st} :** A measure of short-term perception of flicker obtained for a ten-minute interval. This value is the standard output of the IEC flickermeter.~~

4. History

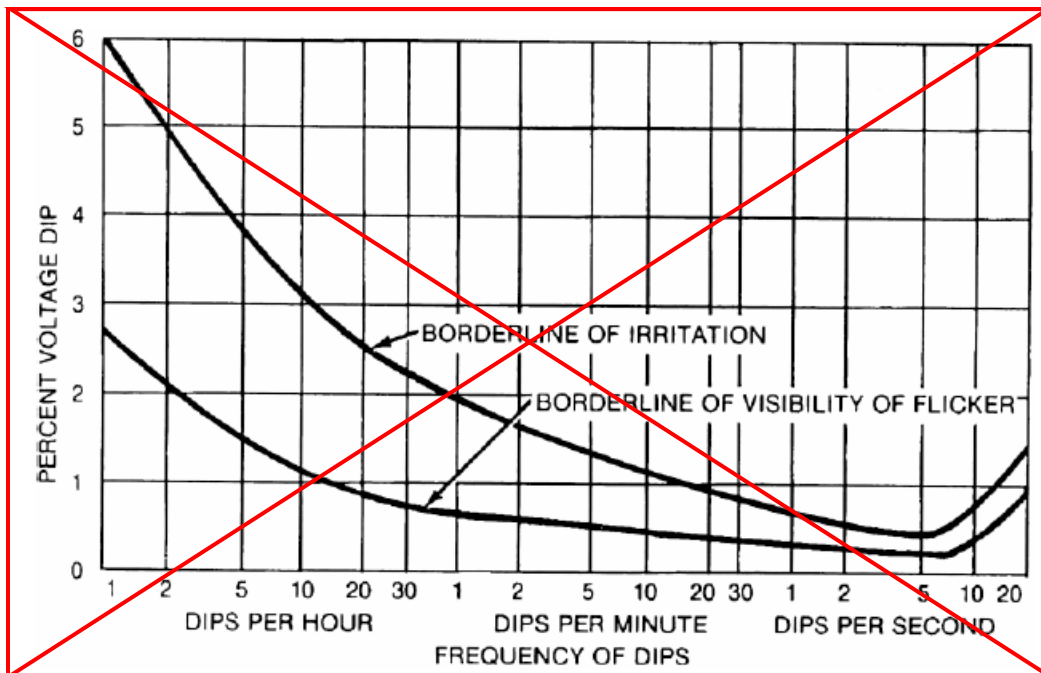
Variation in light output from an incandescent lamp due to changes in the applied voltage may have been experienced as far back as 1801 when Sir Humphry Davy passed current through a platinum strip, producing light. Since that time the incandescent lamp has undergone many changes in filament design and housing techniques, leading to its commercialization by the 1880s. Early dc lighting systems were often powered by generators installed within the building and were not subjected to voltage fluctuations by other loads. By 1895 the world's first large-scale generating plant at Niagara Falls was operational, later sending ac power to factories and cities up to 20 miles away in Buffalo (Gawronski, et al. [B8]). From that point forward the electrification of North America grew rapidly, with homes and factories now being supplied from electrical distribution systems, giving rise to the modern problem of light flicker. Studies, including those by H.E. Ives in 1909 [B21] and Dr. Irving Langmuir in 1914 [B28], concluded that flicker was a complex phenomenon resulting from the magnitude of the fluctuation, frequency and physiological or psychological factors.

In 1925 General Electric published a perceptibility curve developed from a collection of flicker studies that would later be known as the GE flicker curve. A 1937 report prepared by Utilities Coordinated Research, Inc. [B39] published the flicker curves used by several utilities that demonstrated a wide range of recommended limits, the result of varying individual sensitivity. More important, this report provided the definitions of cyclic flicker as the result of periodic fluctuations and noncyclic flicker as the result of occasional fluctuations.

The GE flicker curve, the most widely adopted flicker curve in the industry, is a composite of many of the studies from the 1930s (Walker [B46]) and was published by General Electric in its Distribution Data Book GET-1008L. Beginning in 1976, IEEE Std 141-1993 [B16] included the GE flicker curve, while the earlier 1969 version contained a curve from Consolidated Edison Company. Similar adoption of the GE flicker curve took place in the second revision of IEEE Std 519™-1992 [B17] and the curve itself is shown in Figure 1. One curve represents the borderline where most people began to perceive light flicker and another curve represents the borderline of irritation. The curves show maximum sensitivity to flicker at 7–8 fluctuations per second. The curves were developed based on standard rectangular modulations of the 60-Hz sine wave. Such curves are suitable for step changes in RMS voltages, but are not suitable for predicting flicker caused by other sources like arc furnaces, which are random in nature and have irregular wave shapes. Additional drawbacks of these curves include the unsuitability to handle complex voltage modulation due to use of adaptive var compensation for flicker control of seam welders and the inability to address multiple dosage issues (Halpin [B10]). Despite these drawbacks, these curves are still used by many electric utilities today as a tool for imposing flicker limits on industrial customers connected to the grid.



(New)



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Figure 1—[GE flicker tolerance curve \[B14\]](#)

