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TECHNICAL REPORT

colour inside

High-voltage switchgear and controlgear –
Part 312: Guidance for the transferability of type tests of high-voltage/low-voltage prefabricated substations

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 312: Guidance for the transferability of type tests of high-voltage/low-voltage prefabricated substations

FOREWORD

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IEC TR 62271-312, which is a Technical Report, has been prepared by subcommittee 17C: Assemblies, of IEC technical committee 17: High-voltage switchgear and controlgear.

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

Draft TR	Report on voting
17C/737/DTR	17C/753B/RVDTR

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

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

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.

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- withdrawn,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.

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HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 312: Guidance for the transferability of type tests of high-voltage/low-voltage prefabricated substations

1 Scope

This document refers to high-voltage / low-voltage prefabricated substations (hereinafter prefabricated substations) as specified in IEC 62271-202:2014.

This document, among other options as agreed between manufacturer and user, can be used for the transferability of type tests performed on one or more prefabricated substations with a defined set of ratings and arrangement of components to another prefabricated substation with a different set of ratings or different arrangement of components. It supports the selection of appropriate representative test objects for that purpose in order to optimize the type testing procedure for a consistent conformity assessment.

This document utilises a combination of sound technical and physical principles, manufacturer and user experience and mutually agreed upon methods of calculation to establish pragmatic guidance for the transferability of type test results, covering various design and rating aspects.

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 60050-441:1984, *International Electrotechnical Vocabulary (IEV) – Part 441: Switchgear, controlgear and fuses*
IEC 60050-441:1984/AMD1:2000

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

IEC 60076-2, *Power transformers – Part 2: Temperature rise for liquid-immersed transformers*

IEC 60076-7, *Power transformers – Part 7: Loading guide for mineral-oil-immersed power transformers*

IEC 60076-11, *Power transformers – Part 11: Dry-type transformers*

IEC 60076-12, *Power transformers – Part 12: Loading guide for dry-type power transformers*

IEC 60282-1:2020, *High-voltage fuses – Part 1: Current-limiting fuses*

IEC 61439-1:2020, *Low-voltage switchgear and controlgear assemblies – Part 1: General rules*

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

IEC 62271-200:2011, *High-voltage switchgear and controlgear – Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV*

IEC 62271-202:2014, *High-voltage switchgear and controlgear – Part 202: High-voltage/low-voltage prefabricated substation*

IEC TR 62271-208:2009, *High-voltage switchgear and controlgear – Part 208: Methods to quantify the steady state, power-frequency electromagnetic fields generated by HV switchgear assemblies and HV/LV prefabricated substations*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-441, IEC 62271-202 and the following apply.

NOTE Some standard terms and definitions are recalled here for ease of reference.

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
prefabricated substation
prefabricated and type-tested assembly comprising an enclosure containing in general power transformers, high-voltage and low-voltage switchgear and controlgear, high-voltage and low-voltage interconnections, auxiliary equipment and circuits

Note 1 to entry: The term type-tested assembly includes prefabricated substations verified based on the transferability of type test results in accordance with this document.

[SOURCE: IEC 62271-202:2014, 3.101, modified – New Note 1 to entry.]

3.2
prefabricated substation under consideration
prefabricated substation being verified based on the transferability of type test results in accordance with this document

3.3
component
essential part of the prefabricated substation, which serves one or several specific functions

Note 1 to entry: Examples of components include power transformer, high-voltage switchgear and controlgear, low-voltage switchgear and controlgear, etc.

[SOURCE: IEC 62271-202:2014, 3.105, modified – Addition of "power" in Note 1 to entry.]

3.4
enclosure
part of a prefabricated substation providing protection against external influences to the components and a specified degree of protection for operators and the general public with respect to approach to, or contact with, live parts and against contact with moving parts

[SOURCE: IEC 62271-202:2014, 3.103, modified – Replacing “substation” by “components" in the definition.]

3.5
class of enclosure
difference of temperature rise between the power transformer in the enclosure and the same power transformer outside the enclosure at normal operating conditions

[SOURCE: IEC 62271-202:2014, 3.112, modified – In the definition, "power" was added, "normal service conditions as defined in 2.1" was replaced by "normal operating condition", and the note was deleted.]

3.6
compartment
part of a prefabricated substation enclosed except for openings necessary for interconnection, control or ventilation

Note 1 to entry: A compartment can be designated by the component contained therein, for example, power transformer, high-voltage switchgear and controlgear, low-voltage switchgear and controlgear respectively.

[SOURCE: IEC 62271-202:2014, 3.104, modified – In Note 1 to entry, addition of "power".]

3.7
prefabricated substation layout
three-dimensional spatial arrangement of main components, covers, doors, ventilation openings and compartments, if any

Note 1 to entry: Relative clearances and distances from main components to one another and to the enclosure can vary.

3.8
high-voltage switchgear compartment
compartment inside the prefabricated substation where the high-voltage switchgear and controlgear or high-voltage electrical protection of the circuit is installed

3.9
switchgear and controlgear
general term covering switching devices and their combination with associated control, measuring, protective and regulating equipment, also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures

[SOURCE: IEC 60050-441:1984, 441-11-01]

3.10
family of high-voltage switchgear and controlgear
functional units designed to be physically combined in assemblies and providing a range of ratings and characteristics (e.g. current, voltage, degree of protection)

[SOURCE: IEC TR 62271-307:2015, 2.102, modified – Addition of "high-voltage" in the term.]

3.11
main circuit
all conductive parts of a prefabricated substation included in a circuit which is intended to transmit electrical energy

[SOURCE: IEC 62271-202:2014, 3.107]

3.12
high-voltage interconnection
electrical connection between the terminals of the high-voltage switchgear and controlgear and the high-voltage terminals of the power transformer

[SOURCE: IEC 62271-202:2014, 3.105.1, modified – Replacing "high-voltage/low-voltage power transformer" by “power transformer” in the definition.]

3.13
low-voltage interconnection
electrical connection between the low-voltage terminals of the power transformer and the incoming terminals of the low-voltage switchgear and controlgear

[SOURCE: IEC 62271-202:2014, 3.105.2, modified – Replacing "high-voltage/low-voltage power transformer" by "power transformer" in the definition.]

3.14
test object
item submitted to a test, including any accessories, unless otherwise specified

[SOURCE: IEC 60050-151:2001, 151-16-28]

3.15
transferability criteria
principle for evaluating based on the design parameters, which can be applied to validate the performance of an untested prefabricated substation based on the positive results of a test performed on another prefabricated substation for a specific characteristic

4 Use of transferability criteria

4.1 General

Because of the variety of types of prefabricated substations, size of enclosures, layout and different types of components, it is neither practical nor affordable to perform type tests with all the possible variations and combinations. Therefore, the performance of a particular prefabricated substation can be evaluated with reference to type test reports of other prefabricated substation(s). This document gives support for the transferability of type test results concerning the following characteristics according to 6.1 of IEC 62271-202:2014:

- temperature rise;
- dielectric;
- electromagnetic field;
- mechanical;
- short-circuit; and
- internal arc.

Subclauses 5.2 to 5.7 provide, for each kind of characteristic, a non-exhaustive list of design parameters, which should be analysed for the transferability of type test results.

The analysis should be based on sound technical and physical principles and may be supported by calculations, if applicable.

For each characteristic, the design parameters of the prefabricated substation under consideration, listed in the respective column of Table 2 to Table 7, should be compared with the design parameters of the already type-tested prefabricated substation(s) by applying the transferability criteria provided in the same tables. The affirmation of every transferability criteria for a determined characteristic supports the type test results transferability from the original prefabricated substation(s) to the prefabricated substation under consideration. The transferability of the type test results of a particular characteristic does not imply immediate acceptance of other characteristic(s), as each characteristic should be independently assessed. For example, the affirmation of item 7 in Table 2 for transferability assessment of temperature rise type test results reads: power transformer total losses of the prefabricated substation under consideration should be equal or smaller than those of the type-tested prefabricated substation.

If any of the transferability criteria cannot be affirmed, further evidence e.g. by technical arguments, calculation or simulation, or specific tests may be used and it can be subjected to agreement between the manufacturer and the user. Calculations can only be applied in a comparative sense as indicated in 4.3.

4.2 Design parameters for transferability criteria

Some ratings of a prefabricated substation are not linked to the parameters of specific main components. For example, a layout change can significantly affect the performance of a prefabricated substation characteristic.

The criteria for the transferability of type test results available for a prefabricated substation depend on a number of design parameters such as the examples listed in Table 1. Every prefabricated substation is characterized by its own set of design parameters.

The transferability of type test results of a component with regard to its particular product standard is outside the scope of this document.

Table 1 – Examples of design parameters

Design parameter
Thermal conductivity of enclosure material (steel, reinforced concrete, polyester)
Insulation type of the power transformer (oil- or dry-type)
Effective cross-section of ventilation openings (inlet and outlet)
Degree of protection (IP code) of the enclosure
Distance from components incorporating the main circuits of a prefabricated substation to the enclosure
Mechanical strength of the enclosure roof material
Material of high voltage interconnections conductors
Design, position and cross-section area of gas flow cooling device(s)
NOTE This table includes examples only; it is not intended to be complete.

4.3 Use of calculations

4.3.1 General

For the purpose of this document, calculations and simulations may only be applied in a comparative sense. Calculation results available for a type-tested prefabricated substation can be used for validation and be compared with calculation results obtained for the prefabricated substation under consideration. The comparison is always based on the design parameters and the acceptance criteria provided in Table 2 to Table 7.

In many cases the performance of a given prefabricated substation, with respect to a particular type test, cannot be evaluated by a single value of a design parameter due to the complexity of the design. For example, the low-voltage interconnection layout can vary considerably along the current path. Calculations have the potential to compare the respective design parameter with spatial resolution supporting a comparison using technical arguments and expertise.

Depending on the type test and the particular design parameter, sometimes a simple model of the relevant prefabricated substation can be sufficient using an analytical or empirical formula, and sometimes a complete three-dimensional simulation model should be required using a complex numerical tool provided that the results of the simulation tool are consistent and repeatable.

The validation of software tools and calculation methods themselves is outside the scope of this document. Some of these calculation methods are briefly mentioned below as examples.

4.3.2 Temperature rise calculations

The assessment procedure is applied to the prefabricated substation under consideration taking into account the total losses generated inside the prefabricated substation, the layout, and the area and mounting conditions of the enclosure walls and the effective area of the ventilation openings. The air temperature inside the enclosure in various locations is the parameter to compare.

For complex geometries, a comparison may be performed by thermal networks, where the whole assembly with all components is divided into discrete elements built from heat generating resistors and heat conducting and convection elements. Furthermore, more complex CFD tools (computational fluid dynamics) or other techniques such as nodal tools may be applied requiring a complete three-dimensional model of the prefabricated substation and main components.

IEC 61439-1 gives conditions for the verification of temperature rise by calculation and IEC TR 60890 [1][1] provides calculation procedures for low voltage assemblies, which can also be applied to a prefabricated substation while having due regard for the particular limitations of this calculation method.

4.3.3 Electric field calculations

Since IEC 62271-202:2014 only requires dielectric type tests on interconnections between the main components (i.e. interconnection between the high-voltage switchgear and controlgear and the power transformer and interconnection between the power transformer and the low-voltage switchgear and controlgear), the dielectric withstand performance of two prefabricated substations may be assessed by an electric field simulation of both designs comparing the resulting electric field strengths.

When the installation conditions can affect their dielectric withstand, finite element (FE) or finite volume (FV) software tools exist, which allows the simulation of complex three-dimensional geometries. It should be noted that this document does not provide information for the extrapolation but only for the interpolation of design parameters, e.g. extending validity to higher values of electric field strengths is not covered.

4.3.4 Electromagnetic field calculations

In case the reference prefabricated substation has been evaluated following the calculation methodology described in IEC TR 62271-208, the same procedure should be applied to the prefabricated substation under consideration in a comparative sense.

4.3.5 Mechanical stress calculations

The mathematical methods of calculation make provision for the full assessment in relation to the mechanical withstand capability of the enclosure. Furthermore, national structural codes and other local regulations may also make provision for the assessment in relation to the mechanical withstand capability of the enclosure.

4.3.6 Short-circuit current calculations

This subclause may only be applied to the interconnection between the components, (i.e. interconnection between the high-voltage switchgear and controlgear and the power transformer and interconnection between the power transformer and the low-voltage switchgear and controlgear) and the earthing circuit of the prefabricated substation.

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

With respect to the short-time and peak current withstand performance, guidance and calculation formulas for bus-bar designs can be found in IEC 60865-1 [4] and IEC TR 60865-2 [5]. This includes the determination of mutual electromagnetic forces between phase conductors and the resulting mechanical stresses, which may overstress conductors and damage insulators. The mechanical stresses on conductors and forces on the supports may be assessed through stress analysis programs, when applying the calculated electro-magnetic forces. Additionally, a calculation of the thermal stress using $I_k^2 t_k$ can be done when the assessment is made for a lower I_k and higher t_k than those tested, considering that short-time withstand current (I_k) and duration of short-circuit (t_k) are in accordance with 4.5 and 4.7 of IEC 62271-202:2014.

4.3.7 Internal arc calculations

The assessment of the effects of an internal arc inside of a prefabricated substation may be substantiated by pressure-rise calculations and hot gas flow simulations for the compartments, exhausting ducts and pressure relief volumes [7, 8].

The calculations are able to provide the pressure-rise in the compartments under consideration. They also provide parameters for the mechanical strength design of pressure relief device elements, if any. An assessment of the strength of the enclosure walls under the pressure stress can be made for simple geometries using calculation formula, or otherwise using finite element mechanical stress analysis.

The flow of hot gases expelled from the high-voltage switchgear and controlgear or high-voltage interconnection in the event of an internal arc, may be simulated by computational fluid dynamics (CFD) programs.

However, it is, at the time of the publication of this document, not possible to simulate the ignition of indicators, which is an important acceptance criterion in the type test.

4.4 Information needed for transferability of type test results

Prefabricated substation type test reports include general arrangement drawings and component ratings. However, it may not contain sufficient or precise information about some design aspects (e.g. layout, clearance distances) necessary for the transferability assessment of a given characteristic. For the transferability of type test results, the Table 2 to Table 7 should be used to provide the required information for each design parameter of both prefabricated substations. Only the table that is relevant for the characteristic under evaluation may be used.

The applicable type test reports of the type-tested prefabricated substation should be provided in as far as they are concerned with the transferability assessment.

It is recommended that the manufacturer provides the relevant information on the design parameters of the type-tested prefabricated substation to be included in any type test report in addition to the information required by the product standards. See Annex B for general guidance on information that should be included in a type test report.

Most often single value design parameters are not sufficient to perform the evaluation. In this case, relevant drawings of both objects may be necessary.

