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TECHNICAL REPORT

Noise measurement method on power capacitors

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NOISE MEASUREMENT METHOD ON POWER CAPACITORS

FOREWORD

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IEC 63396 has been prepared by technical committee 33: Power capacitors and their applications. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
33/658/DTR	33/663/RVDTR

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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

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- withdrawn,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

INTRODUCTION

Power capacitors are important equipment for HVDC project, but at the same time they are also the main noise source. However, there is no IEC document which is specific to the noise measurement on power capacitors until now.

In recent years, Chinese authoritative testing organizations have conducted a large number of experiments in this area. Now, many laboratories in China are able to simulate the actual operating conditions of power capacitors in HVDC converter stations for noise testing.

This new technical report is aimed to document a feasible method to measure power capacitor's noise in AC and DC systems, in particular in HVDC converter stations, based on the experience developed in China. Furthermore, the testing laboratories could also check and validate periodically the common technical parameters of the noise measurement on power capacitors in an uniform way by this method, in order to promote the practical application of the measurement method and possibly to improve it (in view of a possible future conversion of the technical report to a technical specification).

This document is intended to fill the gap in this technical field, and to promote the construction of environmentally friendly AC and DC substations.

NOISE MEASUREMENT METHOD ON POWER CAPACITORS

1 Scope

The object of this Technical Report is to document a method for the sound pressure level measurement on power capacitor units, by which the sound power level of power capacitor units is determined.

This method is applicable to shunt capacitor units and AC filter capacitor units for AC power systems with a nominal voltage of 1 kV and above and a frequency of 50 Hz or 60 Hz.

This method also applies to the DC filter capacitor units.

Other measurements on power capacitor units can be implemented with reference to this method.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61260-1:2014, *Electroacoustics – Octave-band and fractional-octave-band filters – Part 1: Specifications*

IEC 61672-1:2013, *Electroacoustics – Sound level meters – Part 1: Specifications*

ISO 3744:2010, *Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering methods for an essentially free field over a reflecting plane*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
noise
unwanted sound

[SOURCE: IEC TS 61973:2012, 3.1.13]

3.2
sound pressure
p
fluctuating pressure superimposed on the static pressure

Note 1 to entry: Sound pressure is expressed in pascals (Pa).

Note 2 to entry: Sound pressure is usually expressed through the use of a decibel scale, as sound pressure level.

[SOURCE: IEC TS 61973:2012, 3.1.3]

3.3
sound pressure level
L_p
logarithm of the ratio of the RMS value of a given sound pressure to the reference sound pressure

$$L_p = 10 \log \frac{p^2}{p_0^2} = 20 \log \frac{p}{p_0}, \quad (1)$$

where:

p is the measured RMS sound pressure, in pascals;

p_0 is the reference RMS pressure of 2×10^{-5} Pa, which corresponds to the 0 dB as threshold of audibility.

Note 1 to entry: $\log(x)$ means the logarithm with base 10 of x; this convention is used throughout this document.

Note 2 to entry: The sound pressure level (L_p) is expressed in decibels (dB).

Note 3 to entry: Sound pressure level is measured with sound level meters, which normally incorporate a frequency-weighting filter. For further details see 3.2.3 of IEC TS 61973:2012.

Note 4 to entry: Since the sound level distribution measured around sound emitting objects is usually non-uniform it is normally necessary to assess sound levels on spatial average figures gained from several measuring positions rather than on one single discrete position.

[SOURCE: IEC TS 61973:2012, 3.1.4]

3.4
sound power
P
through a surface, product of the sound pressure, p, and the component of the particle velocity, u_n, at a point on the surface in the direction normal to the surface, integrated over that surface

Note 1 to entry: Sound power is expressed in watts.

Note 2 to entry: The quantity relates to the rate per time at which airborne sound energy is radiated by a source.

[SOURCE: ISO 3744:2010, 3.20]

3.5
sound power level
L_w
ten times the logarithm to the base 10 of the ratio of the sound power of a source, P, to a reference value, P_0, expressed in decibels (dB)

$$L_W = 10 \log \frac{P}{P_0} \quad (2)$$

where the reference value, P_0, is 1 pW

Note 1 to entry: If a specific weighting as specified in IEC 61672-1 and/or specific frequency bands are applied, this is indicated by appropriate subscripts; e.g. $L_{W(A)}$ denotes the A-weighted sound power level.

