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INSTRUMENT TRANSFORMERS – Part 15: Additional requirements for voltage transformers for DC applications

ICS 17.220.20

Saudi Standards, Metrology and Quality Org (SASO)

Foreword

The Saudi Standards ,Metrology and Quality Organization (SASO) has adopted the International standard No. IEC 61869-15: 2018 “INSTRUMENT TRANSFORMERS – Part 15: Additional requirements for voltage transformers for DC applications ” issued by the international Electrotechnical Commission(IEC). The text of this international standard has been translated into Arabic so as to be approved as a Saudi standard without introducing any technical modification.

CONTENTS

INTRODUCTION

This document applies to voltage transformers (VT) intended to be used in DC applications with the following functions:

- measure DC voltage (with significant harmonics);
- withstand DC voltage.

Two main technologies of DC converters exist today: LCC and VSC

- Line-commutated converters (LCC) are based on thyristor converters. They are characterized by a single direction of current flow, and a voltage polarity reversal possibility. Significant voltage and current harmonics exist up to frequencies of about 3 kHz to 4 kHz.
- Voltage source converters (VSC) are based on transistor converters. They are characterized by a bi-directional current flow and a single voltage polarity. Voltage and current harmonics exist up to frequencies of about 20 kHz.

The position of the DCVTs on the DC system is illustrated in Figure 1501.

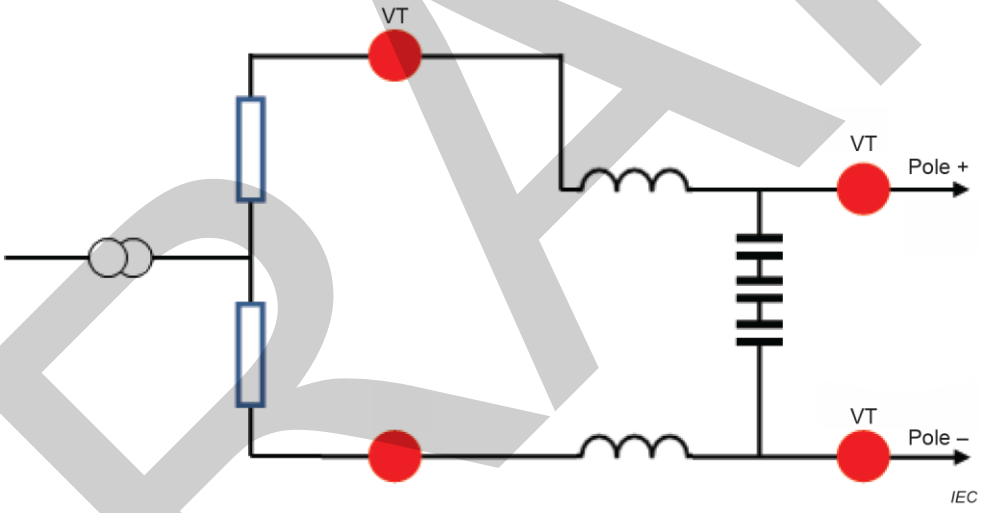


Figure 1501 – Position of the DCVT's in the DC scheme

Table 1501 gives an overview of the voltage waveshape as well as the main characteristics of the VT.

Table 1501 – Voltage on DCVT's

Voltage	Characteristics
	Pure DC application High-accuracy measurement Harmonics measurement Metering, control and protection purpose

The actual technology used for DCVT's are resistive voltage dividers (with or without additional capacitance). However, other technologies could be used in the future (for example, optical voltage sensors).

This document includes some specific requirements applicable to resistive voltage dividers, but can be applied to any technology.

INSTRUMENT TRANSFORMERS –

Part 15: Additional requirements for voltage transformers for DC applications

1 Scope

This part of IEC 61869 provides all requirements specific to voltage transformers to be used in DC applications (DCVTs), whatever the technology used. The output signal can be analogue or digital.

It is applicable to newly manufactured voltage transformers used for measuring, protection and/or control applications in DC power systems with a rated voltage above 1,5 kV.

This document covers passive voltage dividers as well as active voltage transformers, used for measurement, control and protection.

The general configuration of a single-pole low-power instrument transformer is described in Figure 601 of IEC 61869-6:2016.

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.

Clause 2 of IEC 61869-6:2016 is applicable, with the following additions:

IEC TS 60815-4:2016, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 4: Insulators for DC systems*

IEC TS 61245, *Artificial pollution tests on high-voltage ceramic and glass insulators to be used on DC systems*

IEC 61869-1:2007, *Instrument transformers – Part 1: General requirements*

IEC 61869-6:2016, *Instrument transformers – Part 6: Additional general requirements for low-power instrument transformers*

IEC 61869-9:2016, *Instrument transformers – Part 9: Digital interface for instrument transformers*

3 Terms, definitions, abbreviated terms and symbols

For the purposes of this document, the terms and definitions given in Clause 3 of IEC 61869-1:2007, of IEC 61869-6:2016 and of IEC 61869-9:2016 are applicable with the following additions and modifications.

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

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

3.1 General definitions

3.1.1501
instrument transformer for DC application
instrument transformer intended to be used in DC applications with at least one of the following functions:

- measure DC current or DC voltage (with significant harmonics);
- withstand DC voltage.

3.1.1502
voltage transformer for DC application
DCVT
instrument transformer for DC application in which the secondary signal, under normal conditions of use, is substantially proportional to the primary voltage

3.2 Definitions related to dielectric ratings

3.2.2
highest voltage for equipment
$\boldsymbol{U_m}$
Definition 3.2.2 of IEC 61869-1:2007 is replaced by the following one:

highest value of DC voltage for which the equipment is designed to operate continuously, in respect of its insulation as well as other characteristics that relate to this voltage

3.3 Definitions related to current ratings

3.3.1501
maximum peak fault current
$\boldsymbol{I_{sc}}$
maximum peak value of current occurring during a fault condition of the DC power system

3.4 Definitions related to accuracy

3.4.1501
absolute error
ε_V
error (expressed in V) that a voltage transformer introduces into the measurement and which arises from the fact that the actual transformation ratio is not equal to the rated transformation ratio

Note 1 to entry: The absolute error is defined by the following formula:

$$\varepsilon_V = K_r \cdot U_s - U_p$$

where

K_r is the rated transformation ratio;