If a comparison is substantiated by calculations, numerical data or by formula, the type of software used, the reference number of the calculation report and short summary of the input parameters and results should be given.

Documents providing traceability of the analysis performed may be established. Such documents should form part of the report for the transferability of type test results to the prefabricated substation under consideration.

5 Application of transferability criteria

5.1 General

Various design parameters have been considered in addition to those provided in 5.2 to 5.7, the impact of which are considered to be sufficiently negligible. To facilitate a practical transferability process, only those design parameters which could reasonably influence the transferability of type test results from the type-tested object to the prefabricated substation under consideration have been provided in this document.

5.2 Temperature rise tests

The transferability criteria for the temperature rise performance of a prefabricated substation are summarised in Table 2. The objective is to ensure that the temperature rise of each component within the prefabricated substation under consideration is equal or lower when compared to the type-tested prefabricated substation. Furthermore, the design parameters and associated acceptance criteria are intended to ensure that each component operates at an internal ambient temperature equal to or lower than that of the type-tested object.

For transferability of temperature rise type test results, the rated class of enclosure shall be the same. Therefore, it is not possible to assign a different class of enclosure without further type testing.

A temperature rise assessment of the high voltage switchgear and controlgear is not required. Refer to 6.5.102 of IEC 62271-202:2014.

NOTE The assessment of the low-voltage assemblies used within prefabricated substations can be done in accordance with 10.10.3 of IEC 61439-1:2020.

This list of design parameters does not consider prefabricated substations with forced ventilation for the transferability of temperature rise type test results because this type of ventilation is out of the scope of IEC 62271-202:2014.

Table 2 – Transferability criteria for temperature rise performance

Item	Design parameter	Acceptance criterion	Condition
(1)	(2)	(3)	(4)
1	Layout and enclosure		
1.1	Type of the substation	same	Same type of substation (non-walk-in type vs. walk-in type). Same prefabricated substation layout. Same class of enclosure
1.2	Prefabricated substation compartment volume(s)	≥	
1.3	Thermal conductivity of material(s) – walls – roof – doors and covers	≥	NOTE 1
1.4	Degree of protection (IP code)	≤	IEC 60529 [11]
2	Ventilation openings		
2.1	Air inlet cross-section area	≥	NOTE 2
2.2	Air outlet cross-section area	≥	NOTE 2
2.3	Air outlet/air inlet cross-section ratio	≥	

Item	Design parameter	Acceptance criterion	Condition
(1)	(2)	(3)	(4)
2.4	Air drag coefficient [ζ] of the ventilation openings, if any	≤	In the absence of air-drag coefficient, the type of ventilation openings should be the same. NOTE 3
3	Difference in height between mid-points of the air inlet and air outlet ventilation openings	≥	
4	Clearance between low-voltage switchgear and controlgear and the power transformer	≥	Only applicable if both components are in the same compartment
5	Difference in height from mid-point of the tank of the oil-filed power transformer or the mid-point of the winding of a dry-type power transformer to the mid-point of the corresponding air outlet ventilation opening	≥	
6	Power transformer insulation type (oil or dry-type)	same	
7	Power transformer total losses	≤	
8	Maximum current of the low-voltage circuit	≤	Rated current of the low-voltage assembly, according to IEC 61439-1, may be equal or higher than the maximum current of the low-voltage circuit. NOTE 4
9	Type and arrangement of interconnections (e.g. solid bars vs. cable, vertical bars vs. horizontal bars)	same	NOTE 4
NOTE 1 Solar radiation is not considered. NOTE 2 The cross-section area of a ventilation opening is the smallest area perpendicular to the air flow direction. NOTE 3 See A.2.2 for air-drag coefficient [ζ] definition. NOTE 4 The conductor material, cross-section, number of conductors/phase and lengths can vary with due consideration of the temperature rise limits of high-voltage and low-voltage interconnections given in Table 14 of IEC 62271-1:2011 and Table 6 of IEC 61439-1:2011 respectively.			

5.3 Dielectric tests

The prefabricated substation shall be verified with respect to its dielectric performance. In accordance with 6.2 of IEC 62271-202:2014, since the high-voltage switchgear and controlgear, power transformer(s) and low-voltage switchgear and controlgear contained in a prefabricated substation should be type-tested with respect to their own relevant standards, this subclause primarily applies to the interconnections between the main components when changes to their design and/or installation arrangements affects their dielectric withstand capability.

NOTE The assessment of high-voltage metal-enclosed switchgear and controlgear and of high-voltage solid-insulation enclosed [2] switchgear and controlgear assemblies used within prefabricated substations can be done in accordance with IEC TR 62271-307 [3].

The criteria listed in Table 3 should be affirmed, where applicable, for

– the interconnection between the high-voltage switchgear and controlgear and the power transformer;

– the interconnection between the power transformer and the low-voltage switchgear and controlgear.

For the high-voltage interconnection, the transferability criteria are only applicable when the interconnection is required to be subjected to dielectric tests according to 6.2.101.1 of IEC 62271-202:2014. Exempted are therefore those interconnections made of earth-shielded high-voltage cables connected using type-tested earth-shielded connectors or by other types of terminations which have been type-tested on both sides, the high-voltage switchgear and controlgear and the power transformer, in the same installation conditions within the prefabricated substation.

If necessary for dielectric performance, insulating barriers and supplementary insulation may have been included in the type-tested object(s) according to 6.2.101 and 6.2.102 of IEC 62271-202:2014 and therefore transferability of type test assessment may only be performed on interconnections having a similar arrangement and design of such insulation.

The impact of insulating barriers and/or additional insulation is difficult to assess. Changes in the design of such insulating parts can normally impede the transferability of type test results, unless it can be evinced that the design change is insignificant.

The transferability criteria of Table 3 are also applicable to the following two situations where dielectric type tests are required by IEC 62271-202:

– where non-earth-shielded high-voltage interconnections are used within enclosures made of non-conductive material, the insulation between the non-earth-shielded live parts of the interconnection and the enclosures shall withstand the dielectric tests in accordance with 6.2.101.2.2 of IEC 62271-202:2014;
– where the low-voltage interconnections are partially or totally covered by a non-metallic enclosure, the arrangement shall withstand the dielectric tests in accordance with 6.2.102 of IEC 62271-202:2014.

Table 3 – Transferability criteria for dielectric withstand performance

Item	Design parameter	Acceptance criterion	Condition
(1)	(2)	(3)	(4)
1	Rated voltage(s) and insulation level(s)	≤	
2	Clearance between phases	≥	
3	Clearance to earth	≥	
4	Creepage distance	≥	NOTE 1
5	Electrical properties of insulating material(s) of interconnections and enclosures of non-conductive material	≥	A comparative result between two materials might be required (e.g. Comparative Tracking Index according to IEC 60112 [9], evaluating resistance to tracking and erosion according IEC 60587 [10])
6	Surface roughness of live parts	≤	
7	Radius of conductive parts	≥	Not only the radius of live parts, but also the radius of all other conductive parts facing live parts (e.g. earthing devices, enclosure, LV wiring, supporting structures) should be considered. NOTE 2

NOTE 1 The field distribution along the insulating surface is also relevant.

NOTE 2 The geometry of insulated conductive parts and other insulating materials affects the electric field as well.

5.4 Electromagnetic field tests

Guidance for measurement of electromagnetic fields generated by prefabricated substations is given in IEC TR 62271-208.

The transferability of electromagnetic type test results only applies to electromagnetic field outside the prefabricated substation with all covers and doors in closed position in normal service conditions.

NOTE Apart from the main components (e.g. switchgear and controlgear, power transformer, etc.) and high-voltage and low-voltage interconnections placed within a prefabricated substation, the electric and magnetic fields in service are dependent on the physical arrangement and installation conditions of incoming and outgoing cables and their loads, which is outside the scope of this document.

The evaluation of a prefabricated substation can be carried out based on an existing report from a type-tested prefabricated substation. The transferability criteria listed in Table 4 should be taken into consideration for the assessment.

Table 4 – Transferability criteria for electromagnetic field performance

Item	Related to	Design parameter	Acceptance criterion	Condition
(1)	(2)	(3)	(4)	(5)
1	Substation	Layout	same	
2	Substation	Distance from components incorporating the main circuits of a prefabricated substation to the external surface of the enclosure	≥	
3	Substation	Rated voltages of high-voltage circuits	≤	Only applicable to non-earth-shielded high-voltage circuits. The type of high-voltage switchgear and controlgear (i.e. metal-enclosed or solid insulation enclosed) should be the same. NOTE 1
4	Substation	Rated normal currents	≤	NOTE 1
5	Substation	Rated frequency	50 Hz or 60 Hz	Tests performed at 50 Hz or 60 Hz prove both frequencies
6	Enclosure	Permeability and conductivity of the enclosure material(s)	≥	
7	Interconnections	Type of interconnection shielding	same	NOTE 2
8	Interconnections	Distance between phases	≤	
9	Interconnections	Phase sequence by 2 or more cables / phase	same	
10	Power transformer	Type of insulation	same	NOTE 3
11	Low-voltage switchgear and controlgear	Distance between main circuit phases	≤	
12	Low-voltage switchgear and controlgear	Permeability and conductivity of the enclosure material	≥	If any

NOTE 1 More than one rated value is applicable: see Clause 4 of IEC 62271-202:2014.

NOTE 2 Non-shielded interconnections can be replaced by shielded interconnections in the prefabricated substation under consideration, considering that a shield is always better than no shield.

NOTE 3 Refer to type of insulation: liquid-immersed or dry-type.

5.5 Mechanical tests

The enclosure used for the prefabricated substation can be verified with respect to its ability to withstand mechanical loads and impacts. The assessment of the components used within the prefabricated substation (e.g. switchgear and controlgear, power transformer, etc.) is excluded from the scope of this document.

The ability of the prefabricated substation to withstand the following mechanical loads and impacts is to be assessed:

– wind pressure,
– roof loads, and
– mechanical impact.

The above calculations and/or tests are applicable to the enclosure of a prefabricated substation. Any changes in the design of the prefabricated substation enclosure influencing the mechanical strength might affect the ability of the enclosure to withstand wind pressure, roof loads and mechanical impact. Changes should be evaluated with respect to their influence on the mechanical strength. The transferability of type test results to the prefabricated substation under consideration may be carried out when the type-tested enclosure design and the associated arrangement and design of access doors, covers, ventilation openings and roof (as applicable) is considered to represent a mechanically equal or weaker condition.

Table 5 provides the transferability criteria to be evaluated in relation to the ability of the enclosure to withstand mechanical stress.

Table 5 – Transferability criteria for the mechanical strength of the enclosure

Item	Related to	Design parameter	Acceptance criterion	Condition
(1)	(2)	(3)	(4)	(5)
1	Walls	Basic design of enclosure walls	same	The basic design of the enclosure walls is the same, but the material(s) and dimensions may be different
		Mechanical strength of material	≥	
		Height of the enclosure walls above ground level. See NOTE 1	≤	
		Width and height of individual wall sections	≤	
		Mechanical strength of reinforcements (if applicable)	≥	
		Centre line distance between reinforcements (if applicable)	≤	
		Fastening system used to secure enclosure walls	same	
		Enclosure wall fastener fixing centres distance (if applicable)	≤	

Item	**Related to**	**Design parameter**	**Acceptance criterion**	**Condition**
(1)	(2)	(3)	(4)	(5)
2	Doors and covers	Method of mounting doors and covers (e.g. external-mounted, flush-mounted / recessed, etc.)	same	The basic design of the enclosure doors and covers are the same, but the material(s) and dimensions may be different
		Mechanical strength of material	≥	
		Height of the door above ground level. See NOTE 2	≤	
		Width and height of individual doors and covers	≤	
		Mechanical strength of reinforcements (if applicable)	≥	
		Centre line distance between reinforcements (if applicable)	≤	
		Mechanical strength of door hinges / locking mechanism / door stays / cover fasteners	≥	
		Door hinge / cover fastener fixing centres distance	≤	
3	Roof	Type of roof design and pitch (e.g. flat, single-pitched, dual-pitched (gable), etc.). See NOTE 1	same	The basic design of the enclosure roof is the same, but the material(s) and dimensions may be different
		Mechanical strength of material	≥	
		Width and length of individual roof sections	≤	
		Mechanical strength of reinforcements (if applicable)	≥	
		Centre line distance between reinforcements (if applicable)	≤	
		Mechanical strength of roof fasteners (if applicable)	≥	
		Roof fastener fixing centres distance (if applicable)	≤	
4	Ventilation openings	Type of ventilation opening design (e.g. louvre, grille, mesh, etc.)	same	The basic design of the ventilation openings is the same, but the material(s) and dimensions may be different. The number of openings and overall cross-section area of the inlet and/or outlet openings may also be different. The influence of filter material (if any) is considered to be negligible
		Mechanical strength of material	≥	
		Width and height of individual ventilation openings	≤	
		The number of openings	≤	
		Mechanical strength of reinforcements (if any)	≥	
		Centre line distance between reinforcements (if any)	≤	
		Method of fastening ventilation openings to enclosure structure (if applicable)	same	

NOTE 1 For wind pressure and roof load type test transferability purposes only.

NOTE 2 For wind pressure type test transferability purposes only.

5.6 Short-time withstand current and peak withstand current tests

Transferability of the short-time and peak withstand current type test results obtained on the main and earthing circuits of prefabricated substations to other prefabricated substations should consider the different components of the substation.

Since the high-voltage switchgear and controlgear, power transformer(s) and low-voltage switchgear and controlgear contained in a prefabricated substation have been type-tested with respect to their short-circuit current withstand capability according to their relevant standards, this subclause applies only to the high-voltage interconnections, low-voltage interconnections and earthing circuits (refer to 6.6 of IEC 62271-202:2014).

If current limiting devices were present in the type-tested prefabricated substation and protecting the interconnection, then the following extension criteria are applicable:

– self-tripping circuit-breakers: same or lower tripping values (current, time characteristic);
– the alternative type of fuse is such that the cut-off current and operating I^2t of the alternative type, as established by test-duty 1 and/or test-duty 2 of IEC 60282-1:2020, are not greater than those of the fuses used in the type-tested prefabricated substation.

Table 6 lists particular design parameters of the circuits and provides associated acceptance criteria.

