IEC 62271-211

Edition 2.0 2024-09

INTERNATIONAL STANDARD

High-voltage switchgear and controlgear – Part 211: Direct connection between power transformers and gas-insulated metal-enclosed switchgear for rated voltages above 52 kV

IEC 62271-211:2024-09(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.130.10

ISBN 978-2-8322-9578-6

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HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 211: Direct connection between power transformers and gas-insulated metal-enclosed switchgear for rated voltages above 52 kV

FOREWORD

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IEC 62271-211 has been prepared by subcommittee 17C: Assemblies, of IEC technical committee 17: High-voltage switchgear and controlgear. It is an International Standard.

This second edition cancels and replaces the first edition of IEC 62271-211:2014. This edition constitutes a technical revision.

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

a) re-numbering of clauses according to IEC 62271-1:2017,
b) Clause 3: updating definition about bushing (3.1), updating some pressure definitions (3.6, 3.7, 3.8, 3.9), rewording definition about proctor density (3.11), new term very-fast-front overvoltage (3.12),

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c) Clause 5 (former clause 4): add a subclause 5.1 General, according to IEC 62271-1:2017 and IEC 62271-203:2022,
   1) subclause 5.5: new first paragraph, rewording second paragraph,
   2) subclause 5.8: modify the term "Rated duration of thermal short-time current" of the bushing,
d) Clause 6 (former Clause 5): restructure and rewording of subclauses:
   1) 6.1 (former 5.3): requirements about gas and vacuum tightness of the transformer bushing
   2) 6.3 (former 5.2): harmonization with IEC 62271-203:2022 about typical maximum pressure in service for SF_6, other gases and gas mixtures,
   3) 6.4 (former 5.8), rewording
   4) 6.5 (former 5.1), some rewording and modification
   5) 6.6 (former 5.4), some rewording, updated references
   6) 6.7 (former 5.5), some rewording
   7) 6.8 (former 5.6), some rewording
   8) 6.9 (former 5.7), slight rewording,
e) Clause 7 (former clause 6) type tests: some rewording and clarifications about references,
f) Clause 8 (former clause 7) routine tests:
   1) 8.2 (former 7.2): add a paragraph about SF_6-mixtures and other gases than SF_6,
   2) 8.3 (former 7.3): update reference to relevant on-site test according to IEC 62271-203:2022,
g) Clause 9 Guide to the selection of switchgear and controlgear (new): informative, to have a reference to IEC 62271-203:2022,
h) Clause 11 (former 10): updated headline and updated reference according to IEC 62271-1:2017,
i) new Clauses 12 Safety and 13 Environmental aspects: Adding of references to safety and environmental aspects,
j) correction of errors in Corrigendum 2 of IEC 62271-211:2017,
k) modified orientation of Figure 1 to Figure 4 for easier reading of the tables,

The text of this International Standard is based on the following documents:

Draft	Report on voting
17C/935/FDIS	17C/945/RVD

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 International Standard 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/publications.

A list of all parts in the IEC 62271 series, published under the general title *High-voltage switchgear and controlgear*, can be found on the IEC website.

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HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 211: Direct connection between power transformers and gas-insulated metal-enclosed switchgear for rated voltages above 52 kV

1 Scope

This part of IEC 62271 is applicable to single- and three-phase direct connections between gas-insulated metal-enclosed switchgear (GIS) for rated voltages above 52 kV and transformer arrangements to establish electrical and mechanical interchange ability and to determine the limits of supply for the transformer connection.

Direct connections are immersed on one end in the transformer oil or insulating gas and on the other end in the insulating gas of the switchgear.

Transformer arrangements are single-phase transformers with single-phase enclosed arrangement, three-phase transformers with three single-phase enclosed arrangements or three-phase transformers with a three-phase enclosed arrangement with three transformer bushings.

The connection satisfies the requirements of IEC 62271-203 for gas-insulated metal-enclosed switchgear, IEC 60076 for power transformer and IEC 60137 for completely immersed bushings.

