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Station Service Voltage Transformers (SSVT)

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STATION SERVICE VOLTAGE TRANSFORMERS (SSVT)

FOREWORD

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Draft	Report on voting
38/788/FDIS	38/789/RVD

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

The language used for the development of this International Standard is English.

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The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

STATION SERVICE VOLTAGE TRANSFORMERS (SSVT)

1 Scope

This document describes electrical and mechanical requirements of single-phase station service voltage transformers with system voltages of 46 kV or higher and with the maximum rated voltage of the power winding of 1 000 V.

This document is a basis for the establishment of performance and limited electrical and mechanical interchangeability requirements of the equipment are described. It is also a basis for assistance in the proper selection of such equipment.

A station service voltage transformer (SSVT) is a single-phase transformer to be connected line-to-earth on an effectively earthed system. It can be used either as an individual unit for supplying single-phase loads, or in a three-phase bank to support three-phase loads. A typical application is to supply substation power such as lighting, pump and motor loads. The SSVT can be provided with a measuring winding when requested by the user.

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 60060-1:2010, *High-voltage testing techniques – Part 1: General definitions and test requirements*

IEC 60060-2, *High-voltage testing techniques – Part 2: Measuring systems*

IEC 60071-2:2023, *Insulation co-ordination – Part 2: Application guidelines*

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

IEC 60076-5, *Power transformers – Part 5: Ability to withstand short circuit*

IEC 60270, *High-voltage test techniques – Partial discharge measurements*

IEC 60376, *Specification of technical grade sulphur hexafluoride (SF_6) and complementary gases to be used in its mixtures for use in electrical equipment*

IEC 60475, *Method of sampling insulating liquids*

IEC 60480, *Specifications for the re-use of sulphur hexafluoride (SF_6) and its mixtures in electrical equipment*

IEC 60567, *Oil-filled electrical equipment – Sampling of free gases and analysis of free and dissolved gases in mineral oils and other insulating liquids – Guidance*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60867, *Insulating liquids – Specifications for unused liquids based on synthetic aromatic hydrocarbons*

IEC 60836, *Specifications for used silicon insulating liquids for electrotechnical purposes*

IEC 60944, *Guide for the maintenance of silicon transformer liquids*

IEC 61099, *Insulating liquids – Specifications for unused synthetic organic esters for electrical purposes*

IEC 61869-1:2023, *Instrument transformers – Part 1: General requirements*

IEC 61869-3:2011, *Instrument transformers – Part 3: Additional requirements for inductive voltage transformers*

IEC 61869-99:2022, *Instrument transformers – Part 99: Glossary*

IEC 62262, *Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK Code)*

IEC 62770, *Fluids for electrotechnical applications – Unused natural esters for transformers and similar electrical equipment*

ASTM D2225, *Standard Test Methods for Silicone Liquids Used for Electrical Insulation*

ASTM D3487, *Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus*

ASTM D5222, *Standard Specification for High Fire-Point Mineral Electrical Insulating Oils*

ASTM D6871, *Standard Specification for Natural (Vegetable Oil) Ester Fluids Used in Electrical Apparatus*

CISPR TR 18-2:2017, *Radio interference characteristics of overhead power lines and high-voltage equipment – Part 2: Methods of measurement and procedure for determining limits*

IEEE Std 4™-2013, *High-Voltage Testing Techniques*

IEEE Std C57.12.70™, *IEEE Standard Terminal Markings and Connections for Distribution and Power Transformers*

IEEE Std C57.12.80™-2010, *IEEE Standard Terminology for Power and Distribution Transformers*

IEEE Std C57.12.90™-2015, *IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers*

IEEE Std C57.13™-2016, *IEEE Standard for Requirements for Instrument Transformers*

IEEE Std C57.13.5™, *IEEE Standard of Performance and Test Requirements for Instrument Transformers of a Nominal System Voltage of 115 kV and Above*

IEEE Std C57.19.100™, *IEEE Guide for Application of Power Apparatus Bushings*

IEEE Std 693™, *IEEE Recommended Practice for Seismic Design of Substations*

NEMA 107-2016, *Methods of measurement of radio influence voltage (RIV) of high-voltage apparatus*

NEMA 250, *Enclosures for Electrical Equipment (1000 Volts Maximum)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61869-99, IEEE Std C57.12.80™, and the following apply.

ISO, IEC and IEEE 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
- IEEE Standards Dictionary Online: available at http://dictionary.ieee.org

3.1 General definitions

3.1.1
station service voltage transformer
SSVT
line-to-earth connected single-phase transformer that can be used either as an individual unit for supplying single-phase loads, or in a three-phase bank to supply three-phase loads and can be provided with a measuring winding

EXAMPLE A typical application is to supply power to the control house and yard loads inside a substation.

3.1.2
enclosure
housing affording the type and degree of protection suitable for the intended application

Note 1 to entry: This definition needs the following explanations under the scope of this document:

1) enclosure provides protection for persons or animals against access to hazardous parts;
2) enclosure provides protection for equipment against the harmful effects of mechanical impact;
3) barriers, shapes of openings or other means – whether attached to the enclosure or formed by the enclosed equipment – suitable to prevent or limit penetration, are considered as part of the enclosure, except when they can be removed without the use of a key or tool.

[SOURCE: IEC 60050-151:2001, 151-13-08, modified – the Note to entry has been added.]

3.1.3
primary terminal
terminal to which the voltage to be transformed is applied

3.1.4
secondary terminal
terminal which transfers the power to the secondary circuit or transmits the secondary signal to measuring instruments, meters and protective or control devices or similar apparatus

3.1.5
neutral terminal
terminal intended for connection to a neutral point of a network

3.1.6
secondary circuit
external circuit connected to the secondary terminals

[SOURCE: IEC 61869-99:2022, 3.1.4]

3.1.7
pressure relief device
device suitable to limit dangerous over-pressures inside the SSVT

[SOURCE: IEC 61869-99:2022, 3.2.61, modified – Reference to "instrument transformer" replaced with "SSVT".]

3.1.8
zero period acceleration
ZPA
acceleration level of the high-frequency, non-amplified portion of the response spectrum, corresponding to the maximum (peak) acceleration of the time history used to derive the spectrum

Note 1 to entry: The ZPA is assumed to be the acceleration at 33 Hz or greater.

[SOURCE: IEEE Std 693™-2018- 3.1, modified – second part of the definition moved to a Note.]

3.1.9
IEC profile
iteration of this document where the user of this document follows the IEC references

3.1.10
IEEE profile
iteration of this document where the user of this document follows the IEEE references

3.2 Definitions related to voltage and dielectric aspects

3.2.1
nominal system voltage
suitable approximate value of voltage used to designate or identify a system

[SOURCE: IEC 60050-601:1985, 601-01-21, modified – the term "nominal voltage of a system" has been replaced with "nominal system voltage", which is the common term in North America.]

3.2.2
highest voltage of a system
maximum system voltage
U_{sys}
highest value of operating voltage which occurs under normal operating conditions at any time and any point in the system

Note 1 to entry: Transient overvoltages due e.g. to switching operations and unusual temporary variations of voltage, are not taken into account.

[SOURCE: IEC 60050-601:1985, 601-01-23, modified – the term "maximum system voltage" and symbol have been added; the word "abnormal" replaced with "unusual" in the definition.]

3.2.3
highest voltage for equipment
maximum equipment voltage
U_m
highest value of line-to-line voltage (RMS value) for which the equipment is designed in respect of its insulation as well as other characteristics which relate to this voltage in the relevant equipment standards under normal operating conditions

[SOURCE: IEC 60050-614:2016, 614-03-01, modified – the term "maximum equipment voltage" and symbol have been added; in the definition "greatest" has been replaced with "highest" and "service conditions" replaced with "operating conditions".]

3.2.4
rated primary voltage
U_{pr}
value of the primary line-to-earth voltage of the SSVT on which its performance is based

3.2.5
rated secondary voltage
U_{sr}
value of the secondary voltage of the SSVT to be developed at no-load between the secondary terminals with rated primary voltage

3.2.6
harmonic factor
ratio of the RMS value of harmonic content to the RMS value of an alternating quantity

[SOURCE: IEC 60050-161:1990, 161-02-23, modified – "total" has been omitted from the term.]

3.2.7
rated voltage factor
F_v
multiplying factor to be applied to the rated primary voltage to determine the maximum voltage at which an SSVT must comply with the relevant thermal and optional accuracy requirements for a specific time

3.2.8
rated insulation level
test voltages, under specified conditions, that the insulation is designed to withstand

Note 1 to entry: These test voltages can be for instance:

a) rated lightning impulse and short duration power frequency withstand voltages;

b) rated lightning and switching impulse withstand voltages (phase-to-earth).

[SOURCE: IEC 60050-421:1990, 421-09-02]

3.2.9
earth fault factor
at a given location of a three-phase system, and for a given system configuration, ratio of the highest RMS value of line-to-earth power frequency voltage on a healthy line conductor during an earth fault affecting one or more line conductors at any point on the system, to the RMS value of line-to-earth power frequency voltage which would be obtained at the given location in the absence of such earth fault

[SOURCE: IEC 60050-614:2016, 614-03-06, modified – The term "ground fault factor, US" has been omitted.]

3.2.10
effectively earthed neutral system
system on which the neutral is connected to earth solidly or through an impedance of sufficiently low value to reduce transient oscillations and to give a current sufficient for selective earth fault protection

Note 1 to entry: A three-phase system with effectively earthed neutral at a given location is a system characterized by an earth fault factor at this point which does not exceed 1,4. This condition is obtained approximately when, for all system configurations, the ratio of zero-sequence reactance to the positive sequence reactance is less than 3 and the ratio of zero sequence resistance to positive sequence reactance is less than one.

Note 2 to entry: A three-phase system with non-effectively earthed neutral at a given location is a system characterized by an earth fault factor at this point that may exceed 1,4.

3.2.11
solidly earthed neutral system
system whose neutral point(s) is (are) earthed directly

[SOURCE: IEC 60050-601:1985, 601-02-25]

3.3 Definitions related to windings

3.3.1
winding
assembly of turns forming an electric circuit associated with one of the voltages assigned to the SSVT

[SOURCE: IEC 60050-421:1990, 421-03-01, modified – Reference to transformer or reactor replaced with SSVT.]

3.3.2
primary winding
winding to which is applied the voltage to be transformed

[SOURCE: IEC 60050-321:1986, 321-01-05, modified – removed "(of a voltage transformer)" from the term.]

3.3.3
secondary winding
winding which supplies power to the secondary circuit or voltage to measuring instruments, meters, protective or control devices

3.3.4
power winding
secondary winding that supplies power to the secondary circuit

3.3.5
measurement winding
additional winding that supplies the voltage circuits of measuring instruments, meters, relays or similar apparatus

Note 1 to entry: The accuracy of measuring windings depends not only on the load and the power factor of the winding itself, but also on the load and power factor of the power windings.

3.3.6
section
electrically conductive part of an SSVT insulated from other similar parts and equipped with terminals

EXAMPLE Primary or secondary reconnectable windings, shielding to be externally earthed, temperature sensors.

3.3.7
tap
connection made at some intermediate point in a winding to permit changing of the ratio

[SOURCE: IEC 60050-421:1990, 421-05-01, modified – The term "tapping" removed, and "to permit changing the ratio" added to the definition.]

3.4 Definitions related to ratings

3.4.1
rating
numerical values assigned to the quantities which define the operation of the SSVT in the condition specified in this document and on which the manufacturer's guarantee and tests are based

3.4.2
rated value
value of a quantity used for specification purposes, established for a specified set of operating conditions of a component, device, equipment, or system

Note 1 to entry: Voltages and currents are always expressed by their RMS values, unless otherwise specified.

[SOURCE: IEC 60050-151:2001, 151-16-08, modified – Note to entry added.]

3.4.3
rated frequency
f_r
frequency at which the SSVT is designed to operate and on which the requirements of this document are based

[SOURCE: IEC 60050-421:1990, 421-04-03, modified – symbol added, and "and on which the requirements of this document are based" added, and changed "transformer or reactor" to "SSVT".]

3.4.4
rated output power
S_r
conventional value of apparent power assigned to a winding which, together with its rated voltage, determines its rated current

3.4.5
rated current
I_r
current flowing through terminals of a winding which is derived by dividing the rated output power S_r by the rated voltage of the winding

3.4.6
reference temperature
temperature defined as 20 °C plus the rated average winding temperature rise

[SOURCE: IEEE C57.12.80-2010, 3.368, modified – removed "unless otherwise stated" and the second sentence.]

3.4.7
temperature rise
difference between the temperature of the part under consideration and ambient air temperature

[SOURCE IEC 60050-151:2001, 151-16-26, modified – "a reference temperature" replaced by "ambient air temperature" and the note deleted.]

3.4.8
rated arc-proof current
I_{arc}
maximum current, within a specified withstand duration, for which the internal arc classification applies

3.5 Definitions related to losses

3.5.1
no-load loss
active power absorbed when the rated primary voltage U_{pr} at rated frequency f_{r} is applied to the primary winding with the other windings open-circuited

3.5.2
no-load current
current flowing through a line terminal of a winding when a given voltage is applied at rated frequency, the other winding(s) being open-circuited

Note 1 to entry: Normally the applied voltage is the rated voltage and the energized winding, if fitted with taps, is connected on its principal tapping.

Note 2 to entry: The no-load current of a winding is often expressed as a percentage of the rated current of the same winding.

3.5.3
load loss
absorbed active power at rated frequency f_{r} and reference temperature associated with a pair of windings when rated current is flowing through the terminals of one of the windings, and the terminals of the other winding are short-circuited

Note 1 to entry: Other windings, if existing, are open circuited.

3.5.4
total loss
sum of the no-load loss and the load loss

Note 1 to entry: For a two-winding SSVT there is only one winding combination and one value of load loss. For a multi-winding SSVT there are several values of load loss corresponding to the different two-winding combinations (see IEC 60076-8:1997, Clause 7). A combined load loss figure for the complete SSVT is referred to a specified winding load combination.

3.5.5
short-circuit impedance
percent impedance, US
equivalent series impedance $Z = R + jX$, in ohms, at rated frequency and reference temperature, across the terminals of one winding of a pair, when the terminals of the other winding are short-circuited and other windings, if existing, are open-circuited

Note 1 to entry: In an SSVT having a tapped winding the short-circuit impedance is referred to a particular tapping. Unless otherwise specified the rated voltage tap applies.

Note 2 to entry: This quantity can be expressed as a fraction z of the reference impedance Z_{ref}, of the same winding of the pair and expressed in percent, hence the term "percent impedance".

In percentage notation:

$$z(\%) = 100\frac{Z}{Z_{\text{ref}}} \tag{1}$$

where:

$$Z_{\text{ref}} = \frac{U^2}{S_{\text{r}}} \tag{2}$$

U is the voltage (rated voltage or tapping voltage) of the winding to which Z and Z_{ref} belong;

S_{r} is value of rated output power.

The relative value is also equal to the ratio between the applied voltage during a short-circuit measurement which causes the relevant rated current (or tapping current) to flow, and rated voltage (or tapping voltage). This applied voltage is referred to as the short-circuit voltage of the pair of windings.

3.5.6
short circuit voltage
impedance voltage
voltage required to be applied at rated frequency to the line terminals of a winding of a single-phase transformer, to cause the rated current to flow through these terminals when the terminals of the other winding are short-circuited

Note 1 to entry: The value is normally related to the appropriate reference temperature.

Note 2 to entry: The impedance voltage is usually expressed as a percentage of the rated voltage of the winding to which the voltage is applied.

Note 3 to entry: When expressed in relative form (in %) the short circuit voltage has the same value as the short circuit impedance in %.

3.5.7
voltage drop or rise for a specified load condition
voltage regulation for a specified load condition
arithmetic difference between the no-load voltage of a power winding and the voltage developed at terminals of the same winding at a specified load and power factor, the voltage supplied to the power winding being equal to:

– its rated value if the SSVT is connected to the rated voltage tap (the no-load voltage of the power winding then being equal to its rated value)
– the tap voltage if the SSVT is connected to another tap

Note 1 to entry: The difference is generally expressed as a percentage of the no-load voltage of the power winding.

Note 2 to entry: For SSVTs with multiple windings (also applicable to measuring windings) the voltage drop depends not only on the load and power factor of the winding itself, but also on the load and power factor of the other windings.

[SOURCE: IEC 60050-421:1990, 421-07-03, modified – In the definition, "winding" has been replaced with "power winding", "transformer" has been replaced with "SSVT" and "tapping" replaced with "tap"; the existing note to entry deleted and replaced with two new notes to entry.]

