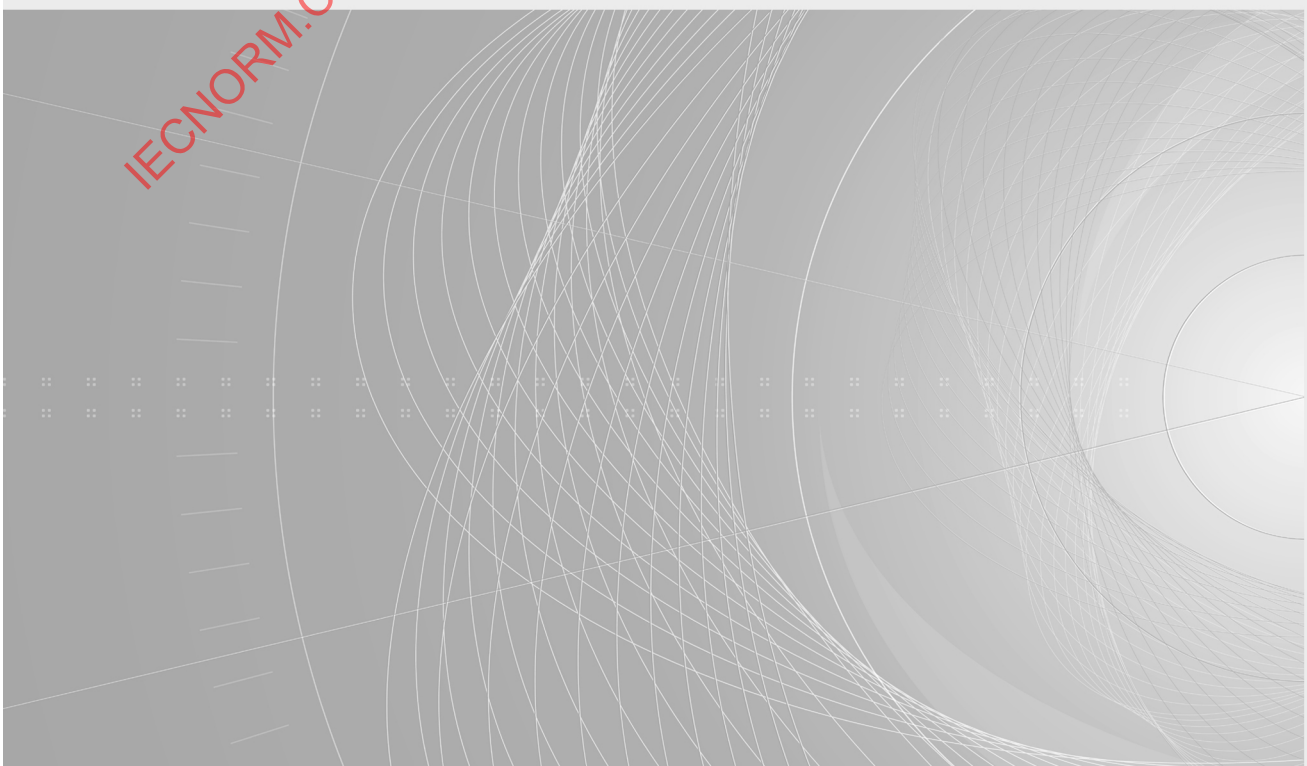
IEC TS 63042-301

Edition 1.0 2018-12

TECHNICAL SPECIFICATION

UHV AC transmission systems – Part 301: On-site acceptance tests



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UHV AC transmission systems – Part 301: On-site acceptance tests

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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UHV AC TRANSMISSION SYSTEMS –

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FOREWORD

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

IEC TS 63042-301, which is a Technical Specification, has been prepared by IEC technical committee 122: UHV AC transmission systems.

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

Enquiry draft	Report on voting
122/57/DTS	122/65A/RVDTS

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

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

A list of all parts in the IEC 63042 series, published under the general title *UHV AC transmission systems*, can be found on the IEC website.

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

INTRODUCTION

With the increase in voltage levels, the reliability and safety of high-voltage electric equipment is facing new challenges. There is a need to have consensus on a series of technical criteria and requirements for on-site acceptance tests for electrical equipment of UHV AC transmission systems exceeding 800 kV to detect the damages or abnormal conditions that may occur during the transportation and installation processes and to determine whether equipment can be put into operation reliably and safely for power systems.

This Technical Specification proposes on-site acceptance tests, relevant test items, test methods, and evaluation criteria for transformers, circuit breakers, GIS, surge arresters, voltage and current transformers, shunt reactors, series compensators, insulators, disconnectors, earthing switches and high-speed earthing switches.

UHV AC transmission systems –

Part 301: On-site acceptance tests

1 Scope

This part of IEC 63042, which is a technical specification, applies to on-site acceptance tests of electrical equipment with the highest voltages of AC transmission system exceeding 800 kV.

The electrical equipment exceeding 800 kV includes the following items:

- power transformers;
- circuit breakers;
- gas insulated switchgear (GIS);
- surge arresters;
- voltage and current transformers;
- shunt reactors;
- series compensators;
- insulators;
- disconnectors and earthing switches;
- high-speed earthing switches.

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 60376, *Specification of technical grade sulfur hexafluoride (SF_6) for use in electrical equipment*

IEC 60480, *Guidelines for the checking and treatment of sulfur hexafluoride (SF_6) taken from electrical equipment and specification for its re-use*

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

IEC 62271-4, *High-voltage switchgear and controlgear – Part 4: Handling procedures for sulphur hexafluoride (SF_6) and its mixtures*

IEC 62271-100:2008, *High-voltage switchgear and controlgear – Part 100: Alternating current circuit-breakers*

IEC 62271-102:2018, *High-voltage switchgear and controlgear – Part 102: Alternating current disconnectors and earthing switches*

IEC 62271-112:2013, *High-voltage switchgear and controlgear – Part 112: Alternating current high-speed earthing switches for secondary arc extinction on transmission lines*

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

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

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

3.1
on-site acceptance tests
inspections and tests performed (or checked) in order to verify the correct operation and dielectric integrity of the equipment after shipping and on-site installation

3.2
UHV AC
highest voltage of AC transmission system exceeding 800 kV

4 General

On-site acceptance tests for newly installed electrical equipment are an important approach to judge whether equipment is normal or abnormal after transportation and installation. Repetition of the full programme of routine tests, already performed in the factory is not required; however some of the tests should be repeated for confirmation of the correct operation of the equipment taking into account the different conditions on-site.