For the purpose of this document the term “switchgear” is used for “gas-insulated metal-enclosed switchgear and the term “transformer” is used for “power transformer”.

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 60076 (all parts), *Power transformers*

IEC 60076-1:2011, *Power transformers – Part 1: General*

IEC 60137:2017, *Insulated bushings for alternating voltages above 1 000 V*

IEC 61936-1:2021, *Power installations exceeding 1 kV AC and 1,5 kV DC – Part 1: AC*

IEC 62271-1:2017, *High-voltage switchgear and controlgear – Part 1: Common specifications for alternating current switchgear and controlgear*
IEC 62271-1:2017/AMD1:*2021*

IEC 62271-203:2022, *High-voltage switchgear and controlgear – Part 203: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV*

IEC 62271-207:2023, *High-voltage switchgear and controlgear – Part 207: Seismic qualification for gas-insulated switchgear assemblies, metal enclosed and solid-insulation enclosed switchgear for rated voltages above 1 kV*

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62271-1, as well as the following apply.

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

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

3.1
bushing
device that enables one or several conductors to pass through an enclosure and insulate the conductors from it

[SOURCE: IEC 60050-471:2007 [1][1], 471-02-01, modified – "an enclosure" inserted after "pass through" and "a partition such as a wall or a tank" deleted. Notes 1 and 2 were deleted.]

3.2
completely immersed bushing
bushing, both ends of which are intended to be immersed in an insulating medium other than ambient air (e.g. oil or gas)

[SOURCE: IEC 60050-471:2007 [1], 471-02-04]

3.3
gas-insulated switchgear (GIS) enclosure
part of gas-insulated metal-enclosed switchgear retaining the insulating gas under the prescribed conditions necessary to maintain safely the highest insulation level, protecting the equipment against external influences and providing a high degree of protection to personnel

Note 1 to entry: The enclosure can be single-phase or three-phase.

[SOURCE: IEC 62271-203:2022, 3.103, modified – the acronym GIS has been added]

3.4
main circuit end terminal
part of the main circuit of a gas-insulated metal-enclosed switchgear forming part of the connection interface

[SOURCE: IEC 62271-209:2019 [2], 3.2]

3.5
transformer connection enclosure
part of the gas-insulated metal-enclosed switchgear which houses one end of a completely immersed bushing fitted on a power transformer and a main circuit end terminal

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

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3.6
maximum external operating gas pressure
maximum pressure of the gaseous insulating medium in which the bushing is partially or completely immersed when in operation

Note 1 to entry: It is at least equal to the maximum pressure in the transformer connection enclosure of the GIS at the highest temperature that the gas used for insulation can reach under specified maximum service conditions.

Note 2 to entry: In case of gas-insulated transformers it is also the maximum insulating pressure of the gaseous insulating medium in which the end of the bushing is immersed into the power transformer, when in operation, the bushing-power transformer connection assembly carrying its rating continuous current at the maximum ambient temperature.

[SOURCE: IEC 60137:2017, 3.32 – modified: Note 1 to entry and Note 2 to entry were added]

3.7
enclosure design pressure
relative pressure used to determine the design of the enclosure

Note 1 to entry: It is at least equal to the maximum pressure in the enclosure at the highest temperature that the gas used for insulation can reach under specified maximum service conditions.

Note 2 to entry: The transient pressure occurring during and after a breaking operation (e.g. circuit-breaker) is not considered in the determination of the design pressure.

[SOURCE: IEC 62271-203:2022, 3.114]

3.8
filling pressure p_{re} for insulation
filling density ρ_{re} for insulation
pressure (in Pa), for insulation, referred to the standard atmospheric air conditions of +20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, to which the assembly is filled before being put into service

[SOURCE: IEC 62271-1:2017, 3.6.5.1, modified – deleted the terms "and/or switching", deleted "or automatically replenished"]

3.9
minimum functional pressure p_{me} for insulation
minimum functional density ρ_{me} for insulation
pressure (in Pa), for insulation, referred to the standard atmospheric air conditions of +20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, at which and above which the characteristics of the switchgear-power-transformer connection are maintained

[SOURCE: IEC 62271-1:2017, 3.6.5.5, modified – deleted the terms "and/or switching", added "the characteristics of the switchgear-power-transformer connection" deleted "rated characteristics of switchgear and controlgear"]

3.10
insulated junction
all parts which are needed to insulate between the transformer and the switchgear, including but not limited to the insulating flange

3.11
proctor density
highest dry density of a soil for a given compaction effort depending on the amount of water the soil contains during soil compaction of controlled magnitude according Proctor Standard test

Note 1 to entry: Proctor Standard test is defined in ASTM D-698 [3]. However, other tests methods exist providing similar information, but not always equivalent, like for example ISO 17892-2 [4], BS 1377-1 [5], UNE 103500 [6], NF P 94-093 [7] and DIN 18127 [8].

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3.12
very-fast-front overvoltage
VFFO
transient overvoltage, usually unidirectional with time to peak T_f ≤ 0,1 µs, and with or without superimposed oscillations at frequency 30 kHz < f < 100 MHz

Note 1 to entry: Transient overvoltage generated by switching operations in GIS have a time to peak in a range of nanoseconds. They are usually named VFTO (very fast transients overvoltage) or related to the grounded encapsulation named as very-fast-front transient ground potential rises.

[SOURCE: IEC 60071-1:2019 [9], 3.17.2.3, modified – Note 1 to entry added]

4 Normal and special service conditions

4.1 Normal service conditions

Subclause 4.1 of IEC 62271-203:2022 is applicable.

4.2 Special service conditions

Subclause 4.2 of IEC 62271-203:2022 is applicable.

5 Ratings

5.1 General

When dimensioning a direct connection between a switchgear and a power-transformer the following rated values apply.

5.2 Rated voltage (U_r)

The rated voltage shall be the rated voltage of the switchgear, selected from the following standard values:

72,5 kV – 100 kV – 123 kV – 145 kV – 170 kV – 245 kV – 300 kV – 362 kV – 420 kV – 550 kV

NOTE Values 800 kV and higher are not considered because there is little experience at this time.

5.3 Rated insulation level (U_d, U_p, U_s)

The rated insulation level for the GIS part in the direct connection enclosure shall comply with the related rated voltage values given in the product standard IEC 62271-203. The rated insulation level for the transformer bushing shall be selected from the values given in the product standard IEC 60137.

NOTE Transformers can be tested at other insulation level values, according to their relevant standard.

The rated insulation level for a direct connection shall fulfil at least the requirements of IEC 62271-203.

5.4 Rated frequency (f_r)

Subclause 5.4 of IEC 62271-1:2017 is applicable.

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5.5 Rated continuous current (I_r)

This rating defines the RMS value of the current the direct connection can carry continuously for its service conditions (see Clause 4).

The connection interface is shown in Figure 1 as parts 3 and 4. The dimensions of the connection interfaces shown in Figure 2 allow a maximum value of 3 150 A for the rated continuous current at normal service conditions i.e. maximum ambient temperature of 40 °C (see 4.1).

The contact surfaces of the connection interface shall be silver-coated, copper-coated or bare copper.

For the rated continuous current, the connection between switchgear and power transformer shall be designed so that the temperature of the transformer connection enclosure and the temperature of the connection interface do not exceed the values given in 7.5.6 of IEC 62271-1:2017.

5.6 Rated short-time withstand current (I_k) and rated thermal short-time current (I_{th})

For the rated short-time withstand current of the GIS part of the direct connection, 5.6 of IEC 62271-1:2017 applies; for the rated thermal short-time current of the bushing 4.3 of IEC 60137:2017 applies.

It is recommended to assign the same value for both short-time rated currents for GIS and bushing.

5.7 Rated peak withstand current (I_p) and rated dynamic current (I_d)

For the rated peak withstand current of the GIS part of the direct connection, 5.7 of IEC 62271-1:2017 applies; for the rated dynamic current of the bushing 4.4 of IEC 60137:2017 applies.

It is recommended to assign the same value for the rated peak withstand current for the GIS and the rated dynamic current for the bushing.

5.8 Rated duration of short-circuit (t_k) and of thermal short-time current (t_{th})

For the rated duration of the short-circuit current of the GIS part of the direct connection, 5.8 of IEC 62271-1:2017 applies; for the rated duration of the thermal short-time current of the bushing 4.3 of IEC 60137:2017 applies.

It is recommended to assign the same value for the rated duration of short-circuit for the GIS and the rated duration of the thermal short-time current for the bushing.

6 Design and construction

6.1 Gas and vacuum tightness

Subclause 6.16 of IEC 62271-203:2022 is applicable with the following addition:

For conditions up to the maximum external operating gas pressure inside the transformer connection enclosure of the GIS, the bushing shall minimize the gas insulated media diffusing into the transformer. The leak rate shall be equal or less than 10 Pa·cm^3/s, see 9.10.3 of IEC 60137:2017.

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The bushing shall prevent liquid insulating media entering from the transformer or the bushing into the GIS. Visual inspection is sufficient evidence, see 9.10.3. of IEC 60137:2017.

The bushing shall be capable of withstanding the vacuum conditions when the transformer connection enclosure is evacuated, as part of the gas filling process of the GIS and shall be capable of withstanding the vacuum conditions when the transformer is evacuated as part of its gas or oil filling process.

The relevant requirements and acceptance criteria for the bushing are described in 8.11 to 8.13 and 9.7 to 9.10 of IEC 60137:2017.

In the case of a gas-insulated transformer the gas compartment of the transformer shall be completely separated and managed independently from the switchgear.

6.2 Gas pressure for insulation of the bushing inside the gas-insulated switchgear (GIS) enclosure

The filling pressure p_{re} (or density) of any gas for insulating is assigned by the switchgear manufacturer.

The minimum functional pressure for insulation p_{me}, used to determine the design of the bushing insulation, shall be agreed between the switchgear manufacturer and the bushing manufacturer.

However, the minimum functional pressure for insulation p_{me} of the bushing inside the GIS enclosure shall be below or equal to the minimum functional pressure of GIS.

NOTE If SF_6 is used as the insulating gas, a minimum functional gas pressure for insulation of not more than 0,35 MPa (absolute) at 20 °C is commonly used to determine the bushing insulation.

6.3 Pressure withstands requirements

The bushing connected to the GIS shall be capable of withstanding the maximum pressure in service of the GIS. Typical maximum pressures in service are up to 1,1 MPa (absolute) for SF_6 and up to 1,5 MPa (absolute) for other gases and gas mixtures.

NOTE The former given value for SF_6 of "at least 0,85 MPa (absolute) at 20 °C" is approximately in correlation with a "typical maximum pressure in service of 1,1 MPa (absolute) for SF_6" at a maximum value of 80 °C at the outer surface of a metallic encapsulation, considering rated continuous current of 3 150 A and maximum ambient temperature of 40 °C. The above mentioned typical maximum pressure values were introduced in IEC 62271-203:2022.

The transformer connection enclosure and all pressurized connected parts of the GIS shall satisfy the requirements provided in 6.104 of IEC 62271-203:2022 for the design pressure determined by the switchgear manufacturer as specified in 6.104.2 of IEC 62271-203:2022.

The enclosure design pressure of the transformer connection enclosure may be lower than the gas pressure which is used to determine the mechanical strength of the bushing in a type test.

6.4 Standard dimensions and tolerances

6.4.1 General

Standard dimensions are specified to ensure compatibility between switchgear and transformer connections conforming to this document and agreement is required between the switchgear and transformer manufacturers.

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6.4.2 Single-phase direct connection between oil-filled transformer and switchgear

Standard dimensions for single-phase transformer connection enclosures, main circuit end terminals, bushing end terminals and bushing flanges are shown in Figure 2.