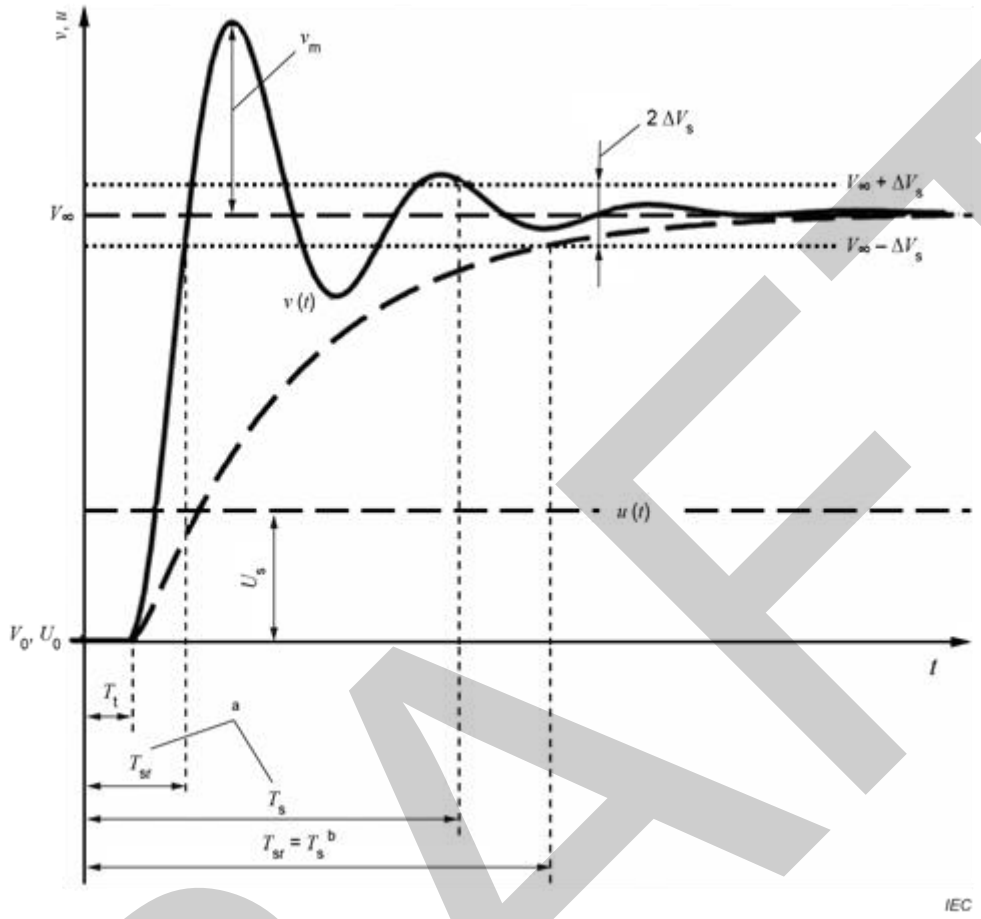
U_p is the DC value of the actual primary voltage in steady state;

U_s is the DC value of the output voltage.

3.5 Definitions related to other ratings

3.5.1501
step response
duration between the instant when the measurand (or quantity supplied) is subjected to a specified abrupt change and the instant when the indication (or quantity supplied) reaches, and remains within specified limits of, its final steady-state value

Note 1 to entry: See graphical explanation in Figure 1502.



[a] For periodic behaviour

[b] For aperiodic behaviour

u	Input variable
U_o	Initial value of the input variable
U_s	Step height of the input variable
v	Output variable
V_0, V_∞	Steady-state values before and after application of the step
v_m	Overshoot
$2\ \Delta v_s$	Specified tolerance limit
T_{sr}	Step response time
T_s	Settling time
T_t	Dead time

Figure 1502 – Typical step responses of a system

Note 2 to entry: The dead time includes the delay time.

[SOURCE: IEC 60050-311:2001, 311-06-04 and IEC 60050-351:2013, 351-45-27, modified – Notes to entry of the sources have been deleted and a new Note 1 to entry has been added.]

3.5.1502
step response time
T_{sr}
for a step response, the duration of the time interval between the instant of the step change of an input variable and the instant when the output variable reaches for the first time a specified percentage of the difference between the final and the initial steady-state values

Note 1 to entry: The step response time includes the delay time of the voltage transformer.

[SOURCE: IEC 60050-351:2013, 351-45-36 modified – Note 1 to entry of the source has been deleted and a new Note 1 to entry has been added, and the symbol has been added.]

3.5.1503
settling time
T_s
for a step response, the duration of the time interval between the instant of the step change of an input variable and the instant when the difference between the step response and their steady-state value remains smaller than the transient value tolerance

Note 1 to entry: The settling time includes the delay time of the voltage transformer.

[SOURCE: IEC 60050-351:2013, 351-45-37 modified – Note 1 to entry of the source has been deleted and a new Note 1 to entry has been added, and the symbol has been added.]

3.5.1504
overshoot
v_m
for a step response of a transfer element, the maximum transient deviation from the final steady-state value of the output variable, usually expressed in percent of the difference between the final and the initial steady-state values and for reference-variable step response or disturbance-variable step response of a control system the maximum transient deviation from the desired value

[SOURCE: IEC 60050-351:2013, 351-45-38, modified – Note 1 to entry has been deleted and the symbol has been replaced.]

3.7 Index of abbreviated terms and symbols

The table in 3.7 of IEC 61869-6:2016 is replaced by the following one:

DCVT	voltage transformer for DC application
F	mechanical load
I_{amax}	maximum supply current
I_{ar}	rated supply current
I_{sc}	maximum peak fault current
IT	instrument transformer
K	actual transformation ratio
K_r	rated transformation ratio
R_{br}	rated burden
t_d	delay time
t_{dr}	rated delay time
T_s	settling time
T_{sr}	step response time
T_t	dead time
U_{ar}	auxiliary power supply voltage
U_m	highest voltage for equipment
U_{pr}	rated primary voltage
U_{sr}	rated secondary voltage
v_m	overshoot
ε	ratio error

ε_V	absolute error

5 Ratings

5.1 General

Subclause 5.1 of IEC 61869-1:2007 is replaced by the following one:

If applicable, the ratings of voltage transformers, including their auxiliary equipment, shall be selected from the following ones:

- highest voltage for equipment (U_m);
- rated primary voltage (U_{pr});
- rated delay time (t_{dr});
- rated secondary voltage (U_{sr});
- insulation level;
- rated burden (R_{br});
- rated accuracy class;
- rated step response time (T_{sr}).

The rating applies at the standardized reference atmosphere (temperature 20 °C, pressure 101,3 kPa, and humidity 11 g/m^3) as specified in IEC 60071-1.

NOTE The ratings are specified by the purchaser depending on the characteristics of the whole DC system application.

5.2 Highest voltage for equipment

There are no standard values for highest voltage for equipment.

However, a tentative list of standard values is given in Annex 15A.

5.3 Rated insulation levels

5.3.1 General

Subclause 5.3.1 from IEC 61869-1:2007 is replaced by the following one:

The standard values of insulation level of IEC 60071-1 are not applicable to DC systems.

Methods of calculation for applied dielectric test voltages are given in the relevant clauses of this document.

Additionally, indication for impulse withstand voltage values are given in Annex 15A.

5.3.3 Other requirements for insulation of primary terminals

5.3.3.1 Partial discharges

Subclause 5.3.3.1 of IEC 61869-1:2007 is replaced by the following one:

The partial discharge level measured during the power-frequency voltage withstand test, shall not exceed the limits specified in Table 3.

Table 3 – Partial discharge test voltages and permissible levels

PD test voltage (r.m.s.) kV	Maximum permissible PD level pC	
	Type of insulation	
	immersed in liquid or gas	solid
1,5 $U_m/\sqrt{2}$	10	50
1,2 $U_m/\sqrt{2}$	5	20

5.4 Rated frequency

Subclause 5.4 of IEC 61869-1:2007 is replaced by the following one:

The rated frequency is equal to 0 (which means DC).

5.5 Rated output

5.5.602 Standard values for the rated delay time (t_{dr})

Subclause 5.5.602 of IEC 61869-6:2016 is replaced by the following one:

The standard values for rated delay time are:

5 µs – 25 µs – 100 µs

In the case of a pure passive DCVT, the rated delay time is 0.

5.5.1501 Standard values of rated secondary voltage

The standard values of rated secondary DC voltage are:

5 V – 10V – 50 V

5.6 Rated accuracy class

5.6.1501 Accuracy class designation

The accuracy class is designated by the highest permissible percentage of voltage error at rated primary voltage and with the rated burden.

5.6.1502 Standard accuracy classes

The standard accuracy classes are:

0,1 – 0,2 – 0,5 – 1 – 3

5.6.1503 Limits of ratio error

The ratio error for the DC component, measured at the secondary terminals, shall not exceed the values given in Table 1502, expressed as a percentage of the measured voltage. A graphical representation of error limits is shown in Figure 1503.