On-site acceptance test results should be analysed and compared carefully with those from the factory test. The influence of different test conditions, such as humidity and the ambient temperature and pressure, should be taken into consideration when making comparisons.

5 Power transformers

5.1 General

UHV power transformers have very high level of voltage, large capacity and large size. If the UHV power transformer is adopted with split type installation on site, it is recommended to carry out separate tests on the main transformer and the voltage regulating and compensating transformer respectively.

NOTE For the procedure followed for on-site tests, the test method refers to the same kind of tests described in relevant publications for factory tests, such as IEC 60076 and/or the IEC 60599 series.

UHV power transformers should be subjected to on-site acceptance tests as specified below:

- Leak testing with pressure (tightness test)
- Winding resistance measurement
- Ratio test
- Polarity check
- Insulation resistance test on each winding to earth and between windings including bushings

- Dissipation factor (tan δ) and capacitance measurement on each winding to earth and between windings including bushings
- Core and frame insulation check
- Tests on bushings
- Insulating oil test
- Dissolved gas analysis (DGA) test
- Excitation current measurement at low voltage
- Frequency-response analysis (FRA)
- Short-circuit impedance measurement

The following items are optional:

- Induced voltage test with partial discharge measurement
- Applied voltage test

NOTE The above optional test items are based on agreement between purchaser and supplier.

5.2 Leak testing with pressure (tightness test)

The transformer main tank should withstand a pressure of 30 kPa or any specified value pressure applied on the top-level of oil in the oil conservator and maintained for 24 hours or any specified period without any leakage and damage.

5.3 Winding resistance measurement

Winding resistance measurement tests should include the following:

- Measurement should be performed for all windings at all tap positions (if any).
- Measured values should be compared with the factory test results. The deviation should be within ±5 % or otherwise specified.
- Measured values should be compared with the average value of three phase windings. The deviation should be within ±3 % or otherwise specified.

5.4 Ratio test

Ratio tests should include the following:

- The voltage ratio should be measured on each tap.
- Voltage ratio should correspond to the value on nameplate and the factory test result.

5.5 Polarity check

The polarity of single-phase transformers should be checked. The polarity should be the same as that identified on the nameplate.

5.6 Insulation resistance test on each winding to earth and between windings including bushings

Insulation resistance tests should be made for each winding with respect to earth and between windings.

5.7 Dissipation factor (tan δ) and capacitance measurement on each winding to earth and between windings

Dissipation factor (tan δ) and capacitance measurement on each winding to earth and between windings should include the following:

- Terminals to be tested should be connected to the test instrument and the terminals not being tested should be short-circuited and connected to earth. Test voltage should be 10 kV or agreement between purchaser and supplier.
- Tan δ measurement results should be compared with the factory test result considering the temperature difference and the difference should be within ±0,001 or otherwise specified. The difference of the capacitance value should be within ±1 % of the factory test result or otherwise specified.

5.8 Core and frame insulation check

Insulation resistance check should be made between core to frame, core to tank and frame to tank. For details see IEC 60076-1.

5.9 Tests on bushings

5.9.1 Visual inspection

Visual inspections should be made on each bushing. See 9.10 of IEC 60137:2017.

5.9.2 Tan δ and capacitance measurement

- The measurement is only applicable to capacitance-graded bushings. After installation of the transformer and reactor bushings, tan δ and capacitance of the insulation should be measured. The test voltage should be 10 kV or agreement between purchaser and supplier. Voltage tap (if any) should be short-circuited with the test tap.
- The deviation between measured capacitance value and factory test value should be lower than ±1 %, depending on the number of layers up to 5 % or agreement between purchaser and supplier.

See 9.1 of IEC 60137:2017.

5.9.3 Tap withstand voltage

A rated frequency voltage withstand test should be applied to or induced at the tap for 1 min with the bushing mounting flange earthed. The voltage tap should be tested at 20 kV or agreement between purchaser and supplier. The test tap should be tested at 2 kV or agreement between purchaser and supplier.

For voltage tap, different suppliers may give different suggested value of test voltage. It is advised to refer to the product specification or consult the supplier before testing.

5.10 Insulating oil tests

The test requirements of insulating oil filling into electrical equipment should be as per Table 1 or agreement between purchaser and supplier.

Table 1 – Requirements of insulating oil

No.	Item	Requirements
1	Visual examination	Transparent, inclusion-free, no suspended matter
2	Particle count in oil	Granularity(5 μm ~ 100 μm): ≤ 1 000/100 mL Granularity (> 100 μm): None
3	Dielectric strength (kV)	≥70（2.5 mm gap, spherical electrode）
4	Dissipation factor (90 °C) %	After filling into equipment ≤ 0,7
5	Water content mg/ kg (50 °C)	≤10 after filling
6	Total dissolved gas (volume fraction) %	≤ 0,5
7	DGA	Refer to relevant clauses of this document
NOTE 1 For details see IEC 60422 and IEC 60296. NOTE 2 Requirement criteria of insulating oil are means of the finished of all oil treatment.		

5.11 Dissolved gas analysis (DGA) test

The DGA test should be carried out after the completion of oil treatment. If a dielectric test is required, the DGA test should be carried out after the dielectric test. See IEC 60599.