Table 6 – Transferability criteria for short-time and peak withstand current performance

Item	Design parameter	Acceptance criterion	Condition
(1)	(2)	(3)	(4)
1	Rated short-time withstand currents (I_k)	≤	NOTE 1
2	Rated peak withstand currents (I_p)	≤	NOTE 1
3	Rated duration of short-circuit (t_k)	≤	NOTE 1
4	Centre distance between phase conductors	≥	
5	High-voltage interconnection layout and low-voltage interconnection layout	same	
6	Mechanical strength of conductor supports	≥	NOTE 2
7	Mechanical strength of parts used to mount conductor supports	≥	NOTE 2 and NOTE 3
8	Centre line distance between conductor supports	≤	
9	Cross-section area of conductors	≥	Connections of the conductors are scaled and have the same or greater clamping force and contact area. Conductor cross-section shape should be the same. NOTE 4 and NOTE 5
10	Type of high-voltage and low-voltage terminations	same	Both sides
11	Material of conductors	same	NOTE 4 and NOTE 5
12	Temperature class of insulating material in contact with conductors	≥	

NOTE 1 Subclauses 4.5, 4.6 and 4.7 from IEC 62271-202:2014 apply. The short-circuit duration t_k can be longer, as long as the condition for $I_k^2 t_k$ is respected, i.e. equal or smaller.

NOTE 2 Strength includes mechanical resistance to compression, traction, and bending loads.

NOTE 3 The enclosure can provide the base for the mechanical support.

NOTE 4 In case of earthing circuits, in some designs, conductors can include parts of the metallic enclosure being used as earthing circuit.

NOTE 5 Conductors include connections in the main circuit and in the earthing circuit up to the earthing terminal.

5.7 Internal arc tests

Prefabricated substations for which an internal arc classification (IAC) has been assigned have been subjected to an internal arc test for verification as specified in IEC 62271-202:2014. Depending on the purpose of the type test transferability assessment, criteria should be considered with respect to the high-voltage switchgear and controlgear and high-voltage interconnection, the type of accessibility, the substation design and layout or with respect to the IAC ratings and the installation conditions.

Internal arc gas flow depends on the substation layout and its compartments. Exhausting ducts, gas flow cooling devices, pressure relief devices and expansion volumes play a fundamental role in the heat and pressure control management during an internal arc. For the purposes of transferability of type test results, the following volumes are defined:

– Volume of high-voltage switchgear compartment (V_{HVC}): expansion volume inside the prefabricated substation where the high-voltage switchgear and controlgear is installed, excluding the volume occupied by the high-voltage switchgear and controlgear and all the other components inside the given volume segregated from all other volumes of the substation by intermediate walls and floor.

– Primary expansion volume (V_{PEV}): immediate expansion volume of the hot gases just after the high-voltage compartment where the internal arc is ignited. In some cases, the primary expansion volume is the same as the volume of the high-voltage switchgear compartment (V_{HVC}).

– Secondary expansion volume (V_{SEV}): if applicable, subsequent expansion volume behind the primary expansion volume, segregated from it by gas flow cooling devices or pressure relief devices or just an opening.

– Total net expansion volume (V_{NEV}): the sum of the primary and secondary expansion volumes.

Detailed guidance on interpretation and illustrative examples are included in Clause A.7.

In 6.102.7 of IEC 62271-202:2014, the possibility of transferring type test results to other prefabricated substation designs or representative parts of it is described just in general terms. The transferability of type test results to the prefabricated substation under consideration should consider the acceptance criteria provided in Table 7.

Table 7 – Transferability criteria for internal arc fault withstand performance

Item	Design parameter	Acceptance criteria	Condition
(1)	(2)	(3)	(4)
1	Rated arc fault current and peak current	≤	Referring to IEC 62271-200:2011, AA.4.3.2. See NOTE 1
2	Rated arc fault duration	≤	
3	HV switchgear and controlgear family	same	Referring to IEC 62271-202:2014, 6.102.7, same direction of gas flow from the internal arc
4	Layout of the prefabricated substation	same	Provided that distances between components are equal or larger than in the type-tested one
5	V_{HVC}: Volume of high-voltage switchgear compartment	≥	See A.7.5.1. See NOTE 2
6	V_{PEV}: Primary expansion volume	≥	See A.7.5.1
7	V_{NEV}: Total net expansion volume	≥	See A.7.5.1
8	Cross-section of ventilation openings	≥	Type of ventilation opening design to be the same
9	Design, position, cross-section of the cooling device(s) and gas flow	same	If any
10	Distances between high-voltage switchgear and controlgear assembly and the prefabricated substation enclosure (walls, doors, covers, roof, floor and ventilation openings)	≥	For internal arc accessibility type B, transferability of type test results cannot be done from a prefabricated substation with a height higher or equal than 1,9 m above ground to a prefabricated substation with a height lower than 1,9 m above ground level (see IEC 62271-202:2014; AA.3.2)
11	Mechanical strength of the enclosure, including partition walls, doors, covers, roof, floor and ventilation openings	≥	For all compartments affected by internal arc dynamic pressure, see items (1), (2) and (4) of Table 5
12	The shortest path length of hot gases in the last compartment to the closest ventilation opening before leaving the substation	≥	Path length measured from an arc gas flow cooling device, pressure relief devices or just an opening, if any, at the entry of the last expansion volume to the closest ventilation opening
13	Type of high-voltage electrical protection of the circuit	same	If test is needed according to IEC 62271-202:2014, Figure AA.6 and Figure AA.7
14	Type of high-voltage interconnection	same	See NOTE 3

NOTE 1 Type tests performed at 60 Hz can prove 50 Hz, type tests performed at 50 Hz with 2,6 × I_k can prove 60 Hz (IEC 62271-200:2011, AA.4.3.2).

NOTE 2 According to 6.102.3 of IEC 62271-202:2014, dummy mock-up(s) can be used to reduce volume during the test.

NOTE 3 The transferability is also valid from unscreened to screened solid insulated high-voltage interconnections.

6 Transferability of type test reports

6.1 General

The guidance for the transferability of type test reports can be applied, but is not limited to the following situations:

a) when the validity of a type test performed on one prefabricated substation design for one characteristic is transferred to another prefabricated substation design,

b) when an analysis is carried out using available type test reports from other prefabricated substation design(s) to determine if the test results validate the design of the prefabricated substation under consideration with respect to the specified characteristic,

c) when the type test validity of a previously type-tested prefabricated substation design is extended to a design modification.

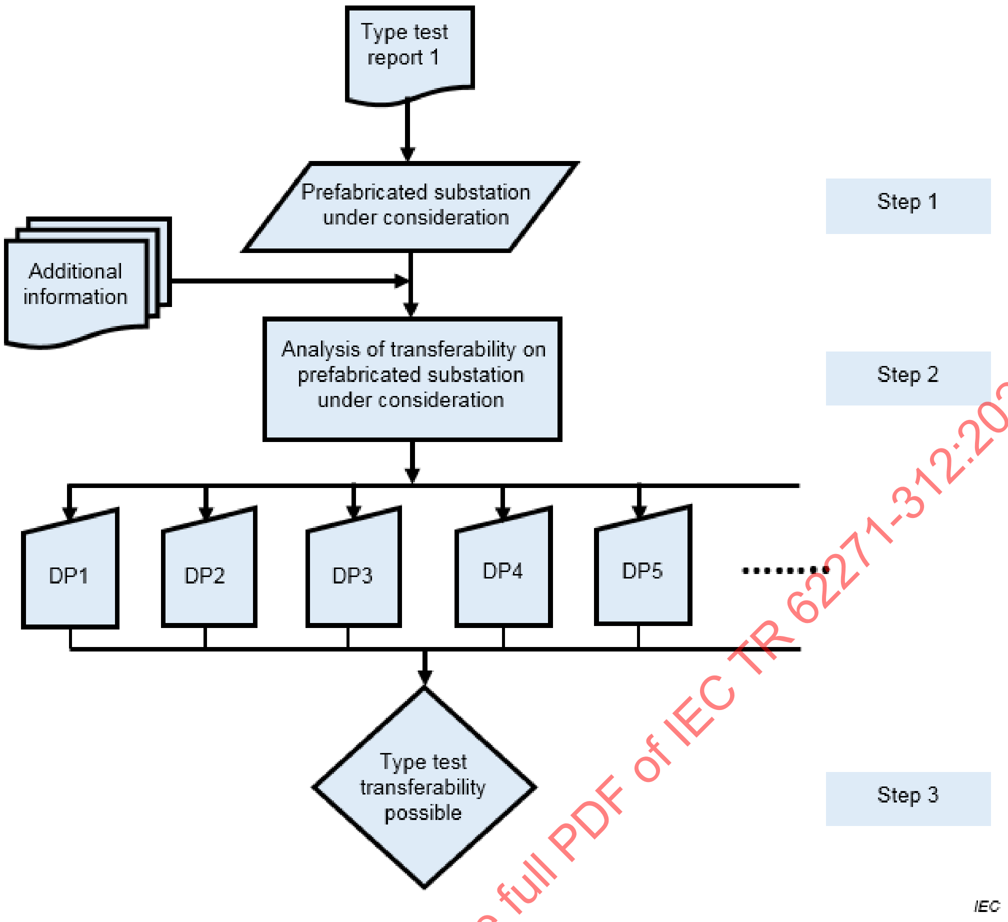
6.2 Transferability of a type test report to another prefabricated substation (situation a))

Figure 1 shows how to assess the transferability of a type test result to another prefabricated substation design by the following steps:

step 1: examine the report with respect to the description of the tested prefabricated substation and collect additional information (e.g. from referenced drawings);

step 2: compare the relevant design parameters of the tested prefabricated substation with the extension criteria proposed in Clause 4 applicable to the considered type test (e.g. difference in height between average air inlet and air outlet for the temperature rise test) by using technical arguments, calculations or simulations;

step 3: check the new prefabricated substation design to determine if it shares the same design parameters, or if it has design parameters which could be considered as covered by the tested prefabricated substation (e.g. difference in height between average air inlet and air outlet equal to or greater than that of the tested object). The check should also reveal contradicting design parameters, which may restrict the transferability of type test results concerning other characteristics.



Key

DP = design parameter

Figure 1 – Transferability of one type test report

If the new prefabricated substation design can be checked positively with respect to the proposed criteria, no further tests are required, and the available type test report is acceptable for the prefabricated substation under consideration.

6.3 Validation of a substation design by existing type test reports (situation b))

Figure 2 shows how one may check available type test reports from other prefabricated substation design(s) to determine if those test results validate a given prefabricated substation design with respect to the specified characteristic(s):

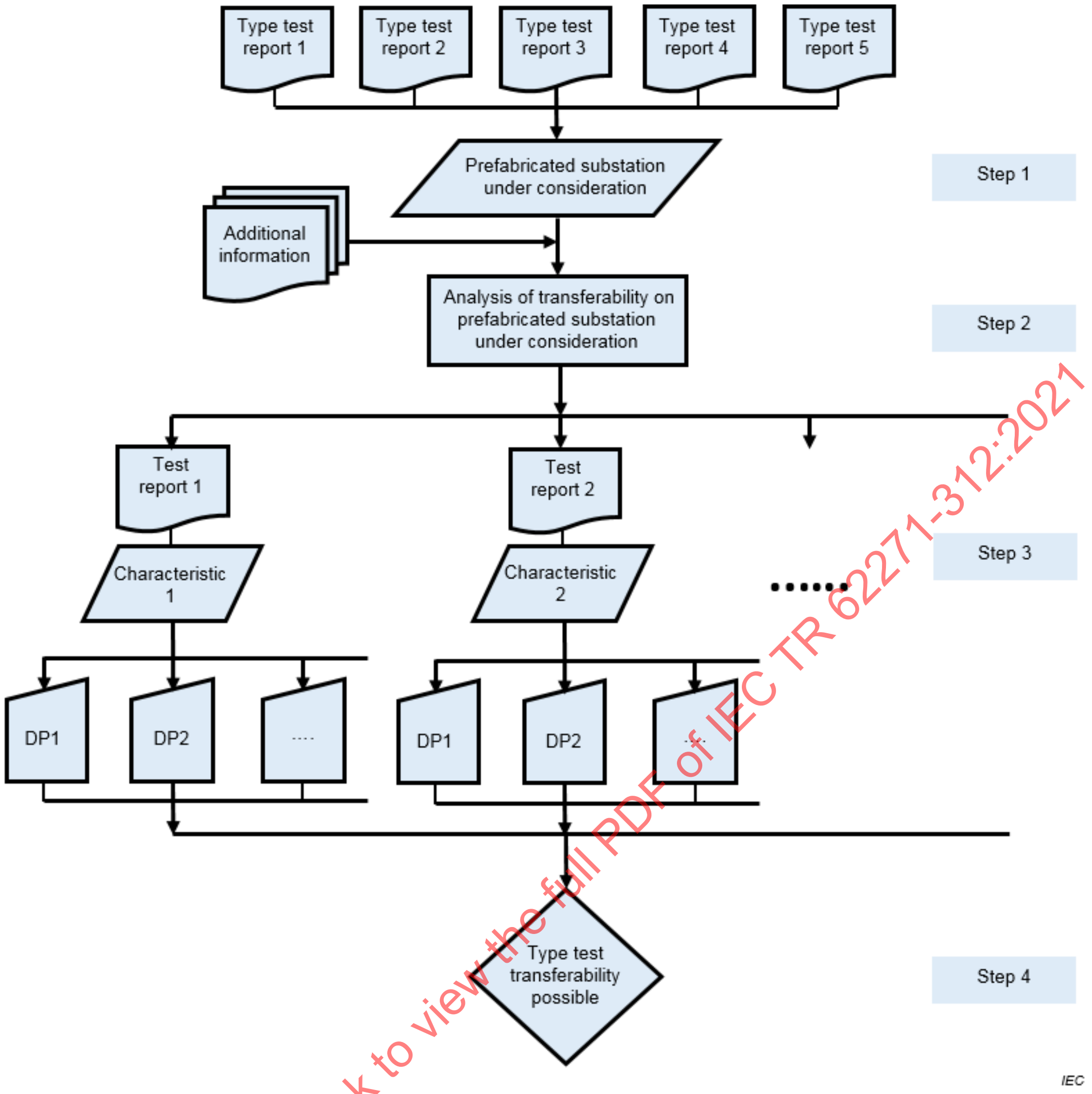
step 1: identify the layout and different components used in the prefabricated substation under consideration;

step 2: for each characteristic, identify the tested substation design from which transferability of type test results could be assessed and collect additional information (e.g. from referenced drawings) that could be useful regarding design parameters;

step 3: compare the relevant design parameters of the prefabricated substation under consideration to the considered type-tested prefabricated substation using the design parameters provided in Table 2 to Table 7 and technical arguments, calculations or simulations;

Repeat the same exercice for each characteristic.

step 4: check the available type test reports and incorporate the type test report, if appropriate, in the supporting documentation of the assessment.



Key

DP = design parameter

Figure 2 – Validation of a prefabricated substation by existing test reports

6.4 Validation of a design modification (situation c))

Situation c) may be evaluated in the same way as described for situation b) starting with the modified prefabricated substation design.