~~from IEEE Std 141-1993/IEEE Std 519-1992~~

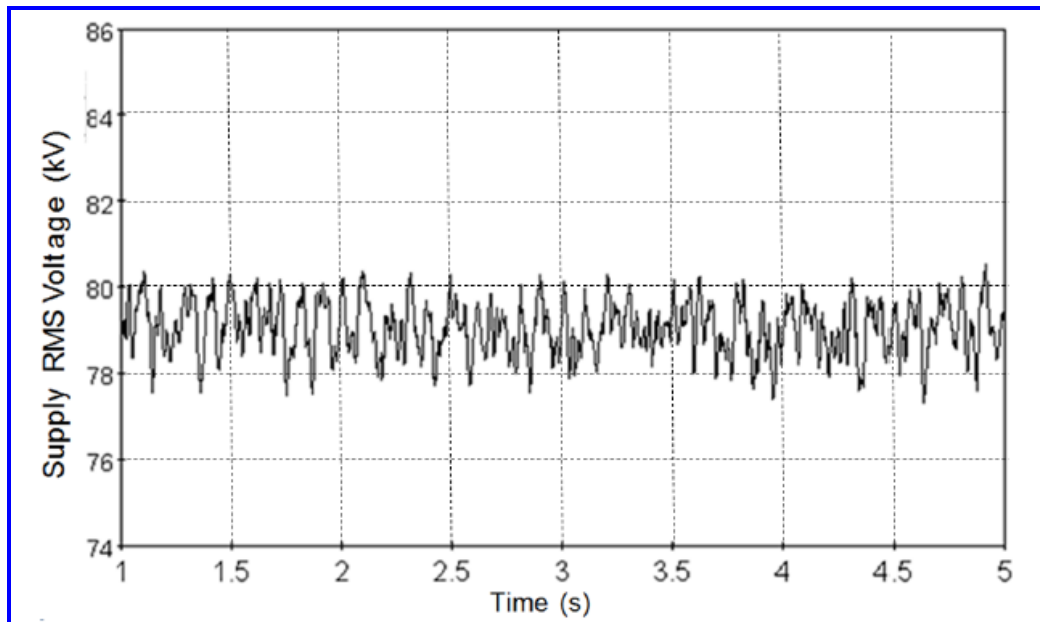
[In Europe, studies of the lamp-eye-brain response were performed as early as 1917 by K. Simons \[B38\] who recognized complexities of the human response to flicker. Later works by H. de Lange \[B25\], \[B26\] and C. Rashbass \[B34\] were used in the development of the UIE/IEC Flickermeter during the 1970s. In 1986 IEC-868 was published, providing the design specifications for a universal flickermeter to replace several national flickermeters that were already in use \(Cai, \[B3\]\). IEC 61000-4-15 was published in 1992; however, only the 230 V, 50 Hz incandescent lamps were covered. The IEEE worked closely with UIE and IEC to expand coverage to the 120 V, 60 Hz lamp, resulting in an internationally accepted standard in 2003. In 2004, IEEE Std 1453 was published, adopting the flickermeter standard and providing recommended levels. The 2011 publication adopted the 2010 edition of IEC 61000-4-15, moving the recommended acceptable flicker levels to its annex, facilitating the adoption of IEC 61000-3-7 in IEEE Std 1453.1. This technical report published by the IEC provided guidance on the connection of fluctuating loads to utility systems.](#)

5. Recommendations for characterizing flicker levels

5.1 Introduction to flicker

[Fluctuations in system voltage can result in observable changes in the light output of electric lamps and is mostly a problem when it is observed by the human eye and is severe enough to be perceived as flicker. It can be an annoyance and hindrance to workplace productivity and affect visually induced worker discomfort.](#)

[Voltage fluctuations are systematic variations of the voltage envelope or a series of random voltage changes, the magnitude of which does not normally exceed the voltage ranges specified by ANSI C84.1 \[B1\]. A plot of the RMS voltage magnitude vs. time such as that in Figure 2 can be used to illustrate the variations. The characteristic shown is due to the randomly changing arc characteristic as scrap steel is melted in an electric arc furnace \(EAF\).](#)

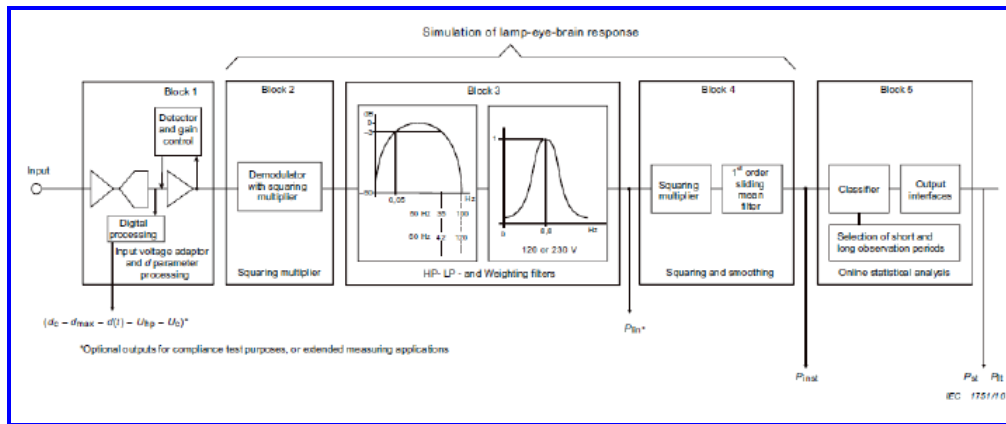


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Figure 2— Example of voltage fluctuations caused by an EAF operation

5.2 IEEE 1453 flicker monitoring procedures

Flicker monitoring has been standardized over most of the world using a meter that is completely described in IEC 61000-4-15. This measurement method is based on many years of combined research by engineers and scientists in the areas of the human ocular system, brain reaction, and lamp response. Figure 3 is a block diagram of the flicker meter. The short description of individual blocks is given after the figure.



(New)