[SOURCE: ISO 3744:2010, 3.21]

3.6
reference box
hypothetical right parallelepiped terminating on the reflecting plane(s) on which the noise source under test is located, that just encloses the source including all the significant sound radiating components and any test table on which the source is mounted

Note 1 to entry: The test table as small as possible be used.

Note 2 to entry: Reference radiating plane of capacitor unit is the cuboid surface consisting of the six sides of the capacitor unit enclosure only and excluding the wiring terminals.

[SOURCE: ISO 3744:2010, 3.10]

3.7
measurement surface
S
hypothetical surface of an area, S, on which the microphone positions are located at which the sound pressure levels are measured, enveloping the noise source under test and terminating on the reflecting plane(s) on which the source is located

[SOURCE: ISO 3744:2010, 3.14]

3.8
background noise
noise from all sources other than the noise source under test

Note 1 to entry: Background noise includes contributions from airborne sound, noise from structure-borne vibration, and electrical noise in the instrumentation.

Note 2 to entry: The background noise considers noise from the associated power equipment which operates and stops simultaneously with the capacitor unit.

[SOURCE: ISO 3744:2010, 3.15]

3.9
synthesis of sound pressure level
superposition of sound pressure levels generated by two or more sound sources at a certain point in the sound field

3.10
directivity index
D^{*}_{Ii}
measure of the extent to which a noise source under test radiates sound in the direction of the i_{th} microphone position on a measurement surface, relative to the mean sound radiation over the measurement surface

$$D_{Ii}^{*} = L_{pi(ST)} - (\overline{L'_{p(ST)}} - K_1) \tag{3}$$

where

$L_{pi(ST)}$ is the background noise-corrected time-averaged (or single event time-integrated) sound pressure level for the i_{th} microphone position on the measurement surface, with the noise source under test (ST) in operation, in decibels;

$\overline{L'_{p(ST)}}$ is the mean (energy average) time-averaged (or single event time-integrated) sound pressure level over all the microphone positions on the measurement surface for noise source under test, in decibels;

K_1 is the background noise correction, in decibels.

[SOURCE: ISO 3744:2010, 3.24]

3.11
fundamental current
current with a frequency equal to the power frequency of the AC system connected with the capacitor

3.12
harmonic current
current with a frequency that is a multiple of the power frequency of the AC system connected with the capacitor

3.13
capacitor unit
assembly of one or more capacitor elements in the same container with terminals brought out

[SOURCE: IEC 60050-436:1990, 436-01-04]

3.14
shunt capacitor
power capacitor intended to be connected in parallel with a network

Note 1 to entry: These capacitors are used primarily for power factor correction by reactive power compensation.

[SOURCE: IEC 60050-436:1990, 436-02-02]

3.15
AC filter capacitor
power capacitor intended to form part of a circuit designed to reduce one or more harmonic currents present in the AC network

3.16
DC filter capacitor
power capacitor used to suppress the harmonics of the DC network

4 Noise measurement

4.1 Power injection conditions for capacitors

4.1.1 Current injection conditions for shunt capacitor units

The maximum injection current of shunt capacitor units is applied as follows:

a) Fundamental current is not greater than 1,1I_e, where I_e is the rated current for the capacitor unit.

b) The root mean square value of fundamental current and harmonic currents is not greater than 1,3I_e.

During noise test of shunt capacitor units, both fundamental current and harmonic currents that specified for test are injected simultaneously, if practicable.

The controlled deviation of the amplitude of injected fundamental current and harmonic currents of each order is not greater than 3 %.

Typical test circuits for shunt capacitor units noise measurement are documented in Figure B.1 in Annex B.

4.1.2 Current injection conditions for AC filter capacitor units

During a noise test of AC filter capacitor units, both fundamental current and harmonic currents that are specified for test are injected simultaneously, if practicable.

The controlled deviation of the amplitude of injected fundamental current and harmonic currents of each order are not greater than 3 %.