The accuracy shall be guaranteed for the whole range of temperature, both for the outdoor and the indoor part of the voltage transformer and for both polarities.

Table 1502 – Limits of ratio error for DCVT (classes from 0,1 to 3)

Accuracy class	Ratio error ± %					
	at % of rated voltage					
	5	20	40	70	100	125
0,1	1	0,2	0,1	0,1	0,1	0,1
0,2	2	0,4	0,2	0,2	0,2	0,2
0,5	3,5	1	0,5	0,5	0,5	0,5
1	5	2	1	1	1	1
3	10	5	3	3	3	3

For voltage lower than 5 % of the rated voltage, the absolute error ε_V shall not increase above the value at 5 % of the rated voltage.

NOTE The purpose of this requirement is to consider a minimum value of error due to offset voltage and noise.

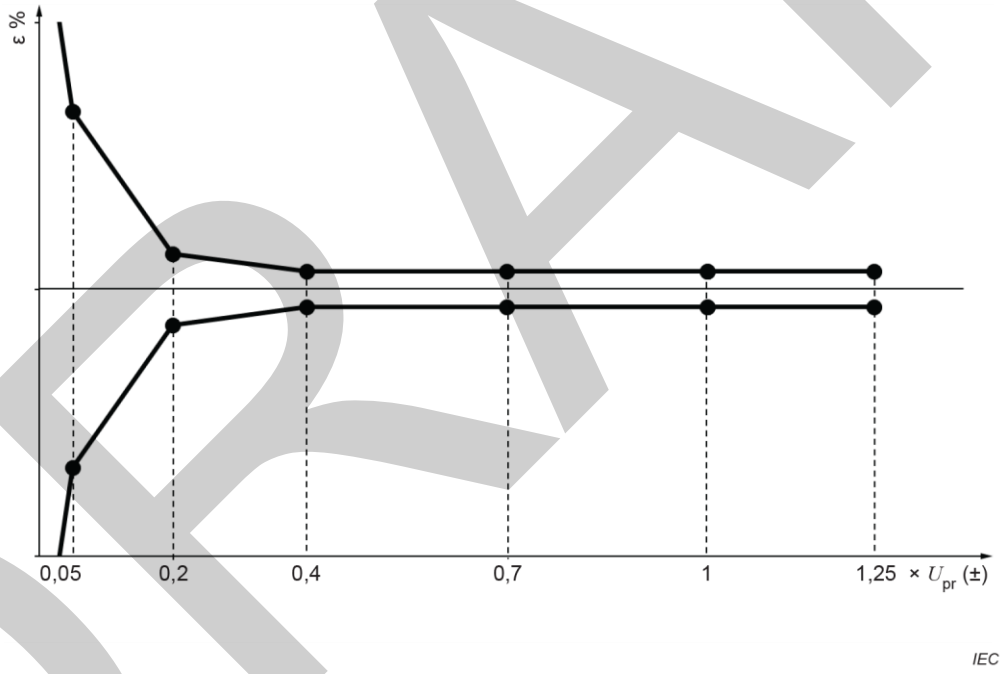


Figure 1503 – Accuracy limits of a DCVT

5.6.1504 Accuracy requirements for harmonic measurement

This subclause is applicable for the measurement of the ripple of the DC voltage.

When required, Subclause 6A.4.3 of IEC 61869-6:2016 is applicable.

5.1501 Rated step response time

The standard values for the rated step response time are:

25 µs – 100 µs – 500 µs

6 Design and construction

6.6 Requirements for the external insulation

6.6.1 Pollution

Subclause 6.6.1 of IEC 61869-1:2007 is replaced by the following one:

This subclause is applicable to voltage transformers having U_m equal to or above 20 kV.

The purchaser shall specify the minimum creepage distance or the minimum USCD (see IEC TS 60815-4:2016) or, alternatively, the DC site pollution severity.

The necessary creepage distance shall be determined from the USCD by:

$$\text{USCD} \times U_m$$

where USCD is the minimum nominal unified specific creepage distance (mm/kV), see IEC 60050-471:2007, 471-01-16.

For indoor voltage transformers, the minimum USCD value shall be 14 mm/kV.

For outdoor voltage transformers, if artificial pollution tests are required, they shall be performed in accordance with 7.4.1501.

NOTE Values for USCD for outdoor voltage transformers are considered in IEC TS 60815-4:2016. These values are strongly dependent on the insulator material. Additional factors relating to the insulator profile and insulator material are also specified.

6.7 Mechanical requirements

Subclause 6.7 of IEC 61869-1:2007 is replaced by the following one:

The required static load that voltage transformers shall be able to withstand is given in Table 7. The figures include loads due to wind and ice.

The specified test loads are intended to be applied in any direction at the level of the primary terminals.

Table 7 – Static withstand test loads

Highest voltage for equipment, U_m kV	Static withstand test load, F N
	Voltage transformers
Up to 100	500
> 100 up to 300	1 000
> 300 up to 500	1 250
> 500	1 500
The sum of the loads acting in routinely operating conditions should not exceed 50 % of the specified withstand test load. In some applications, voltage transformers with through current terminals should withstand rarely occurring extreme dynamic loads (e.g. short circuits) not exceeding 1,4 times the static test load. For some applications, it may be necessary to establish the resistance to rotation of the primary terminals. The moment to be applied during the test is agreed between the manufacturer and the purchaser.	

6.8 Multiple chopped impulse on primary terminals

Subclause 6.8 of IEC 61869-1:2007 is replaced by the following one:

If additionally specified, the primary terminals of oil-immersed voltage transformers having U_m equal to or above100 kV shall withstand multiple chopped impulses in accordance with 7.4.2 of IEC 61869-1:2007.

NOTE Requirements and tests relate to the behaviour of the internal shields and connections carrying high-frequency transient currents. The test can also be applied to ratings below this level.

6.9 Internal arc fault protection requirements

Subclause 6.9 of IEC 61869-1:2007 is replaced by the following one:

These requirements apply to oil-immersed and gas-insulated voltage transformers having U_m equal to or above 100 kV, for which an internal arc fault protection class is additionally specified.

If additionally specified, the instrument transformer shall be able to withstand an internal arc of the specified current and duration.

The applied current is a symmetrical sinusoidal current. The r.m.s. current value is

$$I_{sc}/\sqrt{2}$$

The arc fault duration shall be defined in accordance with Table 8.

It shall be considered that compliance with these requirements is achieved if the instrument transformer passes the test described in 7.4.6. of IEC 61869-1:2007.

Table 8 – Arc fault duration and performance criteria

Protection stage	Arc fault duration s	Internal arc fault protection class I	Internal arc fault protection class II
1	0,2	Fracture of the housing and fire permitted, but all projected parts to be confined within the containment area	No external effect other than the operation of suitable pressure relief device
2	0,5		No fragmentation (burn-through or fire acceptable)

6.11 Electromagnetic compatibility (EMC)

6.11.1 Requirement for radio interference voltage (RIV)

Subclause 6.11.2 of IEC 61869-1:2007 is replaced by the following one:

The RIV requirement applies to voltage transformers having U_m equal to or above 100 kV to be installed in air-insulated substations.

During test with power-frequency voltage, the radio interference voltage shall not exceed 2 500 µV at 1,1 × U_m / √2.

NOTE This requirement is included to meet certain electromagnetic compatibility regulations.

6.13 Markings

6.13.1501 Terminal markings

The markings shall identify:

a) the primary and the secondary terminals;

b) the relative polarity of terminals.

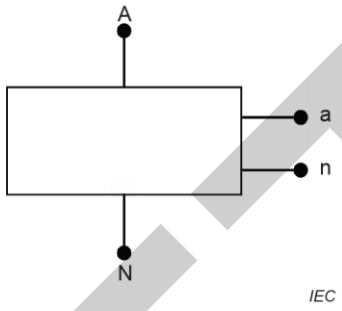
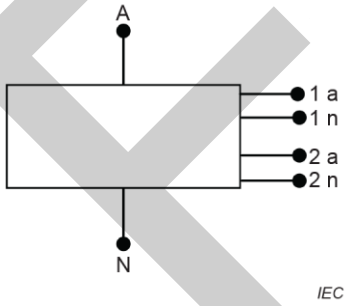
6.13.1502 Method of marking

The primary terminals shall be marked clearly and indelibly, either on their surface or in their immediate vicinity. If possible, the secondary terminals shall be identified clearly and indelibly, either on the surface of the DCVT or in the immediate vicinity of the terminals.

6.13.1503 Terminal markings

Terminal markings shall be in accordance with Table 1503.

Table 1503 – Markings of terminals

Line primary terminal Secondary terminals Ground primary terminal	 DCVT with one secondary output
Line primary terminal Secondary terminals Ground primary terminal	 DCVT with two secondary outputs

6.13.1504 Rating plate markings

Subclause 6.13 of IEC 61869-1:2007 and IEC 61869-6:2016 is replaced by the following one:

All voltage transformers shall carry at least the following markings:

a) manufacturer's name or other mark by which the manufacturer can be readily identified;
b) year of manufacture and a serial number or a type designation, preferably both;
c) highest voltage for equipment (U_m);
d) insulation level;
e) rated primary voltage (U_{pr});
f) accuracy class;

When the instrument transformer is intended for both DC and AC measurements, the accuracy for both applications shall be marked separately.

g) temperature category;
h) mass in kg (when ≥ 25 kg);
i) thermal class of insulation if different from Class A.

If several classes of insulating material are used, the one which limits the temperature rise should be indicated.

In addition, the following information should be marked (if applicable):

j) maximum static mechanical load;
k) type of insulating fluid;
l) rated filling pressure;
m) minimum functional pressure;

n) insulating fluid volume (or mass) contained in the voltage transformer;

o) on transformers with secondary converters, the use of each one and its corresponding terminals.

For analogue secondary output, the following information shall be marked:

p) rated secondary output voltage;

q) rated burden (R_{br});

r) rated delay time (t_{dr}), if different from 0;

s) on voltage transformers with two or more secondary terminals, the ratings of each one (e.g. transformation ratio, accuracy class).

The rating plate of all DCVTs, where practicable, shall be readable from ground level and carry the markings given in Tables 1504 to 1506.

Table 1504 – Rating plate marking for common rating plate

Rating	Symbol	Analogue output	Digital output
Type designation		x	x
Manufacturer's name or mark		x	x
Highest voltage for equipment	U_m	x	x
Insulation level		x	x
Rated primary voltage	U_{pr}	x	x
Temperature category		x	x
Mass in kg		x	x
Thermal class of insulation		x	x
Maximum static mechanical load		x	x
Type of insulating fluid		x	x
Rated filling pressure Minimum functional pressure		x	x
Insulating fluid volume (or mass)		x	x

Table 1505 – Rating plate marking for each secondary converter

Rating	Symbol	Analogue output	Digital output
Accuracy class		x	x
Rated transformation ratio	K_r		x
Rated secondary output voltage	U_{sr}	x	
Rated burden	R_{br}	x	
Rated delay time	t_{dr}	x	
Maximum delay time			x

Table 1506 – Rating plate marking for auxiliary power supply

Rating	Symbol	Analogue output	Digital output
Auxiliary power supply voltage	U_{ar}	x	x
Auxiliary power supply frequency		x	x
Supply current (nominal conditions)	I_{ar}	x	x
Maximum supply current (overload conditions)	I_{amax}	x	x

All information shall be marked in an indelible manner on a rating plate securely attached to the transformer (at least the common rating plate) or to the secondary auxiliary cabinet for the secondary converter and auxiliary power supply, if present.

6.602 Requirements for electrical transmitting system and electrical wires for output link

6.602.1 Connectors

Subclause 6.602.1 of IEC 61869-6:2016 is replaced by the following one:

Screw terminals are the standard interface.

For applications requesting a high bandwidth, it is preferable to use a coaxial connector. In this case, the centre pin shall correspond to the "a" terminal.

6.1501 Digital interface

Refer to the different clauses and annexes of IEC 61869-9:2016.

NOTE Digital interfaces for DC applications are still under development, and the full adequacy of IEC 61869-9 has still to be improved.

6.1502 Design requirements for DC voltage dividers

The capacitors shall comply with Subclause 6.1 of IEC 60815-1, regarding their individual insulation level.

7 Tests

7.1 General

7.1.2 List of tests

Table 10 of IEC 61869-1:2007 is replaced by the following table.

Table 10 – List of tests

Tests	Subclause
Type tests	**7.2**
Temperature rise test	7.2.2
Impulse voltage withstand test on primary terminals	7.2.3
Wet test for outdoor type transformers	7.2.4
Polarity reversal test with partial discharge measurement	7.2.1501
Electromagnetic compatibility tests	7.2.5
Test for accuracy	7.2.6
Test for accuracy versus harmonics	7.2.1502
Verification of the degree of protection by enclosures	7.2.7
Enclosure tightness test at ambient temperature	7.2.8
Pressure test for the enclosure	7.2.9
Low-voltage component voltage withstand test	7.2.601
Measurement of the step response time	7.2.1503
Routine tests	**7.3**
Power-frequency voltage withstand test on primary terminals	7.3.1
Partial discharge measurement	7.3.2
Power-frequency voltage withstand test between sections	7.3.3
DC applied voltage withstand test with partial discharge measurement	7.3.1501
Power-frequency voltage withstand test on secondary terminals	7.3.4
Test for accuracy	7.3.5
Verification of markings	7.3.6
Enclosure tightness test at ambient temperature	7.3.7
Pressure test for the enclosure	7.3.8
Power-frequency voltage withstand test for low-voltage components	7.3.601
Measurement of capacitance	7.3.1502
Measurement of resistance	7.3.1503
Special tests	**7.4**
Chopped impulse voltage withstand test on primary terminals	7.4.1
Multiple chopped impulse test on primary terminals	7.4.2
Transmitted overvoltage test	7.4.4
Mechanical tests	7.4.5
Internal arc fault test	7.4.6
Enclosure tightness test at low and high temperatures	7.4.7
Gas dew point test	7.4.8
Corrosion test	7.4.9
Fire hazard test	7.4.10
Pollution tests	7.4.1501
Vibration tests	7.2.602
Test for accuracy on the composite signal	7.4.1502
Ageing test for R and C components	7.4.1503

7.1.3 Sequence of tests

Subclause 7.1.3 of IEC 61869-1:2007 is replaced by 7.1.3.1501 and 7.1.3.1502 .

7.1.3.1501 Sequence of type tests

The sequence of tests is not specified and may be agreed between the purchaser and the supplier.

Before starting the type test sequence, the following routine tests shall be performed:

- power-frequency voltage withstand tests on primary terminals;
- partial discharge measurement.

NOTE The partial discharge measurement is generally performed together with the power-frequency voltage withstand test.

After the type test sequence, the voltage transformer shall be subjected to all routine tests detailed in 7.3.

The DC applied voltage test may be performed before the polarity reversal test. In this case, it does not need to be repeated after the type test sequence.

7.1.3.1502 Sequence of routine tests

The sequence of tests is not specified, but the accuracy tests shall be performed after the dielectric tests.

7.2 Type tests

7.2.1 General

Subclause 7.2.1 of IEC 61869-6:2016 is applicable with the following addition:

Type tests on DCVTs are considered as valid if they have been performed on a device of comparable design, with similar specific design stresses. Evidence shall to be provided by the manufacturer.

7.2.2 Temperature rise test

Subclause 7.2.2 of IEC 61869-6:2016 is applicable with the following modifications:

The second and third paragraphs are replaced by the following ones:

For the temperature rise test, the following test methods may be used for temperature measurement:

- for gas-insulated equipment: infrared camera and gas pressure variation measurements;
- for oil-insulated equipment: infrared camera measurement.

The voltage to be applied is the highest voltage for the equipment (U_m). The test shall be continued until the temperature of the transformer has reached the steady-state temperature.

The corresponding time shall be noted on the test report.

7.2.3 Impulse voltage withstand test on primary terminals

7.2.3.2 Lightning impulse voltage test on primary terminals

Subclause 7.2.3.2.1 of IEC 61869-1:2007 is applicable to voltage transformers having U_m equal to or above 20 kV.

7.2.3.3 Switching impulse voltage test

Subclause 7.2.3.3 of IEC 61869-1:2007 is applicable to voltage transformers having U_m equal to or above 100 kV.

7.2.4 Wet test for outdoor type transformers

Subclause 7.2.4 of IEC 61869-1:2007 is applicable with the following modifications:

For voltage transformers having U_m equal to or above 100 kV, the test shall be performed with switching impulse voltage test of both polarities, with the voltage corresponding to the insulation level.

For voltage transformers having U_m < 100 kV, the test shall be performed with power-frequency voltage defined in 7.3.1.

7.2.5 Electromagnetic Compatibility (EMC) tests

7.2.5.1 RIV test

Subclause 7.2.5.1 of IEC 61869-1:2007 is applicable to voltage transformers having U_m equal to or above 100 kV, with the last three paragraphs replaced by the following ones:

The test shall be performed with AC power supply.

A pre-stress voltage of $1{,}25 \times U_m/\sqrt{2}$ shall be applied and maintained for 30 s.

The voltage shall then be decreased to $1{,}1 \times U_m/\sqrt{2}$ in about 10 s and maintained at this value for 30 s before measuring the radio interference voltage.

The voltage transformer shall be considered to have passed the test if the radio interference level at $1{,}1 \times U_m/\sqrt{2}$ is in accordance with 6.11.2.

7.2.5.2 Immunity test

Subclause 7.2.5.2 of IEC 61869-6:2016 is applicable in the case of electronic DCVTs.

7.2.6 Tests for accuracy

7.2.6.1501 General

Test circuits are given in Annex 6D of IEC 61869-6:2016 for analogue outputs and Annex 9D of IEC 61869-9:2016 for digital outputs.

To prove compliance with the specified accuracy class, the test shall be made at each value of voltage given in Table 1502, at rated burden, and at ambient temperature, unless otherwise specified.

In a first step, the accuracy shall be measured in a short time (less than 0,05 times the thermal time constant), at ambient temperature, with increasing voltages.

Then the voltage is reduced to U_{pr} and maintained up to the thermal stabilization. The accuracy is measured and the accuracy variation at U_{pr} is determined.

From this result, the accuracy variation at intermediate voltages and maximum voltage (125 %) is estimated according to the thermal characteristics of the resistors.

The errors shall be within the limits of the relevant accuracy class, both at the time the test voltage is applied and after the correction of the accuracy variation.

The accuracy variations shall be noted on the type test report, as a characteristic of the voltage divider.

The stability is considered after a period of 3 times the time constant, which shall be defined by the supplier.

For primary voltage equal to zero, the measured absolute error shall not exceed the value of the absolute error allowed at 0,05 × U_{pr}.

NOTE This test can be performed together with the temperature-rise test.

7.2.6.1502 Basic accuracy tests for DCVT with analogue output

For analogue output with rated delay time, it is not necessary to insert a delay time device between the reference transformer and the accuracy measurement system.

7.2.6.1503 Basic accuracy tests for DCVT with digital outputs

Subclause 7.2.6 of IEC 61869-9:2016 is applicable with replacement of the two last paragraphs by the following ones:

Accuracy tests shall be performed over a minimum period, during which several measurements shall be averaged. The details of the test arrangement and timing and/or bandwidth of the test system shall be provided in the accuracy test report.

The measurement period needs to be sufficient to secure the accuracy measurement considering ripple oscillations and the effect of the sampling. Time should be less than 10 s.

7.2.601 Low-voltage component voltage withstand test

Subclause 7.2.601 of IEC 61869-6:2016 is replaced by the following one:

A low-voltage component of a DCVT is the low voltage part of RC-dividers or R-dividers when placed outside the main housing, as shown in Figure 1504.

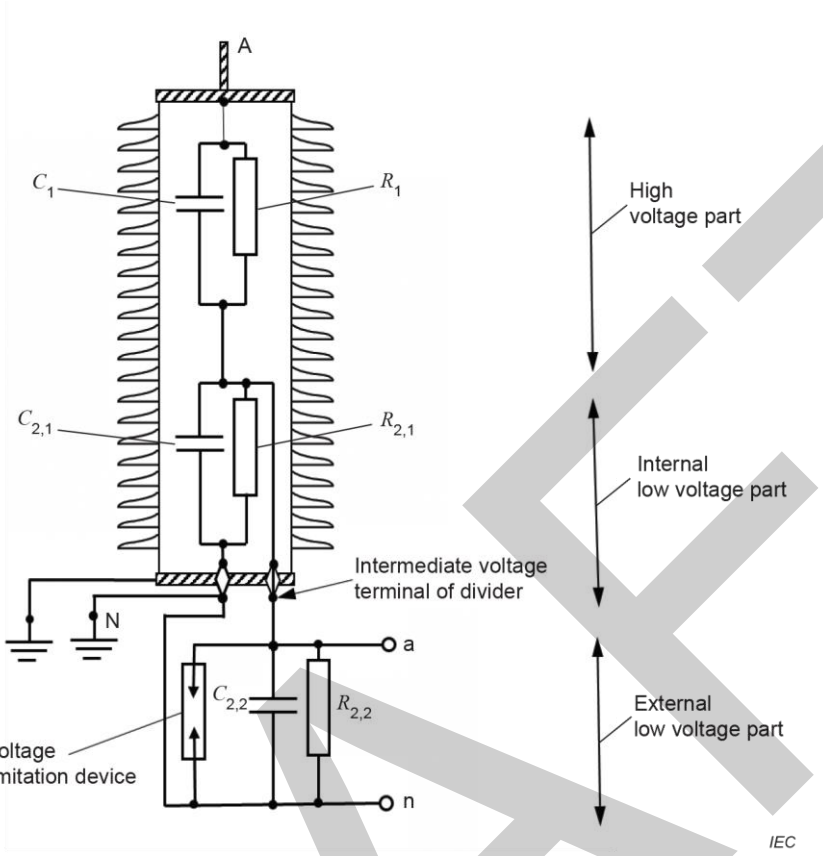


Figure 1504 – RC divider with low-voltage part outside the main housing

To test this external secondary part, five positive and five negative lightning impulses 1,2/50 µs with the test value in accordance with 5.3.5 of IEC 61869-6:2016 shall be applied as shown in Figure 1505. The voltage limitation device shall be disconnected. This test verifies the voltage withstand of the complete external low voltage part to earth.

