conditions and to ensure that all the different types of termination are considered. In that case, the technical justification of this reduction of tested ports shall be provided in the test specification.

13.4 Test specification

13.4.1 Visual inspection

The visual inspection verifies the mechanical, dimensional and appearance conformance of the electronic equipment; see 4.1.

The visual inspection shall be carried out before and after tests to check whether any damage or deterioration has occurred resulting from the tests.

13.4.2 Performance test

The performance test verifies that the functional requirements for the electronic equipment are fulfilled with the specified performance criteria (see 4.3).

The performance test is carried out according to the performance test specification and performance test procedure written by the supplier either for type test or for routine test.

The performance test shall be carried out at room temperature, see 13.3.2.

The performance test shall consist of a comprehensive series of measurements of the functional characteristics of the equipment to verify that its performance criteria are in accordance with the functional requirements of the concerned equipment, including any special requirements of its individual specification, and general requirements of this standard.

The performance test carried out during the type test may differ from the one carried out during the routine test.

13.4.3 DC Power supply test

13.4.3.1 General

The test verifies the performance of the electronic equipment connected to the battery voltage supply system, see 5.2.

To carry out the DC power supply tests, EN 61000-4-29 may be used as a guide. The rated voltage noted in EN 61000-4-29 has to be replaced by the nominal voltage.

If the electronic equipment has a large number of similar battery referenced I/O ports, which are electrically identical, then a sufficient number shall be selected to simulate actual operating conditions and to ensure that all the different types of termination are considered. In that case, the technical justification of this reduction of tested ports shall be provided in the test plan.

In all cases, the voltage and time duration of the test waveform shall be monitored at the input of the equipment during the test.

The rising/falling edge of the waveforms in the figures below are only indicative and can differ in detail.

13.4.3.2 Supply voltage variations

Tests shall be performed to prove correct functioning at nominal supply voltage and at the specified upper and lower voltage limits (see Table 4).

Tests shall be performed to prove correct functioning for the continuous supply voltage range between 0,7 U_n and 1,25 U_n.

13.4.3.3 Temporary supply overvoltages

Temporary supply overvoltages shall be assumed to be generated with respect to the system power supply return potential.

Electronic equipment shall be tested, for each duration (0,1 s and 1 s), with a sequence of 10 overvoltage events. The repetition time should be between 10 s minimum and 1 min maximum (between each test

event). If the equipment needs more than 1 min recovery time between test events, this shall be justified in the test specification, noted in the test report and defined in the datasheet of the equipment.

Temporary supply overvoltages up to 1,4 U_n and not exceeding 0,1 s shall not cause deviation of function **(performance criterion A)**, see Figure 7.

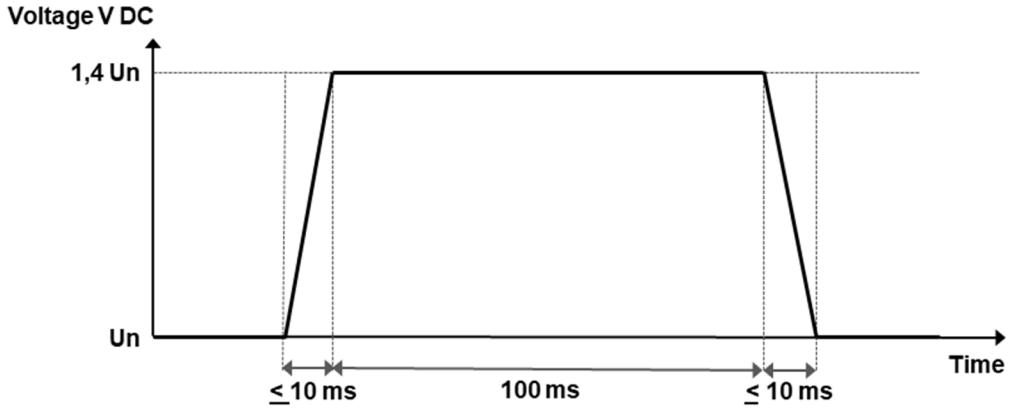

Figure 7 — Temporary supply overvoltages up to 0,1 s

Temporary supply overvoltages up to 1,4 U_n and not exceeding 1 s the equipment shall fulfil **performance criterion B**, see Figure 8.