Typical test circuits for AC filter capacitor units noise measurement are documented in Figure B.1.

4.1.3 Current and voltage injection conditions for DC filter capacitor units

During a noise test on DC filter capacitor units, both DC voltage and harmonic currents that are specified for test are injected simultaneously, if practicable.

The controlled deviation of the amplitude of DC voltage and harmonic currents of each order injected are not greater than 3 %.

Typical test circuits for DC filter capacitor units noise measurement are documented in Figure B.2.

4.2 Measuring environment

Noise measurement on power capacitor units is carried out in hemi-anechoic rooms meeting the qualifications described in Annex A or Annex B of ISO 3744:2012. Environments with background noise not more than 30 dB and without acoustic wave reflection that affects appreciably the measurement results are acceptable alternatives.

The background noise at each measuring point is measured before and after noise measurement, and the difference between the two average sound pressure levels is maintained within 3 dB. It is preferable that the background A-weighted sound pressure level be at least 10 dB lower than the power capacitor's sound under the specified test conditions. When these conditions are not satisfied, at least the method given in 4.6.2 is followed.

4.3 Characteristics for basic acoustic instruments

The sound meters used for measuring sound pressure levels are compliant with the characteristics set out in IEC 61672-1:2013, class 1, and they are calibrated according to ISO 3744:2010.

The octave or one-third-octave band filters are selected so as to meet the requirements specified in IEC 61260-1:2014.

4.4 Arrangement of the power capacitors

The arrangement mode of the test object is such to be consistent with the installation and design requirements of actual projects. A fixing method that basically does not affect the generation and propagation of power capacitor noise is adopted. Generally, the power capacitor unit is fixed to a rack as in the actual installation.

The bottom surface of the power capacitor unit is kept parallel to the reflecting plane (floor) of the test room and remains at a vertical distance of 0,8 m from the reflecting plane (floor) during the test.

The container of power capacitor unit and the rack are reliably grounded.

4.5 Arrangement of the microphone

The microphone is positioned close to the measurement surface. The number and position of the microphones are described in Annex A.

4.6 Measurement on sound pressure levels

4.6.1 General

The measurement is made when the background noise level is approximately constant.

The A-weighted sound pressure level of the background noise is measured before the noise measurement of the power capacitor unit (test object). When measuring the background noise, the microphone is located at the same position as when measuring the noise of the test object.

The A-weighted sound pressure level at each measuring point is recorded and the rapid response indication of the instrument is used to confirm and avoid measurement errors caused by transient background noise.

After the measurement is completed and the power supply of the test object is removed, the background noise is measured again immediately.

At the beginning and the end of each measurement, the entire sound pressure level measuring system can be checked by means of a sound calibrator meeting the requirements of IEC 61672-1:2013, class 1. Without any further adjustment, the difference between the readings of two consecutive checks is maintained within 0,3 dB. If this value is exceeded, the results of measurements obtained after the previous satisfactory check are discarded and the measurement process is repeated.

4.6.2 Calculation of average sound pressure level at measurement surface

The average A-weighted sound pressure level $\overline{L_{pA0}}$ is obtained by averaging the root-mean-square A-weighted sound pressure level L_{pAi} on the surface of the parallelepiped over the space, which is calculated using equation (4).

$$\overline{L_{pA0}} = 10\log\left(\frac{1}{N}\sum_{i=1}^{N}10^{0,1L_{pAi}}\right)\ \text{dB(A)}, \tag{4}$$

where:

N is the total number of sound pressure level measuring points of the samples.

Average A-weighted sound pressure level of background noise $\overline{L_{bpA}}$ is obtained based on the measured values before and after the test. It is calculated according to equation (5).

$$\overline{L_{bpA}} = 10\log\left(\frac{1}{M}\sum_{i=1}^{M}10^{0,1L_{bpAi}}\right)\ \text{dB(A)}, \tag{5}$$

where:

M is the total number of background sound pressure level measuring points.

L_{bpAi} is A weighted sound pressure level of background noise measured at each measuring point.

