IEEE Standard for Harmonic Control in Electric Power Systems

IEEE Power and Energy Society

Developed by the
Transmission and Distribution Committee

IEEE Std 519™-2022
(Revision of IEEE Std 519-2014)

STANDARDS

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Approved 13 May 2022

IEEE SA Standards Board

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This standard addresses steady-state limitations. Transient conditions exceeding these limitations may be encountered. This document sets the quality of power that is to be provided at the point of common coupling. This document does not cover the effects of radio-frequency interference; however, guidance is offered for wired telephone systems.

Keywords: harmonics, IEEE 519™, power quality, steady-state

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Introduction

This introduction is not part of IEEE Std 519-2022, IEEE Standard for Harmonic Control in Electric Power Systems.

This standard shall be applied at interface points between system owners or operators and users in the power system. The limits in this standard shall apply at a point of common coupling (PCC) between the system owner or operator and a user, where the PCC is usually taken as the point in the power system closest to the user where the system owner or operator could offer service to other users. Frequently for service to industrial users (i.e., manufacturing plants) via a dedicated service transformer, the PCC is at the HV side of the transformer. For commercial users (office parks, shopping malls, etc.) supplied through a common service transformer, the PCC is commonly at the LV side of the service transformer.

The limits in this standard represent a shared responsibility for harmonic control between system owners or operators and users. Users produce harmonic currents that flow through the system owner's or operator's system, which lead to voltage harmonics in the voltages supplied to other users. The amount of harmonic voltage distortion supplied to other users is a function of the aggregate effects of the harmonic current producing loads of all users and the impedance characteristics of the supply system.

Harmonic voltage distortion limits are provided to reduce the potential negative effects on user and system equipment. Maintaining harmonic voltages below these levels necessitates that

— All users limit their harmonic current emissions to reasonable values determined in an equitable manner based on the inherent ownership stake each user has in the supply system.

— Each system owner or operator takes action to decrease voltage distortion levels by modifying the supply system impedance characteristics as necessary.

In order to allow the system owner or operator to control the system impedance characteristics to reduce voltage distortion when necessary, users should not add equipment that affects the impedance characteristic in a way such that voltage distortions are increased. In effect, such actions by a user could result in producing excessive voltage harmonic distortion. Such equipment additions (that lead to undesirable system impedance characteristics) should be controlled by the user in the same manner as current harmonic-producing devices operated by the user.

Contents

IEEE Standard for Harmonic Control in Electric Power Systems

1. Overview

Nonlinear loads connected to electric power systems include static power converters, arc discharge devices, saturated magnetic devices, and, to a lesser degree, rotating machines. Static power converters of electric power are the largest nonlinear loads and are used in industry for a variety of purposes, such as electrochemical power supplies, adjustable speed drives, and uninterruptible power supplies. These devices are useful because they can convert ac to dc, dc to dc, dc to ac, and ac to ac. These nonlinear devices are key elements for energy savings.

Nonlinear loads change the sinusoidal nature of the ac power current (and consequently the ac voltage drop), thereby resulting in the flow of harmonic currents in the ac power system that can cause interference with communication circuits and other types of equipment. These harmonic currents also lead to increased losses and heating in numerous electromagnetic devices (motors, transformers, etc.). When reactive power compensation in the form of power factor improvement capacitors is used, resonant conditions can occur that may result in high levels of harmonic voltage and current distortion when the resonant condition occurs at a harmonic associated with nonlinear loads.

Common sources of harmonic currents in power systems include power electronic converters, arc furnaces, static volt-ampere reactive (VAR) systems, inverters for distributed generation, ac phase controllers, cycloconverters, and ac-dc converters (rectifiers) commonly used in switched mode power supplies and pulse width modulated (PWM) motor drives. Each of these harmonic-producing devices can have fairly consistent harmonic current emission characteristics over time or each may present a widely-varying characteristic depending on the control of the device, the characteristics of the system, and other variables.

1.1 Scope

This standard establishes goals for the design of electrical systems that include both linear and nonlinear loads. The voltage and current waveforms that may exist throughout the system are described, and waveform distortion goals for the system designer are established. The interface between sources and loads is described as the point of common coupling and observance of the design goals will reduce interference between electrical equipment.

The voltage and current distortion limits in this standard shall apply at the user point of common coupling (PCC) to overall installation containing harmonic producing loads (nonlinear equipment). Users are directed to other applicable standards such as IEEE Std 1547™ or IEEE Std 2800™ for current distortion limits of inverter-based resources (IBR) installations.[1] When no other applicable standard exists, users shall continue to use footnote “c” under Table 2 through Table 4 in this standard for IBR connected to transmission systems.

[1]Information on references can be found in Clause 2.

If an installation has a mix of harmonic producing loads and IBR at the same facility, users are directed to use Figure 1 in this document to determine whether IEEE 519 limits apply at the PCC.

This standard addresses steady-state limitations. Transient conditions exceeding these limitations may be encountered. This document sets the quality of power that is to be provided at the point of common coupling. This document does not cover the effects of radio-frequency interference; however, guidance is offered for wired telephone systems.

The limits given in this document are based on assumptions that are technically justifiable at the PCC between the system owner/operator and user. These assumptions, and therefore the limits in this document, are not necessarily valid at any other point in the power system. For this reason, the limits given in this document are not intended to be used for the evaluation of equipment.