Figure 3—Functional block diagram for the IEC flickermeter

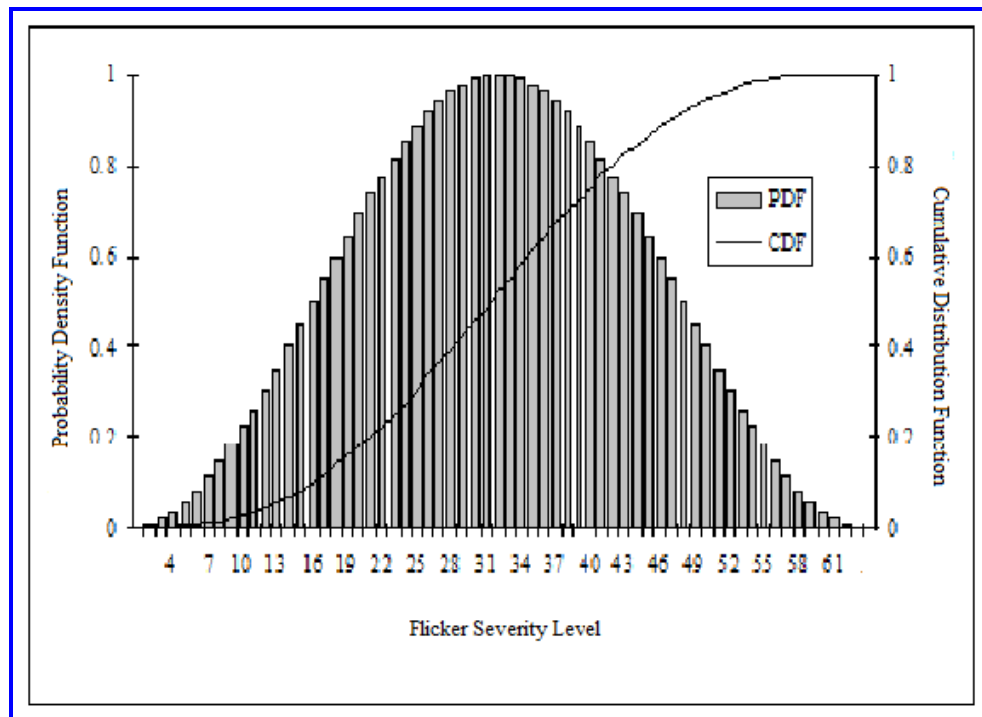
Block 1 is an input voltage adapter that scales the input half-cycle RMS value to an internal reference level. This allows flicker measurements to be made based upon a percent ratio rather than dependent upon the input carrier voltage level.

Block 2 is simply a squaring demodulator that squares the input to separate the low frequency (0.5–30 Hz) voltage fluctuation (modulating signal) from the main voltage signal (carrier signal), thus simulating the behavior of the incandescent lamp.

Block 3 consists of multiple filters that serve to filter out unwanted frequencies produced by the demodulator and also to weight the input signal according to the incandescent lamp eye-brain response. The lamp eye-brain response is represented with a 4th order bandpass filter, also known as the weighting filter. This filter has the purpose of weighting the input based upon the particular characteristics of the lamp.

Block 4 consists of a squaring multiplier and sliding mean filter. The input voltage signal is squared to simulate the non-linear eye-brain response, while the sliding mean filter averages the signal to simulate the short-term storage effect of the brain. The output of this block is considered to be the instantaneous flicker level. A level of unity on the output of this block corresponds to perceptible flicker.

The output of the Block 4 of the flickermeter is statistically processed in Block 5. The output is divided into suitable classes, thus creating a histogram. A PDF (probability density function) is created based upon each class and from this a CDF (cumulative distribution function) can be formed. The CDF can be thought of as the probability that the instantaneous flicker sensation will not exceed a certain level. Figure 4 gives a graphical demonstration of both the probability density and cumulative distribution functions for 64 classes.



(New)

Figure 4—Cumulative distribution and probability density curves

Flicker level evaluation can be divided into two categories, short-term and long-term. Short-term evaluation of flicker severity, P_{st} , is based upon an observation period of 10 min. This period is based upon assessing disturbances with a short duty-cycle or those that produce continuous fluctuations. P_{st} can be found using Equation (1).

$$P_{st} = \sqrt{0.0314P_{0.1} + 0.0525P_{1s} + 0.0657P_{3s} + 0.28P_{10s} + 0.08P_{50s}} \quad (1)$$

(New)

where, the percentages $P_{0.1}$, P_{1s} , P_{3s} , P_{10s} and P_{50s} are the flicker levels that are exceeded 0.1, 1.0, 3.0, 10.0, and 50.0 percent of the time. These values are taken from the cumulative distribution curve (CDF) discussed previously. The suffix s represents the smoothed value obtained using Equation (2) through Equation (5). It may be noted that “ P ” terms on the right side of these equations represent the flicker levels that are exceeded a percent of the time specified as sub-script. For example, $P_{0.7}$ in Equation (2) represents the flicker level that is exceeded 0.7% of the time.

$$P_{1s} = \frac{P_{0.7} + P_1 + P_{1.5}}{3} \quad (2)$$

$$P_{3s} = \frac{P_{2.2} + P_3 + P_4}{3} \quad (3)$$

$$P_{10s} = \frac{P_6 + P_8 + P_{10} + P_{13} + P_{17}}{5} \quad (4)$$

$$P_{50s} = \frac{P_{30} + P_{50} + P_{80}}{3} \quad (5)$$

(New)

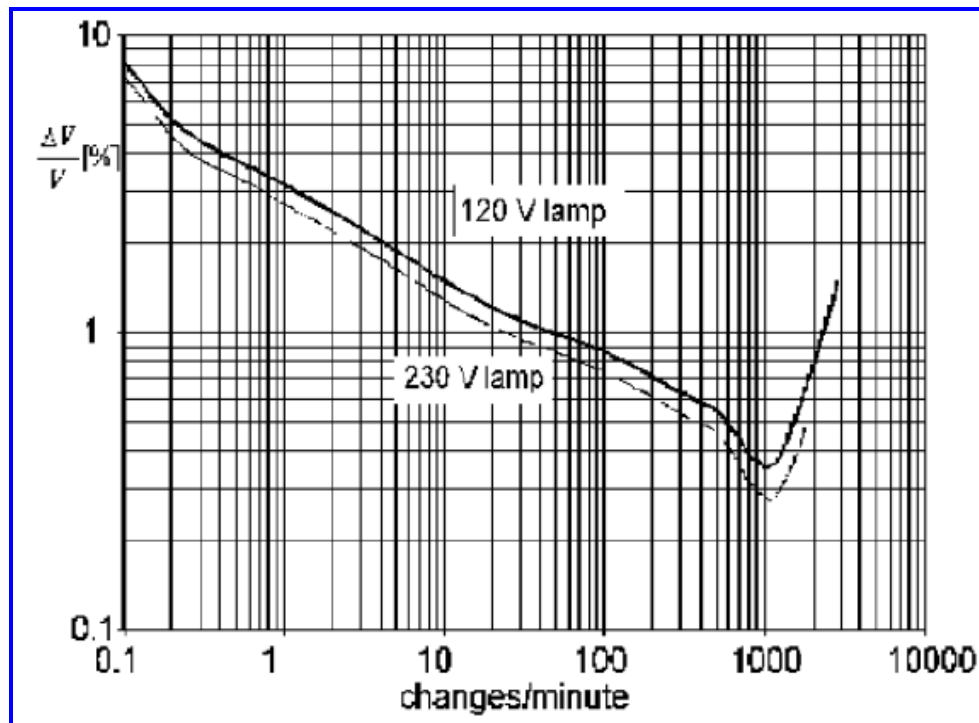
The long term flicker severity, P_{lt} , is calculated from 12 successive P_{st} values using Equation (6). In Equation (6) a cubic summation of flicker sensation was considered. Cubic summation is applicable where the risk of coincident voltage changes is small and the majority of cases fall under this category.

