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TECHNICAL SPECIFICATION

Bushings – Seismic qualification

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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BUSHINGS – SEISMIC QUALIFICATION

FOREWORD

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- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- The subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 61463, which is a Technical Specification, has been prepared by subcommittee 36A: Insulated bushings, of IEC technical committee 36: Insulators.

This second edition cancels and replaces the first edition published in 1996 and Amendment 1:2000. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) the seismic spectrum profile has been substituted with the one of IEEE Std 693-2005, worldwide used as a reference;
b) the acceptance criteria have been reviewed and the maximum permissible stress for each main material has been harmonized with the relevant IEC Standard for that material;
c) a load on the head has been prescribed when the bushing is subject to the vibration test;
d) the sine sweep test has been added as a method of search of resonance frequency, worldwide used.

The text of this document is based on the following documents:

Enquiry draft	Report on voting
36A/178/DTS	36A/179/RVC

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

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

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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

As it is not always possible to define accurately the seismic severity at the bushing flange level, IEC TS 61463, which is a Technical Specification, presents three alternative methods of qualification. The three methods are equally acceptable. If the required response spectrum (RRS) at the bushing flange is not known, a severity (in terms of acceleration values) based on standard response spectra at the ground level may be used to carry out qualification through one of the three methods described in this document.

When the environmental characteristics are not sufficiently known, qualification by static calculation is acceptable. Where high safety reliability of equipment is required for a specific environment, precise data are used, therefore qualification by dynamic analysis or vibration test is recommended. The choice between vibration testing and dynamic analysis depends mainly on the capacity of the test facility for the mass and volume of the specimen, and, also if non-linearities are expected.

When qualification by dynamic analysis is foreseen, it is recommended that the numerical model be adjusted by using vibration data (see Clause 5).

This document was prepared with the intention of being applicable to bushings whatever their construction material and their internal configuration.The information contained, originally directed to porcelain bushings, has been partially updated to include also composite bushings.

BUSHINGS – SEISMIC QUALIFICATION

1 Scope

IEC TS 61463, which is a Technical Specification, is applicable to alternating current and direct current bushings for highest voltages above 52 kV (or with resonance frequencies placed inside the seismic response spectrum), mounted on transformers, other apparatus or buildings. For bushings with highest voltages less than or equal to 52 kV (or with resonance frequencies placed outside from the seismic response spectrum), due to their characteristics, seismic qualification is not used as far as construction practice and seismic construction practice comply with the state of the art.

This document presents acceptable seismic qualification methods and requirements to demonstrate that a bushing can maintain its mechanical properties, insulate and carry current during and after an earthquake.

The seismic qualification of a bushing is only performed upon request.

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 60068-2-47, *Environmental testing – Part 2-47: Test – Mounting of specimens for vibration, impact and similar dynamic tests*

IEC 60068-2-57, *Environmental testing – Part 2-57: Tests – Test Ff: Vibration – Time-history and sine-beat method*

IEC 60068-3-3:1991, *Environmental testing – Part 3-3: Guidance – Seismic test methods for equipments*

IEC 60137, *Insulated bushings for alternating voltages above 1 000 V*

IEC 61462, *Composite hollow insulators – Pressurized and unpressurized insulators for use in electrical equipment with rated voltage greater than 1 000 V – Definitions, test methods, acceptance criteria and design recommendations*

IEC 62155, *Hollow pressurized and unpressurized ceramic and glass insulators for use in electrical equipment with rated voltages greater than 1 000 V*

IEC 62217, *Polymeric insulators for indoor and outdoor use – General definitions, test methods and acceptance criteria*

ISO 2041, *Mechanical vibration, shock and condition monitoring – Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60068-3-3, IEC 60137, IEC 61462, ISO 2041 and the following 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
critical cross-section
section of the bushing that is most likely to fail during an earthquake

3.2
response spectrum
plot of the maximum response to a defined input motion of a family of single-degree-of-freedom bodies at a specified damping ratio

[SOURCE: IEC 60068-2-57:2013, 3.18, modified — The words "as a function of their natural frequencies and at a specified damping ratio" has been replaced by "at a specified damping ratio".]

