IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems

IEEE Power and Energy Society

Sponsored by the
Transmission and Distribution Committee

IEEE
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USA

IEEE Std 519™-2014
(Revision of
IEEE Std 519-1992)

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Abstract: Goals for the design of electrical systems that include both linear and nonlinear loads are established in this recommended practice. 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.

This recommended practice 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

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Introduction

This introduction is not part of IEEE Std 519-2014, IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems.

The uses of 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.

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 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. This recommended practice is to be used for guidance in the design of power systems with nonlinear loads. The limits set are for steady-state operation and are recommended for "worst case" conditions. Transient conditions exceeding these limits may be encountered. In any case, the limit values given in this document are recommendations and should not be considered binding in all cases. Because of the nature of the recommendations, some conservatism is present that may not be necessary in all cases.

This recommended practice should be applied at interface points between system owners or operators and users in the power system. The limits in this recommended practice are intended for application 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 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.

The limits in this recommended practice 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 and

— 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 passive equipment that affects the impedance characteristic in a way such that voltage distortions are increased. In effect, such actions by a user could amount to producing excessive voltage harmonic distortion. Such passive 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

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1. Overview

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1.1 Scope

This recommended practice 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 minimize interference between electrical equipment.

This recommended practice 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.

1.2 Purpose

This recommended practice is to be used for guidance in the design of power systems with nonlinear loads. The limits set are for steady-state operation and are recommended for "worst case" conditions. Transient conditions exceeding these limits may be encountered. In any case, the limit values given in this document are recommendations and should not be considered binding in all cases. Because of the nature of the recommendations, some conservatism is present that may not be necessary in all cases.

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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 Standard 61000-4-7, General Guide on Harmonics and Interharmonics Measurement and Instrumentation, for Power Supply Systems and Equipment Connected Thereto.[1]

IEC Standard 61000-4-30, Power Quality Measurement Methods.

IEC Standard 61000-4-15, Testing and Measurement Techniques—Flickermeter—Functional and Design Specifications.

IEEE Std 1453™, IEEE Recommended Practice—Adoption of IEC 61000-4-15:2010, Electromagnetic compatibility (EMC)—Testing and Measurement Techniques—Flickermeter—Functional and Design Specifications.[2]

3. 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.[3]

harmonic (component): A component 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.

interharmonic (component): A frequency component of a periodic quantity that is not an integer multiple of the frequency at which the supply system is operating (e.g., 50 Hz or 60 Hz).

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).

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

maximum demand load current: This current value is established at the point of common coupling and should be taken as the sum of the currents corresponding to the maximum demand during each of the twelve previous months divided by 12.

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.

[1] IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, 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/).
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[3] IEEE Standards Dictionary Online subscription is available at: http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

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

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.

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 nonsimultaneous 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: At a particular location, the ratio of the available short-circuit current, in amperes, to the load current, in amperes.

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 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.

4. Harmonic measurements

For the purposes of assessing harmonic levels for comparison with the recommended limits in this document, any instrument used should comply with the specifications of IEC 61000-4-7 and IEC 61000-4-30. The most relevant portions of the IEC specifications are summarized in 4.1 through 4.4.

4.1 Measurement window width

The width of the measurement window used by digital instruments employing Discrete Fourier Transform techniques should 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. and 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 should 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) should be calculated for each 24-hour period for comparison with the recommend 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) should be calculated for each 7-day period for comparison with the recommended limits in Clause 5. These statistics should be used for both voltage and current harmonics with the exception that the 99th percentile short time value is not recommended for use with voltage harmonics.

5. Recommended harmonic 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 recommended for both voltages and currents. The recommended values 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 must work cooperatively to keep actual voltage distortion below objectionable levels. The underlying assumption of these recommended 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 recommended limits in this clause apply only at the point of common coupling and should 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 recommended 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 Recommended harmonic voltage limits

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

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

All values should 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.

Table 1—Voltage distortion limits

Bus voltage V at PCC	Individual harmonic (%)	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 can have up to 2.0% THD where the cause is an HVDC terminal whose effects will have attenuated at points in the network where future users may be connected.

Information on voltage interharmonic limits is given in Annex A and is based on lamp flicker assessed using the measurement technique described in IEEE Std 1453 and IEC 61000-4-15. The information of Annex A is 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. Due consideration should be given to these effects and appropriate interharmonic current limits should be developed starting from the information in Annex A on a case-by-case basis using specific knowledge of the supply system, connected user loads, and provisions for future users.

5.2 Recommended 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. At the PCC, users should limit their harmonic currents as follows:

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

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

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

All values should be in percent of the maximum demand current, I_L. This current value is established at the PCC and should be taken as the sum of the currents corresponding to the maximum demand during each of the twelve previous months divided by 12. 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 (odd harmonics)[a, b]						
I_{SC}/I_L	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	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]Even harmonics are limited to 25% of the odd harmonic limits above.

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

[c]All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.

where

I_{sc} = maximum short-circuit current at PCC

I_L = maximum demand load current (fundamental frequency component) at the 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.

5.3 Recommended 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 < $V \leq$ 161 kV. At the PCC, users should limit their harmonic currents as follows:

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

— Weekly 99th percentile short time (10 min) harmonic currents should be less than 1.5 times the values given in Table 3.

— Weekly 95th percentile short time (10 min) harmonic currents should be less than the values given in Table 3.

All values should be in percent of the maximum demand current, I_L. This current value is established at the PCC and should be taken as the sum of the currents corresponding to the maximum demand during each of the twelve previous months divided by 12. 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 (odd harmonics) [a, b]						
I_{sc}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	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]Even harmonics are limited to 25% of the odd harmonic limits above.

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

[c]All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.
where
I_{sc} = maximum short-circuit current at PCC
I_L = maximum demand load current (fundamental frequency component) at the 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 Recommended 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. At the PCC, users should limit their harmonic currents as follows:

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

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

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

All values should be in percent of the maximum demand current, I_L. This current value is established at the PCC and should be taken as the sum of the currents corresponding to the maximum demand during each of the twelve previous months divided by 12. 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 (odd harmonics)[a, b]						
I_{sc}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	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]Even harmonics are limited to 25% of the odd harmonic limits above.

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

[c]All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.

where
I_{sc} = maximum short-circuit current at PCC
I_L = maximum demand load current (fundamental frequency component) at the PCC under normal load operating conditions

For interharmonic current components with frequencies which 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.

5.5 Recommendations for increasing harmonic current limits

It is recommended that the values given in Table 2, Table 3, and Table 4 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
↓	↓

The multipliers in Table 5 can be obtained as shown in Equation (3) where p is the pulse-order of a three-phase rectifier-based converter ($p = 6, 12, 18, 24$, etc.). These converters produce dominant or characteristic harmonic currents at orders of $p(n \pm 1)$, 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 3 apply regardless of the method used to reduce the harmonics that would be considered "non-characteristic harmonics" for a p-pulse converter as long as all "non-characteristic harmonics," including even-order harmonics, are kept below 25% of the limit values given in Table 2, Table 3, or Table 4 as appropriate.

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

Annex A

(informative)

Interharmonic voltage limits based on flicker

For interharmonic components that are not integer multiples of the power frequency, system owners or operators may limit the weekly 95th percentile short time harmonic voltages to the values shown graphically in Figure A-1 up to 120 Hz for 60 Hz systems. Depending on the voltage level, the integer harmonic limits in Table 1 may be more restrictive and should be used. The portions of the 0–120 Hz range where the integer harmonic limits of Table 1 are more restrictive are appropriately labeled in Figure A-1. The numerical values corresponding to Figure A-1 are given in Table A-1 for voltages at the PCC less than 1 kV. It is important to recognize that the suggested voltage interharmonic limits are based on lamp flicker assessed using the measurement technique described in IEEE Std 1453 and IEC 61000-4-15. These voltage interharmonic limits correlate with a short-term flicker severity Pst value equal to 1.0 for 60 Hz systems; different (but similar) limit values can be derived for 50 Hz systems. The recommended limits in Figure A-1 are 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. Due consideration should be given to these effects and 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.

There is no limit on the 60 Hz component in Figure A-1. The 5% maximum applies to frequency components very near (but not equal to) 60 Hz.

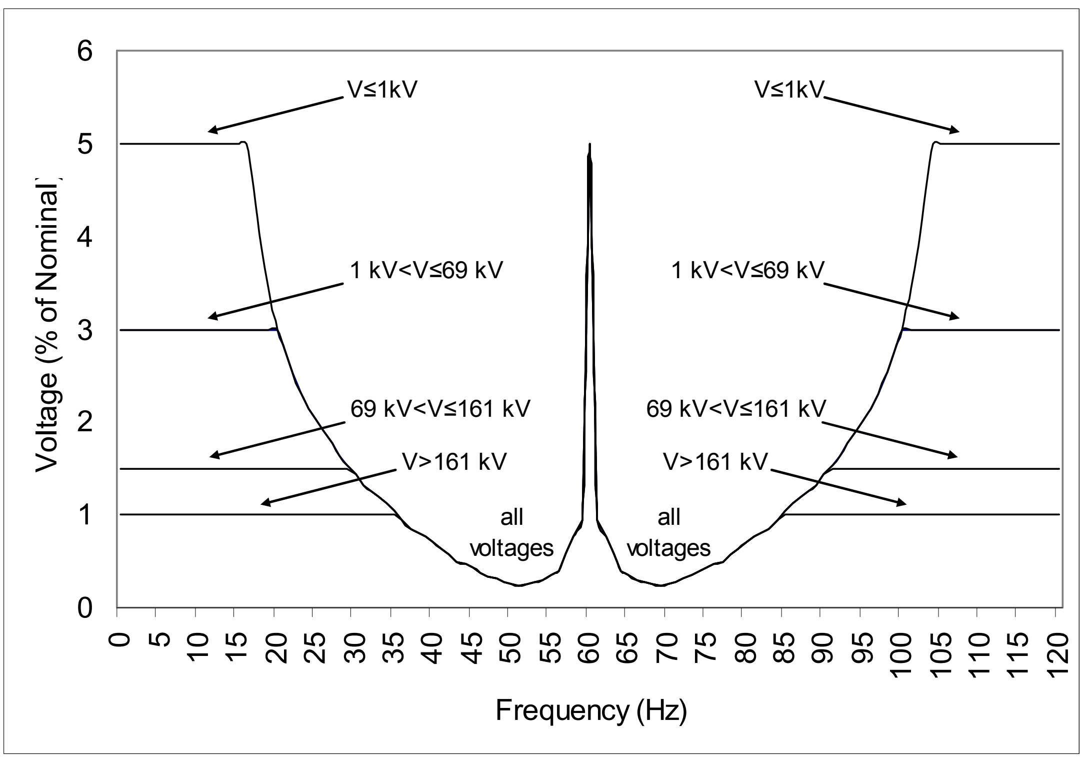

Figure A-1—Interharmonic voltage limits based on flicker for frequencies up to 120 Hz for 60 Hz systems

Table A-1—Voltage interharmonic limits corresponding to Figure A-1 for PCC voltage less than 1 kV[a, b]

Frequency (Hz)	Magnitude (%)	Frequency (Hz)	Magnitude (%)	Frequency (Hz)	Magnitude (%)	Frequency (Hz)	Magnitude (%)
16	5.00	27	1.78	38	0.81	49	0.28
17	4.50	28	1.64	39	0.78	50	0.25
18	3.90	29	1.54	40	0.71	51	0.23
19	3.45	30	1.43	41	0.64	52	0.25
20	3.00	31	1.33	42	0.57	53	0.27
21	2.77	32	1.26	43	0.50	54	0.29
22	2.53	33	1.20	44	0.48	55	0.35
23	2.30	34	1.13	45	0.43	56	0.40
24	2.15	35	1.05	46	0.38	57	0.58
25	2.03	36	0.95	47	0.34	58	0.77
26	1.90	37	0.85	48	0.31	59	0.95

[a]The values for frequencies above 60 (but less than 120) Hz are identical to those given in this table except the frequency of interest must be subtracted from 120 Hz before reading the corresponding value. For example, the interharmonic voltage limit for 61 Hz is equal to that given in the table for 120 – 61 = 59 Hz, which is 0.95%.

[b]The frequency resolution in Table A-1 is 1 Hz. The resolution available using the methods recommended in Clause 4 is 5 Hz. Special instrumentation to be agreed upon at the time of its use, may be needed to obtain 1 Hz resolution.

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).

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

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. 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 and the notch area of the line-to-line voltage at PCC should be limited 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.

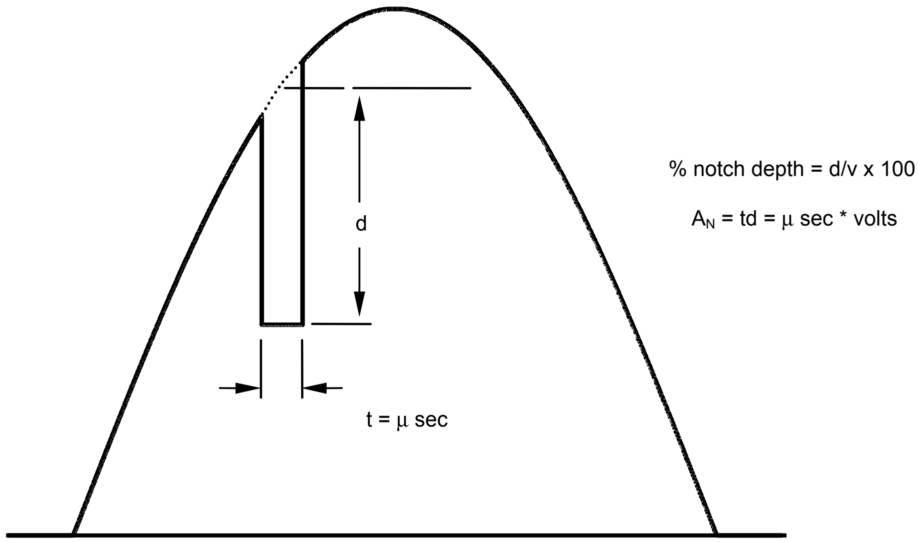

Figure C-1—Definition of notch depth and notch area

Annex D

(informative)

Bibliography

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.

[B1] IEEE Std C57.110™-1986, IEEE Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Current.[4, 5]

[B2] IEEE Std 18™-1992, IEEE Standard for Shunt Power Capacitors.

[B3] IEEE Std 368™-1977 (Withdrawn), IEEE Recommended Practice for Measurement of Electrical Noise and Harmonic Filter Performance of High-Voltage Direct-Current Systems.[6]

[B4] IEEE Std 1100™-2005, IEEE Recommended Practice for Powering and Grounding Electronic Equipment.

[B5] IEEE Std 1159™-2009, IEEE Recommended Practice for Monitoring Electric Power Quality.

[B6] IEEE Std 1531™-2003, IEEE Guide for Application and Specification of Harmonic Filters.

[4] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).
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[6] IEEE Std C57.110-1986 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (http://global.ihs.com/).