If the deviation of the background A weighted sound pressure levels $\overline{L_{bpA}}$ measured before and after the test exceeds 3 dB, and the difference between the higher one and the uncorrected average A-weighted sound pressure level $\overline{L_{pA0}}$ is less than 8 dB, the measurement is invalid and the test is repeated. However, when the uncorrected average A-weighted sound pressure level is less than the guaranteed value, the test object can be deemed to meet the requirements of the guaranteed value of sound level, and this situation is recorded in the test report.

If the higher value of the background A-weighted sound pressure levels $\overline{L_{bpA}}$ measured before and after the test deviates from the uncorrected average A-weighted sound pressure level $\overline{L_{pA0}}$ by less than 3 dB, the measurement is invalid and the test is repeated, except if the uncorrected average A-weighted sound pressure level is less than the guaranteed value; under this circumstance, the test object can be deemed to meet the requirements of the guaranteed value of the sound level, and this situation is recorded in the test report.

When the difference between the higher of the background A-weighted sound pressure levels and the synthesized sound pressure level of the test object and the background is less than 3 dB, other measurement methods can be considered. Although a small difference between the synthesized sound pressure level and the background sound pressure level is allowable, it is still necessary to lower the difference to less than 6 dB, as far as possible. When it is indeed less than 6 dB and is greater than 3 dB, correction is made according to equation (6).

$$\overline{L_{pA}} = 10\log\left(10^{0,1\overline{L_{pA0}}} - 10^{0,1\overline{L_{bpA}}}\right) \text{ dB(A)}, \qquad (6)$$

where:

$\overline{L_{bpA}}$ is the smaller of the two calculated average A-weighted sound pressure levels of background noise.

$\overline{L_{pA}}$ is the Synthetic A-weighted sound pressure level after background noise correction.

The above requirements are summarized and test acceptance criteria shown in Table 1.

Table 1 – Test acceptance criteria

The difference between $\overline{L_{pA0}}$ and the higher value of $\overline{L_{bpA}}$	The difference between $\overline{L_{bpA}}$ before and after test	Conclusion
≥ 8 dB(A)	—	Accepted
< 8 dB(A)	< 3 dB(A)	Accepted
< 8 dB(A)	> 3 dB(A)	Retest
< 3 dB(A)	—	Retest

NOTE If $\overline{L_{pA0}}$ is less than the maximum requirement sound pressure level value of the test object, the test object can be deemed to meet the sound pressure level requirement, therefore retest would be unnecessary and this situation is recorded in the test report.

4.7 Calculation of sound power level

A-weighted sound power level of test object L_{WA} is calculated based on the corrected measured average A weighted sound pressure level according to equation (7):

$$L_{\mathrm{WA}} = \overline{L_{pA}} + 10\log\frac{S}{S_0}, \qquad (7)$$

where:

$\overline{L_{pA}}$ is the surface time-averaged sound pressure level for the noise source under test, in dB;

S is the area of the measurement surface, in square metres. It is calculated according to equation (A.1);

S_0 is the reference surface area, S_0 = 1 m^2.

5 Measurement of uncertainty

When the sound power level of the same capacitor unit is measured with the procedures specified in this document in different laboratories meeting the conditions of Clause 4, the results obtained can show a certain dispersion, which is evaluated by the measurement uncertainty $u(L_W)$.

The measurement uncertainty $u(L_W)$ of the sound power level determined in accordance with this document is estimated by the total standard deviation σ_{tot}:

$$u(L_W) \approx \sigma_{tot} \ , \tag{8}$$

where $u(L_W)$ and σ_{tot} are both expressed in decibels (dB).

The total standard deviation σ_{tot} is expressed by σ_{R0} and σ_{omc}, as in equation (9):

$$\sigma_{tot} = \sqrt{\sigma_{R0}^2 + \sigma_{omc}^2} \ , \tag{9}$$

where:

σ_{R0} is the standard deviation due to repeatability and reproducibility of all conditions and environments, including the test method, test environment, and test personnel;

σ_{omc} is the standard deviation due to the instability of loading and installation conditions of test object.