3.3
rigid equipment
equipment whose natural frequency is greater than 33 Hz is considered rigid for the purpose of this technical specification

3.4
standard frequency range
predominant frequencies of a typical earthquake

Note 1 to entry: This range is generally between 0,3 Hz and 33 Hz.

Note 2 to entry: This range is sufficient to determine the critical frequencies of the equipment and for its testing. In certain cases the test frequency range may be extended or reduced dependent on the critical frequencies present, but this shall be justified.

3.5
zero period acceleration
high frequency asymptotic value of acceleration of a response spectrum (above the cut-off frequency of 33 Hz)

Note 1 to entry: This acceleration corresponds to the maximum acceleration of the time history used to derive the spectrum.

4 Symbols and abbreviated terms

a_{bg} equivalent maximum acceleration to the centre of gravity of the bushing during the seismic event

a_f maximum acceleration of the bushing flange

a_g maximum acceleration of the ground resulting from the motion of a given earthquake

NOTE a_g is equal to the zero period acceleration (ZPA) of Figure 2.

d damping of the bushing

d_p distance between the centre of gravity of the part of the bushing which is under consideration and the critical cross-section

f_0 first natural frequency of the bushing

K superelevation factor between ground and bushing flange: factor accounting for the change in the acceleration from the ground to the flange due to the amplification by foundation, buildings and structure

m_p mass of the part of the bushing which is under consideration

M_s bending moment at the critical cross-section of the part of the bushing considered, due to an earthquake

R response factor derived from the required response spectrum (RRS) as the ratio between the response acceleration and the ZPA (see Figure 3)

RRS required response spectrum: response spectrum specified by the user

S_c coefficient established to take into account the effects of both multifrequency excitation and multimode response

S_a spectral acceleration

ZPA zero period acceleration (see a_g)

5 Methods of seismic qualification

Seismic qualification should demonstrate the ability of a bushing to withstand seismic stresses and to maintain its required function without failure, during and after an earthquake of a specified severity (see Clause 6).

As bushings are mounted on apparatus or buildings, the seismic qualification of the bushing must consider the behaviour of the system on which the bushing is fixed. In the seismic qualification of a bushing, all parts should be included, which contribute to the stresses in the critical cross-sections during a seismic event, for example the conductor and inner spacer in gas insulated bushings.

Three methods and combinations thereof are described in this document:

– qualification by static calculation (Clause 7);
– qualification by dynamic analysis (Clause 8);
– qualification by vibration test (Clause 9).

A combination of the methods may be used

– to qualify a bushing which cannot be qualified by testing alone (e.g. because of size and/or complexity of the apparatus),
– to qualify a bushing already tested under different seismic conditions, and
– to qualify a bushing similar to a bushing already tested but which includes modifications influencing the dynamic behaviour (e.g. change in the length of insulators or in the mass).

Vibrational data (damping, critical frequencies, stresses of critical elements as a function of input acceleration) for analysis can be obtained by

a) a dynamic test on a similar bushing,
b) a dynamic test at reduced test level, and
c) determination of natural frequencies and damping by other tests such as free oscillation tests or sine sweep tests (see Annex B).

The methods result in the value of M_s which is determined for each part of the bushing on either side of the flange. The stress due to this moment should be combined with the other stresses acting in the bushing, and it should be demonstrated that the bushing withstands the combined stress (Clause 10).

The different methods of seismic qualification are illustrated in the flow chart given in Annex A.

6 Severities

6.1 At the ground

The ground acceleration depends upon the seismic conditions of the site where the apparatus is to be located. When it is known, it should be prescribed by the relevant specification. Otherwise, the severity level should be selected from Table 1.

Table 1 – Ground acceleration levels

Ground acceleration reference	Description of earthquake					
	General	*ZPA* = a_g m/s²	Richter scale magnitude	UBC zone[a]	Intensity MSK[b]	RRS
AG2	Light to medium earthquakes	2 (0,2 g)	< 5,5	1 to 2	< VIII	Figure 1[c]
AG3	Medium to strong earthquakes	3 (0,3 g)	5,5 to 7,0	3	VIII to IX	Figure 1[c]
AG5	Strong to very strong earthquakes	5 (0,5 g)	> 7,0	4	> IX	Figure 1

[a] Approximate Uniform building code zone (International conference of building officials).