3.6 Definitions related to gas insulation

3.6.1
closed pressure system
volume that is replenished only when needed by manual connection to an external gas source

3.6.2
rated filling pressure
pressure referred to the standard atmospheric air conditions (20 °C and 101,3 kPa) to which the gas-insulated SSVT is filled before being put in service, or replenished as needed

[SOURCE: IEC 61869-99:2022, 3.6.7, modified – changed "instrument transformer" to "SSVT" and "periodically replenished" to "replenished as needed".]

3.6.3
minimum functional pressure
pressure referred to the standard atmospheric air conditions (20 °C and 101,3 kPa) at which, and above which, rated insulation and other characteristics of the gas-insulated SSVT are maintained and at which gas replenishment becomes necessary

[SOURCE: IEC 61869-99:2022, 3.6.8, modified – "instrument transformer" replaced with "SSVT".]

3.6.4
absolute leakage rate
amount of gas escaped by time unit under standard atmospheric conditions (20 °C and 101,3 kPa)

Note 1 to entry: The absolute leakage rate is typically expressed in pascal meter cubed per second (Pa·m^3/s).

[SOURCE: IEC 61869-99:2022, 3.6.9]

3.6.5
relative leakage rate
F_{rel}
absolute leakage rate related to the total amount of gas in the SSVT at rated filling pressure (or density)

Note 1 to entry: Relative leakage rate is typically expressed in per cent per year (%/y).

[SOURCE: IEC 61869-99:2022, 3.6.10, modified – "instrument transformer" replaced with "SSVT".]

3.7 Index of abbreviated terms

The abbreviated terms are given in Table 1.

Table 1 – Index of abbreviated terms

Abbreviated term	Full term
F_{rel}	Relative leakage rate
F_v	Rated voltage factor
f_r	Rated frequency
GNAN	Gas natural air natural (cooling method)
I_{arc}	Rated arc-proof current
I_r	Rated current
KNAN	K-fluid[a] natural air natural (cooling method)
ONAN	Oil natural air natural (cooling method)
SSVT	Station service voltage transformer
S_r	Rated power

Abbreviated term	Full term
U_m	Highest voltage for equipment / Maximum equipment voltage
U_{pr}	Rated primary voltage
U_{sr}	Rated secondary voltage
U_{sys}	Highest voltage of a system / Maximum system voltage
[a] K-type cooling medium is a fluid with fire point greater than 300 °C	

4 Profiles and use of normative references

This document can be used with either IEC or IEEE normative references but the references shall not be mixed. For the IEC profile (3.1.9), IEC references are used; for the IEEE profile (3.1.10), IEEE references are used. The purchaser shall include in the enquiry and order which normative references are to be used. By default, if the choice of normative references is not specified, IEC references shall be used. For SSVTs intended for installation in North America, IEEE references are used.

See Annex C for technical information exchange during contracting stage.

5 Environmental conditions

5.1 Normal (usual) environmental conditions

5.1.1 General

SSVTs conforming to this document shall be suitable for operation at rated power under the following normal environmental conditions.

5.1.2 Temperature

The temperature of the cooling air (ambient temperature) does not exceed 40 °C, and the average temperature of the cooling air for any 24 h period does not exceed 30 °C.

The minimum ambient air temperature is −30 °C.

5.1.3 Altitude

The altitude does not exceed 1 000 m (3 300 ft).

5.1.4 Other environmental conditions

Other environmental conditions are as follows:

a) solar radiation up to a level of 1 000 W/m^2 should be considered;
b) the ambient air may be polluted by dust, smoke, corrosive gases, vapours or salt. The pollution or contamination does not exceed the medium level defined in IEC 60815-1 or IEEE C57.19.100™;
c) the wind speed does not exceed 34 m/s (76 mph);
d) the presence of condensation or precipitation;
e) the ice coating does not exceed 20 mm (0,79 in).

NOTE These environmental conditions are consistent with normal environmental conditions for outdoor instrument transformers according to IEC 61869-1.

5.1.5 Primary voltage

The primary voltage wave shape is approximately sinusoidal. The harmonic factor of the primary voltage does not exceed 0,05 per unit.

5.1.6 Load current

The load current is approximately sinusoidal. The harmonic factor of the load current does not exceed 0,05 per unit.

5.1.7 Step-down operation

Unless otherwise specified, an SSVT shall be utilized in a step-down operation in which the outgoing power from the SSVT is at a lower voltage than the incoming power.

5.1.8 Operation above rated voltage or below rated frequency

5.1.8.1 Capability

SSVTs shall be capable of the following:

a) Operating continuously above rated voltage or below rated frequency, at maximum rated power for any tap, without exceeding the limits of observable temperature rise in accordance with 6.18 when all of the following conditions are present:
   1) Secondary voltage and the ratio of secondary voltage over frequency do not exceed 105 % of rated values
   2) Load power factor is 80 % or higher
   3) Frequency is at least 95 % of rated value.
b) Operating continuously above rated voltage or below rated frequency, on any tap at no load, without exceeding limits of observable temperature rise in accordance with 6.18, when neither the voltage nor the ratio of secondary voltage over frequency exceed 110 % of rated values.

5.1.8.2 Maximum continuous SSVT operating voltage

The primary voltage shall not exceed the specified highest voltage for equipment (U_m). Preferential values of U_m are listed in Table 4. System conditions may require voltage transformation ratios involving tap voltages higher than the maximum system voltage for regulation of the secondary voltage.

The current associated with the power rating on the nameplate shall not be exceeded at any operating voltage.

NOTE Normal load power factor is 80 % or higher. A lower power factor may affect secondary voltage drop (or rise). The voltage drop (or rise) can be calculated as instructed in 6.5.4.

5.1.8.3 Rated voltage factor (F_v)

The SSVT shall be capable of operating at a line-to-earth overvoltage according to Table 2 without any damage. When specified by the user, the following F_v and time duration options can be selected:

Table 2 – Standard values of rated voltage factor

F_V	Duration	Applicability	Source
1,1	Continuous	Default for all voltage levels	IEEE
1,2	Continuous		IEC
1,25	60 s		IEEE/IEC
1,4	60 s	Optional	IEEE
1,5	30 s	Optional	IEC

5.2 Special (unusual) environmental conditions

5.2.1 General

Conditions other than those described in 5.1 are considered special environmental conditions and, when prevalent, shall be brought to the attention of those responsible for the design and application of the SSVT. Examples of some of these conditions are listed in 5.2.2 and in 5.2.4.

5.2.2 Special (unusual) temperature

For installations located in a place where the ambient temperature can be significantly outside the normal environmental condition range stated in 5.1.2, the preferred ranges of minimum and maximum temperature to be specified should be:

a) −50 °C to 40 °C for very cold climates;

b) −5 °C to 50 °C for very hot climates.

NOTE Under certain conditions of solar radiation, appropriate measures, e.g. roofing, forced ventilation, etc., can be necessary in order not to exceed the specified temperature rises. Alternatively, the SSVT power can be derated.

5.2.3 Altitude correction factor for altitudes greater than 1 000 m

The coordination withstand voltages are considered valid up to an altitude of 1 000 m. To consider the reduced withstand capability of the air at an installation site with an altitude above 1 000 m, the required type test insulation withstand level of external insulation at standard reference atmospheric conditions shall be determined by multiplying the withstand voltage required at the environmental site by an altitude correction factor K_a. The correction factor shall not be applied for routine tests, because a routine test validates the quality of the internal insulation only.

The altitude correction factor shall be determined in accordance with IEC 60071-2:2023, 7.2.2, using Formula H.11 from Annex H of IEC 60071-2:2023 as follows:

$$K_a = e^{m\left(\frac{H-1000}{8\,150}\right)} \quad (3)$$

where

H is the altitude above sea level (in meters);

m is as follows:

- m = 1,0 for co-ordination lightning impulse withstand voltages;
- m = 1,0 for power-frequency withstand voltages in the case of wet tests;
- m is in accordance with Figure 1 for co-ordination switching impulse withstand voltages.

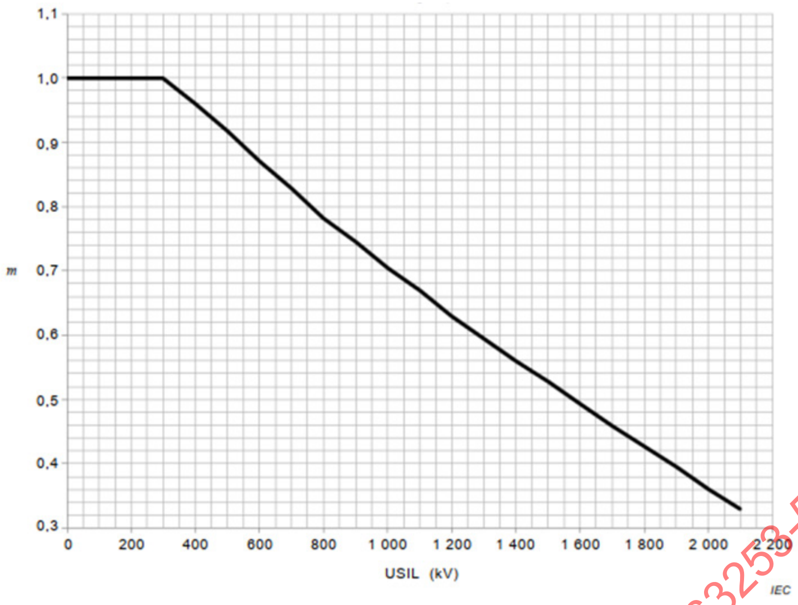


Figure 1 – Factor *m* for the switching impulse withstand test

To withstand a voltage at an altitude greater than 1 000 m, it can be necessary to increase the arcing distance of the SSVT's insulator. If the increase of the arcing distance is based on a verified arcing distance of a similar product, it can be considered valid without further testing.

If the withstand voltages corrected for altitude cannot be validated by an increased arcing distance of a similar product, external insulation shall be tested in accordance with IEC 60071-2:2023.

It is considered that the altitude does not affect the internal insulation.

5.2.4 Loading beyond rated power

Any overload rating, if needed, shall be defined by the user.

5.2.5 Other special (unusual) environmental conditions

Other special environmental conditions include the following:

a) Damaging fumes or vapours, excessive or abrasive dust, explosive mixtures of dust or gases, steam, salt spray, etc.

b) Special vibration, tilting, shock, or seismic conditions.

c) Special transportation or storage conditions.

d) Special space limitations.

e) Special maintenance problems.

f) Special duty or frequency of operation, or high-current short-duration loading.

g) Unbalanced AC voltages, or departure of AC system voltages from a substantially sinusoidal wave form.

h) Conditions exceeding those listed in 5.1.

i) Special voltage conditions (transient overvoltages, resonance, switching surges, etc.) can require special consideration in insulation design.

j) Unusually strong magnetic fields. It should be noted that solar magnetic disturbances may result in the flow of telluric currents in transformer neutral(s).

6 Ratings

6.1 Secondary voltage

The maximum rated voltage of the power winding shall be 1 000 V.

The rated voltage of a secondary winding is equal to the no-load secondary voltage and may be higher than the nominal secondary voltage. This is to compensate for the voltage drop due to loading which occurs with unity or lagging load power factors.

The rated voltage of the secondary winding is equal to the rated voltage of the primary winding divided by the turns ratio. At least two of the following shall be known in order to design an SSVT:

1) rated voltage of the primary winding;
2) rated voltage of the secondary winding;
3) turns ratio.

The values in the above list may be established based on a calculation of voltage drop as described in 6.5.4 if the necessary parameters are known. Alternatively, they may be based on the maximum secondary voltage allowed by standards or operating practices applicable to the installation.

The rated secondary voltage shall be shown on the SSVT nameplate.

6.2 Cooling classes of SSVTs

SSVTs shall use the ONAN or KNAN mode of cooling for liquid-immersed SSVTs and GNAN mode of cooling for gas-filled SSVTs.

6.3 Frequency

Unless otherwise specified, SSVTs shall be designed for operation at a frequency of 50 Hz or 60 Hz.

6.4 Rated power

Power ratings are for continuous duty and are based on not exceeding the limits of temperature rise. The temperature rise shall not exceed the temperature rise class or insulation class as given in 6.18.

Preferred power ratings for SSVTs are:

25 – 50 – 75 – 100 – 167 – 250 – 333 – 500 kVA

These ratings are based on the normal temperature and altitude environmental conditions specified in 5.1.

6.5 Voltage ratings and taps

6.5.1 General

Standard nominal system voltages and maximum system voltages are listed in Table 4.

6.5.2 Voltage ratings

The voltage ratings are at no load.

6.5.3 Ratings of SSVT taps

Whenever an SSVT is provided with taps from a winding for de-energized operation, they shall be full power taps.

6.5.4 Voltage drop or rise (voltage regulation) for a specified load condition

The voltage drop or rise (voltage regulation) for a specified load condition may need to be calculated to help ensure compliance with system standards or operating practices.

Examples of formulae for calculating regulation are shown in Formula (4) and Formula (5):

a) When the load is lagging:

$$U_{\text{reg}} = \sqrt{\left(R + F_{\text{p}}\right)^2 + \left(X + q\right)^2} - 1 \tag{4}$$

b) When the load is leading:

$$U_{\text{reg}} = \sqrt{\left(R + F_{\text{p}}\right)^2 + \left(X - q\right)^2} - 1 \tag{5}$$

where:

U_{reg} is the voltage drop or rise (voltage regulation)

F_{p} is power factor of load

q = $\sqrt{1 - F_{\text{p}}{}^2}$

R is resistance factor of SSVT, which is equal to the load loss in kilowatts divided by the rated power in kilovoltamperes

X is reactance factor of SSVT: $X = \sqrt{Z^2 - R^2}$

Z is impedance factor of SSVT, which is equal to the short circuit impedance in percentage multiplied by 100.

The quantities F_{P}, q, R, X, and Z are on a per-unit basis. Results shall be multiplied by 100 to obtain the percentage of regulation.

6.6 Connections

Standard connection arrangements shall be in accordance with IEEE Std C57.12.70™ or IEC 60076-1, however the arrangement may be varied by the manufacturer when design conditions so dictate. The connection arrangements for measuring are as specified in IEEE Std C57.13™ or IEC 61869-3.

6.7 Markings

6.7.1 Polarity of single-phase SSVTs

The polarity of SSVTs covered by this document shall be as follows: the voltage at terminals A or H1 shall be in phase with the voltage at terminal a or X1.

6.7.2 Terminal markings

Terminal markings shall be in accordance with IEEE Std C57.13 or IEC 61869-3.

6.7.3 Nameplates

A durable weatherproof nameplate designed to be legible for the life of the equipment shall be affixed to the outside of each SSVT by the manufacturer. Unless otherwise specified, it shall be made of corrosion-resistant material. It shall bear the rating and other essential operating data as specified in Table 3. This document recognizes the use of metric (SI) and imperial (U.S. customary) units for data appearing on SSVT nameplates. It should be noted that although this document recognizes the possibility of using SI units as an alternative to the U.S. customary units used in the past, it is not intended that both appear on the specific nameplate. However, units used shall be explicitly shown.

Table 3 – Nameplate information

1	Serial number [a]
2	Month/year of manufacture
3	Model / Style number
4	Cooling class (ONAN, GNAN, KNAN)
5	Frequency
6	Rated output power [a]
7	Rated primary and secondary voltages [a]
8	Voltage factor
9	Insulation levels (BIL, BSL)
10	Temperature rise class or insulation class
11	Polarity (Subtractive)
12	Highest voltage for equipment and rated voltage factor
13	Short-circuit impedance
14	Short-circuit voltage [%] (alias impedance voltage)
15	Arc-proof current and duration (if applicable)
16	Approximate total mass in kg or weight in lb
17	Winding and connection diagram (optional placement on separate nameplate)
18	Name and location (country) of manufacturer
19	The abbreviation SSVT
20	Type of insulating liquid (generic name preferred) [b] or gas type
21	Conductor material (of each winding)
22	Liquid volume or mass of gas
23	Measuring accuracy class (if applicable)
24	Rated burden of the measuring winding (if applicable)
25	Power winding load range for rated measuring winding accuracy
26	Rated filling pressure, minimal functional pressure and alarm pressure (if applicable)
27	Standard reference number including edition

[a] The letters and numerals showing kVA, serial number, and voltage ratings shall have a minimum height of 4,00 mm (0,157 in) whether engraved or stamped. The height of other letters and numerals shall be optional with the manufacturer.

[b] For liquid filled units, the nameplate shall state: "Contains no detectable level of PCB at the time of manufacture".

6.8 Turns ratio

6.8.1 General

The turns ratio of an SSVT is the ratio of the number of turns in the primary winding to that in the secondary winding.

6.8.2 Taps

When an SSVT has taps for changing its voltage ratio, the turns ratio is based on the number of turns corresponding to the normal rated voltage of the respective windings to which operating and performance characteristics are referred.

6.9 Accuracy ratings of measurement windings

6.9.1 General

The accuracy of measuring windings will vary with loading of the power winding. The variation is influenced by both load kVA and power factor (F_p) of the power winding. Non-sinusoidal load currents may result in non-sinusoidal measuring voltages.

The accuracy performance of the measurement winding shall be specified over a range of load of the power winding. The load range for different power factors may be specified separately. Ratio and phase error limits may be specified separately for a specific load range.

As a minimum, the following values for which the guaranteed accuracy performance is achieved shall be specified:

– power winding load range at unity power factor;

– power winding load range at 0,8 lagging power factor.

If only one range is specified, it shall apply to both values of the power factor.

Other accuracy ratings may be specified by the user.

The load range may be expressed in kVA or as a percentage of rated output power S_r.

Examples of correctly specified measurement winding information:

Example 1:	IEC Class 0,5 75 VA Power winding load range:	0 kVA to 5 kVA
	IEEE Class 0,6 WXY Power winding load range:	0 kVA to 5 kVA
Example 2:	IEC Class 3P 200 VA Power winding load range:	0 % to 25 % at F_P = 0,8
		0 % to 35 % at F_P = 1,0
	IEEE Class 1,2 WXYZ Power winding load range:	0 % to 25 % at F_P = 0,8
		0 % to 35 % at F_P = 1,0
Example 3:	IEC Class 0,5 75 VA Power winding load range:	0 kVA to 5 kVA at F_P = 0,8
		0 kVA to 7,5 kVA at F_P = 1,0
	Class 1,0 75 VA Power winding load range	0 kVA to 10 kVA at F_P = 0,8
		0 kVA to 15 kVA at F_P = 1,0

IEEE Class 0,6 WXY Power winding load range:	0 kVA to 5 kVA at F_P = 0,8
	0 kVA to 7,5 kVA at F_P = 1,0
Class 1,2 WXY Power winding load range:	0 kVA to 10 kVA at F_P = 0,8
	0 kVA to 15 kVA at F_P = 1,0

Example 4: (applicable to both IEC and IEEE) Voltage (ratio) error ±3 %, phase error ±250 min

Power winding load range:	0 % to 75 % at F_P = 0,8
	0 % to 100 % at F_P = 1,0

6.9.2 Assignment of accuracy class

Accuracy class shall be according to Clause 5 of IEEE C57.13-2016 or IEC 61869-3:2011, 5.6.

6.9.3 Accuracy classification for SSVT with two secondary measuring windings or tapped secondary windings

The burden on any two secondary terminals affects the accuracy on all other terminals. The burden stated in the accuracy ratings is the total burden on the SSVT. The accuracy class shall apply with the burden divided between the secondary outputs in any manner.

6.10 Short-circuit impedance

The short-circuit impedance shall be referred to a temperature equal to the rated average winding temperature rise by resistance, specified in Table 7, plus 20 °C.

When specifying short-circuit impedance, the user may specify a minimum value, in order to limit short-circuit current, a maximum value, in order to limit voltage drop due to loading, or a preferred range of impedance.

Each SSVT design has an inherent short-circuit impedance. It is recommended to limit restrictions on short-circuit impedance to those which are necessary for the application.

6.11 Total losses

The total losses of an SSVT are equal to the sum of the no-load losses and the load losses.

The reference temperature for the load losses of an SSVT shall be the temperature rise class specified in Table 7 plus 20 °C. The standard reference temperature for the no-load losses of an SSVT shall be 20 °C.

6.12 Rated insulation levels of primary terminals

6.12.1 Line terminal

SSVTs shall be designed to provide coordinated power frequency and impulse insulation levels on line terminals and power frequency insulation levels on neutral terminals. The coordinated levels shall be identified by the highest voltage for equipment and basic lightning impulse insulation level (BIL). The BIL will be selected dependent on the degree of exposure of the SSVT and characteristics of the overvoltage protection system.

Table 4 – Basic impulse insulation levels and power frequency withstand voltages

Nom. system voltage (IEEE)	Highest voltage for equipment (U_m)	Source	Lightning impulse voltage (BIL)[a]		Switching impulse voltage (BSL)	Power frequency withstand voltage	
(kV, RMS)	(kV, RMS)		(kV, peak)		(kV, peak)	(kV, RMS)	
			Full wave	Chopped wave[c]		Dry	Wet[b]
46	48,3	IEEE	250	290	—	95	95
	52	IEC	250	290	—	95	95
69	72,5	IEC	325	375	—	140	140
		IEEE/IEC	350	400	—	140	140
	100	IEC	450	520	—	185	185
115	123	IEEE/IEC	450	520	—	185	185
		IEEE/IEC	550	630	—	230	230
138	145	IEEE/IEC	550	630	—	230	230
		IEEE/IEC	650	750	—	275	275
161	170	IEEE/IEC	650	750	—	275	275
		IEEE/IEC	750	865	—	325	325
230	245	IEEE	900	1 035	—	395	395
		IEC	950	1 090	—	395	395
		IEEE/IEC	1 050	1 210	—	460	460
	300	IEC	950	1 090	750	396	—
		IEC	1 050	1 210	850	460	—
345	362	IEC	1 050	1 210	850	460	—
		IEEE/IEC	1 175	1 350	950	510	—
		IEEE/IEC	1 300	1 500	975	575	—
	420	IEC	1 300	1 500	950	570	—
		IEC	1 425	1 640	1 050	630	—
500	550	IEC	1 425	1 640	1 050	630	—
		IEEE/IEC	1 550	1 785	1 175	680	—
		IEEE	1 800	2 070	1 300	830	—
765	800	IEC	1 950	2 250	1 425	880	—
		IEEE/IEC	2 100	2 420	1 550	975	—
	1 100	IEC	2 250	2 590	1 550	1 100	—
		IEC	2 400	2 760	1 675		—
		IEC	2 550	2 930	1 800		—
	1 200	IEC	2 250	2 590	1 675	1 200	—
		IEC	2 400	2 760	1 800		—
		IEC	2 700	3 105	1 800		—

[a] Caution – The selection of a lower BIL for a given nominal system voltage also reduces other requirements as tabulated in this Table 4 and should be supported by insulation coordination studies. The acceptability of these reduced requirements should be evaluated for a specific SSVT design and application.

[b] For test procedures, see IEEE Std 4™ or IEC 60060.

[c] The minimum time to chopping shall be 3 μs.

6.12.2 Creepage distance requirements

The following minimum creepage values in Table 5 are based on $U_m / \sqrt{3}$. These values may need to be adjusted for factors such as shape, number of sheds, and bushing inclination.

Table 5 – Creepage distances as a function of $U_m / \sqrt{3}$

Contamination	Creepage distance
Light	28 mm/kV
Medium	35 mm/kV
Heavy	44 mm/kV
Extra heavy	54 mm/kV or greater

The definitions of contamination levels are provided in IEEE C57.19.100 and IEC 60815-1.

6.12.3 Basic lightning impulse insulation level (BIL)

A BIL from Table 4 shall be assigned to the line terminal of the HV winding.

6.12.4 Switching impulse insulation level (BSL)

Windings for U_m equal to or greater than 300 kV shall be designed for the BSL associated with the assigned BIL as shown in Table 4.

6.12.5 Neutral terminals

The neutral terminal of the primary winding shall withstand a 19 kV RMS applied-voltage test according to clause 8.5.3 of IEEE C57.13-2016 or 3 kV power frequency withstand voltage test, according to IEC 61869-1:2023, 5.4.2. In some cases the voltage ratio adjustment is achieved by tapping the primary winding in its part close to the neutral terminal. In this case the SSVT is considered to have multiple neutral terminals.

6.13 Rated insulation levels of secondary terminals

6.13.1 Secondary power windings terminals

The rated power frequency withstand voltage of secondary power windings is 5 kV (RMS) for 60 s. For windings divided into two or more sections the same rating applies between sections.

6.13.2 Secondary measuring windings terminals

The rated power frequency withstand voltage of secondary measuring windings is 3 kV (RMS) for 60 s. For windings divided into two or more sections the same rating applies between sections.

6.14 Insulation resistance requirements

The insulation resistances between individual windings and earth and between windings shall be measured at a voltage not less than 1,0 kV (DC). The measured values shall not be less than 200 MΩ.

6.15 Earth shield requirements

The SSVT shall be provided with an earth shield between the primary winding and the secondary windings. The existence of the earth shield shall be verified by 9.4.12.

NOTE The earth shield provides some degree of protection in the secondary circuit against an insulation failure between the primary and secondary windings.

6.16 Dissolved gas and water content requirements for new mineral oil-immersed SSVTs

For new mineral oil-immersed SSVTs, the maximum concentration of the dissolved gas and water content in the oil, after all tests, shall be in accordance with the values in Table 6.

The minimum sensitivity of gas spectrum analyzer shall be in accordance with the last column of Table 6.

Table 6 – Dissolved gas and water content for new mineral oil-immersed SSVTs

Component		Maximum concentration (p.p.m.)	Minimum sensitivity (p.p.m.)
Hydrogen	H_2	15,0	2,0
Carbon monoxide	CO	40,0	5,0
Carbon Dioxide	CO_2	200,0	10,0
Methane	CH_4	5,0	0,1
Ethylene	C_2H_4	2,0	0,1
Ethane	C_2H_6	3,0	0,1
Acetylene	C_2H_2	Not detectable	0,1
Water	H_2O	10,0	3,0

NOTE Table values from IEEE C57.13.5™.

6.17 Internal arc requirements

6.17.1 General

An SSVT, when designed to limit the hazardous effects of an internal arc, shall conform during the test with the requirements defined for the classes as provided in 6.17.1 and 6.17.2.

The special features of internal arc protection shall be specified in the enquiry, including the rated arc-proof current. The basis for determination of the rated arc-proof current shall be the phase to earth fault current calculation at the location where the SSVT will be installed. This may be significantly lower than system three-phase short-circuit current.

The values of rated arc-proof current should be selected from the R 10 series, specified in IEC 60059.

NOTE 1 The R 10 series comprises the numbers 1 – 1,25 – 1,6 – 2 – 2,5 – 3,15 – 4 – 5 – 6,3 – 8 and their products by the powers of 10.

NOTE 2 If the specified rated arc-proof current is higher than the actual phase to earth fault current it can require over-design of the SSVT.

6.17.2 Internal arc protection class I

A specific design with a feature that, during an internal arc test with the arc taking place at a location, which is technically most probable, the debris of the SSVT will be confined to a circle centred at the SSVT. The diameter of this circle is equal to the sum of twice the height of the SSVT and the diameter, or largest horizontal dimension, of the SSVT.

6.17.3 Internal arc protection class II

A specific design with a feature that, during an internal arc test with the arc taking place at a location, which is technically the most probable, will not fracture the insulator or housing of the SSVT.

NOTE The above definitions regarding the classification of internal arc protection apply only to the test conditions specified in this document. The SSVT can have different performance during an in-service internal arc fault. Refer to Annex B for more information regarding the interpretation of internal arc protection. The performance does not apply to any internal pressure relief device (e.g. rupture disc and protective cover, if applicable) provided with the SSVT.

6.18 Temperature rise and loading conditions for SSVT

The limits of observable temperature rise in SSVTs when tested in accordance with their ratings shall be as given in Table 7.

SSVTs of standard temperature rise may be operated at rated power at altitudes higher than 1 000 m (3 300 ft) provided that the cooling air temperature does not exceed the values in Table 8 for the respective altitudes. If this is done, the standard temperature limits will not be exceeded.

It is recommended that when SSVTs with standard temperature rise are used in standard ambient temperatures at altitudes greater than 1 000 m (3 300 ft), the maximum power be reduced below rating by 0,4 % for each 100 m (330 ft). If this is done, the standard temperature rise will not be exceeded.

The top-oil temperature is the temperature of the top layer of the insulating fluid, which for SSVTs is generally measured approximately 50 mm below the top of the housing surrounding the core and windings.

Table 7 – Limits of temperature rise

	30 °C ambient, 24 h average				
Type of SSVT	**Insulation class**	**Average winding temperature rise (K)**	**Hottest spot winding temperature rise (K)**	**Top-oil temperature rise (K)**	**Other metallic parts temperature rise (K)**
Oil insulated	55 65	55 65	65 80	55 65	65 80
Gas insulated	120 (E) 130 (B) 155 (F) 180 (H)	75 85 110 135	90 100 125 150	N/A	80

Table 8 – Maximum allowable 24 h average temperature of cooling air to permit SSVT to operate at rated power

Insulation Class	Average winding temperature rise (K)	Cooling air temperature (°C) at altitude (m)			
		1 000	2 000	3 000	4 000
55	55	30	28	26	23
65	65	30	27	25	22
120 (E)	75	30	27	24	21
130 (B)	85	30	27	23	20
155 (F)	110	30	26	21	17
180 (H)	135	30	25	19	14
It is recommended that the average temperature of the cooling air be calculated by averaging 24 consecutive hourly readings. Alternatively, the average of the maximum and minimum daily temperature may be used. The value that is obtained in this manner is usually slightly higher than the true daily average.					

Terminals for use in air shall be designed so that their maximum operating temperature when tested with their ratings do not exceed the values provided in Table 9.

Table 9 – Maximum operating temperature of power terminals intended for bolted connection in air

Performance	Bare copper or aluminum terminals (°C)	Tin-plated terminals (°C)	Silver-plated terminals (°C)	Stainless steel terminals (°C)
Maximum operating temperature	90	105	115	115

6.19 Partial discharge requirements

Maximum partial discharge voltages are provided in Table 15 of 9.4.8.

6.20 RIV requirements

Maximum RIV voltages are provided in Table 16 of 9.5.5.4.

7 Construction

7.1 Tank pressure requirements for liquid-filled SSVTs

Tank pressure under rated conditions for sealed SSVTs shall not exceed two atmospheres (101,3 kPa relative or 14,7 psig) unless requirements of applicable Pressure Vessel Code (BPV) are met.

7.2 Mechanical performance requirements

7.2.1 Overview

All SSVTs shall comply with the following mechanical performance requirements described in 7.2.2 and 7.2.3.

7.2.2 Sealing requirements tests

7.2.2.1 General

All SSVTs shall be sealed against leakage of insulating medium for the normal environmental conditions stated in 5.1.

7.2.2.2 Liquid filled SSVTs

The manufacturers shall review the sealing tests outlined in Table 10 and adopt the one most suitable for their SSVTs. Other test methods can also be fully acceptable.

The manufacturer shall submit the routine sealing test procedure and acceptance criteria to the user for approval.

Table 10 – Sealing test options for liquid filled SSVTs

Test	Average oil temperature °C	Internal pressure kPa relative	Time h
(I)	50	35	24
(II)	50	103	12
(III) [a]	85	0	12
(IV)	25	35	60
(V)	25	103	24

[a] This document recommends this procedure for SSVTs equipped with oil expansion diaphragms or bellows. Other procedures as shown in this Table 10, with application of pressure, e.g. by clamping the oil expansion diaphragms or bellows, instead of raising the average oil temperature of the SSVT to 85 °C should also be considered acceptable.

7.2.2.3 Gas-filled SSVTs

The construction of the tank shall be in accordance with the national standards on enclosures for gas-filled electrical equipment. The manufacturer shall submit the certificate of the tank to the user for approval before the routine tests.

The tightness characteristic of a gas-filled SSVT shall be consistent with a minimum maintenance and inspection philosophy.

The tightness of closed pressure systems for gas is specified by the relative leakage rate F_{rel} of the gas-filled SSVT.

The standardized value in ambient temperature prevailing in factories (10 °C to 40 °C) is 0,5 % per year, for SF_6 and SF_6-N_2 mixtures.

Lower leakage rates can be specified according to national regulations and regional practice. An increased leakage rate at extreme temperatures is acceptable, provided that this rate resets to a value not higher than the maximum permissible value at normal ambient air temperature prevailing in factories. The increased temporary leakage rate shall not exceed the following values (where T_L is the lower limit of the ambient temperature range):

a) For low ambient temperature (T_L = −5 °C, −10 °C, −15 °C, −25 °C and −40 °C): 1,5 %/year

b) For ultra-low ambient temperature (T_L = −50 °C): 3,0 %/year

The manufacturer shall submit the routine sealing test procedure and acceptance criteria to the user for approval.