5.12 Excitation current measurements at reduced voltage

Excitation current measurements at low voltage should include the following:

- The excitation current should be measured at the same low test voltage as the factory test. The test should be carried out before the winding resistance measurement to avoid the influence of residual flux in the core.
- The value of excitation current at low test voltage should be compared with the factory test results. The difference should be less than 30 % or agreement between purchaser and supplier.

NOTE If a higher excitation current is needed a higher voltage could be applied.

5.13 Frequency-response analysis (FRA)

The FRA should be performed for each winding of transformers. For details see IEC 60076-18.

5.14 Short-circuit impedance measurement at reduced current

A short-circuit impedance measurement at reduced current should include the following:

- The short-circuit impedance should be measured at the same reduced current as in the factory test.
- The value of short-circuit impedance at reduced current should be compared with the factory test result. The difference should be less than 5 % or agreement between purchaser and supplier.

As an option, if purchaser and supplier agree, Subclauses 5.15 and 5.16 may be applicable.

5.15 Induced voltage tests with partial discharge measurement

The test may be made on-site. For details see IEC 60076-3. The value of the accepted partial discharge may be agreed between purchaser and supplier.

5.16 Applied voltage tests

The test may be made on-site. For details see IEC 60076-3. The applied voltage test may include the following:

- The test voltage may be applied between all terminals of the winding under test connected together and all terminals of the remaining windings, core, frame and tank of the transformer, connected together to earth;
- Test voltage may be 80 % of the factory test value and the time duration may be 1 minute, or agreement between purchaser and supplier;
- The test voltage may be as nearly as possible to a sine-wave form. The peak value divided by √2 may be equal to the test value;
- The test is successful if no collapse of the test voltage occurs.

6 Circuit breakers

6.1 General

After installation, and before being put into service, the circuit breaker (CB) should be tested in order to check the correct operation and the dielectric integrity of the equipment.

A programme of site commissioning checks and tests should be agreed between supplier and purchaser. Repetition of the full programme of routine tests, already performed in the factory is not required; however some of the tests should be repeated for confirmation of

- absence of damage;
- compatibility of separate units;
- correct assembly;
- correct performance of the assembled circuit-breaker.

In general, this is achieved when the commissioning tests include, but are not limited to the following test program with a record of the test results in a test report:

- Dielectric test on main circuit;
- Dielectric test on auxiliary circuit;
- Measurement of the resistance of the main circuit;
- Checks after installation including gas tightness test, gas quality, insulation resistance test;
- Mechanical test and measurement;
- Test of accessories.

The supplier and purchaser should agree on a commissioning test plan for tests on site.

6.2 Dielectric test on main circuit

For dielectric tests on the main circuit of circuit breaker, power frequency voltage test should be performed and the test voltage and procedure on main circuit for circuit breaker are the same as that for the metal-enclosed switchgear and controlgear. See Subclause 7.2.

6.3 Dielectric test on auxiliary circuit

Dielectric tests on auxiliary circuits should be performed to confirm that transportation and storage of the circuit-breaker have not damaged these circuits. However, it is recognized that such circuits contain vulnerable sub-components and the application of the full testing voltage for the full duration can cause damage. In order to avoid this, and to avoid the temporary removal of proven connections, the supplier should detail the test process that demonstrates that damage has not occurred as well as the method of recording the results from this test process.

See also 10.2.102.3.1 of IEC 62271-100:2008.

6.4 Measurement of the resistance of the main circuit

Measurement of the resistance of the main circuit need only be made if interrupting units have been assembled on site. The measurement should be made with a direct current in accordance with 10.2.102.3.2 of IEC 62271-100:2008.

Dynamic resistance measurements (DRM) could be carried out as an additional tool for the assessment of the condition of the circuit-breaker during its lifetime.

6.5 Checks after installation including gas tightness tests, gas quality, insulation resistance test

6.5.1 General

The supplier should produce a programme of commissioning checks and tests. This should be based on, but is not limited to, the programme of checks and tests given here.

6.5.2 General checks

- Assembly conforms to supplier's drawings and instructions;
- Tightness of circuit-breaker, its fastenings, fluid systems and control devices;
- External insulation and, where applicable, internal insulation are undamaged and clean;
- Paint and other corrosion protection are sound;
- Operating devices, especially operating releases, are free from contamination;
- Adequacy and integrity of the earth connection up to and including the interface with the substation earthing system;

and, where applicable:

- Record the number on the operations counter(s) at delivery;
- Record the number on the operations counter(s) at completion of all on-site testing;
- Record the number on the operations counter(s) at first energization.

6.5.3 Checks of electrical circuits

- Conformity to the wiring diagram.
- Correct operation of signaling (position, alarms, lockouts, etc.).
- Correct operation of heating and lighting.

6.5.4 Checks of the insulation and/or extinguishing fluid(s)

For UHV gas filled CB SF_6 is commonly used.

- Check of filling pressure/density
- Quality checks, to confirm the acceptance levels of IEC 60376, IEC 60480 and IEC 62271-4. These quality checks are not required on sealed equipment and new gas used from sealed bottles. A dew point check and a check of the total impurities should be carried out to confirm the supplier's acceptance levels.

In addition to the quality issues for SF_6, the following checks for gas mixtures should be performed:

- Quality to be confirmed prior to energization.

6.5.5 Checks on operating fluid(s), where filled or added to on site

Subclause 10.2.102.1.4 of IEC 62271-100:2008 is applicable.

6.5.6 Site operations

See 10.2.102.1.5 of IEC 62271-100:2008.

6.6 Mechanical test and measurement

The mechanical tests and measurements should be taken in order to compare them with the values both recorded during the routine tests and guaranteed by the supplier. These values serve as the reference for future maintenance and other checks and will enable any drift in operating characteristics to be detected.