$$P_{lt} = \sqrt[3]{\frac{1}{12} \sum_{j=1}^{12} P_{stj}^3}$$

(6)

(New)

The original IEC standard (IEC 61000-4-15) was based on the effects of voltage fluctuations on a 60 W incandescent light on 230 V systems. A 60 W incandescent light bulb designed for 120 V is not as sensitive to the same voltage fluctuations as a 60 W, 230 V lamp because the filament is thicker (longer thermal time constant) to handle the higher current levels associated with the same power rating. As a result, an additional weighting curve was developed for 120 V applications, which are more common in North America. The 120 V and 230 V weighting curves are compared in Figure 5.



(New)

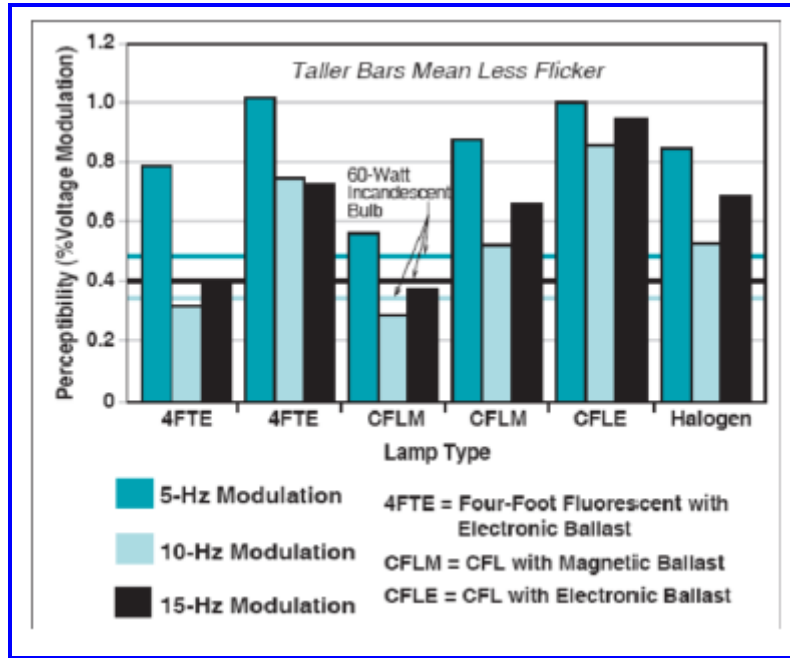
Figure 5—Comparison of flickermeter weighting curves for different voltage levels

5.3 Flicker performance of different lamp types

There is a need to understand the flicker performance of new lighting technologies such as CFLs (compact fluorescent lamps) and LED (light emitting diode) lamps especially with their ever-increasing penetration levels in electricity networks. The human eye has different perception thresholds for different lamp types as documented in a publication by EPRI on the testing that it carried out on different lamp types (PQTN Brief No. 24 [B31]). The lamps that were tested included the following:

- Two four-foot fluorescent fixtures with electronic ballasts (64 W and 80 W)
- Two CFLs with magnetic ballasts (13W and 15W)
- One 15 W CFL with an electronic ballast
- One 45 W halogen lamp
- One standard 60 W incandescent bulb

The averaged test results for this limited survey of six human subjects are shown in Figure 6. It shows the average perceptibility to three different levels of frequency modulation in the voltage supplied to the five types of light fixtures for six human subjects. It may be noted that the values for the incandescent lamp are illustrated as horizontal lines and there are two test samples each for 4-ft fluorescent fixtures with electronic ballasts and CFLs with magnetic ballasts. It can be seen that with exception of a CFL with magnetic ballast, the incandescent lamp is the most sensitive to flicker. An IEC-compliant flickermeter described earlier in the document is designed and calibrated for incandescent lamps and is therefore not suitable for other lamp types.



(New)

Figure 6— Test results on perception thresholds of humans

Gain factor (GF) is a measure that may be used to quantify flicker performance of a lamp type and is computed as a ratio of percentage change in its light output (luminous flux Φ) to the percentage change in input voltage (U) as shown in Equation (7).

$$GF = \frac{\left(\frac{\Delta\Phi}{\Phi} \right)}{\left(\frac{\Delta U}{U} \right)} \quad (7)$$

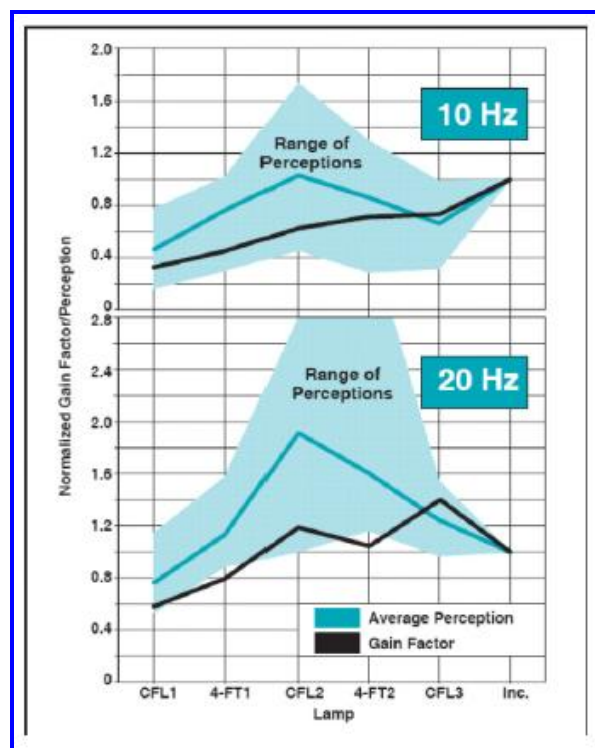
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A higher value of GF for a lamp signifies its greater sensitivity to flicker. The advantage of using this measure is that it disregards a factor of perception that is unique for each person. As a result, this approach allows comparison of lamp sensitivities in a systematic and reproducible manner.