7.2.3 Mechanical strength of the SSVT

All SSVTs intended for pedestal mounting shall be capable of withstanding the following non-simultaneous mechanical stresses:

a) Static terminal loads according to load values shown in Table 11 and Table 12;

b) Wind load is determined based on the specified requested wind speed. SSVT strength to withstand a wind force may be demonstrated by using a static analysis;

c) If the SSVT's high voltage insulator is installed with its center line not in the vertical direction, a resulting mechanical stress produced by an ice coating of 20 mm (0,79 in) may be added into the total mechanical stress on the insulator;

d) Seismic performance qualification shall be performed as per the latest edition of IEEE Std 693 or the latest revision of IEC 61869-1.

Table 11 – Static terminal loads for high voltage terminals

Highest voltage for equipment U_m	Static terminal load in N (lb)
≤ 170	1 000 (225)
245 to 362	1 250 (281)
≥ 420	1 500 (337)

Table 12 – Static terminal loads for low voltage terminals

Rated terminal current in A	Moment in N-m (ft-lb)
≤ 500	100 (75)
> 500	135 (100)
NOTE The ft-lb values are rounded up to the nearest whole number.	

Unlike high voltage bushings, low voltage bushings normally have the length of the insulation part relatively shorter than the terminal part. The typical length of the insulation part is from less than 25 mm (1 inch) up to about 50 mm (2 inches), while the typical length of the connecting terminal part might be well above 100 mm (4 inches). As the testing force could be applied anywhere on the terminal, different locations of the applied force on the terminal might cause significantly different bending moment values at the sealing surface of the bushing (to an SSVT wall), and consequently alter the result of the cantilever test. Therefore, the test requirement is specified as a moment to eliminate the effect of the testing force location.

For example, the test requirement values in Table 12, with current less than or equal to 500 A, is equivalent to a testing force of 680 N (150 lbf), at the end of a bushing which has 150 mm (6 inches) total length from the end of the terminal to the sealing surface.

The sum of loads acting in routine operating conditions should not exceed 50 % of the specified terminal load.

Test procedure is specified in 9.5.2.

7.3 Liquid insulation system

7.3.1 Insulating liquids

SSVTs shall be filled with a suitable insulating liquid such as:

a) Mineral oil: New, unused mineral oil shall meet the requirements of ASTM D3487 or IEC 60296.

NOTE 1 IEEE Std C57.106™ and IEC 60422 provide information concerning the acceptance and maintenance of mineral oil, including dielectric test breakdown criteria according to oil application, age, and test method.

b) Less flammable hydrocarbon fluid: New, unused less flammable hydrocarbon fluid shall meet the requirements of ASTM D5222 or IEC 60867.

NOTE 2 IEEE Std C57.121™ provides information concerning the acceptance and maintenance of less-flammable fluid in transformers.

c) Silicone fluid: New, unused silicone fluid shall meet the requirements of ASTM D2225 or IEC 60836.

NOTE 3 IEEE Std C57.111™ and IEC 60944 provide information concerning the acceptance and maintenance of silicone insulating fluid in transformers.

d) Natural ester fluid: New, unused natural ester fluid shall meet the requirements of ASTM D6871 or IEC 62770.

NOTE 4 IEEE Std C57.147™ provides information concerning the acceptance and maintenance of natural ester fluids in transformers.

e) Synthetic ester fluid: New, unused synthetic ester fluid shall meet the requirements of IEC 61099.

NOTE 5 IEC 61203 provides information concerning the acceptance and maintenance of synthetic ester fluids in transformers.

There are other insulating fluids that may be suitable and are commercially available. At the time of writing of this document, neither ASTM specifications nor IEEE guides provide guidelines for use of liquids other than those mentioned above.

7.3.2 Insulating liquid preservation

SSVTs shall be equipped with an insulating liquid preservation system such as the following examples:

a) Sealed tank system
b) Gas-oil seal system
c) Metallic bellows

NOTE Various insulating liquid (oil) preservation systems are described and defined in IEEE Std C57.12.80.

7.4 Gas insulation system

7.4.1 Requirements for gases in SSVTs

The equipment manufacturer shall specify the type and the required quantity, quality and density of the gas to be used in an SSVT and provide the user with necessary instructions for renewing the gas and maintaining its required quantity and quality. This requirement does not apply to sealed pressure systems.

For sulfur hexafluoride (SF_6)-filled SSVTs, new SF_6 shall comply with ASTM D 2472 or IEC 60376.

In order to prevent condensation, the maximum allowable moisture content within gas-filled SSVTs filled with gas at rated filling density for insulation shall be such that the dew point is not higher than −5 °C for a measurement at 20 °C. Corrections shall be made for measurement made at other temperatures. For the measurement and determination of the dew point, refer to IEEE C37.122.5™ or to IEC 60376 and IEC 60480.

NOTE Attention is drawn to the need to comply with local regulations relevant to pressure vessels, e.g., ASME Boiler and Pressure Vessel Code.

7.4.2 Pressure monitoring devices

Closed pressure systems filled with compressed gas and having a minimum functional pressure above 203 kPa (29,4 psia) shall be provided with pressure (or density) monitoring devices, to be continuously, or at least periodically, checked as part of the maintenance program.

The pressure/density monitors shall have switches for low pressure alarming and/or tripping.

For SSVTs having a minimum functional pressure not higher than 203 kPa (29,4 psia), such means should be subject to agreement between manufacturer and user.

7.4.3 Tank construction and maximum gas leakage rates

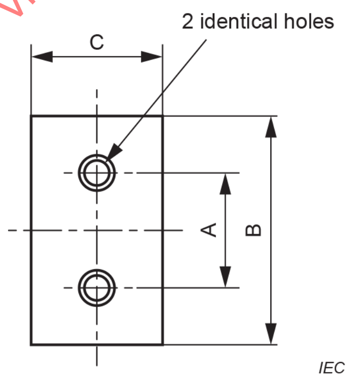
The construction of the tank shall meet the requirements of 7.2.2.3.

7.5 Earthing

7.5.1 SSVT tank earthing

A tank earthing pad shall be provided and consist of a copper-faced steel pad, aluminum pad or a stainless-steel pad without copper facing. Minimum thickness of the copper facing shall be 0,4 mm (0,015 in).

The recommended dimensions for the earthing pad are shown in Figure 2.



Profile	A	B	C
	mm (In)	mm (In)	mm (In)
IEEE	44,5 (1,75)	88,9 (3,50)	50,8 (2,00)
IEC	50,0 (1,97)	100,0 (3,94)	40,0 (1,57)

Figure 2 – Recommended earth pad dimensions

The earth pad shall be welded on or cast into the base or on the tank wall near the base. If the base is detachable, the earth pad shall be located on the tank wall. The preferred location of the earth pad is the right-side tank wall as viewed facing the low voltage terminal box.

For SSVTs following the IEEE profile, the holes should be threaded ½-13 UNC with a minimum depth of 13 mm (0,5 in). Thread protection is recommended. Alternatively, two through holes may be provided. The diameter of the through holes should be 14,3 mm (0,562 in). In this case the thickness of the earthing pad should be 10 mm (or 0,375 in) minimum.

For the SSVTs which are determined to follow the IEC profile, the earth pad dimensions may comply with applicable national standards.

7.5.2 Earthing of core

The SSVT core shall be electrically connected to the SSVT tank in such a way to avoid a circuit loop.

7.6 Degrees of protection by enclosures

7.6.1 General

Degrees of protection shall be specified, for all enclosures of SSVTs containing live parts, as well as for enclosures for appropriate low-voltage control and/or auxiliary circuits.

The following parts shall be considered as an enclosure, if existing:

– Low-voltage terminal box(es);
– Compensation equipment for thermal dilatation of oil.

NOTE Other components can be considered as enclosures according to the definition in 3.1.2.

7.6.2 Protection of persons against access to hazardous parts and protection of the equipment against ingress of solid foreign objects

The degree of protection of persons provided by an enclosure against access to hazardous parts of the main circuit, control and/or auxiliary circuits shall be indicated by means of a designation specified in IEC 60529 for SSVTs that follow the IEC profile and NEMA 250 for SSVTs that follow IEEE profile.

NOTE Generally the protection of persons against access to hazardous parts of live circuit, or control or auxiliary circuits, and the protection of the SSVTs against foreign objects, can be provided by the immediate surroundings of the SSVT, such as substation fence, building, module enclosure, and so on. Further protection can be required as a feature of the whole SSVT or parts of it.

7.6.3 Protection against ingress of water

7.6.3.1 General

The degree of protection provided by an enclosure against ingress of water may be indicated by means of a designation specified in IEC 60529 for SSVTs that follow the IEC profile and NEMA 250 for SSVTs that follow IEEE profile.

7.6.3.2 Recommended protection level

The recommended minimum degree of protection for low-voltage control and/or auxiliary enclosures for SSVTs is IP54 or NEMA 3, depending on the profile.

7.6.4 Protection of equipment against mechanical impact under normal environmental conditions

The mechanical degree of protection of enclosures of SSVTs shall comply with the requirements of IEC 62262, as there is no NEMA equivalent at the time of writing of this document.

For SSVTs, the recommended level of protection against effects of mechanical impacts is impact level IK10 (Protected against 20 Joules Impact).

Corresponding tests are specified in 9.6.5.2.

7.6.5 Tank or enclosure finish

Temperature limits and tests shall be based on as-delivered finish. It should be noted that some designs may have unpainted finish. It should be noted that metallic-flake paints, such as aluminium and zinc, have properties that increase the temperature rise of SSVTs, except in direct sunlight.

8 Short-circuit characteristics

8.1 Short-circuit withstand requirements

8.1.1 General

SSVTs shall be designed and constructed to withstand the mechanical and thermal stresses produced by external short-circuits on the low voltage winding.

Short-circuit withstand capability can be adversely affected by the cumulative effects of repeated mechanical and thermal overstressing produced by short-circuits and loads beyond the nameplate rating. It is not feasible to continuously monitor and quantitatively evaluate the degrading effects of such duty; short-circuit tests, when required, should be performed prior to placing SSVT(s) in service.

8.1.2 Duration of short-circuit tests

When short-circuit tests are performed, the duration of each test shall be 0,25 s except that one test satisfying the symmetrical current requirement shall be made for a longer duration. The duration of the long test shall be 2 s.

For special applications when longer fault durations are common in service, special long-duration tests should be specified at purchase. When making consecutive tests without allowing time for winding cooling, care should be taken to avoid exceeding temperature limits (specified in 8.3) for SSVTs under short-circuit conditions.

8.1.3 Number of short-circuit shots

The short-circuit test sequence shall consist of two "short" tests with asymmetrical current and one "long" test with symmetrical current.

8.2 Short-circuit current calculations

8.2.1 Symmetrical current

It should be noted that the required RMS value of symmetrical current in each winding shall be determined by calculation as shown in Formula (6) and Formula (7).

$$I_{\mathrm{SC}} = \frac{I_{\mathrm{R}}}{z} \tag{6}$$

$$I = \frac{I_{\mathrm{SC}}}{I_{\mathrm{R}}} \tag{7}$$

where

I is the symmetrical short-circuit current in multiple of normal base;

I_{SC} is the symmetrical short-circuit current (A, RMS);

I_R is the rated current on the given tap connection (A, RMS);

z is the relative short-circuit impedance of the SSVT on the given tap connection, in percent (see 3.5.5).

8.2.2 Asymmetrical current

The first-cycle asymmetrical peak current that the SSVT is required to withstand shall be determined as shown in Formula (8) and Formula (9).

$$I_{SC(pk\,asym)} = KI_{SC} \tag{8}$$

$$K = \left\{1 + \left[e^{-\left(\phi + \frac{\pi}{2}\right)\frac{r}{x}}\right]\sin\phi\right\}\sqrt{2} \tag{9}$$

where

Φ is arc tan (x/r) (radians);

e is the base of natural logarithm;

x/r is the ratio of effective AC reactance to resistance, both in ohms, in the total impedance that limits the fault current for the SSVT connections when the short-circuit occurs.

8.3 Temperature limits of SSVTs for short-circuit conditions

The temperature of the conductor material in the windings of SSVTs under the short-circuit conditions specified in 8.1.1 through 8.1.3, as calculated by methods described in 8.2, shall not exceed 250 °C for copper conductor. A maximum temperature of 250 °C shall be allowed for aluminum alloys that have resistance to annealing properties at 250 °C equivalent to aluminum at 200 °C, or for applications of aluminum where the characteristics of the fully annealed material satisfy the mechanical requirements. In setting these temperature limits, the following factors were considered:

a) Gas generation from oil or solid insulation,
b) Conductor annealing,
c) Insulation aging.

8.4 Calculation of winding temperature during a short-circuit

The final winding temperature θ_1 at the end of a short-circuit of duration, t, shall be calculated as shown in Formula (10) and Formula (11). All temperatures are in degrees Celsius.

$$\theta_1 = \theta_0 + \frac{2 \times (\theta_0 + 235)}{\frac{106000}{J^2 \times t} - 1} \quad \text{for copper} \tag{10}$$

$$\theta_1 = \theta_0 + \frac{2 \times (\theta_0 + 225)}{\frac{45700}{J^2 \times t} - 1} \quad \text{for aluminium} \tag{11}$$

where

θ_0 is the initial winding temperature in degrees Celsius (°C);

J is the short-circuit current density in amperes per square millimeter (A/mm^2), based on the RMS value of the symmetrical short-circuit current;

t is the duration in seconds (s).

Formula (10) and Formula (11) are based on adiabatic condition and are valid for only a short-time duration, not exceeding 10 s.

9 Tests

9.1 General

Tests shall be done at the factory or other testing facilities designated by the manufacturer.

9.2 Dielectric tests

9.2.1 General

Dielectric tests should be done with the SSVT at ambient temperature between 10 °C and 40 °C, and unless otherwise specified, the voltage shall be measured in accordance with IEEE Std 4 or IEC 60060-2.

9.2.2 Dielectric tests at factory

The purpose of dielectric tests in the factory is to check the insulation and workmanship and, when required, to demonstrate that the SSVT has been designed to withstand the specified insulation tests.

For SSVT using compressed gas for insulation, dielectric tests shall be performed at minimum functional pressure (density) as specified by the manufacturer. The ambient temperature and pressure of the gas shall be measured and noted before test(s).

9.2.3 Dielectric tests by end user

It is recognized that the dielectric tests impose a severe stress on the insulation and, if applied frequently, will accelerate ageing of the insulation and may cause premature failure/breakdown. The imposed stress is more severe when the applied voltage is higher. Hence, periodic testing is not advisable.

It is recommended that user tests of insulation are not in excess of 75 % of the factory test voltage; for old apparatus rebuilt in the field, tests should not be in excess of 75 % of the factory test voltage; and the periodic insulation tests by the user should not be in excess of 65 % of the factory test voltage. Tests done by the user for design approval may be made at 100 % of the factory test voltage.

9.3 Overview of tests for SSVTs

9.3.1 General

Table 13 – Routine, type, and other tests for SSVTs

Test				Comments	Clause
	Routine	Type	Special		
Resistance measurements of windings	*				9.4.1
Verification of terminal markings and polarity	*				9.4.2
Winding insulation resistance	*				9.4.3
No-load losses and excitation characteristics with respect to rated voltage	*		*		9.4.4
Load-losses and impedance measurements	*			These measurements shall be taken at all secondary winding taps.	9.4.4.2
Capacitance and dissipation factor requirements	*		*	Measurements for LV winding to be made upon user request.	9.4.5
Applied voltage test	*				9.4.6
Induced voltage test	*	*			9.4.7
Partial discharge measurement	*				9.4.8
Routine leak test	*			7.2.2.2 for oil-filled, 7.2.2.3 for gas-filled	9.4.9
Routine accuracy performance test	*	*		For SSVTs which contain windings with measurement / protection output	9.4.10
Routine lightning impulse tests	*		*	Routine test for units 300 kV and above. For units below 300 kV this test is a special test at user request.	9.4.11
Earthing shield check	*				9.4.12
Dissolved gas and water content analysis	*	*		Routine tests for 362 kV and above units.	9.5.1
Mechanical test		*			9.5.2
Type lightning impulse tests		*			9.5.3
Switching impulse voltage test in wet condition		*		Type tests for 300 kV and above units.	9.5.4
External radio influence voltage (RIV) test		*		Type test for 245 kV and above units.	9.5.5
Induced voltage test in wet conditions		*		This test is done without PD measurements. Type test for units below 300 kV.	9.5.6
Temperature rise and loading conditions		*			9.5.7
Endurance chopped wave test			*		9.6.1
Internal arc test			*		9.6.2
Low temperature sealing system type test for gas-filled SSVTs			*	For gas filled units only. Test on similar sealing systems shall be valid for qualifying the system down to lowest ambient temperature.	9.6.3
Seismic qualification			*		9.6.4
Verification of degree of protection by enclosure			*		9.6.5
Short-circuit test			*		9.6.6

Routine, type, and special tests shall be performed in accordance with the requirements of Table 13. The sequence of tests listed in Table 13 does not imply the order in which these tests are to be performed.