1.2 Purpose

This standard is to be used for guidance in the design of power systems with nonlinear loads. The limits set are for steady state operating conditions. In any case, the limit values given in this document should not be considered binding in all cases. Some conservatism is present that may not be necessary in all cases.

This standard shall be applied at a PCC between system owners or operators and users in the power system. The limits in this standard are intended for application at a PCC between the system owner or operator and a user, where the PCC is usually taken as the point in the power system closest to the user where the system owner or operator could offer service to another user. Frequently for service to industrial users (i.e., manufacturing plants) via a dedicated service transformer, the PCC is at the HV side of the transformer. For commercial users (office parks, shopping malls, etc.) supplied through a common service transformer, the PCC is commonly at the LV side of the service transformer.

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1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).[2, 3]

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

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 61000-4-7: Electromagnetic compatibility (EMC)—Part 4-7: Testing and measurement techniques—General guid.[4]

IEC 61000-4-15: Electromagnetic compatibility (EMC)—Part 4-15: Testing and measurement techniques—Flickermeter—Functional and design specifications.

IEC 61000-4-30: Electromagnetic compatibility (EMC)—Part 4-30: Testing and measurement techniques—Power quality measurement methods.

IEEE Std 1453™-2015, IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems.[5, 6]

IEEE Std 1547-2018, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.

IEEE Std 2800-2022, IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBR) Interconnecting with Associated Transmission Electric Power Systems.

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3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[7]

harmonics (harmonic components): Components of order greater than one of the Fourier series of a periodic quantity. For example, in a 60 Hz system, the harmonic order 3, also known as the "third harmonic," is 180 Hz.

interharmonics (interharmonic components): Frequency components of a periodic quantity that are not an integer multiple of the frequency at which the supply system is operating (e.g., 75 Hz on a 50 Hz or 60 Hz system).

inverter-based resource: Any source of electric power that is connected to the transmission system (TS) via power electronic interface, and that consists of one or more IBR unit(s) capable of exporting active power from a primary energy source or energy storage system to a TS.

inverter-based resource unit (IBR unit): An individual inverter device or a grouping of multiple inverters connected together at a single point of connection (POC).

I-T product: The inductive influence expressed in terms of the product of root-mean-square current magnitude (I), in amperes, times its telephone influence factor (TIF).

maximum demand load current: This current value is established at the point of common coupling and shall be taken as the sum of the rms currents corresponding to the 15 min or 30 min maximum demand during each of the twelve previous months divided by 12. If 12 months of data is not available due to the length of time in service, then the maximum 15 min or 30 min apparent power demand for each month should be summed over the total number of months available, and then divided by the number of months. For situations where the installation is a proposed new installation, the maximum demand load current shall be based on the projected 15 min or 30 min maximum monthly apparent power demand over the course of the year following operation of the proposed harmonic producing loads listed on the service application.

notch: A switching (or other) disturbance in the normal power voltage waveform, lasting less than 0.5 cycles, which is initially of opposite polarity than the waveform and is thus subtracted from the normal waveform in terms of the peak value of the disturbance voltage. This includes complete loss of voltage for up to 0.5 cycles.

notch area: The area of the line voltage notch. It is the product of the notch depth, in volts, times the width of the notch measured in microseconds.

notch depth: The average depth of the line voltage notch from the sine wave of voltage.

point of common coupling (PCC): Point on a public power supply system, electrically nearest to a particular load, at which other loads are, or could be, connected. The PCC is a point located upstream of the considered installation.

pulse number: The total number of successive non-simultaneous commutations occurring within the converter circuit during each cycle when operating without phase control. It is also equal to the order of the principal harmonic in the direct voltage, that is, the number of pulses present in the dc output voltage in one cycle of the supply voltage.

short circuit ratio (SCR): At a particular location, the ratio of the available short circuit current, in amperes, to the maximum demand load current, in amperes.

[7] *IEEE Standards Dictionary Online* is available at: http://dictionary.ieee.org. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

telephone influence factor (TIF): For a voltage or current wave in an electric supply circuit, the ratio of the square root of the sum of the squares of the weighted root-mean-square values of all the sine wave components (including alternating current waves both fundamental and harmonic) to the root-mean-square value (unweighted) of the entire wave.

total demand distortion (TDD): The ratio of the root-mean-square of the harmonic content, considering harmonic components up to the 50th order and specifically excluding interharmonics, expressed as a percent of the maximum demand load current. Harmonic components of order greater than 50 may be included when necessary.

total harmonic distortion (THD): The ratio of the root-mean-square of the harmonic content, considering harmonic components up to the 50th order and specifically excluding interharmonics, expressed as a percent of the fundamental. Harmonic components of order greater than 50 may be included when necessary.

V-T product: Inductive influence expressed in terms of the product of root-mean-square voltage magnitude (V), in volts, times its telephone influence factor (TIF).

3.2 Acronyms and abbreviations

IBR	inverter-based resource
PCC	point of common coupling
PWM	pulse width modulated
SCR	short circuit ratio
TDD	total demand distortion
THD	total harmonic distortion
TIF	telephone influence factor

4. Harmonic measurements

For the purposes of assessing harmonic levels for comparison with the limits in this document, any instrument used shall comply with the specifications of IEC 61000-4-7 and IEC 61000-4-30, Class A. IEC 61000-4-30 defines two classes of instruments: Class A and Class S. For Class A instruments, measurements are required to be made at least up to the 50^{th} order. However, Class S instruments require measurements only to the 40^{th} order. For purposes of IEEE 519 evaluation, measurements shall be made at least up to the 50^{th} order. The most relevant portions of the IEC specifications are summarized in 4.1 through 4.4. Research on methods for measurements in the range beyond what is covered by this document are underway.