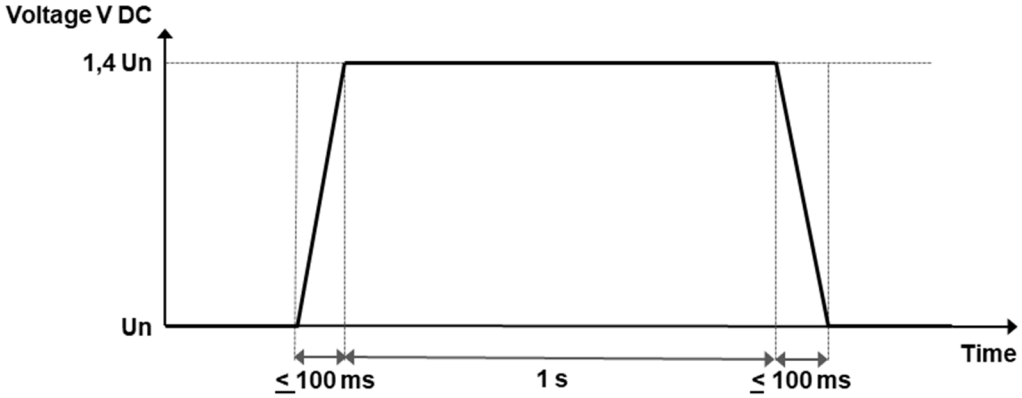

Figure 8 — Temporary supply overvoltages up to 1 s

If the equipment is specified for a wide input voltage range, temporary supply overvoltage shall be tested according to the highest specified nominal input voltage.

EXAMPLE 1 Equipment specified for a grouping of the nominal input voltages 24 V and 28 V: temporary supply overvoltage test is carried out at 28 V x 1,4 = 39,2 V.

EXAMPLE 2 Equipment specified for a grouping of the nominal input voltages from 48 V to 110 V: temporary supply overvoltage test is carried out at 110 V x 1,4 = 154 V.

13.4.3.4 Temporary supply undervoltage

Those tests cover requirements specified in 5.2.3 related to temporary supply undervoltage. Electronic equipment shall be tested, for the duration of 0,1 s, with a sequence of 10 undervoltage events. The repetition time should be between 10 s minimum and 1 min maximum (between each test event). If the equipment needs more than 1 min recovery time between test events, this shall be justified in the test specification, noted in the test report and defined in the datasheet of the equipment.

Temporary supply undervoltage down to 0,6 U_n and not exceeding 0,1 s shall not cause deviation of function **(performance criterion A)**, see Figure 9.

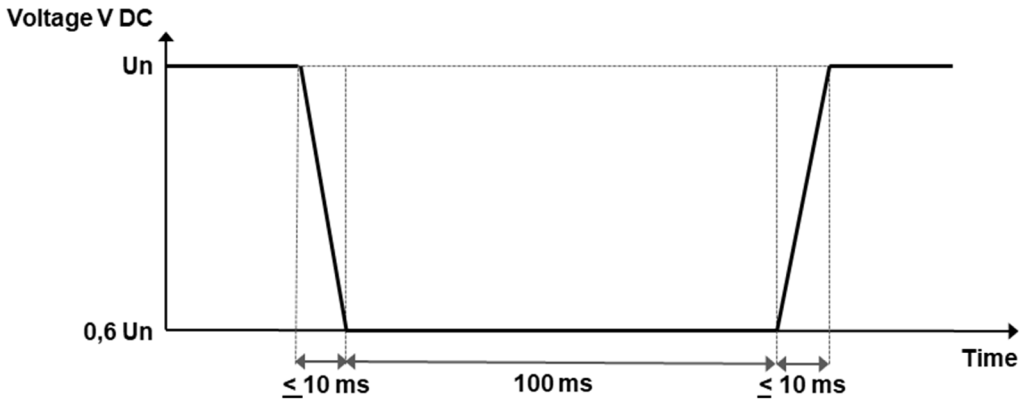

Figure 9 — Temporary supply undervoltage

If the equipment is specified for a wide input voltage range, temporary supply undervoltage shall be tested according to the lowest specified nominal input voltage.

EXAMPLE 1 Equipment specified for a grouping of the nominal input voltages 24 V and 28 V: temporary supply undervoltage test is carried out at 24 V x 0,6 = 14,4 V.

EXAMPLE 2 Equipment specified for a grouping of the nominal input voltages from 48 V to 110 V: temporary supply undervoltage test is carried out at 48 V x 0,6 = 28,8 V.

13.4.3.5 Interruptions of supply voltage

Possible causes of the physical phenomena and the supply voltage interruption classes are given in 5.2.4.

In order to realize the low impedance condition, a test generator shall be used which is able to supply both current directions (to source and sink current). Specific characteristics for the generator operating in "low impedance" conditions can be found in EN 61000-4-29.

To verify that performance criterion A is fulfilled, the maximum interruption time for the relevant class shall be applied. Electronic equipment shall be tested with a sequence of 10 interruption events.

The repetition time should be between 10 s minimum and 1 min maximum (between each test event).