[b] MSK (Medvedev-Sponheuer-Karnik) corresponds to modified Mercalli intensity scale.

[c] Values for AG2 and AG3 are obtained by multiplying the values from Figure 2 by 2/5 and 3/5 respectively.

The selected qualification level should be in accordance with expected earthquakes of maximum ground motions for the site location, for which certain structures, systems and components are designed to remain functional. These structures are those essential to assure proper function, integrity and safety of the total system (S_2 type earthquakes, according to IEC 60068-3-3).

For qualification, it should be assumed that

- the horizontal movements as described in Table 1 act in any direction
- the severities of the vertical accelerations are 50 % of the horizontal (if a different value is used, a justification shall be provided), and
- both directions may reach their maximum values simultaneously.

The ground motion can be described by natural time histories when known, or by artificial time histories, which should comply with the RRS; this is used as input for dynamic analysis or vibration test on the complete apparatus.

NOTE Information on the correlation between seismic qualification levels, seismic zone and seismic scales is given in IEC 60721-2-6 [1][1] and IEC 60068-3-3.

6.2 At the bushing flange

The severity at the bushing flange (see Figure 5) may be available from the manufacturer of the apparatus and structures (i.e. transformers, gas insulated apparatuses (GIS), building) in terms of RRS or maximum acceleration (a_f). Where no information is available, the following simplified formula is used in order to establish an acceleration value at the flange of the bushing.

$$a_f = K \times a_g$$

The superelevation factor K can be

[1] Numbers in square brackets refer to the Bibliography.

– calculated by finite element analysis including soil interaction or any other careful modelling, or
– derived from results from calculations or tests on comparable apparatus or structures, or
– taken from typical values obtained from experience.

So far, very little experience is reported. Unless more background information is available, K should be assumed to be 1 for through-wall bushings, 1,5 for GIS bushings and for transformer bushings directly mounted on the transformer cover, and 2 for transformer bushings mounted on a turret. If the mounting configuration on the transformer is not known, K will be assumed as 1,5.

See also IEC 60068-3-3:1991, Table 4.

7 Qualification by static calculation

This method is valid for rigid equipment. It may be extended to flexible equipment, such as a bushing, taking into consideration the response factor R, as an alternative to the method by analysis. This allows simpler evaluation with increased conservatism.

Using the static calculation method, the bending moment in the critical cross-section of the part of the bushing under consideration is calculated from an equivalent acceleration of the centre of gravity of that part (a_{bg}):

$$M_s = a_{bg} \times d_p \times m_p$$

This acceleration, a_{bg}, is calculated from the flange acceleration a_f by multiplication with a coefficient S_c and the response factor R (see Annex C):

$$a_{bg} = a_f \times S_c \times R$$

The value of S_c depends on the natural frequency f_0 of the mounted bushing:

$f_0 \leq 8$ Hz	$S_c = 1,5$
$8 < f_0 < 33$ Hz	$S_c = 1 + 0,5 \times (33 - f_0) / (33-8)$
$f_0 \geq 33$ Hz	$S_c = 1,0$

If the natural frequency f_0 is not known, the conservative value $S_c = 1,5$ should be used.

The value R can be established by one of the following methods.

a) From the spectrum at the bushing flange (if available).

b) When the spectrum at the bushing flange is not known, the spectrum at the ground (Figure 2) may be used assuming that the levels at all frequencies are equally amplified (K factor) from the ground to the flange. For such cases, the values of R are summarized in Figure 3. The value of R is derived from the RRS (Figure 2 and Table 4) by dividing the spectrum values with the ZPA value of asymptotic acceleration.

   In order to correctly use the R values, it is necessary to know the first natural frequency f_0 and the damping d % of the bushing mounted on its supporting structure. The natural frequency can either be calculated as indicated for the superelevation factor or found by a free oscillation test as described in Annex B.

c) R may be assumed to be equal to 2,5 when information for frequency f_0 and damping d % of the bushing mounted on a transformer is not available. The value of 2,5 corresponds to the frequency range 1,1 Hz to 8 Hz and 5 % damping ratio (ref. to Figure 3 and Table 5).