4.1 Measurement window width

The width of the measurement window used by digital instruments employing Discrete Fourier Transform techniques shall be 12 cycles (approximately 200 ms) for 60 Hz power systems (10 cycles for 50 Hz power systems). With this window width, spectral components will be available every 5 Hz (e.g., 0, 5, 10…50, 55, 60, 65, 70,… Hz). For the purposes of this document, a harmonic component magnitude is considered to be the value at a center frequency (60, 120, 180, etc. or 50, 100, 150, etc. Hz for 60 Hz and 50 Hz power systems, respectively) combined with the two adjacent 5 Hz bin values. The three values are combined into a single rms value that defines the harmonic magnitude for the particular center frequency component.

4.2 Very short time harmonic measurements

Very short time harmonic values are assessed over a 3-second interval based on an aggregation of 15 consecutive 12 (10) cycle windows for 60 (50) Hz power systems. Individual frequency components are aggregated based on an rms calculation as shown in Equation (1) where F represents voltage (V) or current (I), n represents the harmonic order, and i is a simple counter. The subscript vs is used to denote "very short." In all cases, F represents an rms value.

$$F_{n,vs} = \sqrt[2]{\frac{1}{15}\sum_{i=1}^{15} F_{n,i}^{2}} \tag{1}$$

4.3 Short time harmonic measurements

Short time harmonic values are assessed over a 10-minute interval based on an aggregation of 200 consecutive very short time values for a specific frequency component. The 200 values are aggregated based on an rms calculation as shown in Equation (2) where F represents voltage (V) or current (I), n represents the harmonic order, and i is a simple counter. The subscript sh is used to denote "short." In all cases, F represents an rms value.

$$F_{n,sh} = \sqrt[2]{\frac{1}{200}\sum_{i=1}^{200} F_{(n,vs),i}^{2}} \tag{2}$$

4.4 Statistical evaluation

Very short and short time harmonic values shall be accumulated over periods of one day and one week, respectively. For very short time harmonic measurements, the 99th percentile value (i.e., the value that is exceeded for 1% of the measurement period) shall be calculated for each 24-hour period for comparison with the limits in Clause 5. For short time harmonic measurements, the 95th and 99th percentile values (i.e., those values that are exceeded for 5% and 1% of the measurement period) shall be calculated for each 7-day period for comparison with the limits in Clause 5. These statistics shall be used for both voltage and current harmonics with the exception that the weekly 99th percentile short time value is not recommended for use with voltage harmonics. Percentile values shall be computed using a linear interpolation algorithm.

5. Harmonic distortion limits

Because managing harmonics in a power system is considered a joint responsibility involving both end-users and system owners or operators, harmonic limits are required for both voltages and currents. The limits in this clause are based on the fact that some level of voltage distortion is generally acceptable and both system owners or operators and users should work cooperatively to keep actual voltage distortion below objectionable levels. The underlying assumption of these limits is that by limiting harmonic current injections by users, voltage distortion can be kept below objectionable levels. In the event that limiting harmonic currents alone does not result in acceptable levels of voltage distortion, system owners or operators should take action to modify system characteristics so that voltage distortion levels are acceptable. The acceptable voltage distortion levels form the basis of the harmonic voltage limits in 5.1.

The limits in this clause apply only at the PCC and shall not be applied to either individual pieces of equipment or at locations within a user's facility. In most cases, harmonic voltages and currents at these locations could be found to be significantly greater than the limits at the PCC due to the lack of diversity, cancellation, and other phenomena that tend to reduce the combined effects of multiple harmonic sources to levels below their algebraic summation.

5.1 Voltage distortion limits

At the PCC, system owners or operators shall limit line-to-neutral voltage harmonics as follows:

- Daily 99th percentile very short time (3 s) values shall be less than 1.5 times the values given in Table 1.
- Weekly 95th percentile short time (10 min) values shall be less than the values given in Table 1.

All values shall be in percent of the rated power frequency voltage at the PCC. Table 1 applies to voltage harmonics whose frequencies are integer multiples of the power frequency up to and including the 50th harmonic.

Table 1—Voltage distortion limits

Bus voltage V at PCC	Individual harmonic (%) $h \leq 50$	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV < $V \leq 69$ kV	3.0	5.0
69 kV < $V \leq 161$ kV	1.5	2.5
161 kV < V	1.0	1.5[a]

[a]High-voltage systems are allowed to have up to 2.0% THD where the cause is an HVDC terminal whose effects are found to be attenuated at points in the network where future users may be connected.

Information on voltage interharmonic limits considering effects such as lamp flicker is given in informative Annex A.

5.2 Current distortion limits

The current distortion limits shall apply to a user's PCC primarily with harmonic producing loads. For installations with primarily inverter-based resources, users are directed to other applicable standards such as IEEE Std 1547-2018 or IEEE Std 2800-2022. For installations where there is a mix of both loads and inverter-based resources, the decision tree in Figure 1 shows when IEEE Std 519 limits shall apply at the installation PCC.