If the equipment needs more than 1 min recovery time between test events, this shall be justified in the test specification, noted in the test report and defined in the datasheet of the equipment.

To verify that performance criterion C is fulfilled it is suggested to test with different interruption times greater than the time given in the relevant class.

Tests shall be carried out at nominal voltage and nominal load / operating conditions.

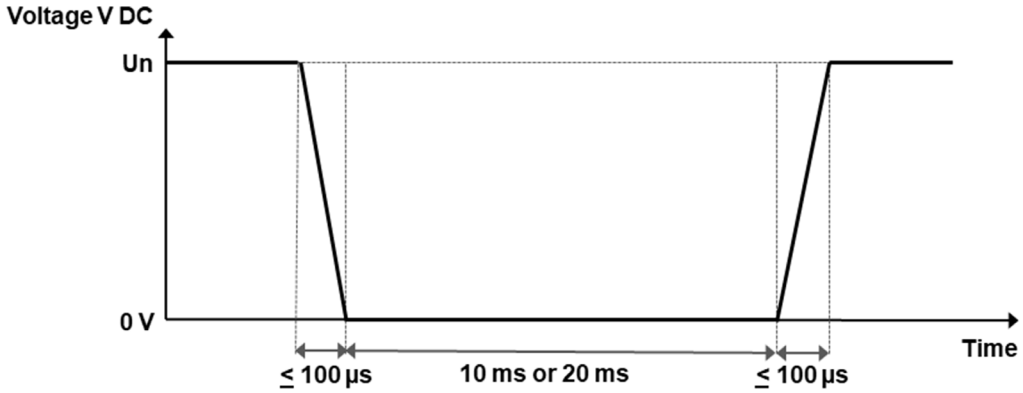

Figure 10 — Interruption of supply voltage

If the equipment is specified for a wide input voltage range, interruption of supply voltage shall be tested at the lowest specified nominal input voltage.

EXAMPLE 1 Equipment specified for a grouping of the nominal input voltages 24 V and 28 V: interruption test of supply voltage is carried out at 24 V.

EXAMPLE 2 Equipment specified for a grouping of the nominal input voltages from 48 V to 110 V: interruption test of supply voltage is carried out at 48 V.

13.4.3.6 Supply change-over

During supply change-over, the equipment shall operate satisfactorily under the conditions stated in 5.2.5.

The requirements and performance criteria are listed in Table 12:

Table 12 — Supply change-over classes

Class	Requirements	Performance criterion	Duration of supply undervoltage
C1	From Un to 0,6 Un and back to Un (without interruptions)	A	100 ms (See Figure 11)
C2	During a supply break starting at Un NOTE The supply break is an open circuit and not a short circuit ("High impedance" condition)	B	30 ms (See Figure 12)
In case of class C1, no additional test is required if the undervoltage test has passed.			

Electronic equipment shall be tested with a sequence of 10 change-over events.

The repetition time should be between 10 s minimum and 1 min maximum (between each test event).

If the equipment needs more than 1 min recovery time between test events, this shall be justified in the test specification, noted in the test report and defined in the datasheet of the equipment.