These measurements involve a check of the operation of the alarm and lockout devices (pressure switches, relays, transducers, etc.) where applicable:

- Measurements of the characteristic insulating and/or interrupting fluid pressures (where applicable)
- Measurements of characteristic operating fluid pressures (if applicable)
- Measurement of consumption during operations (if applicable)
- Verification of the rated operating sequence
- Measurement of time quantities
- Record of mechanical travel characteristics
- Checks of certain specific operations

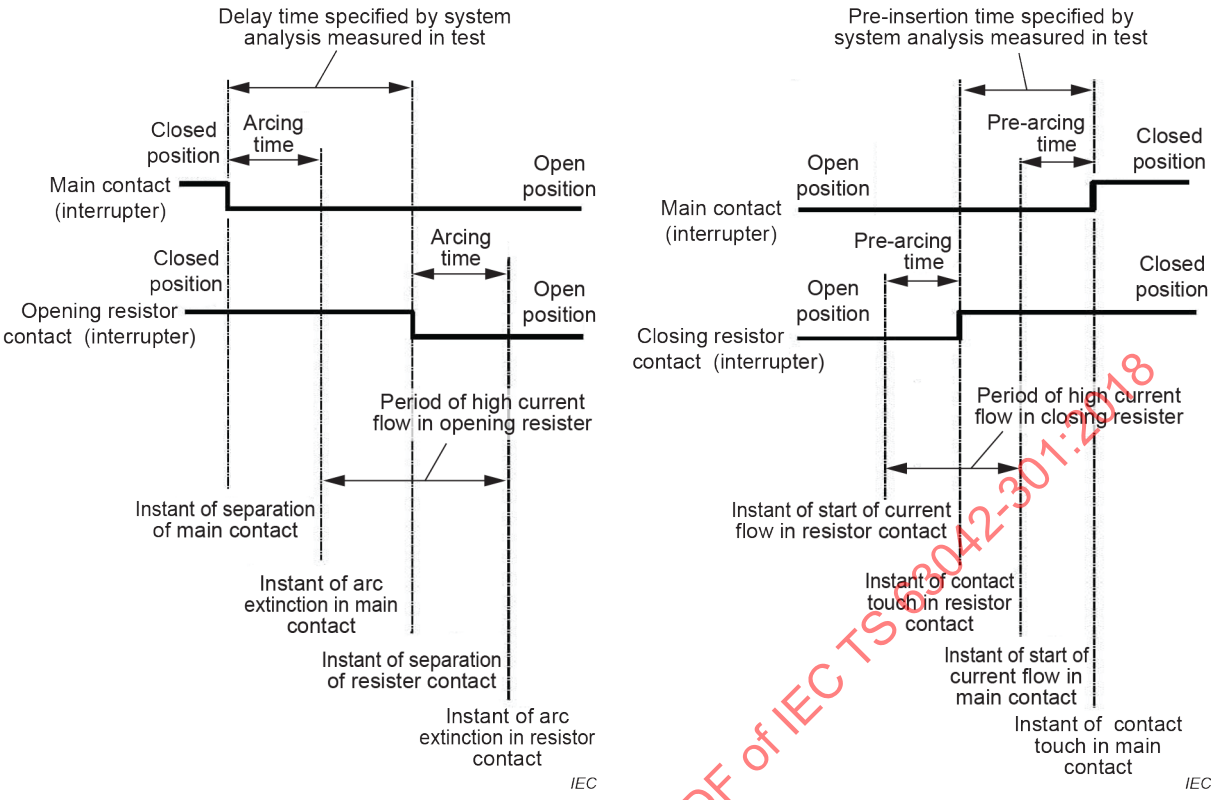
Subclause 10.2.102.2 of IEC 62271-100:2008 is applicable with the following addition:

- Verification of timing of opening resistor and closing resistor
- Verification of delay time between opening time of main interrupter and opening resistor interrupter

NOTE 1 This test generally applies to CB with opening and / or closing resistor.

- Verification of pre-insertion time of closing resistor

NOTE 2 This test generally applies to CB with closing resistor. For details see Figure 1.



a) Opening operation **b) Closing operation**

Figure 1 – Delay time of opening resistor and pre-insertion time of closing resistor

6.7 Test of accessories

Further tests can be done depending on the agreement between supplier and purchaser. The following tests are practical examples:

- Bushing current transformer test;
- Gas bushing test;
- Verification of gas density relay;
- Verification of oil pressure relay;
- Counter check;
- Oil leakage test of hydraulic operating mechanism.

7 GIS

7.1 General

After installation, and before being put into service, the GIS should be tested in order to check the correct operation and the dielectric integrity of the equipment.

These tests and verifications comprise:

- dielectric tests on the main circuits;
- dielectric tests on auxiliary circuits;
- measurement of the resistance of the main circuit;
- gas tightness tests;
- checks and verifications;

- gas quality verifications.

To ensure minimum disturbance, and to reduce the risk of moisture and dust entering enclosures and thus preventing correct operation of the switchgear, no obligatory periodic inspections or pressure tests concerning the enclosures are specified or recommended when the gas-insulated substation is in service. Reference should be made, in any case, to the supplier's instruction book.

The supplier and purchaser should agree on a commissioning test plan for tests on site.

7.2 Dielectric tests on the main circuits

Since it is especially important for GISs, the dielectric integrity should be checked in order to eliminate fortuitous causes (wrong fastening, damage during handling, transportation, storage and installation, presence of foreign bodies, etc.) which might in the future give rise to an internal fault.

Because of their different purpose, these tests should not replace the type tests or the routine tests carried out on the transported units and, as far as possible, in the factory. They are supplementary to the dielectric routine tests with the aim of checking the dielectric integrity of the completed installation and of detecting irregularities as mentioned above. Normally, the dielectric test should be made after the GISs have been fully installed and gas-filled at the rated filling density, preferably at the end of all on-site tests, when newly installed.

Some parts may be disconnected for the test, either because of their high charging current or because of their effect on voltage limitation, such as:

- high voltage cables and overhead lines;
- power transformers and, occasionally, voltage transformers;
- surge arresters and protective spark gaps.

Generally, 10.2.101.2 of IEC 62271-203:2011 is applicable with the following addition:

One of the following two test procedures should be chosen:

Procedure B (preferred and recommended):

- Power-frequency voltage test with duration of 1 min at the value specified in Table 2, column (2); and
- Partial discharge measurements with test voltage for PD measurement $U_{\text{pd-test}}$ (>1 min) $U_{\text{pd-test}} = 1.2\ U_{\text{r}} / \sqrt{3}$, however with $U_{\text{pre-stress}} = U_{\text{ds}}$ of Table 2, column (2)

  With

  U_{r} is rated voltage for equipment,

  $U_{\text{pre-stress}}$ is pre-stress voltage

  $U_{\text{pd-test}}$ is test voltage for PD measurement.

  A PD measurement at $U\text{r} / \sqrt{3}$ is also recommended since this measurement may be helpful in determining the need for maintenance of the equipment after a period of service.

  For practical application of PD measurements, see Annex C of IEC 62271-203:2011.

Procedure C (alternative to procedure B):

- Power-frequency voltage test with duration of 1 min at the value specified in Table 2, column (2); and
- Lightning impulse tests with three impulses of each polarity and with the value specified in Table 2, column (3).

Table 2 – On-site test voltages

Rated voltage for equipment U_r kV (r.m.s. value)	On-site short-duration power-frequency withstand voltage U_{ds} kV (r.m.s. value)	On-site lightning impulse withstand voltage U_{ps} kV (peak value)
(1)	(2)	(3)
1 100	865	1 920
1 200	865	1 920

Values of column (2) are only applicable for SF_6 insulation or when SF_6 is a major part of the gas mixture. For other insulation, refer to Tables 1 and 2 of IEC 62271-1:2017, applying a factor 0,8 on column (2).

The on-site test voltages have been calculated as follows:

U_p (rated lightning impulse withstand voltage, phase-to-earth): 2 400 kV

U_{ds} (on-site test value) = U_p x 0,45 × 0,8 (column (2))

U_{ps} (on-site test value) = U_p x 0,8 (column (3))

All values have been rounded up to the next higher modus 5 kV.

If another insulation level than the preferred values of U_p = 2 400 kV is specified, the on-site test voltage should be calculated according to the above procedure.

For information about voltage waveforms, voltage application and assessment of the test, see 10.2.101.2 of IEC 62271-203:2011.

7.3 Dielectric tests on auxiliary circuits

Auxiliary and control circuits of switchgear and controlgear should be subjected to short-duration power-frequency voltage withstand tests. Each test should be performed:

- between the auxiliary and control circuits connected together as a whole and the frame of the switching device;
- if practicable, between each part of the auxiliary and control circuits, which in normal use may be insulated from the other parts, and the other parts connected together and to the frame.

See 8.3 of IEC 62271-1:2017.

7.4 Measurement of the resistance of the main circuit

Overall measurements should be made on the complete installation, under conditions as similar as possible to those of the routine test on transported units.

The resistance measured should not exceed the maximum values permitted for the routine tests on transport units, taking into account the differences of the two test arrangements (number of devices, contacts and connections, length of conductors, etc.).

See 10.2.101.4 of IEC 62271-203:2011.

7.5 Gas tightness tests

A qualitative gas tightness test should be carried out on all field assembled connections. A leakage detector may be used.

See 10.2.101.5 of IEC 62271-203:2011 and addition, 8.5 of IEC 62271-1:2017 for on-site gas tightness tests.

7.6 Checks and verifications

The following should be verified:

- conformity of the assembly with the supplier's drawings and instructions;
- sealing of all pipe junctions, and the tightness of bolts and connections;
- conformity of the wiring with the diagrams;
- proper function of the electrical, pneumatic and other interlocks;
- proper function of the control, measuring, protective and regulating equipment including heating and lighting.

See 10.2.101.6 of IEC 62271-203:2011.

7.7 Gas quality verifications

In order to get a reliable measurement, the moisture content should be checked at least 5 days after final filling of gas. For SF_6, the moisture content should not exceed the limit defined in 6.2 of IEC 62271-1:2017.

For checking the condition of the gas during service, reference is made to IEC 60480.

For handling precautions, reference is made to IEC 62271-4.

NOTE Care should be taken to minimize the release of gas into the atmosphere during sampling and/or checking operations (e.g. by providing a collecting bag or receiver installed on the outlet valve of the checking device when determining moisture content).

See 10.2.101.7 of IEC 62271-203:2011.

8 Surge arresters

8.1 General

On-site acceptance tests after shipping and site assembly should be performed to check the correct operation and the dielectric integrity of metal-oxide surge arresters. If the arrester is delivered incompletely and assembled on site, it should be checked for correct mounting by any appropriate method adopted by the supplier. The test methods and their descriptions listed below are applicable for metal-oxide surge arresters:

- insulation resistance test;
- insulation resistance test of the base insulator;
- leakage current test;
- checks and verifications;
- tests of accessories.

8.2 Insulation resistance test

Insulation resistance should be measured.

As an example in some countries, the insulation resistance is tested at 5 000 V and the tested insulation resistance value should not be lower than 2 500 MΩ.

8.3 Insulation resistance test of the base insulator

Insulation resistance of the base insulator should be measured.

As an example in some countries, the insulation resistance is tested at 2 500 V and the tested insulation resistance value should not be lower than 50 MΩ. The surge counter should be disconnected before measurement.

8.4 Leakage current test

Total leakage current and resistive leakage current should be measured under dry condition and operation voltage. The measured values should meet the requirements of the supplier and purchaser.

8.5 Checks and verifications

The following should be verified:

- Appearance should show no visible damage;
- Appearance after installation, such as the piling order of arrester units and the shield ring, etc., should be according to the drawing and instruction manual of the supplier.

8.6 Tests of accessories

There should be no damage of the appearance or the script clear of the counter. The initial number of the counter should be recorded.