For gas-filled SSVTs, the gas pressure shall be set, for all electrical tests, unless otherwise stated, at the minimum functional pressure, which corresponds to the equivalent gas density at 20 °C for which the second alarm level is set.

9.3.2 Routine tests

Routine tests shall be performed on every SSVT to verify that the product meets the design specifications.

9.3.3 Type tests

Type tests shall be done on an SSVT of new design to determine the adequacy of the design and manufacture of a particular model of SSVT or its component parts. Adequacy includes but is not limited to: meeting assigned ratings, operating satisfactorily under normal environmental conditions or under special conditions if specified, and compliance with appropriate industry standards. Type tests are done on an SSVT that is representative of the ratings assigned to all other SSVTs of basically the same design and construction subject to user acceptance. The applicable portion of these type tests may also be used to evaluate modifications of a previous design and to ensure that performance has not been adversely affected. Reports of a previously performed type test may be accepted in lieu of the same test on a representative SSVT, if the manufacturer shows that there is no significant variation in the design and construction between the tested object and the prototype. Type tests are not required to be repeated unless the design, construction or material is changed.

NOTE Additional type tests can be specified by the user. (Examples: temperature rise, mechanical test, wet voltage withstand.)

The type tests should preferably be carried out on a single sample. Routine tests shall be performed before and after the type test. For the convenience of scheduling, other samples of the same design and construction are allowed. In order to meet the purpose of the dissolved gas analysis, the dielectric tests shall be performed on the same SSVT.

9.3.4 Special tests

Special tests are test performed optionally according to a standardized procedure to check the conformity to a specific requirement

EXAMPLES: seismic qualification, internal arc, short-circuit, etc.

9.4 Routine test procedures

9.4.1 Resistance measurement of windings

The resistance of all windings, including tapped portions of the windings, shall be measured. The measured values shall be corrected to the average winding temperature rise class per Table 7.

The gas pressure of a gas-filled SSVT may be at any setting for the test.

The resistance data obtained shall be compared with the design values to verify proper construction.

9.4.2 Verification of terminal markings and polarity

The terminal markings and polarity shall be verified for all windings. The test shall be performed during the unit assembly and repeated as a part of the accuracy test.

The terminal markings and polarity shall be in accordance with the nameplate and schematic diagram.

9.4.3 Winding insulation resistance

The insulation resistance of the individual winding to earth and between windings shall be measured at a voltage not less than 1,0 kV (DC).

The insulation resistance shall be in accordance with 6.14.

9.4.4 Losses measurement

9.4.4.1 No-load losses and excitation current measurement

The no-load losses and excitation current of the SSVT shall be measured in accordance with 8.2.3 of IEEE Std C57.90™-2015 or IEC 60076-1, with the voltage corresponding to the rated voltage applied to one of the windings and with the other windings open-circuited.

The impressed voltage shall be measured with both the RMS-voltmeter and the average-voltmeter (but RMS calibrated). The form factor is defined as:

$$k = \left(\frac{U_{\text{RMS}}}{U_{\text{avg}}}\right)^2 \tag{12}$$

where

U_{RMS} voltage measured with the RMS voltmeter, and

U_{avg} voltage measured with the average-voltmeter.

NOTE The form factor is an indication of waveform distortion.

The excitation current and the form factor shall be included in the routine test report.

The gas pressure of a gas-filled SSVT may be at any setting equal to or higher than the pressure given in 9.3.1 for the test.

The measured excitation current shall be compared with the design value to verify proper construction.

9.4.4.2 Load losses and short circuit impedance measurements

The short-circuit impedance and load loss for a pair of windings shall be measured at rated frequency with voltage applied to the terminals of one winding, with the terminals of the other winding short-circuited, and with possible other windings open-circuited. The supplied current should be equal to the relevant rated current but shall not be less than 50 % thereof. The measurements shall be performed quickly, so that temperature rises do not cause significant errors.

For SSVTs that have multiple neutral terminals, for adjusting the SSVT's voltage ratio, in order to adjust the SSVT's voltage ratio, the short-circuit impedance shall be measured in the connection corresponding to the rated voltage ratio.

For SSVTs having other provisions for adjusting the voltage, the short-circuit impedance shall be measured in the connection corresponding to the rated voltage ratio.

NOTE If the voltage adjustment range exceeds ±5 %, the user may specify additional testing points corresponding to other voltage ratio connections.

The short-circuit impedance can be measured by the wattmeter, voltmeter, ammeter method. The wattmeter, voltmeter, ammeter method is shown in Figure 3.

It is recommended that the high-voltage winding be excited and the low-voltage winding be short-circuited.

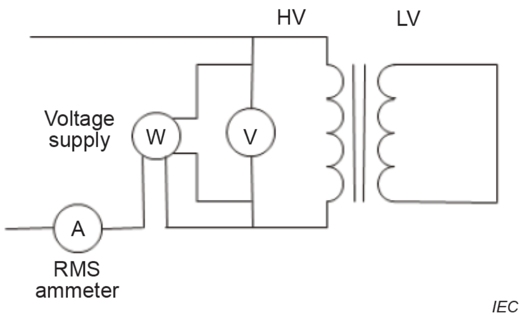


Figure 3 – Circuit for measuring impedance: wattmeter, voltmeter, ammeter method

The measured value of load loss shall be multiplied with the square of the ratio of rated current to test current. The resulting figure shall then be corrected to reference temperature. The I^2R loss (R being DC resistance) is taken as varying directly with the temperature and all other losses inversely with the temperature. The measurement of winding resistance shall be made according to 9.4.1. The temperature correction procedure is detailed in Annex D.

The short-circuit impedance is represented as reactance and AC resistance in series. The impedance is corrected to reference temperature assuming that the reactance is constant and that the AC resistance derived from the load loss varies as described above.

The short circuit voltage (alias impedance voltage), as a percentage, shall be included in the routine test report and on the SSVT's nameplate.

9.4.4.3 Tolerances for losses

Unless otherwise specified, the losses represented by a test of a transformer shall be subject to the following tolerances: The no-load losses of a transformer shall not exceed the specified no-load losses by more than 10 %. The total losses shall not exceed specified total losses by more than 10 %. Individual component losses shall not exceed 15 % of the specified component loss, provided that the tolerance for total losses is not exceeded. Failure to meet the loss tolerances shall not warrant immediate rejection but shall lead to consultation between user and manufacturer regarding further investigation of possible causes and the consequences of the higher losses.

It is important to note that this clause is only an acceptance criterion and is not intended to replace a manufacturer's guarantee of losses for economic loss evaluation purposes.

9.4.4.4 Accuracies required for measuring losses

Measured values of electric power, voltages, currents, resistances, and temperatures are used in the calculations of reported data. Test procedures in accordance with IEEE Std C57.12.90 or IEC 60076 (all parts) are required. To ensure sufficient accuracy in the measured and calculated data, the requirements set out in Table 14 shall be met.

Table 14 – Test system accuracy requirements

Quantity measured	Test system accuracy
Losses	±3,0 %
Voltage	±0,5 %
Current	±0,5 %
Resistance	±0,5 %
Temperature	±1,5 °C

9.4.4.5 Tolerances for impedance

The tolerances for impedance shall be as follows:

a) The impedance of a two-winding SSVT (including windings for series- parallel operation) shall have a tolerance of ±10 % of the specified value.
   Differences of impedance between duplicate two-winding SSVTs, when two or more units of a given rating are produced by one manufacturer at the same time, shall not exceed 7,5 % of the specified value.

b) SSVTs shall be considered suitable for operation in parallel when reactances come within the limitations of the preceding paragraphs, provided that turns ratios and other controlling characteristics are suitable for such operation.

9.4.5 Capacitance and dissipation factor measurements

The capacitance and dissipation factor of the SSVT shall be measured at power frequency at the following test voltages:

a) 10 kV (RMS) (or lower for SSVTs which have neutrals rated lower than 10 kV)

   The measurement at 10 kV is optional as the values are useful as a reference for commissioning.

b) $U_{\mathrm{m}}/\sqrt{3}$.

c) 2,5 kV (RMS) for LV winding

   The measurement at 2,5 kV is optional as the values are useful as a reference for commissioning..

The test shall be performed before and after the dielectric tests.

The dissipation factor shall be in accordance with the following requirements:

1) For oil-immersed SSVTs:
   i) The dissipation factor shall be 0,5 % maximum at a reference ambient temperature of 20 °C, and
   ii) The absolute increase of the dissipation factor value measured after compared with the value measured before the dielectric tests, shall be less than 0,1 %. The increase of capacitance measured after dielectric tests compared with that measured before the dielectric tests shall be less than the value produced by the breakdown of one capacitive element.
2) For gas-filled SSVTs:
   i) The dissipation factor shall be 0,15 % maximum at a reference ambient temperature of 20 °C, and
   ii) The absolute increase of the dissipation factor value measured after compared with the value measured before the dielectric tests, shall be less than 0,03 %. The change in capacitance value shall be less than 5 %.

The dielectric dissipation factor shall be corrected taking into account the resistance of the coil.

9.4.6 Applied voltage tests

9.4.6.1 General

For the applied voltage test, all windings shall be short-circuited. All other terminals and parts (including tank and core, if accessible) shall be connected to earth and to the other terminal of the SSVT being tested.

9.4.6.2 Applied voltage test on the neutral terminal

With the earth link temporarily removed from the neutral terminal of the SSVT, the test voltage specified in 6.12.5 shall be applied between the neutral terminal and the earth for 60 s.

For an SSVT with multiple neutral terminals, all terminals shall be shorted as required in 9.4.6.1.

The gas pressure of a gas-filled SSVT may be at any setting equal to or less than the pressure given in 9.2.2 for the test.

The SSVT shall be considered as having met the requirements if no external and internal disruptive discharge or collapse of voltage is observed.

9.4.6.3 Applied voltage test on secondary windings

9.4.6.3.1 Applied voltage test on secondary power windings

The test voltage specified in 6.13.1 shall be applied to the secondary power windings for 60 s.

For windings divided into two or more sections, the test voltage shall be applied between sections also.

The SSVT shall be considered as having met the requirements if no disruptive discharge or collapse of voltage is observed.

The test frequency shall be the rated frequency of the SSVT.

9.4.6.3.2 Applied voltage test on secondary measuring windings

The test voltage specified in 6.13.2 shall be applied to the secondary power windings for 60 s.

For windings divided into two or more sections, the test voltage shall be applied between sections also.

The SSVT shall be considered as having met the requirements if no disruptive discharge or collapse of voltage is observed.

The test frequency shall be the rated frequency of the SSVT.

9.4.7 Induced voltage test

These tests are done by applying voltage as specified in Table 4 to one winding with all the other windings open. At the manufacturer's discretion, the test may be performed by exciting the secondary winding with a voltage of sufficient magnitude to induce the specified test voltage in the primary winding, or by exciting the primary winding directly at the specified test voltage.

The test voltage shall be measured at the high-voltage side in each case. The frame, case (if any), core (if intended to be earthed) and one terminal of each secondary winding and the other terminal of the primary winding shall be connected together and to earth.

As this test (if done at rated frequency) may overexcite the SSVT under test, the frequency of the applied voltage shall be such as to prevent saturation of the core. Ordinarily this requirement necessitates the use of a frequency of 100/120 Hz or more when exciting 50/60 Hz SSVTs. For those types that have large distributed capacitance, the excitation current increases with the frequency of the applied voltage, making it necessary to guard against an excitation current that will exceed 200 % normal (usual) load current based on the thermal rating. When frequencies higher than 120 Hz are used, the severity of the test is unusually increased, and for this reason, the duration of the test shall be reduced in accordance with the following formula:

$$T_\mathrm{d} = \frac{(2 \cdot f_\mathrm{r})}{f_\mathrm{t}} \times 60 \qquad (13)$$

where

T_d is the duration of test [s],

f_r is the rated frequency [Hz],

f_t is the test frequency [Hz],

with a minimum duration of 15 s.

The voltage should be started at one third or less of the full value and be increased gradually to full value in not more than 15 s. After being held for the duration of time specified according to Formula (13), it should be reduced gradually in not more than 15 s to one third the maximum value, or less, and the circuit opened.

For an SSVT with multiple neutral terminals, the induced voltage test shall be performed once, with only one of the neutral terminals earthed. This earthed neutral terminal shall correspond to the lowest ratio, thus providing the highest stress on the high voltage winding. The SSVT shall be considered as having met the requirements if no disruptive discharge or collapse of voltage is observed.

9.4.8 Partial discharge test

Partial discharge (PD) tests are intended to determine the freedom of internal insulation from damaging internal discharges.

The preferred arrangement for making the partial discharge test is to have the SSVT under test to be fully assembled prior to conducting the test; however, during the partial discharge test, if external fittings or hardware on the assembled SSVT being tested results in interfering with the test, they may be removed or provided with supplementary shielding.

At the discretion of the manufacturer, the induced voltage test and partial discharge tests may be performed together.

If necessary, external electrodes may be used for the primary terminal and the tank of the SSVT. The test method shall be in accordance with IEC 60270.

The magnitude of the pre-stress voltage shall be in accordance with Table 15. Subsequently the voltage shall be reduced to the level of the prescribed test voltage in accordance with Table 15, which shall then be maintained for a minimum of 30 s. The average partial discharge intensity shall be measured during this time. It is recommended that the reduction from the pre-stress to test voltage be done over approximately 10 s.

The SSVT shall be considered as having met the requirements if the partial discharge intensity measured at the prescribed test voltage level is equal to or less than the limit given in Table 15. The extinction voltage shall be recorded.

When performing the partial discharge test, the power supply should be relatively free from partial discharge. The partial discharge level of the power supply at the required voltage levels shall not exceed the limits given in Table 15. Preferably, the background partial discharge level should be half of the prescribed maximum levels for the SSVT under test. The measuring circuit shall have sufficient sensitivity to clearly detect a signal of the limits given in Table 15.

The test voltage shall be applied to primary terminal. The neutral terminal, one end of each secondary winding, and the tank, shall be earthed.

A partial discharge test shall be made after all dielectric tests are completed; however, the partial discharge test may be performed while decreasing the voltage after the induced test. If the measured PD level exceeds the permitted limits, a separate test shall be performed and shall govern.

Table 15 – Partial discharge test voltages

Highest voltage for equipment (U_m)/ Max. system voltage [kV, RMS]	Profile	Power frequency withstand voltage (PFWV) [kV, RMS]	Pre-stress voltage [kV, RMS]	Test voltage at which the PD level shall be ≤ 5pC [kV, RMS]	Test voltage at which the PD level shall be ≤ 10 pC [kV, RMS]
48,3	IEEE	95	50	N/A	33
52	IEC	95	76	36	52
72,5	IEC	140	112	50	72
72,5	IEEE	140	72	N/A	48
100	IEC	185	148	69	100
123	IEC	185	148	85	123
123	IEC	230	184	85	123
123	IEEE	185	185	N/A	107
123	IEEE	230	185	N/A	107
145	IEC	230	184	100	145
145	IEC	275	220	100	145
145	IEEE	275	220	N/A	126
170	IEC	275	220	118	170
170	IEC	325	260	118	170
170	IEEE	325	260	N/A	147
245	IEC	395	316	170	245
245	IEC	460	368	170	245
245	IEEE	395	315	N/A	212
245	IEEE	460	370	N/A	212
300	IEC	395	316	208	300
300	IEC	460	368	208	300

Highest voltage for equipment (U_m)/ Max. system voltage [kV, RMS]	**Profile**	**Power frequency withstand voltage (PFWV)** [kV, RMS]	**Pre-stress voltage** [kV, RMS]	**Test voltage at which the PD level shall be ≤ 5pC** [kV, RMS]	**Test voltage at which the PD level shall be ≤ 10 pC** [kV, RMS]
362	IEC	460	368	251	362
362	IEC	510	408	251	362
362	IEEE	510	410	N/A	300
362	IEEE	575	460	N/A	300
420	IEC	570	456	291	420
420	IEC	630	504	291	420
550	IEC	630	550	381	550
550	IEC	680	550	381	550
550	IEEE	680	545	N/A	435
550	IEEE	830	665	N/A	435
800	IEC	880	800	554	800
800	IEC	975	800	554	800
800	IEEE	975	780	N/A	665
1 100	IEC	1 100	1 100	762	1 100
1 100	IEEE	1 100	953	N/A -	953
1 200	IEC	1 200	1 200	831	1 200
1 200	IEEE	1 200	1 039	N/A	1 039

9.4.9 Routine leak test

9.4.9.1 Routine leak test for oil-immersed SSVTs

The routine leak test for oil-immersed SSVTs shall be performed in accordance with 7.2.2.2.

The SSVT shall be considered as having withstood the test if there is:

a) No permanent deformation of the tank,
b) No sign of oil leakage, and
c) No significant pressure reduction (if applicable).

9.4.9.2 Routine leak test for gas-filled SSVTs

The sealing test on gas-filled SSVTs shall be performed by using a cumulative test method (as described for sealing system type test). The measurement shall be performed at normal ambient temperature with the SSVT filled at the rated pressure (or density) corresponding to the normal ambient temperature.

The SSVT shall be considered as having withstood the test if the gas leakage is lower than or equal to the 20 °C limit as provided in 7.2.2.3.

9.4.10 Routine ratio and accuracy tests

9.4.10.1 Ratio test for power windings

The test shall be performed in accordance with IEEE Std C57.12.90-2015, 7.3. or with IEC 60076-1:2011, 11.3.

9.4.10.2 Accuracy test for measuring / protection windings

The test shall be performed in accordance with IEEE Std C57.13-2016, 10.1 or with IEC 61869-3:2011, 7.3.5. The accuracy measurement shall be performed at no load on the power winding.

It should be noted that testing of accuracy performance with simultaneous loading of the power winding and measuring windings to verify the guaranteed accuracy as specified in 6.9.1 is very demanding. Both loading capability and sufficient tolerances on the power winding burden are difficult to achieve. Therefore, the adequate verification of guaranteed accuracy performance with the power winding loaded as described in 6.9.1 is subject to agreement between the manufacturer and the user.

9.4.10.3 Tolerances for ratio

The voltage ratios between windings shall be such that, with the SSVT at no load and with rated voltage on the winding with the least number of turns, the voltages of all other windings and all tap connections shall be within 0,5 % of the rated voltages. However, when the volts per turn of the winding exceeds 0,5 % of the rated voltage, the voltage ratio of the winding on all tap connections shall be to the nearest turn.

9.4.11 Lightning impulse tests

9.4.11.1 General

For SSVTs of U_m 300 kV and above, the test shall be performed as a routine test.

9.4.11.2 Test procedure and criteria

The routine lightning impulse test shall be the simplified version of the type test outlined in 9.5.3 with the following modifications.

The specified test voltage shall be applied to the line side with the neutral terminal earthed through a low-impedance shunt for impulse current measurement terminal. All other terminals shall be earthed.

The applied voltage wave shall be of negative polarity only, and the test shall be carried out in the following sequence:

a) One or two reduced wave(s) with 50 % to 70 % of the full wave value as provided in Table 4,
b) One full wave,
c) Two chopped waves of the value provided in Table 4,
d) Two full waves

It is not permitted to condition the insulation of the test sample by applying several reduced full wave tests.

Reduced waves are only permitted for the sake of checking the waveshape parameters and for the determination of the impulse generator charging voltage.

If more than two reduced waves are needed before the full wave impulses, the reason justifying the use of more than two reduced waves shall be clearly described in the test report.

Reduced waves having voltage values less than 50 % of the full wave value may be applied at any moment without any number of application limitations.

The SSVT shall be considered as having met the requirements if:

1) Neither external nor internal disruptive discharge is observed,
2) No audible noise is noted from the SSVT,
3) No deviation is detected between the reduced wave and full wave impulse records and/or between full wave impulse records and
4) No internal insulation failure is found with the capacitance and dissipation factor measurement.

For capacitive graded insulation systems having multiple capacitive layers, impulse current shall be recorded because of its effectiveness to detect internal faults during the impulse test.

Any changes in the impulse current waveshape such as sudden current spikes, bursts or discontinuities occurring after the impulse voltage peak may be an indication of a partial puncture within the insulation body and should be carefully investigated. Comparison with the reduced impulse current waveshape may ease the evaluation process.

9.4.11.3 Chopped-wave test

For this test, the applied voltage wave shall be chopped by a suitable air gap. It shall have a crest value and time to flashover in accordance with Table 4.

To avoid recovery of insulation strength if failure has occurred during a previous impulse, the time interval between the application of the last chopped wave and the first following full wave shall be minimized and shall not exceed 10 min.

The gap, or other equivalent chopping device, shall be located as close as possible to the terminals of the SSVT without influencing the electric field distribution around the SSVT and consequently the discharge probability. The distance between the chopping device and the test object shall not exceed a lead length greater than the total height of the SSVT (tank plus bushing). The impedance between the tested terminal and the earthed end of the chopping device shall be limited to that of the necessary leads. The voltage zero following the instant of chopping shall occur within 1 µs. However, for some winding designs (particularly low-voltage windings of high stray capacitance and some layer windings), the circuit response after chopping cannot be oscillatory; it can be overdamped. For such cases, the time interval to the first voltage zero after the instant of chopping may be significantly greater than 1 µs.

The chopping device for the chopped voltage wave shall be set up as close to the SSVT as possible in order to maximize the oscillatory voltage after the chopping. Moreover, it is not permitted to add a series resistance in the chopping circuit even if the overshoot is greater than 30 %.

NOTE This method will increase the likelihood that the steepness of the voltage collapse (dv/dt) is as high as possible.

The use of a chopping gap made of sphere gap(s) (single or multiple sphere gaps) is the preferred chopping method since it usually gives faster voltage collapse. The use of a rod-rod chopping gap is also permissible since this method more accurately replicates in-service flashover of an air insulator. Notably, the rod-rod gap requires a greater distance between its electrode for a given operating voltage than does a sphere gap. The extended arc length of the rod-rod gap provides more natural circuit damping than the shorter arc length of a sphere gap.

If the above prescribed maximum lead length to the chopping gap cannot be achieved because of the presence of SSVT accessories such as coolers or any other SSVT accessories, then the shortest possible lead length should be used during tests.

9.4.12 Earth shield check

A three-terminal capacitance and dissipation factor measurement in the earthed specimen mode and at a voltage of 1,0 kV (RMS) shall be performed to determine:

a) The capacitance of the primary winding to earth C_p,

b) The capacitance of the secondary winding to earth C_s, and

c) The capacitance between the primary and secondary windings C_{ps}.

For gas-filled SSVTs the test may be performed at any setting of the gas pressure.

The evidence of the presence of the earth shield if given when the measured capacitances are in accordance with Formula (14):

$$\frac{1}{C_{ps}} = \frac{1}{C_p} + \frac{1}{C_s} \tag{14}$$

The SSVT shall be considered as having met the earth shield presence check if $\frac{1}{C_{ps}}$ is within ±10 % of the value determined with Formula (14).

9.5 Type test procedures

9.5.1 Dissolved gas and water content analysis

Dissolved gas analysis (DGA) is required as a routine test for oil-immersed SSVTs rated 362 kV and above.

For oil-immersed SSVT designs, the dissolved gas and water content analysis shall be performed as per IEEE C57.13.5 or IEC 60567 and IEC 60475:

a) At the commencement of the type test program, and

b) At the specified reference point of the type test sequence.

The SSVT design is considered as having met the requirements if the last set of results is in accordance with Table 6.

If more than two samples are used for the type test program as described in 9.3.3, then the third oil sample should be taken four days after the completion of the last dielectric test in order to get a homogeneous dissolved gas content within the oil.

If the SSVT is tested with a limited oil volume, the manufacturer may replenish the oil removed for the test before shipping the SSVT.

These limits apply only to mineral oil immersed SSVTs. For other liquids the appropriate limits have not yet been determined. However, DGA should still be done to gain experience and manufacturers may apply their own limits.

9.5.2 Mechanical test

9.5.2.1 General

The SSVT shall be subjected to a test load applied to the SSVT terminals.

The test loads shall be increased smoothly within 30 s to 90 s to the test load values in accordance with 7.2.2. When the value is reached, it will be maintained for at least 60 s. During this time the deflection shall be measured. The test load shall then be released smoothly, and the residual deflection shall be recorded.

The SSVT shall be completely assembled, installed in the same position as in service, with the frame rigidly fixed.

Liquid-immersed SSVTs shall be filled with the insulation medium specified for operation and subjected to the operating pressure.

Gas-insulated free-standing SSVTs shall be filled with gas at rated filling pressure.

Successful completion shall be determined with the absence of permanent deformation of the SSVT and the absence of oil or gas leakage during the test and within 2 h after the test.

9.5.2.2 Test procedure for primary terminal

The test load shall be applied horizontally to the terminal as indicated in Figure 4. Test load values shall be in accordance with Table 11.

The test load shall be applied to the center of the terminal.

Depending upon the shape and location of the terminal, such as a spade on the dome diameter, a vertical test load may be specified to confirm the terminal strength.

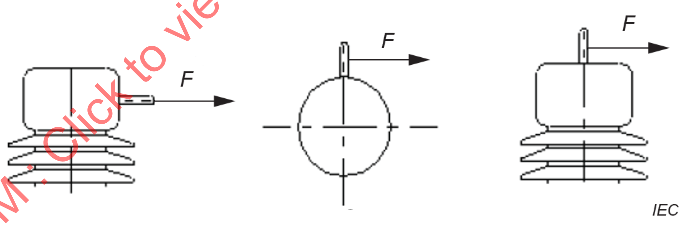


Figure 4 – Application of the test loads to the primary terminals

9.5.2.3 Test procedure for secondary terminals

The test load shall be applied to the external terminal or extending conductor, respectively normal to the longitudinal axis of the secondary bushing (Figure 5) or the support insulator(s), (Figure 6). The test load shall be determined per the following Formula (15):

$$F = \frac{M}{D} \tag{15}$$

where:

F is the test load (N or lbf),

M is the test moment (N·m or ft·lb), specified in Table 12, *D* is the distance (m or ft), from the location of the applied test load to the sealing surface with regard to the SSVT tank wall, of the bushing (Figure 5), or from the extending conductor to the end of the support insulator(s) (Figure 6).

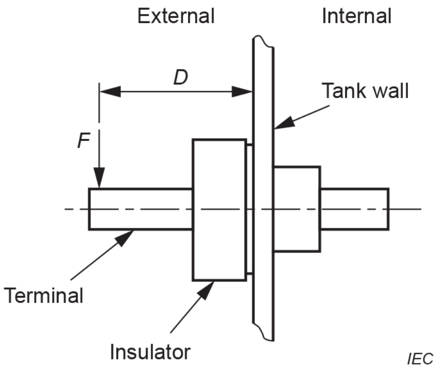


Figure 5 – Application of the test load to the secondary terminals

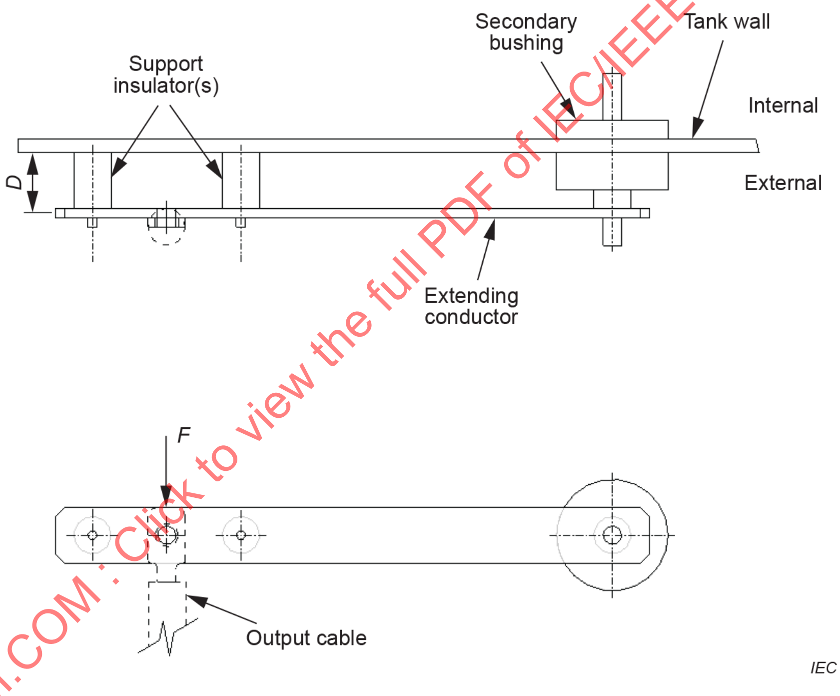


Figure 6 – Example of the application of the test load to the secondary extending conductor

The SSVT shall be subjected to a cantilever force applied to the SSVT terminals in accordance with 7.2.2 for a duration of 1 min.

Successful completion shall be determined with the absence of permanent deformation of the SSVT and the absence of oil or gas leakage during the test and within 2 h after the test.

9.5.3 Lightning impulse voltage test on the primary winding

The test voltage shall be applied between the primary terminal and the earth terminal of the SSVT. All the terminals of the secondary windings and the base frame shall be earthed during the test.

The wave shape of the voltage shall be 1,2 μs (±30 %) / 50 μs (±20 %). The test voltage shall be in accordance with Table 4.

The chopping device for the chopped voltage wave shall be set up as close to the SSVT as possible in order to maximize the oscillatory voltage after the chopping. No series resistance shall be added in the chopping circuit even if the overshoot is greater than 30 %.

Both the voltage and the earth current oscillograms shall be taken.

It is recommended that the test series should begin with the negative polarity sequence and continue with the positive polarity sequence.

The negative polarity sequence comprises the following applications of voltage wave:

a) One or two reduced waves with 50 % to 70 % of full wave value as provided Table 4,
b) One full wave,
c) Two chopped waves of the value provided in Table 4,
d) Fourteen full waves, and
e) One reduced wave.

The positive polarity sequence comprises the following applications of voltage wave:

f) One or two reduced waves with 50 % to 70 % of full wave value as provided in Table 4,
g) Fifteen full waves, and
h) One reduced wave.

No more than two reduced waves can be applied before the test sequence with positive polarity.

It is not permitted to condition the insulation system of the test unit by applying several reduced full wave tests.

Reduced waves are only permitted for the sake of checking the waveshape parameters and for the determination of the impulse generator charging voltage.

If more than two reduced-waves are needed before the full wave impulses, the reason justifying the use of more than two reduced waves shall be clearly described in the test report.

Reduced waves having voltage values less than 50 % of the full wave value may be applied at any moment without any number of application limitations.

The design shall be considered as having met the requirements if:

1) The number of external disruptive discharges is not more than two for the sequence of each polarity,
2) No deviation is detected between the reduced wave and full wave impulse records and/or between full wave impulse records,
3) No deviation is detected between the two chopped waves before the instant of chopping,
4) No internal disruptive discharge or puncture of the solid insulation is observed,
5) No audible noise is noted from the SSVT during the test, and
6) No internal insulation failure is found with the capacitance and dissipation factor measurement.

For capacitive graded insulation systems having multiple capacitive layers, impulse current shall be recorded because of its effectiveness to detect internal faults during the impulse test.

Any changes in the impulse current waveshape such as sudden current spikes, bursts or discontinuities occurring after the impulse voltage peak may be an indication of a partial puncture within the insulation body and should be carefully investigated. Comparison with the reduced impulse current waveshape may ease the evaluation process.

9.5.4 Switching impulse voltage test in wet conditions

The test shall be performed only on SSVT designs of a nominal system voltage of 300 kV and above.

The voltage shall be applied on the primary terminal with the neutral terminal of the SSVT earthed through a low-ohmic resistive shunt. One end of each secondary winding and the base frame shall be earthed.

The preparation of the SSVT and wetting procedure shall be in accordance with IEEE Std 4-2013, 11.2 or with IEC 60060-1:2010, 4.4. The precipitation conditions shall be as described under the "Standard test procedure" as outlined in IEEE Std-4-2013™, Table 5 or in IEC 60060-1:2010, Table 2.

The voltage waveshape shall be a 250 µs ± 20 % / 2 500 µs ± 60 % (or [200 to 300] µs / [1 000 to 4 000] µs) standard wave shape. The test voltage shall be in accordance with Table 4. The applied wave shall be at positive polarity only. Atmospheric correction as defined in IEEE Std 4 or IEC 60060-1 shall be applied.

The test sequence shall consist of:

a) One or two reduced waves with 50 % to 70 % of rated value provided in Table 4, and
b) Fifteen full waves.

It is not permitted to condition the insulation system of the test unit by applying several reduced full wave tests.

Reduced waves are only permitted for the sake of checking the waveshape parameters and for the determination of the impulse generator charging voltage.

If more than two reduced waves are needed before the full wave impulses, the reason justifying the use of more than two reduced waves shall be clearly described in the test report.

The design shall be considered as having met the requirements if:

1) The number of external disruptive discharges is not more than two.
2) No deviation is detected between the reduced wave and full wave impulse records and/or between full wave impulse records;
3) No internal disruptive discharge or puncture of the solid insulation is observed;
4) No audible noise is noted from the SSVT during the test, and;
5) No internal insulation failure is found with the capacitance and dissipation factor measurement.

For capacitive graded insulation systems having multiple capacitive layers, impulse current shall be recorded because of its effectiveness to detect internal faults during the impulse test.

NOTE Any changes in the impulse current waveshape such as sudden current spikes, bursts or discontinuities occurring after the impulse voltage peak can be an indication of a partial puncture within the insulation body. Comparison with the reduced impulse current waveshape can ease the evaluation process.

9.5.5 External radio interference voltage (RIV) test

9.5.5.1 General

The external radio interference voltage (RIV) meter and the method used for the test shall be in accordance with CISPR 18-2 or NEMA Std. 107.

The SSVT shall be assembled with the primary terminal, connector and corona ring(s), if provided. The SSVT shall be set up at a level above ground not greater than the height of the supporting structure used in service. Metallic pipe(s) of approximately 2 m (78,7 in) in length with sphere terminations, for the simulation of the bus or line connections in service shall be assembled on the primary terminal.

The test connections and their ends shall not be a source of radio interference.

As the radio interference voltage level can be affected by fibres or dust deposit on the insulators, it is permitted to wipe the insulators with a clean cloth before taking a measurement.

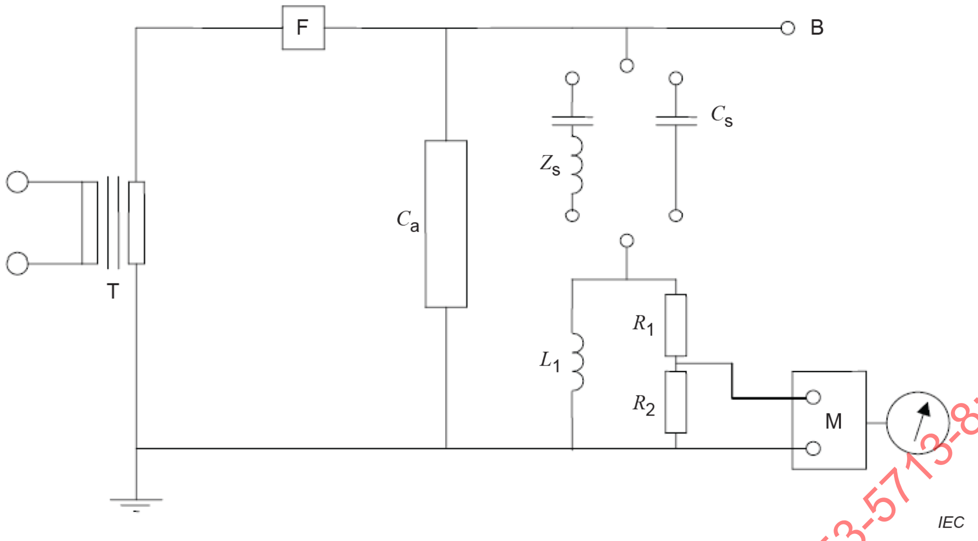
The test shall be performed under the following atmospheric conditions:

– Temperature: from 10 °C to 40 °C;
– Pressure: from 87 kPa to 107 kPa;
– Relative humidity: from 45 % to 75 %.

NOTE No correction factors for atmospheric conditions in accordance with IEEE Std 4 or IEC 60060-1 are applicable to radio interference tests.

9.5.5.2 RIV test performed according to CISPR 18-2

The test circuit is shown in Figure 7.



Key

T	test high voltage generator
C_a	test object
C_s, Z_s	coupling capacitance or impedance
L_1, R_1, R_2	tuned detection circuit
F	filter
B	corona-free termination
M	measuring set with input resistance RM

Figure 7 – RIV measuring circuit according to CISPR 18-2

The test voltage shall be applied between the HV terminal of the primary winding of the SSVT under test and earth. The frame, case (if any), core (if present and intended to be earthed) and one terminal of each secondary winding shall be connected to earth.

The measuring circuit should preferably be tuned to a frequency in the range of 0,5 MHz to 2 MHz, the measuring frequency being recorded. The results shall be expressed in microvolts.

The impedance between the test conductor and earth, shall be 300 Ω ± 40 Ω with a phase angle not exceeding 20° at the measuring frequency.

A capacitor, C_s, may also be used instead of the filter $Z_s = C_2 + L_2$ and a capacitance of 1 000 pF is generally adequate.

The filter F shall have a high impedance at the measuring frequency in order to decouple the power frequency source from the measuring circuit. A suitable value for this impedance has been found to be 10 000 Ω to 20 000 Ω at the measuring frequency.

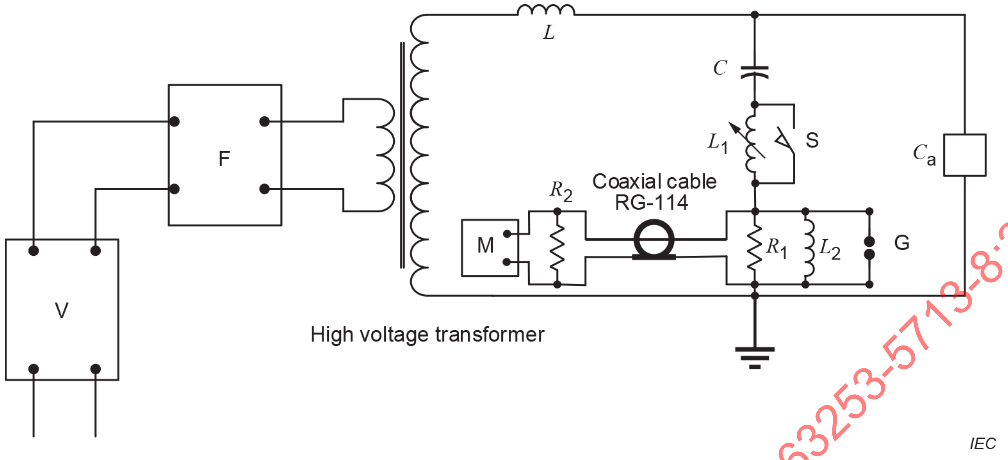
The radio interference background level (radio interference caused by external field and by the high-voltage SSVT) shall be maximum 50 % (preferably 30 % or lower) of the specified radio interference level.

Care should be taken to avoid disturbances caused by nearby objects to the SSVT and to the test and measuring circuits.

Calibration methods for the measuring instruments and for the measuring circuit are given in CISPR 18-2.

9.5.5.3 RIV test performed according to NEMA 107

The test circuit is shown in Figure 8. Only the test circuit given in 3-3 c) of NEMA 107 may be used as an alternative to the test circuit according to CISPR 18-2.



Key

V	variable voltage source
F	power line filter
C_a	test object
C	coupling capacitor
L_1	variable tuning inductor, if necessary
S	series shorting switch where L_1 is not required
L	radio-frequency choke, impedance greater than 1 500 Ω at measuring frequency
G	protective gap
L_2	power frequency drain coil, impedance greater than 1 500 Ω at measuring frequency
R_1	non-inductive resistor 100 Ω
R_2	non-inductive resistor 185 Ω
Coaxial cable	characteristic impedance 185 Ω
M	measuring meter with input resistance greater than 1,0 MΩ

Figure 8 – RIV measuring circuit according to NEMA 107 (alternative 3-3 c)

The test voltage shall be applied between the HV terminal of the primary winding of the SSVT (C_a) and earth. The measuring circuit should preferably be tuned to a frequency of 1,0 MHz. Other frequencies ranging from 0,015 MHZ to 30 MHz can also be used. The test frequency shall be stated in the test report. The results shall be expressed in microvolts.

The impedance between the test conductor and earth, shall be 65 Ω ± 10 % with a phase angle not exceeding 20° at the measuring frequency.

Capacitor C shall be equal to or higher than of 1 000 pF.

The radio-frequency choke L shall have a high impedance at the measuring frequency in order to decouple the power frequency source from the measuring circuit. A suitable value for this impedance has been found to be at least 1 500 Ω at the measuring frequency.

The radio interference background level (radio interference caused by external field and by the high-voltage SSVT) shall be maximum 50 % of the specified radio interference level.

Care should be taken to avoid disturbances caused by nearby objects to the SSVT and to the test and measuring circuits.

Calibration methods for the measuring instruments and for the measuring circuit are given in NEMA 107.

9.5.5.4 Test voltages and maximum RIV voltage

The test voltage, in accordance with Table 16, shall be applied to the primary terminal of the SSVT and the meter readings shall be corrected with the calibrated RIV factor to obtain the external RIV level of the tested SSVT.

The SSVT shall be considered as having met the requirements if the external RIV level is in accordance with Table 16.

Table 16 – External radio interference voltage (RIV)

Highest voltage of equipment (U_m) (line to line) kV, RMS	RIV test voltage (line to earth) kV, RMS	Maximum radio interference voltage if measured according to CISPR 18-2[a] µV	Maximum radio interference voltage if measured according to NEMA 107[b] µV
245	156	1 150	250
300	191	1 150	250
362	230	1 600	350
420	267	2 300	500
550	349	2 300	500
800	508	2 300	500
1 100	699	2 300	500
1 200	762	2 300	

[a] 300 Ω

[b] alternative 3-3c, 65 Ω

9.5.6 Induced voltage test in wet conditions

The test shall be performed only on SSVTs of a nominal system voltage below 300 kV. This test is performed without PD measurements.

The test shall be performed as outlined in 9.4.7. The preparation of the SSVT and wetting procedure shall be in accordance with IEEE Std 4-2013, 11.2 or with IEC 60060-1:2010, 4.4. The precipitation conditions shall be as described under the "Standard test procedure" as outlined in IEEE Std 4-2013, Table 3 or in IEC 60060-1:2010, Table 2. Atmospheric correction as defined in IEEE Std 4 or IEC 60060-1 shall be applied. The design shall be considered as having met the requirements if:

a) No disruptive discharge or collapse of test voltage is observed during the test, and

b) No internal insulation failure is found with the capacitance and dissipation factor measurement.

9.5.7 Temperature rise test

9.5.7.1 General

All temperature rise tests shall be made under the normal conditions of the means, or method, of cooling.

All temperature rise tests shall be made with the SSVT under test in the orientation and under the conditions for which it is designed to operate. If the SSVT is designed for use in any one of several orientations, or under several possible conditions, the test shall be made in the orientation and condition that is expected to result in the greatest temperature rise. Tests shall be done at rated power when tested using the combination of connections and taps that give the highest average winding temperature rise. This will generally involve those connections and taps resulting in the highest losses.

The SSVT shall be mounted in a normal manner. "Mounted in a normal manner" shall be interpreted to mean that the heat dissipation due to conduction and radiation shall not be substantially influenced by unusual heat transfer to, or from, surrounding objects. SSVTs shall be completely assembled with normal finish, and if oil-filled, they shall be filled to the recommended level. For gas-filled SSVTs, the gas pressure shall be at the minimum operating pressure. This corresponds to the equivalent gas density at 20 °C for which the second alarm level is set.

Temperature rise tests shall be made in an area as free from drafts as possible.

NOTE In general, this condition is met when the air velocity does not exceed 0,5 m/s.

The design shall be considered as having met the requirements of 6.18 if the temperature rise is in accordance with Table 7 and Table 9.

9.5.7.2 Ambient or cooling air temperature

The ambient temperature shall be the temperature of the air surrounding the SSVT under test.

The ambient temperature shall be not less than 10 °C nor more than 40 °C during a temperature rise test.

As a minimum, three thermometers or temperature sensors shall be used for the measurement of the ambient temperature. They shall be distributed around the periphery of the SSVT at approximately the same level as the centre of the maximum vertical heat-dissipating surface of the SSVT, at a horizontal distance adequate to prevent the SSVT under test from influencing the readings (1 m to 2 m (39,4 in to 78,7 in) is usually sufficient). They shall be placed in non-metallic containers filled with approximately half-liter of oil.

The temperature rise depends on both the winding losses and the core losses. Only that part of the temperature rise due to the winding losses is affected by the ambient temperature, as the core losses are not appreciably changed over the temperature range in which SSVTs usually operate.

9.5.7.3 Temperature rise measurements

Provision shall be made to measure the surface temperature of all metal parts surrounding, or adjacent to, the outlet leads or terminals carrying large currents.

When possible, the top liquid temperature of oil-filled SSVTs shall be measured by a thermometer or temperature sensor immersed to approximately 5 cm (1,97 in) below the top liquid surface.

The bulbs of the spirit thermometer or other temperature-reading means used for taking temperatures of the SSVT surfaces in air shall be covered by small felt pads, or the equivalent, cemented to the SSVT. If thermocouples are used, the leads shall be so arranged that excessive heat is not conducted to or from the junction.

The ultimate average temperature rise of the windings shall be determined by the resistance method whenever practical.

NOTE SSVTs typically have insulation structures that are similar to instrument transformers, where temperature sensors cannot be installed at the expected hotspot locations. Moreover, due to the typical operating flux density and typical winding assemblies of an SSVT, neither direct measurements nor calculations are required, as the average winding temperature rise requirement is considered sufficient to also meet the hot-spot winding temperature rise requirement.

To avoid measurement errors, the first resistance measurement shall be taken after the measuring current has stabilized. The time required shall be determined during the measurement of the winding resistance reference temperature. An equal or slightly longer time shall be allowed when making ultimate and cooling rate temperature measurements. Measurements of temperature rise by the resistance method shall not include contact resistances.

The SSVT shall be considered in thermal equilibrium with the ambient air if both of the following conditions are met:

a) When the duration of test is equal to or longer than 3 times the thermal time constant (Annex A) of the SSVT and,
b) When the first and last of three consecutive temperature rise readings (difference between the temperature of the tank cover and the average ambient temperature) taken, without shutdown, at intervals of no less than 1/3 of the time constant show the change of temperature rises is equal to or less than 1 K.

9.5.7.4 Determination of winding temperature at time of shutdown

A correction shall be made for the cooling that occurs from the time that the power is shut off to the time that the hot resistance is measured.

The recommended method of determining the temperature of the winding at the time of shutdown shall be by measuring the resistance of the windings, as the SSVT cools, immediately after shutdown and extrapolating to the time of shutdown. At least four measurements shall be taken at intervals of not more than 3 min but no less than the time required for the measuring current to stabilize. If the current does not exceed 15 % of the rated current of the winding, it may be maintained during the entire period.

9.5.7.5 Determination of average temperature by the resistance method

The average temperature of a winding shall be determined by the following formula:

$$\theta_t = \left[\left(\frac{R_t}{R_o}\right) \times (T + \theta_o)\right] - T \quad (16)$$

where:

T is for copper equal to 234,5 (°C),

T is for EC aluminium equal to 225 (°C),

θ_t is the temperature in degrees Celsius corresponding to the resistance of the winding at time of shutdown,

θ_o is the temperature in degrees Celsius corresponding to the reference resistance of the winding,

R_t is the resistance of the winding at time of shutdown,

R_o is the reference resistance of the winding.

9.5.7.6 Determination of temperature rise from temperature measurements

The temperature rise is the corrected total temperature minus the ambient temperature at the time the observations were made.

9.5.7.7 Correction of observed temperature rise for variation in altitude

When tests are performed at an altitude not exceeding 1 000 m above sea level, no altitude correction shall be applied to the temperature rise. The allowable temperature rise at altitudes above 1 000 m is calculated as:

$$\theta_r = \theta_m \times \left[1 - 0{,}004 \times \left(\frac{h - 1000}{100}\right)\right] \quad (17)$$

where

θ_r is the temperature rise with standard conditions,

θ_m is the measured temperature rise corrected to 30 °C conditions,

h is the altitude in meters above sea level.

9.5.7.8 Test methods for temperature rise test

9.5.7.8.1 General

The tests shall be performed by one of the following methods:

a) Actual loading
b) Simulated loading
   1) The loading back (opposition) method, in which rated voltage and current are induced in the SSVT under test.
   2) The short-circuit method, in which appropriate total losses are produced by the effect of short-circuit current. Caution shall be exercised when using the short-circuit method. Usually and contrary to power transformers, the no-load losses could be a significant percentage of the total losses. Adding these losses to the short-circuited SSVT during the constant power part of the temperature rise test may overstress the SSVT windings. This method shall only be used with the consent of the manufacturer.
   3) The open-circuit and short-circuit method, in which the temperature rises of the two tests are added together to determine the total temperature rise.
c) Thermal duplicate

9.5.7.8.2 Actual loading

Actual loading is the most accurate method, but energy requirements may be excessive for some SSVTs.

9.5.7.8.3 Simulated loading

9.5.7.8.3.1 Loading back method

This method requires two SSVTs, tested by connecting their respective primary and secondary windings as shown in Figure 9. SSVTs shall be tested with the combination of connections and taps that give the highest average winding temperature rise. This process will generally involve those connections and taps resulting in the highest losses. In the case of internally earthed SSVTs, caution should be taken for possible elevated tank voltages.

a) Apply rated voltage at rated frequency to one set of windings. Circulate load current by opening the connections of either pair of windings at one point and impress a voltage across the break just sufficient to circulate rated current at rated frequency for the connection and loading used. The total loss applied during this test shall be the same as the sum of the no-load loss and load loss measured according to 9.4.4.1 and 9.4.4.2.

b) Perform temperature rise measurements in accordance with 9.5.7.3.

c) Determine temperature rise in accordance with 9.5.7.4 and 9.5.7.5.

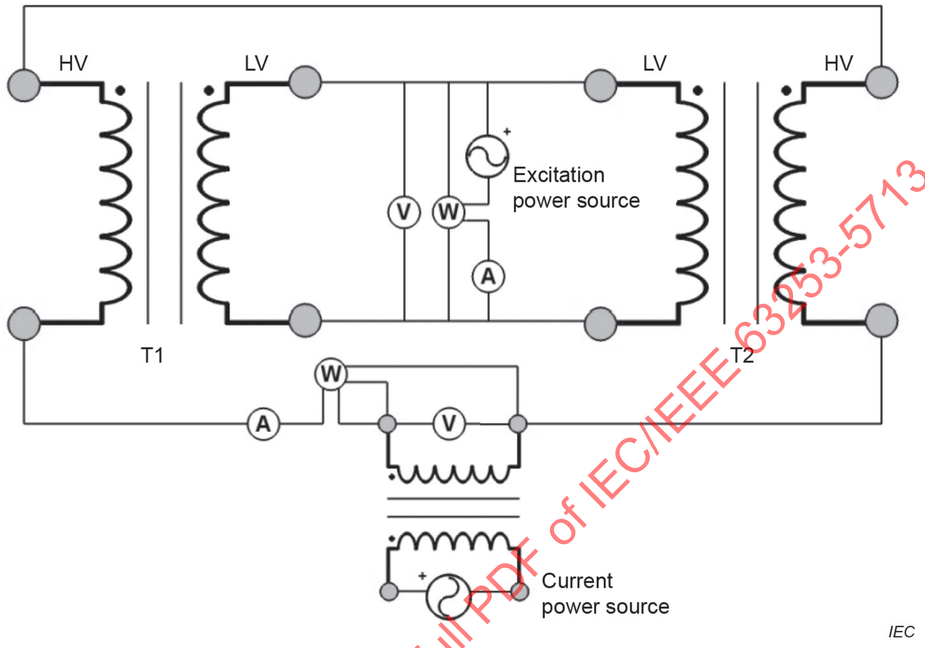


Figure 9 – Example of loading back method

It is preferred to use duplicate SSVTs, but it is not mandatory as long as the SSVT under test is energized at the required voltage and current levels. This method provides the closest simulation to actual loading as both no-load and load losses are present in the SSVT. The excitation and loading power sources do not necessarily need to be in phase; the power sources may be in phase or 120° out of phase.

NOTE In the connection scheme shown in Figure 9, even if SSVTs T1 and T2 are duplicate, their respective loading conditions are not identical. T1 will see an apparent inductive load at nearly zero power factor whereas T2 will see an apparent capacitive load at nearly zero power factor. As a consequence, the voltage appearing on the secondary side of the SSVTs will be different. The voltage on T1 will drop due to its impedance while voltage on T2 will increase. Therefore, parts of the SSVT cores will be either over-excited (T2) or under-excited (T1) and the no-load losses and noise will vary accordingly. Which parts of the core would experience this depends on the construction of the SSVTs. This test method is not an exact representation of an actual loading of an SSVT at a power factor near unity, but is nevertheless a good approximation.

9.5.7.8.3.2 Short-circuit method

Conduct the short-circuit method as follows:

a) Prior to making the total loss run (see step b), measure load loss at rated current and frequency for the combination of connections and taps that give the highest average winding temperature rise. This process will generally involve those connections and taps resulting in the highest losses. This thermal connection load loss shall be measured in accordance with 9.4.4.2 and reported at the reference temperature as defined in 6.11. The required total losses for the total loss run shall be the sum of thermal connection load loss plus no-load loss measured in accordance with 9.4.4.

b) For the total loss run, short-circuit one or more windings and circulate sufficient current at rated frequency to produce the required total losses as determined in step a).

c) Determine liquid temperature rises as described in 9.5.7.3.

d) For the rated current run, reduce the current in the windings to the rated current value for the connection and the loading used. Hold the current constant for 1 h.

e) Determine temperature rise in accordance with 9.5.7.4 and 9.5.7.5.

f) Repeat the rated current run (step d) for temperature rise measurements on additional terminal pairs if needed to meet the time limit criteria of 9.5.7.4.

g) Determine average winding temperature rise in accordance with 9.5.7.5.

9.5.7.8.3.3 Open-circuit and short-circuit method

a) Perform an open-circuit test to determine the temperature rises due to the no-load losses.

b) Perform a test at rated current in primary/secondary winding with the secondary/primary winding(s) short-circuited to determine the temperature rises due to load losses.

Add the temperature rises from a) to the temperature rises from b) to get the total temperature rises.

If test a) has previously been performed on an SSVT with identical core or one having the same or higher losses, then the temperature rises from the previous test may be used in lieu of repeating a). If in addition the core has been upgraded to a lower loss material, then this still applies.

NOTE 1 The no-load part of the temperature rise test can require a long time to get accurate results and generally this test can last for several days, typically around 3 to 4 days.

NOTE 2 When fiber optic or other sensors are being used to continuously monitor internal temperatures during the test, the thermal time constant can be determined from the resulting curve (see Annex A).

NOTE 3 This test method is new and therefore can be improved in the future.

9.5.7.8.4 Determination of thermal duplicate temperature rise data

A temperature rise test may be omitted if thermal test data is available for a thermal duplicate SSVT. In this case, the calculated data based upon the thermal test data may be submitted as thermal duplicate test data. A thermal duplicate is an SSVT with thermal design characteristics identical to a design previously tested, or whose differences in thermal characteristics are within agreed upon variations, such that the thermal performance of the thermal duplicate SSVT meets the required temperature rise limits.

9.6 Special test procedures

9.6.1 Endurance chopped wave test for liquid filled SSVT

9.6.1.1 General

The test is applicable for SSVTs with U_m of 345 kV and above.

The test shall be performed with the SSVT at normal ambient temperature in accordance with IEEE Std 4-2013 or IEC 60060-1.

The voltage of the chopped wave shall be 80 % of the rated lightning impulse voltage (full wave) provided in Table 4 and the polarity shall be negative only.

The test consists of 600 consecutive chopped waves. The time, between consecutive applications shall be approximately 1 min.

If agreed between manufacturer and user, the number of chopped wave tests may be reduced to 100.

9.6.1.2 Test sequence

The endurance chopped wave test program shall be performed in the following sequence:

a) Before the test, an oil sample shall be taken from the SSVT for dissolved gas content analysis, if the test object is an oil-immersed SSVT;

c) As a minimum, 600 chopped wave tests shall be applied to the SSVT at a rate of approximately one impulse per minute;

d) At least three days after the test, an oil sample shall be taken from the SSVT, if it is oil-immersed, for dissolved gas content analysis;

e) The SSVT shall then be dismantled for autopsy.

9.6.1.3 Requirements of the applied wave

The applied voltage wave shall be a standard 1,2 µs / 50 µs impulse chopped close to the peak. The chopping time, for example is the time interval from the chopping instant to the zero crossing of the applied voltage and shall be equal to or less than 0,32 µs. A longer chopping time is acceptable provided that the chopping device is located at a distance equal to or less than the total height of the SSVT and that no additional resistance is introduced in series between the SSVT and the chopping device as described in IEEE Std 4-2013, 8.6.2.1. The voltage shall be measured and recorded in accordance with IEEE Std 4-2013, 8.

9.6.1.4 Chopping device

The applied voltage shall be chopped with a suitable device. Because a shorter chopping time than normal is critical for the test, a chopping device made of multiple series connected sphere gaps should preferably be used instead of a rod gap.

9.6.1.5 SSVT connections

The test voltage shall be applied to the primary terminal, while the neutral terminal shall be earthed through a current sensor. The secondary winding terminals shall be short-circuited and earthed.

9.6.1.6 Measurement of voltage and current

For each application of the wave, the peak voltage shall be measured with a peak voltmeter or a digital oscilloscope After a series of fifty consecutive tests, oscillograms of the voltage and current(s) shall be taken and compared with earlier tests.

9.6.1.7 Detection of failure

The design shall be considered as having met the requirements if:

a) After the endurance chopped-wave test, the SSVT passes the capacitance and dissipation factor test in accordance with 9.4.5,

b) After the endurance chopped-wave test, the SSVT passes the induced voltage and the partial discharge tests in accordance with 9.4.7 and 9.4.8,

c) For oil-immersed SSVT, there is no significant increase of the dissolved gas content compared with those before the test, and

d) The inspection and autopsy of the complete internal insulation structure for the dismantled SSVT reveal no trace of tracking or burn marks.

A significant increase of dissolved gas content is considered, with the exception of acetylene, to be twice the maximum acceptable limit shown in Table 6. There shall not be any increase in acetylene concentration.

9.6.2 Internal arc test

9.6.2.1 General

The internal arc test is a destructive test intended to verify that an SSVT satisfies the internal arc protection class, see 6.17 for additional information. This test is not a guarantee of containment under all short-circuit conditions, but a test to demonstrate conformance with an agreed set of conditions. Internal arc testing does not guarantee performance in the event of failure in a substation. More information on the internal arc test can be found in Annex B.

9.6.2.2 Test prerequisites and documentation

Before the test, the manufacturer shall submit the insulation design report to the user for review. The report shall include a description of the insulation system for the SSVT. With the necessary calculations, drawings and electric field studies, the manufacturer shall justify the location of the fuse element within the test sample. The dimensions and material of the earth shield lead shall form part of the report. The manufacturer shall also describe the strategy of limiting the hazardous effects in the event of an internal arc.

The test shall be performed to verify the design with the special features intended to limit the hazardous effects of an internal arc. The manufacturer shall submit proof that the implemented measures are also representative of production units, and not limited to the unit under test.

Some SSVT constructions (e.g. SSVTs with multi-sectioned windings), are designed to drastically decrease the energy of the internal arc. For such units, it is possible that the internal arc testing as described in this subclause 9.6.2.2 will not be fully applicable, as the arc is not incepted over the entire insulation system. In such cases, additional testing, calculations and documentation should be presented to demonstrate the performance under internal arc conditions. Calculations, supporting documentation, and tests should be agreed upon by the manufacturer and the user.

In the event that an SSVT of similar design is already qualified, the manufacturer shall provide the documents demonstrating the ability of the non-qualified SSVT to withstand an internal arc fault without performing any additional test.

9.6.2.3 Requirement of the fuse wire installation

The fuse wire shall be positioned in a location defined according to the following criteria:

a) Location where the dielectric stress is the highest in respect to SSVT performance;
b) Location with the highest probability of arc inception due to the construction of the SSVT, and/or most probable failure mode;
c) Location that is the least favorable for controlled pressure relief.

In case of conflicting locations, criteria given in a) and b) above have precedence.

9.6.2.4 Test conditions

The test shall be conducted under the following conditions:

a) The test current shall be the rated arc-proof current initiated as close as possible to the voltage zero crossing in order to obtain a fully asymmetrical current.
b) The tolerance on RMS value is ±5 %. The tolerance on duration is ± ½ cycle.
c) The tolerance on the angle of initiation of fault current shall be ±15°.
d) The frequency of the test current shall be between 48 Hz and 62 Hz. For laboratories using short-circuit generators, this frequency tolerance applies to the first 6 cycles of short-circuit current. After this time, the frequency may fall below the lower frequency limit.

e) If the arc-proof current is below 25 kA, the duration of the test shall be 0,3 s. If the arc-proof current is 25 kA or above, the duration shall be 0,2 s.

f) The power source shall be capable of maintaining a sinusoidal current throughout the entire course of the test. It shall also be capable of obtaining, as a minimum, an asymmetrical peak current of 2,7 times the RMS symmetrical current in the presence of the arc voltage, and

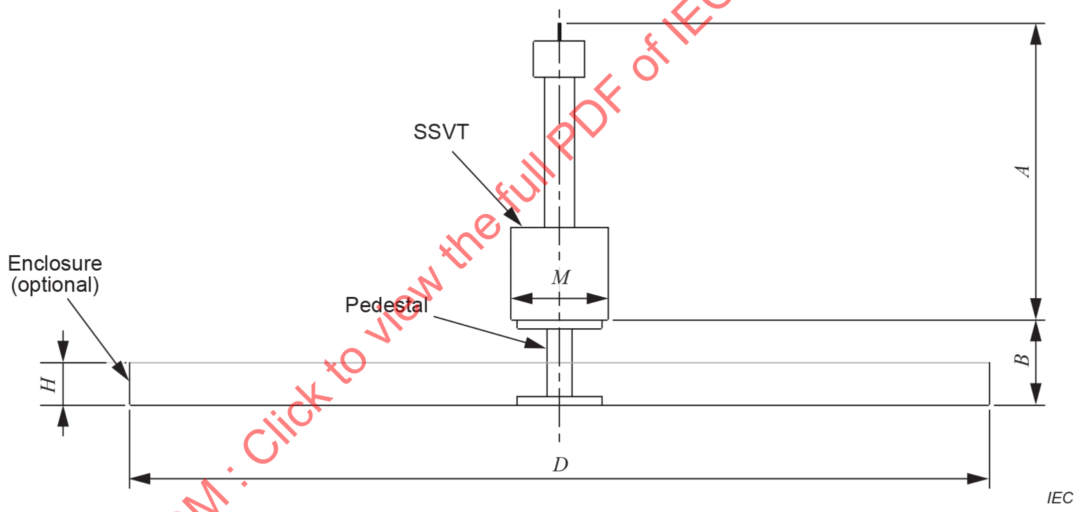
g) For the gas-filled SSVT, the gas pressure shall be set at the rated filling value.

The arc shall be initiated by means of fuse wire. The fuse wire material and size shall be selected so that the wire will melt within the first 30 electrical degrees after the initiation of the test current.

For environmental reasons and to not release SF_6 and SF_6 arc by-products in the environment, the SF_6 gas shall be replaced by an alternative gas such as nitrogen, air or CO_2.

The SSVT shall be mounted on a pedestal of minimum 500 mm (19,7 in) height to simulate service conditions. Figure 10 shows the test setup.

A containment area encircling the tested SSVT, or an optional physical enclosure for projected parts, shall be defined using Formula (18) below with a minimum diameter of 1 800 mm (70,9 in).



Key

A Height of the tested SSVT

B Height of the pedestal, greater than or equal to 500 mm (20 in)

M Diameter or largest horizontal dimension of the SSVT

H Height of the enclosure/containment area. *H* is in a range from zero (no enclosure) to *B* (as high as the pedestal)

D Diameter of the enclosure/containment area.

Figure 10 – Internal arc fault test setup

$$D = M + 2 \cdot (A + B - H) \quad (18)$$