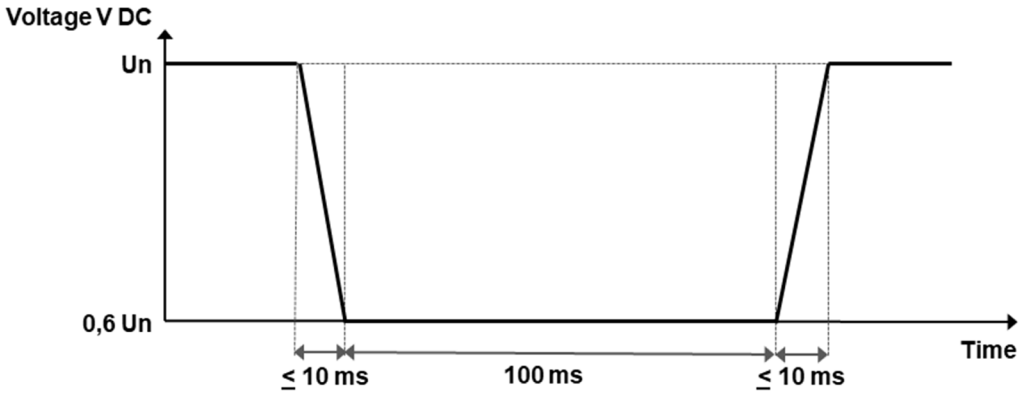

Figure 11 — Supply change-over Class C1

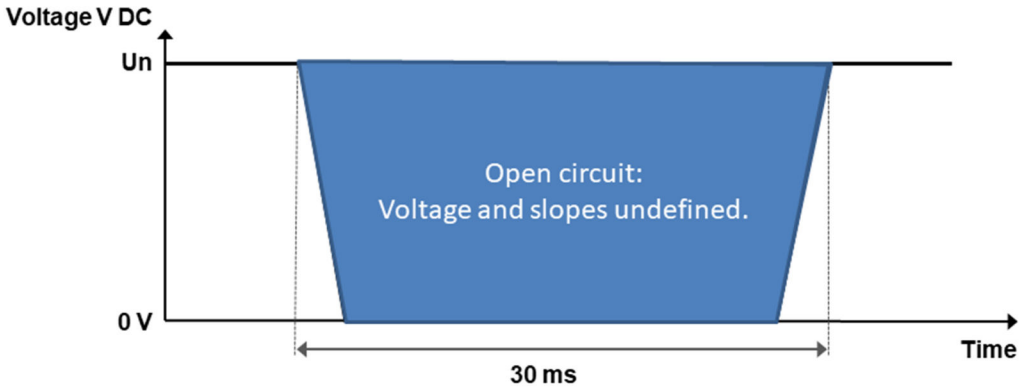

Figure 12 — Supply change-over Class C2

Tests shall be carried out at nominal load / operating conditions.

If equipment is specified for a wide input voltage range, supply change-over of voltage supply shall be tested at the lowest specified nominal input voltage, see examples in 13.4.3.5.

13.4.4 Low temperature test

This test shall be carried out in accordance with EN 60068-2-1:2007 (test Ad), using low-air velocity.

Equipment shall be tested according to its operating temperature class; low operating temperature (T_{TEST}) shall be taken from Table 1 of this standard.

After the initial performance test, the equipment is placed in a test chamber at room temperature (see 13.3.2), without any voltage applied.

After the chamber has cooled down, the equipment is thermally stabilized by leaving it for a sufficient period of time at test temperature (T_{TEST}).

In any case, the stabilization time period shall not be less than 2 h, see Figure 13.

At the end of this period the equipment shall be switched on and continuous operational checks shall be carried out, keeping the equipment at low temperature according to EN 60068-2-1:2007 not less than 30 min.

The continuous operational checks should also include some on/off cycles.

After the recovery period, the initial performance test shall be repeated.

Test acceptance requirements:

During and after the test, the equipment is checked and shall work as intended within its specified limits **(performance criterion A)**.

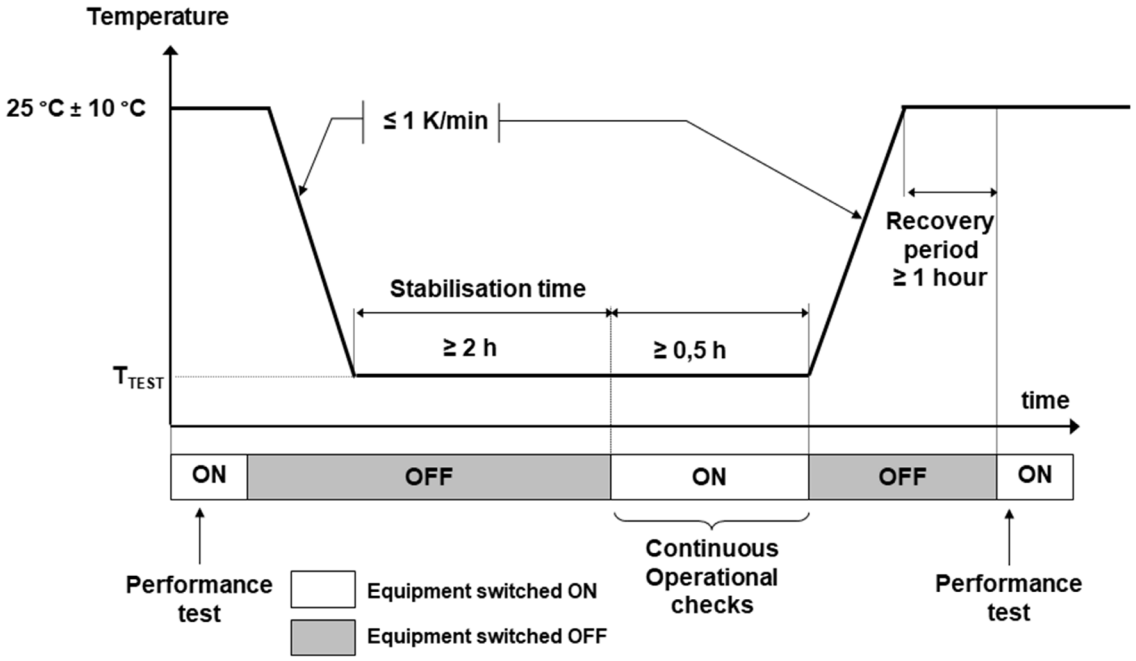

Figure 13 — Low temperature test

Equipment start-up condition shall be at its nominal voltage.