Annex A
(informative)

Rationale for the transferability criteria

A.1 General

The definition of an acceptance criterion for each of the design parameters listed in Table 2 to Table 7 rests on proven technical and physical principles and manufacturer and user experience. The evaluation of the criteria should be performed out of a generalized view assuming that the manufacturer has designed the prefabricated substation according to the same technical and physical principles on which the criteria are based. In case of doubts concerning acceptance criteria further evidence is needed to support transferability of type test results, like for example calculations or detailed drawings. In the following, those technical and physical principles, which result in the selection of extension criteria i.e. design parameters and corresponding acceptance criteria in Table 2 to Table 7, are provided.

A.2 Temperature rise

A.2.1 Layout and enclosure

A.2.1.1 General

Temperature rise performance of a prefabricated substation has significant dependence on main components layout, their relative distances to ventilation openings and clearances to the enclosure and partition walls if any. All these design parameters are grouped under the layout term.

A.2.1.2 Type of the substation (items 1.1 and 1.2 of Table 2)

For the purpose of this document, prefabricated substations, whether operated from the inside (walk-in type) or the outside (non-walk-in type), can incorporate internal compartments due to specific safety aspects or component operational or maintenance procedures. The main component layout, clearances between them and the enclosure, and distances to ventilation openings affect the temperature rise behaviour of the prefabricated substation. Because of this complex combination of factors, transferability of temperature rise type test results is only considered for the same prefabricated substation layout.

In general, the geometry of the prefabricated substation should be comparable regardless of whether it is a non-walk-in type or it is a walk-in type prefabricated substation. On the other hand, the convection flow in the volume of each compartment is relevant for the heat transfer from components to, as an example, the enclosure of the substation. Therefore, when the prefabricated substation under consideration has the same layout and equal or larger volume than the type-tested one, the transferability of type test results is possible. Figure A.1 gives examples of non-walk-in type prefabricated substations and Figure A.2 gives examples of walk-in type prefabricated substations.

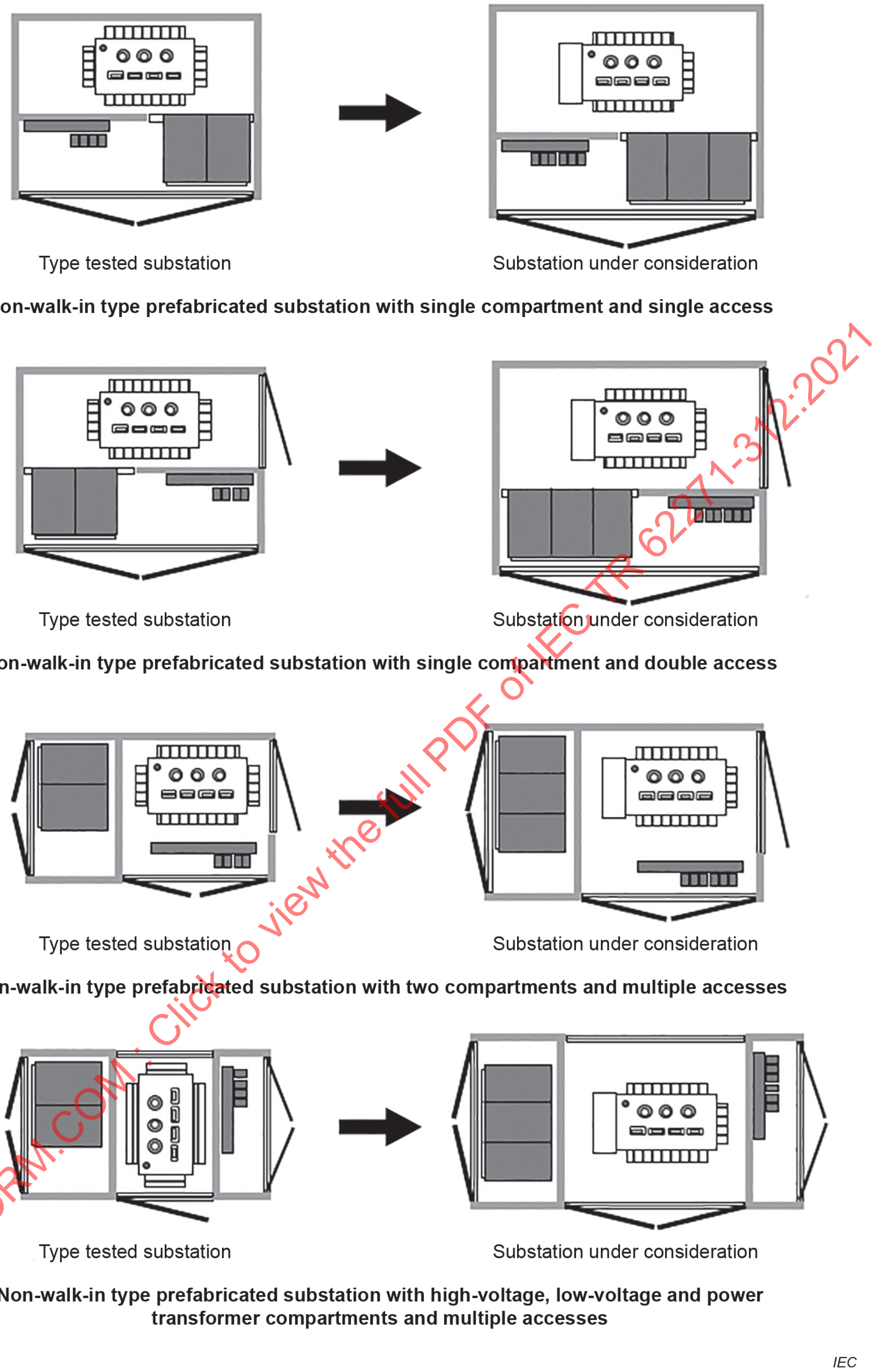


Figure A.1 – Different examples of non-walk-in type-tested prefabricated substation and related prefabricated substation under consideration

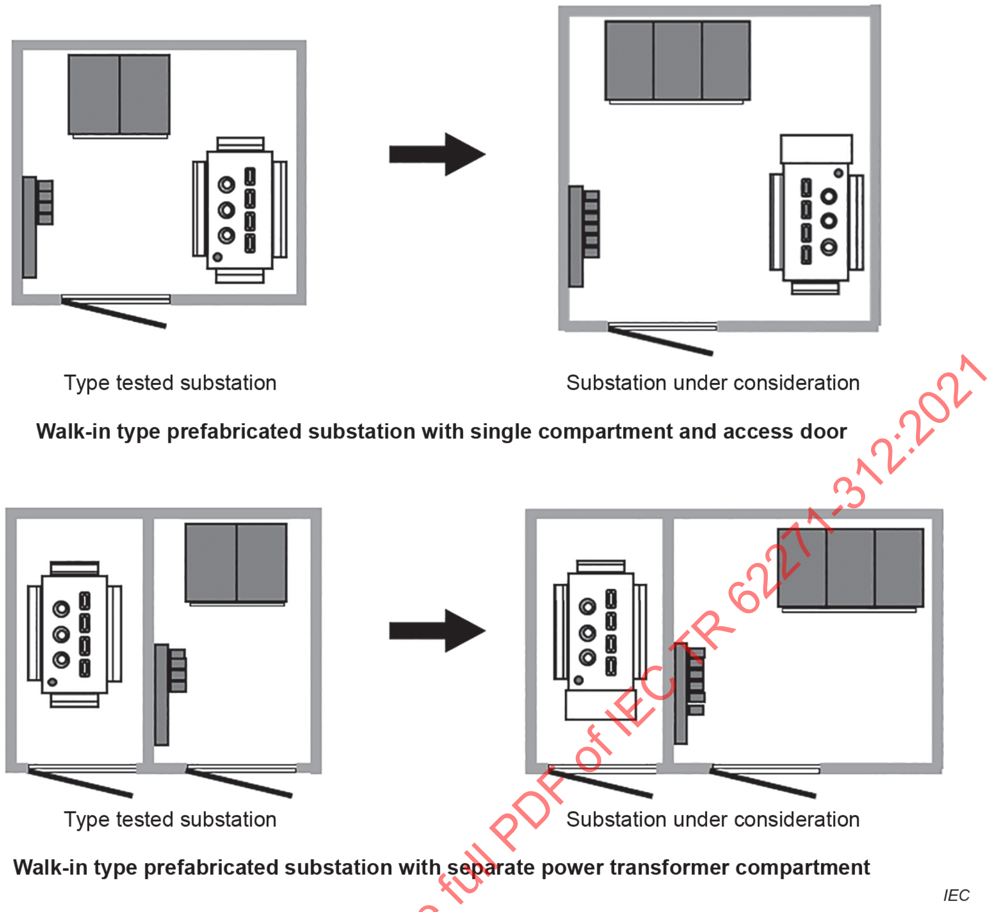


Figure A.2 – Different examples of walk-in type-tested prefabricated substation and related prefabricated substation under consideration

A.2.1.3 Thermal conductivity of material (item 1.3 of Table 2)

The thermal conductivity [W/(m K)] of the prefabricated substation enclosure depends on the material properties. The enclosure radiates a determined amount of heat and therefore has influence on a prefabricated substation temperature rise test. The thermal conductivity of the enclosure under consideration should be equal or higher than the type-tested prefabricated substation for type test results transferability assessment. Table A.1 shows some examples.

Table A.1 – Material thermal conductivity

Material	**[W/(m K)]**
Concrete	0,7÷ 1,8
Stainless steel sheet	16
Mild steel sheet	47 ÷ 58
Aluminum sheet	205
Polyester	0,05

In case of a non-homogeneous material (e.g. sandwich panel) is used for the construction of walls, covers or roof, a detailed analysis may be required to compare their thermal conductivity performance.

A.2.1.4 Degree of protection (IP code) (item 1.4 of Table 2)

The ability to evacuate heat from the prefabricated substation is critical for main components electrical performance and service continuity. The degree of protection, IP code according to IEC 60529 [11], of the prefabricated substation under consideration including enclosure, doors, ventilation openings, conduits, etc. should be equal or lower to the type-tested prefabricated substation.

A.2.2 Ventilation openings (items 2.1, 2.2, 2.3 and 2.4 of Table 2)

The number of ventilation openings, their size, type of design and their position within the enclosure determine the prefabricated substation temperature rise test results and the class of the enclosure. All these parameters influence the natural ventilation process.

Natural convection is the mechanism responsible for the evacuation of the majority amount of power losses produced by the main components in normal working conditions. The renewal of heated air is directly proportional to the net free area of ventilation openings and the ability of cooler air to replace it. The cross-section area of a ventilation opening is the smallest area perpendicular to the air flow direction. Larger ventilation openings have no negative impact on air motion while the inlet to outlet surface ratio remains equal or bigger.

Air flow resistance is dependent on the type of ventilation design. The air-drag coefficient or (flow resistance coefficient) [ζ] is a dimensionless measure of the pressure loss in a flow-through component, such as a ventilation opening. The effective cross-section area of a ventilation opening is the product of the cross-section area and the air-drag coefficient.

The same method or formula used to determine the air-drag coefficient should be used for both the type-tested prefabricated substation and the prefabricated substation under consideration.

In the absence of air-drag coefficient, the type of ventilation openings design should be the same. The Figure A.3 below shows some different design patterns.

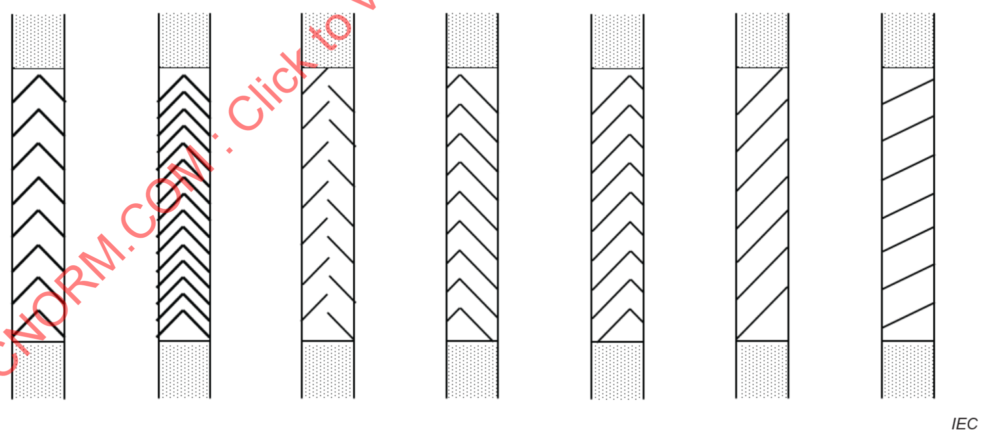


Figure A.3 – Types of ventilation opening designs

A.2.3 Distances between ventilation openings and power transformer (items 3 and 5 of Table 2)

According to fluid mechanics, the air pressure at the lower air ventilation opening is greater than at the upper ventilation opening. This pressure difference results in a net upward movement of air.

Movement of air into and out of buildings is due to difference in indoor-to-outdoor air density resulting from temperature and moisture differences. The greater the thermal difference and the height between air inlet and outlet of the prefabricated substation (see Figure A.4), the greater the movement of air into and out of the enclosure.

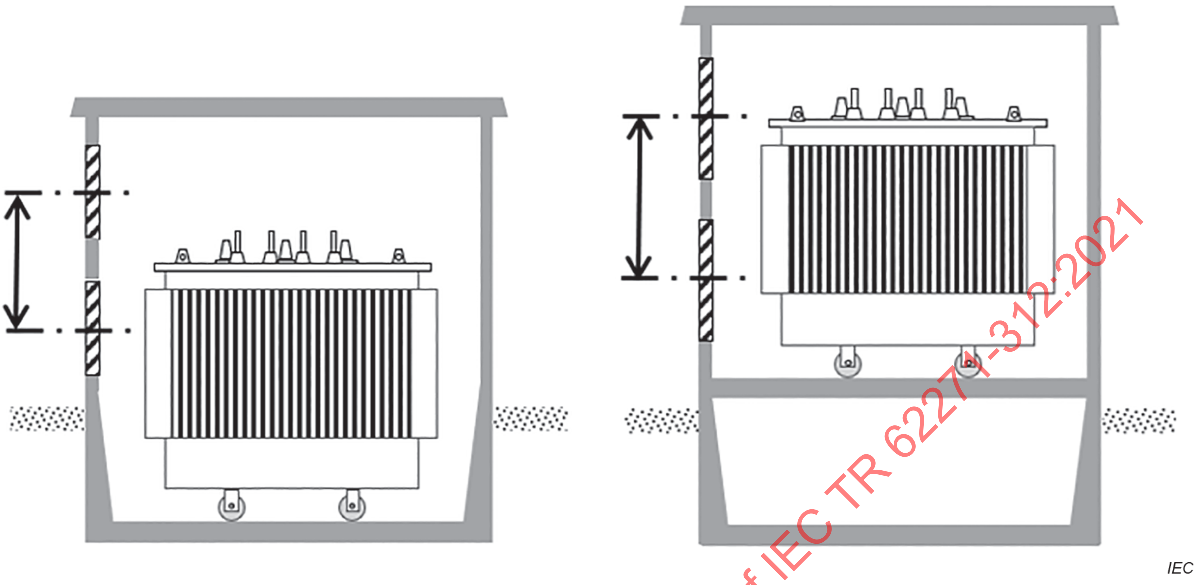


Figure A.4 – Distance from air inlet and air outlet ventilation openings

When cooler inlet air is heated, resulting in natural convection, heat energy is transferred from the bottom to top as a result of differences in fluid density. The greater the distance, the bigger the difference in air density and heat energy transfer. For transferability of type test results the distance between heat source (power transformer mid-point) and air outlet mid-point in the prefabricated substation under consideration (see Figure A.5) should be equal or greater than the type-tested one.