6.4.3 Three-phase direct connection between oil-filled transformer and switchgear

The minimum dimensions of the three-phase direct connection between oil-filled transformer and switchgear are defined by the minimum phase-to-phase distance arising out of d_8 and the minimum phase to ground distance arising out of $d_3/2$ taking into account three single-phase bushings as specified in Figure 2.

Transformer tolerances for a typical direct connection of a three-phase power transformer connected to a single-phase gas-insulated metal enclosed switchgear are shown as an example in Figure 3, see also 6.4.5.

Three-phase direct connections are considered up to 170 kV with reference to Figure 4.

6.4.4 Connection between gas-insulated transformer and switchgear

In case of a gas insulated transformer, the standard dimensions of Figure 2 could be inappropriate. Therefore, the detailed dimensions of the direct connection between the gas insulated power transformer and the gas-insulated metal-enclosed switchgear will deviate. It is the responsibility of the switchgear manufacturer and the transformer manufacturer to define it. This connection can take place by using a partition rather than a bushing.

NOTE For direct connection between gas-insulated transformer and switchgear there is little experience currently.

6.4.5 Transformer tolerances

Tolerances shown in Figure 3 and Figure 4 are given for guidance as reference tolerances permitted after installation of the transformer ready for operation including the installed bushings.

6.4.6 Mounting of the transformer on its foundation

Transformers with direct connections shall be supplied with appropriate jacking pads for lifting and appropriate angles for the fixing of the transformer on its foundation; both facilities allowing a horizontal and vertical movement to adapt to the needs for the connection to the switchgear.

Care shall be taken for mounting the transformer on its foundation in order not to restrict the allowable operation tolerances in Figure 3 and Figure 4 when directly connected to a switchgear.

Transformers installed on rails usually do not comply with this requirement.

To comply with the requirement of a horizontal movement of the transformer during installation and not interfering with the installation process, either in indoor or outdoor, it is best practice in civil engineering for such purpose to apply anchor bolts in conjunction with the usage of corrugated permanent formwork.

6.5 Limits of supply

A typical direct connection is shown in Figure 1.

The limits of supply of the switchgear manufacturer and transformer manufacturer shall be according to Figure 1.

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To minimize circulating currents between the switchgear and the transformer, bonding conductors according to IEC 61936-1 shall be provided by the switchgear manufacturer between the different single-phase switchgear enclosures; capable of carrying continuously the rated current of the transformer in normal operation. If circulating currents higher than 250 A are expected via the single-phase transformer connection enclosure, an insulated junction between the GIS and the transformer is necessary, see Figure 1 Part 9. This applies to the direct connection of three-phase and single-phase power transformers according to IEC 60076 series.

NOTE 1 The tank of a transformer is not designed to carry any considerable undefined continuous circulating currents. Practical experiences have shown that a load current of up to 1 250 A can be carried without additional precautions in the enclosure of the interface between the GIS and the transformer. This is due to the fact that approximately 80 % of the load current is carried by the bonding conductor of the switchgear, to be installed preferably at the end of the switchgear enclosure at the transformer. Thus, approximately 20 % of the load current, therefore up to 250 A, could generate continuous circulating currents in the transformer enclosure. The confirmation of the current value in the bonding conductor and through the transformer enclosure can be made by calculation.

NOTE 2 In case of higher circulating currents the user will clarify with the transformer manufacturer to confirm the maximum acceptable current via the transformer encapsulation to avoid the insulated junction, if possible.

An insulated junction may be also needed to achieve isolation between the transformer tank and the neighbouring earthed switchgear enclosures, and to achieve correct operation of the user's protection schemes for GIS and transformer faults.

The insulation level across the insulated junction shall be designed to withstand a power-frequency test voltage of 5 kV RMS, for 1 min.

To limit the very-fast-front transient ground potential rises which may occur when a switching device operates, non-linear resistors may be connected in parallel with the insulated junction. The number and the characteristics of the non-linear resistors shall be determined by the switchgear manufacturer. See [10].