Equipment specified for a wide input voltage range shall be tested at the lowest specified nominal input voltage and at the highest nominal input voltage specified for this equipment.

Tests at lowest and highest nominal input voltage can be sequenced in a single cycle, providing that the stabilisation time and that the continuous operational checks time are respected at T_{TEST} temperature for both test voltages.

EXAMPLE 1 Equipment specified for a grouping of nominal input voltages from DC 72 V to DC 110 V: the low temperature test is carried out at DC 72 V and at DC 110 V.

EXAMPLE 2 Equipment specified for a grouping of nominal input voltages from DC 24 V to DC 72 V: the low temperature test is carried out at DC 24 V and at DC 72 V.

13.4.5 Dry heat test

13.4.5.1 General

This test shall be carried out in accordance with EN 60068-2-2:2007, (test Bd), using low-air velocity unless a different type of cooling is normally used for the equipment (internal or external cooling). In that case, the normal configuration of the equipment shall be replicated.

The temperature value for this test is:

— dependent on the operating temperature class (OTx);

— for cycle B and C dependent on the classes of increased operating temperature at switch-on (STx).

See Table 1 and Table 2 for details.

Equipment shall be tested at its rated voltage.

NOTE The rated voltage is representing the realistic situation during operation of the equipment and can cause more power dissipation than the nominal voltage.

Equipment specified for a wide input voltage range shall be tested at rated voltage corresponding to the lowest specified nominal input voltage and to the highest nominal input voltage specified for this equipment.

Tests at lowest and highest nominal input voltage can be sequenced in a single cycle, providing that the stabilisation time and that the continuous operational checks time are respected at T_{TEST} temperature for both test voltages.

EXAMPLE Equipment specified for a grouping of the nominal input voltages between DC 24 V and DC 110 V: the dry heat test is carried out at DC 24 V x 1,15 = DC 27,6 V and at DC 110 V x 1,15 = DC 126,5 V.

13.4.5.2 Dry heat thermal test — Cycle A

After the initial performance test, the switched off equipment is placed in a test chamber at room temperature which will be progressively raised to the maximum operating temperature (T_{TEST}) according to the selected temperature class (OTx), see Figure 14.

The temperature of the whole equipment (internal and external) shall be stabilized for a time of at least 2 h. Then the equipment is switched on and left in the test chamber for a minimum period of 6 h, in which operational checks shall be carried out at the maximum operating temperature (T_{TEST}).

The continuous operational checks should also include some on/off cycles.

The switched off equipment is then cooled down to room temperature and a further performance test shall be carried out after the stabilization time of at least one hour.

Test acceptance requirements*:*

During and after the test, the equipment shall work as intended within its specified limits **(performance criterion A)**.