9 Voltage and current transformers

9.1 Capacitive voltage transformers (CVTs)

9.1.1 General

For the procedure followed for on-site tests, the test method should refer to the same kind of tests described in relevant publications, such as IEC 61869-5. The test methods and their descriptions listed below are applicable for UHV CVTs.

Checks and verifications include the following:

- insulation resistance measurement low-voltage terminal to earth terminal;
- capacitance and dissipation factor (tan δ) measurement;
- tightness of liquid-filled capacitors;
- winding resistance measurement of electromagnetic units;
- insulation resistance measurement of each component of electromagnetic units;
- connection check between components of electromagnetic units;
- tightness of electromagnetic units;
- accuracy check (determination of error);
- damper check.

A low-frequency withstand test on capacitive voltage dividers is optional based on agreement between supplier and purchaser.

9.1.2 Insulation resistance measurement of low voltage terminal to earth terminal

Insulation resistance measurement of low-voltage terminal to earth terminal should be made.

As an example, in some countries, the insulation resistance is tested at 2 500 V and the tested value of insulation resistance should not be lower than 1 000 MΩ.

9.1.3 Capacitance and dissipation factor (tan δ) measurement

Capacitance and dissipation factor (tan δ) measurement should include the following:

- Measurement of capacitance and tan δ of each divider unit should be performed at 10 kV. Measurement of capacitance and tan δ of the intermediate voltage capacitor should be performed at rated voltage. The value of tan δ should not be greater than 0,2 %;
- The deviation of the capacitance of each capacitor unit and intermediate voltage capacitor unit should be between −5 % ~ +10 % of rated value;
- If the value of tan δ measured at 10 kV doesn't meet the requirement, it should be measured at the rated voltage instead. When the value of tan δ measured at rated voltage meets the requirement, the capacitor voltage divider can be considered to be acceptable.

9.1.4 Tightness of the liquid-filled capacitor voltage dividers

Tightness of the liquid-filled capacitor voltage dividers should be checked: no surface defects that could affect the satisfactory performance should be tolerated.

9.1.5 Winding resistance measurement of electromagnetic units

Winding resistance measurement of electromagnetic units should include the following:

- Measurement should be performed for all windings of intermediate transformers, compensation reactors and dampers. The resistance of the primary winding of intermediate transformers and compensation reactor windings can be measured together when possible;
- For the resistance of intermediate transformers and compensation reactor windings, relevant deviation should be within ±10 % of the factory test value at the same temperature. For dampers, the relevant deviation should be within ±15 % of the factory test value.

9.1.6 Insulation resistance measurement of each component of electromagnetic units

Insulation resistance between terminals of intermediate transformer secondary windings and earth, insulation resistance of intermediate transformer primary windings to earth, insulation resistance of compensation reactor windings to earth, as well as insulation resistance of damper to earth should be tested and should meet the requirements of the supplier and the purchaser.

Different suppliers and purchasers may give different suggested values of test voltage and insulation resistance. As an example, in some countries, the test voltage is 2 500 V, and insulation resistance should not be lower than 1 000 MΩ.

9.1.7 Connection check between components of electromagnetic units

Connection between components of electromagnetic units should be checked and should be conform to the name plate.

9.1.8 Tightness of electromagnetic units

No surface defects that could affect the satisfactory performance in service should be tolerated.

9.1.9 Accuracy check (determination of error)

Accuracy checks should include the following:

- During measurement, the layout of a high-voltage lead should be as close as possible to the actual operation condition;
- The checks should be performed on all gate metering voltage transformers;
- Error measurement should not be replaced by voltage ratio measurement methods with a voltage ratio tester;
- A polarity check should be performed simultaneously with error measurement, and the labelling of each connecting terminals should be checked;
- Both difference methods and voltage coefficient measurement methods can be applied to accuracy check;
- Checks should be performed on each secondary winding separately except for residual windings. The access load of checked windings should be between 25 % ~ 100 % of rated load, and for other windings the load should be between 0 % ~ 100 % of rated load. The power factor of the secondary load should be considered as 1 if there is no other special requirement given by the purchaser;
- Checks for the metering winding and the measuring winding (0,2 level and 0,5 accuracy level) should be performed at 80 %, 100 %, and 120 % of rated voltage or as agreed upon between the supplier and purchaser;
- Error characteristic measurement of protection windings should be performed at 2 %, 5 %, and 100 % of rated voltage.

NOTE The last three checks depend on the agreement between the supplier and the purchaser.

9.1.10 Damper check

Check whether the damper has been connected correctly with the specified secondary winding terminal.

9.2 Bushing-type CTs

9.2.1 General

On-site acceptance tests for bushing-type CTs include the following:

- insulation resistance test;
- resistance measurement;
- applied voltage test on secondary windings;
- determination of error and polarity check;
- excitation test.

9.2.2 Insulation resistance test

Insulation resistance between each secondary winding and earth and on secondary windings should be tested and should meet the requirements of the supplier and the purchaser.

Different suppliers and purchasers give different suggested values of test voltage and insulation resistance. As an example, in some countries, the test voltage is 2 500 V and the insulation resistance should not be lower than 1 000 MΩ.

9.2.3 Resistance measurement

The resistance measurements should include the following:

- Compare the DC resistance of secondary winding with factory test result when converted to the same temperature. The difference should not exceed 10 %;
- For CTs with the same batch, model, and specification, the difference of their tested value of the secondary winding DC resistance should not exceed 10 %.

9.2.4 Applied voltage test on secondary windings

Power frequency withstanding voltage between secondary windings and windings to earth of current transformers is 3 kV, with time duration of 1 min.

9.2.5 Determination of error and polarity check

The determination of error and polarity should include the following:

- Polarity check should be performed simultaneously with determination of error, or DC method should be adopted and terminal markings should be checked;
- For multi-transformation ratio windings, measurement of only the full range error of one transformation ratio should be done and verify the error at least at 20 % of the rated current and the transformation ratio of all windings should conform to the value given on the nameplate;
- For determination of error, the direct method (difference value method) should apply. If the applied current cannot reach the specified value, the indirect method can be adopted with the precondition that the error at 20 % of I_r (rated current) point has been measured by direct method.

9.2.6 Excitation test

The excitation tests should include the following:

- The test should be carried out when the CT excitation characteristic is required by the relay protection;
- If the CT is a multi-tap type, the measurement can be taken at the tap in use or at the tap with the maximum transformation ratio and the result should meet the requirement specified by the supplier and the purchaser;
- Apply the voltage across the windings under test in the steps of 500 V and raise the voltage up to rated knee point voltage. At each voltage, the magnetizing current should not be more than factory value within a deviation of 5 %.

10 Shunt reactors

10.1 General

Most of the test items or conditions of shunt reactors are the same as those of Clause 5.

NOTE For the procedure followed for field tests, the test method refers to the same kind of tests described in relevant publications for factory tests, such as IEC 60599 and IEC 60076 series.

Shunt reactors and neutral-earthing reactors (if any) should be subjected to on-site tests as specified below:

- leak testing with pressure (tightness test);
- winding resistance measurement;
- insulation resistance tests including bushings;
- dissipation factor (tan δ) and capacitance measurement on each winding to earth and between windings;
- core and frame insulation check;
- tests on bushings;

- insulation oil tests;
- DGA test.

The following item is optional:

- applied voltage test.

10.2 Leak testing with pressure (tightness test)

Oil tank of shunt reactors should withstand a pressure of 30 kPa or any specified value pressure applied on the top-level of oil in oil conservator and maintained for 24 hours or any specified period without any leakage and damage.

10.3 Winding resistance measurement

Winding resistance measurement tests should include the following:

- measurement should be performed for all windings at all tap positions (if any);
- measured values should be compared with the factory test results. The deviation should be within ±5 %;
- measured values should be compared with the average value of three phase windings. The deviation should be within ±2 % otherwise specified.

10.4 Insulation resistance tests on each winding to earth and between windings including bushings

Insulation resistance tests should be made for each winding with respect to earth and between windings.

10.5 Dissipation factor (tan δ) and capacitance measurement on each winding to earth and between windings

Dissipation factor (tan δ) and capacitance measurement on each winding to earth and between windings should include the following:

- Terminals to be tested should be connected to the test instrument and the terminals not being tested should be short-circuited and connected to earth. Test voltage is 10 kV AC.
- Tan δ measurement results should be compared with the factory test result considering the temperature difference and the difference should be within ±0,001 and the difference of the capacitance value should be within ±1 % of the factory test results.

10.6 Core and frame insulation check

Insulation resistance check should be made between core to frame, core to tank and frame to tank. For details see IEC 60076-1.

10.7 Tests on bushings

10.7.1 Visual inspection

The visual inspection should be made on each bushing. For details see 9.10 of IEC 60137:2017.

10.7.2 Tan δ and capacitance measurement

The measurement is only applicable to capacitance-graded bushings. For details see 9.1 of IEC 60137:2017. Tan δ and capacitance measurement should include the following:

- after installation of the transformer bushings, tan δ and capacitance of the insulation should be measured at 10 kV while voltage tap (if any) should be short-circuited with the test tap;
- the deviation between measured capacitance value and factory test value should be lower than ±1 % (similar to 5.7 for tan δ) or depending on the number of layers up to 5 %.

10.7.3 Tap withstand voltage

A rated frequency voltage withstand test should be applied to or induced at the tap for 1 min with the bushing mounting flange earthed. Voltage tap should be tested at 20 kV. The test tap should be tested at 2 kV.

NOTE For voltage tap, different suppliers might give different suggested value of test voltage. It is advised to refer to the product specification or consult the supplier before testing.

10.8 Insulating oil tests

Test requirements of insulating oil filling into electrical equipment should be as per Table 1. See Subclause 5.10.

10.9 DGA test

The DGA test should be carried out after the completion of oil treatment. If a dielectric test is required, the DGA test should be carried out after the dielectric test. See IEC 60599.

10.10 Applied voltage tests

The test should be made on-site. For details, see IEC 60076-3. The applied voltage test should include the following:

- The test voltage should be applied between all terminals of the winding under test connected together and all terminals of the remaining windings, core, frame and tank of the transformer, connected together to earth;
- The test voltage value should be 80 % of the factory test value and the time duration should be 1 min;
- The test voltage should be as near as possible to a sine-wave form. The peak value divided by $\sqrt{2}$ should be equal to the test value;
- The test is successful if no collapse of the test voltage occurs.

11 Series compensators

11.1 General

Series compensators should be subjected to on-site tests as specified below:

- test on capacitors;
- test on metal oxide varistors;
- test on damping devices;
- test on spark gaps;
- test on current transformers;
- test on by-pass switches;
- test on disconnect switches;
- test on insulators;
- test on control and protection systems.

11.2 Test on capacitors

On-site tests for capacitors should include the following:

- Capacitance measurement

  The capacitance measured by a bridge or other special instruments should meet the following requirements:

  – Capacitor unit: deviations from factory test values should not exceed ±2 %;

  – Capacitor bank: deviations from rated values should not exceed ±1 %;

  – Difference between single phase bridge arm of capacitor should not exceed: ±0,5 %;

  – The ratio between the maximum and the minimum of the capacitance measured among the three phases of the capacitor bank should not exceed 1,01.

- Unbalanced current measurement of capacitor bank

  Unbalanced current of capacitor bank is measured using the current-voltage method. The measured value should meet the recommendations of the supplier.

- Insulation resistance measurement between terminals and container

  Insulation resistance of capacitor unit should be measured between the pole and the case.

  As an example, in some countries the insulation resistance is measured at 2 500 V and the insulation resistance value should not be lower than 2 000 MΩ.