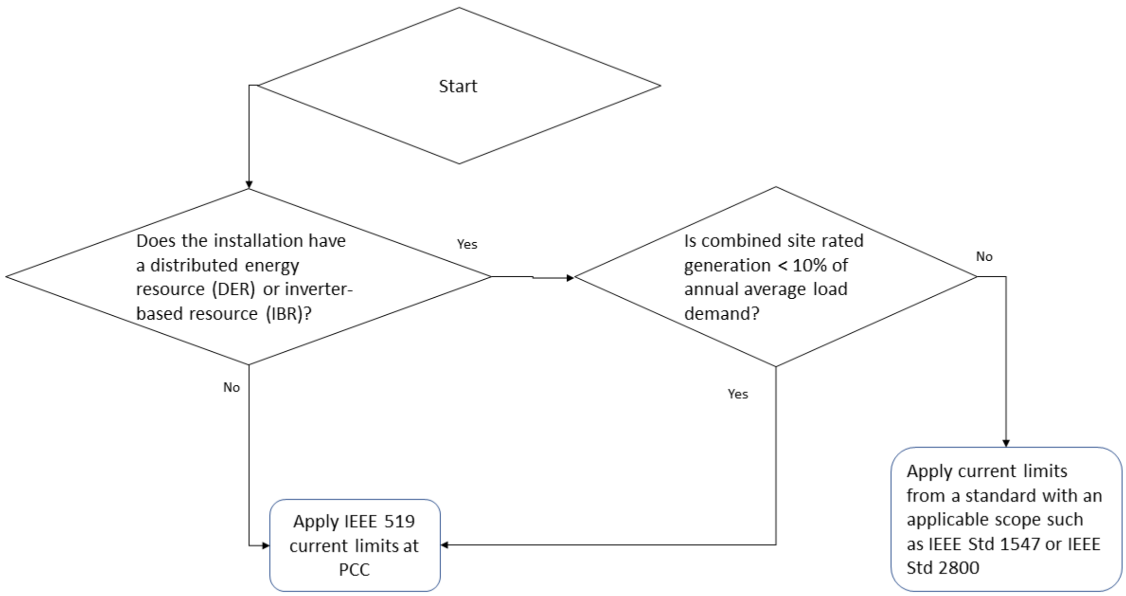

Figure 1— Decision tree for applying current distortion limits at PCC

5.3 Current distortion limits for systems nominally rated 120 V through 69 kV

The limits in this subclause apply to users connected to systems where the rated voltage at the PCC is 120 V to 69 kV. These limits shall not be used for the evaluation of an individual nonlinear load, but rather, for the evaluation of the installation containing such nonlinear loads. At the PCC, users shall limit their harmonic currents as follows:

— Daily 99th percentile very short time (3 s) harmonic currents shall be less than 2.0 times the values given in Table 2.

— Weekly 99th percentile short time (10 min) harmonic currents shall be less than 1.5 times the values given in Table 2.

— Weekly 95th percentile short time (10 min) harmonic currents shall be less than the values given in Table 2.

All values shall be in percent of the maximum demand load current, I_L and shall be established at the PCC. Table 2 applies to harmonic currents whose frequencies are integer multiples of the power frequency.

Table 2—Current distortion limits for systems rated 120 V through 69 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order[b]						
I_{SC}/I_L	$2 \le h < 11$[a]	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
< 20[c]	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50 < 100	10.0	4.5	4.0	1.5	0.7	12.0
100 < 1000	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

[a] For $h \le 6$, even harmonics are limited to 50% of the harmonic limits shown in the table.

[b] Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

[c] Power generation facilities are limited to these values of current distortion, regardless of actual I_{sc}/I_L unless covered by other standards with applicable scope.
where:
I_{sc} = maximum short-circuit current at PCC
I_L = maximum demand load current at PCC under normal load operating conditions

For interharmonic current components with frequencies that are not integer multiples of the power frequency, users should limit the components to sufficiently low levels so as to not produce undesirable effects on the power system and connected equipment. Limiting values and appropriate statistical indices should be developed on a case-by-case basis starting from the guidance of Annex A and considering the specifics of the supply system, connected user loads, and provisions for other users.

5.4 Current distortion limits for systems nominally rated above 69 kV through 161 kV

The limits in this subclause apply to users connected to systems where the rated voltage V at the PCC is 69 kV < $V \le$ 161 kV. These limits shall not be used for the evaluation of an individual nonlinear load, but rather, for the evaluation of the installation containing such nonlinear loads. At the PCC, users shall limit their harmonic currents as follows:

- Daily 99th percentile very short time (3 s) harmonic currents shall be less than 2.0 times the values given in Table 3.
- Weekly 99th percentile short time (10 min) harmonic currents shall be less than 1.5 times the values given in Table 3.
- Weekly 95th percentile short time (10 min) harmonic currents shall be less than the values given in Table 3.

All values shall be in percent of the maximum demand load current, I_L and shall be established at the PCC. Table 3 applies to harmonic currents whose frequencies are integer multiples of the power frequency.

Table 3—Current distortion limits for systems rated above 69 kV through 161 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order[b]						
I_{sc}/I_L	$2 \leq h < 11$[a]	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	TDD
< 20[c]	2.0	1.0	0.75	0.3	0.15	2.5
20 < 50	3.5	1.75	1.25	0.5	0.25	4.0
50 < 100	5.0	2.25	2.0	0.75	0.35	6.0
100 < 1000	6.0	2.75	2.5	1.0	0.5	7.5
> 1000	7.5	3.5	3.0	1.25	0.7	10.0

[a] For $h \leq 6$, even harmonics are limited to 50% of the harmonic limits shown in the table.