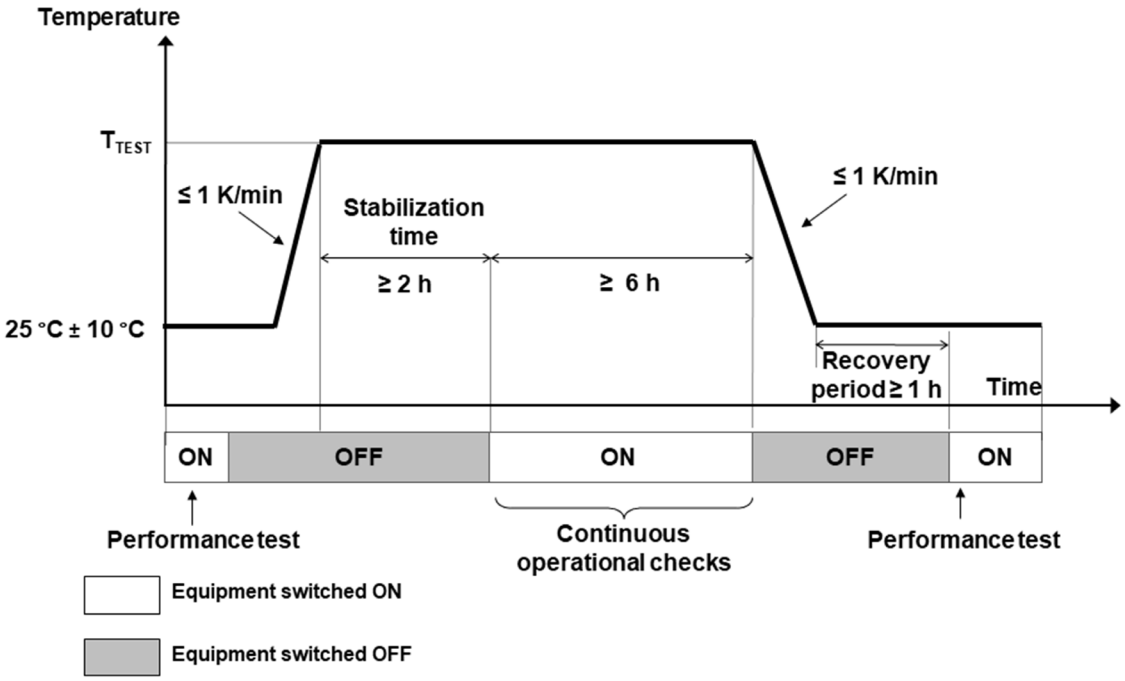

Figure 14 — Dry heat thermal test — Cycle A

13.4.5.3 Dry heat thermal test — Cycle B

After the initial performance test, the switched off equipment is placed in a test chamber at room temperature which will be progressively raised to the maximum operating temperature (T_{TEST}) according to the selected temperature class (OTx), see Figure 15.

The temperature of the whole equipment (internal and external) shall be stabilized for a time of at least 2 h. Then the equipment is switched on and left in the test chamber for a minimum period of 6 h, in which operational checks shall be carried out at the maximum operating temperature (T_{TEST}).

These continuous operational checks should also include some on/off cycles.

Once this test phase is complete, the equipment is switched off and operating temperature is gradually increased to the "Switch-on extended" operating temperature (T_{TEST}+15 °C). Then the equipment is switched on and additional start-up continuous operational checks shall be carried out.

This "Switch-on extended" operating temperature shall be maintained at least for 10 min (see Figure 15 for details).

The switched off equipment is then cooled down to room temperature and a further performance test shall be carried out after the stabilization time of at least one hour.

Test acceptance requirements:

During and after the test, the equipment shall work as intended within its specified limits **(performance criterion A)**.

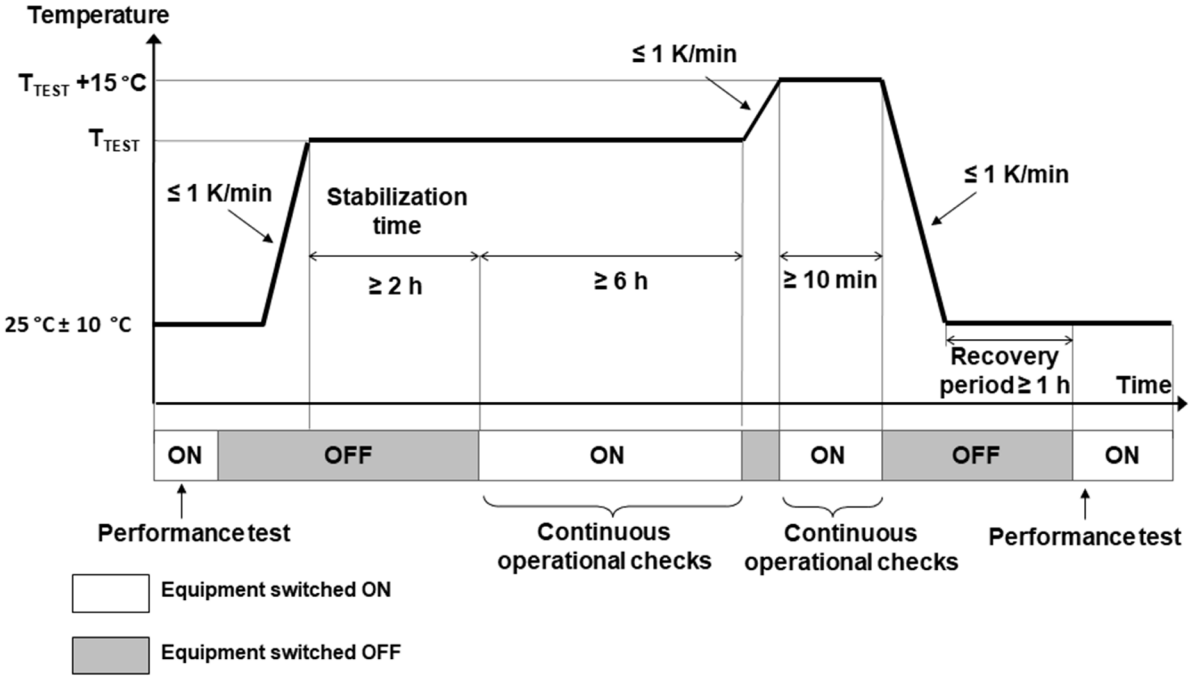

Figure 15 — Dry heat thermal test — Cycle B

13.4.5.4 Dry heat thermal test - Cycle C

After the initial performance test, the switched off equipment is placed in a test chamber at room temperature which will be progressively raised to the "Switch-on extended" operating temperature (T_{TEST} + 15°C) according to the selected temperature class (OTx), see Figure 16.