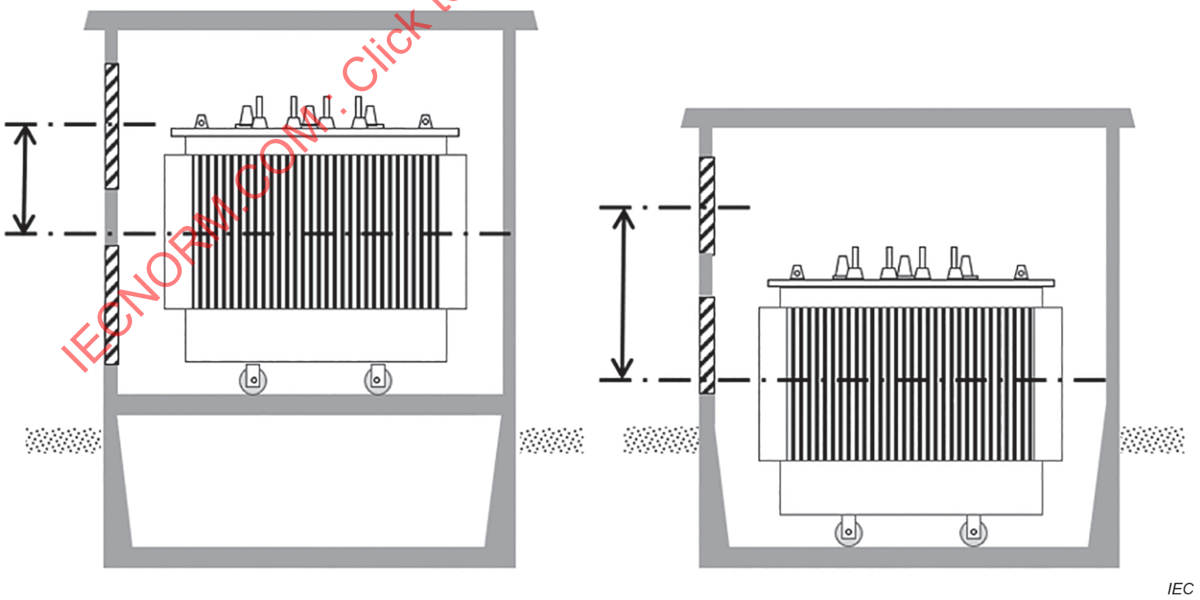
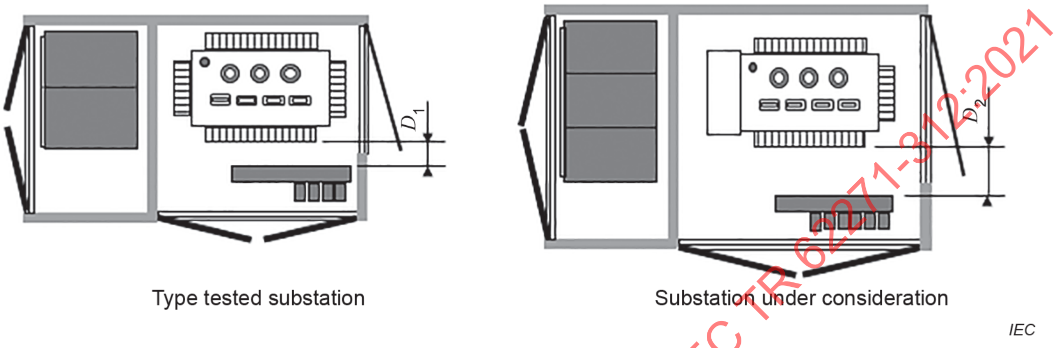


Figure A.5 – Difference in height between power transformer and air outlet ventilation openings

A.2.4 Clearance between low-voltage-switchgear and controlgear and the power transformer (item 4 of Table 2)

Low-voltage-switchgear and controlgear, low-voltage interconnection and power transformer are the major heat sources and significantly influence the temperature rise type test. Low-voltage switchgear and controlgear and power transformer placed in the same compartment can produce adverse thermal interaction affecting allowable main component temperature rise. Because of this, when both main components are placed in the same compartment, the clearance between them (see Figure A.6) should be equal or higher when compared to type-tested layout.



Key

D = distance between low-voltage-switchgear and controlgear and the power transformer

Figure A.6 – Clearance between low-voltage-switchgear and controlgear and the power transformer

A.2.5 Power transformer insulation type (item 6 of Table 2)

According to 6.5.101 of IEC 62271-202:2014, the test shall demonstrate that the temperature rises of the power transformer inside the enclosure do not exceed those measured on the same power transformer outside the enclosure by more than the value which defines the class of enclosure.

Product standards define temperature limits of each power transformer insulation type:

– The top oil temperature rise for liquid-immersed power transformers is given in IEC 60076-2 and for dry-type power transformers is given in IEC 60076-11.

– The hot-spot temperature for liquid-immersed power transformers is given in IEC 60076-7 and for dry-type power transformers it is given in IEC 60076-12.

Since the type of power transformer design determines the class of enclosure, the insulation type of the power transformer cannot be changed without new type tests.

A.2.6 Power transformer total losses (item 7 of Table 2)

The power transformer total losses are the sum of the no-load losses and the load losses as defined in 3.6.1 and 3.6.3 of IEC 60076-1:2011.

The power transformer total losses provide the major energy contribution to the temperature rise within the prefabricated substation and subsequent classification of the enclosure. An increase in the total losses can produce an unacceptable temperature-rise for the expected lifespan of the components.

A.2.7 Current of the low-voltage circuit (items 8 and 9 of Table 2)

The maximum current of the low-voltage circuit is the output of the power transformer when the selected power transformer tapping produces the highest current in the low-voltage circuit.

It is common sense that low-voltage switchgear and controlgear rated current has to be equal or bigger than the maximum current of the low-voltage circuit, described above. Following this rule, the temperature-rise of the circuit can be equal or smaller provided that the type and arrangement of low-voltage interconnections remain equal as a design change cannot be properly assessed.

A.3 Dielectric

A.3.1 General

Design parameters such as clearance between phases and clearance to earth and the corresponding acceptance criteria should be taken into consideration when evaluating the transferability of dielectric type test results. The principles behind each design parameter listed in Table 3 are given below.

A.3.2 Clearances (items 2 and 3 of Table 3)

Phase to phase and phase to earth clearances are directly related to the dielectric withstand capability. Larger clearances increase the dielectric withstand capability compared to the type-tested arrangement of the interconnection provided that all other design parameters listed in Table 3 are unchanged or enhanced with respect to dielectric properties.

Phase to phase and phase to earth clearances could be smaller for an interconnection arrangement having a higher number of parallel phase conductors per phase or a larger conductor cross-section to cope with higher rated current. Even if the conductors are arranged in the same manner (i.e. vertical, horizontal or trefoil alignment) dielectric withstand capability could be reduced compared to the type-tested interconnection arrangement. For a smaller number of parallel conductors or smaller conductor cross-section, the opposite might be true and transferability of dielectric type test results is possible. If the arrangement of conductors differs significantly, even with equal or larger clearances, the transferability of dielectric type test results of the interconnection cannot be assessed without further technical analysis.

The installation of additional earthing facilities or test points may reduce the clearance to earth, hence reducing the dielectric withstand capability compared to the type-tested interconnection.

A.3.3 Insulating supports and material (items 4 and 5 of Table 3)

An increased creepage distance for insulating supports, with the same dielectric properties of the material, increases the dielectric withstand capability compared to the type-tested supports. However, the dielectric withstand capability might be influenced by the electric field distribution along the insulating surface. Therefore, the distribution should not be changed considerably e.g. by parts at a floating potential or by the introduction of additional components.

The insulating material should have equal or improved electrical properties compared to the materials of the type-tested interconnection. If these properties cannot be determined from available specifications, a test of properties might be necessary, as written in the condition to item 5, to support transferability of type test results.

A.3.4 Live parts (items 6 and 7 of Table 3)

Live parts with a lower surface roughness produce a more uniform electric field distribution, avoiding higher local electric field strength, and hence increasing the dielectric withstand capability.

Conductors with a larger radius, including bends and corners in the path, result in a lower local electric field strength that increases the dielectric withstand capability. This criterion is also applicable to other conductive parts at high potential and even to earthed parts. The influence of earthed parts needs to be evaluated when they are opposite to live parts and may influence the electric field.

A.4 Electromagnetic field

A.4.1 General

The electromagnetic field generated by a prefabricated substation comprises the values of the electric and the magnetic fields outside the prefabricated substation. The electromagnetic field is dependent on voltage, current, dimensions, layout and materials used.

The general principles behind each design parameter, described in Table 4, are defined in detail in the following subclauses.

A.4.2 Substation layout and distance from components to external surfaces of the enclosure (items 1 and 2 of Table 4)

A.4.2.1 General

Prefabricated substations can have different layouts, clearances between components and distances to the external surfaces of the enclosure. Changes in layout and/or relative position of main components have an effect on the electromagnetic field at accessible external surfaces of the prefabricated substation.

A.4.2.2 Layout (item 1 of Table 4)

Due to the complexity of the three-dimensional spatial distribution of electromagnetic fields resulting from the main circuits, it is difficult to predict the impact of layout changes on the resulting electromagnetic field outside the enclosure. Therefore, no fundamental layout changes are allowed for the principle of transferability of type test results.

The following Figure A.7 illustrates some examples of alternative layouts that should not be subjected to a type test results transferability assessment.

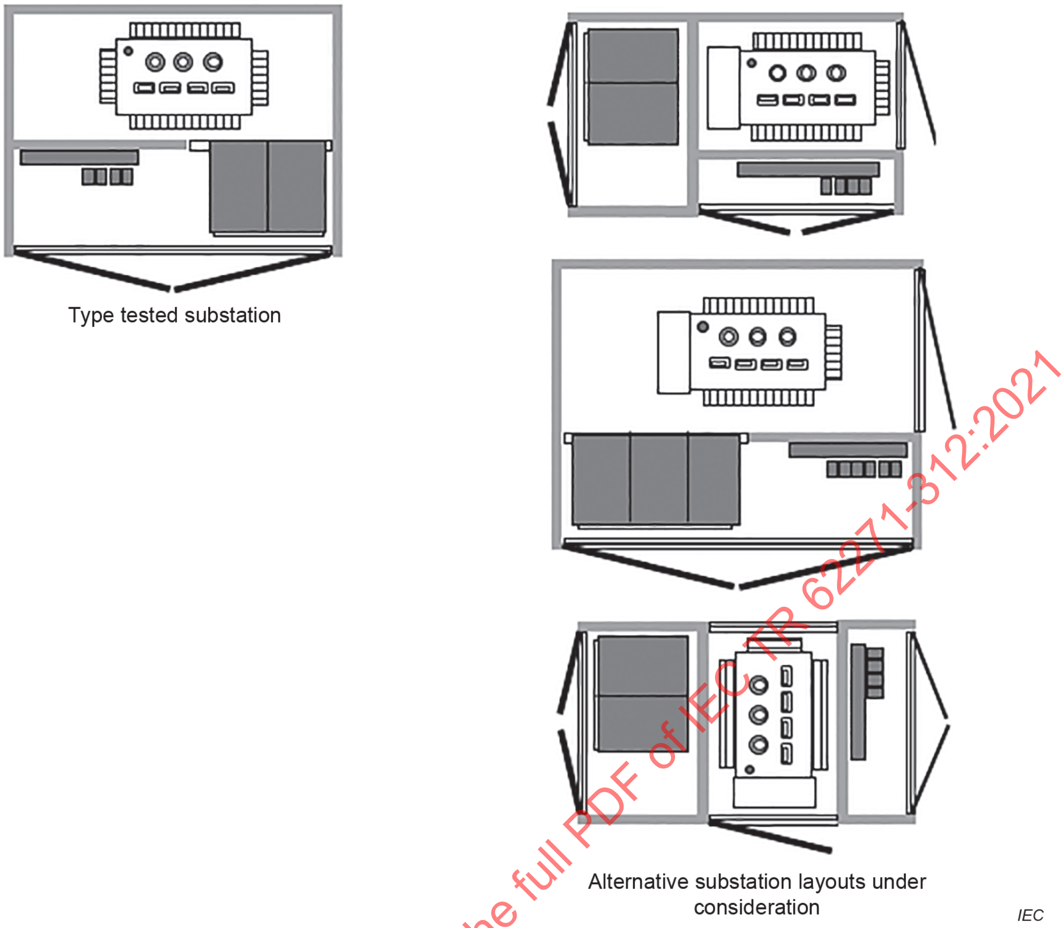
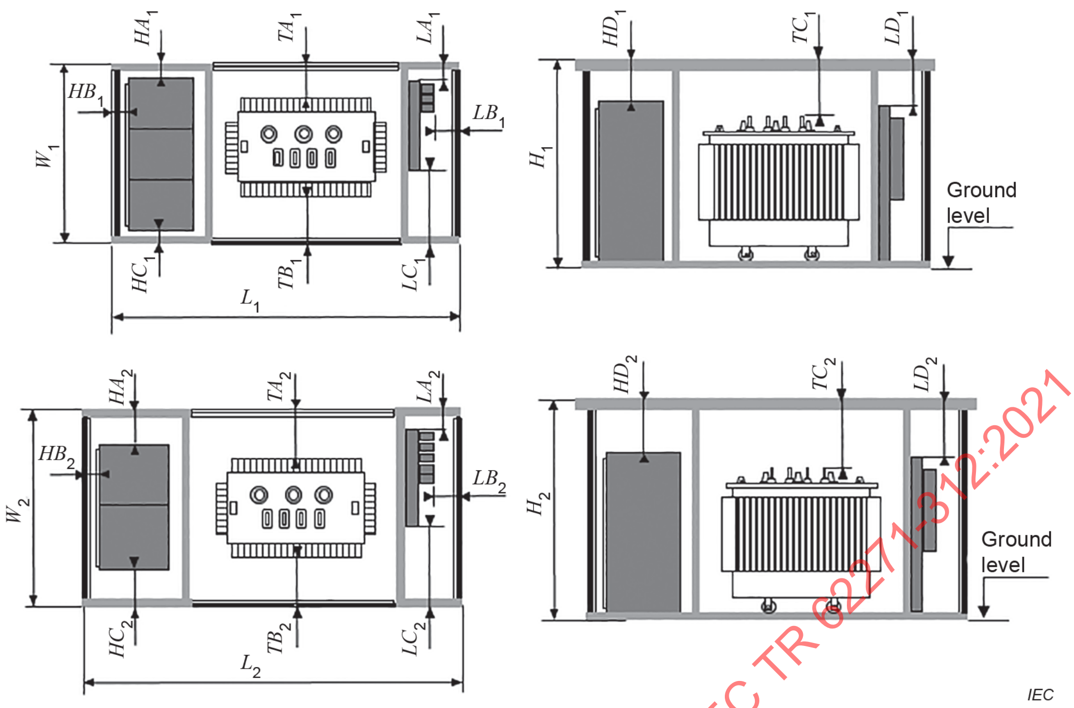


Figure A.7 – Prefabricated substation not acceptable alternative layouts

A.4.2.3 Distances (item 2 of Table 4)

The electromagnetic field decreases as a function of the increasing distance from the source. When the distances from main components incorporating the main circuits to the enclosure surfaces increase, the electromagnetic field outside the enclosure decreases. Therefore, the main components of the prefabricated substation under consideration should have distances to the enclosure equal or larger than the type-tested prefabricated substation.