According to this document two different locations (shown in Figure 1) are acceptable for the insulated junction

a) location "A" between the flange of the transformer connection enclosure, part 6 in Figure 1, and the flange of the bushing, part 10 in Figure 1, or

b) location "B" between the transformer connection enclosure, part 6 in Figure 1, and the next switchgear housing, part 14 in Figure 1.

If the insulated junction is needed, the standard dimensions in accordance with Clause 8 shall be kept.

Independent of the existence of an insulated junction, bonding conductors between the single-phase enclosures of the switchgear need to be provided by the switchgear manufacturer in accordance with IEC 61936-1 and IEC 62271-203.

Bonding conductors always need to be provided between single-phase enclosed direct connection arrangements of single-phase, two-phase or three-phase transformers.

Bonding conductors need not be provided for a three-phase transformer with a three-phase enclosed direct connection arrangement.

In the case of not having an insulated junction, bonding conductors shall be designed to limit the circulating current via the transformer tank to the permitted values as specified in this clause.

Both with and without an insulated junction the appropriate bonding connection shall be made at the end of the transformer connection enclosure towards the bushing, i.e. location marked "A" in Figure 1.

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In case of location marked "B" in Figure 1 the bonding conductor shall be made at the end of the switchgear housing towards the bushing.

The transformer, including the bushing, shall be designed according to the relevant product standards to withstand very-fast-front overvoltage (VFFO) generated by the switchgear.

If an insulated junction is applied, its design shall be also able to withstand the same value of the very fast transient overvoltages generated by the switchgear.

NOTE 3 Alternatively to the insulating junction an insulating spacer can be used.

6.6 Mechanical forces applied on the connection interface

Normal loads, whose occurrence and level can be planned or predicted, applicable to bushings at the connection interface (parts 3 and 4 in Figure 1) are given in IEC 60137:2017, Table 1, level I (see cantilever operating loads); the minimum normal load however shall not be less than 2 kN, acting either transversely or axially to the connection interface. Table 1 of IEC 60137:2017 gives values for bushing installed up to 30° from the vertical.

If higher normal loads are to be expected at the connection interface, then the higher loads shall be selected from IEC 60137:2017, Table 1, Level II (heavy load).

For exceptional circumstances, whose probability of occurrence during lifetime of products is very small or accidental (e.g. short-circuit current or seismic loads), the cantilever test load level II of Table 1 in IEC 60137:2017 shall be used.

In case of seismic requirements as special service conditions according to subclause 4.2 of IEC 62271-203:2022, a seismic calculation shall be carried out to identify the location of mechanical reinforcements, see IEC 62271-207.

NOTE IEC 62271-207 covers seismic qualification requirements, test procedures for qualifications, qualification by combined tests and numerical analysis and evaluation of the seismic qualification.

It is the responsibility of the switchgear manufacturer to ensure that the seismic loads are not exceeding the specified load level II of Table 1 in IEC 60137:2017 or to agree with the bushing manufacturer that the bushing shall withstand the higher forces.

The selection of the appropriate bushing is under the responsibility of the transformer manufacturer considering the maximum occurring short circuit forces between phase and ground, respectively also between phases in the case of a three-phase enclosure at both ends of the bushing.

In the case of different rated withstand currents of the GIS in respect to those of the transformer, the higher rated withstand currents apply to calculate the mechanical forces to be supported by the connection interface.

6.7 Mechanical forces applied on the bushing flange

The flange of the bushing attached to the transformer connection enclosure is subjected in service, in addition to the maximum external operating gas pressure inside the transformer connection enclosure of the GIS, to the following loads:

– part of the weight of the switchgear not supported by the switchgear's own supporting structures;
– part of the wind load, if applicable, not supported by the switchgear's own supporting structures;
– expansion or contraction stresses due to the temperature variations of the transformer tank and the gas-insulated switchgear (GIS) enclosure.

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