- AC withstand voltage test between terminals and container

  The test should be performed in accordance with 5.6 of IEC 60143-1:2015. The test voltage should be 75 % of the voltage value of the factory test.

11.3 Tests on metal oxide varistors

On-site tests for metal oxide varistors should include the following:

- Insulation resistance measurement

  As an example in some countries the insulation resistance is measured at 5 000 V and the insulation resistance between conductor and earth is not lower than 2 500 MΩ.

- DC reference voltage measurement

  DC reference voltage should be measured on the varistor unit. The tested current value of each varistor column should not be lower than 1 mA. The difference between the measured value and the factory test value should not exceed ±5 % and should satisfy the specified value.

- Leakage current measurement at 75 % of the DC reference voltage

  Leakage current at 75 % of the DC reference voltage should meet the specifications of the supplier.

11.4 Tests on damping equipment

On-site tests for damping devices should include the following:

- Damping reactor

  Inductance should be measured using current-voltage method. Measurement should be kept away from strong magnetic sources. The deviation between the measured value and the factory value should not exceed ±5 %.

  DC resistance should be measured using double DC bridge or DC resistance tester. Measurement should be kept away from strong magnetic field sources. The deviation between the measured value and the factory value should not exceed ± 10 %.

- “Linear resistance + gap” type damping resistor

  The deviation between the measured resistance value and the factory value should not exceed ±5 %.

Gap distance should be measured or gap discharge voltage should be tested using DC voltage generator. The deviation between the measured value and the factory value should not exceed ±10 %.

- "Linear resistance + nonlinear resistance" type damping resistor

  Insulation resistance to earth of damping resistor should be measured at 2 500 V and the insulation resistance should meet the supplier's requirement.

  The DC reference voltage and leakage current of nonlinear resistance should be measured. The deviation between the measured value and the factory value should not exceed ±5 %. The leakage current at 75 % of the reference voltage should not exceed 1,2 times the factory value or 500 μA.

11.5 Tests on spark gaps

On-site tests for spark gaps should include the following:

- DC resistance measurement of current limiting resistor for gaps

  The deviation between the measured value and the factory value should not exceed ±5 %.

- Insulation resistance measurement of bushings

  For 66 kV and above capacitive type bushings, insulation resistance of bushings' end screen to flange should be measured.

  As an example, in some countries the insulation resistance is measured at 2 500 V and the insulation resistance should not be lower than 1 000 MΩ.

- AC withstand voltage test of bushings

  AC withstand voltage test of bushings should be performed in accordance with IEC 60071-1.

- Tan δ and capacitance measurement of bushings

  The tan δ of 20 kV and above non-pure porcelain bushings should be not greater than the value in Table 3, at ambient temperature not lower than 10 °C.

  The deviation between the measured value of capacitive type bushings and the value on the product nameplate or the factory value should not exceed ±5 %.

Table 3 – Tan δ (%) of bushings

Major insulation type of bushings	Maxima of tan δ (%)
Organic composite insulation[1]	0,7
Gas	1,5
Casting resin	1,5
Oil immersed paper	0,7
Resin immersed paper	0,7
[1] Medium loss test of organic composite insulating sleeve should be conducted in a dry place.	

- Dielectric loss and capacitance measurement of capacitor for gaps

  The deviation between the measured value and the factory value should not exceed ±5 %. The dielectric loss should meet the technical requirements of the supplier and purchaser.

- AC withstand voltage test of high insulated pulse transformer

  The test voltage should be 80 % of the factory test value with duration of 1 min. No evidence of discharge of the sample is allowed to occur during the test.

- Functional test of gap trigger control system

  The gap trigger command should be issued by the series compensator control and protection system, and the gap trigger control system should work correctly.

- AC withstand voltage test of gap

The tested gap should have no discharge phenomenon during the test, and the gap should work normally. AC withstand voltage test value of gap should be not less than 1,05 times of the limiting voltage of the capacitor bank.

- Triggered discharge test of gap

  The triggered discharge test should be conducted twice. Triggered discharge test voltage value of gap should be not more than 1,8 times of the rated voltage of the capacitor bank or the recommended value of the supplier.

11.6 Tests on current transformers

On-site tests for current transformers should include the following:

- Insulation resistance measurement of windings

  As an example, in some countries the insulation resistance is measured at 2 500 V and the insulation resistance should not be lower than 1 000 MΩ.

- Measurement of tan δ of 35 kV and above current transformer

  The test voltage of tan δ of current transformer windings should be 10 kV. The tan δ should not exceed the value in Table 4.

  The test voltage of tan δ of end screen should be not less than 2 kV.

NOTE This test is applicable to oil-immersed current transformer and inapplicable to current transformer with SF_6 insulation and epoxy resin insulation structure. Silicone grease, etc. and other dry current transformers can reference it.

Table 4 – Limiting value of tan δ (%)

Rated voltage (kV)	20 to 35	66 to 110	220
tan δ in % for oil-immersed current transformer	2,5	0,8	0,6
tan δ in % of oil-immersed current transformer end screen	-	2	

- AC withstand voltage test

  AC withstand voltage test should be conducted at 80 % of factory value. The voltage of AC withstand voltage test among secondary windings and case or the earth should not be less than 2 kV.

  The voltage of AC withstand voltage test on the end screen to earth of 110 kV current transformer should not be less than 2 kV.

- DC resistance measurement of windings

  The deviation of DC resistance and the average value between primary winding and secondary winding of current transformers with the same type, the same specification and the same batch should be no more than 10 %.

- Polarity check

  It should conform to the design requirements, nameplate and label.

- Ratio test

  It should conform to the design requirements, nameplate and label.

- Voltage-current characteristic curve measurement of current transformer

  When relay protection has requirements on voltage-current characteristics of current transformer, the test should be performed. The test result should conform to the technical requirements of the supplier.

- Sealing performance check (when applicable)

  Appearance should have no oil stains.