Illustration of the distance criterion (item 2 of Table 4) for the high-voltage switchgear and controlgear, power transformer and low-voltage switchgear and controlgear is given in Figure A.8 for a typical prefabricated substation layout. All dimensions X2 or XX2 should be equal or higher than corresponding dimensions X1 or XX1. This criterion also applies to high-voltage interconnection and low-voltage interconnection (not represented in the figure).



Key

W = width of the prefabricated substation

L = length of the prefabricated substation

H = height of the prefabricated substation

HA = high-voltage switchgear and controlgear left hand side distance to the enclosure

HB = high-voltage switchgear and controlgear front distance to the enclosure

HC = high-voltage switchgear and controlgear right hand side distance to the enclosure

HD = high-voltage switchgear and controlgear upper distance to the enclosure

TA = power transformer left hand side distance to the enclosure

TB = power transformer right hand side distance to the enclosure

TC = power transformer upper distance to the enclosure

LA = low-voltage switchgear and controlgear right hand side distance to the enclosure

LB = low-voltage switchgear and controlgear front distance to the enclosure

LC = low-voltage switchgear and controlgear left hand side distance to the enclosure

LD = low-voltage switchgear and controlgear upper distance to the enclosure

Figure A.8 – Distances from main components to external surfaces of the enclosure

A.4.3 Rated voltages (item 3 of Table 4)

The electric field strength is a linear function of the voltage. For the purpose of transferability, the field strengths for different voltages may be interpolated from higher to lower values of voltage.

A.4.4 Rated normal currents (item 4 of Table 4)

Magnetic field linear interpolation from higher to lower values of current is acceptable in all cases since it can only result in an overestimation of the magnetic field.

The magnetic field strength is a linear function of the current when the magnetic shielding effect is negligible, which is the general case in most prefabricated substations, except where specific shielding elements are used.

A.4.5 Rated frequency (item 5 of Table 4)

In the frequency range up to and including 60 Hz, the actual value of frequency does not significantly affect the levels of generated electric fields for any given values of voltage. Therefore, evaluation at any frequency up to and including 60 Hz is considered valid.

Similarly, the difference in attenuation of magnetic fields by metallic enclosures at 50 Hz and 60 Hz can be ignored for the purpose of this document. For this reason, an evaluation at 50 Hz is considered applicable also for 60 Hz and vice versa. Figure A.9 shows, as an example, the negligible variation of the magnetic field generated around a conductor in the event of different frequencies with the same continuous current.

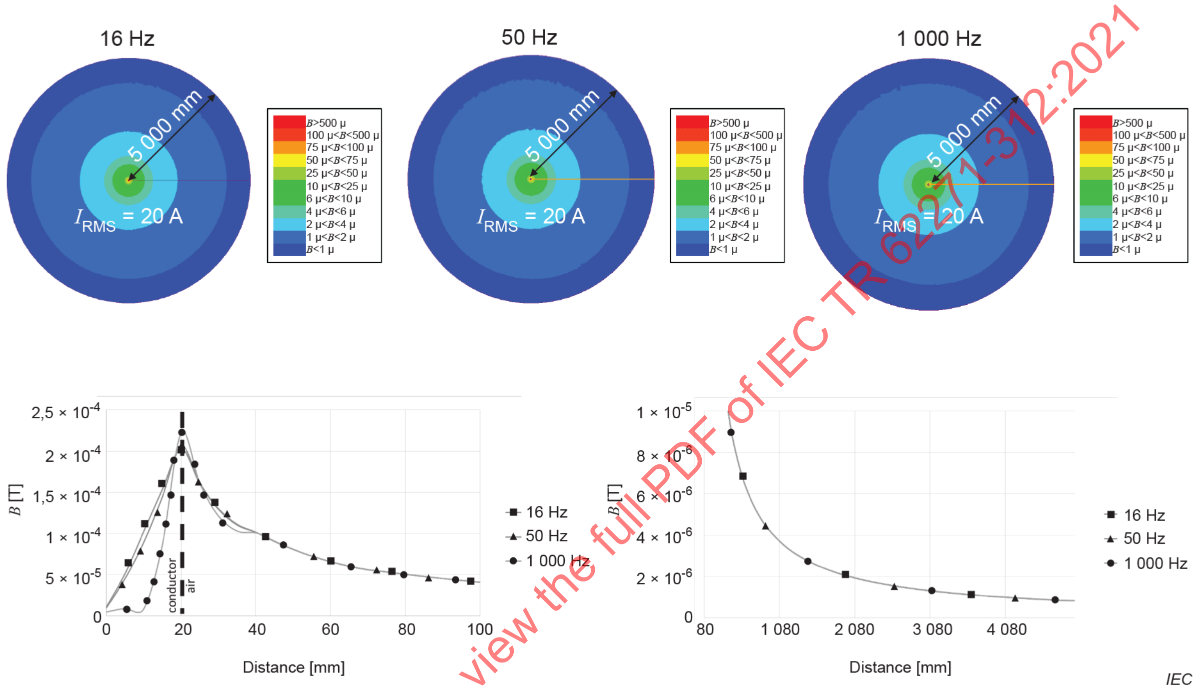


Figure A.9 – Frequency influence on magnetic field

A.4.6 Permeability and conductivity of the enclosure material(s) (items 6 and 12 of Table 4)

High permeability and high conductivity materials can cause significant distortions of the magnetic field. Two different measures can be considered to reduce the magnetic field at 50 Hz: magnetostatic shielding and shielding by eddy currents (see Figure A.10).

Figure A.10 – Magnetic field behaviour under shielded technologies

– Magnetostatic shielding is based upon the ferromagnetic properties of materials. Consequent to the low magnetic resistance, the ferromagnetic material concentrates the magnetic field lines. In this way, a protected zone is created inside (for external source of magnetic field) or outside (for internal source of magnetic field) the ferromagnetic shield.

NOTE In spite of its high shielding efficiency, magnetostatic shielding is seldom used because of the high cost of the ferromagnetic material that is needed.

– Shielding by eddy currents (conductive shielding). The shielding effect is obtained by induced currents in a coupled circuit that constitutes the shielding. The induced currents produce an electric field opposite to the inducing field. This results in a reduction of the resulting magnetic field and a deviation of the magnetic field lines.

In case an enclosure material with a higher permeability or higher conductivity is used, the resulting magnetic field is reduced.

Therefore, it is allowed that the enclosure, of the prefabricated substation or the low-voltage switchgear and controlgear, under consideration can be made of similar material or material with a higher permeability or higher conductivity than the type-tested one.

A.4.7 Interconnections (items 7, 8 and 9 of Table 4)

The resulting magnetic field of a three-phase system strongly depends on the distance between phases, geometry and number of cables per phase:

– the smaller the distance between phases, the lower the field strength;

– from a geometrical point of view, the delta shape configuration results in the lowest field strength;

– when using more than one cable per phase, different configurations are possible resulting in (significantly) higher or lower field strength. Some examples of magnetic field variation according to three different phase arrangements are given in Figure A.11 below. For this study, the calculation method was done considering the following premises:

  - 240 mm^2 cable cores loaded by 1 200 A (RMS) installed within the grid of 30 mm according to the three cases schemes,
  - Neutral conductors were omitted – no harmonics calculated,
  - Horizontal and vertical lines were placed around the group of conductors with the spacing of 0,5 m, 1 m, 1,5 m, 2 m, 3 m and 4 m from an outmost conductor,
  - Maximum value of magnetic field |B| along these lines was located,
  - The magnetic field magnitude was divided by current and plotted.

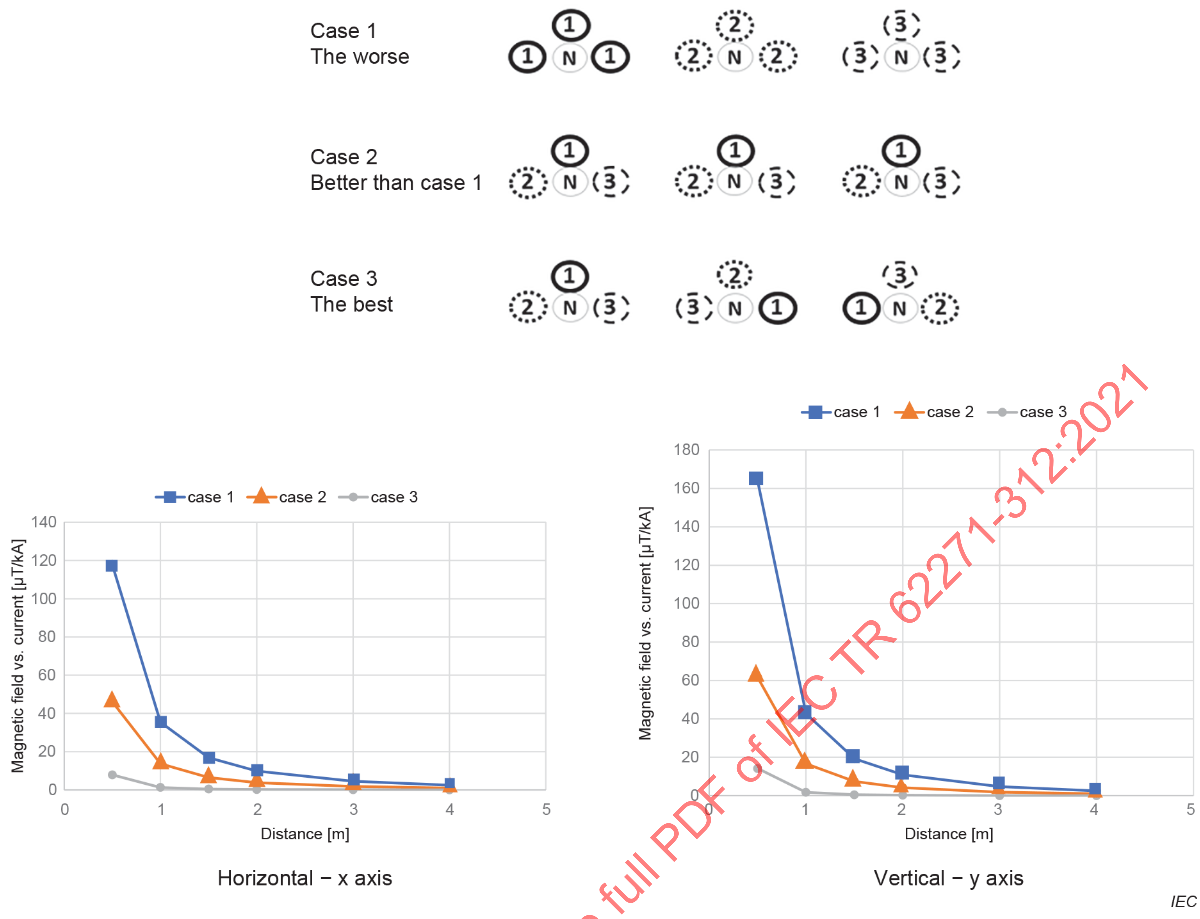


Figure A.11 – Example of magnetic field for different distributions of phase currents in a three-phase interconnection having the same geometry and number of cables per phase

Another parameter influencing the resulting magnetic field is the type of interconnection shielding. Any type of shielding (see also A.4.6) is always better than no shielding with regard to the resulting magnetic field. Therefore, it is allowed that the prefabricated substation under consideration can have shielded interconnections instead of non-shielded ones used in the type-tested prefabricated substation.

Consideration should also be given to whether the terminals of the power transformer are enclosed or not as this may modify shielding properties of the interconnections.

A.4.8 Power transformer type of insulation (item 10 of Table 4)

A wide range of power transformers is available for use in prefabricated substations, having different type of insulation: liquid-immersed or dry-type. In the case of liquid-immersed technology, the presence of a metallic oil tank modifies the electric field once it is earthed. Each particular technology requires specific bushings and power cable arrangement that influence the generated magnetic field in the proximity.

Therefore, it is not allowed that the prefabricated substation under consideration can have a power transformer with a different type of insulation than the one used in the type-tested prefabricated substation.

A.4.9 Distance between main circuit phases of the low-voltage switchgear and controlgear (item 11 of Table 4)

Depending on the construction of the low-voltage switchgear and controlgear assemblies, the resulting electromagnetic field can vary under the same rated current and rated voltage conditions.

If the centre distance between phases in the low-voltage switchgear is larger than the low-voltage switchgear installed during the type-tested prefabricated substation, the resulting electromagnetic field is higher (Ampère's law / Gauss law).

Therefore, it is only allowed that the prefabricated substation under consideration has low-voltage phase distances smaller or equal to the low-voltage phase distances in the type-tested prefabricated substation.

A.5 Mechanical stress

A.5.1 General

For the transferability of mechanical stress type test results, design parameters are based on the comparison of the mechanical strength of the prefabricated substation enclosure (i.e. physical properties).