No insulation breakdown is permitted.

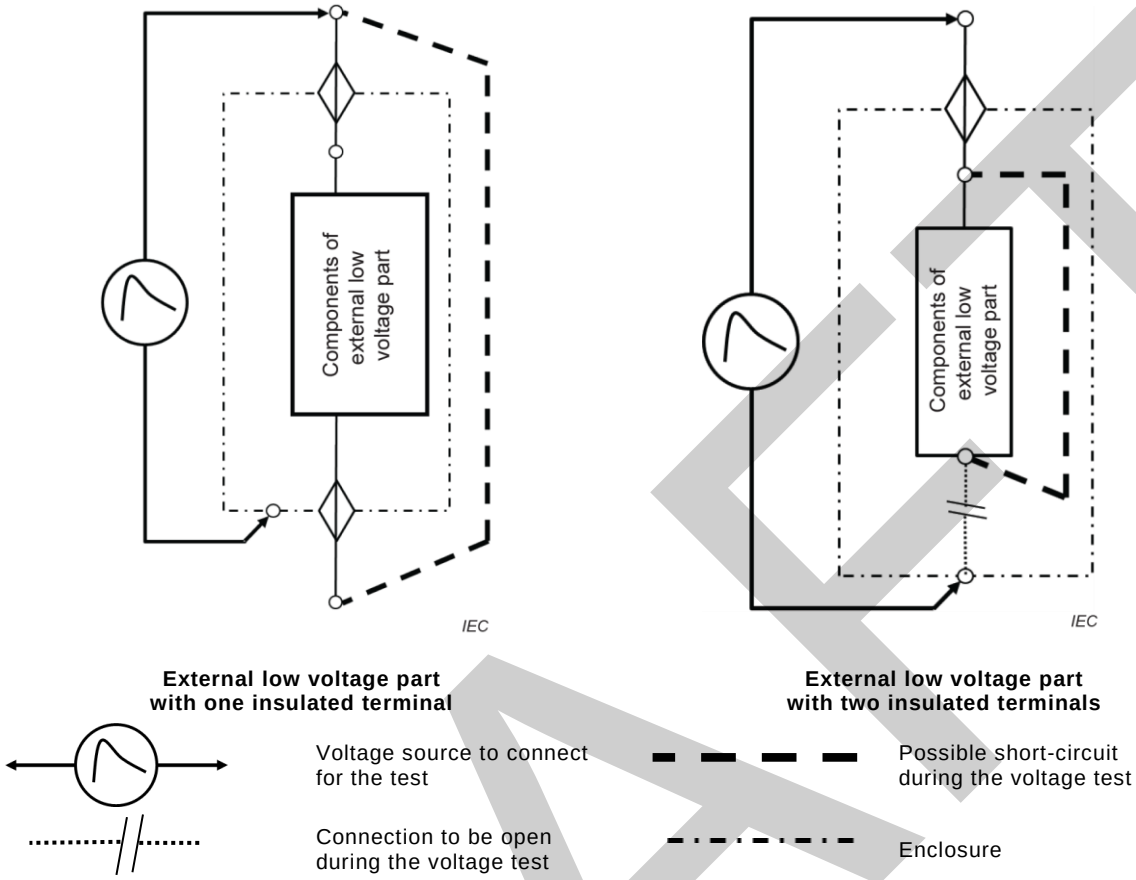


Figure 1505 – Connection for voltage withstand test of the external low voltage part of a DCVT

7.2.1501 Polarity reversal test with partial discharge measurement

This test is applicable to DCVTs having U_m equal to or above 100 kV.

If not otherwise specified, this test is not applicable to DCVTs for VSC applications.

NOTE VSC application is described in the Introduction.

During the test, the ambient temperature shall be between 10 °C and 40 °C. Before the test, the device shall be at ambient temperature.

A double polarity reversal shall be used, as shown in Figure 1506.

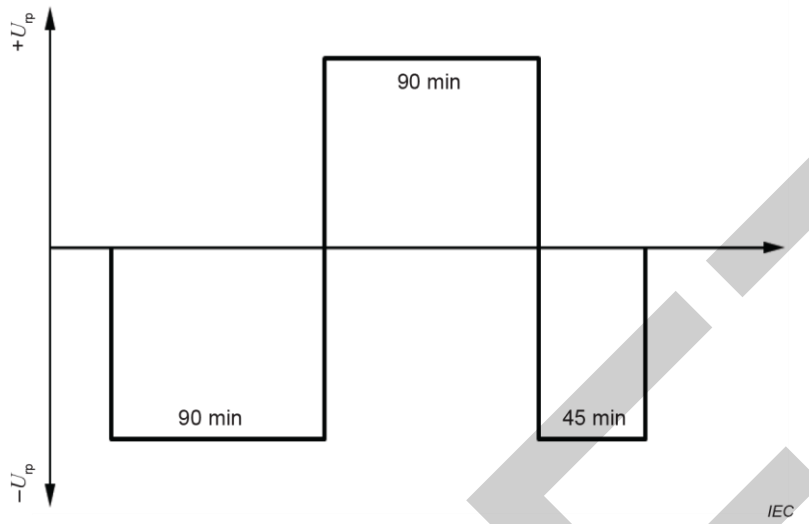


Figure 1506 – Polarity reversal test profile

No preconditioning of the insulation at lower voltage is permitted. After the DC applied voltage withstand test, the voltage transformer shall normally be earthed and completely discharged before the polarity reversal test is initiated. The time duration required for a complete discharge shall be agreed between the parties depending on the type of voltage transformer and shall be sufficient to avoid any undue influence of the trapped charges on the results of this test.

However, to save time during routine tests and upon agreement between the parties, the polarity reversal test may be initiated at any time after the DC applied voltage withstand test.

The test sequence shall include:

- 90 min at negative polarity, followed by
- 90 min at positive polarity, followed by
- 45 min at negative polarity, and
- reduction of the voltage to zero.

The time for the polarity reversal shall be as short as possible, consistent with the testing equipment, but never more than 2 min. The polarity reversal is considered as complete when the voltage has reached 100 % of the test value. The partial discharge levels shall be monitored during the entire test sequence.

Partial discharges shall be measured in accordance with IEC 60270.

The polarity reversal test voltage (U_{rp}) shall be calculated as follows:

$$U_{rp} = 1{,}25 \times U_m$$

The voltage transformer shall be considered to have passed the test if the following conditions are met:

- No more than 10 pulses of partial discharge with a magnitude equal to or greater than 2 000 pC are recorded during the last 30 min of the test time. Pulses that are proven to be external to the test object shall be disregarded.
- No disruptive discharges on the non-self-restoring insulation shall occur. If there is an internal breakdown, the voltage transformer shall be considered to have failed the test. It

is assumed that an internal breakdown has occurred if the value of the resistance and the capacitance of the HV part, measured after the test, differ from the values measured before the test by more than 2 %. If a flashover occurs, the test shall be repeated once only. If, during the repetition of the test, no flashover or internal breakdown occurs, the voltage transformer shall be considered to have passed the test.

7.2.1502 Tests for accuracy versus harmonics

Annex 6A of IEC 61869-6:2016 is applicable.

7.2.1503 Measurement of the step response time

The test shall be performed on the voltage transformer completely assembled. The step response test shall be performed with the rated burden and the original transmission cable, if they exist.

The primary test voltage should be the rated primary voltage and represents an impulse voltage characteristic with an accuracy of ±3 %. The step voltage can be generated by an impulse voltage generator. In case of difficulties in generating the primary signal with the specified rise time, the test procedure may be adapted, using a reduced input voltage signal, provided that the linearity of the system is proven, and the secondary signal level permits an accurate measurement.