EPRI used this approach in computing the gain factors for different lamp types in the mid-1990s (PQTN Brief No. 36 [B32]). Square wave modulation was used to simulate voltage variations at test frequencies of 10 Hz and 20 Hz. The testing involved eight observers and the following lamps:

- == Two CFLs with magnetic ballast
- == Two four-foot fluorescent
- == One CFL with electronic ballast
- == One 60 W incandescent lamp

The test results that included gain factor and perception were normalized based on incandescent lamps and are presented in Figure 7. It shows the correlation between gain factor measurement and human perception of the flicker.



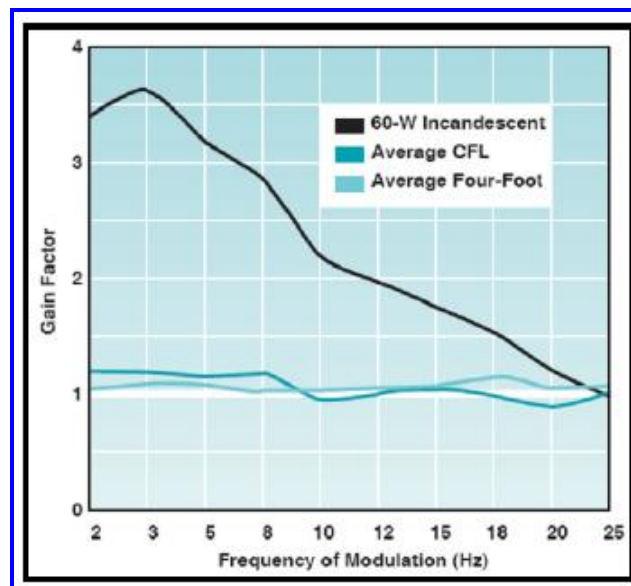
(New)

Figure 7—Quantifying flicker performance of lamps

Further tests (PQTN Brief No. 37 [B33]) were carried out by EPRI on 1995-vintage lighting products that included the following:

- == Twenty-three CFLs (three samples each)
- == Eleven 4-ft fluorescent fixtures (three samples each)
- == 60 W, 120 V incandescent lamp

This testing encompassed a frequency range between 2 Hz and 25 Hz and the plot of resultant gain factors is shown in Figure 8. It is evident that, unlike for incandescent lamps, the gain factor of fluorescent fixtures is independent of frequency. Also, the average gain factor of a CFL is less than half that of an incandescent lamp at 8.8 Hz (most sensitive frequency for humans).



(New)

Figure 8—Gain factor variation over the test frequency range

[The applicability of the findings presented previously to advances made in modern lighting technologies including CFL and LED lamps has been confirmed by the testing that was carried out in 2013 \(Sharma and Sharp \[B37\]\). Thus, it can be concluded that different lighting technologies differ in flicker performance. The IEC-compliant flickermeter described earlier in the document is designed and calibrated for incandescent lamps and is therefore not suitable for other lamp types. The authors of “Proposal for improving UIE/IEC Flickermeter” \[B4\] have suggested use of different weighting filters in Block 3 of the flickermeter to adapt it for other lamp types such as CFLs and LED lamps. One of the challenges is the unpredictability of the flicker performance of modern lighting, especially the prevalent dimmable technologies \(Sharma and Sharp \[B37\]\).](#)

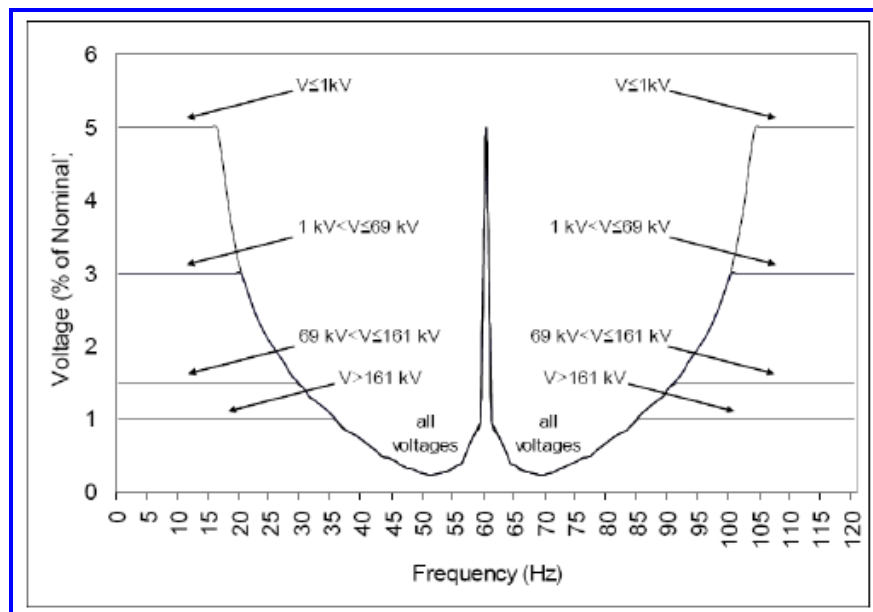
[5.4 Impact of interharmonic voltages on light flicker](#)

[Interharmonics in power system can lead to oscillating luminous flux and thus become a source of light flicker \(IEEE Task Force on Harmonics Modeling and Simulation \[B20\]\). The references demonstrate the equivalence of Amplitude Modulation \(AM\) to the superposition of sinusoidal interharmonic components of proper amplitudes and phase angles to the fundamental \(Langella and Testa \[B25\], Gallo, et al. \[B6\]\). The IEC flickermeter standards only required testing with reference to amplitude voltage modulation, which was the first cause of light flicker identified.](#)

[For this reason, computations in IEC-compliant flickermeters are based on the measurement of fluctuations in RMS supply voltage producing light flicker on incandescent lamps. It means that these meters are capable of detecting light flicker only due to low-frequency interharmonics \(below twice the fundamental frequency\) as higher order interharmonics do not cause much RMS variation in incandescent lamps in absence of significant harmonics. Hence these meters have been found to be unable to properly measure light flicker produced by lamp technologies other than incandescent \(Kim, et al. \[B22\], Slezingr \[B40\]\).](#)

Interharmonic voltage limits based on flicker (for frequencies up to 120 Hz for 60 Hz systems) were introduced in IEEE Std 519™-2014 [B18] (see Figure 9). In some other specific cases involving lamp technologies different from incandescent and a wider frequency range, interharmonic-flicker curves in IEEE Std 519-2014 [B18] and Tayjasanant, Wang, and Xu [B42] may be consulted.

Annex A reports some information about the impact of interharmonics on the light flicker produced by lamps technologies different from incandescent and on the performance of flickermeters. Firstly, the perfect equivalence between amplitude modulation and interharmonics is graphically explained; then, interharmonic-flicker curves (Tayjasanant, Wang, and Xu [B42]), experimentally obtained on different types of lamp technologies (Drapela, J., and P. Taman [B5], Slezinger, J. and J. Drapela [B40]) are used to show interharmonic voltage magnitudes producing $P_{st} = 1$. Finally, compact analytical formulae are used (Gallo [B6]) to illustrate IEC flicker response to interharmonics.



(New)

Figure 9—Interharmonic voltage limits based on flicker for frequencies up to 120 Hz for 60 Hz systems (IEEE Std 519 [B18])

6. Recommendations for flicker limits and evaluation procedure

This clause summarizes recommended planning levels and the procedure for determining and compliance of emission limits for individual customers. Different planning levels are recommended for different voltage levels. The emission limits applied to individual customers are developed based on these “planning levels,” which are developed in IEC 61000-3-7.

Four different voltage levels are defined in Table 1 and the flicker planning levels are developed. This document deals primarily with planning levels at MV (medium voltage) and HV-EHV (high voltage to extra high voltage) because these are usually the voltages at the PCC with customers that may have fluctuating loads. These planning levels are designed to make sure that the flicker levels at LV connection points do not actually exceed the “compatibility level” that is defined to help ensure proper operation of customer equipment.

Table 1 – System voltage levels

System	System voltage (V_r)
LV	$V_r \leq 1 \text{ kV}$
MV	$1 \text{ kV} < V_r \leq 35 \text{ kV}$
HV	$35 \text{ kV} < V_r \leq 230 \text{ kV}$
EHV	$V_r > 230 \text{ kV}$

(New)

6.1 Planning levels

6.1.1 Indicative values

The planning levels (denoted as L_{Pst} and L_{Plt}) recommended for PCCs at MV, HV, and EHV systems are shown in Table 2. The planning levels are developed to be the basis for applying emission limits for individual customers with PCC at these different voltages. The individual customer emission limits are developed using a procedure that allots each customer some portion of a planning level after allowing for flicker that propagates from other network voltage levels (or locations). Emission limits for individual loads (denoted as E_{Pst} and E_{Plt}) are set so that their aggregate effects do not cause overall flicker at PCC to exceed an adopted planning level.

Table 2 — Recommended planning levels

	Flicker planning levels	
	MV	HV-EHV
L_{Pst}	0.9	0.8
L_{Plt}	0.7	0.6

(New)

These planning levels assume unity transfer coefficient (less than 1.0 in practice) between MV or HV systems and LV systems and may need upward adjustment as follows.

Transfer coefficient of flicker between two points A and B with dominant flicker source at point A is the level of flicker that can get transferred between the two points. It is defined as the ratio of the P_{st} values measured at the same time in the two locations as shown in Equation (8):

$$T_{PstAB} = \frac{P_{st}(B)}{P_{st}(A)} \quad (8)$$

(New)

The methods to compute transfer coefficient in the absence of any measurements are detailed in Annex B. An example of the impact of the transfer coefficient (T_{PstHL}) between HV and LV having a value of 0.9 is reflected in the revised indicative planning level for HV system as shown in Equation (9):

$$L_{PstHV_revised} = \frac{L_{PstHV}}{T_{PstHL}} = \frac{0.8}{0.9} = 0.89 \quad (9)$$

(New)

These planning levels are selected to help ensure that the compatibility levels are not exceeded at LV locations where lighting loads are connected. Note that compatibility levels are not actually defined for the MV, HV, and EHV levels since lighting customers are not directly connected at these levels. The compatibility levels for LV are 1.0 for $P_{st95\%}$ and 0.8 for $P_{lt95\%}$.

6.1.2 Evaluation—assessment procedure

The following procedure is recommended for ongoing evaluation against the chosen planning levels. The procedure is based on continuous monitoring of a continuous fluctuating load (or monitoring when the fluctuating load is active) with an instrument that is compliant with IEC 61000-4-15 for a full week. It is suggested that the following procedure may be repeated for each phase. Alternatively, the individual values for all the three phases may be combined for the collective analysis if the loading is known to be balanced.

- 1) Obtain an array of P_{st} values for each day resulting in 144 values for each phase.

2) Calculate an array of P_{lt} values for each day. Each P_{lt} value is calculated from twelve P_{st} values spaced 10 minutes apart using a cubic relationship as described in Equation (6). It is recommended that sliding window approach be used in which the oldest P_{st} measurement is replaced by the newest P_{st} value at each 10 minute interval resulting in 144 P_{lt} values in a day for each phase. The statistical analysis in the subsequent steps should be carried out after carrying out the necessary filtering to exclude faults and other non-load created voltage fluctuations.

3) Combine the P_{st} values for a full week (Sunday midnight to Sunday midnight), resulting in 1008 values for each phase and calculate summary statistics for the week.

$$P_{st99\%}, P_{st95\%}$$

4) Combine the P_{lt} values for a full week (Sunday midnight to Sunday midnight), resulting in 1008 P_{lt} values for each phase when the sliding window approach is used, and calculate P_{lt} summary statistics for the week.

$$P_{lt99\%}, P_{lt95\%}$$

5) The statistical values calculated represent the actual flicker levels. These can be compared with the system flicker planning levels.