A prefabricated substation enclosure usually consists of the following key components that require verification with respect to their ability to withstand the required mechanical loads and impacts specified in IEC 62271-202:2014:

– walls;

– doors and covers;

– roof; and

– ventilation openings.

Corrosion tests are excluded from the scope of this document.

A.5.2 Common design parameters to be assessed for the key components

A.5.2.1 General

For each of the key components of the prefabricated substation given in A.5.1 that require verification, the following common design parameters are provided in Table 5.

A.5.2.2 Basic design (items 1, 2, 3 and 4 of Table 5)

The basic design of the enclosure key components is required to be the same. Some examples of basic designs which are not considered the same are:

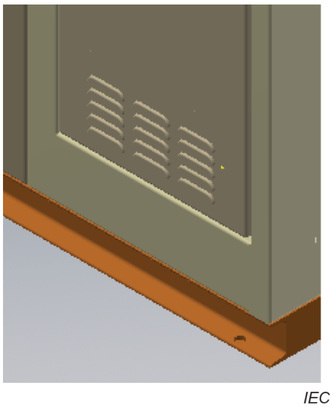
– Walls: metallic versus concrete, welded versus fastened, with or without ventilation openings;

– Doors and covers: external mounted versus flush mounted (see Figure A.12), single versus double door, type of locking devices, ventilated versus non-ventilated;

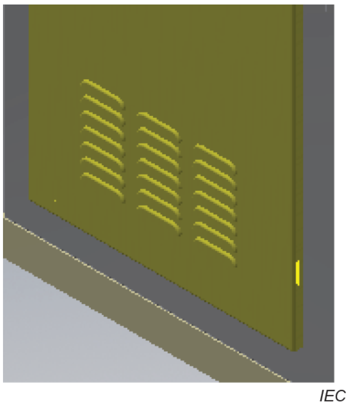
– Roof: flat versus single pitched versus dual pitched (gabled) (see Figure A.13);

– Ventilation openings: louvre versus grille versus mesh, metallic versus polyester.

Basic design material(s) and dimensions of the prefabricated substation under consideration may differ while the intrinsic mechanical properties compared to the type-tested prefabricated substation are not impaired as it is explained in the following subclauses.

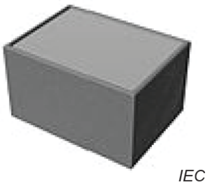


a) **Flush-mounted door**

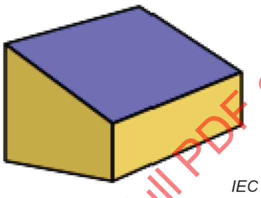


b) **External-mounted door**

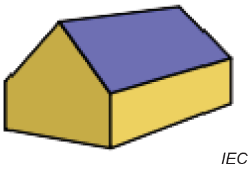
Figure A.12 – Examples of different door designs



a) **Flat roof**



b) **Single-pitched roof**



c) **Dual-pitched (gable) roof**

Figure A.13 – Examples of different roof designs

A.5.2.3 Mechanical strength of material (items 1, 2, 3 and 4 of Table 5)

Where different materials are used for the enclosure key components, a comparative assessment of the intrinsic mechanical properties of the material(s) is required. Where the same material is used, the material thickness is considered sufficient when determining its relative mechanical strength. Refer to the considerations provided in A.5.3.

A.5.2.4 Height of enclosure walls and doors (items 1 and 2 of Table 5)

For the transferability of wind pressure type tests, the height of the walls and doors above ground increases its exposure to wind forces. For the transferability of roof load type tests, the height of the walls should also be taken into consideration.

A.5.2.5 Surface dimensions (items 1, 2, 3 and 4 of Table 5)

On an equal thickness and mechanical reinforcement basis, components having equal or smaller surface dimensions (i.e. in length and/or height and/or width) when compared to the type-tested object are considered to provide the same or increased mechanical strength. The surface dimensions should not be confused with the surface area (being the product of the surface dimensions). A reduced surface area, considered alone, does not necessarily translate into reduced surface dimensions. Acceptance criteria specific to ventilation openings are provided in Table 5.

A.5.2.6 Reinforcements (items 1, 2, 3 and 4 of Table 5)

The mechanical strength of reinforcements (if applicable) used to strengthen the enclosure key components is required to be equal or greater. For the same kind of reinforcement (if applicable), the spacing between the axes of reinforcements (centre line distance between reinforcements) should be equal or smaller.

A comparative assessment of the intrinsic mechanical properties of the material(s) is required. As an example for a reinforced concrete enclosure, the concrete coating of the metallic reinforcement should be equal or thicker while the distance from the neutral axe of the wall and the metallic reinforcement axe should be equal or bigger (if applicable). Refer to the considerations provided in A.5.3.

A.5.2.7 Fastening (items 1, 2, 3 and 4 of Table 5)

The method of fastening, for example, welding, riveting, bolting, etc. (where applicable) used to secure the enclosure key components is required to be the same. For the purposes of the mechanical withstand requirements applicable to prefabricated substations, the mechanical strength of the fasteners (if applicable) used to secure the enclosure key components is required to be equal or greater. The fastener fixing centres should be equal or less. A comparative assessment of the intrinsic mechanical properties of the fastener material(s) used may be required. Refer to the considerations provided in A.5.3.

A.5.3 Considerations for different enclosure materials, fasteners and reinforcements (items 1, 2, 3 and 4 of Table 5)

Where alternative materials are used, the following intrinsic mechanical properties of the material should be considered with consideration to the particular mechanical withstand requirement:

– Mechanical impact: impact strength (fracture toughness) at the minimum service temperature. Variations in temperature within the normal service conditions can significantly affect the mechanical impact strength of the materials (for example, synthetic materials) used for parts of the enclosure.
– Wind pressure and roof loads: tensile strength (yield strength) and stiffness (modulus of elasticity). Yield strength (one type of tensile strength) is an indication of the maximum stress that can be developed in a material without causing plastic deformation. It is the stress at which a material exhibits a specified permanent deformation and is a practical approximation of the elastic limit. Components should withstand the force(s) incurred during use and cannot deform plastically (i.e. beyond its elastic limit). Stiffness is the extent to which a solid material (object) resists deformation in response to an applied force.

When assessing the mechanical strength of reinforcements (if any), the section modulus and/or other geometric properties of the reinforcing member(s) may be used. Section modulus is a geometric property for a given cross-section used in the design of beams or flexural members. For example, if two beams are made of the same material, when comparing the section modulus of the two beams, the beam with higher section modulus is stronger and capable of withstanding higher loads.

A.6 Short-time withstand current and peak withstand current

A.6.1 General

Short-circuit currents generate electromagnetic forces between the phase conductors, which depend on the course of the current carrying path including bends and corners. These mutual forces can be calculated for simple conductor geometries by analytical equations, for complex geometries, however, finite-element simulation tools are needed. The smaller the centre distance between conductors, the higher the mutual forces. The ability of the interconnections to cope with these forces is determined by the strength of all supports considering steady state and transient components of the current. In addition, all movable contacts and fixed connections are important. All these influences should be considered in the evaluation of design parameters.

However, for the transferability of type test results, only the most relevant design parameters are considered to facilitate a practical transferability process. The general principles behind each of the design parameters (items) included in Table 6 are given in more detail below.

A.6.2 Rated short-time and peak currents (items 1 and 2 of Table 6)

The lower the value of the short-circuit current, the lower the electromagnetic forces between the phase conductors. Lower electromagnetic forces reduce the mechanical stress on the construction.

For a given duration of a short-circuit current, the lower the value of the short-circuit current, the lower the temperature-rise of the conductors. A lower temperature-rise reduces the temperature impact on insulating materials in contact with the conductors.

A.6.3 Rated duration of short-circuit (item 3 of Table 6)

Given a value of short-circuit current, the lower the duration of the short-circuit, the lower the temperature-rise of the conductors. A lower temperature-rise reduces the temperature impact on insulating materials in contact with the conductors.

A.6.4 Centre distance between phase conductors (item 4 of Table 6)

Given a length of conductors and a short-circuit current, if the centre distance between phases is larger than in the type-tested prefabricated substation, the mutual forces between phases are lower on the conductors.

A.6.5 Conductors (items 5, 9 and 11 of Table 6)

The electromagnetic forces due to bends and corners in the conductor path can exceed the mutual forces between phases. Transferability of type test results may be carried out when conductors have the same layout and all bending radius of the conductors have equal or larger values than in the original geometry.

The mutual electromagnetic forces between two conductors are determined by their centre distances, not by the cross-section area of the conductors. However, because of the heating effect of the current, possible current density effects and mechanical strength, it should be ensured that the cross-section area of the conductors is the same or larger than in the type-tested prefabricated substation, while ensuring they keep the same conductor cross-section shape. The similarity of the connections, for example between busbars, should be evaluated with regard to local heating effects.

The material of the conductors first determines the heat loss in relation to the material resistivity, second the mechanical stability of the conductors and third the current carrying capability of connections. Because these connections may involve a complicated behaviour, a deviation from the original conductor material cannot be permitted without type test.

In case of metallic enclosure prefabricated substation, the earth fault current may not only be conducted via conductors made specifically for this purpose, but also via the enclosure. In this specific case and for the same enclosure material, conductivity and cross-section area of the conductors should be the same or larger for the transferability of type test results.

A.6.6 Insulating conductor supports (items 6, 7 and 8 of Table 6)

The supports should be designed according to the same principles and have the same or higher strength than the type-tested ones.

For conductors supported by a row of insulators, the strength of the design is not only determined by the strength of the supports, but also by the arrangement of the supports. As a minimum requirement, the distance between supports should be the same or smaller to ensure the withstand capability of the conductor supports. This criterion should be evaluated for all supports of all conductors.

The mechanical withstand performance of the conductor support is also determined by the strength of its support base frame. Support base frame(s) also considers the strength of partitions and bushings which may be difficult to assess simply by geometry. If different partitions and bushings are used, transferability of type test results may not be possible.

A.6.7 Type of high-voltage and low-voltage terminations (item 10 of Table 6)

A termination is the assembly of components and installation method used to connect the interconnections to the equipment at either end. The type of the high-voltage or low-voltage interconnection terminations has an impact on the mechanical strength of the interconnection. The mechanical strength of each type of termination is very complex to compare. Therefore the type of termination should be the same as the prefabricated substation type-tested one.

A.6.8 Temperature class of insulating material in contact with conductors (item 12 of Table 6)

The short-circuit current heats up the conductors. All parts of the supports or termination components in contact with the conductors experience the same increase in temperature as the conductor. For the purpose of transferability of type test results, different materials from those used in the type-tested assembly may be used if they have the same or higher temperature class.

A.7 Internal arc

A.7.1 General

Internal arc classification (IAC) is demonstrated for a prefabricated substation by the relevant internal arc type test and meeting the acceptance criteria specified in 6.102.5 of IEC 62271-202:2014. These criteria evaluate potential issues arising during the test on the high-voltage switchgear and controlgear, on the enclosure of the prefabricated substation and on the high-voltage interconnections such as opening of doors and covers, enclosure fragmentation and burn through, ignition of indicators simulating clothing, and the integrity of earthing connections. The fulfilment of all these acceptance criteria provides evidence that the prefabricated substation under consideration performance is at least equivalent to the type-tested level of protection in the event of an internal arc.

Pressure-rise and hot gases are effects produced by the internal arc. They exert mechanical and thermal stress on the prefabricated substation. The severity of the arc fault within the high-voltage switchgear and controlgear and in the high-voltage interconnections is related to the amount of energy generated by the arc, the volume in which the arc energy is deposited, and the efficiency of the gas flow cooling or pressure relief device, if any. Finally, the amount and path of vented hot gases determine the probability of indicator ignition in combination with the installation conditions.

Based on the above considerations, the design parameters given in Table 7 have been determined for the assessment on transferability of type test results. The rationale behind all design parameters (items) listed in Table 7, which is applicable to the design of the prefabricated substation under consideration equipped with the same family of high-voltage switchgear and controlgear, is provided below.

A.7.2 Rated arc fault current, arc fault peak current and arc fault duration (items 1 and 2 of Table 7)

For a given high-voltage switchgear and controlgear, the lower the value of the short-circuit current and/or arc duration, the lower the energy generated by the internal arc. Correspondingly, the thermal stress and dynamic pressure-rise decrease. Therefore, the mechanical and thermal stress on the enclosure is lower.

Referring to AA.4.3.2 of IEC 62271-200:2011, type tests performed at 60 Hz may prove 50 Hz and type tests performed at 50 Hz with rated peak withstand current (I_p) 2,6 × I_k may prove 60 Hz.

A.7.3 High-voltage switchgear family (item 3 of Table 7)

According to 6.102.7 of IEC 62271-202:2014, the transferability of internal arc type test results of a prefabricated substation is only possible with the same direction of the gas flow from the internal arc. This should be ensured if the functional units considered in the prefabricated substation under consideration are of the same family of high-voltage switchgear and controlgear and having the same direction of gas flow from the internal arc.

In case every particular functional unit of the high-voltage switchgear and controlgear assembly tested within the prefabricated substation was internal arc classified on its own in accordance with IEC 62271-200 (see AA.6 of IEC 62271-202:2014), every functional unit of the high-voltage switchgear and controlgear assembly of the prefabricated substation under consideration should also be internal arc classified on its own in accordance with IEC 62271-200 (see AA.6 of IEC 62271-202:2014), even being from the same family of high-voltage switchgear and controlgear.

In case any functional unit of the high-voltage switchgear and controlgear assembly within the type-tested prefabricated substation was not internal arc classified on its own in accordance with IEC 62271-200 or within a prefabricated substation in accordance with IEC 62271-202:2014 (Clause AA.6), transferability of type test results is not possible, even being from the same family of high-voltage switchgear and controlgear.

For all cases, high-voltage switchgear and controlgear internal arc classified on its own in accordance with IEC 62271-200 should comply with installation conditions defined in this type test. This means that installation conditions and distances within the substation should be respected when considering transferability of internal arc type test results according to IEC 62271-202:2014.

NOTE The assessment of high-voltage metal-enclosed switchgear and controlgear and of high-voltage solid-insulation enclosed [2][2] switchgear and controlgear assemblies used within prefabricated substations can be done in accordance with IEC TR 62271-307 [3].

2 Numbers in square brackets refer to the Bibliography.

A.7.4 Layout of the prefabricated substation (item 4 of Table 7)

Due to the variety of types of prefabricated substations, size of enclosures, arrangements and mix of components, the transferability of internal arc type test results is only given when the considered prefabricated substation has:

– the same basic design,
– the same three-dimensional spatial arrangement of the compartments,
– same or larger size of one or more compartments.