[b] Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

[c] Power generation facilities are limited to these values of current distortion, regardless of actual I_{sc}/I_L unless covered by other standards with applicable scope.
where
I_{sc} = maximum short-circuit current at PCC
I_L = maximum demand load current at PCC under normal load operating conditions

For interharmonic current components with frequencies that are not integer multiples of the power frequency, users should limit the components to sufficiently low levels so as to not produce undesirable effects on the power system and connected equipment. Limiting values and appropriate statistical indices shall be developed on a case-by-case basis starting from the guidance of Annex A and considering the specifics of the supply system, connected user loads, and provisions for other users.

5.5 Current distortion limits for systems nominally rated above 161 kV

The limits in this subclause apply to users connected to general transmission systems where the rated voltage V at the PCC is greater than 161 kV. These limits shall not be used for the evaluation of an individual nonlinear load, but rather, for the evaluation of the installation containing such nonlinear loads. At the PCC, users shall limit their harmonic currents as follows:

— Daily 99th percentile very short time (3 s) harmonic currents shall be less than 2.0 times the values given in Table 4.

— Weekly 99th percentile short time (10 min) harmonic currents shall be less than 1.5 times the values given in Table 4.

— Weekly 95th percentile short time (10 min) harmonic currents shall be less than the values given in Table 4.

All values shall be in percent of the maximum demand load current, I_L and shall be established at the PCC. Table 4 applies to harmonic currents whose frequencies are integer multiples of the power frequency.

Table 4—Current distortion limits for systems rated > 161 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order[b]						
I_{sc}/I_L	$2 \le h < 11$[a]	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
< 25[c]	1.0	0.5	0.38	0.15	0.1	1.5
25 < 50	2.0	1.0	0.75	0.3	0.15	2.5
≥ 50	3.0	1.5	1.15	0.45	0.22	3.75

[a] For $h \le 6$, even harmonics are limited to 50% of the harmonic limits shown in the table.

[b] Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

[c] Power generation facilities are limited to these values of current distortion, regardless of actual I_{sc}/I_L unless covered by other standards with applicable scope.
where
I_{sc} = maximum short-circuit current at PCC
I_L = maximum demand load current at PCC under normal load operating conditions

For interharmonic current components with frequencies that are not integer multiples of the power frequency, users should limit the components to sufficiently low levels so as to not produce undesirable effects on the power system and connected equipment. Limiting values and appropriate statistical indices shall be developed on a case-by-case basis starting from the guidance of Annex A and considering the specifics of the supply system, connected user loads, and provisions for other users.

5.6 Recommendations for increasing harmonic current limits

The individual harmonic limits given in Table 2, Table 3, and Table 4 may be increased by a multiplying factor when actions are taken by a user to reduce lower-order harmonics. The multipliers given in the second column of Table 5 are applicable when steps are taken to reduce the harmonic orders given in the first column.

Table 5—Recommended multipliers for increases in harmonic current limits

Harmonics orders limited to 25% of values given in Table 2, Table 3, and Table 4	Multiplier
5, 7	1.4
5,7,11,13	1.7
5,7,11,13,17,19	2.0
5,7,11,13,17,19,23,25	2.2
↓	Multiplier = $\sqrt{\frac{p}{6}}$

NOTE—p is the pulse number order of a three-phase rectifier-based converter.

The multipliers in Table 5 can be obtained as shown in Equation (3) where p is the pulse-number of a three-phase rectifier-based converter (p = 6, 12, 18, 24, etc.). These converters produce dominant or characteristic harmonic currents at orders of $(pn) \pm 1$, where n is a simple counter, n = 1, 2, 3 etc., and significantly lower current magnitudes at other orders. However, the recommended multipliers in Table 5 apply regardless of the method used to reduce the applicable harmonics listed in column 1 of Table 5 as long as those applicable harmonics listed in column 1 are kept below 25% of the limit values given in Table 2, Table 3, or Table 4 as appropriate.[8]

$$\text{Multiplier} = \sqrt{\frac{p}{6}} \tag{3}$$

[8] The intent of this sentence is to credit methods other than through the inherent harmonic reducing characteristics associated with increasing the pulse number of three-phase diode rectifier-based converters. For example, filters, phase-shifting transformers, active front-end rectifiers and other harmonic reducing methods may not necessarily have pulse orders associated with them. However, if those alternate methods reduce the harmonic orders listed in column 1 of Table 5 to less than 25% of the applicable limits listed in Table 2 through Table 4, the appropriate multiplier in column 2 of Table 5 applies.

Annex A

(informative)

Interharmonic voltage limits

A.1 Premise

Interharmonic components are not integer multiples of the power frequency (IEEE Task Force [B8]). The previous version of the IEEE Std 519-2014 [B6], in Annex A, suggested voltage interharmonic limits correlated with a short-term flicker severity Pst value equal to 1.0 for 60 Hz systems, and were assessed using the measurement technique described in IEEE Std 1453 and IEC 61000-4-15. The suggested voltage interharmonic limits were based on avoiding effects of light flicker produced by incandescent lamps.