1) 95% probability value should not exceed the planning level.

2) 99% probability value may exceed the planning level by a factor (1–1.5) depending on system conditions to be determined by the system operator.

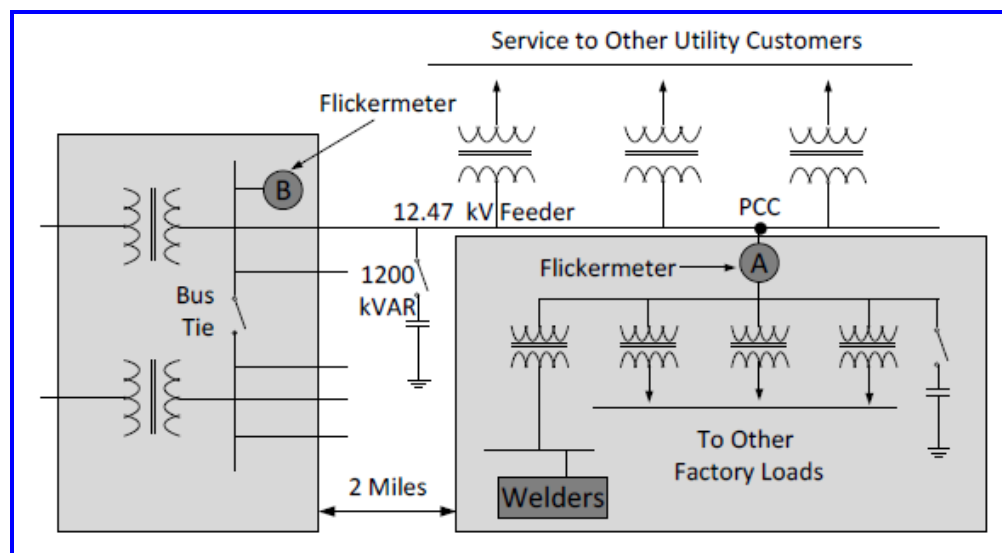
6.2 Determining individual customer emission limits

A detailed procedure for determining emission limits for fluctuating loads connected to MV, HV, and EHV systems is provided in IEC 61000-3-7. It is important to ensure that the fluctuating loads stay in continued compliance with their determined emission limits and the guidelines and recommended approach for the same are presented in 6.3.

6.3 Evaluating compliance with emission limits

Flicker contribution of a facility is typically assessed at its defined PCC. The example of PCC is graphically illustrated in Figure 10, which shows a common scenario of a facility employing fluctuating loads being served off a radial feeder.

In this case, the metering point A is nearest to the PCC and provides the worst-case fluctuations that may be seen by a neighboring customer. Metering point B provides data at the substation level, and is a measure of what is seen by other feeders on that substation.



(New)

Figure 10 – PCC Illustration

The following evaluation procedure is recommended for ongoing assessment of compliance with the flicker limits at the PCC. The procedure is based on continuous monitoring with an instrument that is compliant with IEC 61000-4-15 [B14]. It is suggested that the following procedure may be repeated for each phase. Alternatively, the individual values for all the three phases may be combined for the collective analysis if the loading is known to be balanced. The procedure is performed based on a weekly evaluation of customer compliance with flicker limits.

- a) Make the necessary adjustments in specified customer emission limits for the system short-circuit capacity. If the short-circuit capacity during the period of the measurements is lower than the level specified in the customer contract, then an adjustment should be performed as follows:

$$E_{Pst_actual} = E_{Pst_contract} \times \frac{S_{sc_contract}}{S_{sc_actual}} \quad (10)$$

(New)

where

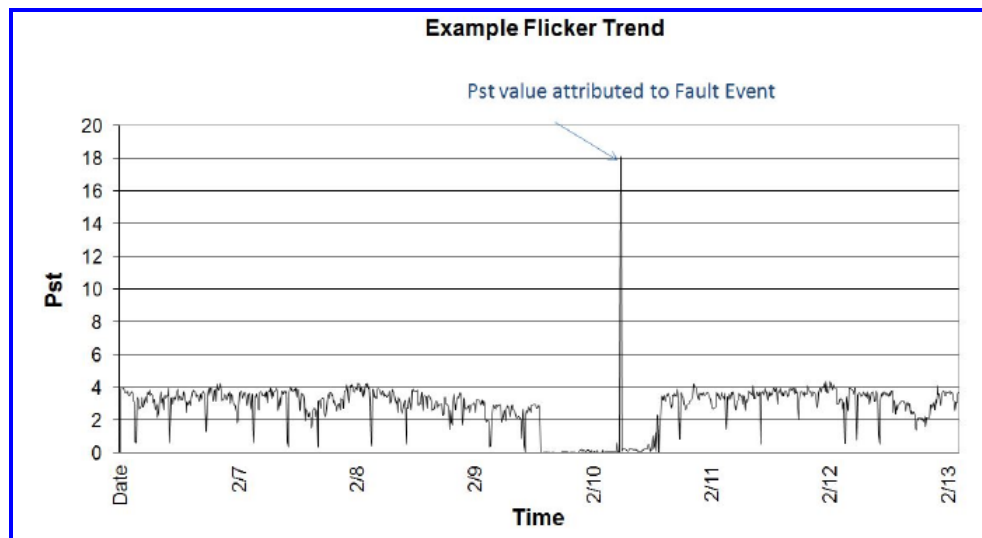
E_{Pst} is the customer emission limit

S_{sc} is the short-circuit capacity

Term *contract* in the subscript refers to the contract level and *actual* refers to the period of measurements.

- b) Obtain an array of P_{st} values for each day resulting in 144 values for each phase.

- c) Calculate an array of P_{lt} values for each day from the P_{st} values in previous step. It is recommended that sliding window approach be used in which the oldest P_{st} measurement is replaced by the newest P_{st} value at each 10 minute interval resulting in 144 P_{lt} values in a day for each phase. The statistical analysis in the subsequent steps should be carried out after carrying out the necessary filtering to exclude faults and other non-load created voltage fluctuations. A sample flicker trending at PCC of a facility running a fluctuating load is shown in Figure 11. It identifies a high P_{st} value that is attributed to a network fault event that needs to be excluded for assessing flicker contribution of the facility.