Figure A.14 a) shows, as example, a small non-walk-in type substation and a larger size non-walk-in type prefabricated substation design, while Figure A.14 b) shows an example of different sized walk-in type prefabricated substations.

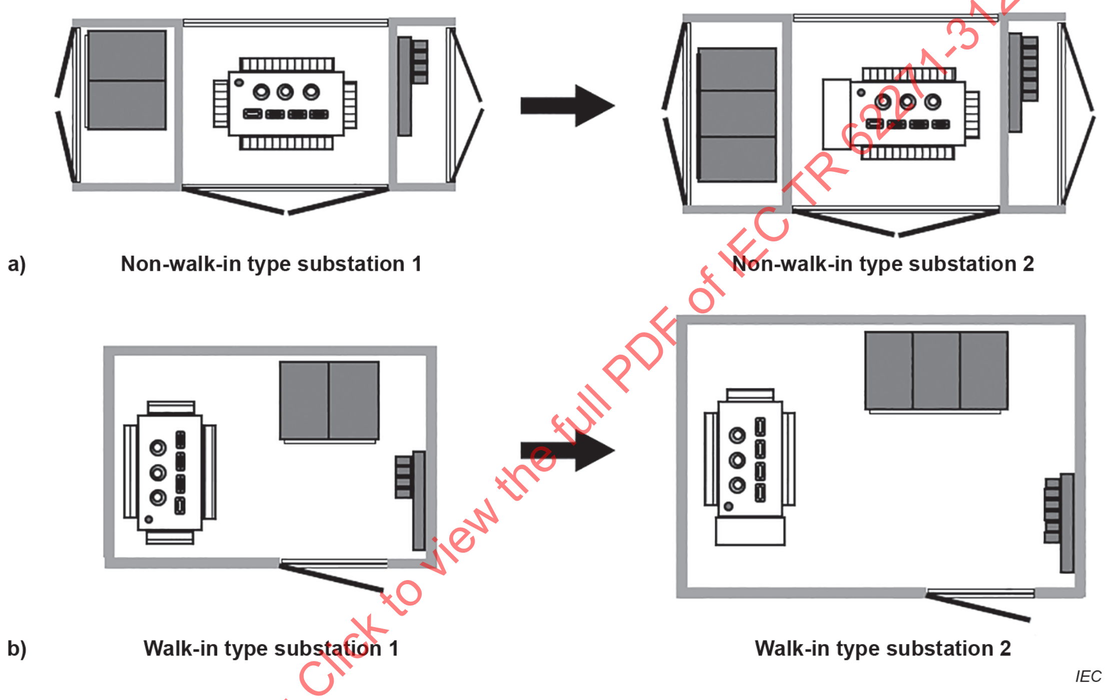


Figure A.14 – Different size of prefabricated substations with same layout

When the layout of a larger prefabricated substation, like in Figure A.14, is equal to the layout of a smaller prefabricated substation, the transferability of the internal arc type test results from the smaller prefabricated substation to the larger prefabricated substations (high-voltage room volume 2 > high-voltage room volume 1) is possible.

A.7.5 Expansion volumes (items 5, 6 and 7 of Table 7)

A.7.5.1 Definition of volumes

a) V_{HVC} = Volume of high-voltage switchgear compartment

Expansion volume inside the prefabricated substation where the high-voltage switchgear and controlgear is installed, excluding the volume occupied by the high-voltage switchgear and controlgear and all other components inside a given volume segregated from all other volumes of the substation by intermediate walls and floor.

b) V_{PEV} = primary expansion volume

Immediate expansion volume of the hot gases just after the high-voltage compartment where the internal arc is ignited and:

– the secondary expansion volume, or

– a gas flow cooling device located in the path of the hot gases, if any, or
– a pressure relief device (e.g., cover or flap) directly to the outside of the enclosure.

When the gas flow cooling device forms indivisible part of the high-voltage switchgear and controlgear, then the volume of this device is considered to be part of the high-voltage switchgear and controlgear.

In some cases, the primary expansion volume is the same as the volume of the high-voltage switchgear compartment (V_{HVC}).

V_{PEV} also includes any high-voltage switchgear and controlgear volume available for the expansion of hot gasses during an internal arc, for example the high-voltage switchgear and controlgear connection compartment of the test object unit or adjacent ones. If this is the case, type test report should preferably include detailed information.

c) V_{SEV} = secondary expansion volume (if applicable)

If applicable, subsequent expansion volume behind the primary expansion volume, segregated from it by gas flow cooling devices or pressure relief devices or just an opening, if present, accessible for expansion of the hot gases during an internal arc.

d) V_{NEV} = total net expansion volume

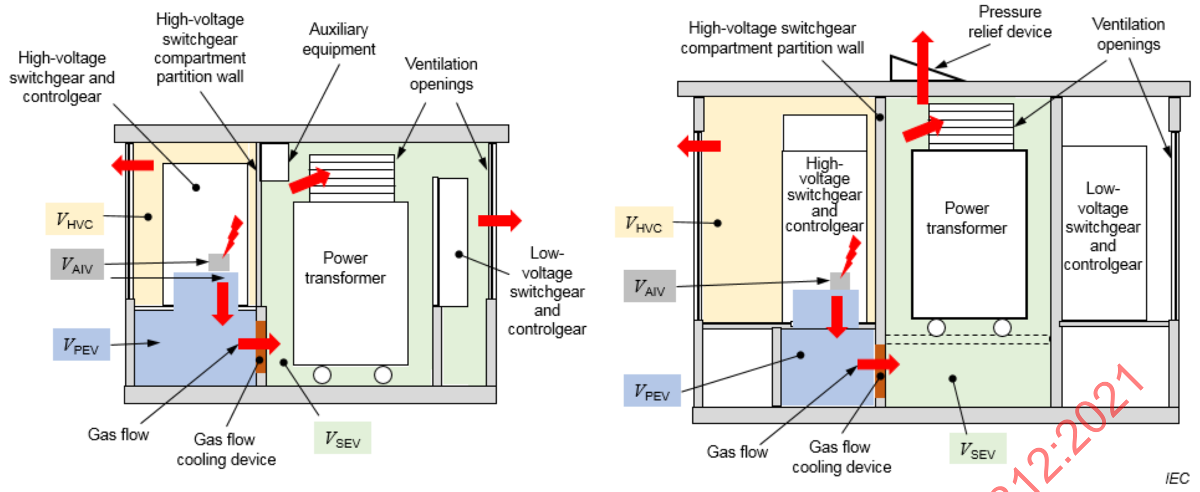
$V_{NEV} = V_{PEV} + V_{SEC}$

e) V_{AIV} = arc ignition volume

Volume of the high-voltage compartment in which the ignition of the internal arc took place during the test

A.7.5.2 Examples of expansion volume in a prefabricated substation

Figure A.15 to Figure A.19 show the gas flow in case of an internal arc, designed expansion volumes, compartments where a potential increase of pressure can be detected and other design parameters that should be considered for different designs and arrangements of prefabricated substations.



Key

V_{HVC} = volume of high-voltage switchgear compartment V_{HVC} ≥ tested volume

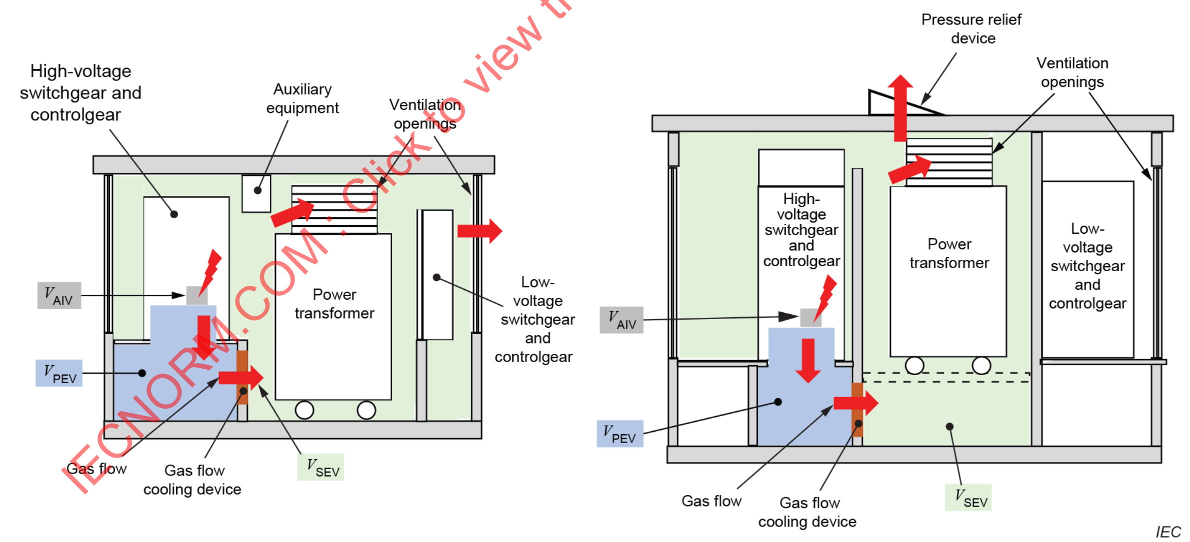
V_{PEV} = primary expansion volume V_{PEV} ≥ tested volume

V_{SEV} = secondary expansion volume

V_{NEV} = total net expansion volume = V_{PEV} + V_{SEV} V_{NEV} ≥ tested volume

V_{AIV} = arc ignition volume

Figure A.15 – Gas flow in a non-walk-in type and walk-in type prefabricated substations with separate high-voltage switchgear compartment



Key

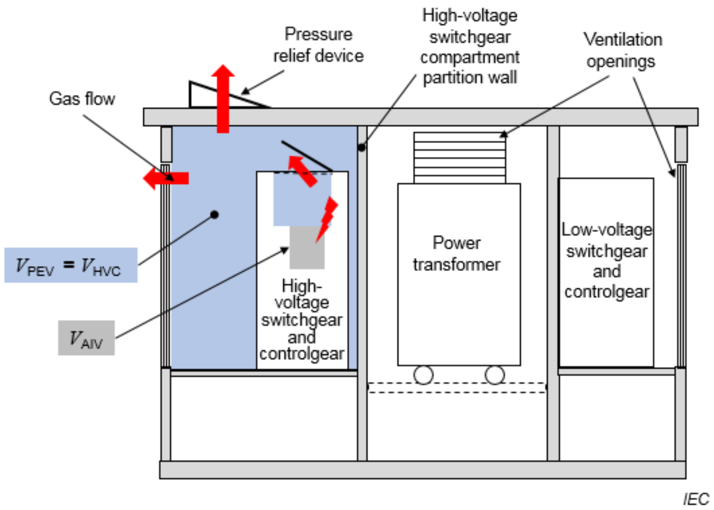
V_{PEV} = primary expansion volume V_{PEV} ≥ tested volume

V_{SEV} = secondary expansion volume

V_{NEV} = total net expansion volume = V_{PEV} + V_{SEV} V_{NEV} ≥ tested volume

V_{AIV} = arc ignition volume

Figure A.16 – Gas flow in a non-walk-in type and walk-in type prefabricated substations without separate high-voltage switchgear compartment



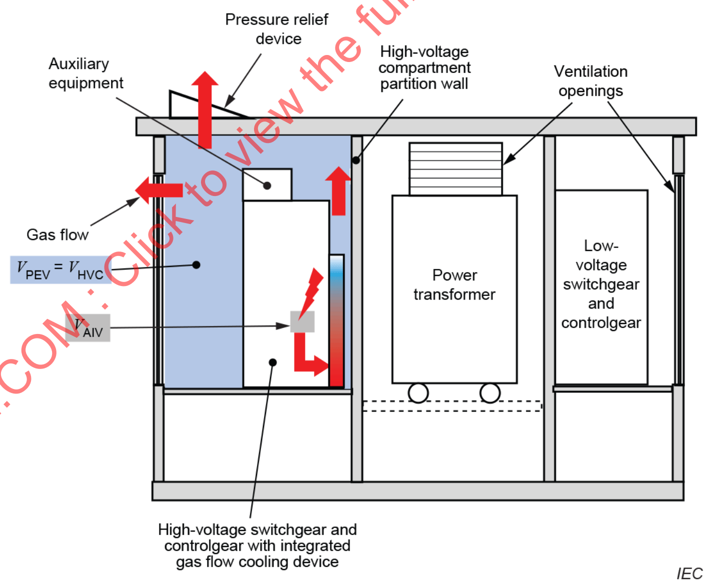
Key

V_{HVC} = volume of high-voltage switchgear compartment

V_{PEV} = primary expansion volume V_{PEV} = V_{HCV} ≥ tested volume

V_{AIV} = arc ignition volume

Figure A.17 – Gas flow in a walk-in type prefabricated substation with high-voltage switchgear compartment without gas flow cooling device



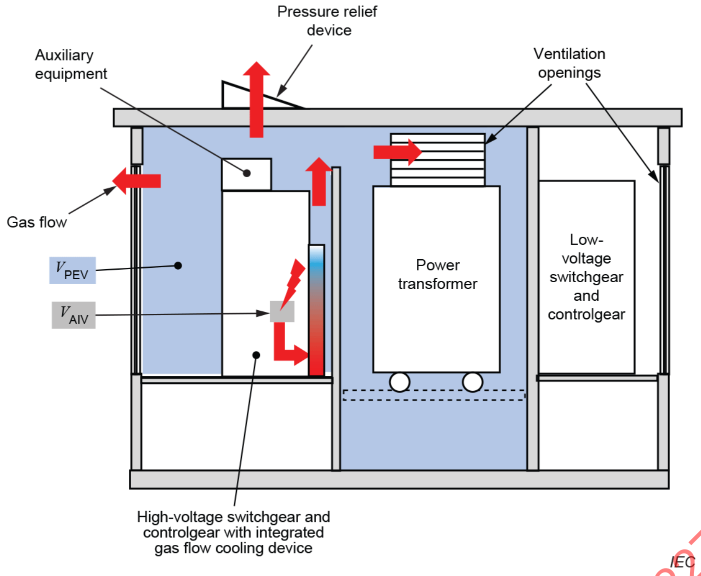
Key

V_{HVC} = volume of high-voltage switchgear compartment

V_{PEV} = primary expansion volume V_{PEV} = V_{HVC} ≥ tested volume

V_{AIV} = arc ignition volume

Figure A.18 – Gas flow in a walk-in type prefabricated substation with high-voltage switchgear compartment and high-voltage switchgear and controlgear with integrated gas flow cooling device



Key

V_{PEV} = primary expansion volume

V_{AIV} = arc ignition volume

V_{PEV} ≥ tested volume

Figure A.19 – Gas flow in a walk-in type prefabricated substation and high-voltage switchgear and controlgear with integrated gas flow cooling device without separate high-voltage switchgear compartment