The recommended limits were not based on the effects of interharmonics on other equipment and systems such as generator mechanical systems, motors, transformers, signaling and communication systems, and filters. IEEE Std 519-2014 [B6] suggests that due consideration be given to these effects and that appropriate interharmonic current limits should be developed on a case-by-case basis using specific knowledge of the supply system, connected user loads, and provisions for future users.

A.2 Limits rationale

In this section, rationale for low voltage (LV) limits of non-generation installations is discussed in terms of the general shape of a potential limit curve. The limits curve represents the main ideas that emerged during the work of the interharmonic distortion task force (IHD-TF), formed in the framework of the Harmonics WG (519) of the IEEE PES T&D Committee, to analyze the issues and challenges behind the proposal to update interharmonic limits in the present revision of the IEEE Std 519, which are recalled in A.3.

The numerical values reported in the limit curves as well as the frequency range represented are not to be intended as prescriptive. Appropriate numbers should be based on specific needs (local, country, conditions, etc.).

Voltage levels, current limits, and user allocation (share) will be discussed in a future stage as well as the opportunity to introduce a limitation of the total interharmonic distortion that could accompany individual subgroups limits.

A.2.1 Limit curves for countries not adopting ripple control

Starting from the definition of interharmonic component given by IEC 61000-4-7 [B5] (paragraph 3.4.2), $Y_{C,k}$ is the r.m.s. value of a spectral component, $Y_{C,k \neq h \times N}$, with a frequency between two consecutive harmonic frequencies, N being the number of cycles of the fundamental frequency in measurement window of about 200 ms (N=12 @ 60 Hz).

The interharmonic centered subgroup is defined as shown in Equation (A.1):

$$Y_{isg,h}^2 = \sum_{k=2}^{N-2} Y_{C,(N\times h)+k}^2 \text{ with } h=0, 1, \ldots, \tag{A.1}$$

Interharmonics subgroups should be limited to proper values to avoid possible light flicker problems from modern lighting technologies over twice the system fundamental frequency [$h \geq 2$ in Equation (A.1)]. The IEC Flickermeter is necessary to assess voltage limits around the fundamental due to the difficulties in measuring very low voltage magnitudes with available instruments compliant with IEC 61000-4-7 [B5]. Interharmonic subgroups around the fundamental [h=0 and h=1 in Equation (A.1)]) should be limited to proper values due to the need to be more restrictive than IEC flickermeter for some interharmonic frequencies.

Figure A.1 shows a representation of a potential limit curve for 60 Hz systems using combination of IEC Flickermeter and IEC interharmonic centered subgroups limited to 0.3% as an example of suitable values up to 1 kHz and to 0.5% up to 2.5 kHz (the x-axis range in the figure is limited to 1170 Hz for the sake of clarity). The limit curve can be interpreted as suitable for application to single interharmonic components.

More complex limit curves could be based on a different definition of interharmonic subgroups reflecting the sensitivity of modern lamps to interharmonics that is higher around odd harmonics than around even harmonics. Figure A.2 shows an example of potential limits for 60 Hz systems using a combination of an IEC Flickermeter and a different interharmonic subgroups definition. The numbers reported (0.5% for interharmonics around even harmonics, 0.3% for interharmonics at a proper distance away between ±20 Hz around odd harmonics and 0.5% from 1 kHz to 2.5 kHz around harmonics regardless their order is even or odd) are also in this case an example of suitable values. Also in this case, the x-axis range in the figure is limited to 1170 Hz for the sake of clarity.

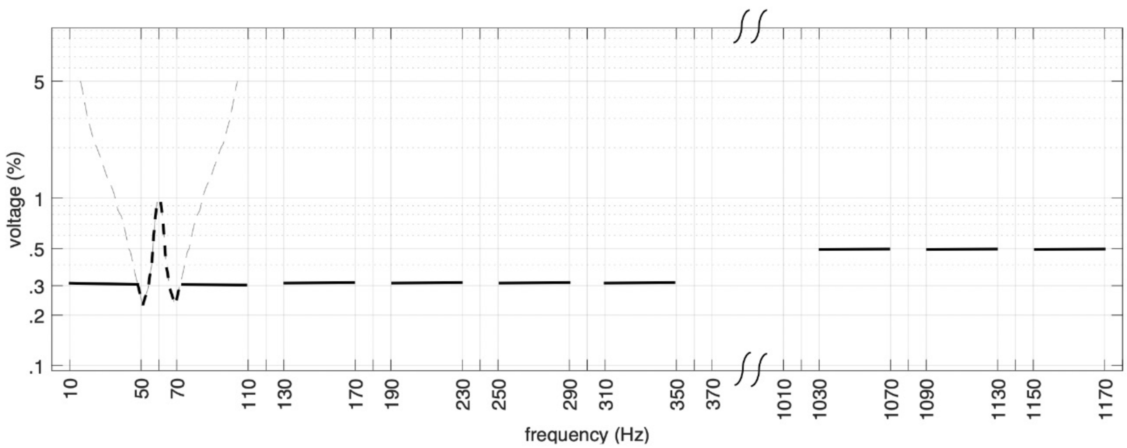

Figure A.1—Example of limit curve using the combination of IEC Flickermeter and IEC interharmonic subgroups limited to 0.3%

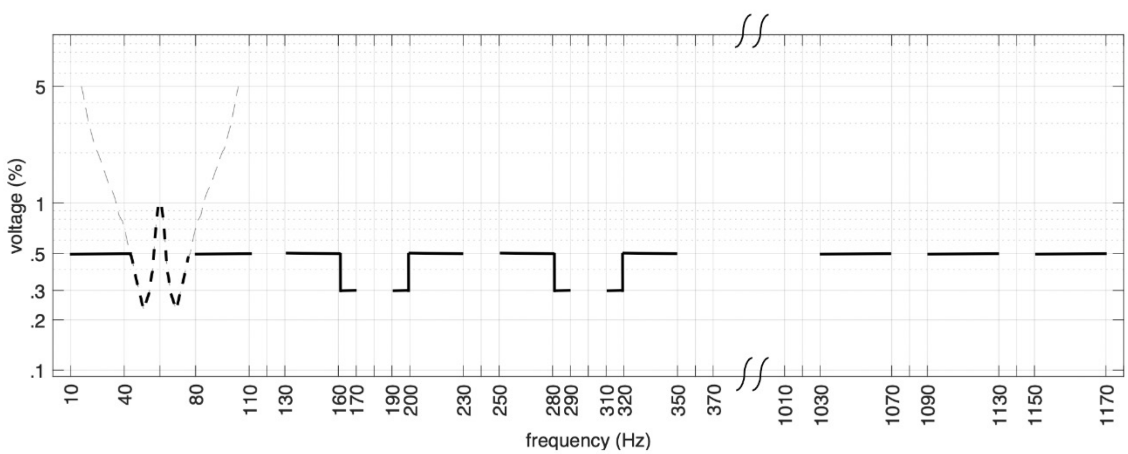

Figure A.2—Example of limit curve using the combination of IEC Flickermeter and a different interharmonic subgroup definition

A.2.2 Limits for countries adopting ripple control

In some countries (e.g., Australia, Austria, Belgium, Czech Republic, Germany, Finland, France, Netherland, New Zealand, Sweden, Switzerland, etc.), ripple control signaling (carrier signal amplitude-modulated by a set of rectangular pulses, i.e., telegram) is widely used. Ripple control signaling uses harmonic and interharmonic frequencies as carriers in range from 168 Hz to 1350 Hz (different regions will have different ripple frequencies). Therefore, compatibility of voltage interharmonics with ripple control is necessary (Drapela and Slezingr [B2], Rahman, et al. [B9]) and requires country-based limits.

IEC 61000-2-2 [B4] recommends the reference level of 0.2% of the nominal supply voltage at the defined frequency, locally specific. This level is justified considering that ripple control receiver's response level can be as low as 0.3% of the nominal supply voltage; therefore, an unintended interharmonic voltage in excess of this value can cause interference if its frequency is the same as the defined operational frequency of the receivers.

A.3 Summary of the work done by the interharmonic distortion task force

Some of the results of the work done by the interharmonic distortion task force are reported in Drapela, et al. [B3].

In the aforementioned paper, the main interharmonic effects, separated, for historical reasons in lighting and non-lighting equipment, were briefly recalled.

Analyzing the sensitivity of lighting equipment (LEDs) to single interharmonic components (i.e., voltages magnitudes and frequencies producing Pst = 1), it was confirmed that in a range around the system fundamental frequency very strict limits (e.g., 0.2% of the rated power frequency voltage at the PCC) should be applied. It was evident that over twice the system fundamental frequency, interharmonic voltages should be limited to values up to 0.3% in a proper range around odd harmonics.

While analyzing the sensitivity of non-lighting equipment, it was evident that even more restrictive limits (e.g., 0.1%) should be applied in the so-called subharmonic range (i.e., below the system fundamental frequency).

In summary, the literature and standard review has shown that if sensitive equipment is installed and a risk analysis shows the necessity, the interharmonic voltages should be limited to the following:

a) 0.1% in the subharmonic range
b) 0.2% around the fundamental (at a proper distance away of about ±10 Hz)
c) 0.3% around odd harmonics (at a proper distance away of about ±10 Hz)
d) > 0.3% around even harmonics

These limits appear to be very restrictive so they should be applied if sensitive equipment are installed, and a risk analysis has shown their necessity.

In the same paper, the interharmonic distortion task force reviewed existing standards and recommendations from around the world. The majority of the standards analyzed fixed interharmonic voltage limits according to sensitivity of lighting and non-lighting equipment. They suggest the use of the interharmonic subgroup concept of IEC 61000-4-7 [B5] instead of individual components. The positive effect of this choice is a reduced number of limits and the ability to contain the amount of data to handle. The negative effect of this choice is that it results in very restrictive (unnecessarily conservative) limits for interharmonic components that do not create light flicker problems, in particular in the frequency range around even harmonics. Moreover, IEEE Std 519-2014 [B6] and IEC 61000-2-2 [B4] rely on the IEC Flickermeter to assess voltage limits around the fundamental due to the difficulties in measuring very low voltage magnitudes with available instruments compliant with IEC 61000-4-7 [B5].

Annex B

(informative)

Telephone influence factor (TIF)

The TIF weighting is a combination of the C message weighting characteristic, which accounts for the relative interfering effect of various frequencies in the voice band (including the response of the telephone set and the ear), and a capacitor, which provides weighting that is directly proportional to frequency to account for the assumed coupling function. TIF is a dimensionless quantity that is indicative of the waveform and not the amplitude and is given by Equation (B.1).

$$\mathrm{TIF} = \sqrt{\sum\left[\frac{\left(X_n \times W_n\right)}{X}\right]^2} \tag{B.1}$$

where

X = total rms voltage or current
X_n = single frequency rms current or voltage at the frequency corresponding to harmonic order n
W_n = single frequency TIF weighting at the frequency corresponding to harmonic order n

In practice, telephone interference is often expressed as a product of the current and the TIF, i.e., the *I-T* product, where the *I* is rms current in amperes and *T* is TIF as calculated in Equation (B.1). Alternatively, it is sometimes expressed as a product of the voltage and the TIF weighting, where the voltage is in rms kV, i.e., the *kV-T* product. The single frequency weighting values, based on 1960-vintage C-message weighting, are listed in Table B.1. Refer to IEEE Std 776-2018 [B7] for more information. Linear interpolation may be used as necessary in Table B.1.

Table B.1—Weighting values (W_f)

FREQ	W_f	FREQ	W_f	FREQ	W_f	FREQ	W_f
60	0.5	1020	5100	1860	7820	3000	9670
180	30	1080	5400	1980	8330	3180	8740
300	225	1140	5630	2100	8830	3300	8090
360	400	1260	6050	2160	9080	3540	6730
420	650	1380	6370	2220	9330	3660	6130
540	1320	1440	6560	2340	9840	3900	4400
660	2260	1500	6680	2460	10340	4020	3700
720	2760	1620	6970	2580	10600	4260	2750
780	3360	1740	7320	2820	10210	4380	2190
900	4350	1800	7570	2940	9820	5000	840
1000	5000						

B.1 Guidelines for *I-T* product

Table B.2 provides representative *I-T* guidelines for distribution systems operating at voltages less than (or equal to) 34.5 kV where it is more likely to have joint use of facilities, particularly poles and structures, involving electric power and telephone/communications companies. These guidelines should not be considered as recommended limits due to the wide range of variability in system and equipment compatibility that is encountered in practice. The use of categories is for illustration purposes only and is provided in the event that it is desirable to assess or compare interference potentials in multiple areas of a particular electrical system.

Table B.2—*I-T* guidelines for distribution systems[a]

Category	Description	*I-T*
I	Levels most unlikely to cause interference	Up to 10 000[b]
II	Levels that might cause interference	10 000 up to 25 000
III	Levels that probably will cause interference	Greater than 25 000

[a]These values of *I-T* product are for circuits with an exposure between overhead systems, both power and telephone. Within an industrial plant or commercial building, the exposure between power distribution cables and telephone lines with twisted pairs is extremely low and no interference is normally encountered; the use of fiber optic cables for communications virtually eliminates the entire concern.
[b]For some areas that use a ground return for either telephone or power circuits, this value may be as low as 1500.

Annex C

(informative)

Limits on commutation notches

C.1 Recommended limits on commutation notches

The notch depth in line-to-line at PCC voltage waveforms should be limited as percentage of nominal peak voltage value as shown in Table C.1.

Table C.1—Recommended limits on commutation notches

	Special applications[a]	General system	Dedicated system[b]
Notch depth	10%	20%	50%
Notch area (A_N)[c, d]	16400	22800	36500

[a] Special applications include hospitals and airports.
[b] A dedicated system exclusively supplies a specific user or user load.
[c] In volt-microseconds at rated voltage and current.
[d] The values for A_N have been developed for 480 V systems. It is necessary to multiply the values given by V/480 for application at all other voltages.

These limits are recommended for low-voltage systems in which the notch area is easily measured on an oscilloscope or power quality monitor with oscilloscope capability. In the event that direct measurement is not possible, detailed simulations including advanced models of the supply system and loads may provide approximate waveforms that may be used in place of oscilloscope measurements. The relevant variables for use in Table C.1 are defined in Figure C.1.

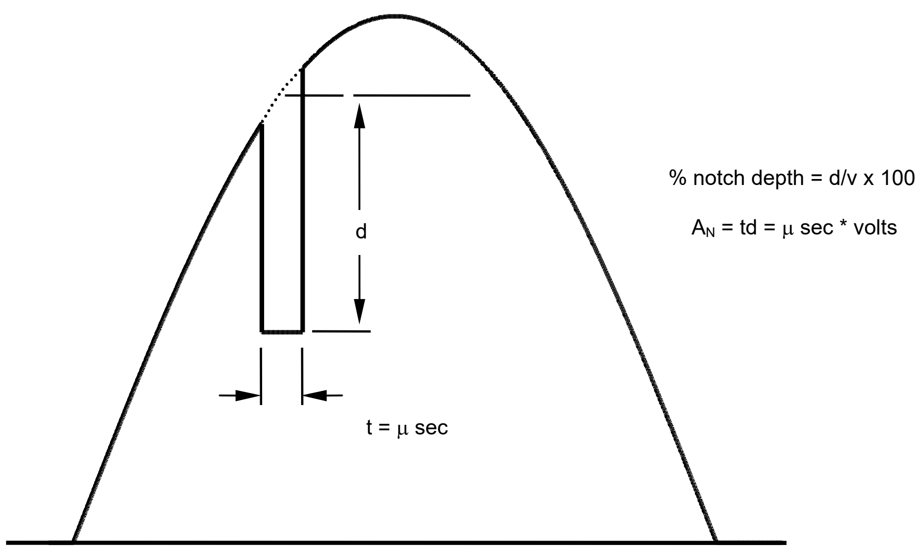

Figure C.1—Definition of notch depth and notch area

Annex D

(informative)

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Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

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