(New)

**Figure 11 — Example flicker trend due to fluctuation
load impacted by network fault event**

- d) Combine the P_{st} values for a full week (Sunday midnight to Sunday midnight) and calculate summary statistics for the week (maximum 1008 values).

$$P_{st99\%}, P_{st95\%}$$

- e) Combine the P_{lt} values for a full week (Sunday midnight to Sunday midnight) and calculate summary statistics for the week (maximum 1008 values based on a sliding window).

$$P_{lt99\%}, P_{lt95\%}$$

- f) The statistical values calculated represent the actual flicker levels. We will refer to these values obtained from the direct measurements as follows (general term for each P_{st} index, same terminology can be applied to the P_{lt} indices).

$$P_{st_actual}$$

- g) Calculate the estimated contribution of the customer ($P_{st_customer}$) to the flicker levels. The procedures for estimating contribution of single customer are presented in 6.4.

- h) These statistics can be compared with the adjusted customer emission limits.

1) 95% probability value should not exceed the emission limit.

2) 99% probability value may exceed the emission limit by a factor (1–1.5) depending on system conditions to be determined by the system operator.

6.4 Estimating flicker contribution of single customer

In order to estimate the flicker contribution made by an individual customer, it is necessary to exclude the contribution of the background flicker in the system. The following methods are recommended depending on the magnitude of background levels.

6.4.1 Low background flicker levels

If the background levels are low ($P_{st_background} \leq 0.5$), the flicker being caused by the new customer can be estimated by the following method:

Assume that the limit (99th percentile) for the acceptable level of flicker at the PCC for a new customer is set at E_{Pst} .

Measure the background levels of flicker before connecting the customer (this should be 99th percentile value computed over at least a two week period). The value thus obtained is $P_{st_background}$.

Finally, the actual levels of flicker (99th percentile) after connecting the customer are measured at P_{st_actual} .

In most cases, the flicker that is caused by the new customer can be estimated by assuming the flicker levels add using cubic summation.

$$P_{st_customer} = \sqrt[3]{P_{st_actual}^3 - P_{st_background}^3} \quad (11)$$

(New)

This value can be compared with the customer flicker limit.

$P_{st_customer}$ should be less than E_{Pst}

As a practical measure, the background flicker will typically have to be measured before the new fluctuating load starts up. A two week measurement period prior to startup would be reasonable. The background levels can also be checked periodically during any plant shutdowns.

6.4.2 High background flicker levels

If the background flicker levels are substantial ($P_{st \text{ background}} > 0.5$), the method in 6.4.1 can result in significant errors. One method that involves correlation between the fluctuating current and the observed voltage fluctuations to determine the emission level of a particular fluctuating load is presented here.

In cases where multiple flicker-producing facilities are fed from the same supply, the most reliable method of assessing the flicker contribution from each source is to remove one of the contributors from the circuit and measure only the flicker from the other. This is not often practical and the following method may be suitable for identifying flicker contribution of individual sources.

The underlying principle of the approach is that the customer contribution to the overall flicker levels can be correlated to the current drawn by it with the utility source impedance being the correlation coefficient. Any voltage variation that is not related to a current variation, through the utility impedance, must therefore be coming from the utility system itself.

It may be noted that point of evaluation (POE) for this method may not be the actual PCC. The procedure for the implementation of this approach is presented here (refer to Figure 12). It may be noted that the algorithm itself will have to be implemented in a time-domain modeling and simulation platform:

- a) Measure the voltage waveform ($V_M(t)$) at the point of evaluation (POE) and current waveform ($i_M(t)$) drawn by the flicker source.
- b) Use $V_M(t)$ to compute $P_{st \text{ POE}}$ using IEC method [B14]. This represents the overall flicker levels at the POE.
- c) Compute emission voltage $V_E(t)$ using flicker source current, utility source impedance and a constant utility open circuit voltage (assumed). It represents the voltage that would appear at POE if this was the only source of voltage fluctuations.

$$V_E(t) = V_R(t) - R_S \times i_M(t) - L_S \times \frac{di_M(t)}{dt} \quad (12)$$

(New)

where

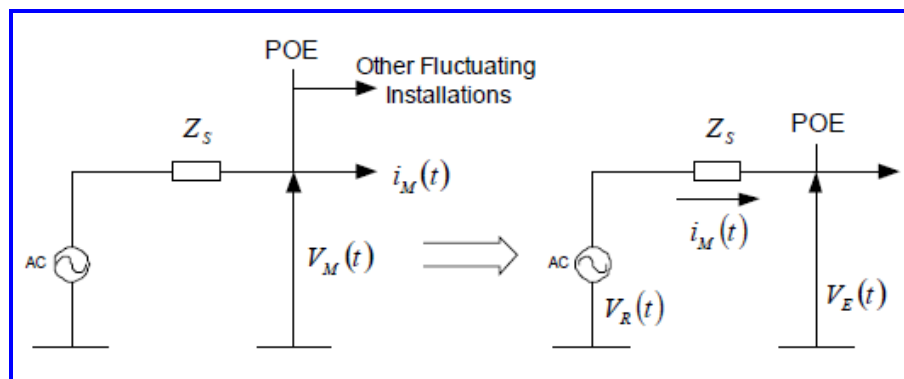
$V_R(t)$ represents the voltage at the monitoring point if the system was unloaded and whose angle should be equal to that of the voltage waveform $V(t)$ computed using the Equation (13).

$$V(t) = V_M(t) + R_S \times i_M(t) + L_S \times \frac{di_M(t)}{dt} \quad (13)$$

(New)

- d) Use $V_E(t)$ to compute $P_{st_emission}$ using IEC method. This is the flicker that can be attributed to the customer.

In case POE is different from PCC, the flicker will have to be estimated at PCC from those obtained at POE by taking into account the circuit impedance between the two locations.



(New)

Figure 12 — Measurement-based approach for estimating flicker contribution of single customer