The front time corresponds to the definitions of lightning impulse definition with a front time of 1,2 µs, with a relative tolerance of ±30 %.

The time to half value corresponds to the definitions of switching impulse definition with a time to half value of 2 500 µs, with a relative tolerance of ±60 %.

The test shall be performed one time for each polarity. Each test shall be recorded with the reference curve together with the step response curve of the test object.

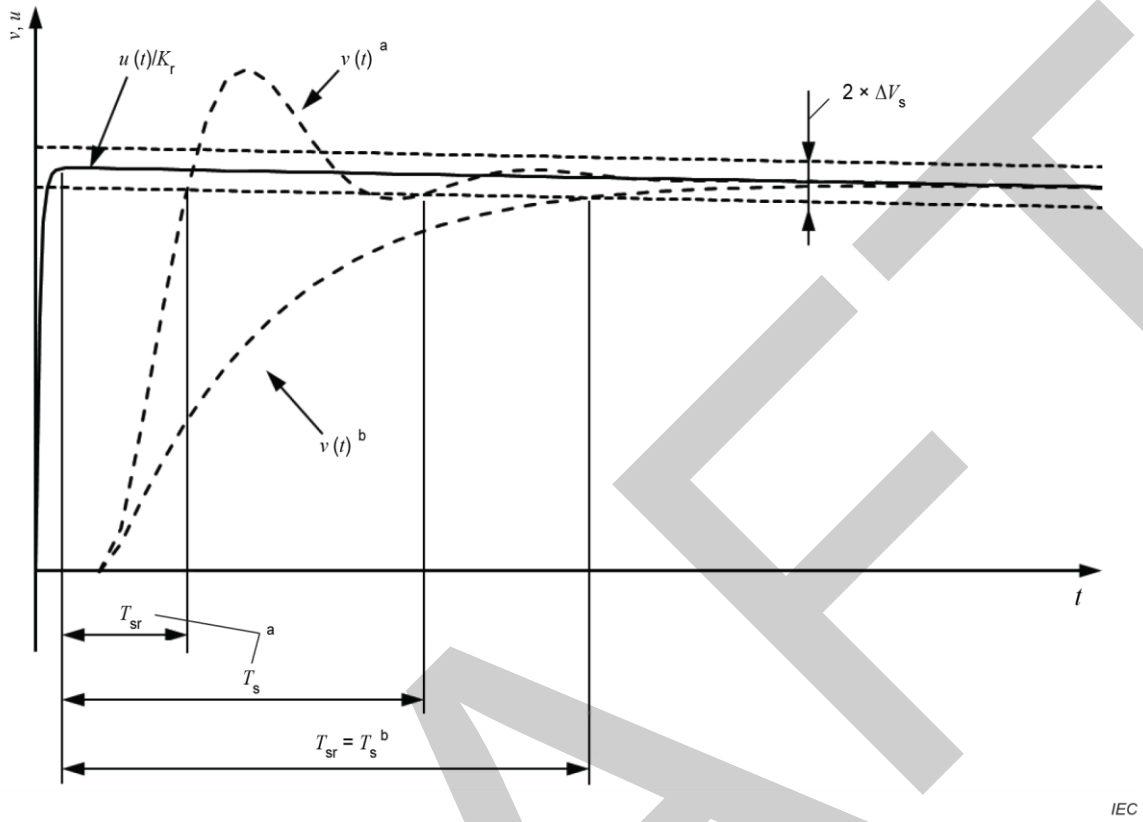
The primary voltage is measured with a reference divider. The output of the reference divider and the output voltage of the DCVT is measured with a transient recorder (see Figure 1507).

The tolerance limit ΔV_s is defined as 5 % of the steady-state value of the output signal V_∞.

NOTE A reduced tolerance limit can be defined by agreement between the purchaser and the manufacturer.

The voltage transformer shall be considered to have passed the test if:

- the measured step response time T_{sr} is lower than the rated step response time;
- the settling time T_s is less than 10 times the rated step response time T_{sr}.



Key:

u(t) Input voltage

v(t) Output voltage of test object

a For periodic behaviour

b For aperiodic behaviour

Figure 1507– Measurement of the step response time

7.3 Routine tests

7.3.1 Power-frequency voltage withstand tests on primary terminals

Subclause 7.3.1 of IEC 61869-1:2007 is replaced by the following one:

The power-frequency withstand test shall be performed in accordance with IEC 60060-1.

The test voltage is calculated as follows:

$$U_{AC} = 1{,}5/\sqrt{2} \times U_m$$

with a minimum value of 3 kV. The duration shall be 60 s.

Other values may be specified in the case of special applications.

NOTE In some special applications (example: some neutral voltage measurement applications), the specified test voltage can be insufficient.

Dielectric tests shall be made on a voltage transformer completely assembled, as in service.

The test voltage shall be applied between the primary terminal and the earth.

The frame and the case (if any) shall be connected to earth.

7.3.2 Partial discharge measurement

7.3.2.2 Partial discharge test procedure

Subclause 7.3.2.2 of IEC61869-1:2007 is applicable with the following addition:

NOTE For DCVTs, only Procedure A is applicable.

7.3.4 Power-frequency voltage withstand tests on secondary terminals

Subclause 7.3.4 of IEC 61869-6:2016 is applicable with the following addition:

If a low-voltage limitation device is connected to earth, it shall be disconnected during this test.

When there is an internal galvanic link between the secondary terminal "n" and ground, this test is required only as a type test. In this case, the connection between the secondary terminal "n" and ground shall be opened for the test.

7.3.5 Test for accuracy

7.3.5.1501 Basic test for accuracy

The routine tests for accuracy are in principle the same as the type tests in 7.2.6. The accuracy shall be measured in a short time (less than 0,05 times the thermal time constant), at ambient temperature. The accuracy measurement shall be adjusted with the corrections defined during the type test.

7.3.5.1502 Accuracy determination by resistance measurement

This method is applicable for a passive voltage divider. The resistances of the high and low voltage part of the voltage transformer shall be determined at low voltage with a precision resistance-measurement device.

The measurement of the low-voltage part shall include the transmitting cable.

The measurement of the resistance values shall be performed for both the positive and negative polarities of the measuring equipment source and the resistance shall be taken as the average value of these two measurements.

The resistance values shall be measured before and after the high-voltage tests.

The maximum resistance variation between the voltage measurements shall not be more than 0,2 times the limit of ratio error at U_{pr} corresponding to the accuracy class.

For the calculation of the divider ratio of the DCVT, the resistance values based on the measurements after the high-voltage tests shall be used.

Recommended test voltages for resistance measurement of the HV and LV arm are as follows:

< 100 kΩ	< 100 MΩ	< 300 MΩ	< 400 MΩ	< 700 MΩ
U_{test} > 10 V_{DC}	U_{test} > 100 V_{DC}	U_{test} > 200 V_{DC}	U_{test} > 250 V_{DC}	U_{test} > 280 V_{DC}

7.3.1501 DC applied voltage withstand test with partial discharge measurement

This test is applicable to DCVTs having U_m equal to or above 20 kV.

Dielectric tests shall be performed on a voltage transformer completely assembled.

During the test, the temperature of the voltage transformer shall be between 10 °C and 40 °C.

No preconditioning of the voltage transformer at a lower voltage level is permitted and the DC voltage shall be raised to the test level within a period not exceeding 1 min. The DC voltage shall then be held for 1 h, after which the voltage shall be reduced to zero within a period not exceeding 1 min. Positive polarity shall be used.

The DC test voltage shall be calculated as follows:

$$U_{DC} = 1{,}5 \times U_m$$

The voltage transformer shall be considered to have passed the test if the following conditions are met:

- No more than 10 pulses of partial discharge with a magnitude equal to or greater than 2 000 pC are recorded during the last 30 min of the test. Pulses that are proven to be external to the test object shall be disregarded. If this condition is not met, then the test may be extended for 30 min, with the same criteria applying. Only one 30-min extension is allowed.
- No disruptive discharges on non-self-restoring insulation shall occur. If there is an internal breakdown, the voltage transformer shall be considered to have failed the test. It is assumed that an internal breakdown has occurred if the value of the resistance and the capacitance of the HV part, measured after the test, differ from the values previously measured by more than 2 %. If a flashover occurs, the test shall be repeated once only. If, during the repetition of the test, no flashover or puncture occurs, the voltage transformer shall be considered to have passed the test.

7.3.1502 Measurement of capacitance

For DCVTs, capacitance C_1 shall be measured at voltages of 10 % and 100 % of U_{pr} before and after the dielectric test to reveal the change in capacitance due to the puncture of one or more elements. They shall be measured at rated power frequency.

The capacitance shall be measured using a method that excludes errors due to harmonics and to accessories in the measuring circuit.

7.3.1503 Resistance measurement

For DCVTs, the resistance R_1 of the primary part shall be measured with a voltage > 100 V DC before and after the dielectric tests.

The resistance of the secondary part R_2 shall be measured before and after the dielectric tests. The DC test voltage shall have at least the same value as the rated secondary voltage, but not be higher than twice the rated secondary voltage.

This test may be replaced by the accuracy measurement in accordance with 7.3.5.1502.

7.4 Special tests

7.4.1 Chopped impulse voltage withstand test on primary terminals

Subclause 7.4.1 of IEC 61869-1:2007 is replaced by the following one:

The test is applicable to voltage transformers having U_m equal to or above 20 kV.

The test shall be carried out with negative polarity only and combined with the negative polarity lightning impulse test in the manner described below.

The voltage shall be a standard lightning impulse as defined in IEC 60060-1, chopped between 2 µs and 5 µs. The chopping circuit shall be so arranged that the amount of overswing of opposite polarity of the recorded impulse shall be limited to approximately 30 % of the peak value.

The test voltage of the full impulse shall be in accordance with the rated lightning impulse withstand voltage.

The chopped impulse test voltage shall be in accordance with 5.3.3.2 of IEC 61869-1:2007.

The sequence of impulse applications shall be as follows:

- one full impulse;
- two chopped impulses;
- fourteen full impulses.

After the test, the voltage transformer shall pass successfully the test for accuracy in accordance with 7.3.5.

7.4.1501 Pollution tests

7.4.1501.1 Artificial pollution test

The test is applicable to voltage transformers having U_m equal to or above 100 kV.

An artificial pollution test may be applied to voltage transformers having porcelain insulators to be used outdoors and exposed to polluted atmospheres.

If a test is deemed necessary, the specific test method to be applied and the degree of pollution severity shall be specified or agreed upon between the purchaser and the manufacturer at the time of ordering. Proposals for artificial pollution test methods are described in IEC TS 61245.

NOTE The reproducibility of artificial pollution tests on insulators, with weather sheds of silicon rubber, performed in different laboratories has not been established in a manner consistent with other standardized tests. However, further guidance will become available as research continues and when appropriate inter-laboratory comparisons are made. The problem is under consideration by the IEC.

The DC withstand test voltage shall be specified. In general, it coincides with the highest voltage for equipment. The tests are usually carried out at negative polarity.

The specified characteristics of the voltage transformer are confirmed if no flashover or puncture occurs during three consecutive individual tests performed in accordance with the specified or agreed procedure. If there is a puncture, the voltage transformer shall be considered to have failed the test. If only one flashover occurs, a fourth test shall be performed and the voltage transformer shall then be considered to have passed the test if no further flashover or puncture occurs.

7.4.1501.2 Even-wetting DC voltage test

The even-wetting test may be applied to all outdoor voltage transformers having U_m equal to or above 100 kV.

The voltage transformer shall be mounted in a manner representative of the mounting in service.

The test circuit shall be in accordance with IEC 60060-1.

The standard even-wetting test procedure described in IEC 60060-1 shall be used, except for the test duration.

Rain with different characteristics representing very light or light conductive layers on the insulator surface or having different precipitation rates may be agreed between the manufacturer and the purchaser. The rain precipitation shall be adjusted before starting the test.

The test voltage to be applied to the voltage transformer shall be equal to 1,25 U_{m}.

The test voltage shall be maintained at this value for 1 h.

The voltage transformer shall be considered to have passed the test if no flashover or puncture occurs. If there is a puncture, the voltage transformer shall be considered to have failed the test. If a flashover occurs, the test shall be repeated once only, after verifying the rain conditions. The voltage transformer shall be considered to have passed the test if no further flashover or puncture occurs.

7.4.1502 Accuracy tests on the composite signal

The purpose of the test is to measure the accuracy on the DC component and on harmonic components, when supplied simultaneously.

The accuracy on the DC voltage component shall comply with the specifications of 5.6.1503, while pure sinusoidal harmonic components are supplied (one at a time) to the primary side.

The 5-kV voltage components shall be supplied with the following frequencies:

- for low-bandwidth DC applications: 100 Hz, 500 Hz, 1kHz, 1,5 kHz, 3 kHz;
- for high-bandwidth DC applications: 100 Hz, 2,5 kHz, 5 kHz, 7,5 kHz, 10 kHz, 15 kHz, 20 kHz.

The accuracy of the AC voltage components shall comply with the specifications of Annex 6A of IEC 61869-6:2016, while the rated DC primary voltage is supplied to the primary side.

NOTE Additional frequencies can be specified depending on the application.

7.4.1503 Ageing test for R and C components

This test is intended to prove that the voltage divider accuracy is not influenced by ageing.

This test shall be performed on three samples of resistance elements and a capacitor element. It consists of five cycles as follows:

- 12 h in an ambient temperature of −50 °C;
- 200 h at 30 °C and 1,5 times the equivalent rated voltage.

After five cycles, the values shall be measured and the maximum variation shall be less than 5 % for the capacitor, and less than the maximum error corresponding to the accuracy class for the resistor.

Annex 15A
(informative)

Proposed rated insulation level applicable to voltage transformers for DC application

Insulation coordination for HVDC systems is currently under consideration by the IEC.

However, instrument transformer manufacturers need references for the design and testing of their devices.

For AC and DC applied dielectric tests, test voltage is defined in 7.2 and 7.3.

The present annex proposes a test voltage for impulse tests, based on generally adopted system voltages and test voltages. These are indicative values, and system designers could be forced to define other insulation levels, based on specific insulation coordination conditions.

For a system voltage below 200 kV, too many applications exist and it is not possible to define any standard values. Insulation levels shall be defined by the system designer.

After publication of the rated system voltages and rated insulation levels, the present annex will be disregarded.

Table 15A.1 – Proposed rated primary terminal insulation levels for voltage transformers for DC application

Rated system voltage kV	Highest voltage for equipment Um kV	Rated lightning impulse withstand voltage (peak) kV	Rated switching withstand voltage (peak) kV
200	210	500	390
250	262	750	650
320	336	900 750 660 [a]	650 612 -- [a]
400	412	1 175 790 [a]	950 760 [a]
500	515	1 425 1 300 [a]	1 175 1 360 [a]
600	617	1 650 2 100	1 280 1 675
800	816	1 950 2 300	1 600 1 800
1 100	1 120	2 300	2 100
[a] cable connection			

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