The temperature of the whole equipment (internal and external) shall be stabilized for a time of at least 2 h. Then the equipment is switched on.

The “Switch-on extended” operating temperature value shall be maintained for at least 10 min. Then, the equipment is gradually cooled down to the maximum continuous operating temperature (T_{TEST}) and maintained for at least 6 h. Operational checks shall be carried out over the whole switched ON time.

These continuous operational checks should also include some on/off cycles. The switched off equipment is then cooled down to room temperature and a further performance test shall be carried out after the stabilization time of at least one hour.

Test acceptance requirements:

During and after the test, the equipment shall work as intended within its specified limits **(performance criterion A)**.

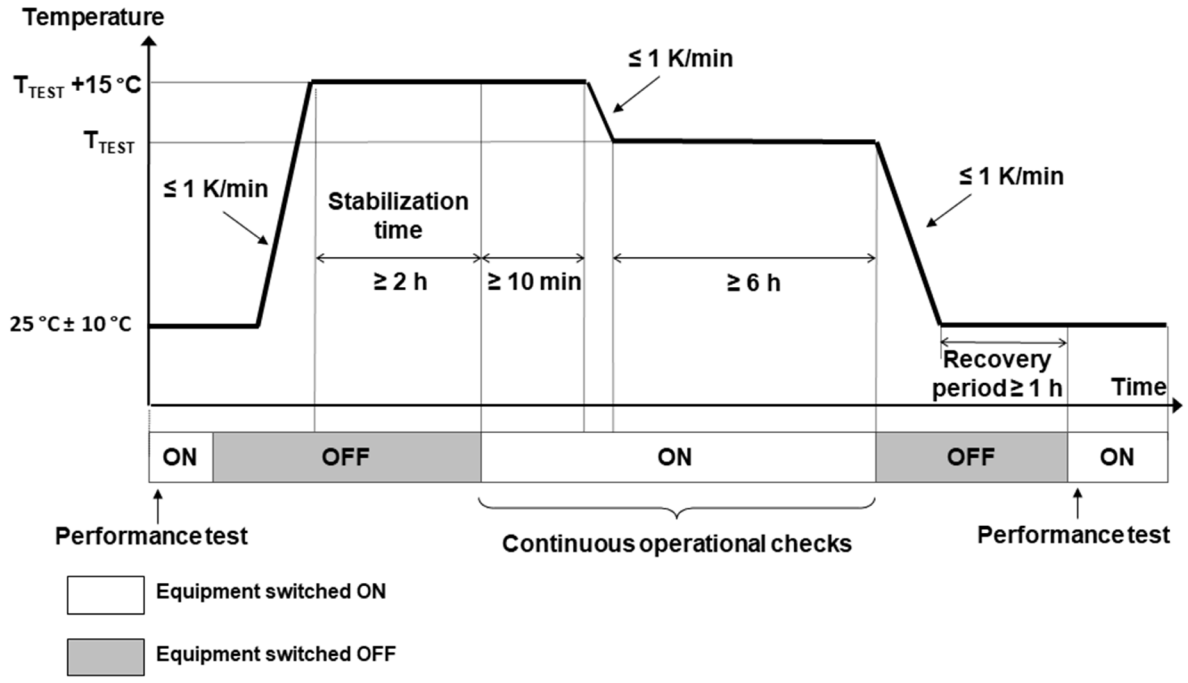

Figure 16 — Dry heat thermal test — Cycle C

13.4.6 Low temperature storage test

Where the equipment is to be exposed to temperatures less than its minimum operating temperature, then a low temperature storage test may be carried out. This test shall be carried out in accordance with EN 60068-2-1:2007 (test Ab).

Equipment without transportation packaging is placed, without any voltage applied, in a test chamber.

The temperature value for the test shall be −40 °C and the time period after stabilization shall be 16 h minimum.

After the recovery period, a performance test shall be carried out at room temperature.

Test acceptance requirements:

After the recovery period, the equipment shall work as intended within its specified limits **(performance criterion A)**.

13.4.7 Insulation test

13.4.7.1 General

The aim of this test (insulation resistance test and voltage withstand test) is to ensure that the mounted components, their metal connections and enclosures, and the routing of printed circuit board tracks and wires (if any), are not located too close to surrounding metal parts or fixings.