In addition to the standard deviation σ_{tot}, the expanded measurement uncertainty also depends on the degree of confidence that is desired. For a normal distribution of sound power levels, there is 90 % confidence that the true value lies within the measured value ±1,64σ_{tot}, and 95 % confidence that the true value lies within the measured value ±1,96σ_{tot}.

The expanded measurement uncertainty U (in dB) is derived from σ_{tot} using equation (10):

$$U = k\sigma_{tot} \ , \tag{10}$$

where k is the coverage factor.

The expanded measurement uncertainty depends on the degree of confidence that is desired. For a normal distribution of measured values, there is 95 % confidence that the true value lies within the range $(L_W - U)$ to $(L_W + U)$. This corresponds to a coverage factor of k = 2.

If the purpose of determining the sound power level is to compare the result with a limit value, it can be more appropriate to apply the coverage factor for one-sided normal distribution. In that case, the coverage factor is k = 1,6, corresponding to a degree of confidence of 95 %.

For measurements under the environmental conditions meeting the conditions of Clause 4 using the methods specified and the measuring system recommended in this document, the standard deviation, σ_{omc}, for measurement uncertainty due to instability of loading and installation conditions of the test object is 0,28 dB; and the upper bound value of standard deviation σ_{R0} due to reproducibility of the test method, test environment, and test personnel is 0,50 dB (smaller for repeated measurements in the same hemi-anechoic room).

For the coverage factor k = 2 for normal distribution of measured values corresponding to a confidence level of 95 %, the expanded measurement uncertainty derived from the standard deviation above is:

$$U = k\sigma_{tot} = k\sqrt{\sigma_{R0}^2 + \sigma_{omc}^2} = 2 \times \sqrt{0{,}50^2 + 0{,}28^2} \approx 1{,}1 \text{ (dB)}. \quad (11)$$

For the coverage factor k = 1,6 for one-sided normal distribution corresponding to a confidence level of 95 %, the expanded measurement uncertainty derived from the standard deviation above is:

$$U = k\sigma_{tot} = k\sqrt{\sigma_{R0}^2 + \sigma_{omc}^2} = 1{,}6 \times \sqrt{0{,}50^2 + 0{,}28^2} \approx 0{,}9 \text{ (dB)}. \quad (12)$$

The sound power level finally determined can be expressed as $L_{\mathrm{W}} \pm U$ in dB.

6 Test report

The noise test report of the power capacitor units normally includes the following information:

a) the name of the power capacitor manufacturer and manufacturing time;

b) the date and place of testing;

c) the reference document (e.g. this document);

d) the schematic diagram of the test circuit;

e) the product model, factory serial number, rated capacity, rated current, rated voltage, rated frequency, rated capacitance and shell size of the relevant products;

f) the internal dimensions of the hemi-anechoic room, the installation location and method of the test object;

g) the total number and arrangement of measuring points (attached drawings);

h) the total area of the measurement surface, as calculated;

i) other parameters such as noise measuring instruments model, factory serial number, accuracy and calibration;

j) the test conditions, including the injected fundamental voltage, fundamental current, harmonic frequency, harmonic voltage and harmonic currents of the test object;

k) the calculated values of A-weighted background noise sound pressure level at each measuring point before and after the test, and the average sound pressure level of A-weighted background noise at each measuring point before and after the test;

l) the A-weighted sound pressure level of each measuring point and the calculated value of the uncorrected average A-weighted sound pressure level of the test object;

m) possible explanations of whether background, environment and air pressure correction are necessary;

NOTE If correction are needed, the corrected average A-weighted sound pressure level are normally reported separately after the uncorrected values.

n) the calculation result of the sound power level of the test object;

o) possibly, the list of attendees at the test;

p) name and signature of the person in charge of the test report.

A typical format of the power capacitor noise test report is presented in Annex C.

Annex A
(informative)

Microphone arrangement on noise measurement surface of power capacitors

A.1 Measurement surface

In this document, a right parallelepiped with sides parallel to those of the reference box is used as the measurement surface. The entire measurement surface is within the internal space of the hemi-anechoic room. Figure A.1 shows the schematic diagram for the installation position of test object relative to the measurement surface.

The area of the measurement surface is given by equation (A.1):

$$S = 4(ab + bc + ca) \;, \tag{A.1}$$

where:

$a = d + 0{,}5L$, in m;

$b = d + 0{,}5W$, in m;

$c = d + H + e$, in m;

L, W and H are the length, width, and height of the reference box respectively; d is the measurement distance (taken as 1 m in this technical report), and e is the height of the capacitor under test above ground (e = 0,8 m).

Dimensions in metres

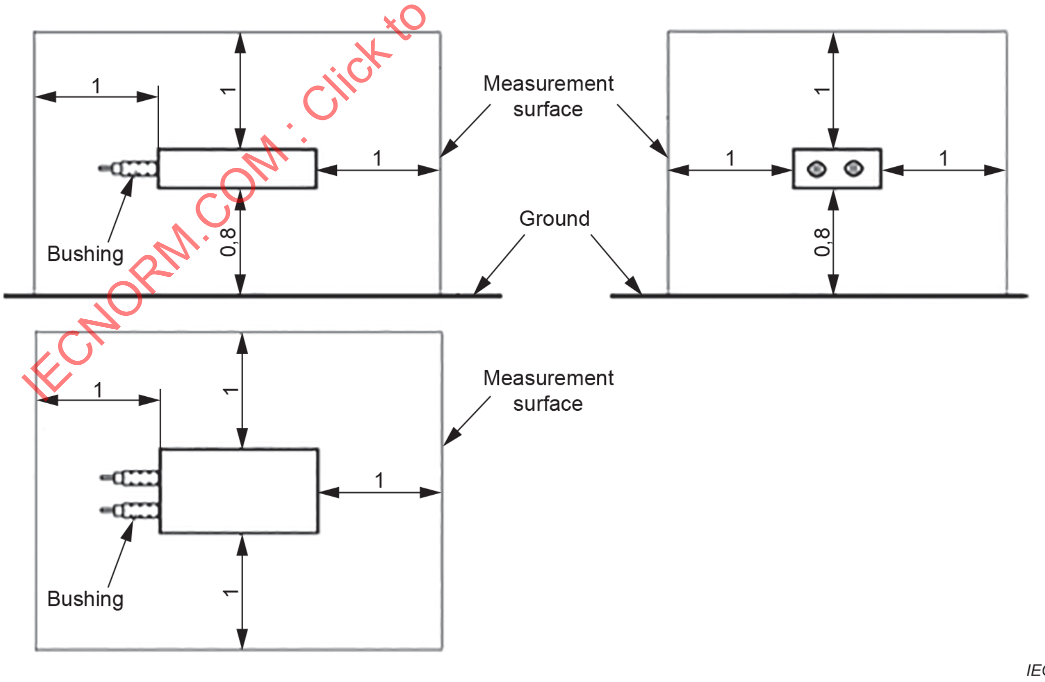

Figure A.1 – Schematic diagram of installation of the test object

A.2 Measurement positions and orientation of microphone

Seventeen points are arranged on the measurement surface. See Figure A.2 and Table 1 for distribution and coordinate of the points.

For the purpose of the test, the microphones are located on the measurement positions and be perpendicular to the measurement surface. If a measurement position is at the crossing of multiple surfaces, the microphone can point face to the centre of the test object.

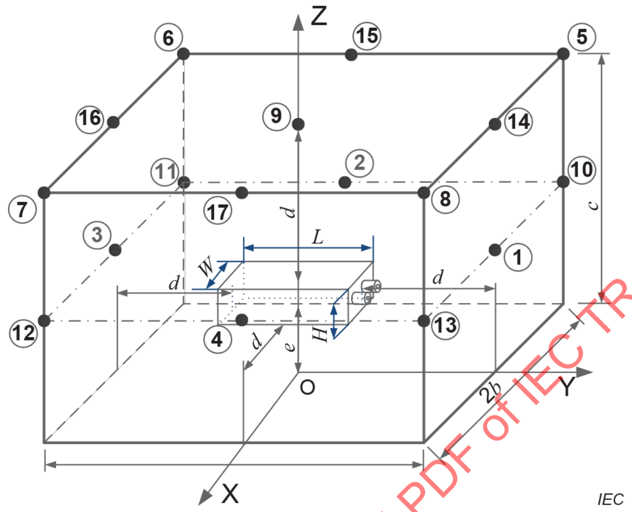

Figure A.2 – Microphone positions on the parallelepiped measurement surface

Table A.1 – Coordinates of measurement positions on the parallelepiped measurement surface

Measurement Position	*x*	*y*	*z*
1	0	a	c/2
2	-b	0	c/2
3	0	-a	c/2
4	b	0	c/2
5	-b	a	c
6	-b	-a	c
7	b	-a	c
8	b	a	c
9	0	0	c
10	-b	a	c/2
11	-b	-a	c/2
12	b	-a	c/2
13	a	b	c/2
14	0	a	c
15	-b	0	c
16	0	-a	c
17	b	0	c

Annex B
(informative)

Typical test circuit for power capacitor noise measurement

B.1 Shunt and AC filter power capacitor noise test circuit

The test circuit shown in Figure B.1 can be used, if the test object is a shunt or AC filter power capacitor. According to the indications of 4.1.1 and 4.1.2, the harmonic power supply outputs the fundamental wave and the harmonic currents of the set frequencies, which are loaded on the capacitor unit under test through the transformer. According to the power supply capacity, the shunt reactor is used to compensate for the loading of specific frequency (usually power frequency) current.

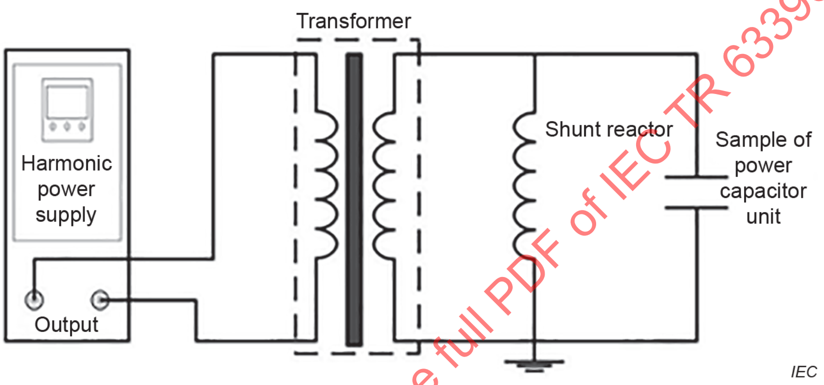

Figure B.1 – Schematic diagram of shunt and AC filter power capacitor noise test circuit

B.2 DC filter power capacitor noise test circuit

The test circuit shown in Figure B.2 is used, if the test object is a DC filter power capacitor. According to the indications of 4.1.3, the harmonic power supply outputs harmonic currents with set frequencies, which are loaded on the capacitor unit under test through the transformer. At the same time, the DC test voltage is applied by DC power supply.

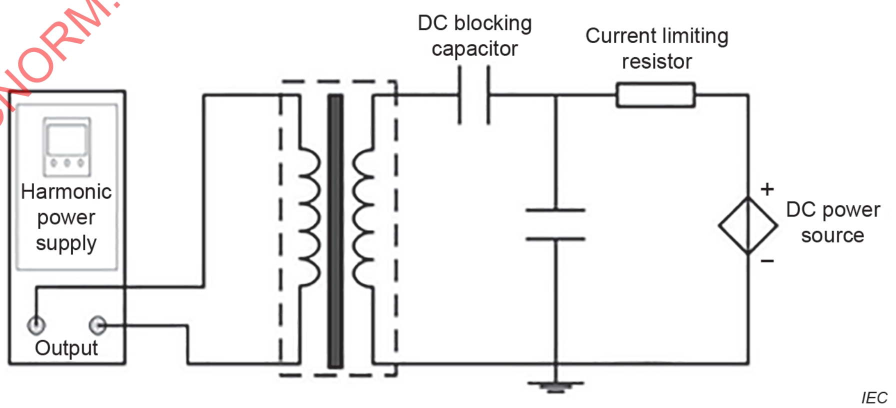

Figure B.2 – Schematic diagram of DC filter power capacitor noise test circuit