The test verifies that the design of circuits meets the requirements for galvanic isolation.

The test shall be carried out on fully assembled parts of equipment, and/or complete equipment dependent upon the scope of supply. For this test no alteration of the original equipment is permitted (e.g. component removal).

The insulation test consists of three parts:

- an insulation resistance test before the voltage withstand test;
- the voltage withstand test;
- an insulation resistance test after the voltage withstand test.

After the insulation test the equipment shall work as intended and within its specified limits. All measured values shall be recorded in the test report.

Where galvanic isolation is required, test voltages shall be applied between the two sides of the isolation barrier and the measured insulation resistance values shall be recorded.

Each equipotential area shall be defined and tested against functional earth and against all adjacent equipotential areas.

An equipotential area can be formed by ELV circuits that have internal electronic earth potential (0 V) electrically connected to the functional earth (see Annex K). In this case, insulation test against functional earth is not required.

The voltage withstand test procedure shall be arranged such that equipotential areas are subjected to the minimum number of applications of the dielectric test voltage.

The earth continuity shall be ensured for subracks and PBAs with exposed metal parts which can be touched.

13.4.7.2 Insulation resistance test

The insulation resistance test shall be carried out at DC 500 V and the resistance values shall be recorded for all the equipotential areas defined for the insulation test. During the test, the equipment shall not be powered on.

Test acceptance requirements:

For a single equipotential area on a fully assembled part of equipment (e.g. on a single PBA), the minimum value of the insulation resistance after the voltage withstand test shall be higher than 20 MΩ.

For assembled equipment (e.g. control electronics in traction converter), the minimum value of the insulation resistance of equipotential areas depends on the extent of the complete circuit. The insulation resistance at the interfaces to the vehicle shall be agreed between the involved parties.

In the case of high-impedance bleeder resistors between adjacent equipotential areas or between an equipotential area and functional earth, the effect of these resistors shall be deducted.

13.4.7.3 Voltage withstand test

The test shall be performed with AC test voltage (50 Hz or 60 Hz) according to Table 13. If not applicable (e.g. when EMC filter capacitors are mounted between active signals and functional earth) DC test voltage according to the same table shall be used.

Each equipotential area shall be defined and tested against functional earth and against all surrounding equipotential areas.

The test voltage shall be applied by gradually increasing the voltage amplitude to the test voltage (i.e. in more than 1 s), and maintained at the specified level for:

— Type test: 1 min;

— Routine test: 10 s.

For type test always the initial test voltage shall be applied.

For routine test, in case of repetition of the voltage withstand test during the life cycle of the same equipment, the test voltage may be reduced to 80 % of the initial test voltage to avoid pre-damages by partial discharges. For the same reason, if the same electronic equipment integrated into a subsystem is used, it may be disconnected or removed from the subsystem during the voltage withstand routine test or type test carried on this subsystem.

During the test, the equipment shall not be powered on.

An insulation resistance test shall be carried out before and after the voltage withstand test. Significant differences in the results shall be analysed and justified in the test report.

The nominal battery voltage and/or I/O voltage of each equipotential area define the test voltage according to Table 13.

For equipment powered by voltage not covered by this standard, see the applicable standards (e.g. EN 61287-1, EN 60077-1).

The test shall be applied to all insulated ports including power supply, I/O-ports and communication ports.

Table 13 — Test voltages of voltage withstand test

Nominal battery voltage and/or I/O voltage	Test voltage
< DC 72 V or AC 50 V_{RMS}	AC 500 V or DC 750 V
DC 72 V ≤ DC V < DC 125 V or from AC 50 to 90 V_{RMS}	AC 1 000 V or DC 1 500 V
DC 125 V ≤ DC V < DC 315 V or from AC 90 to 225 V_{RMS}	AC 1 500 V or DC 2 200 V

Where part of the electronic equipment is galvanically connected to a power circuit, then this part of the equipment shall be subject to the same dielectric tests as that circuit.

Attention is drawn to the fact that for battery referenced ports, a higher impulse withstand voltage is applicable, in respect of EN 50121-3-2:2016 surge requirements.

Test acceptance requirements:

Neither disruptive discharge nor flashover shall occur.

13.4.8 Cyclic damp heat test

This test shall be carried out in accordance with EN 60068-2-30:2005 (test Db variant 2); see Figure 17 and Figure 18.

During the 2 cycles of the test, the equipment under test shall not be powered except during the operational check at the beginning of the 2nd cycle.

Temperatures: + 55 °C and + 25 °C

Number of cycles: 2 (breathing effect)

Time: 2 × 24 h

Initial measurement:

- a performance test shall be carried out.

Intermediate measurements: